TABLE SHOWING THE ZONES INTO WHICH THE OXFORD CLAY AND KELLAWAYS BEDS HAVE BEEN DIVIDED BY DIFFERENT AUTHORS

Ages.	*Buckman 1913 and 1915.*	*Morley Davies 1916.*	*Neaverson 1925.*	*Spath 1926.*	*Morley Davies 1929.*	*Brinkmann 1929.*	*Pringle 1930.*	*Adopted Here.*
	scarburgense							
base of CARDIOCERATAN (*cordatum* zone s.l.)	*vernoni*	*præcordatum*		*precordatus* (with *vernoni* and *renggeri*)	*præcordatum*		*scarburgense*	*præcordatum* (= *scarburgense* auct.)
	gregarium					*tenuicostatum*		
	vertumnus			*mariæ* (with *vertumnus* and *renggeri*)	*vertumnus*		*mariæ*	
QUENSTEDTOCERATAN (= Vertumniceratan) (*lamberti* zone s.l.)	*renggeri*	*renggeri*			*renggeri*		*renggeri*	*renggeri*
	lamberti		*lamberti*	*lamberti* (with *lalandei* and *bicostata*)		*lamberti*	*lamberti*	*lamberti*
							proniæ	
	athleta	*athleta*	*athleta*		*athleta*		*athleta*	*athleta* (with *proniæ* and *spinosum*)
						spinosum (= *ornatum* auct.)		
		duncani	*duncani*	*duncani* (with *athleta* and *proniæ*)	*duncani*		*duncani*	*duncani*
	ornatum							
KOSMOCERATAN (*ornatum* or *athleta* zone s.l.)		*reginaldi* (with *castor* and *pollux*)	*castor*		*reginaldi*		*castor*	*reginaldi* (with *coronatum*, *castor* and *pollux*)
	coronatum	*coronatum*	*coronatum*			*castor* and *pollux* (with *coronatum*)	*coronatum*	
		elizabethæ or *jason*	*elizabethæ*	*fraasi* (with *castor* and *pollux* and *coronatum*)	*stutchburii*		*elizabethæ*	
	anceps							
			conlaxatum (with *jason*)			*jason* (= *conlaxatum*)	*conlaxatum*	*jason* (= *conlaxatum*, with *elizabethæ*, &c.)
REINECKEIAN (*anceps* zone s.l.)	*calloviense*			*anceps* (with *calloviense* and *gulielmi*)	*calloviense*		*calloviense*	*calloviense*
	kœnigi			*rehmanni* (with *königi*)	*kœnigi*		*kœnigi*	*kœnigi*

CHAPTER XII

OXFORD CLAY AND KELLAWAYS BEDS

Zones (Plates XXXVI–VII).	*Strata.* *Dorset–Humber.*		*Strata.* *Yorks.*	
Cardioceras præcordatum [1]	OXFORD CLAY	Clays with ammonites chiefly as pyritic casts.	Basal Lower Calc. Grit.	
Creniceras renggeri [2]	OXFORD CLAY	Clays with ammonites chiefly as pyritic casts.	OXFORD CLAY	'Kelloway Rock' auctt.
Quenstedtoceras lamberti [3]	OXFORD CLAY	Clays with ammonites chiefly as pyritic casts.	OXFORD CLAY / HACKNESS ROCK	'Kelloway Rock' auctt.
Peltoceras athleta	OXFORD CLAY	Clays with ammonites chiefly as pyritic casts.	HACKNESS ROCK	'Kelloway Rock' auctt.
Kosmoceras duncani	OXFORD CLAY	Clays with ammonites chiefly as pyritic casts.	HACKNESS ROCK	'Kelloway Rock' auctt.
Erymnoceras reginaldi [4]	OXFORD CLAY	Shaly clay with compressed Kosmocerates	HACKNESS ROCK	'Kelloway Rock' auctt.
Kosmoceras jason [5]	OXFORD CLAY	Shaly clay with compressed Kosmocerates	HACKNESS ROCK	'Kelloway Rock' auctt.
Sigaloceras calloviense	KELLAWAYS ROCK		?	'Kelloway Rock' auctt.
Proplanulites kœnigi	KELLAWAYS CLAY		KELLAWAYS ROCK & SHALES 50 ft. +	'Kelloway Rock' auctt.

I. DORSET TO THE MARKET WEIGHTON AXIS

(a) The Dorset Coast

THE Oxford Clay, like the other Jurassic rocks outcropping at Weymouth, covers a small area completely separated from the main outcrop to the north by the overstepping Chalk of the Downs. The low ground floored by the soft Oxford Clay has been hollowed out from the east to form Weymouth Bay, behind which lie the Lodmoor Marshes and the Radipole Backwater.

[1] This species was described by R. Douvillé, first as a *Cardioceras*, then as a *Quenstedtoceras*; but, although its characters are said to be to some extent intermediate, Douvillé's figures show it to be a typical cordate *Cardioceras*; indeed, he said that it passed by insensible gradation into *Cardioceras cordatum* (1912, *Mém. Soc. géol. France*, vol. xix, p. 62, pl. IV, figs. 10–20); see also Morley Davies, *Geol. Mag.*, 1916, p. 397, and Buckman, *T.A.*, vol. v, 1924, p. 32. As a zonal index it replaces '*scarburgense*' auctt., the true *scarburgense* having proved to be something different (Buckman, *T.A.*, vol. v, 1924, p. 32). The zone was originally called the Pre-*cordatus* zone by Buckman (1913, *Q.J.G.S.*, vol. lxix, p. 159).

[2] Between the *renggeri* and *præcordatum* zones Buckman placed three zones, ***vertumnus***, ***gregarium*** and ***vernoni***, found only in Yorkshire. It is not fully known to what extent any or all of these are contemporary with the faunas south of the Humber, but the *vernoni* zone may safely be regarded as synonymous with the *præcordatum* zone and probably the other two with the *renggeri*.

[3] Made genotype of *Bourkelamberticeras* Buckman, 1920, *T.A.*, vol. iii, p. 17. (Synonym.)

[4] Introduced by Morley Davies, *Geol. Mag.*, 1916, and retained by him in the *Handbook of the Geology of Great Britain*, 1929. It is equivalent to Buckman's zone of *Erymnoceras coronatum*, which corresponds according to Brinkmann with the maximum of *Kosmoceras castor* and *K. pollux*.

[5] According to Brinkmann (1929), *Kosmoceras conlaxatum* Buckman, which was used as index of the basal zone of the Oxford Clay by Neaverson, is a synonym of *K. jason* Reinecke, which therefore takes priority. The zone as used here includes the *elizabethæ* zone of Morley Davies (1916) and Neaverson (1925), *K. elizabethæ* (Pratt) being according to Brinkmann (1929) synonymous with *K. ornatum* (Schloth.) *non auctt.* Morley Davies (1929) chose *Kosmoceras stutchburii* (Pratt) as index, but according to Brinkmann that species is a synonym of *K. gulielmii* (Sowerby). Note: the *lamberti* to *præcordatum* zones comprise Oppel's zone of *Am. biarmatus*.

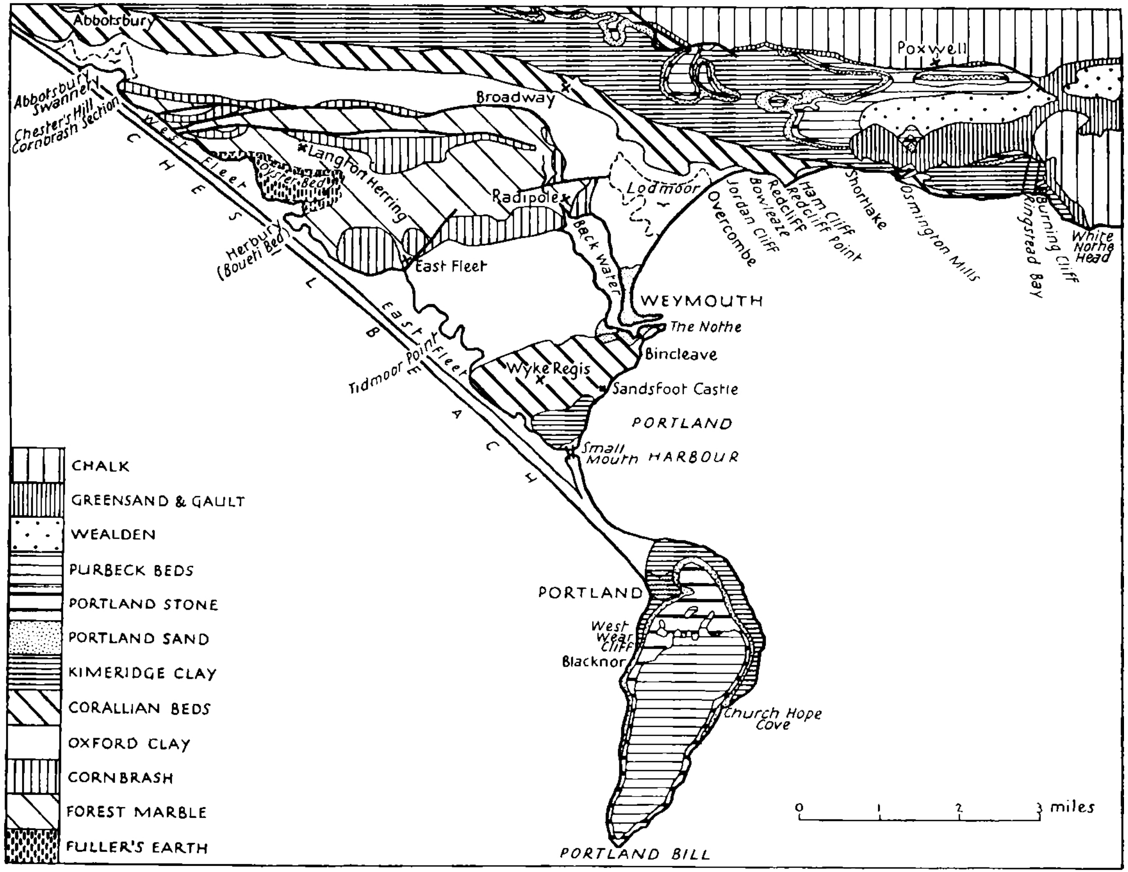


FIG. 61. Sketch-map of Weymouth and Portland.

The clay underlies the bay from Redcliff and Jordan Hill in the north to the entrance to the harbour in the south, and in both directions it dips below sea-level under the Corallian Beds. Thus the lowest zones rise to the surface in the centre of the bay, where there are no exposures, only an esplanade separating the sea from the town and the marshes.

Only at the north end of the bay, under Jordan Hill (between Overcombe and Bowleaze) and on the east side of Redcliff Point (Ham Cliff) are there any natural cliff-sections; here the upper half of the clay is exposed, from the junction with the Corallian down to the *lamberti* zone. These zones occupy about half the total thickness of the Oxford Clay and Kellaways Beds, which has been estimated to reach about 500 ft. The old exposure at the south end of the bay has been obliterated by the fortification of the Nothe.

The base of the Lower Calcareous Grit, and so of the Corallian formation, falls in the midst of the Cardioceratan deposits. The grits become bluish-grey and argillaceous downwards, but there is nevertheless a sharp lithic change to the grey, soapy Oxford Clay below. Immediately beneath the grit at Ham Cliff and Jordan Cliff, and faulted up to sea-level at the end of Redcliff Point, are the RED NODULE BEDS.[1] These clays contain, as their name implies, lines of red claystone nodules, which occasionally enclose fossils: the types of *Modiola bipartita* Sowerby and *Thracia depressa* (Sow.) were obtained from them over a century ago. The beds are most conspicuous, however, by reason of the large quantities of *Gryphæa dilatata* which they contain, often of great size.

Below the Red Nodule Beds, and forming the greater part of Jordan Cliff, are thick clays which Buckman named the JORDAN CLIFF CLAYS. These are also full of large specimens of *Gryphæa dilatata*, of which they are, indeed, the chief repository. They yield in addition a fauna of small Cardiocerates, denoting the lower part of the *præcordatum* zone, and the large *Peltoceratoides hoplophorus* (S. Buck.).[2] The Red Nodule Beds are presumed to be the upper part of the same zone.

The lowest clays of all exposed on the coast north of Weymouth are seen for a short distance beneath the fault east of Redcliff Point. They belong to the *lamberti* zone (see fig. 65, p. 382).

Lower zones, down to the Kellaways and Cornbrash, are to be seen sporadically in small banks around the north shore of Radipole Backwater, but it is difficult to make out the sequence.

Westward the Weymouth Anticline brings Cornbrash, Forest Marble and Fuller's Earth to the surface, dividing the Oxford Clay into two strips, dipping away north and south. The northern strip is narrow and strikes the West Fleet backwater at Abbotsbury Swannery, where the shore is shelving and affords no exposure. The southern strip is shorter and twice as broad, but the coast-sections along the East Fleet are poor and discontinuous owing to the protective action of the Chesil Beach; while the harder rocks often form low cliffs, the clays tend to melt down in grassy banks. There are a number of small exposures, however, the best of which is at Tidmoor Point, behind

[1] Called by Buckman the Red Beds, an inappropriate name, preoccupied by Damon for Corallian deposits higher in the same cliffs.

[2] *T.A.*, 1925, pl. DLXIV, and 1927, pl. DCCIII (named '*Peltomorphites*', a synonym of *Peltoceratoides* according to Spath, 1931, *Pal. Indica*, N.S., vol. ix, p. 558).

the rifle-range. Here the clays of the *lamberti* zone crop out in a low, slipped cliff, and yield pyritic Quenstedtocerates.[1] There is also a band of small *Oxytoma*, belemnites, &c. Buckman distinguished the clays here as the TID(E)MOOR POINT BEDS, and correlated them with the lowest clays seen east of Redcliff Point.[2]

The lower zones are ill-exposed on the shore and the Kellaways Beds are probably carried below sea-level by a fault at East Fleet village. Two large brickyards less than a mile inland, south of Chickerell, however, display magnificent sections of several zones. The more westerly brickyard, half a mile due south of Chickerell Church, shows a 60 ft. face of shaly clays with crushed Kosmocerates and small bivalves (*Nucula*, &c.), principally belonging to the *duncani* zone. At many levels there occur sporadically large flattened spheroidal septaria, some of which contain badly preserved ammonites suggestive of *Erymnoceras reginaldi*. One dogger of intensely hard stone found somewhere low down in the pit, of much harder, more splintery matrix than the rest, was crowded with *Erymnoceras coronatum* in good preservation (*reginaldi* zone).

The more easterly brickyard (that of the Dorset Brick, Stone and Ball Clay Co.), at a lower level, shows one of the best sections of the Kellaways Beds in the South of England. At the top of the pit is the Kellaways Rock—sand and yellow sandy clay with doggers and lenticles of hard sandstone, crowded with *Gryphæa bilobata* Sow. Below are dug some 10 ft. of blue Kellaways Clay full of *Proplanulites* spp., *Cadoceras sublæve* (Sow.) and *Cadoceras tolype* Buck. There are also numerous small round nodules, some of which are crowded with beautifully preserved shells of an *Oxytoma*.

Small faulted tracts of Oxford Clay occur a short distance inland almost as far west as Bridport and from a faulted patch beneath the Fleet many fossils weather out and are cast up on the beach west of Langton Herring.[3] At Compton Valence, in the midst of the downs, a diminutive inlier has been brought to light by the erosion of a valley in the Chalk.

(b) North Dorset and Wiltshire: the Vale of Blackmoor to the Vale of the White Horse

From its emergence on the north side of the Dorset Downs the Oxford Clay forms all along its outcrop a continuous low-lying vale, most of which was until a few centuries ago thickly forested. The Blackmoor Vale in the south merges northward into the timbered vales of Penselwood and later of Braydon Forest, which leads on to the Vale of the White Horse, forming the valley of the Upper Thames as far as Oxford. Braydon Forest, lying between Malmesbury, Cricklade and Chippenham, was not cleared until the reign of Charles I, and both there and in Penselwood extensive areas of woodland still remain.

Throughout this tract the Oxford Clay and Kellaways Beds vary little in thickness, totalling from 550 to 600 ft., or a little more than on the Dorset coast. The estimated thickness in the south is 560 ft., while the Westbury boring proved 600 ft., and the Swindon boring 573 ft.

[1] Specimens are figured in *T.A.*, 1920, pl. CLIV; 1922, pl. CCCXXXIX; 1925, pl. CLIV A.
[2] S. S. Buckman, *T.A.*, 1923, vol. iv, p. 41; and 1925, vol. v, p. 66.
[3] W. J. Arkell, 1932, *Geol. Mag.*, vol. lxix, pp. 44–5.

Exposures are nowadays neither numerous nor very instructive, being limited to a few scattered brickyards. In the past, however, more or less complete sections have been furnished by railway-cuttings, long since grassed over. Three of these were fully described, and two became famous for the abundance of perfectly preserved ammonites and belemnites which they yielded. The main G.W.R. line from Swindon to Bath, built in 1840–1, passed over Oxford Clay for 10 miles between Wootton Bassett and Chippenham. For most of this distance the line was raised on an embankment and to obtain materials long pits were dug beside the railway. The pits are now lakes filled with rushes and water-lilies, but during their excavation they yielded many hundreds of fossils to local collectors.

The richest harvest of all was reaped in a cutting near Christian Malford, 4 miles from Chippenham, where the lower shales of the Oxford Clay (*jason–duncani* zones) were laid bare. S. P. Pratt [1] described some of the ammonites from here, and scores of specimens, flattened but otherwise perfectly preserved, have found their way into museums all over the country. Most of Pratt's types have recently been figured by Buckman in the last parts of *Type Ammonites*. They include the familiar species *Kosmoceras elizabethæ*, *K. stutchburii*, and *K. sedgwicki*, all of which Brinkmann has recently declared to be nothing more than varieties of other forms previously named (*K. ornatum* Schloth., *K. gulielmii* Sow. and *K. jason* Reinecke). The belemnites, *Cylindroteuthis puzosi* (d'Orb.) [= *B. owenii* auct.] and *Belemnopsis hastatus* (Blainv.) were sometimes found with their ink-sacs preserved.

The second cuttings were made on the Weymouth branch of the G.W.R. at Trowbridge, and were described by R. N. Mantell and the fossils by G. A. Mantell and John Morris in 1848–50.[2] From here Morris figured the type of *Erymnoceras reginaldi* (named after Reginald Mantell). Although the deepest cuttings average only 14 ft. in depth, they exposed about 45 ft. of the Lower Oxford Clay, up to at least the *reginaldi* and probably the *duncani* zone, as well as the Kellaways Beds. From the latter large quantities of *Sigaloceras calloviense* and *Proplanulites kœnigi* were obtained, while in the overlying shales the crushed ammonites and belemnites were as abundant as at Christian Malford, and much lignite was found.

The most recent cuttings were made in 1898, during the construction of the G.W.R.'s South-Wales-Direct line, which crossed Oxford Clay for 9 miles west of Wootton Bassett. For most of this distance the line was raised on an embankment, but this time no pits were dug as abundant material was available from the cuttings and tunnel which were being driven through the Forest Marble and Great Oolite farther west. Several cuttings were, however, made in the Oxford Clay and were described by H. B. Woodward, and again four years later by Messrs. Reynolds and Vaughan.[3]

Immediately west of Wootton Bassett Railway Station, under the bridge, the highest $9\frac{1}{2}$ ft. of the Oxford Clay was seen below the Corallian, but the only fossil found was a *Thracia*. This clay may be a lateral replacement of what is

[1] S. P. Pratt, 1841, *Ann. Mag. Nat. Hist.*, N.S., vol. viii, pp. 161–5. The best account of the cuttings and their fossils is by Oppel, in *Die Juraformation*, pp. 535–6.

[2] R. N. Mantell and J. Morris, 1850, *Q.J.G.S.*, vol. vi, pp. 310–19; G. A. Mantell, 1848, *Phil. Trans. Roy. Soc.*, vol. cxxxviii B, pp. 171–83.

[3] H. B. Woodward, 1899, *Sum. Prog. Geol. Surv.* for 1898, pp. 188–92; S. H. Reynolds and A. Vaughan, 1902, loc. cit.

elsewhere Lower Calcareous Grit sands. Ammonites indicating the Cardioceratan zones, and also *Quenstedtoceras lamberti*, were found in a cutting near Brinkworth, while farther west, 1½ miles east of Somerford Railway Station, another cutting showed the shaly Lower Oxford Clay, with *Kosmoceras jason* and other species of the zone. A brick pit at Rodbourne near by still displays the *reginaldi* zone, with crackers from which large specimens of the index fossil, measuring over 1 ft. in diameter, may be obtained. Another brickpit at Purton is also still worked, but there the clay is singularly barren. Prof. Morley Davies tells me that prolonged search resulted in his finding one ammonite, identified by Buckman as *Cardioceras dieneri*,[1] and denoting the *præcordatum* zone.

The best cutting on this line was that at the west end of the outcrop, passing through Bancombe (or Bincombe) Wood, between Rodbourne and Kingway Barn, near Corston. This laid bare the whole of the Kellaways Beds. The Kellaways Rock was represented by 10–20 ft. of poorly fossiliferous sandy and loamy beds, overlying 20 ft. of Kellaways Clay with septaria. From the latter abundant *Proplanulites kœnigi* were obtained, with *Gowericeras gowerianum* (also denoting the *kœnigi* zone).

The thickest development of the Kellaways Rock exposed in the West of England was seen in a short cutting on the Midland and South-Western Junction Railway at South Cerney, near Cirencester, described by Harker. Here 22 ft. of yellow sands and ferruginous brown sands with nodules and large doggers were passed through. Fossils were again almost entirely absent.[2]

In other places where temporary openings have been made in the Kellaways Rock it has sometimes proved highly fossiliferous, although it is frequently much thinner—a variability remarked on by William Smith. An altogether peculiar development was described by Richardson[3] at Calcutt, near Cricklade, where a well proved above the Cornbrash 18 ft. of Kellaways Clay, followed by 18 ft. of Kellaways Rock (very hard calcareous sandstone), overlain in turn by 13 ft. of clay and then 25 ft. of fine-grained grey sand. If all these are rightly included in the Kellaways Beds, their total thickness there is 74 ft. The only comparable record is that of the deep boring at Swindon, where the Kellaways Beds were said to be 60 ft. thick, and where both of the zone fossils were found.[4]

The best locality for studying the fossiliferous facies of the rock is still the old type-locality at Kellaways, 2 miles north-east of Chippenham. The exposures are disappointing on a casual visit, consisting of mossy banks and projecting rocks in the side of the River Avon, and to study them it is necessary to stand in the river with waders. The best sections are in the banks of an artificial watercourse north-east of Peckingell Farm, about half a mile below Kellaways Bridge, and also in the main river near by. The rock is from 3 ft. to 6 ft. thick, the upper part being a mass of fossils embedded in brownish micaceous sandstone. Both the palaeontological and the lithological facies are very suggestive of some of the Upper Cornbrash. In order of abundance the principal fossils are: *Microthyris ornithocephala* (Sow.), *Gryphæa bilobata*

[1] 1925, *T.A.*, vol. v, p. 66. (The lower record attributed to him on the same page is a mistake and should be deleted; see the *errata*.)

[2] A. Harker, 1884, *Proc. Cots. N.F.C.*, vol. viii, pp. 176–87.

[3] L. Richardson, 1922, *Geol. Mag.*, vol. lix, pp. 354–5.

[4] H. B. Woodward, 1895, *J.R.B.*, p. 37.

Sow. (some very small, not much larger than the Microthyrid), *Pleuromya recurva* (Phil.), *Rhynchonelloidea socialis* (Dav.), *Modiola bipartita* (Sow.), *Camptonectes lens* (Sow.), *Pseudomonotis* sp. and *Oxytoma expansa* (Phil.), with others less common. In William Smith's time the rock was quarried for road-metal in several small pits about Kellaways, but these have long since been filled in or obliterated. Two brickyards south of Chippenham still show sections of the upper part, more sandy and less fossiliferous. *Gryphæa bilobata* is nearly everywhere the commonest fossil.[1]

(c) Oxford to Bedford and Huntingdon

The Oxford Clay continues from the Vale of the White Horse with little appreciable change past Oxford and under the low-lying tracts of Bedfordshire to the Fens. Everywhere it forms flat and heavy land, except where along the northern or western fringe the Kellaways Rock is developed, rising into a low escarpment above the Cornbrash. Through Wiltshire and Berkshire the highest zones build the base of the ridge of Corallian sands and limestones, and here their outcrop is very narrow and exposures are lacking. These conditions are changed somewhat to the east of Oxford owing to the disappearance of the Corallian, or rather its passage into clay, and the clays immediately underneath it have a wider outcrop and are occasionally seen in brickyards.

There are no natural lines of demarcation between adjacent parts of the clay belt from the Dorset coast to the Market Weighton Axis, but since this tract is too large to describe as a whole, arbitrary divisions have to be chosen. A convenient district for separate treatment is the type locality of Oxford and the adjoining counties to the east, where the zonal sequence has been elucidated in some detail. It is a district too, which is remarkable for an easterly overstep of the upper zones of the Oxford Clay by the equivalents of the Corallian (Argovian). This unconformity was detected by Prof. A. Morley Davies, who showed in 1916 that about Ampthill, Sandy and Woburn the *martelli* zone of the Argovian rests directly on the *renggeri* zone of the Oxford Clay, the whole of the Cardioceratan and part of the Quenstedtoceratan strata having been cut out (fig. 62, p. 348).

At Oxford the total thickness has been estimated at about 450 ft. It is probable that the easterly overstep of the Corallian in Buckinghamshire and Bedfordshire reduces the Oxford Clay considerably, but still farther east it probably thickens again, for 300 ft. was proved at Bluntisham, and H. B. Woodward considered 500 ft. a reasonable estimate for the Huntingdon district.[2]

Immediately north-east of Oxford the Oxford Clay forms the low-lying tract known as Otmoor, which was an undrained swamp until 1825–30, and is still waterlogged for a large proportion of the year. The highest zones crop out round the southern fringe of Otmoor and about the projecting hills at Brill.

[1] A representative selection of the ammonite fauna of the Kellaways Rock type-locality has been figured from time to time by Buckman, *T.A.*, pls. CCXXVIII, CCLV, CCLXXV, CCXC, CCXCIII, CCXCIV, CCCLXXIX, DVII, DXXXVII, DXXXVIII, DLXXXVI, DLXXXVII, DCXIV, and a revised list of all the fossils by J. Pringle and S. S. Buckman is to be found in the 'Geol. Marlborough', 1925, *Mem. Geol. Surv.*, pp. 11–12. Another revision is needed already, however.

[2] 1895, *J.R.B.*, p. 56.

SUMMARY OF THE OXFORD CLAY ABOUT OXFORD

Præcordatum Zone. The actual junction with the Lower Calcareous Grit can nowhere be seen, though it was formerly exposed in a brick-pit at New Marston, to the west of the Cherwell (in the outskirts of Oxford), and has several times been pierced by wells. One well was described by Prof. Morley Davies at Studley,[1] where the Arngrove Stone (basal Corallian, *cordatum* zone) rested on clay with finely-ribbed Cardiocerates of the *tenuicostatum* type, which he found in several places to characterize the upper part of the *præcordatum* zone. He also described the same horizon in the G.W.R.

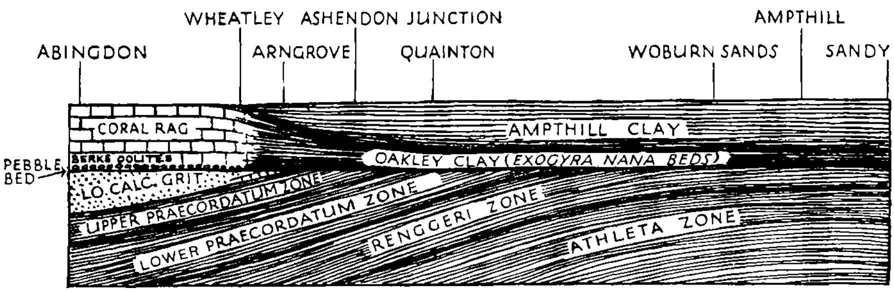


FIG. 62. Diagrammatic section from the borders of Berkshire and Oxfordshire into Bedfordshire showing the unconformity at the base of the *martelli* zone. (Adapted from Morley Davies, *Geol. Mag.*, 1916, p. 399, with alterations to the Corallian part.)

cutting immediately north of the tunnel in Rushbeds Wood, near Brill, where the ammonites[2] were associated with *Gryphæa dilatata* Sow. and its variety *discoidea* Seeley.[3]

The best section of the *præcordatum* zone is opened at a lower level in the zone, at Studley (or Horton, or Horton-cum-Studley) brickyard, by the roadside ½ mile south-east of the village. Ten feet of clay are seen, in which are hundreds of large Gryphæas. When collected in large numbers they can be arranged in lines connecting up several forms usually regarded as distinct species, especially *G. dilatata* Sow., *G. discoidea* (Seeley), *G. controversa* Roem., and *G. exaltata* Rollier. The pit is principally noteworthy, however, for yielding numerous well-preserved Cardiocerate ammonites in the form of attractive brown or ochreous casts, which display the suture lines to advantage. They include *C. præcordatum* R. Douv., *C. cardia* Buck., *C. costellatum* Buck., *C.* cf. *quadratoides* Nikitin, all species of rather stout proportions as compared with the fine-ribbed *tenuicostatum*-like species found in the higher part of the zone. There are also minute Perisphinctids, and the genus of *Cardioceras*-like ammonites which Buckman named after this locality, *Hortoniceras*. Prof. Morley Davies records that the *præcordatum* zone was also exposed in the brickyard near Quainton Road junction, and in a cutting on the Great Central Railway north of Wotton Railway Station (ENE. of Brill).[4]

Renggeri and Lamberti Zones. These zones are the least often

[1] A. M. Davies, 1907, *Q.J.G.S.*, vol. lxiii, p. 40.
[2] Originally recorded as *C. cordatum* and distinguished later.
[3] A. M. Davies, 1907, *P.G.A.*, vol. xx, p. 185.
[4] A. M. Davies, 1916, *Geol. Mag.* [6], vol. iii, p. 397.

seen of all in the district, but they were studied by Prof. Davies in the Ludgershall railway-cutting north of Brill and numerous fossils were collected. There was a well-marked zone of *Creniceras renggeri*, but no evidence for a separate *lamberti* zone was seen, *Quenstedtoceras* and *Creniceras* being mixed throughout.[1] Prof. Davies pointed out that, except for the absence of Phylloceras, the greater abundance of *Quenstedtoceras* and the presence of *Kosmoceras*, there was a remarkable resemblance between the fauna of this zone at Ludgershall and equivalent beds in the Bernese Jura, described by de Loriol.[2] The Bernese fauna was later obtained at the same horizon in the borings for coal in Kent.

The *renggeri* zone is also worked in the upper part of the brickfield at Woburn Sands and either the *renggeri* or the *lamberti* zone again at Sandy, Beds., in the region where the higher strata are missing and the *martelli* clay of the Corallian rests upon it non-sequentially. At Oxford the *renggeri* and/or *lamberti* zones were at one time exposed at Summertown, but the great clay pit is now derelict. There are still indications of the base of the *lamberti* zone in the form of rare occurrences of *Quenstedtoceras* in the very top of the pit at Wolvercote.

Athleta Zone. The *athleta* zone is well exposed in the large brickyard at Wolvercote, on the north side of Oxford.[3] *Peltoceras athleta* occurs near the present base of the pit, in a band of clay 2½ ft. thick, overlying a 6-in. band of cementstone. Dr. J. Pringle restricts the zone to these two beds, giving it a thickness of only 3 ft. The characteristic fauna besides the zone fossil comprises the small, much incoiled, and almost equilateral *Gryphæa lituola* Lamk., together with the brachiopods *Aulacothyris bernardina* (d'Orb.) and *Rhynchonella spathica* (Lamk.). The same *Gryphæa* and *Aulacothyris* were found by Prof. Davies to characterize the zone in the Ludgershall railway-cutting and again in Woburn Green brickyard. At Wolvercote 18 ft. of clays with a band of cementstone succeed the horizon at which this fauna is found, thus comprising the greater part of the section now exposed. The fauna includes three species of *Peltoceras*, but not apparently *P. athleta*; and as it is chiefly characterized by Kosmocerates of the *proniæ* and *subnodatum* types Dr. Pringle has considered it a separate zone of *K. proniæ* Teisseyre. Its separation has not, however, been substantiated by studies in other districts, and it is more convenient to consider it, on the strength of its Peltocerates, as a part of the *athleta* zone. The range of *Kosmoceras proniæ*, according to Brinkmann, extends from the top of the *athleta* zone down to the upper limit of the true *castor* and *pollux* (our *reginaldi*) zone.

Duncani to Jason Zones. The Lower Oxford Clay or typical Kosmoceratan, from the *duncani* zone down to the top of the Kellaways Rock, is nowhere well exposed near Oxford, though the top of the *duncani* zone is sometimes reached in the base of the Wolvercote brickyard and was formerly exposed in the Summertown pit. The presence of the *jason* zone was proved in 1924 by a boring at Gosford Hill, Kidlington, where Dr. Pringle found *Kosmoceras stutchburii* (Pratt) and *K. effulgens* Buck.[4] (? = *jason*).

[1] A. M. Davies, 1916, loc. cit., p. 396.
[2] 1898–1900, *Mém. Soc. pal. Suisse*, vols. xxv–xxvii.
[3] J. Pringle, 1926, 'Geol. Oxford', 2nd ed., *Mem. Geol. Surv.*, p. 36.
[4] J. Pringle, 1926, loc. cit., p. 35; and S. S. Buckman, 1925, *T.A.*, pl. DXCVII.

The best exposures of the Oxford Clay in the central part of England (south of the Peterborough district) are in the lower zones at Calvert, near Claydon, 5 miles south of Buckingham (Pl. XV) and at Bletchley. Here enormous brick-pits have grown up since the coming of the railway in 1898, when a branch brickworks was started at Calvert by Messrs. Itter of Peterborough. The beds dug are the shaly clays of the *reginaldi* and *jason* zones, with their hundreds of crushed and iridescent ammonites. The deep borings, for which Calvert is renowned, were started, one in the floor of the main pit, about 70 ft. below surface, the other nearly at ground level.[1] They passed through 32 ft. of clays below the floor of the pit, making 97 ft. of Oxford Clay in all. The only ammonites encountered were *Kosmoceras sedgwickii* (Pratt) (? = *jason* Rein.), and *K.*? *stutchburii* (Pratt); and judging by these fossils and because the clays rested directly on the Bathonian limestones, it was presumed that the Kellaways Beds were missing, as was definitely the Cornbrash. In view of the great thickness of the clays, however, the possibility must not be lost sight of that the Kellaways Beds may be represented but unfossiliferous.

The lower zones of the Oxford Clay are repeatedly well exposed in extensive brickworks at Charndon and Bletchley, Bucks., and Wootton Pillinge (Stewartbury), Beds. At the last two places the pits or 'knot holes' are of vast extent and present a vertical face 70 ft. deep, but in spite of these facilities for study, the elucidation of the successive faunas still remains unattempted. The type specimen of *Kosmoceras duncani*, figured by Sowerby, came from St. Neots.

Calloviense and **Kœnigi Zones** (KELLAWAYS BEDS). The Kellaways Beds seem to be feebly developed from the neighbourhood of Cirencester through the Thames Valley, for they have hardly ever been exposed.

In the Shipton-on-Cherwell railway-cutting north of Oxford, 5 ft. of yellow and grey sands overlay 10 ft. of clay above the Cornbrash, and a similar section is still visible at Akeley brickyard, north of Buckingham. At the latter place A. H. Green many years ago recorded *Proplanulites kœnigi*.[2]

About Bedford the Kellaways Beds regain considerable importance. Numerous sections have shown in the past that the sands are about 10 ft. thick and contain large concretionary doggers of grey-hearted sandstone like those at South Cerney near Cirencester, and yielding *S. calloviense*, *Gryphæa bilobata*, *Oxytoma expansa*, *Pleuromya recurva*, *Camptonectes lens*, *Entolium demissum* and lignite. Beneath is about the same thickness of stiff Kellaways Clay, from which *Gowericeras gowerianum*, mentioned in the old lists, probably came. The beds can still be seen in the waterworks pit, but one of the best exposures was in the Midland Railway cutting north of Oakley Railway Station, now overgrown.

A boring at Bletchley in 1887 encountered pebbles and blocks of granitic rocks in what Jukes-Browne, Cameron and later H. B. Woodward supposed to be the Kellaways Rock, thickened to 54 ft. This view was accepted until 1913, when the Calvert borings, not many miles away, enabled Prof. Morley Davies to revise the interpretation of the Bletchley record and to show that the granitic rocks are much more likely to have belonged to the base of the

[1] The site of the boring from which gas rose under pressure has been covered up by tip-heaps.

[2] A. H. Green, 1864, 'Geol. Banbury, Woodstock, &c.', *Mem. Geol. Surv.*, p. 41.

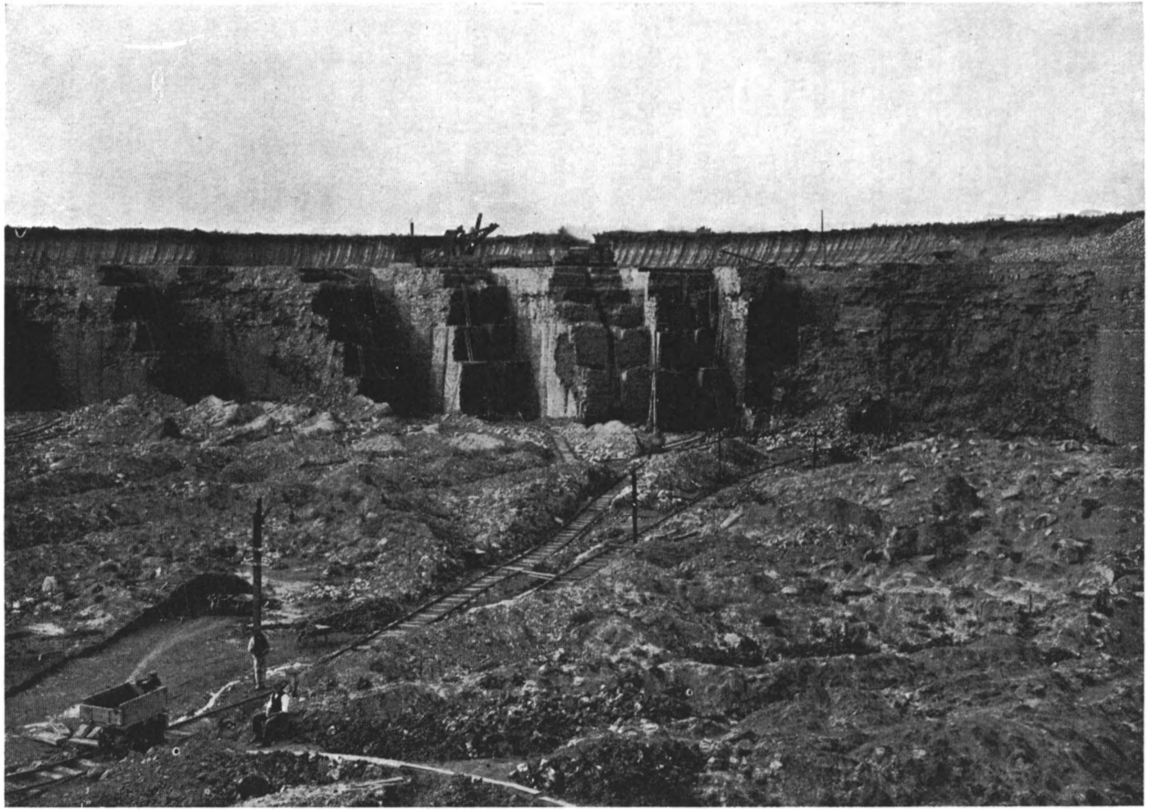


Photo. *Geol. Survey.*

Lower Oxford Clay, Calvert Brickyard, Bucks.

The photograph shows the face being worked by hand in stages, a system now replaced by steam excavators (of which a small one is seen on the top, removing overburden).

PLATE XV

attenuated Lower Lias, on, or not far above, the Palaeozoic floor.[1] This was in accordance with the expectations of Prof. Kendall, who had in 1905 suggested that formations lower than the Kellaways were probably present.[2]

(d) Peterborough and the Fens to the Humber

The Oxford Clay underlies large areas of the Fens, sometimes protruding through the alluvium as islands, as at Whittlesey and Ramsey. Northward through Lincolnshire the outcrop gradually narrows, but there is only a gradual decrease in thickness towards the Humber, for in North Lincolnshire the thickness is still in the neighbourhood of 300 ft. Towards the east attenuation is more rapid. A boring at Southery, in the Norfolk Fens, proved only 200 ft., with complete absence of the Kellaways zones.[3]

A large proportion of the outcrop is masked by deep deposits of alluvium and Drift. This applies especially to the Fenland and its borders, and also to the valley of the Ancholme, draining into the Humber in the north. The few railway-cuttings of the past have all been opened along the western margin of the outcrop, and have shown only the lowest zones of the clay and the Kellaways Beds. On the whole, exposures of the Upper Beds are small and scattered, and with the extinction of local brick-making industries most of the small pits mentioned by the earlier writers have become grassed over.

The Middle and Lower Oxford Clay, at least in the Peterborough district, are now exposed far more completely than ever before. This is due to the growth within the present century of an enormous brick-making trade, centred around that town on account of the good railway transport which it affords. Fletton, Kingsdyke, Yaxley, and indeed the whole landscape in the vicinity of Peterborough, are now dominated by a forest of chimneys, and the very name of Peterborough recalls bricks. The huge clay pits, like those at Calvert but duplicated many times, have to some extent compensated the geologist for the loss of the local exposures whose decline and extinction all this centralization has brought about. But the compensation is not all that could be desired, for whereas the old local industries gave information concerning many zones over the length and breadth of the outcrop, the new excavations, although far larger, all show about the same part of the formation and they are concentrated around one locality. However, the opportunities for studying the succession of ammonite faunas which the Peterborough brick industry has provided are held to be the best in Europe, and a study of them has revolutionized our knowledge of the lower zones of the Oxford Clay.

For records of the highest zones, in the absence of recent research, and in view of the probability that investigations would not now yield much new information, it is necessary to resort to the accounts of Judd and Roberts and other writers of the last century.

J. W. Judd recognized an upper group of clays 'with Ammonites of the group of the *cordati*', but stated that it was usually concealed by Drift. This division was exposed to a depth of 40 ft. north of Bardney Railway Station, east of Lincoln, and judging from the ammonites recorded (allowing for archaic

[1] H. B. Woodward, 1895, *J.R.B.*, p. 49, with refs.; A. M. Davies, 1913, *Q.J.G.S.*, vol. lxix, p. 332.
[2] P. F. Kendall, 1905, *Report of Royal Commission on Coal Supplies*, p. 195.
[3] J. Pringle, 1923, *Sum. Prog. Geol. Surv.* for 1922, pp. 126–39.

nomenclature) it represents the *præcordatum* zone and perhaps some slightly earlier strata.[1] '*Ammonites cordatus*' and '*A. lamberti*' were also recorded from a small brickyard at Langworth, north-east of Lincoln, where the base of the *præcordatum* and the top of the *renggeri* or *lamberti* zones may be presumed to have been seen. The *lamberti* zone also appears to have been worked at Timberland, Lincs. There are records of '*Ammonites*' [*Hecticoceras*] *hecticus* at Langworth [2] and near Cambridge, in which neighbourhood also Cardiocerates of the *præcordatum* zone abound in the Oxford Clay; while Prof. Davies informs me that he has seen specimens of *C. renggeri* from St. Ives.

The old records are too untrustworthy to base on them any conclusions as to the presence or absence of separate zones of *renggeri* and *lamberti*, but modern evidence is forthcoming at Eye Green, north-east of Peterborough. Here Dr. Neaverson has described the clays at the top of the pit as yielding a fauna of the coarser-ribbed and feebly-rostrated Quenstedtocerates of the type of *Q. lamberti*, without *Creniceras* but with *Hecticoceras*.[3] This he interprets as confirmation of Buckman's suggestion that there should be a *lamberti* horizon below and separate from the *renggeri* zone. Thus the evidence at Eye Green contradicts that of the Buckinghamshire railway-cuttings examined by Prof. Morley Davies and illustrates how different zonal schemes are likely to be evolved by the several palaeontologists working in different districts.

The whole of the remaining zones down to the base of the Oxford Clay are exposed several times in the great brick pits around Peterborough, at Eye Green, Kingsdyke, Fletton, Farcet, &c. There is wide difference of opinion concerning the interpretation of the detailed ammonite succession. In 1925 Dr. E. Neaverson published a valuable paper in which he set forth a zonal classification as follows, in descending order: [4]

lamberti
athleta
duncani
castor
coronatum
elizabethæ
conlaxatum (with *jason*)

In the following year Dr. R. Brinkmann, having obtained a grant from the Academy of Sciences at Göttingen, spent some two months at Peterborough collecting the ammonites *in situ* and studying them by the most painstaking statistical methods. In 1929 he published a lengthy report on the results, followed by a monograph on the genus *Kosmoceras*.[5] The report contains 250 pages, 129 tables and 55 diagrams, in which the object, methods and conclusions are set forth. Since they concern the whole principles of the zonal classification of the Oxford Clay, they must receive attention before any more can be said.

Brinkmann set out with the object of determining accurately the succession

[1] In confirmation of this Prof. Davies informs me that he has purchased *renggeri* forms bearing Bardney labels.
[2] J. W. Judd, 1875, 'Geol. Rutland', *Mem. Geol. Surv.*, pp. 232–9.
[3] E. Neaverson, 1925, *P.G.A.*, vol. xxxvi, pp. 27–37.
[4] E. Neaverson, 1925, loc. cit.
[5] R. Brinkmann, 1929, *Abh. Gesell. Wiss. zu Göttingen*, N.F., vol. xiii, parts 3 and 4, 373 pp., and see review in *Geol. Mag.*, 1931, vol. lxviii, pp. 373–6.

of the innumerable forms of *Kosmoceras* contained in the clays, using minute quantitative methods to define them. He confined his attention to three of the pits, those of the London Brick Co. south of Fletton and between Kingsdyke and Whittlesey, and that of the Itter Brick Co. at Kingsdyke. These overlap so as to provide a continuous section of 13 metres (43 ft.), which he divided into centimetres for purposes of collecting, thus obtaining 1,300 horizons. From numbered horizons in this section he collected and measured 3,000 specimens. At the same time he paid particular attention to the lithology of the various beds with the object of discovering, if possible, the conditions under which they were deposited; and, as already mentioned in Chapters I and III, his conclusions are of considerable interest, especially because he was able to work with lineages.

Methods of determining ammonite evolution upon a quantitative basis naturally depend upon the measurement and documentation of the characters of large numbers of individuals at each horizon. The average variation in any particular character at a given horizon is taken by Brinkmann to indicate a definite phase, and comparison of the figures for successive horizons shows the rate of evolution per unit thickness of strata. The two chief potential sources of error in this operation are: first, that the measurements are largely made upon crushed material; secondly, that the assumption is involved that the assemblage of individuals preserved in any particular bed is a truly representative selection of the living population. Brinkmann argues that neither source of error is so serious as to interfere with the conclusions. In the first place he finds that the errors in measurements due to distortion of the shells are negligible in comparison with the degree of individual variation. In the second place he believes that, although the assemblage preserved at any given level may be selected posthumously by wave or current action, it is safe to assume as a working hypothesis that it truly represents the living population. He emphasizes that the greater concentration of ammonites in the shell-beds is purely an artificial one, due ultimately to tectonic disturbances and not to fluctuations in the population.

The conclusions bearing upon evolution and ammonite systematy to which these considerations lead are of the highest importance. Brinkmann recognizes at Peterborough only thirteen species of Kosmocerates, belonging to four lineages, which he regards as natural subgenera of the single genus *Kosmoceras*. In the synonymy of the genus he places twenty-one of Buckman's genera.

This simplification results from the rational conception of the subgenus as an evolutionary chain or lineage, in which the species are successive links, of arbitrarily-chosen but uniform length. The four subgenera, *Anakosmoceras*, *Zugokosmoceras*, *Spinikosmoceras* (all due to Buckman) and *Kosmoceras sensu stricto*, he finds evolved continuously side by side. The Oxford Clay could therefore be rationally zoned by any of these subgenera, successive species being taken to mark successive zones (true biozones, as defined above, p. 22), but not by all of them together, as is usually done.

The principal systematic rearrangements made by Brinkmann, affecting Dr. Neaverson's zonal table, are the following: he regards *K. conlaxatum* S. Buck., the zonal index to Dr. Neaverson's lowest zone, as synonymous with *K. jason* (Rein.); he regards *K. elizabethæ* (Pratt), the index to the second zone, as synonymous with the true *K. ornatum* Schloth., of which he selects and figures a lectotype; *K. castor*, used as index to Dr. Neaverson's fourth zone, he considers a misidentification, and declares that the true *K. castor* (Rein.) lived contemporaneously with *Erymnoceras coronatum* (index of Dr. Neaverson's third zone). Further, he states that *K. ornatum* has hitherto been misidentified and that *K. ornatum* auctt. is synonymous with *K. spinosum* (Sow.); finally that *K. stutchburii* (Pratt), which has recently been chosen by Prof. Davies as index of his lowest zone, is to be regarded as a synonym of *K. gulielmii* (Sow.). (Buckman placed these last not only in different genera, but even in different families.)

Clearly if these conclusions are to be accepted, profound modifications of the previous zonal partition of the Lower Oxford Clay must be made. Brinkmann retains the following zonal table, using the various overlapping subgenera, but eliminating overlapping species so far as possible:

Q. lamberti . .	corresponding to Neaverson's	*lamberti* zone	
K. spinosum (Sow.) (= *ornatum* Quenst.)	,, ,,	*athleta* zone	
K. castor and *pollux* *K. jason* . .	,, ,,	*duncani* *castor* *coronatum* *elizabethæ* *conlaxatum*	zones

Every geologist cannot go into the subject and decide for himself which system is the right one, and the reader on laying down Brinkmann's exhaustive report and monograph may feel at first inclined to accept his conclusions without further question. Nevertheless, those who by diligent research (in many more parts of England besides that with which Brinkmann is acquainted) have gradually built up the existing zonal table are entitled to more consideration than this first impulse would accord them. The succession of faunas described by Dr. Neaverson at Peterborough is no myth, and it accords in general with that determined by Prof. Davies in Buckinghamshire and Bedfordshire, and by Buckman in Yorkshire and Scotland. When we make the necessary changes in nomenclature it remains substantially the same as before, only under a new guise. The further changes advocated by Brinkmann, such as the elimination of a *duncani* zone, and the substitution of a *spinosum* zone for the old *athleta* zone, serve no purpose and only increase confusion. The choice of *K. spinosum* as a zonal index is especially undesirable in view of the fact that it is a 'rediscovered' species, which takes the place of the *K. ornatum* of authors, the true *ornatum* of Schlotheim being, according to Brinkmann, something altogether different. The only justification that can be put forward for such changes is that they make for an ideal zonal scheme of universal application and eliminate 'teilzones' (see pp. 33–4). But this is generally an impossibility in geology, and so long as we cannot work with biozones in other formations, or even in the Oxford Clay in other places, we might as well be consistent and not overhaul our zonal scheme in order to introduce them at Peterborough. The best we can generally hope to do is to determine the succession in a given area or country, noting the teilzones which there succeed one another, and later to compare the sequence with those in other regions. Moreover, the fossils that form useful zonal indices in one country may often be valueless in another, so that it is impossible to restrict ourselves to a given lineage.

Thus we can admit that neither of Pratt's names, *elizabethæ* and *stutchburii*, should be retained, and that Buckman's *conlaxatum* is a synonym of *jason* Reinecke, and still legitimately adhere to the slightly modified zonal table adopted here, viz.:

Zone of *C. præcordatum*
,, *C. renggeri*
,, *Q. lamberti*
,, *P. athleta* } (= *spinosum* zone of Brinkmann)
,, *K. duncani* }
,, *E. reginaldi* (= *coronatum* zone of Buckman and Neaverson)
,, *K. jason* (= *conlaxatum*+*elizabethæ* zones of Neaverson
= *castor* and *pollux*+*jason* zones of Brinkmann).

SUMMARY OF THE SUCCESSION AT PETERBOROUGH[1]

Of the succession of clays and their faunas comprised within these zones as exposed at Peterborough, Dr. Neaverson has given a clear if brief account.

Athleta Zone. The clays with large Peltocerates, some of which can be referred to *P. athleta* (Phil.), contain the same fauna as at Oxford. The most abundant fossils are the *Gryphæa*, best identified as *G. lituola* Lamk., and also the brachiopod *Aulacothyris bernardina* (d'Orb.). It is noteworthy, however, that Kosmocerates of the *proniæ* type do not here occur above this horizon as at Oxford but below, in the clays assigned by Neaverson to the *duncani* zone. This seems to furnish a good reason against the retention of a *proniæ* zone, and indeed Brinkmann declares that the species ranges down to the base of Neaverson's *elizabethæ* zone.

Duncani Zone. The clays of this zone are principally characterized by abundant pyritic casts of ammonites, among the most common of which are species of the subgenus *Kosmoceras sensu stricto* (*K. spinosum* (Sow.), and *K.* cf. *gemmatum* (Phil.), *K. duncani*, &c.), together with *K.* cf. *proniæ* Teiss. There are also some pyritic casts of lamellibranchs, especially *Nuculana* cf. *phillipsi* (Morris), *N.* cf. *longiuscula* (Merian) and *N. cottaldi* de Lor. *Belemnopsis hastata* begins a little below this zone and ranges upwards.

Reginaldi Zone. Dr. Neaverson says:[2]

'The only substantial evidence obtained for the presence of this zone is the occurrence of large specimens of *Erymnoceras reginaldi* (Morris) in Messrs. Itter's brickyard 1¼ miles west of Whittlesey. The specimens occur in shales similar to those of the *elizabethæ* zone but were not *in situ* and the position of the zone in the section could not be located. A poor fragment from similar shale at Fletton is also referred to this species.'

According to Brinkmann *K. duncani* (Sow.) ranges down to below the *reginaldi* horizon; but he misinterpreted *K. duncani* (see note opposite Plate XXXVII, fig. 6). About this level is the maximum of *Cylindroteuthis puzosi*.

Jason Zone. This zone chiefly consists as usual of a considerable thickness of shaly clay full of compressed Kosmocerates. The lithology of the shales,

[1] Based on E. Neaverson, loc. cit., 1925.
[2] 1925, loc. cit., p. 32.

and also many of the species of ammonites and their preservation, are the same as in the Christian Malford railway-cutting and the brickworks at Calvert. *Nucula nuda* is also abundant and was used by Judd as index species. Dr. Neaverson called this the *elizabethæ* zone (= *ornatum* Schloth. *non auctt.* according to Brinkmann) and separated as the *conlaxatum* (= *jason*) zone some basal clays which form the floor of the brickfields at Fletton and Kingsdyke. These basal clays are not favourably exposed for study, but they contain large septaria which are thrown out during the construction of shallow drainage trenches, and from them many ammonites can be collected, uncrushed and excellently preserved. The principal forms are varieties of *K.* (*A.*) *gulielmii* (Sow.) and the true *K.* (*Z.*) *jason* (Reinecke). 'Speaking generally,' Dr. Neaverson remarks, 'the series contains forms which are highly ornamented, and others that show loss of sculpture correlated with a close approximation of the septa as growth proceeded.' *Cylindroteuthis puzosi* also occurs in the septaria.

Calloviense and **Kœnigi Zones** (KELLAWAYS BEDS). Dr. Neaverson describes a small brick-pit north-west of the railway-bridge near Werrington, on the main road north-north-west of Peterborough, where about 4 ft. of dark-blue unfossiliferous clay passes up into a thin band of soft concretionary sandstone, which contains part of the fauna of the Kellaways Rock. *Gryphæa bilobata*, *Oxytoma sp.* and *Entolium demissum* are recorded, but no ammonites.

Far better sections of the Kellaways Beds have been seen from time to time along the western margin of the outcrop, where the Kellaways Rock makes a surface feature and has been cut through during the construction of some of the railways. In a cutting south-west of Bourn, on the Bourn and Saxby line, H. B. Woodward in 1892 saw the 'dense grey shaly clay with selenite, lignite and numerous flattened ammonites' of the *jason* zone, with a band of septaria 10 ft. from the base (perhaps corresponding to that at Peterborough), resting on 2 ft. of calcareous, flaggy, blue-hearted sandstone with abundant *Gryphæa bilobata* and belemnites—the Kellaways Rock. This was in turn separated by a clay from the Cornbrash.[1] A nearly similar section was described by Morris in 1853 in the Casewick cutting. Here *Sigaloceras calloviense* was recorded from the Kellaways Rock, together with most of the characteristic lamellibranchs. The rock, which was ferruginous and passed into brown sandy clay, was separated from the Upper Cornbrash by 10 ft. of 'dark, laminated, unctuous' Kellaways Clay, in which abundant Macrocephaloid ammonites were said to occur.[2]

The sandy development of the Kellaways Rock, always with *Gryphæa bilobata* and certain belemnites, persists at about the same horizon throughout Lincolnshire to the Humber. It continues to be separated everywhere from the Cornbrash by a clay, which varies from 2 ft. to 18 ft. At Brigg a boring proved 2 ft. of Kellaways Rock, with 18 ft. of clay below, while a little to the south a considerable portion of the clay becomes sand, locally consolidated into rock, which may reach a thickness of 20 ft. The greatest recorded thickness of 25 ft. was proved at Sudbrooke, near Lincoln.[3]

[1] H. B. Woodward, 1895, *J.R.B.*, pp. 63–4.
[2] J. Morris, 1853, *Q.J.G.S.*, vol. ix, p. 333.
[3] H. B. Woodward, 1895, *J.R.B.*, pp. 65–7, with refs.

VERTEBRATA OF THE OXFORD CLAY OF PETERBOROUGH

For over thirty years two brothers, C. E. and A. N. Leeds, of Peterborough, assiduously collected the bones of vertebrates from the Oxford Clay of the rapidly-growing brickfields. The collections so formed became renowned, providing subject-matter for numerous papers by Seeley, Lydekker, Hulke, C. W. Andrews and Sir Arthur Smith Woodward.[1] They were eventually purchased by the British Museum and have been described in two magnificent volumes by the late C. W. Andrews.

The exact zonal positions of the specimens are not recorded, but the whole rich fauna must have been yielded by some part of the *jason–athleta* zones inclusive and the majority undoubtedly came from the *jason* zone. The skeletons are said to have 'occurred spread over well-defined old floors in the clay, and could thus with care be recovered almost in their entirety'.[2] This suggests that they occurred on the horizons corresponding with breaks in sedimentation, described by Brinkmann.

An excursion of the Geologists Association visited Peterborough and the Leeds Museum in 1897, under the direction of A. N. Leeds and Sir Arthur Smith Woodward. In the report Sir Arthur gave a valuable summary of the features of the vertebrate fauna,[3] which he has very kindly re-written, bringing it up to date (1932), especially for insertion here:

'The land-reptiles (Dinosauria)', he writes, 'are represented only by imperfect skeletons without the head, and by one portion of lower jaw. They include one Sauropod (*Cetiosauriscus leedsi*) about 60 ft. in length, and two species of an armoured Orthopod which have been referred to *Stegosaurus*, a genus best known from the Upper Jurassic of North America. The lower jaw may belong to one of the latter species; and a small femur seems to be referable to an Orthopod related to the Wealden *Iguanodon*. The Crocodiles *Steneosaurus* and *Metriorhynchus* are represented by many nearly complete skeletons of several species.[4] Both are marine, and *Metriorhynchus* has no bony armour. The Pterodactyles, as might be expected from their mode of life, are scarcely known; but it is very curious that no trace of a Chelonian has hitherto been discovered. The Sauropterygia predominate, and include both the small-headed Plesiosaurians and the large-headed Pliosaurians, of several genera. There are skeletons of individuals of all ages, from the very young to the extremely old. The Ichthyopterygia are represented by an almost toothless ally of *Ichthyosaurus* with comparatively broad and flexible paddles (*Ophthalmosaurus*).

'Fish remains are very abundant, and they are important as supplementing our knowledge of the Upper Jurassic fauna in the Lithographic Stone of Germany, France, and Spain. Whereas the Continental fossils display the general contour of the various fishes embedded in very hard limestone, the specimens in the Oxford Clay were originally macerated and buried in soft clay, from which the different bones and teeth can be washed and examined separately. There are fine groups of teeth of *Hybodus* found in association with the jaws of this shark. There are also many still finer groups of the teeth named *Strophodus*, in undoubted association with the fin-spines named *Asteracanthus* and the hooked head-spines named *Sphenonchus*. Chimæroids are known only by dental plates and fragments of spines.

[1] See bibliography.
[2] A. N. Leeds, 1897, *P.G.A.*, vol. xv, p. 189.
[3] A. Smith Woodward, 1897, loc. cit., p. 190, with full bibliography.
[4] Andrews has described four new species (1909, *Ann. Mag. Nat. Hist.* [8], vol. iii, pp. 299–308).

The remains of Ganoid fishes are especially fine and numerous, and those of *Lepidotus*, the Pycnodont *Mesturus*, *Caturus*, *Eurycormus*, and *Hypsocormus* have added much to our knowledge of the skull in these primitive types. *Leedsia problematica* is a gigantic Pachycormid fish, with a forked tail 9 feet in span.'

LIST OF THE OXFORD CLAY VERTEBRATA FROM PETERBOROUGH[1]

Reptilia.

Cetiosaur[isc]us leedsi (Hulke)
Omosaurus durobrivensis Hulke
A large Stegosaurian
Camptosaurus leedsi Lyd.
Sarcolestes leedsi Lyd.
Rhamphorhynchus sp.
Ophthalmosaurus icenicus Seeley
Muraenosaurus leedsi Seeley
M. durobrivensis Lyd.
M. platyclis Seeley
Picrocleidus beloclis (Seeley)
P. sp.
Tricleidus seeleyi Andrews
Cryptocleidus oxoniensis (Phil.)
Pliosaurus ferox (Sauv.)
Simolestes vorax Andrews
Peloneustes philarcus Seeley
P. evansi (Seeley)
Metriorhynchus superciliosus Desl.
M. brachyrhynchus Desl.
M. sp.
Suchodus durobrivensis Lyd.
Dacosaurus sp.
Steneosaurus edwardsi Desl.
S. leedsi Andr.
S. durobrivensis Andr.
S. obtusidens Andr.
Mycterosuchus nasutus Andr.

Pisces.

Hybodus obtusus Ag.
Asteracanthus ornatissimus Ag.
  var. *flettonensis* A. S. Woodw.
Pachymylus leedsi A. S. Woodw.
Brachymylus altidens A. S. Woodw.
Ischyodus egertoni (Buckland)
I. beaumonti Egerton
Lepidotus leedsi A. S. Woodw.
L. latifrons A. S. Woodw.
L. macrocheirus Eg.
Heterostrophus sp.
Mesturus leedsi A. S. Woodw.
Caturus sp.
C. sp.
Osteorachis leedsi A. S. Woodw.
Eurycormus egertoni (Eg.).
Hypsocormus leedsi A. S. Woodw.
H. tenuirostris A. S. Woodw.
Leedsia problematica A. S. Woodw.
Pholidophorus sp.

II. THE MARKET WEIGHTON AXIS

North of the Humber the Oxford Clay becomes very thin. Its total thickness is not known, but the amount of shaly clays between the top of the Kellaways Rock and the top of the Kimeridge Clay measures rather over 100 ft. near South Cave, and probably not more than half of this is accounted for by Oxford Clay. Only the basal portion has been exposed, and from the recorded Kosmocerates (*K. elizabethae* and *K. comptoni*) this would seem still to belong to the *jason* zone.

The section which showed the base of the Oxford Clay is a deep cutting on the Hull and Barnsley Railway, made in 1883, at Drewton, north of South Cave. It also laid bare a fine section of the Kellaways Rock, which was described in detail by Keeping and Middlemiss.[2] Immediately below the clay were 10 ft. of hard, brown, ferruginous sandy beds, crowded with fossils, especially *Gryphaea bilobata*, *Pseudomonotis* sp., *Rhynchonelloidea socialis* and belemnites, below which were 45 ft. or more of sands, the upper part brownish

[1] C. W. Andrews, 1910, *Descr. Catal. Marine Reptiles Oxford Clay* (*B.M.*), vol. i, p. viii.
[2] 1883, *Geol. Mag.* [2], vol. x, pp. 215–21.

or yellow and containing two lines of large doggers, the lower parts pure white and highly micaceous. The sands were nearly barren except for a band about the middle which was riddled with hollow casts of belemnites.

The section of Kellaways Rock in the Drewton cutting is typical of all the region between the Humber and Newbald, where the outcrop is lost beneath the Chalk. The only variation of note is in the thickness. The sands are, or have been, dug in several pits about Newbald. The largest has been disused for some years, but at the top can still be seen the base of the reddish-brown soft sandstone, crowded with *Gryphæa bilobata* and belemnites. In a pit near Brough were found a number of bones of a saurian, identified as *Cryptocleidus.*[1]

The zonal position of these sands long remained doubtful. Messrs. Keeping and Middlemiss recorded '*Ammonites modiolaris*, *A. kœnigi* and *A. gowerianus*' from the fossiliferous upper 10 ft., but they also mentioned '*A. duncani*' and even '*A. mariæ*', so that probably not much reliance can be placed upon their records. Buckman in 1922 figured a Macrocephalitid form from the Drewton cutting under the new generic name *Catacephalites*, and he considered it to indicate that the Kellaways Rock of South Cave was older than that in other parts of England.[2] Three years later, however, he announced that the same forms had been collected by the Geological Survey in the base of the Kellaways Rock of Wilts., and therefore did not indicate a Macrocephalitan date.[3] In view of the occurrence of typical shales of the *jason* zone immediately above, it seems certain that the Kellaways Rock is a direct continuation of that in Lincolnshire and other parts of England.

The outcrop is concealed beneath the Chalk for a distance of over 13 miles, from between North Newbald and Sancton to north of Kirby Underdale. The disappearance is proved by the occurrence of derived Kellaways ammonites in the base of the Cretaceous to be due to overstep by the Red Chalk. Blake described a section of Red Chalk at Great Givendale with 'here and there nodules full of [*Sigaloceras*] *calloviense* and [*Proplanulites*] *kœnigi*, some of which have been broken up and rolled about in the Red Chalk sea, till their crevices are filled with the latter matrix'.[4]

The importance of the Market Weighton Axis during Callovian and Oxfordian times is attested by a number of facts. Not only does the Oxford Clay attenuate towards it from the south and the north, but in all the Yorkshire Basin north of the axis the facies of the Oxford Clay differs markedly, both lithologically and palaeontologically, from the development over the rest of England. As far as the axis the shales of the *jason* zone are the same from the Dorset coast, while there is reason to suppose that at least the majority of the succeeding zones also are normally developed. North of the axis only the uppermost part (corresponding roughly with the *præcordatum* zone) is a clay, and even that is usually to be likened more to a sandy shale than to the familiar clay of Southern England. All the rest of the zones, or such of them as are present, have become thin ferruginous sandstones or oolitic sandy limestones of varying lithology, often crowded with fossils. Many of the ammonite species are peculiar to Yorkshire and some show affinities with Russian forms.

[1] T. Sheppard, 1900, *Geol. Mag.* [4], vol. vii, pp. 535–8; and see *The Naturalist*, 1931, p. 87.
[2] S. S. Buckman, 1922, *T.A.*, vol. iv, p. 54, pl. CCLXXXIII.
[3] 1925, *T.A.*, vol. v, p. 73.
[4] J. F. Blake, 1878, *P.G.A.*, vol. v, p. 248.

III. THE YORKSHIRE BASIN

(a) The Inland Escarpments of the Howardian, Hambleton and Tabular Hills[1]

No modern palaeontological work has been carried out on the Oxford Clay and Kellaways Beds of the inland escarpments of the Yorkshire Basin; the most recent account available is that written by Fox-Strangways in his Memoir on the Jurassic Rocks of Yorkshire (1892). Until research on modern lines is undertaken, the equivalence of the inland rocks with those on the coast must remain in doubt, and it is safest to continue to use the old terms 'Oxford Clay' and 'Kellaways Rock', although researches on the coast have shown that these names have quite different meanings there from those attaching to them in the rest of England. It is with this proviso that they are now used, their probable zonal equivalence being discussed in a later subsection.

The formation first appears from beneath the Red Chalk at Garrowby, and both the clay and the rock below are traceable from the first, forming a small feature along the foot of the Wolds. The Oxford Clay is not more than 20 ft. thick, and the 'Kellaways Rock' probably from 15 ft. (or less) to 30 ft.

The Oxford Clay thickens to 70 ft. in the neighbourhood of the Derwent, but seems to diminish again beneath the Howardian Hills. The outcrop along these hills can be traced sporadically by a band of wet ground, but there are no good sections, and the thickness therefore cannot be satisfactorily estimated. The Kellaways Rock in the Howardians is a more important feature: it consists of soft sandstone with harder, more siliceous lenticles, which weather out of the surrounding sands, giving rise to prominent headlands or nabs.

A short distance north of the Coxwold faults, the Oxford Clay seems to disappear entirely. Intraformational erosion may have removed some of it, but it is certain that a considerable portion passes into sandstones indistinguishable from the Lower Calcareous Grit. Immediately north of the faults, about Wass and Ampleforth, the clay is still normally developed, though probably not half its thickness at the Derwent; a few miles away, in the cliff-like scarp of Roulston Scar,[2] sandstones with ammonites at least as early as *athleta* date,[3] and with a basal pebble-bed, rest directly on the Kellaways Rock. The 'Kellaways Rock' is here a peculiar, ferruginous reddish variety, crowded with *Gryphæa bilobata* and belemnites, and may be of any age from Proplanulitan to Upper Kosmoceratan, such as that on the coast undoubtedly is (see below).

Along the foot of the great inland cliff of the Hambleton Hills, at least as far as Kepwick, the outcrop is much obscured by landslips and talus. At the north-west end, below Black Hambleton, and in the small outlier on Osmotherley Moor, natural exposures become somewhat clearer, showing that the Oxford Clay returns again for a time and is about 50 ft. thick. The thickness of the 'Kellaways Rock' here is 60–70 ft., and it has become a thick-bedded massive sandstone, partly siliceous, partly soft, with a ferruginous band towards the top, as on the coast.

Eastward across Yorkshire to the sea the outcrop follows the edge of the

[1] Based on C. Fox-Strangways, 1892, *J.R.B.*, pp. 283–99. See map, fig. 27, p. 138, above.
[2] P. F. Kendall, 1915, *Proc. Yorks. Geol. Soc.*, N.S., vol. xix, pp. 284–5.
[3] *Kosmoceras rowlstonense* (Young and Bird), figured by Buckman, 1923, *T.A.*, pl. CDXXXVII

Tabular Hills, where sections are principally to be seen in the sides of becks. Although the general direction of the outcrop along the Tabular Hills is W.–E., it is repeatedly cut back in a zigzag fashion, the characteristic feature of the formation being a series of nabs formed by the Kellaways Rock.

In the west, as in the western escarpment at Roulston Scar, although the total thickness of Oxford Clay and Kellaways Rock thickens to about as much as in the east (120–50 ft.), the proportion of sandstone is much greater—more than 100 ft. This is again due to the lower portion of the Oxford Clay passing into sandstone, which is often separated from the rest of the rock below by a thin clay-band.

In the almost complete absence of palaeontological evidence little can be said as to the zonal significance of these changes. Hudleston visualized the whole of the Middle Oolites as deposited around a shore lying to the north-west, from which the materials were derived (largely from the Millstone Grit? But see p. 581). The nearer the deposits lay to the shore, the higher would be the proportion of arenaceous material, and he believed that over the Vale of York, before the retreat of the escarpment, there might have been seen a continuous succession of sands and sandstones from the Estuarine Series to the Coral Rag.

Towards the east end of the Tabular Hills, on the Hackness outlier and on the coast, the major portion of the 120 to 150 ft. consists of clay, but both its upward and its downward boundaries are indefinite—Fox-Strangways wrote: 'The junction of the upper portion of the Oxford Clay with the base of the Calcareous Grit is so gradual that no exact line can be drawn.' Certainly on the coast the base of the Grit falls within the *præcordatum* zone.[1]

The best sections anywhere inland are afforded by the precipitous gorges of Newton Dale and its tributaries, which cut deep into the heathy plateau formed by the Kellaways Rock. Miles of more or less vertical cliffs expose up to 90 ft. of sandstones comparable with some of the Kellaways Rock of the rest of the county, above which are from 30 ft. to 50 ft. of the softer sandstones representing the lower part of the Yorkshire Oxford Clay (probably about *athleta* date). At the base of all are 10–15 ft. of grey shales full of small crushed lamellibranchs, especially a species of *Pseudomonotis*.

(b) The North Yorkshire Outliers

North of the valley of the Esk a syncline striking E.–W. through Whitby has given rise to the preservation of a large elongated outlier, or rather series of outliers, of the Kellaways Rock from 8 to 12 miles from the main outcrop, forming Roxby and Danby High Moors, Moorsholme Moor and neighbouring heights. The sandstones on these outliers are close-grained and well bedded, with seams of quartz pebbles. The most interesting part is the upper, which is hard and siliceous, and is riddled with the hollow casts of belemnites, the guards completely dissolved away.

'Sometimes as many as 50 of these casts occur in a cubic foot of the bed, and blocks of from three to six inches thick will have a dozen cylindrical perforations right through them. This clearly proves that the Kellaways Rock . . . at some depth below the surface must be a calcareous sandstone, its extremely porous nature being in part due to the dissolution of lime.'[2]

[1] Judging by ammonites in the gritstone matrix in the Leckenby collection.
[2] C. Fox-Strangways, 1892, *J.R.B.*, pp. 284–5.

(c) The Yorkshire Coast

The Oxford Clay and Kellaways Beds are well exposed at intervals in the cliffs from Gristhorpe Bay to Scarborough. The longest section is in Gristhorpe Bay, where the Oxford Clay forms the greater part of Gristhorpe Cliff, but both it and the Kellaways Beds are much obscured by slips, talus and Drift. The whole series is magnificently displayed in Red Cliff, Cayton Bay, but as the cliff is vertical and very high the rocks are scarcely accessible. There is a more accessible but less clear exposure of Oxford Clay on the north side of Cayton Bay, where the Kellaways Rock is faulted down below beach-level. The rock and the shale beneath extend on to Wheatcroft Cliff, and the whole series is again brought down by faults at North Cliff, Scarborough, and in the Castle Hill (fig. 76, p. 430).

The thickness of the Oxford Clay in Gristhorpe and Cayton Bays is about 120 to 150 ft. It is a grey sandy shale, nearly uniform throughout, and it passes upwards gradually into the Lower Calcareous Grit; fossils are everywhere scarce except in the bottom layers at Scarborough. According to Hudleston a thick mass of sandstone like the Lower Calcareous Grit comes in in the lower part of the clay in the north side of Cayton Bay, but the cliff has since become obscured by landslips. It would, however, be only in accordance with expectations, for a similar change certainly occurs inland when the clay is traced towards the north.

The few ammonites that have been collected from the Oxford Clay have been discussed briefly by Buckman,[1] whose conclusions seem to point to the greater part of the clay belonging approximately to the *præcordatum* zone. At least two species, *Klematosphinctes vernoni* (Young and Bird)[2] and *Neumayriceras oculatum* (Phil.)[3], are peculiar to Yorkshire and so afford no help in correlation. Buckman provisionally spoke of the *vernoni* zone, but this had only local value and his subsequent attempt[4] to fit it into sequence with other hemeræ was little more than guesswork. Dr. Spath has since concluded that it is a synonym of the *præcordatum* zone.[5]

The so-called Kellaways Rock, where it first rises from the beach at Newbiggin Wyke, at the south end of Gristhorpe Bay, is only 12 ft. thick. It thickens steadily northward, reaching about 50 ft. in Cayton Bay and 76 ft. in North Cliff, Scarborough. Two essentially different parts can be made out: an upper portion (in the south about half the rock, in the north 25 ft.) crowded with fossils embedded in a variety of matrices, some grey, some blue, some red, often oolitic, but usually more or less ferruginous; and a lower portion consisting of thick beds of almost barren sandstone. The upper portion yielded a wealth of fossils to the Scarborough collector of the middle of last century, John Leckenby, most of whose collections are now in the Sedgwick Museum, Cambridge.[6] They were nearly all obtained from boulders on the beach at the foot of Scarborough Castle Hill, from temporary excavations for buildings on the North Cliff, and from the cliffs and beach in Gristhorpe Bay. Unfortunately the Scarborough locality was long ago covered up by the

[1] S. S. Buckman, 1913, *Q.J.G.S.*, vol. lxix, p. 159.
[2] *T.A.*, 1922, pl. CCCXXXIII.
[3] *T.A.*, 1921, pl. CCXXIV.
[4] *T.A.*, vol. v, 1925, p. 72.
[5] L. F. Spath, 1926, *The Naturalist*, p. 324.
[6] J. Leckenby, 1859, *Q.J.G.S.*, vol. xv, pp. 4–15.

extension of the marine parade round the foot of the hill, while the outcrop in Gristhorpe Cliff has been for many years badly obscured by landslips.

From the numerous ammonites collected by Leckenby and his contemporaries, it is evident that the term Kellaways Rock is a misnomer, and it was to distinguish the Yorkshire rock from that south of the Humber that the mis-spelling Kelloway Rock was formerly retained, an expedient tending only to add to the confusion. Dr. Spath has recently suggested as alternatives HACKNESS ROCK (a term introduced by William Smith as early as 1829–30, which it is appropriate to his memory to revive)[1] or Castle Hill Beds.

Oppel first pointed out that Phillips's 'Kelloway Rock' in Yorkshire contained fossils indicative of the *athleta* zone, which was called Oxford Clay elsewhere; and he used the fact as an argument for including the Lower Oxford Clay in the Callovian Stage.[2] In 1875, also, Hudleston wrote:[3]

'. . . of the petrological group known as the Kelloway Rock, the Upper, or Cephalopoda division, seems to contain ammonites belonging to two geological divisions, of which *A. modiolaris* (Lhuid) and *A. gowerianus* (Sow.) represent callovian forms, whilst *A. duncani* (Sow.), *A. jason* Reinecke (*A. gulielmi* Sow.), *A. lamberti* (Sow.), and many others, are characteristic of the *Ornatus*-clays, or Lower Oxfordian' . . . 'in order to prevent mistakes arising from names it is necessary to point out that the fauna of the upper part of the Kelloway Rock of Yorkshire, as indicated by its ammonites, embraces much of the Oxfordian of English geologists.'

Hudleston also realized that, like so many ferruginous deposits full of Cephalopods, these beds were slowly-formed accumulations representing thick strata elsewhere, and probably of very different ages in different places.

'Are the fossiliferous (Cephalopoda) beds in the upper part of the Kelloway Rock at Scarborough, at Red Cliff, and at Gristhorpe, wholly contemporaneous deposits? At Scarborough the ornati seem to be very plentiful; at Red Cliff, *A. gowerianus*, &c.; at Gristhorpe the cordati, as *A. vertumnus* Leck. (*A. mariæ* d'Orb.), and *A. flexicostatus* Phil. (*A. lamberti* Sow.), &c. This question can only be settled by a very close attention to the precise position of specimens collected during a considerable lapse of time.' And again: 'The deposition of the upper portions alone extended over a period sufficiently long to intercept and entomb amongst other remains the ammonites of two horizons which seem to have been distinguished in other districts.'[4]

Unfortunately the prolonged and careful field investigation advocated by Hudleston has been rendered almost impossible for the reasons just mentioned. In 1913 Buckman published the results of an examination of many of Leckenby's, Young and Bird's and Phillips's types and attempted to arrange the ammonites in sequence according to their matrices, identifying the matrices so far as possible with the beds in Cayton Bay, as described by Leckenby and by Fox-Strangways.[5] The sources of error in such an arm-chair method are so great as to render the results of little practical value. In the first place, the ammonites examined came chiefly from Scarborough and Gristhorpe, at which places, as pointed out by Hudleston, the faunas and matrices are both very different. An attempt to recognize these in the

[1] 'Memoir on the Stratification of the Hackness Hills', 1829–30, printed in *J.R.B.*, vol. i, 1892, pp. 507–14.
[2] A. Oppel, 1856–8, *Die Juraformation*, pp. 538–44.
[3] W. H. Hudleston, 1875, *P.G.A.*, vol. iv, p. 372.
[4] Ibid.
[5] S. S. Buckman, 1913, *Q.J.G.S.*, vol. lxix, pp. 152–68.

inaccessible Red Cliff at Cayton Bay, and that only secondhand from descriptions, was unlikely to prove a profitable task. Nevertheless, the results obtained have a theoretical interest and are suggestive of possibilities open to local geologists who might be able to devote a long time to the task.

According to Fox-Strangways,[1] the uppermost 19 ft. at Red Cliff, Cayton Bay, consists at the west end of one indivisible mass of brownish-red ferruginous rock, which passes eastward into several locally distinct bands. At the top towards the east may be distinguished a very oolitic, hard band, 1 ft. thick, which stands out from the cliff, and overlies 9 ft. of calcareous shale like Oxford Clay. From this clay or its representative at Scarborough were doubtless collected many of the anomalous ammonites recorded from the base of the Oxford Clay of that locality. The hard band or its equivalent were thought by Fox-Strangways and by Buckman to be the same as a fossiliferous band spoken of by Leckenby as the 'calcareous pisolite'. With this Buckman identified the matrix of *A. gregarium* Bean-Leckenby,[2] *A. turgidum* Bean, and the associated fauna, and he named it the *gregarium* zone. The shale below, which at Osgodby Nab is described as oolitic, Buckman identified as the provenance of *Vertumniceras vertumnus* (Bean-Leckenby) and *Quenstedtoceras lamberti* (Sow.) with an associated fauna. Finally, the old records of *Ammonites crenatus* he took to indicate the possible representation of the zone of *Creniceras renggeri*. Thus he divided this topmost 10 ft. of the Hackness Rock into the zones of *gregarium*, *vertumnus* and *lamberti* in descending order, and suspected the presence of a representative of the *renggeri* zone in unknown relation to the rest. Since *Q. gregarium* and *V. vertumnus* are peculiar to Yorkshire and have never been collected *in situ* it is not known whether they attained their acmes separately, or contemporaneously with *Q. lamberti*. For present purposes it is safe to assume only, as does Dr. Spath, that these 10 ft. of beds were probably deposited in the hemeræ *lamberti* and *renggeri* (or *mariæ*).

Next below come ferruginous beds to a maximum thickness (at Red Cliff) of 9 ft. Fox-Strangways describes these as comprising 3 ft. of soft sandstone overlying 6 ft. of red, irony, partly oolitic rock full of Gryphæas; Leckenby divides them into three, a bed of soft sandstone sandwiched between two fossiliferous irony bands. In various matrices identified with these beds Buckman records a number of ammonites, including *Peltoceras athleta*, *Kosmoceras duncani*, and a number of Kosmocerates typical of the basal shales of the Oxford Clay farther south (the *jason* zone).

Perhaps the most peculiar feature of the sequence is the record of *Ammonites kœnigi* by Leckenby in both of his irony bands, and also his records of *A. sublævis*, *A. gowerianus* and *A. chamusseti* in the lower. Buckman identified in the collections the true *Proplanulites kœnigi*, and also several species of *Cadoceras* and two species of *Sigaloceras*, all in a light-brown calcareous matrix with small ooliths. These he believed to have come from Leckenby's lower irony bed.

Thus at Red Cliff between the fauna of the *kœnigi* zone and the Cornbrash there are about 35 ft. of strata, which become still thicker towards the north. At the base are shales formerly associated with the Cornbrash (6–15 ft.) which pass up gradually through yellow sandy shale into sandstone. All the

[1] 1892, *J.R.B.*, p. 280.
[2] Made genotype of *Prorsiceras* Buckman, 1918, *T.A.*, vol. ii, pl. CXVII.

rest of the rock consists of almost barren sandstone with occasional plant-remains. Near the base at Scarborough, however, Hudleston described a shelly bed containing *Trigonia rupellensis*, *Pseudomonotis* sp., *Pholadomya murchisoni* and other bivalves.

Since no ammonites have yet been found in these basal sandstones and shales they must be for the present regarded as part of a greatly-expanded *kœnigi* zone, and so equivalent to the Kellaways Clay and possibly also to the lower part of the true Kellaways Rock of Wiltshire. The presence of a *calloviense* zone is doubtful, for although species of *Sigaloceras* have been found, they have not been proved to occupy any separate stratum of rock, being apparently mixed with the fauna of the *kœnigi* zone.

Thus the greater part of the so-called Kellaways Rock of the Yorkshire coast is still apparently a true representative of at least the lower part of the Kellaways Beds of the rest of England. The name Hackness Rock should therefore be restricted to the highly fossiliferous topmost part, containing the fauna of the Lower and Middle Oxford Clay, and for this hitherto unnamed but important series of beds it is a valuable addition to stratigraphical nomenclature.

IV. EAST SCOTLAND

(a) The Brora District of Sutherland

In East Sutherland rocks of the age of the Oxford Clay and Kellaways Beds cover an area about 3 miles square and attain a thickness of 350–400 ft. (fig. 63, p. 366). They occupy the central and widest part of the narrow coastal strip of Jurassic strata about Brora, bounded inland by the great Ord Fault, which throws them down against the Old Red Sandstone mountains. The softer Jurassic rocks form a low coastal plain, largely obscured by glacial debris and raised beaches.

The coast-sections are at first sight disappointing. Such cliffs as exist are nearly all cut in raised beach material or in blown sand, while the Jurassic substratum protrudes only as reefs and ledges, overgrown with seaweed and covered at high tide.

The Oxford Clay is more favourably exposed for study than the other formations, however, owing to the River Brora having cut a steep-sided valley across the outcrop. Natural and artificial sections along the valley yield considerably more information than those on the shore. In the village of Brora the valley becomes a gorge, whose cliff-like sides are composed of sandstones equivalent to the upper part of the Oxford Clay. Higher upstream, behind Fascally Coal Mine, a large clay-pit has been excavated for the exploitation of the Lower Oxford Clay for a brickworks near by.

The deposits are divisible into three well-marked lithic groups. The highest 200 ft. (approximately) consist of sandstone with sandy shale at the base, united under the term Brora Arenaceous Series; they correspond to the Upper Oxford Clay (*præcordatum*, *lamberti* and *athleta* zones) and to an unknown extent also to the Lower Calcareous Grit. Below is a series of argillaceous shales and clays, the Brora Argillaceous Series, which is from 150 to 225 ft. thick, and spans the Lower Oxford Clay (*duncani* to *jason* zones). At the base of all is a hard band of rock forming the Roof-Bed of the Brora Coal and yielding the fauna of the Kellaways Clay (*kœnigi* zone).

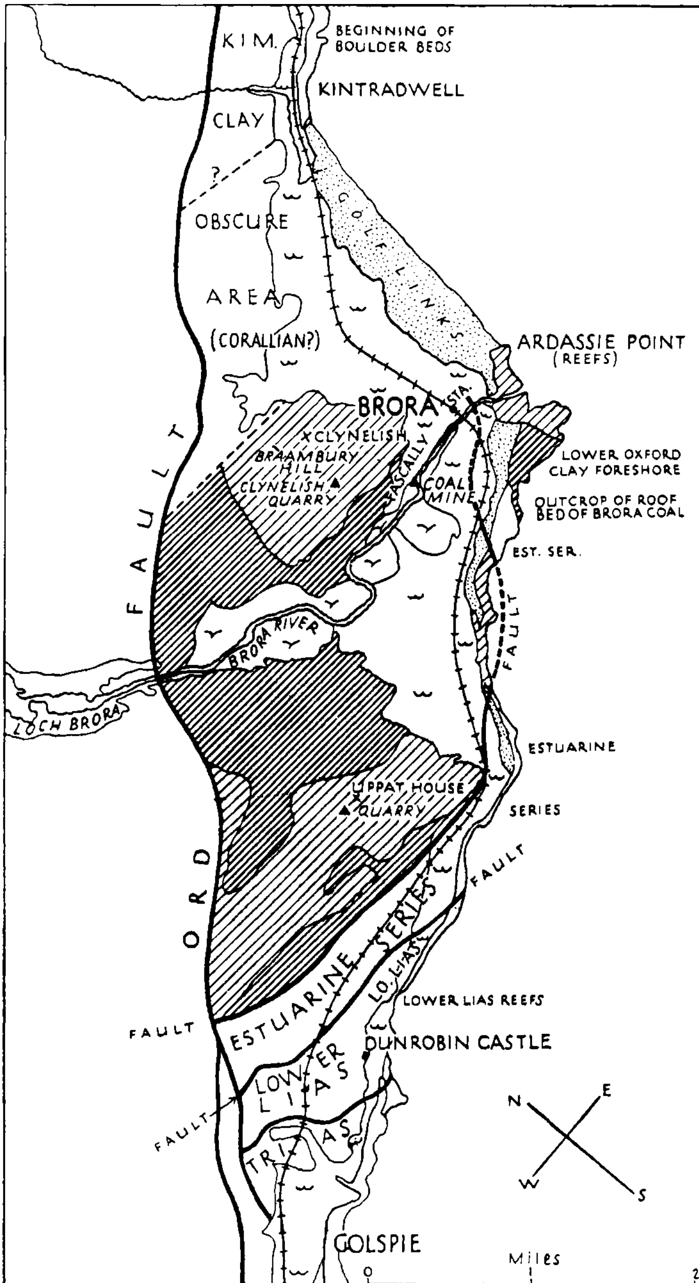


FIG. 63. Sketch-map of the Jurassic area around Brora, Sutherland, showing the position of Fascally Coal Mine, Clynelish Quarry, Uppat Quarry, &c. (Based on the 1-inch map of the Geological Survey of Scotland, Sheet 103.)

Wide hatching = Brora Argillaceous Series; close hatching = Brora Arenaceous Series. Blown sand dotted; alluvium thus: Y; raised beach material thus: ω. (See fig. 28, p. 151.)

SUMMARY OF THE SEQUENCE AT BRORA[1]

Præcordatum Zone (? and **Cordatum Zone** pars) (BRORA SANDSTONE), *c.* 120 ft.

The thick sandstones which form the cliffs of the gorge below the bridges in Brora were estimated by Lee to have a thickness of about 100 ft.[2] Unfortunately they have not in recent times yielded any fossils, and they therefore cannot be exactly dated. The upper portions probably correspond largely with the lower part of the English Lower Calcareous Grit, and the lower portions with the upper subzone of the *præcordatum* zone. A definite Lower Calcareous Grit fauna is found above and an ammonite assemblage dated as *præcordatum* a short distance below.

Three-quarters of a mile north-west of Brora Railway Station the Brora Sandstone rises into one of the highest eminences on the coastal plain, the low rounded Braambury Hill, immediately south of the hamlet of Clynelish. Old quarries scar the south side of the hill, the highest showing 20 ft. of unfossiliferous white sandstone, a lower one showing another 15 ft. of sandstone, chiefly white, with pebbles of quartz and nests of Limas and Pectens. At the top of the lower quarry is a 6 ft. band crowded with casts of *Pseudomonotis braamburiensis* (Phil.).[3] The rock is in places a spongy mass of the casts, but they are poorly preserved and good specimens are not easily obtained.

Præcordatum Zone (pars) (CLYNELISH QUARRY SANDSTONE), *c.* 20 ft.

Farther south, down the hill-side towards the River Brora, ½ mile north-west of Fascally Coal Mine, a large excavation called Clynelish Quarry is still worked, and yields a rich fauna. The sandstone is white and fine-grained, and, though originally soft, it is silicified to a depth of 10 ft. from the surface in such a way as to resemble a fine quartzite, and it is much used for building. The softer lower portion contains abundant casts and moulds of fossils, of which by far the commonest are lamellibranchs of typical Lower Corallian species. The most abundant are *Chlamys fibrosa*, *Chl. splendens*, *Lima rigida*, *L. mutabilis*, *Lucina* sp., *Exogyra nana* and *Gryphæa dilatata* var. *exaltata*. Besides these there are a few species not known elsewhere, such as *Trigonia joassi* Lycett, and a brachiopod figured by Davidson as *Terebratula bisuffarcinata* Schloth., but probably a new species. The ammonites are of uncertain date, for scarcely any of them have been found elsewhere; Buckman considered them to be of late Vertumnicertan age, equivalent to what is here grouped in the *præcordatum* zone. The commonest is *Aspidoceras silphouense* (Y. & B.), which may be found in fair abundance as casts. Of rarer occurrence are casts of *Sutherlandiceras sutherlandiæ* (Sow.),[4] *S. albisaxeum* S. Buck.,[5] *Cardioceras* cf. *cardia* S. Buck. and *Quenstedtoceras* cf. *macrum* (Quenst.).

Lamberti and **Athleta Zones** (FASCALLY SANDSTONE, *c.* 20 ft., and FASCALLY SHALE, 50 ft.).

The beds below the Clynelish Quarry Sandstone are exposed in the banks

[1] Based on G. W. Lee, 1925, 'Geol. Golspie', *Mem. Geol. Surv.*, and observations.
[2] Judd, owing to certain errors, gave an estimate of 400 ft. But see Lee, 1925, loc. cit., p. 86.
[3] The name, derived from this hill, was first used by Sowerby, but as a *nomen nudum*, a Yorkshire specimen being later figured by Phillips and becoming *ipso facto* the type.
[4] *T.A.*, pl. CCCLXIV.
[5] *T.A.*, pl. CCCXX.

of the River Brora east of Fascally Coal Mine (Pl. XIV). The cliffs which there rise sheer from the water show about 15 ft. of brown, grey and rusty FASCALLY SANDSTONE, in which ochreous impressions of *Lucina lyrata* Phil. and *L. discoidalis* Buv. abound. The Survey obtained from the cliffs on the sides of the river a number of specimens of *Quenstedtoceras*, which Buckman compared to *Q. lamberti*, *Q. prælamberti*, and four other species. With them were found some Kosmocerates. A correlation was thus established with the Tidmoor Point Beds. No sign of the *renggeri* zone has been found.

At the base of the sandstones is a row of doggers, from which have been obtained fragmentary Kosmoceratids. The late Dr. Lee and Buckman did not name them, but Dr. Pringle considers them to indicate the horizon of *K. proniæ*,[1] which is here considered to be part of the *athleta* zone (see table, p. 340).

The row of doggers divides the sandstones from about 50 ft. of efflorescent sandy shales, lithologically intermediate between the Brora Arenaceous and the Brora Argillaceous Series. Only the highest part (5 ft. or more) is visible on the banks of the river, in the side of the road leading down to Fascally Coal Mine, and this highest part Buckman originally included in the Fascally Sandstone. It seems advisable, however, to keep it separate, under the name of FASCALLY SHALE; on the foreshore, where the full thickness can be seen, Dr. Lee obtained a measurement of 50 ft.

From the upper part of the Fascally Shale the Survey collected three species of *Peltoceras*, indicative of the *athleta* zone.

Jason-Duncani Zones (BRORA BRICK CLAYS AND BRORA SHALES).

Below the Fascally Shale are at least 200 ft. (225 ft. measured by Lee on the shore) of clays and shales representing the lower part of the Oxford Clay. The entire succession crops out south of the Brora estuary, where it forms muddy platforms accessible at low tide. This is not, however, a favourable locality for studying the fauna, and the best exposures are again to be found on the north bank of the Brora River, near Fascally.

The highest clays, which may be distinguished as the BRORA BRICK CLAYS,[2] are dug in a large open brick-pit immediately above Fascally Coal Mine. The only common fossils are *Cylindroteuthis puzosi* and *Gryphæa* cf. *lituola*, but the Survey have recorded *Kosmoceras* cf. *jason* (Rein.), *K.* cf. *stutchburii* (Pratt) and *K. sedgwickii*? (Pratt), the first two of which Buckman figured as *K. zugium* S. B. (genotype of *Zugokosmoceras*) and *K. interpositum* S. B. Brinkmann has since declared both to be synonymous with *K. grossouvrei* Douv.[3]

Beneath the brick clay is a thick series of shaly clays, little of which is exposed except on the foreshore; they are distinguished by the Survey as the BRORA SHALES. From the shore platforms the Survey have collected numerous Kosmoceratids, to which nearly all the current names have been applied: *duncani*, *elizabethæ*, *castor*, *jason*, *stutchburii*, *sedgwickii*, &c. Until very careful revision of the Kosmocerates collected at Brora has been undertaken, in the light of modern work, the most that can safely be said about these beds is that

[1] J. Pringle, 1930, *P.G.A.*, vol. xli, p. 74.

[2] Buckman referred to the Brick Clay as the 'Fascally Shales (Brickyard Beds)' (*T.A.*, 1923, vol. iv, p. 41), a misnomer, since of all parts of the series this deposit most deserves to be classed as a clay. The Survey use the term Brora Clays (G. W. Lee, 1925, loc. cit., p. 81).

[3] *T.A.*, pls. CCCLXXXIX and CDXIX; Brinkmann, 1929, loc. cit., p. 50.

the whole of the Brora Argillaceous Series corresponds in general with the Lower Oxford Clay (*jason–duncani* zones).[1]

Kœnigi Zone (KELLAWAYS BEDS), 3–5 ft. (+ ?).

Judd recorded *Ammonites calloviense* from Brora, but modern collecting has failed to confirm his record, and it seems probable that the *calloviense* zone is wanting.

The *kœnigi* zone, or stratal equivalent of the Kellaways Clay, forms the ROOF BED of the Brora Coal and is one of the best-known fossiliferous beds of the district. It is a very hard, ferruginous, sandy limestone, weathering red, from 3 ft. to 5 ft. thick, and passing down into grey calcareous sandstone with lenticles of coal. In the early days of the coal-mining at Brora large quantities of the Roof Bed were broken up and brought to the surface, so that fossils could easily be collected. Several were figured in Sowerby's *Mineral Conchology* and so became types of familiar species; notably *Gowericeras gowerianum*, *Pholadomya murchisoni*, *P. acuticostata*, *Protocardia striatula* and *Anatina undulata*.

Nowadays it is difficult to study the Roof Bed. The only exposure, except in the working mine, is in the form of a ledge exposed at low tide on the foreshore half a mile south of Brora. The stone is much overgrown with seaweed and barnacles, and is very untractable with the hammer.

The ammonite fauna, comprising *Gowericeras*[2] and two species of *Proplanulites*, leaves no doubt as to the correspondence of the Roof Bed with the Kellaways Clay.

(b) **Ross-shire**[3]

Twenty miles south of Brora, in the diminutive patch of Jurassic rocks beside the Moray Firth, on the coast of the peninsula which separates the Dornoch from the Cromarty Firth, two shore-sections of Oxfordian beds have been studied by Judd and more lately by Lee. They are situated at Port-an-Righ, 1½ miles south of Balintore (Shandwick), and consist of reefs visible only at low tide. The best exposure stretches along the beach north-east from the Fishermen's hut, while the other, less complete but more comprehensive, lies at Cadh'-an-Righ, a few hundred yards farther south. Both are near the boundary fault, which throws the Oxfordian strata against the Old Red Sandstone at a high angle.

The more northerly section displays 50 ft. of shaly beds containing the fauna of the *præcordatum* zone at top and bottom, and passing up into Corallian Beds. The more southerly exposure also shows part of the *præcordatum* zone, and in addition 14 ft. of shales belonging to the *lamberti* zone, and, after a considerable gap, another 14 ft. of clay and shale of the *jason* zone, resting directly upon the Brora Roof Bed.

The chief interest of the sections lies in the shaly development of the *præcordatum* and *lamberti* zones, which present a marked contrast with the sandstones of the Brora Arenaceous Series only 20 miles to the north. Here

[1] Buckman in 1923, without sufficient knowledge of the conditions under which the strata occur, constructed a hypothetical sequence, introducing several unfortunate stratal terms, not adopted by the Survey and better dropped. *T.A.*, 1923, vol. iv, p. 41, and see explanatory note at top of p. 40.

[2] See *T.A.*, pls. CCLXXXVII* and CDIV.

[3] G. W. Lee, 1925, loc. cit., pp. 99–101, 85–6.

the beds are almost entirely shales, for the most part grey and soft, but occasionally harder and calcareous, forming a shaly-weathering limestone. The Survey have collected a rich fauna of Cardiocerates, belonging to species characteristic of both the upper and the lower subzones of the *præcordatum* zone at Horton-cum-Studley, Oxfordshire; among them are *C. cardia*, *C. præcordatum*, and *C.* cf. *tenuicostatum*. Associated with them are a few lamellibranchs, such as *Gryphæa dilatata*, *Pinna lanceolata* and other familiar species.

From the shales of the *lamberti* zone in the southerly section they obtained *Q. lamberti* and several other species; and from the basal layers of the Lower Oxford Clay an assemblage of the usual Kosmocerates. The absence of the *calloviense* fauna here corroborates the negative evidence obtained in Sutherland.

The Brora Roof Bed, 1–2 ft. thick, is represented by tough calcareous shelly sandstone, weathering olive green, and having at the top a band of ironstone nodules and abundant belemnites. No ammonites were found in it.

V. THE HEBRIDEAN AREA[1]

The extension of the Oxfordian sea over the Hebridean area is proved by relics of typical Oxford Clay, and in two places of Kellaways Beds, in the three islands of Skye, Eigg, and Scalpa. There is reason to believe that the formation underlies the basalts of a large part of the northern end of Trotternish in the north of Skye, for it crops out from underneath the volcanic covering on both sides of the peninsula and round the north end, around Loch Staffin in the east and also on the west coast at Duntulm, Mugsted or Monkstadt and Uig. It was first described at Staffin by E. Forbes in 1851, and in 1878 Judd discovered 'the same beds, with precisely similar characters and fossils' cropping out at low water in Laig Bay, on the island of Eigg. In the present century the Survey have discovered a considerable outcrop around the edge of the basalts of the Strathaird peninsula in the south of Skye, and also small faulted remnants at Strollamus, Skye, and on the adjoining coast of Scalpa.

A remarkable feature of these occurrences is the differences in the zonal position of the lowest members of the Oxfordian formation, resting upon the Great Estuarine Series, in the different places. In Strathaird and Eigg the whole of the formation, with the exception of a localized thin development of the Kellaways Beds, consists of Cardioceratan deposits of *præcordatum* date, grading up into *cordatum* deposits referable to the Lower Calcareous Grit. In Trotternish in the north, however, the sequence appears to have been more fully developed, and Kosmoceratan and Proplanulitan faunas intervene between the Cardioceratan deposits and the Great Estuarine Series.

In Trotternish the formation consists of blue clays and shales with subordinate bands of argillaceous limestone and septarian nodules. The only passable section is on the foreshore in Staffin Bay, for a description of which I am indebted to Mr. Malcolm MacGregor, M.Sc., whose important researches in Northern Trotternish it is hoped will soon be published. He

[1] Based on C. B. Wedd, 1910, 'Geol. Glenelg, Lochalsh and S.E. Skye', pp. 128–31; G. Barrow, 1908, in 'Geol. Small Isles of Inverness-shire', pp. 26–8; G. W. Lee, 1925, in 'Pre-Tert. Geol. Mull, Loch Aline and Oban', pp. 113–14, *Mems. Geol. Surv.*

informs me that the section (which is the one mentioned by Forbes), although the lower beds can only be consulted at low water during spring tides, shows about 100 ft. of dark shales with some thin bands of concretionary limestone. In the basal 20 ft. of the shale, which rests with a 1 ft. pebble bed on the sands and sandstones of the Great Estuarine Series, he found *Quenstedtoceras lamberti* and *Vertumniceras vertumnus*. About 20 ft. from the base is a double band of concretionary limestone, above which he found abundant Cardiocerates of very various styles, *præcordatum*, *cordatum*, *vertebrale* and *excavatum* types being apparently represented; also *Peltoceratoides*, '*Belemnites oweni*', *Gryphæa dilatata*, *Nucula*, &c.[1]

A specimen collected by the Survey and named by Buckman *Kosmoceras degradatum*[2] would seem to indicate the presence of Kosmoceratan deposits also at Staffin.

On the west side of the peninsula, at Uig, Bryce and Tate in 1873 collected *A. lamberti* and *A. jason*, with '*Belemnites oweni*' in dark shales and clays; and near by, at Monkstadt (Mugstok) Murchison as early as 1829 had recorded *A. kœnigi*.[3]

In 1925 the Survey reported the discovery of a tiny faulted patch of Oxfordian strata in Mull, in the right bank of a stream which flows into Duart Bay, at a point 300 yards above the bridge. The rock is a marly, fine-grained sandstone, containing a fossil-bed, from which were collected ammonites identified by Buckman as *Kosmoceras elizabethæ-spoliatum* Quenst., *Reineckeia* spp. and *Phlycticeras* sp. I have seen the material (of which there is a considerable quantity) and, as Dr. Spath points out, the supposed Kosmocerates have keels and are undoubtedly *Amœboceras kitchini* Salf., while the 'Reineckeias' are nothing else than *Raseniæ*. *Reineckeia* therefore still remains undiscovered in Northern England or Scotland (see below, p. 478).

The small faulted fragments overlying the Estuarine Series at Strollamus and Scalpa are much metamorphosed and have yielded no new information. They appear to be Cardioceratan in date.

The occurrences in Strathaird and in Eigg are important and the study of them in recent years by the Survey has added greatly to our knowledge of the Scottish Oxford Clay.

In Strathaird the Oxfordian beds occur over a large part of the promontory, cropping out from below the basalt in the western cliffs, north of Elgol. Here they may reach a thickness of as much as 300 ft., of which an unknown portion near the top should be assigned to the Lower Calcareous Grit; northwards they are overstepped by the basalt. Lithologically the beds are more sandy than in the north of Skye. The upper portion still consists of dark grey or blue micaceous shale, probably altered from a clay, but downwards it becomes

[1] Buckman figured from Staffin *Peltoceratoides torosus* (Oppel), *T.A.*, pl. DLXIII, and the genotype and holotype of *Korythoceras korys*, pl. CCCLXI.

[2] *T.A.*, pl. CDXXXVII.

[3] R. I. Murchison, 1829, *Trans. Geol. Soc.* [2], vol. ii, p. 311. Bryce (1873, *Q.J.G.S.*, vol. xxix, p. 332) misquotes Murchison as recording '*A. kœnigi* in masses . . .' The passage actually reads: 'I . . . found several fossils in blue shale through which a deep canal has recently been cut by Lord Macdonald, to drain the lake of Mugsted. Among the shells are the ammonites königi, ostreæ in masses, many belemnites, flattened tellinæ? &c.' Jones showed that the '?flattened tellinæ' were the Ostracod, *Estheria murchisoni* Forbes, of the Great Estuarine Series, and the masses of *Ostreæ* also indicate that the *Ostrea hebridica* Beds of the Great Estuarine Series were cut through.

more sandy until, in about the lowest 80 ft., it has become a succession of shaly, micaceous or calcareous sandstones and grits. The basement beds are coarse-grained and pebbly, in places forming a striking-looking conglomerate of white quartz and quartzite pebbles, often more than an inch in diameter.

From the base upwards the sandstones yield an unmistakable Upper Oxford Clay fauna, with (according to the specific identifications of 1910) distinct Lower Calcareous Grit elements. Wedd records *Cardioceras cordatum*, *C.* ? *nikitinianum*, *C.* cf. *rotundatum*, *C. rouilleri*, *C. suessi*, *C. tenuicostatum*, *C.* cf. *vertebrale*, *Chlamys fibrosa* and *Pseudomonotis* cf. *ovalis* as making their appearance near the base of the formation. There is here no indication of any other part of the Oxford Clay but *præcordatum* and *cordatum* beds.

Apparently similar conditions would appear, from Barrow's account, to obtain in Eigg, except that there the sandstones are much thinner. The exposures are limited to shore-reefs between tide-marks in Laig Bay, and to a little gorge east of Laig Farm. The upper part of the sequence, exposed on the shore, consists of dark grey shales, like those at Loch Staffin but more friable than those of Strathaird. They have yielded fossils identified as *Cardioceras cordatum* (2 forms, coarsely and finely ribbed), *C. excavatum*, *Aspidoceras perarmatum* and a number of Corallian lamellibranchs, and there can be no doubt that they should be referred to the Lower Calcareous Grit (*cordatum* zone) at least in part, as in Strathaird. Underneath, in the gully near Laig Farm, is a bed of limestone about 8 ft. thick, beneath which are about 12 ft. of calcareous sandstone, neither yielding diagnostic fossils, the latter resting on the Great Estuarine Series.

The presence of Kellaways Beds in at least one locality in Strathaird is proved by large fallen blocks of sandstone lying on the beach, north of Elgol. They contain nests of a small Callovian *Rhynchonelloidea*, cf. *socialis*, together with *Ornithella kellawaysensis*, *Pseudomonotis* sp., and occasional ammonites assigned to *Gowericeras gowerianum*, marking the *kœnigi* zone. The bed from which the blocks fell has not been identified *in situ*, and it is not known whether its position is above or below the basal conglomerate.

The relations of the Oxford Clay to the underlying rocks in the Hebrides are shown by these few remaining relics to be far more non-sequential and irregular than anywhere in England. The isolated patch of Cornbrash in Raasay, the equally isolated occurrences of Kellaways Beds at Elgol and Monkstadt, the restricted area of Lower Oxford Clay in north-east Trotternish, and the overlapping of late *præcordatum* deposits on to the Great Estuarine Series in Eigg and in parts of Strathaird, testify to greater disturbances than were experienced at the period in any other parts of the British Isles.

VI. KENT[1]

The concealed outcrop of the Oxford Clay beneath the Cretaceous rocks under Kent forms a strip from 1 to 3 miles wide, running parallel to the thin Lower Oolites and dipping south with them. Beginning at the coast on the south side of St. Margaret's Bay, it underlies Canterbury, Faversham and Sittingbourne, and passes close to the north of Gillingham and Gravesend.

[1] Based on Lamplugh and Kitchin, 1911, loc. cit.; and Lamplugh, Kitchin and Pringle, 1923, loc. cit.

On this belt and to the south of it the Oxford Clay and Kellaways Beds have been pierced in several borings. The bulk of the Oxford Clay consists of uniform blue-grey clay, of fine texture, with subordinate brown bands, while the *præcordatum* zone is altogether peculiar, consisting of ironshot marls such as are developed on the other side of the Channel. The Kellaways Beds, as usual, proved exceedingly variable.

The Oxford Clay thickens rapidly westward from about 130 ft. at Dover to 200–210 ft. at Brabourne and Chilham, near the line of the railway south-west of Canterbury.[1] The Kellaways Beds also thicken from the coast towards Canterbury and thin out again farther west. The maximum thickness recorded is 43 ft. at Fredville, almost midway between Canterbury and Dover, while farther west, at Brabourne and Harmansole, less than 20 ft. was proved.

SUMMARY OF THE OXFORD CLAY IN KENT

Præcordatum Zone.

At the top of the formation, in and just above the ironshot marls, a rich fauna of Cardiocerates was found. The highest of these were still of *præcordatum* date and, as no palaeontological proof of the *cordatum* zone or Lower Calcareous Grit was found, the *præcordatum* zone is probably directly overlain by the *martelli* beds, as at Quainton. The zone is, however, very differently developed from the typical clays familiar in other parts of England, consisting largely of marls and marlstones full of brown ironshot ooliths, such as are found on the same horizon in the cliffs between Villers and Houlgate in Normandy. For this reason the Survey classed them in their Memoirs as Lower Corallian.

The highest bed in which Cardiocerates were found was a band of hard grey marlstone, about 4 ft. thick, crowded with black-coated fossils. The stratum was recognized at Fredville, Snowdown Colliery, Bere Farm, Brabourne, Chilton, Chilham, and probably also at Guildford. Its ammonites were recorded as *Cardioceras* cf. *excavatum* (Sow.), *C.* cf. *pingue* (Rouill.) and undescribed species, two of which were compared with *C. cordatum* Lahusen (non Sow.) and *C. cordatum* de Loriol (non Sow.); *Aspidoceras* sp., resembling *A. faustum* Bayle; *Peltoceras arduennense* (d'Orb.) in abundance, *P.* cf. *eugenii* (d'Orb.); *Perisphinctes bernensis* de Lor. (pars.), *P.* cf. *variocostatus* (Buckland) and *P.* sp. nov. The commonest lamellibranchs were *Isognomon* cf. *cordati* (Uhlig) and *Unicardium sulcatum* Leckenby, with which were associated such more typically Corallian species as *Chlamys fibrosa*, *C. inæquicostata* (Phil.), *Camptonectes lens* (Sow.), and the brachiopods *Terebratula farcinata* Douv. and *Rhynchonelloidea thurmanni* (Voltz.). This mixed fauna and the abundance of the fossils point to the bed being a product of slow deposition, perhaps spanning parts of the *præcordatum* and *cordatum* zones.

A few feet beneath this interesting bed was an almost equally persistent band of marly, crumbly, locally pisolitic clay, which also yielded a number of fossils of Corallian facies—*Nucleolites dimidiatus* (Phil.), *N. scutatus* Lam., *Holectypus* cf. *oblongus* Wright, a large *Gryphæa*, numerous valves of *Chlamys fibrosa*, and fragments of a large *Perisphinctes* cf. *variocostatus*. Were it not

[1] These figures include the ironshot marls of the *præcordatum* zone, which the Survey classed with their Lower Corallian.

for the Cardiocerates in the marlstone above it, one would certainly group this bed with the Corallian.

Below are 25–35 ft. of olive green and brown marlstones and marls, more or less filled with ironshot grains and on the whole richly fossiliferous. Cardiocerates were again most conspicuous, including *C. cordatum* Lah. (non Sow.), *C. excavatum* Lah. (non Sow.), *C. rouillieri* Lah., *C. tenuicostatum* (Nik.) and undescribed species. Near the base were found *C. nikitinianum* Lah., *Aspidoceras œgir?* (Oppel) and (?)*Peltomorphites williamsoni* (Phil.). *Gryphææ* were not numerous, but such as were found were of the large, massive varieties of *G. dilatata* so characteristic of the *præcordatum* zone inland. Among the most interesting of the fossils were fragments of the stems of *Millericrinus*, suggestive of the Marnes à *Millericrinus* on the same horizon in the Boulonnais.

It is perhaps noteworthy that, although no ironshot oolite occurs in the *præcordatum* zone in Dorset, yet the presence of a quantity of iron in the zone is attested by the red coatings of the nodules in the Red Nodule Beds.

Renggeri and **Lamberti Zones**.

Beneath the *præcordatum* zone numerous Quenstedtocerates were found, as usual in the form of pyritized casts, and among them *Q. lamberti* (Sow.), *Q. leachi* (Sow.), *Q. macrum* (Quenst.) and *Q. goliathum* (d'Orb.) were identified. With these were some species of the genus *Creniceras*, indicating the *renggeri* zone, and indeed the name *Renggeri* Beds was originally applied to this middle division. The lamellibranch fauna provided interesting evidence for the connexion with the Bernese Jura, suggested by the Perisphinctids in the overlying zone, and bearing out Prof. Davies's remarks on the fauna from this zone collected at Ludgershall railway-cutting, Bucks. *Parallelodon* (*Grammatodon*) *concinnum* (Phil.), *P.* (*G.*) *montanayensis*, *Lima* cf. *trembiazensis*, *Nuculana rœderi*, *Perisphinctes* cf. *billodensis*, all species described by de Loriol from the Bernese Jura, were identified. As in other parts of the country and on the Continent, two typical Middle Oxford Clay fossils occurred, the Decapod Crustacean, *Mecocheirus socialis* (Meyer), and the subequilateral and well coiled *Gryphæa*, *G. lituola* Lamk.

Duncani-Jason Zones.

The Lower or Kosmoceratan Oxford Clay is condensed and much of it is full of bivalves, especially *Astarte*, *Nucula* and *Cucullæa*, thus showing that the conditions of deposition were not of the anaerobic type normal at the time in most other parts of England. Probably, too, sedimentation was much interrupted by penecontemporaneous erosion. No evidence of the *athleta* zone was found, but the numerous specimens of *Kosmoceras* in the usual pyritized or crushed condition, and some of *Erymnoceras*, gave evidence of *duncani*, *reginaldi* and *jason* horizons, in descending order. At Fredville and Chilham specimens of *Erymnoceras* occurred a few feet from the base.

Calloviense and **Kœnigi Zones** (KELLAWAYS BEDS).

The Kellaways Rock is sharply demarcated, both lithologically and palaeontologically, from the overlying clays, having always a fauna and certain lithic characters entirely its own. It is more sandy than the Oxford Clay and usually ferruginous, and throughout it *Gryphæa bilobata* and allied species are abundant. The Gryphæas become larger towards the top, those in the lower part being very diminutive, like the small form so common at Kellaways. Other common species, also recalling the fauna at Kellaways and in Yorkshire, are *Oxytoma* sp., *Pseudomonotis* sp., *Pleuromya recurva* and *Entolium demissum*. The ammonites show that the bulk of the rock belongs to the *calloviense* zone. No examples of *Gowericeras* or *Sigaloceras* were found, while only one imperfect fragment of an ammonite resembling a *Proplanulites* was obtained, in the basal bed at Oxney. This is all the palaeontological evidence for the *kœnigi* zone, but there is between the Kellaways Rock and the Cornbrash a bed of clay a few feet thick which may represent the Kellaways Clay. It was classed by Messrs. Lamplugh, Kitchin and Pringle with the Cornbrash, but they likened it to the wrongly-styled 'Clays of the Cornbrash' in Yorkshire, which we have seen are more properly classed with the Kellaways Clay.

CHAPTER XIII

CORALLIAN BEDS

Zones (Plate XXXVIII).	*Stratal Divisions.*	*Dorset Strata.*
Ringsteadia anglica[1] and *Perisphinctes (Dichotomosphinctes) wartæ*[2]	Upper Calcareous Grit	Ringstead Coral Bed
		Ringstead Waxy Clay
		Sandsfoot Grit
	Glos Oolite Series[6]	Sandsfoot Clay
Perisphinctes (Dichotomosphinctes) antecedens[3] and *Perisphinctes martelli*[4]		*Trigonia clavellata* Beds
	Osmington Oolite Series	Osmington Oolite Series
	Berkshire Oolite Series	Bencliff Grit
		Nothe Clay
		Trigonia hudlestoni Bed
Cardioceras cordatum[5]	Lower Calcareous Grit	Nothe Grit

[1] Salfeld's zone of *Ringsteadia anglica* Salf. and *R. pseudocordata* (Bl. & Hudl.), including his rather doubtful zone of *Perisphinctes decipiens* (Sow.), a species which has not yet been properly determined. *P. decipiens* (Sow.) has been recorded in the Sandsfoot Grit, but a separate zone for this is unnecessary, as it contains *Ringsteadiæ* from base to summit. As alternative zonal indices to *P. decipiens*, Salfeld used *P. achilles* d'Orb., a foreign species not yet found in this country and [*Prionodoceras*] *serratum* (Sow.) (the former in his two zonal tables, 1914, *N. Jarb. für Min.*, BB., vol. xxxvii, and the latter in the text, loc. cit., p. 129). *P. serratum,* however, seems to range up to the very top of the *Ringsteadia* zone and possibly also into the zone of *Pictonia baylei* at the base of the Kimeridge Clay (as at Swindon, Salfeld, loc. cit., p. 196); Buckman considered the genus Kimeridgian.

[2] The ammonites (and other fauna) of the Sandsfoot Clay are very little known. Salfeld placed it in his zone of *P. wartæ* and [*Amœboceras*] *alternans* von Buch; but the only specimens truly assignable to *P. wartæ* that I have seen from England are one in the Geological Survey collection from the Westbury Iron Ore (No. 25484) and some collected by Prof. Davies from the Ampthill Clay (see p. 410).

[3] Forms identical with *Perisphinctes antecedens* Salf. are found in the Osmington Oolite Series inland, and this series is stratigraphically so distinct from the Berkshire Oolites that it was formerly for the sake of convenience considered to be a separate zone. It is probable, however, that it is only a subdivision of the broad *martelli* zone, for there are two specimens of *P.* cf. *martelli* in the British Museum from some part of the Osmington Oolite Series near Weymouth. *P. antecedens* occurs in the *Trigonia clavellata* Beds.

[4] The Berkshire Oolite Series had not been differentiated at the time when Salfeld evolved his zonal scheme; it is the chief repository of the *martelli* or *transversarius* fauna. The index fossil is very rare, but allied species abound; Schindewolf coined for them a new generic name, *Martelliceras,* which Dr. Spath declares precisely synonymous with *Perisphinctes sensu stricto* (1931, *Pal. Indica,* NS., vol. ix, p. 401).

[5] *Aspidoceras perarmatum* (Sow.) is sometimes made alternative zonal index; but it is only known from Yorkshire, where it is very rare. *A. catena* (Sow.) is better.

[6] From Glos, near Lisieux, Normandy, where the Glos Sands link up the *T. clavellata* Beds (Grès d'Hennequeville) with the Sandsfoot Clay (Argile noire); see Arkell, 1930, *P.G.A.*, vol. xli, p. 399.

I. DORSET

(a) The Northern Limb of the Weymouth Anticline: Ringstead to Abbotsbury

THE Corallian Beds crop out along both limbs of the Weymouth Anticline, dipping away to north and south beneath the Kimeridge Clay.

The northern outcrop, 13 miles in length and seldom more than ½ mile wide, is marked by a ridge of downs running from the coast at Ringstead and Osmington to the Chesil Bank west of Abbotsbury. The ridge rises westward to a maximum height of 316 ft. above the sea at Linton Hill, near Abbotsbury, and near the end it is crowned by the ancient chapel of St. Catherine; southward lie the Oxford Clay lowlands and to the north the deep valley of the Kimeridge Clay (map, p. 342).

At the west end of the outcrop there are no natural sections exposed by the sea, owing to the protective action of the Chesil Bank, but the east end provides the finest exposures of Corallian rocks in Britain. The entire succession may be measured and studied in detail, through a total thickness of rather more than 200 ft., extending, with several repetitions, along some three miles of cliffs (fig. 64).

In Ringstead Bay in the east, the beds first appear gradually from beneath the Kimeridge Clay in low banks, rising into cliffs as the harder middle portions of the formation are brought up above sea-level. For a considerable distance a steep precipice is formed of the Osmington Oolite Series, capped by the *Trigonia* Beds, dipping gently to the east (Pl. XVI). At the foot is the Bencliff Grit. At Osmington Mills some complicated faulting interrupts the succession, and the Nothe Clay and much of the Lower Calcareous Grit are obscured.

From Osmington Mills westward the Corallian Beds are tilted steeply to the north, and the hard bands of the Osmington Oolite Series run in parallel ridges along the beach, standing nearly on edge. At Shortlake Chine they rise in the cliff and a complete section is provided down to the Oxford Clay, but the Lower Calcareous Grit here is somewhat obscured by vegetation. Towards Redcliff Point an anticlinal flexure brings down the Lower Calcareous Grit almost to sea-level once more, and there are magnificent exposures of this division and of the Nothe Clay on both sides of the Point.[1] At Bowleaze Cove at the west end of Redcliff the base of the Lower Calcareous Grit passes finally out of the cliffs, which thence turn southward and expose only Oxford Clay under Jordan Hill (fig. 65, p. 382).

The succession here and south of Weymouth was systematically described during the last century by Blake and Hudleston[2] and again, with amendments, by H. B. Woodward.[3] In 1926 I re-measured and described all the exposures and during recent years have collected fossils carefully, bed by bed.[4]

[1] The Point itself consists of a small upthrown block of Oxford Clay, largely obscured by slips.

[2] J. F. Blake and W. H. Hudleston, 1877, *Q.J.G.S.*, vol. xxxiii, pp. 260–75.

[3] H. B. Woodward, 1895, *J.R.B.*, pp. 82–94.

[4] A brief correlation was published in 1927, *Phil. Trans. Roy. Soc.*, vol. ccxvi B, pp. 156–9.

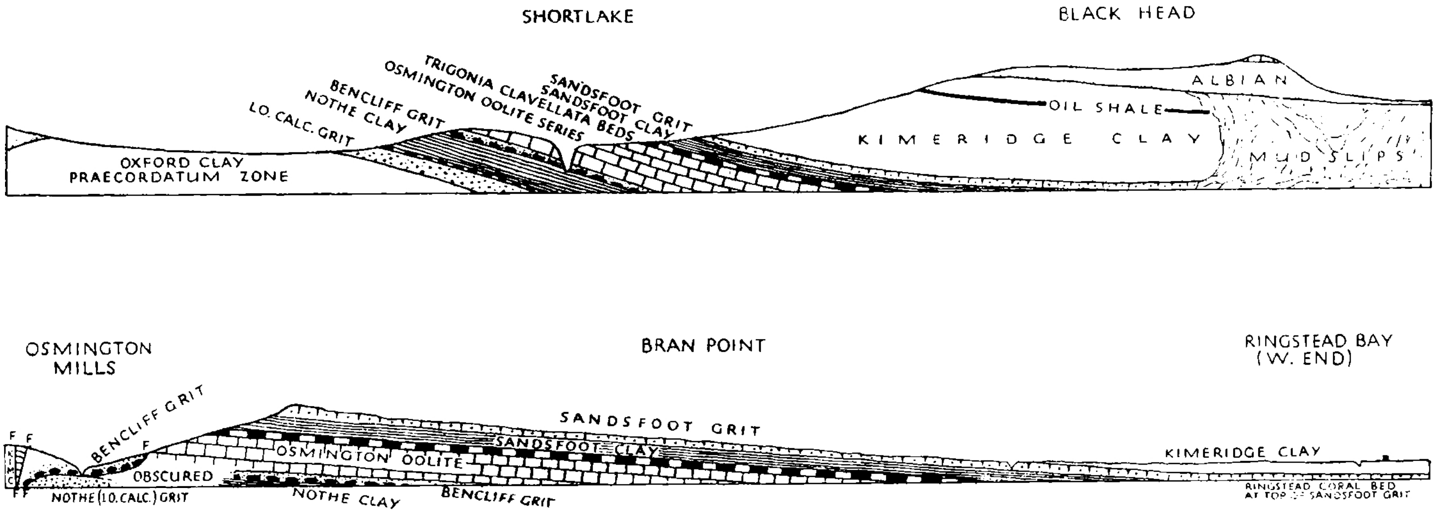


FIG. 64. Sections of the Corallian Beds in the cliffs west of Osmington (above) and east of Osmington (below). Length of each 1·1 miles. The two sections are separated by a ¼ mile of cliffs in which the Corallian Beds dip almost vertically and the strike coincides with the line of the coast. The upper section is continuous with the lower one in fig. 65. (Outline based on Strahan, 1898, 'Geol. Isle of Purbeck and Weymouth', *Mem. Geol. Surv.*, Plate IX.) Vertical scale exaggerated.

SUMMARY OF THE CORALLIAN SERIES, RINGSTEAD TO OSMINGTON[1]

Upper Calcareous Grit, 18–20 ft.

The stratum taken to be the topmost bed of the Corallian is the RINGSTEAD CORAL BED, known as the Kimeridge Grit by Damon and as the Upper Coral Rag by Blake and Hudleston and by Woodward. It rises gradually from the beach in the western side of Ringstead Bay and, though it appears to have been often obscured in the past by slipped Kimeridge Clay and gravel, it has been well exposed in recent years (Pl. XXI). It consists of 8 in. of tough, green, argillaceous limestone, largely made up of shells and broken corals. The commonest fossils are the large *Ctenostreon proboscideum* (Sow.), with which are associated *Chlamys splendens* (Dollf.), *C. nattheimensis* (de Lor.), *Camptonectes lens* (Sow.), *Entolium demissum* (Phil.), *Velata hautcœuri* (Dollf.), *Lima rigida* (Sow.), *Myoconcha texta* (Buv.), *Ostrea delta* Smith, and a number of other lamellibranchs and gastropods, with spines of *Cidaris florigemma* and the corals *Thecosmilia annularis*, *Thamnastræa concinna*, &c.

In a westerly direction, towards Osmington, the fossils become scarcer. Where the bed reappears beyond Osmington, under Black Head, the only species at all abundant is *Ctenostreon proboscideum*. The rock becomes at the same time less tough and is shot with ferruginous ooliths, while farther still, on the Weymouth promontory to the south, it passes into a true ironshot oolite and all fossils are comparatively rare. From this it may be deduced that the coral reef, to which the coral fragments and shells at Ringstead bear witness, lay under the Chalk Downs to the east.

Beneath the Ringstead Coral Bed are the RINGSTEAD WAXY CLAYS, 10 ft. of waxy, ferruginous clay, interrupted by seams of claystone nodules towards the top, and numerous seams of laminated claystone or clay-ironstone throughout, with layers of *Ostrea delta* towards the base. Immediately subjacent to the Coral Bed is a 3-in. band of especially prominent, red clay-ironstone nodules, containing occasional specimens of *Ringsteadia anglica* Salf.

These beds may be correlated approximately with the Westbury Iron Ore of Wiltshire. Recognizable ammonites do not seem to have been obtainable in recent years from the Ringstead Coral Bed itself,[2] but undoubted fragments of *Pictonia* are common in the clay immediately above, while *Ringsteadia* is found immediately below.

The SANDFOOT GRIT, some 25 ft. thick at Sandsfoot Castle, south of Weymouth, measures only about 7 ft. at Ringstead Bay. Where it rises from the beach beneath the Ringstead Waxy Clays, at the west end of the bay, it consists only of a 2-ft. band of bright red sandstone, speckled with white ooliths and quartz grains, and containing fucoid markings, overlying 5 ft. of brown sandy marls. Farther west, at Black Head, Osmington, the single hard band has thickened to 4 ft. and has split up into four bands of red and green ferruginous sandstone, with the same speckling of ooliths and quartz grains. The commonest fossils are *Chlamys midas* (d'Orb.), *Goniomya*, *Pleuromya*, and *Nautilus hexagonus* (Sow.). Blake and Hudleston recorded '*Ammonites decipiens*', and at Sandsfoot *Ringsteadiæ* are not uncommon.

[1] Based mainly on unpublished manuscript.
[2] Damon recorded a dozen species, but most of them, if correctly identified, certainly came from beds above and below. (*Geol. Weymouth*, 2nd ed., 1884, pp. 65–6.)

Glos Oolite Series, 50 ft.

The SANDSFOOT CLAY, probably about 20 ft. thick at Ringstead[1] and about 30 ft. thick at Black Head, consists of grey, blue and brown clay with varying amounts of ferruginous staining and greenish sand. Layers of *Ostrea delta* are abundant near the top and are liberally distributed throughout, the shells being indistinguishable from those in the basal portion of the Kimeridge Clay, except that on an average they died before attaining such an advanced stage of growth.

At the west end of the outcrop, near Abbotsbury, the thickness is much diminished. The deposit is therefore somewhat lenticular.

The TRIGONIA CLAVELLATA Beds, 14½ ft. These beds are the most remarkable in the whole Corallian Series, for they are veritable fossilized shell-banks. They consist of strong courses of tough red and purplish-brown shelly limestone (the Red Beds of Damon) separated by marly partings, the whole crowded with bivalves and other fossils. On some of the slabs valves of *Trigonia clavellata* are massed so closely together that they touch and form a continuous pavement; on other slabs Pectens, oysters, Astartes, &c. predominate. As a source of well-preserved fossils these beds were early renowned, and Sowerby figured several of the species in *The Mineral Conchology*: namely *Trigonia clavellata*, *Gervillia aviculoides*, *Mytilus pectinatus* and *Lopha solitaria*. Besides these, type-specimens of species founded by subsequent investigators have come from the same beds—those of the abundant *Plicatula weymouthiana* Damon, *Pteria pteropernoides* (Blake and Hudleston) and *Chlamys superfibrosa* Arkell. Other abundant species are *Cucullæa contracta* Phil., *Pteroperna polyodon* (Buv.) and *Cerithium muricatum* Sow. Small pieces of coral occur and, very rarely, Perisphinctids. All these seem to belong to the narrow-whorled group of which *P. wartæ* Bukowski is a member, but they resemble Salfeld's 'mut' *antecedens* of North-West Germany rather than the type-form from Poland, which has a marked forward sweep of the secondary ribs on the periphery (see Plate XXXVIII).[2]

Osmington Oolite Series, 63–5 ft.

Blake and Hudleston drew the boundary between the *T. clavellata* Beds and the Osmington Oolite Series far below the occurrence of the *Trigoniæ*. There is a gradual lithological passage between the two divisions, but it is essential to be guided by the palaeontology and, following H. B. Woodward, to restrict the name *T. clavellata* Beds to the beds actually containing this fauna.[3] Below comes a highly variable series of strata, for the most part comparatively barren of fossils. They form the cliffs to the east of Osmington, where they are magnificently exposed and can be studied in detail. Of the total thickness of 63–5 ft. between Ringstead and Osmington in the east, only 6 ft. 3 in. consist of the typical white oolite, such as is used for building.

The true Osmington Oolite is a solid, white, even-grained, oolitic freestone, with some clay-galls and vertical tubiform markings. It occurs in two blocks,

[1] H. B. Woodward (1895, *J.R.B.*, p. 85) states 10–12 ft., but this seems to be an underestimate. The thickness is difficult to determine owing to slips.

[2] There are a few specimens in the British Museum, collected by Damon, and a fragmentary example in my own collection, none of them the true *wartæ*.

[3] H. B. Woodward, 1895, *J.R.B.*, pp. 85, 86, 91.

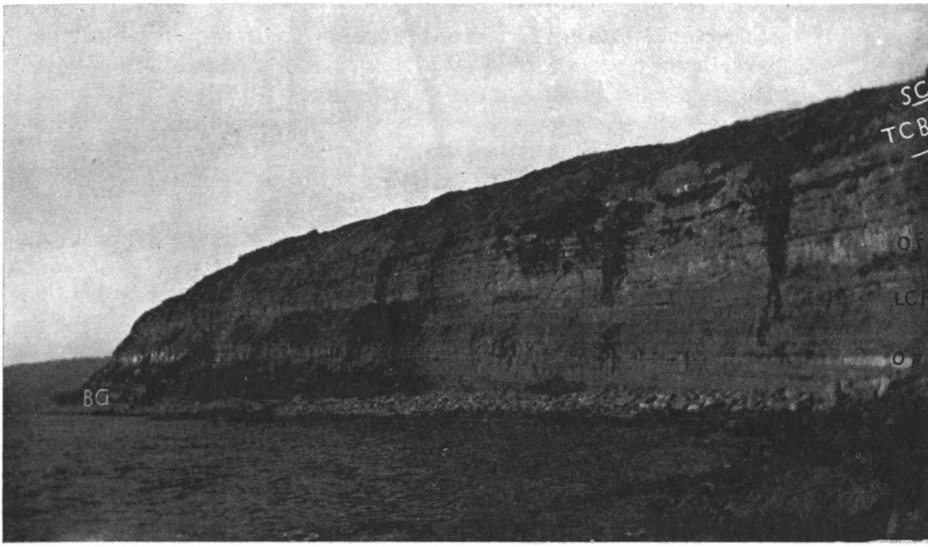


Photo. *W. J. A.*

Osmington Oolite Series, east of Osmington Mills, Dorset.

SC = Sandsfoot Clay capping cliff; TCB = *Trigonia clavellata* Beds; OF = Oolite facies and LCF = Littlemore Clay facies of Osmington Oolite Series; BG = Bencliff Grit.

Photo. *W. J. A.*

Osmington Oolite Series, Bran Point, east of Osmington Mills, Dorset.

The lowest ledge is of gritty oolite and rests directly on the Bencliff Grit; next above it is (Q) the *Chlamys qualicosta* Bed, and (P) the pisolite seam. The strong bands near the top of the cliff towards the point are *Trigonia clavellata* Beds, and the capping is Sandsfoot Clay.

PLATE XVII

Photo. W. J. A.

Redcliff, near Weymouth.

LCG = Lower Calcareous Grit; THB = *Trigonia hudlestoni* Bed; NC = Nothe Clay. A crest of Osmington Oolite is seen behind and above the slope of Nothe Clay and Bencliff Grit (which is mostly concealed).

Photo. W. J. A.

Redcliff, near Weymouth.

The large blocks on the right have fallen from the *Trigonia hudlestoni* Bed.

2 ft. and 4 ft. 3 in. thick. Most of the rest of the sequence consists of blue and grey oolitic or pisolitic marly clays with bands of nodular, grey, argillaceous limestone. From its occurrence in Littlemore railway-cutting, near Oxford, this facies is known as the Littlemore Clay Beds. At the top are over 20 ft. of conspicuously nodular, concretionary, partly oolitic grey and white limestones; this facies too is typically represented in the Midlands, especially about Oxford, where it is known as the Nodular Coralline Rubble.

Near the base is a 1½ ft. band of hard, shelly, oolitic and pisolitic, gritty limestone, crowded with *Chlamys qualicosta* (Etall.), *C. fibrosa* (Sow.), and *Exogyra nana* (Sow.), and above it, separated by 2 ft. of clay, is a seam of loose pisolite. The pisolite (2 ft.) is a very persistent feature, marking the base of the Osmington Oolite Series throughout Dorset and as far as South Wiltshire.

Westward, along the strike, the solid white oolite-facies increases in importance; west of Osmington the 2-ft. seam divides into two, the 4-ft. seam doubles in thickness, and a third seam (4 ft. thick) appears below the others. At the top of Redcliff the white oolite division takes on a facies closely resembling Forest Marble: false-bedding is intensified, much of the oolite grows sandy and fissile, and it is full of clay-galls. In the face of the cliff, 6 ft. out of the total thickness of 13 ft. pass in a short distance into sandy, shaly, greenish clay, with thin films of fissile limestone. This facies is only local, for in a quarry on the top of Jordan Hill, ½ mile to the west, the division is a solid false-bedded oolite once more.

At the west end of the outcrop, about Abbotsbury, a high proportion of the Osmington Oolite Series has passed into hard white oolite, which has been extensively quarried. A thickness of 22 ft. may be seen in a single quarry-face; but fossils are very scarce.

Palaeontologically the Osmington Oolite Series yields little information. It may be said to be characterized principally by the admixture of *Chlamys fibrosa* and *Chlamys qualicosta*. The former seldom, if ever, ranges above it, and the latter has not been found below it. Ammonites are extremely rare, but in the British Museum (Damon Collection) there are two large specimens of *Perisphinctes martelli* Oppel, labelled as from the Osmington Oolite of Osmington, and in a matrix that seems to bear out the labels. Inland, about Oxford, the commonest of the rare ammonites in these beds belong to the group of *P. antecedens* Salfeld; but associated with them are other forms of *Perisphinctes sensu stricto*, which are certainly very closely allied to *P. martelli*—itself a rare species in this country.

Berkshire Oolite Series, 55–60 ft.

The BENCLIFF GRIT (called after Bencliff or Bincleave at Weymouth) is about 14 ft. thick east of Osmington and only about 10 ft. thick farther west, at Shortlake. It consists of yellow and white sands, locally false-bedded, with a few doggers and seams of interlaminated clay, and at the bottom a band of huge doggers of gritstone; these measure over 6 ft. in diameter, and are composed of intensely hard, blue, false-bedded, indurated calcareous grit, with occasional *Gryphæa dilatata* and *Serpulæ*. They are a conspicuous feature on the beach wherever the grits crop out in the cliff—even when, as at Redcliff, the outcrop is completely hidden by slipped ground.

The NOTHE CLAY (from Nothe Point, Weymouth) is 35–40 ft. thick. East

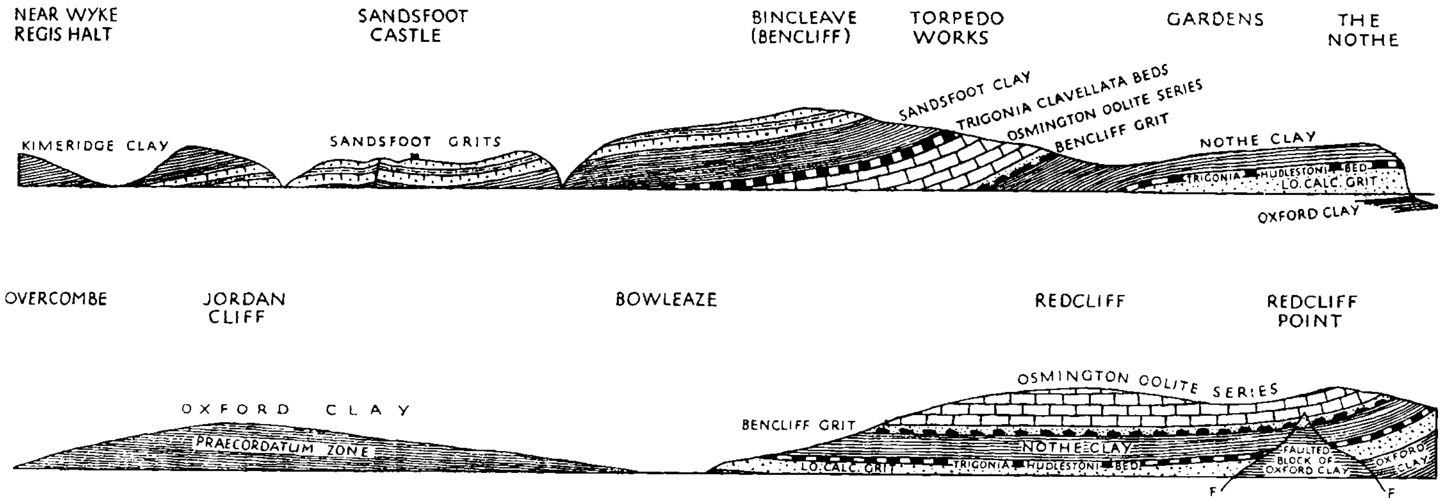


FIG. 65. Sections of the Corallian Beds in the cliffs south of Weymouth (above): distance slightly less than 2 miles (based on H. B. Woodward, 1895, *J.R.B.*, p. 83); and north of Weymouth (below): distance 1·1 miles (outline based on Strahan, 1898, 'Geol. Isle of Purbeck and Weymouth', *Mem. Geol. Surv.*, Plate IX). Vertical scale exaggerated.

and west of Osmington the Bencliff Grit is the lowest bed clearly exposed in ordered sequence, and to study the downward continuation it is necessary to pass westward to Shortlake and Redcliff. At Redcliff the Nothe Clay forms tumbled and slipped ground in the upper part of the cliff on both sides of the Point. About 38–40 ft. may be measured. It consists principally of grey-blue shaly clay, with two thin bands (8–10 in.) of dark-brown ferruginous limestone in the lower part, containing fucoid markings and fossils—*Chlamys fibrosa*, *Lima subantiquata* Roem., *Gervillia aviculoides*, *Modiola bipartita*, *Gryphæa dilatata*, *Pholadomya* and *Pleuromya*. There are also several bands of nodules or nodular limestone.

The Preston Grit or Trigonia hudlestoni Bed (from Preston village, near Redcliff) is 5–6 ft. thick. Blake and Hudleston and other observers included this bed in the Nothe [= Lower Calcareous] Grit, but as it is one of the most fossiliferous beds in the Dorset Corallian, and one of the most valuable for purposes of correlation, it is important to keep it separate, either under Buckman's name, Preston Grit,[1] or as the *Trigonia hudlestoni* Bed.[2] It is a massive band of hard, brownish-grey, gritty, speckled, doubtfully oolitic limestone, full of fucoid markings, which forms a prominent feature west of the point (Pl. XVII). The huge fallen cubes on the foreshore provide good opportunities for collecting, and they have yielded all the essential fauna of the *Trigonia hudlestoni* Beds of the inland Berkshire Oolite Series: *Perisphinctes helenæ* De Riaz, *Cardioceras excavatum* (Sow.), *Cardioceras* cf. *vertebrale* (Sow.), *Aspidoceras* sp., *Goliathiceras* sp., *Trigonia hudlestoni* Lyc., *Camptonectes lens*, *Chlamys fibrosa*, *Chlamys splendens*, *Cucullæa contracta*, *Lima rigida*, *L. subantiquata*, *Ostrea quadrangularis*, *Lopha gregarea*, *Gryphæa dilatata*, *Oxytoma expansa*, *Pseudomonotis ovalis*, &c.[3]

Lower Calcareous Grit, 27 ft.

Blake and Hudleston called the Lower Calcareous Grit the Nothe Grit, after the Nothe promontory, Weymouth, but this term may be suppressed as a synonym. At Redcliff the whole thickness is conveniently exposed on both sides of the Point. It consists of yellow and grey sands, soft, bluish, argillaceous sand, and somewhat shaly and sandy marl, with several beds of doggers or more or less constant bands of gritstone. Towards the west, as pointed out by Blake and Hudleston, the grits and sands die out and pass laterally into clay 'till at Broadwey, due north of Weymouth, they are scarcely discoverable, unless represented by a single 2-ft. block of ferruginous sandstone, lying in the midst of clays; and only a thin band can be identified in the valley south of Abbotsbury, which is excavated down to the Oxford Clay'.[4]

The only abundant fossils in the Lower Calcareous Grit are large specimens of *Gryphæa dilatata*. Most of the fossils recorded by authors undoubtedly came from the *Trigonia hudlestoni* Bed. Even Buckman, as late as 1925, seems to have fallen into the error of identifying fossils in blocks of grit on the shore, broken from the *T. hudlestoni* Bed, and recording them as from the Lower Calcareous Grit.[5]

[1] S. S. Buckman, 1925, *T.A.*, vol. v, p. 64.
[2] W. J. Arkell, 1927, *Phil. Trans. Roy. Soc.*, vol. ccxvi B, p. 158.
[3] W. J. Arkell, 1927, loc. cit., p. 158.
[4] Blake and Hudleston, 1877, loc. cit., p. 264.
[5] S. S. Buckman, 1925, *T.A.*, vol. v, p. 65, bed 7.

Buckman named three subdivisions of the beds at Redcliff, in descending order, Radcliff Grit, Jordan Grit, and Ham Cliff Grit.[1] But the misidentifications just mentioned vitiate his palaeontological distinctions, while his failure to publish measurements makes it difficult to obtain even an approximate idea of what he intended to include under the three terms. The ephemeral nature of the minor lithological units, as demonstrated by their westerly passage into clay, renders any subdivisional terms of doubtful value.

At a level 4 ft. below the base of the *Trigonia hudlestoni* Bed (as well as in it) I have obtained several specimens of *Cardioceras* cf. *excavatum*, *in situ* in the cliff west of Redcliff Point, near Bowleaze Cove. A short distance lower begin curious bands of large nodules of intensely hard, dark-grey, argillaceous gritstone, some of which resemble cannon-balls protruding from the larger doggers or grit-bands. Buckman noticed the highest and most conspicuous layer of these nodules (in his Jordan Grit) and said that they were 'obviously derived', perhaps from the Patellate Layer in the Oxford Clay.[2] Closer inspection, however, makes it certain that they are not derived, but are of concretionary origin. They occur at several levels in the Lower Calcareous Grit, the lowest layer being only 5 ft. from the base, and both the nodules and the surrounding grits sometimes contain the same large Gryphæas. Identical concretions are a conspicuous feature of the Lower Calcareous Grit in Yorkshire, where they are especially well seen at Cayton Bay.

(b) The Southern Limb of the Weymouth Anticline: Weymouth

The southern outcrop, though only 2½ miles in greatest length, is classic ground. The area is triangular, with the base of the triangle running E.–W. from the Nothe to the East Fleet Backwater and the apex near Small Mouth, where the road and the railway to Portland leave the mainland, crossing the mouth of the Fleet to Chesil Bank. On it are built the southern part of the town of Weymouth, with the upland parishes of Rodwell and Wyke Regis, and along its eastern coast are the type-sections at the Nothe Point, Bincleave or Bencliff, and Sandsfoot.

The deterioration of these sections has been so great during the present century that it is no longer possible to study the complete succession. The building of the breakwaters enclosing Portland Harbour has arrested coast erosion, and the cliffs of Sandsfoot Clay have now nearly reached stability, overgrown with thickets and trees; the construction of the torpedo works at Bincleave has closed the exposure of the Osmington Oolite Series to the public, and since the making of the road leading to the works the type-section of the Bencliff Grit has become totally obscured. The fortification of the Nothe long ago destroyed the type-section of the Nothe Grits, while that of the Nothe Clay received its *coup de grâce* in 1931 by the laying out of the cliff as gardens. Finally, a supplementary section of the Osmington Oolites and *Trigonia clavellata* Beds in Rodwell railway-cutting, described by Blake and Hudleston, is completely overgrown.

Only the Sandsfoot Grits can still be clearly seen, forming the striking red cliffs below the perched ruin of Sandsfoot Castle. Even of these the uppermost beds are obscured, but a continuous exposure can be seen in the low banks of the Fleet, south of Wyke Regis. The locality affords an interesting

[1] 1925, loc. cit., p. 65. [2] 1925, loc. cit., p. 65.

comparison with the northern limb of the Weymouth Anticline, for, although according to measurements published by H. B. Woodward in 1895 the total thickness of the Corallian Beds is 196 ft., or 7 ft. less than at Osmington, the Upper Calcareous Grit has expanded to 40 ft. Of this the highest 16 ft. comprise the Ringstead Waxy Clays with ironstone-nodules, correlated at Ringstead and Osmington with the Westbury Iron Ore; and here, in fact, a 1-ft. band of typical ironshot oolite like that at Westbury is found at the top, occupying the stratigraphical position of the Ringstead Coral Bed.

The Sandsfoot Grits proper, 24 ft. thick, consist of ferruginous sand and sandstone, the harder portions crowded with fossils; and in the upper part is a 5-ft. band of clay. The lamellibranch fauna of the grits is exceedingly interesting. It comprises only a small number of species, but they have a restricted range and constitute a highly characteristic assemblage. The most fossiliferous bed is near the base: it is packed with the valves of *Chlamys midas*, *Ostrea delta* and *Pinna sandsfootensis* Arkell, with which are associated the large *Camptonectes sandsfootensis* Ark., *Modiola*, and other forms. The ponderous *Ctenostreon proboscideum* is abundant throughout.[1] Some of the bands are a mass of ramifying fucoid markings, like those seen on a smaller scale in the Nothe Grits. Blake and Hudleston considered that these denoted the actual spot where a colony of algæ grew, but although the suggestion is probably correct, no organic structure has been found in them. The ammonites belong principally to the genus *Ringsteadia*, and the locality yielded a number of the specimens described by Salfeld in his monograph of the genus.

Since this type-section of the British Upper Calcareous Grit has been variously interpreted by Waagen, Blake, Blake and Hudleston, Woodward, and Salfeld, so that considerable doubt concerning the succession has crept into the literature (largely owing to the obscure language of Blake, who considered the uppermost a series of 'Passage Beds'—and what beds are not 'Passage Beds'?), I append the following record of the section, measured along the bank of the Fleet south of Wyke Regis and checked so far as possible at Sandsfoot.

UPPER CALCAREOUS GRIT SOUTH OF WYKE REGIS

Kimeridge Clay.

	ft.	in.
13. Blue-grey shaly clay, with layers of *O. delta*; seen to	6	0
12. *Exogyra nana* and *E. virgula* Bed: brown sandy band locally hardened like Forest Marble, crowded with small *Exogyræ*; as at Ringstead, &c.		8
11. *Rhactorhynchia inconstans* Bed; grey clay, with *Rh. inconstans*, *Exogyra prævirgula* Jourdy, and *Modiola durnovariæ* Ark.; *Pictonia* sp. found at Ringstead	1	8

Upper Calcareous Grit.

WESTBURY IRON ORE BEDS (16 ft.)

	ft.	in.
10. Prominent band of red clay-ironstone nodules		3
9. IRONSHOT OOLITE: dark ferruginous ooliths in a cream-coloured rubbly limestone matrix; large *Serpulæ*, *Modiola* sp., *Exogyra nana* and *Ctenostreon proboscideum* [=Ringstead Coral Bed]	1	0

[1] It was here that Dean Buckland of Oxford collected the type-specimens figured by Sowerby in *The Mineral Conchology*.

	ft.	in.
8. RINGSTEAD WAXY CLAY: Brown and red waxy clay, seen to 3 ft., below which is an unmeasurable gap of perhaps 3–5 ft., and then 6 ft. of blue-grey clay with a few clay-ironstone nodules. [*Ringsteadia anglica* Salf. found near the top of this clay *in situ* at Ringstead.] Total of clay according to Blake and Hudleston . . .	15	0
SANDSFOOT GRITS (24 ft.)		
7. Sand, yellow and ferruginous, full of rubble and fucoid markings, with *Pleuromya* and many broken *O. delta*	4	6
6. Sand, more consolidated, with some prominent hard bands, containing *Pinna sandsfootensis* and full of fucoid markings . . .	3	0
5. Clay, blue and brown . . . . passing down into	5	0
4. Sand, impure, ferruginous, with *Pleuromya* and *O. delta* and impersistent hard grit bands full of fucoid markings. *Ringsteadia pseudo-yo* Salf. found *in situ* at Sandsfoot	8	6
3. Clay, sandy, passing into sand under Sandsfoot Castle . . .	1	6
2. Fossil Bed: hard ferruginous gritstone, a mass of *Chlamys midas*, *Ctenostreon proboscideum*, *Ostrea delta*, &c. This band is very noticeable at the base of the grits at Sandsfoot Castle, where a large *Ringsteadia* was seen *in situ*	2	0
Glos Oolite Series.		
1. SANDSFOOT CLAY, much concealed by slips and vegetation, with abundant *Ostrea delta* at the top. [Total 38–40 ft. at Sandsfoot, according to authors]: seen to about	12	0

It is fairly certain that the ironshot oolite (9) is the equivalent of the Ringstead Coral Bed, although a prominent band of red clay-ironstone nodules occurs above the one and below the other, for near Osmington the coral bed is seen to pass into ironshot oolite westward.

The line here adopted as the top of the Corallian formation (the top of the *Ringsteadia* zone) agrees with that drawn by Waagen and by Blake and Hudleston, but Woodward classed all above Bed 7 with the Kimeridge Clay. The whole of the Sandsfoot Beds, including the Sandsfoot Clay, were stated by Sedgwick in 1826 to be 'within the limits of the Kimeridge Clay',[1] and this truly expresses the affinities of their fauna if the beds are to be parcelled into stages, using the terms Kimeridgian or Oxfordian. Waagen's subsequent conclusion that the Upper Calcareous Grit belongs with the Oxfordian is not upheld by the palaeontology.[2]

The remarks at the beginning of this section show that little remains to be said regarding the downward continuation of the sequence.

The *Trigonia clavellata* Beds form long shore-platforms beneath the cliff of Sandsfoot Clay south of Bincleave. They are 12 ft. thick and highly fossiliferous, but extremely hard. There is no exposure of this horizon on the shore of the Fleet.

The Osmington Oolite Series is somewhat thinner than at Osmington, probably about 45 ft. thick. On the shore of the Fleet it contains interesting beds crowded with *Isodonta triangularis* (Phil.), not noticed elsewhere.

According to Blake and Hudleston the total thickness of the Bencliff Grit

[1] 1826, *Ann. Phil.*, vol. xi, p. 349.
[2] 1865, *Versuch einer allgemeinen Classif.*, p. 24.

in the type-section was 21 ft.[1] It consisted of sand and sandstone, rather more argillaceous in the lower part, with the usual band of hard sandstone doggers at the base. The Nothe Clay was estimated to be 40 ft. thick, and the Nothe Grits about 30 ft. This last estimate included any representative there may have been of the *Trigonia hudlestoni* Bed. No details are preserved, except that Blake and Hudleston stated that the downward passage to clay was abrupt. The hardness of the gritstone bands is the direct cause of the long, narrow promontory of the Nothe. On the shores of the Fleet the lower beds are but obscurely exposed in small discontinuous sections.

(c) North Dorset

The Corallian Beds reappear from beneath the Chalk Downs at the villages of Mappowder and Wootton Glanville, whence they strike north for 16 miles, the outcrop having a width of from one to three miles, and forming pleasantly undulating and wooded country rising above the clay vales on either side. At Mere, near the north end of this outcrop, the Corallian Beds and Kimeridge Clay are cut off by the fault bounding the north side of the Vale of Wardour, so that they end abruptly against the steep down of Greensand and Chalk. Northward for 12 miles they are hidden beneath it.

In the southern half of the area the rocks are known only from a few unsatisfactory openings at Wootton Glanville, Mappowder and Hazelbury Bryant, most of them showing only a few feet of the *Trigonia clavellata* Beds. In the northern half of the area, however, the Osmington Oolite Series yields a good building stone, which is exploited in large quarries under the name of the Marnhull and Todber Freestone. A complete section near the centre of the area is afforded by the railway-cutting at Sturminster Newton, supplemented by a deep road-cutting by the river-side, south of the town. By combining the information derived from all these exposures, and from other quarries at Stour Provost, East Stour, Langham, Cucklington and Silton, the following sequence can be made out:

SUMMARY OF THE CORALLIAN SERIES IN NORTH DORSET [2]

Upper Calcareous Grit.

The only exposure known is in the Sturminster railway-cutting, at the top of which are 14 ft. of rusty yellow sand, much mixed with clay and soil.[3] Traces of the same beds are evident at Silton and elsewhere.

Glos Oolite Series.

The Sandsfoot Clay is 8 ft. 6 in. thick in the Sturminster railway-cutting, and the base appears above the *Trigonia clavellata* Beds in East Stour Quarry.

The *Trigonia clavellata* Beds are an important feature over the whole area, usually consisting of soft, shelly, rather marly limestones, crowded with well-preserved lamellibranchs, as in the Weymouth district. In the Sturminster railway-cutting their total thickness is 15 ft.

At Stour Provost and East Stour, 5 and 6 miles to the north, the total

[1] H. B. Woodward, in enlarging the Bencliff Grit to 35½ ft. (1895, p. 89) included in it 16 ft. of Littlemore Clay Beds clearly belonging to the Osmington Oolite Series and so classed by him at Shortlake and Black Head.
[2] Based mainly on field-notes and Blake and Hudleston.
[3] Blake and Hudleston, 1877, loc. cit., p. 276, fig. 2.

thickness has shrunk to $2\frac{1}{2}$ ft., and the dark, soft, shelly beds are sharply demarcated from the underlying courses of white oolite, belonging to the Osmington Oolite Series. At these places *Trigonia clavellata* abounds, together with *Chlamys qualicosta*, *Chlamys superfibrosa*, *Ostrea delta*, *Astarte morini*, *Nucula menkei*, *Cucullæa contracta*, *Trigonia reticulata*, *Gervillia aviculoides*, *Nerinea* sp., and numerous other bivalves as in the Weymouth district.

At the north end of the district, at Silton near Bourton, and Preston, north-west of Gillingham, rolled corals become conspicuous, mixed with the same fossils as at the Stours. The commonest species belong to the genus *Stylina*, together with *Thamnastræa*, *Thecosmilia*, &c. Another interesting feature here is the development of massive, doggery, blue-hearted calcareous grits, full of casts and impressions of *Trigonia clavellata*. This arenaceous facies is similar to the Grès d'Hennequeville and the Sables de Glos at the type-locality of the Glos Oolite Series on the coast of Normandy. At Silton there is also a local mussel-bank composed of the diminutive *Mytilus varians* Roem., elsewhere recorded only from Germany.[1]

Osmington Oolite Series.

The downward passage from the *Trigonia clavellata* Beds, though more abrupt than in the Weymouth district, is not marked by any interruption in the bedding, the uppermost 10 ft. or so of the white freestones being even-bedded. Beneath this, however, the bulk of the Marnhull and Todber Freestone (15–20 ft. thick) is steeply false-bedded. It is a solid, creamy, fine-grained, hard, oolitic limestone, blue where unweathered. Fossils are scarce, except for micromorphic forms (*Isodonta triangularis*, *Limatula elliptica*, *Chlamys qualicosta*, *Exogyra nana*) and drifted fragments. In the rare shelly bands gastropods, as usual, predominate.

Underneath the Marnhull and Todber Freestone is a variable development of the Littlemore Clay Beds—bands of whitish rubbly claystone alternating with black clay. They are about 8 ft. thick at Sturminster, but thicken southward, where they seem to replace the freestone. In these beds, especially in the road-cutting at Sturminster, *Nucleolites scutatus* abounds, together with the rarer *Acrosalenia angulata* and *Hemicidaris intermedia*.

At the base are a few feet of loose, marly, large-grained oolite and a band of coarse pisolite reminiscent of the Pea Grit of the Cotswolds; the pisoliths are flattened, and measure a third of an inch in diameter. The band floors the village square at Stour Provost, giving it a remarkable appearance. At Cucklington, in the west, the pisolitic beds thicken to about 12 ft. and yield a highly characteristic, coarsely pisolitic stone.[2] Fossils in these beds are uncommon (except for the ubiquitous *N. scutatus* and *E. nana*). Indecisive Perisphinctids occur, but rarely and in bad preservation.

Berkshire Oolite Series and Lower Calcareous Grit.

In the Sturminster neighbourhood the pisolite has been seen in several clear exposures (during road widening in 1927 on both sides of the town, and in the railway-cutting) to rest directly on grey clay, indistinguishable from Oxford Clay. It is possible, however, that this is an argillaceous development

[1] W. J. Arkell, 1929, 'Mon. Corall. Lamell.', *Pal. Soc.*, pp. 52–3.
[2] A piece is figured, *P.G.A.*, 1916, vol. xxvii, p. 132, pl. XXIII.

of the Lower Calcareous Grit, for a short distance to the north grits appear, and, in the eastern entrance to the tunnel west of Gillingham, Blake and Hudleston saw 18 ft. of 'dark blue sandy marl, containing at various levels immense spheroidal doggers of calcareous grit, and sometimes thin layers of alternating sand and clay'.[1] Above this were noted 33 ft. of beds which also may represent parts of the Lower Calcareous Grit, or the Berkshire Oolite Series, or both, but the description and lists of fossils are insufficient for certain correlation. There do not seem to be any other exposures of beds below the level of the pisolite.

II. THE WILTS.-BERKS.-OXON. RIDGE[2]

(a) The Westbury and Calne Area

Just as in North Dorset an isolated range of Corallian Beds closes the mouth of the Vale of Wardour, so again at the mouth of the Vale of Pewsey the formation reappears for a stretch of 9 miles from Westbury to Seend; north of this is another gap, occupied by the Lower Greensand hills of Spye Park and Bromham. Beyond this the main outcrop begins near Calne and continues to Oxford.

The area about Westbury, Seend and Calne contains such special features that it is best described separately. It includes the famous coral reef of Steeple Ashton, perhaps the most noted locality for corals in Britain, and also works at Westbury where the Corallian iron ore is smelted.

SUMMARY OF THE CORALLIAN SERIES, WESTBURY TO CALNE

Upper Calcareous Grit.

Immediately beneath the Kimeridge Clay is the WESTBURY IRONSTONE, 11–14 ft. thick. It consists of an oolitic, more or less argillaceous ore, varying in colour from dark reddish-brown to green, and yielding from 30 to 35 per cent. of iron. The fossils link it to the Sandsfoot Grit in general, and in particular to the Ringstead Waxy Clay and Coral Bed; and on the other side of the Channel to the ironshot oolite of Hesdin l'Abbé, near Boulogne. Several species of *Ringsteadia*—*R. anglica* Salf., *R. pseudocordata* (Bl. and H.), &c.—are abundant, and there is in the Geological Survey collection a fragmentary Perisphinctid[3] resembling the true *P. wartæ* Bukowski. *Ostrea delta*, *Ctenostreon proboscideum*, *Chlamys midas*, *Camptonectes sandsfootensis*, &c. also occur. The surface-extent of the ore is rather limited, but it is said to have been worked also in old pits on the high ground round the church at Steeple Ashton. At Calne there is no sign of it.

Underneath the ore are from 4 ft. to 10 ft. of pale greenish-grey, buff and ferruginous sands, containing only casts of *Pleuromya*.

Glos Oolite Series.

At Westbury the Upper Calcareous Grit rests directly on rubbly grey and white oolite and pisolite apparently belonging to the Osmington Oolite Series. Farther north, at Broad Mead, near East Ashton, a reddish shell-bed appears

[1] Blake and Hudleston, 1877, loc. cit., p. 278.

[2] Based on W. J. Arkell, 1927, *Phil. Trans. Roy. Soc.*, vol. ccxvi B, pp. 67–181; and 1928, *Journ. Ecology*, vol. xvi, pp. 134–49; and Blake and Hudleston, 1877, *Q.J.G.S.*, vol. xxxiii, pp. 283–313.

[3] No. 25484.

above the white oolite, containing drifted corals, *Trigonia clavellata*, *Perna mytiloides*, *Chlamys intertexta*, *Limatula elliptica*, *Trigonia ashtonensis*, *Prorokia problematica* and perisphinctid fragments; this is evidently a continuation of the *Trigonia clavellata* Beds of North Dorset. Near Steeple Ashton the bed passes into a true coral reef—one of the reefs from which the rolled corals of East Ashton and North Dorset were derived. No excavation seems to have been made in the reef, all the specimens in various museums having been picked up on the surface of a field on the north side of a road turning SE. off the high road from Steeple Ashton to Bratton. The best specimens have long since been taken away, but every stone on the field is still a coral. The association is peculiarly rich in species, and the state of preservation, in a red earthy matrix, is better than at any other locality in England. Besides the common species, *Isastræa explanata* (Goldf.), *Thamnastræa* spp., *Thecosmilia annularis* (Flem.), several other corals are abundant, notably *Comoseris irradians* and *Stylina tubulifera*.

Osmington Oolite Series.

The local reef at Steeple Ashton grew upon a foundation of thick white oolites, which can be seen in an old lime-kiln near by, beside the road leading south from the village. Here and at Westbury, as in North Dorset, the upper part of the oolites is even-bedded and the lower and larger part is false-bedded. The fossils, which are chiefly fragmentary, are all worn and coated with calcareous matter, and the beds are looser and more pisolitic than at Marnhull and Todber.

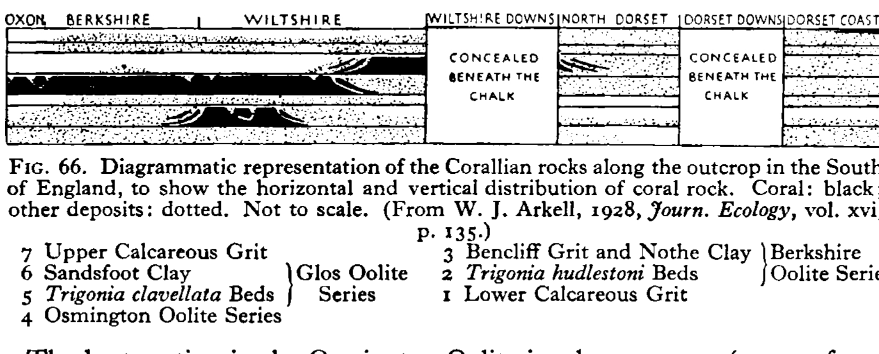


FIG. 66. Diagrammatic representation of the Corallian rocks along the outcrop in the South of England, to show the horizontal and vertical distribution of coral rock. Coral: black; other deposits: dotted. Not to scale. (From W. J. Arkell, 1928, *Journ. Ecology*, vol. xvi, p. 135.)

7 Upper Calcareous Grit
6 Sandsfoot Clay } Glos Oolite Series
5 *Trigonia clavellata* Beds } Glos Oolite Series
4 Osmington Oolite Series
3 Bencliff Grit and Nothe Clay } Berkshire Oolite Series
2 *Trigonia hudlestoni* Beds } Berkshire Oolite Series
1 Lower Calcareous Grit

The best section in the Osmington Oolite is a large quarry (now unfortunately closed) behind the workhouse at Calne, which formerly showed 25 ft. of false-bedded oolites, yielding the CALNE FREESTONE, a material at one time much used locally for building. In the base of this quarry was encountered a remarkable colony of fossil sea-urchins. The tests of some species, especially *Hemicidaris intermedia*, which are usually found only singly, were congregated by the hundred, spread thickly over the bedding-planes of the stone. The species represented were *H. intermedia*, *Cidaris florigemma*, *C. smithii*, *Acrosalenia decorata*, *Glypticus hieroglyphicus*, *Diplopodia versipora*, *Stomechinus gyratus*, *Pseudodiadema pseudodiadema*, and *P. mamillanum*.[1]

The Calne Freestone with its hosts of echinoderms was laid down on the fringe of the great chain of coral reefs that extended through North Wiltshire

[1] A fine collection may be seen in the Wiltshire Museum, Devizes.

and Berkshire to Oxford. Near by can be studied the passage from the Dorset type of oolite to the coral rag so typical for the next 40 miles, and a very illuminating spectacle it provides for the geologist. First Lonsdale and after him Blake and Hudleston described it, beside a brook that runs down from Quemerford and thence towards the town. The oolite and pisolite gradually pass laterally into beds of more obviously detrital materials, with which lenticles of coral rag are intercalated, until eventually the coral rag predominates.

Another facies, that of the Littlemore Clay Beds, is developed 3 miles north of Calne, at Hilmarton, where bands of white argillaceous limestone and clay, containing the Osmington Oolite fauna, recall the typical development at Littlemore. The occurrence of the clay beds coincides with an excessive narrowing of the outcrop, and at this point a brook has cut an opening through the Corallian escarpment—features commonly associated with the local passage of the relatively resistant oolites and coral rag into soft clays.

Berkshire Oolite Series.

A deep boring at Westbury proved 40 ft. of clays beneath the Osmington Oolite and above the Lower Calcareous Grit.[1] Some of this clay (22 ft. out of the 40 ft.) may be accounted for as an argillaceous development of the lower part of the Osmington Oolite Series—a partial passage into Littlemore Clay Beds such as is usual in Dorset. Two quarries almost due west of Hilmarton, upon an outlying ridge of Corallian rocks, however, give a definite indication that the Nothe Clay and at least locally the Bencliff Grit are well developed, as on the Dorset coast. This ridge, known as Spirt Hill, is the key to the sequence in this part of Wiltshire. The high plateau of Bradenstoke and Lyneham to the north is formed of the coral rag resting upon a thin bed of oolite and pisolite. But at Spirt Hill the Osmington Oolite Series, having probably consisted of Littlemore Clay Beds as at the neighbouring village of Hilmarton, has been entirely stripped from its summit; instead, the crest of the hill is formed of yellow sand perhaps 15 ft. thick. Below the sand are about 12 ft. of grey-green mottled clay, the lowest 8 ft. of which are seen in a quarry, resting on a remarkable Pebble Bed, with the coarse, false-bedded sands and doggers of the Lower Calcareous Grit beneath. At the base of the clay is an impersistent band of tough oolitic limestone, yielding only *Chlamys fibrosa*. The general appearance and poverty of fossils recall the Nothe Clay of Redcliff Point, and the presence of the representative of the Bencliff Grit at the top of the hill, exposed in a small sand-pit, completes the analogy.[2]

The Pebble Bed, which henceforth provides a valuable stratigraphical datum, is an interesting stratum. Consisting of a seam of large water-rolled pebbles, packed close together in a soft clay matrix, it has here a thickness of only 4 in., but in many places it is up to 1 ft. thick, and it is traceable in almost every exposure at which the horizon is to be seen as far as Oxford, a distance of 40 miles. The pebbles are well bored by *Lithophaga inclusa* and often encrusted with *Serpulæ* and *Exogyra nana*. They are of three sorts. The largest and most conspicuous, which vary in diameter from about 1 in. to

[1] J. Pringle, 1922, *Sum. Prog. Geol. Surv.* for 1921, pp. 146–53.

[2] W. J. Arkell, field-notes. After this book had gone to press my attention was called to a cutting on the new loop-line at Westbury, where the Pebble Bed has been exposed at its most southerly point, combined with a *Gervillia* and *Trigonia* bed, separated from the oolite by about 12 ft. of clay and marl.

4 in., averaging perhaps 2½ in., consist chiefly of hard, compact claystone, recalling the hard crackers so common in the Oxford Clay. The derivation of at least some of them from the denudation of Oxford Clay is proved by the discovery of a specimen of *Nucula* in one at Littleworth, Berkshire. Locally some of the largest consist of indurated calcareous gritstone, evidently the product of erosion of already-consolidated Lower Calcareous Grit. The third sort are much smaller and consist of extremely hard black 'lydite' and white vein-quartz, of indefinite Palaeozoic origin. These last are identical with many to be seen in the sands of the Lower Calcareous Grit, whence they have doubtless been rederived.[1]

The Pebble Bed at Spirt Hill is especially interesting on account of its containing a number of oysters. The commonest are *Gryphæa dilatata*, together with *Lopha gregarea* and *Ctenostreon proboscideum*, all of which are common to the Corallian and the Upper Oxford Clay. In addition, however, there are specimens of *Gryphæa lituola* Lamk., the much more incurved and narrower species characteristic of the Middle Oxford Clay, and not known elsewhere above the *athleta* zone. The presence of this species and also the segregation of so many oysters of different species in a thin seam with water-worn pebbles suggests that the fossils have been derived from the erosion of Oxford Clay, but against this must be set the fact that they do not appear to have been rolled.

In North Wiltshire, immediately succeeding the Pebble Bed, coral reefs occur, separated by representatives of the Nothe Clay and Bencliff Grit from the Osmington Oolite coral rag above. Coral growth of this early Berkshire Oolite period may be represented in the Calne district by a reef at Westbrook, which Blake and Hudleston believed to be of earlier date than the rest of the coral rag in the neighbourhood. Their belief was based on the observations that *Cidaris florigemma*, usually the predominant urchin of the rag, was here replaced by *C. smithii*; and that the reef grew directly upon sand, which they took to be the Lower Calcareous Grit. This correlation is probably correct, but in view of the presence of Bencliff Grit at Spirt Hill, careful work will be required before the matter can be finally settled. The old limekilns on Sandridge Hill, Westbrook, are now overgrown by a wood, but fortunately they were vividly described by Blake and Hudleston, and whether the rocks they showed should properly be classed with the Berkshire Oolites or with the Osmington Oolites above, they illustrated so well the nature of the Jurassic coral reefs that Blake and Hudleston's description may appropriately be quoted.

'Layer upon layer of large masses of *Thamnastræa concinna* and *Isastræa explanata*,' they wrote, 'bored by the characteristic *Lithophaga inclusa*, and changed not seldom into crystalline limestone in which the organic structure is no longer visible, here spreads over the surface, resting immediately upon a bed of sand. . . . The spaces between the coral growths are filled with rubbly brash, made up of comminuted materials, and sometimes with clay charged with fragments of shells. These intercoralline accumulations obtain the mastery here and there; corals disappear, and we have great rubbly beds of shelly clay and limestone brash forming the whole reef.'[2]

[1] For full discussion of the Pebble Bed see Arkell, 1927, loc. cit., pp. 80–4.
[2] Blake and Hudleston, 1877, loc. cit., p. 288.

Lower Calcareous Grit.

The Lower Calcareous Grit covers several square miles of ground in Bowood Park, where it probably attains its greatest thickness. From 25–30 ft. of yellow sands with bands and doggers of hard grey or blue-hearted gritstone are worked at Seend Cleeve, Derry Hill, Conygre Farm and Bremhill. The hard bands contain *Cardioceras cordatum* and *Nautilus hexagonus*, and at Seend an unusually large fauna of lamellibranchs is found: *Gryphæa dilatata*, *Ostrea quadrangularis*, *Chlamys fibrosa*, *Gervillia aviculoides*, *Pseudomonotis ovalis*, *Oxytoma expansa* and a number of other species, principally from a shelly band at the top.

(b) The Purton Axis

A short distance north of Spirt Hill and Hilmarton the Corallian rocks form a marked feature in the landscape, rising about Lyneham and Bradenstoke well above the 400 ft. contour as an elevated plateau, nearly 4 miles wide. This change is directly due to two causes: to the thick development of coral rag and oolite in the Osmington Oolite Series, and to the disappearance of the soft substratum of Nothe Clay. Typical sections may be seen at Tockenham Wick, beside the main road from Lyneham to Wootton Bassett. The coral rag, with some strong bands of white oolite, rests directly on the Lower Calcareous Grit, with the intervention only of the Pebble Bed.

A short distance south-west of Wootton Bassett the outcrop rapidly narrows once more and the Oxford and Kimeridge Clays are mapped as if they were in contact, the Corallian formation having entirely disappeared. The gap in the Corallian ridge is utilized by the Wilts. and Berks. Canal and the Great Western Railway. Fortunately, when the new railway to the Severn Tunnel was constructed, a fresh cutting was made close to the gap, west of Wootton Bassett Railway Station, and was described by Messrs. Reynolds and Vaughan before it became grassed over. From their description it seems that the gap is caused by the lateral passage of the Osmington Oolite Series into Littlemore Clay Beds, as at Hilmarton.[1] At the same time, from north of Spirt Hill the Lower Calcareous Grit has disappeared or become thinner and passed into clay.

North of Wootton Bassett the outcrop widens once more towards Purton, becoming again a high plateau with a steep escarpment overlooking the clay vale occupied by Braydon Forest. Quarries are numerous, and they all show massive limestones built up of comminuted shells and coral fragments, passing here and there into coral reefs. The detrital limestones, from their great development at Wheatley near Oxford, have been called the Wheatley Limestones, and in this part of England they are a striking facies of the Osmington Oolite Series. Quarries south of Purton Church (fig. 67) show how lenticles of growing coral became established from time to time upon the accumulating banks of debris, only to be repeatedly smothered by fresh accretions at every change in the prevailing currents. Near by, other openings show coral islets, built up of masses of well-preserved *Isastræa explanata*, *Comoseris irradians* and *Thamnastræa concinna*, still in the positions in which they grew.

The patches or islets of corals in the Purton district seem to be completely isolated among detrital limestones, the products of the grinding of the coral

[1] S. H. Reynolds and A. Vaughan, 1902, *Q.J.G.S.*, vol. lviii, p. 751.

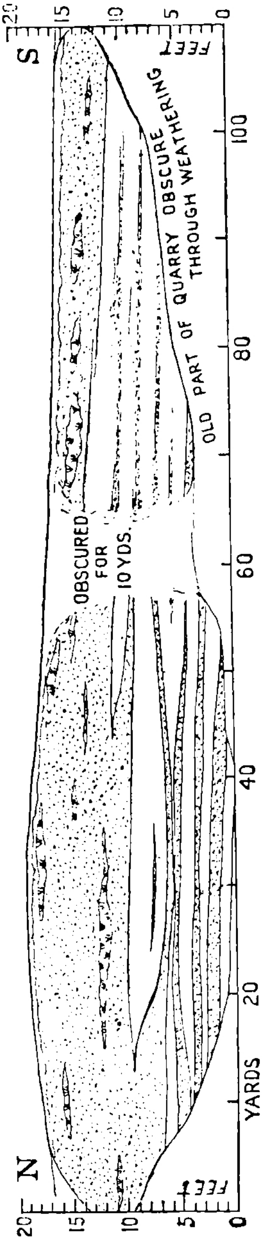


FIG. 67. Section of the Osmington Oolite Series south-east of Purton Church, Wilts., showing coral rag detritus (dotted) with lenticles of coral (*Thamnastræa*) passing laterally into bands of Wheatley Limestones (white). (From Arkell, 1927, *Phil. Trans. Roy. Soc.*, vol. CCXVI B., p. 136, fig. 13.)

reefs by the waves. In some places the corals grew out over a substratum of detritus; in others the debris covered them partially or closed above them. The reefs are of fringing reef type, but are difficult to classify more accurately in terms of modern coral structures. Their thickness probably never exceeds 25 ft. and is usually less, and their distribution seems to have been haphazard. Darwin wrote concerning certain modern fringing reefs: 'It follows . . . that where the sea is very shallow, as in the Persian Gulf and in parts of the East Indian Archipelago, the reefs lose their fringing character and appear as separate and irregularly scattered patches, often of considerable size.' [1] That the sea was shallower than usual in the Purton district is certain on stratigraphical grounds, and this passage of Darwin's seems singularly applicable.

Two miles east of Purton the outcrop for the third time narrows suddenly and there is a gap in the Corallian escarpment, utilized by another branch of the canal and by the railways from Swindon to Cheltenham and Cirencester. Here again the Oxford and Kimeridge Clays have been mapped as if in contact. But one of the railway-cuttings was seen by H. B. Woodward, who described about 20 ft. of clay with bands of 'grey earthy limestone', 'compact coral rock' and 'rubbly irregular grey marly and septarian limestone', the whole full of typical Corallian fossils.[2] Evidently the gap is again caused by a lateral change of facies of the Osmington Oolite Series into Littlemore Clay Beds.

To the east another high plateau of coral rag and Wheatley Limestones juts northward into the vale, about Broad and Little Blunsdon. A useful section in a well sunk into it showed that the Osmington Oolite Series is still se arated from the Lower Calcareous G it by [illegible] thi g [illegible] th [illegible] thi P bbl Bed, as at Purton and about Lyneham and Tockenham.

It is concluded, therefore, that over this area deposition was arrested while the Berkshire Oolites were being laid down from Highworth north-eastward on the one hand and from Spirt Hill south-westward on the other. The best

[1] Charles Darwin, *Coral Reefs*, 3rd ed., 1889, pp. 77–8.
[2] H. B. Woodward, 1895, *J.R.B.*, p. 117.

explanation seems to be that the sea was shallower owing to an axis of uplift (the Purton or Wootton Bassett Axis) and it may be significant that the area coincides with the continuation of the Woolhope–May Hill line of uplift in the Palaeozoic rocks far to the north-west (see p. 80).

The Upper Calcareous Grit of the area of the Purton Axis is very little known. Sands, bright red in colour and separated from the coral rag by clay, begin north of Hilmarton and continue to Wootton Bassett. An old brickyard at Wootton Bassett, long since obscured, yielded a number of *Ringsteadiæ*, in addition to *Pictoniæ* (indicating the basal zone of the Kimeridge Clay). A predominantly argillaceous development of the Upper Calcareous Grit was also proved by the deep boring at Swindon. At the base of the Kimeridge Clay were 6 in. of 'grey and brown earthy limestone with patches of ironshot grains', containing *Prionodoceras serratum*, and evidently a representative of the Westbury Iron Ore, separated by 21 ft. 6 in. of clay from the top of the Osmington Oolite Series;[1] and an identical succession was encountered by a boring on Red Down, near Highworth.[2]

The Lower Calcareous Grit, which forms such a conspicuous feature from the Seend and Calne districts, on by Bremhill to Spirt Hill, is absent over most of the area affected by the Purton Axis. It was proved entirely absent by the railway-cutting at Wootton Bassett and again by a well at Purton, and it is not represented on the Survey map except in two patches; one patch, seen under the Pebble Bed in the quarries at Tockenham Wick, also extends on to the outlier of Grittenham Hill, while the other patch forms Paven Hill, Purton, and the bluff on which Ringsbury Camp is cut. This last patch is of great interest, for it consists largely of a non-calcareous deposit of siliceous sponge-spicules ('*Rhaxella* chert') similar to the Arngrove Stone of Oxfordshire, to be described in a later section. It differs from the Oxfordshire rock, however, in the presence of large scattered ooliths, converted to limonite.

(c) Highworth–Faringdon–Marcham (The Faringdon Ridge)

Only 2 miles to the west of the well in the middle of the Blunsdon plateau, where the Berkshire Oolite Series seems to be represented solely by the

[1] The Osmington Oolite Series at Swindon is in the facies of Littlemore Clay Beds; see Arkell, 1927, loc. cit., p. 146; the account by Whitaker and Edmunds there referred to ('Water Supply of Wilts.', *Mem. Geol. Surv.*, 1925, pp. 85, 86) is the old misleading version, in which the 21½ ft. of clay and overlying 6 in. of ironshot oolite are grouped as Kimeridge Clay; for the revised grouping see Messrs. Chatwin and Pringle's account, 1922, *Sum. Prog. Geol. Surv.* for 1921, p. 164. The ironstone band was encountered by William Smith in the boring for water in the Vale between Swindon and Wootton Bassett, for which he was adviser in 1816–17 (J. Phillips, 1844, *Memoirs of William Smith*, p. 85, where it is duly entered in the diagram).

Salfeld misquotes Woodward as saying that this ironstone band with *P. serratum* was found in Oxford Clay in a cutting on the M.S.W. Jn. Rly. (now G.W.R.) west of Rodbourne Cheney. He then remarks 'was hier Oxford Clay soll, ist mir völlig unklar'. Woodward says nothing of the sort; he is clearly referring to the deep boring at Swindon and he definitely states 'Towards the base of what we included in the Kimeridge Clay at Swindon, there was a bed of iron-shot earthy limestone, six inches in thickness, which yielded *Ammonites cordatus*, var. *excavatus* [*serratus*], a well-known Lower Kimeridge fossil, though found here [also] in the Oxford Clay' (i.e. in the deep boring; see p. 37, where a Cardiocerate is listed from the Oxford Clay under this name). Woodward makes no mention of the ironstone band having been found in the Rodbourne railway-cutting, which was entirely in earlier beds. (H. B. Woodward, 1895, *J.R.B.*, pp. 37, 118; H. Salfeld, 1914, *Neues Jahrb. für Min.*, B–B, xxxvii, p. 196.)

[2] For the Highworth boring see W. J. Arkell, 1927, *Wilts. Arch. Nat. Hist. Mag.*, vol. xliv, pp. 43–5.

Pebble (or Shell-cum-Pebble) Bed, 1 ft. 6 in. thick, the full sequence is developed about Highworth. For the next 20 miles the Berkshire Oolite Series is the chief centre of interest in the geology. It builds the greater part of the hills about Highworth, Hannington and Coleshill, reaching 30 ft. in thickness, and thence, thinner but maintaining its characteristics, it appears in all the quarries along the Faringdon ridge as far as Cumnor and Marcham, on the borders of Oxfordshire. Its rich shell-beds yield some of the best specimens of the Corallian fauna to be obtained in the country. The Pebble Bed may be seen at the base, resting discordantly upon the false-bedded sands of the Lower Calcareous Grit. The Osmington Oolite Series coral rag continues unchanged above, but with its outcrop receded somewhat down the dip-slope, instead of lapping up to the edge of the escarpment as it does over the Purton Axis.

SUMMARY OF THE CORALLIAN ROCKS OF THE HIGHWORTH–MARCHAM AREA

Upper Calcareous Grit and **Glos Oolite Series.**

The Upper Calcareous Grit is most fully developed at Shrivenham, near Highworth, where the Berkshire Oolites also attain their thickest development. There are now no good exposures, but the ferruginous sands form a distinct escarpment rising above the coral rag plateau at Sandhill Farm and round the north and west of the village. Several wells at Shrivenham proved up to 35 ft. of ferruginous sandy beds interdigitating with clays before the coral rag was reached.[1] During the construction of the Wilts. and Berks. Canal, and probably also in the excavation of the pits to obtain materials for the railway-embankment south-east of South Marston, an oolitic ironstone like that at Westbury and Swindon was encountered. *Ringsteadiæ* collected here, some of them by Dean Buckland, are preserved at Oxford and in London, and were mentioned by Salfeld in his monograph of the genus. One species was named *Ringsteadia marstonensis* Salf.[2]

The correspondence of this oolitic ironstone with the Westbury Iron Ore can hardly be questioned, and the 35 ft. of underlying beds together represent the Sandsfoot Grit and Sandsfoot Clay. To the north and west the argillaceous element predominates. An outlier at Red Down, near Highworth, is capped with 20 ft. of clay giving a bright-red soil, overlain by a thin band of Westbury Ironstone, just as at Swindon.[3]

Towards the east the Upper Calcareous Grit is rapidly overstepped by the Kimeridge Clay. At Faringdon all that remains is about 2 ft. of 'reddish-brown and chocolate-coloured ferruginous earth, with black stains from dissolved fossils, and lumps of calcareous clay, ironstone, and fragments of *Ostrea delta* and *Serpula* towards the base', resting upon the surface of the coral rag.[4] A reddish soil is noticeable above the coral rag about Shellingford and Stanford, but nothing is seen east of Shrivenham that could be called undisturbed Upper Calcareous Grit.

Although the *Trigonia clavellata* Beds have nowhere been definitely proved,

[1] 'Water Supply of Berks.', *Mem. Geol. Surv.*, pp. 73–4.
[2] H. Salfeld, 1917, *Palaeontographica*, vol. lxiii, p. 83.
[3] Compare Arkell, 1927, *Wilts. Arch. Nat. Hist. Mag.*, vol. xliv, pp. 43–5, and Chatwin and Pringle, 1922, loc. cit., p. 164.
[4] Blake and Hudleston, 1877, loc. cit., p. 301.

records of a shell-bed immediately above the Osmington Oolite Series in the Swindon boring and again in one of the wells at Shrivenham are suggestive.

Osmington Oolite Series.

The Osmington Oolite Series is continuous throughout the area and consists for the most part of coral rag of somewhat monotonous appearance. The corals are often in the position of growth and seem to have formed a thin fringing reef. Some of the mollusca may be obtained in exceptionally perfect condition, especially the large gastropods, which lie where they dropped in the interstices among the corals. At Kingsdown a small colony of *Terebratula kingsdownensis* Ark. has been found.[1]

The majority of the mollusca associated with the corals belong to a few species, and they are met with over and over again, in all the quarries. The principal constituents of the coral-dwelling fauna are *Chlamys nattheimensis* (de Lor.), *Lima zonata* Ark., *Lithophaga inclusa* (Phil.), *Lopha gregarea* (Sow.), *Exogyra nana* (Sow.) and *Littorina muricata* Sow. Of these the first two, although extremely abundant in their natural habitat, have scarcely ever been found unassociated with corals, while the oysters and *Littorina* are much more abundant about the reefs than elsewhere. The corals that enter most conspicuously into the composition of the reefs are *Thecosmilia annularis* (Flem.), *Thamnastræa arachnoides* (Park.), *Th. concinna* (Goldf.), and *Isastræa explanata* (Goldf.).[2]

In two areas, the one about Highworth, the other from Faringdon to Kingston Bagpuize, the coral rag rests discordantly upon thinly false-bedded, fissile, sandy oolites—the PUSEY FLAGS. About Pusey and Buckland these flags reach a thickness of 10–15 ft., and contain a rich micromorphic fauna, comprising *Protocardia dyonisea* (Buv.), *Isodonta triangularis* (Phil.), *Opis phillipsi* d'Orb., *Chlamys fibrosa* (Sow.), *Pseudomonotis ovalis* (Phil.), &c. Rarely Perisphinctids of the type of *P. martelli* Oppel are found.

In 1927 I regarded the Pusey Flags as a link between the Bencliff Grit and the Osmington Oolite Series;[3] but as they pass down gradually into the Highworth (= Bencliff) Grit, and as the junction between them and the coral rag above is abrupt and discordant, I grouped them with the Berkshire Oolite Series. When the relations of the Pusey Flags to the underlying beds are studied over the whole area, however, it is seen that they overstep the other members of the Berkshire Oolite Series unconformably and come to rest at Pusey directly upon the Lower Calcareous Grit (fig. 68). Moreover, locally they lose their sandy character and become almost a pure oolite, suggesting rather the false-bedded lower portion of the Osmington Oolite Series farther south (the Marnhull and Todber Freestone). Throughout North Dorset and South Wiltshire the false-bedded oolitic freestone is overlain by an even-bedded series, the line of junction being very straight and strongly-marked. It may well be that only the upper or even-bedded portion of the North Dorset Osmington Oolite Series is represented by the coral rag of the Highworth–Faringdon–Marcham district, the Pusey Flags representing the lower, false-bedded portion.

[1] W. J. Arkell, 1927, *Phil. Trans. Roy. Soc.*, vol. ccxvi B, pl. 1, fig. 6.

[2] For an account of the coral fauna and some aspects of coral reef ecology in the Corallian, see W. J. Arkell, 1928, *Journ. Ecology*, vol. xvi, pp. 134–49.

[3] 1927, loc. cit., p. 159, table.

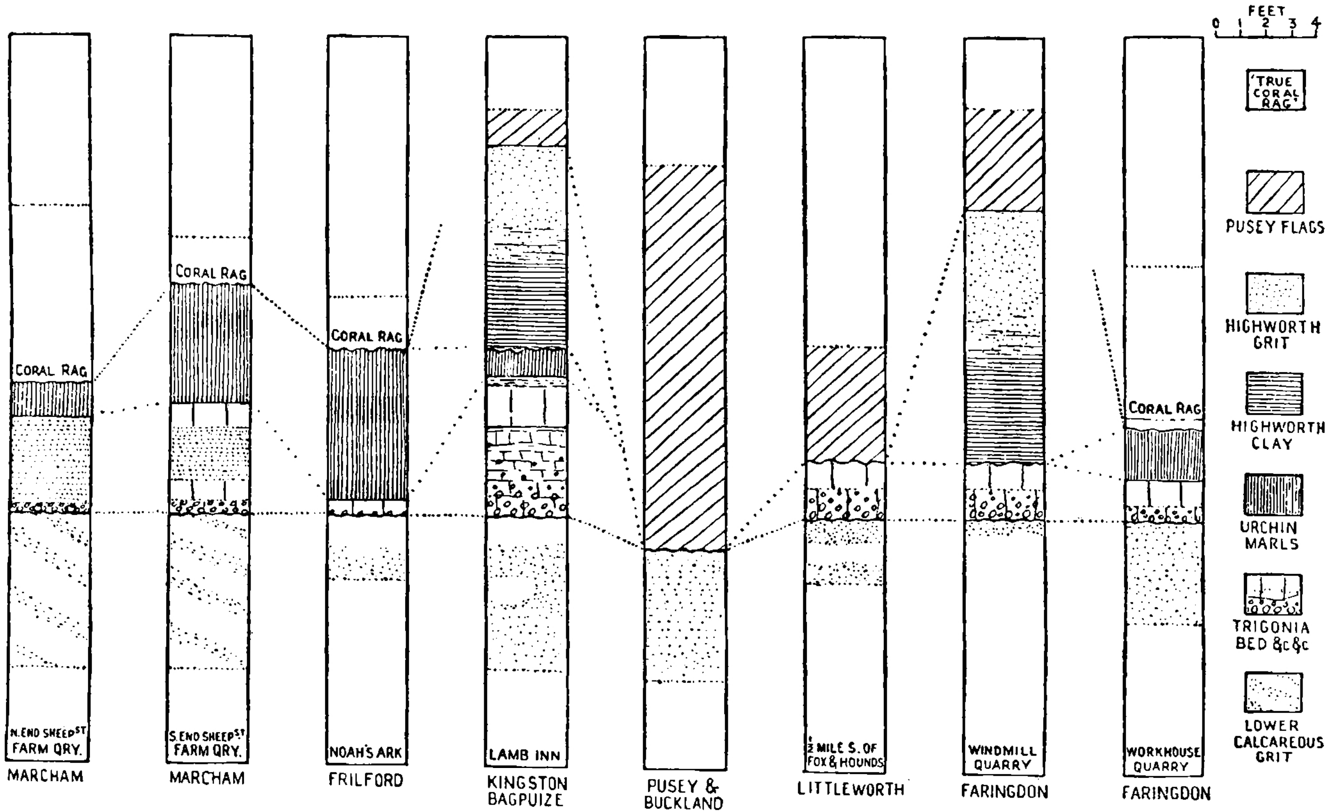


FIG. 68. Exposures of the Berkshire Oolite Series and of the Pusey Flags between Marcham and Faringdon, Berks. (11 miles). Note how the Pusey Flags cut down non-sequentially on to Lower Calcareous Grit about Pusey and Buckland, and elsewhere the ubiquitous Pebble Bed at the base. (From J. Arkell, 1927, *Phil. Trans. Roy. Soc.*, vol. ccxvi B, p. 102, fig. 5.)

It appears from surface-indications that south-west of Sevenhampton the coral rag oversteps all the underlying beds and comes to rest on the Oxford Clay.[1]

Berkshire Oolite Series.

The Bencliff Grit and the Nothe Clay, last seen at Spirt Hill on the far side of the Purton Axis, reappear at Highworth, where they have been called the HIGHWORTH GRIT and HIGHWORTH CLAY. Together they measure 10–12 ft. in thickness, consisting of fine grit-sands, with some doggers, passing down gradually into clay. Most of the water-supply of the old part of the town was derived from the top of the clay, being tapped by means of numerous shallow wells sunk through the coral rag and the subjacent sands. The clay, too, supported two rival brick industries, on the north and south sides of the town. The ruins of the extensive excavations may still be seen beside the road to the station and north of Redlands Court (fig. 69). The upper portion of the sands is false-bedded and can be seen to interdigitate with the Pusey Flags, which at Highworth are only 2 ft. thick. Occasional specimens of *Ostrea quadrangularis* and *Gryphæa dilatata* are almost the only fossils.

For some 3 miles about Faringdon the Highworth Grit and Clay are absent, apparently having been overstepped by the coral rag, but they reappear in the Windmill Pit, 1½ miles east of Faringdon, in the same thickness as at Highworth. In another 2 miles to the east they have been again overstepped by the Pusey Flags, about Pusey and Buckland, but they come in again at the Lamb Inn Quarry, Kingston Bagpuize, before finally disappearing towards Marcham and Oxford.

Beneath the Highworth Clay, in all the quarries where it is seen, are some thin beds known as the URCHIN MARLS. These consist of drab grey marls, variously divided into harder and softer bands, all largely composed of well-formed ooliths and always distinguishable by being crowded with the small urchin, *Nucleolites scutatus*. Their characteristic colour, their densely oolitic texture and the inevitable urchin, render them an easily recognized division from Highworth through Berkshire (including Shellingford where the Highworth Grit and Clay are absent) to Marcham and Garford, a distance of 18 miles. The thickness is 4 ft. at Highworth, 5 ft. at Marcham and the Noah's Ark, Garford (where also *Pygaster semisulcatus* is frequently associated with the more common *Nucleolites*).

Finally come the TRIGONIA HUDLESTONI LIMESTONES,[2] the most interesting part of the Berkshire Oolite Series, with the Pebble Bed at the bottom. They attain their maximum thickness of about 8–10 ft. at Highworth, and may be followed in a score or more of quarries along the Berkshire ridge to Marcham, Garford and Cumnor, everywhere crowded with a rich assemblage of fossils.

The best exposures were until recently the South Quarry, Highworth, and a second large quarry opened since the Great War at Hangman's Elm, beside the road to Shrivenham, 1½ miles south-east of Highworth. From these excavations, and from others actively worked at various points along the outcrop, especially at the Lamb Inn, Kingston Bagpuize, many mollusca have

[1] W. J. Arkell, 1927, loc. cit., geological map.

[2] Formerly called the *Trigonia perlata* Limestones, owing to an error in identification by Lycett; see Arkell, 1930, 'Mon. Corall. Lamell.', *Pal. Soc.*, part 2, p. 73.

been collected. The almost endless variety of Perisphinctids still remain to be worked out, but it is evident that they belong to the assemblage of the *transversarius* zone of the continental Argovian. Perhaps the most commonly represented is *Perisphinctes helenæ* De Riaz, with which are associated numerous forms approaching *P. plicatilis*, *P. martelli*, *P. cloroolithicus*, *P. aripripes*, *P. maximus*, *P. orientale*, *P. parandieri*, and the true *P. biplex* Sowerby (a much misinterpreted species). The Cardioceratids include the *excavatum* type (*C. highmoori* and others), the *maltonense* type, and the *vertebrale* type (*Vertebriceras* of Buckman). There are also Aspidoceratids of several species.

Besides the ammonites, shell-banks composed of masses of lamellibranchs provide an attractive field for the palaeontologist. *Trigonia hudlestoni* and *Trigonia reticulata* form a *Trigonia* Bed at Marcham and Kingston Bagpuize, and with them are always associated *Gervillia aviculoides*, *Isognomon mytiloides*, the large Limas, *L. rigida* and *L. mutabilis*, *Chlamys splendens*, *C. fibrosa*, *Astarte ovata* and many other shells.

Many of these fossils, including the highly characteristic *Perisphinctes helenæ* De Riaz, have been collected in the *Trigonia hudlestoni* Bed at Redcliff Point, near Weymouth, and the lithological resemblance of that bed to the gritty, sparsely-oolitic, greyish, shelly 'fucoidal' limestones at Highworth is unmistakable.

In the old South Quarry, Highworth, two beds of rolled Thecosmilian corals, together about 2 ft. thick, are intercalated in the shelly limestones (fig. 69). When the new quarry at Hangman's Elm was opened these were found to have coalesced and thickened to a bed nearly 3 ft. thick, chiefly composed of the corals *Thecosmilia annularis* and *Montlivaltia dispar*, unrolled and in fine preservation among clay. It was then found that near by, at Upper Farm, the *Trigonia hudlestoni* Limestones pass laterally in a short distance into a small coral reef or islet. Detailed mapping has revealed that several islets exist in the *Trigonia hudlestoni* Limestones in the neighbourhood of Highworth; another is situated on the north side of Red Down, and a third (perhaps the continuation of the same one) on Staplers Hill, north-west of Hannington Railway Station. They are only a few fields in extent, but they can infallibly be recognized by the abundance of corals on the freshly-ploughed land, while the normal assemblage of lamellibranchs and ammonites is noticeably wanting. Small quarries give good sections of two of the reefs, showing typical coral rag, not only composed of the same species of corals as the coral rag of Osmington Oolite date, but also containing the same molluscan 'coral fauna'—*Lima zonata*, *Chlamys nattheimensis* and the rest, with spines of *Cidaris florigemma* and *C. smithii*. From internal evidence alone, therefore, these earlier reefs are indistinguishable from the more widespread rag of Osmington Oolite date, although the two are separated by the Urchin Marls, the Highworth Grit and Clay, and the Pusey Flags.

In the immediate neighbourhood of Faringdon and Coleshill the *Trigonia hudlestoni* Limestones take on a somewhat deeper-water facies, consisting of uniform white oolite, with the shells more sparsely distributed. This has been termed the Faringdon Facies. The limestones of the Highworth district bear a closer resemblance to those of Kingston Bagpuize than to those at Faringdon, and at Kingston fragments of coral are again found in the *Trigonia* bed.

At the eastern extremity of the district, at Marcham, Cothill and Cumnor, the *Trigonia hudlestoni* Limestones become highly charged with sand, and the *Trigonia* Bed is split into two by 2–4 ft. of interlaminated sand and clay. In

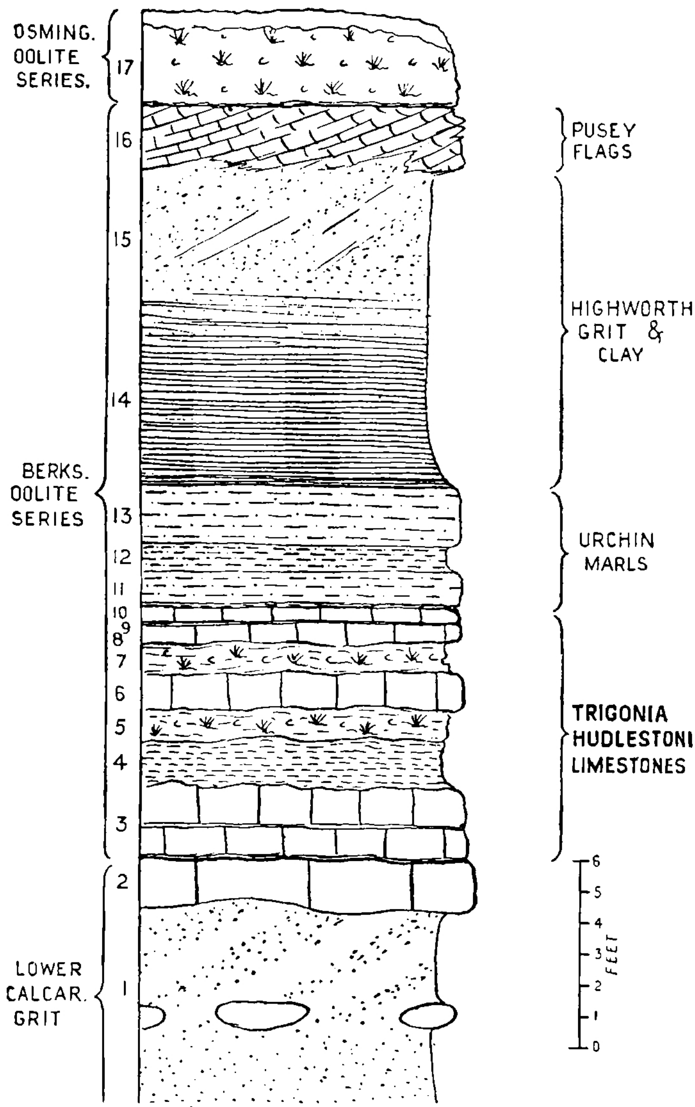


FIG. 69. Section of the Berkshire Oolite Series in the old South Quarries, Highworth, showing two coral beds in the *Trigonia hudlestoni* Limestones. (From Arkell, 1927, *Phil. Trans. Roy. Soc.*, vol. ccxvi B, p. 108, fig. 6.)

this part of the district, too, a new feature is introduced, in the form of an impersistent *Natica* Band. It is best developed at Cumnor and near Cothill, and consists of up to 6 ft. of hard calcareous gritstone enclosing myriads of casts of *Natica* (*Ampullina*) *arguta*, *Ceritella costata*, *Cloughtonia condensata*, and other gastropods. It was classed with the Lower Calcareous Grit until 1930, when the enlargement of the quarry at Cumnor revealed lenticles of the Pebble Bed beneath it. Previously a second impersistent layer of rolled pebbles above had been mistaken for the true Pebble Bed, but it is now established that the peculiarly fine conglomerate sometimes obtained in parts of the quarry occurs cemented on to the under side of the *Natica* Band.[1]

The Pebble Bed here is typical of that exposed in nearly every quarry from Oxford to Spirt Hill. The commonest pebbles are the usual rounded to rather flattish lumps of grey claystone, together with gritstone, lydite and vein-quartz derived from the Lower Calcareous Grit. A unique pebble, about 2½ in. long, was found at the Lamb Inn Quarry, Kingston Bagpuize: a microporphyritic soda-rhyolite, consisting of small crystals of albite in a microlithic, fine-textured, black, silicified matrix.[2] Indications of a special fauna associated with the Pebble Bed are found only at the Lamb Inn Quarry, Kingston Bagpuize, where the pebbles are disseminated through 2 ft. 8 in. of pisolitic rock, containing round-whorled Perisphinctids of Buckman's genus *Cymatosphinctes* (? = *Kranaosphinctes*), not found in the overlying beds, and also a peculiar Aspidocerate, *A.* (*Euaspidoceras*) *crebricostis* Ark.[3]

Lower Calcareous Grit.

The Lower Calcareous Grit consists of the usual yellow sands, with impersistent bands and doggers of hard gritstone. False-bedding is common and is often observed to pass through the doggers, thus proving their secondary origin by some chemical process, which has either concentrated calcareous cement, or partly decalcified and removed cement from the surrounding material, reducing it to sand. The top of the Lower Calcareous Grit is seen in large numbers of sections, but deeper exposures are rare. The best are at Marcham, where for many years large collections of fossils have been obtained, especially the well-known *Aspidoceras* (*Euaspidoceras*) *catena*, *Nautilus hexagonus*, *Pachyteuthis abbreviatus*, and *Cardioceras excavatum*. Drifted wood, often in logs of considerable size, fruits of *Carpolithes* and vertebrae of *Teleosaurus* occur. The false-bedding is especially noticeable at Marcham and in Tubney Wood, as is also the quantity of small pebbles of lydite and vein-quartz. Both the proportion of pebbles and the degree of false-bedding diminish westwards, from which it is deduced that the source of the sands lay in the south-east. The deposit is a sandbank, the materials of which were presumably brought down by some large river, flowing from the landmass occupying the site of the London Basin and the North Sea. It dropped the greater part of its heavier materials on entering the sea, the lighter constituents being carried by a long-shore current south-westward into Wiltshire.

The thickness of the Lower Calcareous Grit is very variable in the east, about Oxford. A boring proved the thickness to be only 11 ft. at Wootton Waterworks, but it is probably nearer 50 ft. at the edge of the escarpment about Cumnor, and a boring at Frilford proved 52½ ft. Thence it increases gradually towards Faringdon, where three borings at Faringdon, Goosey and Shrivenham proved 70 ft., 79 ft., and 76 ft. respectively. This is the area of

[1] W. J. Arkell, 1931, *P.G.A.*, vol. xlii, pp. 44–9.
[2] Ibid., p. 51. Identified by Dr. H. H. Thomas.
[3] W. J. Arkell, 1927, loc. cit., pp. 96–7.

maximum thickness, beyond which a more rapid diminution sets in towards the Purton Axis. In 3 miles, at Highworth, the borings prove 20–30 ft.; 4 miles farther, on the slopes of the Blunsdon plateau, 10–20 ft. is the usual thickness; while in another mile the Lower Calcareous Grit dwindles to a parting of sand and finally disappears against the axis.

It is noteworthy that the area in which the Lower Calcareous Grit attains its maximum thickness coincides with the area in which the Berkshire Oolite limestones take on the Faringdon Facies, thought to indicate deposition in deeper water.[1]

(d) The Oxford Axis

The Corallian rocks in the area immediately surrounding Oxford bear a strong resemblance to those about Purton. The thickness of the Lower Calcareous Grit becomes very variable: although in some places it is as much as 50 ft., in others it diminishes to less than 12 ft. The Berkshire Oolite Series, so important a feature in the area to the south-west, thins down to a mere Shell-cum-Pebble Bed, sometimes only 1 ft. thick. The Osmington Oolite Series develops thick masses of detrital Wheatley Limestones, among which the coral rag occurs once more in 'separate and irregularly scattered patches' as in the Purton district, and it advances again up the dip-slope to cover the plateau to the edge of the escarpment. Finally, the Upper Calcareous Grit and Glos Oolites are entirely absent, the *Rasenia* zones of the Kimeridge Clay resting directly upon the Osmington Oolite Series.

All these considerations point to the action of an elevatory force like that which operated in the Purton district, and it is expressed by calling it the Oxford Axis. It may perhaps be significant that the area lies upon the prolongation of the Sedgley–Lickey Axis (see Chapter III, p. 80).

The absence of the Upper Calcareous Grit and Glos Oolite Series, such conspicuous features on the Dorset coast, called forth some of the earliest observations on non-sequential strata, and these invest the Oxford Axis with considerable historical interest.

The junction of the Kimeridge Clay with the underlying coral rag and Wheatley Limestones could for upwards of a century be seen in a large quarry below the brickyard at the foot of Shotover Hill, but the section has now unfortunately become almost entirely overgrown. As early as 1812 W. D. Conybeare noticed that, when the Kimeridge Clay was stripped off in this quarry, the surface of the stone showed signs of being waterworn and was pitted with small cup-shaped depressions.[2] Four years after the publication of Conybeare's observation, Sedgwick made the following memorable correlation:

> May not the coral rag and superincumbent freestone of Headington Hill together represent the central group of the Weymouth and Steeple Ashton sections? The conjecture seems to be confirmed by the appearance of the beds in Headington Quarries. In that place the top freestone supports the Kimeridge Clay; and the separation between the two is as well-defined as a geometric line. Now the instantaneous passage from one formation to another frequently indicates the absence of

[1] For authorities as to thicknesses, and discussion of the possible source of the sand and pebbles, see Arkell, 1927, loc. cit., pp. 73–82.

[2] W. D. Conybeare, 1822, in Conybeare and Phillips, *Outlines Geol. Engl. and Wales*, p. 189.

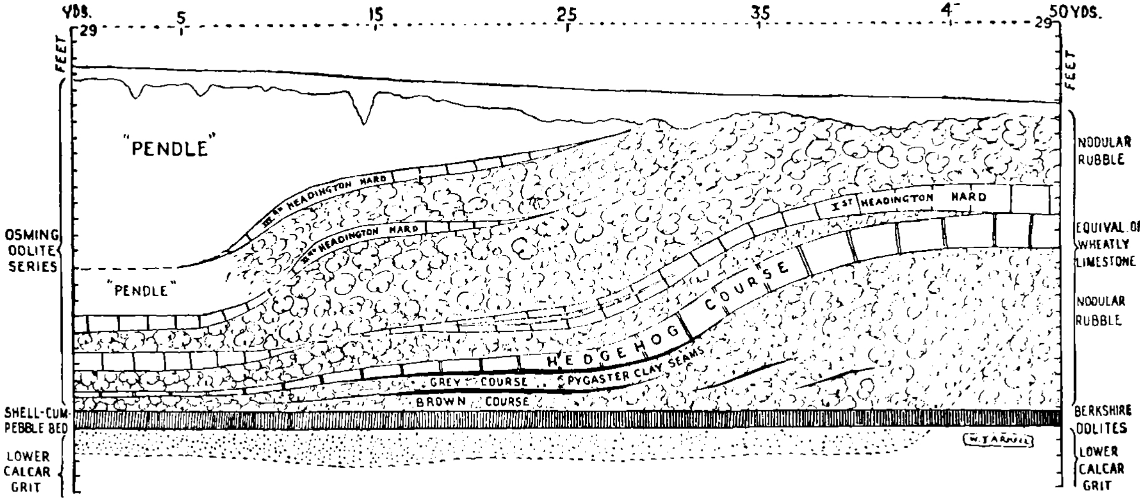


FIG. 70. Section at Magdalen or Workhouse Quarry, Headington, near Oxford, drawn from measurements at 10 yds. intervals, showing the different forms of coral rag debris (with the quarrymen's and other names) false dipping from the reef. At the base is the horizontal Shell-cum-Pebble Bed, yielding abundantly the Berkshire Oolites fauna. (From Arkell, 1927, *Phil. Trans. Roy. Soc.*, vol. ccxvi B, p. 128, fig. 12.)

certain beds or deposits. May not then the upper part of the Weymouth section be wanting near Oxford?[1]

In this passage the Wheatley Limestones and equivalent coral rag were for the first time correlated with the Osmington Oolite Series, and the true position of the Upper Calcareous Grit and Glos Oolite Series ('the upper part of the Weymouth section') was evidently realized. Ten years later Buckland and De la Beche[2] expressed their agreement with Sedgwick's correlation and the ensuing conclusions, and later Phillips also added his confirmation. Finally, one hundred years after the appearance of Sedgwick's memoir, the widening of the London road near Shotover Lodge afforded Dr. Pringle a temporary exposure enabling him to state that the lowest part of the Kimeridge Clay is of *Rasenia* date.[3] The hiatus was thus increased by the addition of the *Pictonia* zone of the Kimeridge Clay to the missing strata.

The Osmington Oolite Series forms an important surface-feature, capping the plateau about Headington and Bullingdon, around the foot of the high ridge of Shotover, and similarly encircling the heights of Boar's Hill and Cumnor Hurst on the other side of the Thames. Northward, as a number of faulted outliers, it caps the hills at Wytham and about Elsfield and Beckley. Thanks to a much greater number of exposures than exist in the Purton district, the lateral passage from true coral rag to the various types of detrital deposits can be followed out in detail. At Headington Quarries, at Wheatley, and on the west side of the Thames at Wootton and Sunningwell, immense quarries have been worked in the WHEATLEY LIMESTONES.[4] They consist of alternate harder and softer bands of the same white detrital material as at Purton, usually non-oolitic and composed entirely of finely-ground fragments of corals and shells. The harder bands were much worked in the eighteenth century as a freestone, to the undoing of some of the colleges in Oxford which employed it in their buildings: it has decayed so rapidly that all have had to be refaced after less than two centuries.

The softer bands have in places a curious nodular structure, hitherto unexplained, and are known as the Nodular Coralline Rubble. At Wheatley, in the weathered face of the old quarries, it is seen to be interbedded with the normal Wheatley Limestone, the two types of rock being composed of identical materials, differing only in the degree of their subsequent cementation. In some of the quarries at Headington tabular masses of coral are intercalated in the detrital material, and they gradually increase and coalesce towards the reefs, the broken fragments at the same time becoming larger. The dip is steeply away from the reefs, and is shown to be only a deposition dip by the fact that the series everywhere rests upon the horizontal Shell-cum-Pebble Bed (fig. 70).

Failure to comprehend the nature of these deposits, owing to insufficient

[1] A. Sedgwick, 1826, *Ann. Phil.*, vol. xi, p. 350.

[2] 1836, *Trans. Geol. Soc.* [2], vol. iv, p. 25.

[3] J. Pringle, 1926, 'Geol. Oxford', 2nd ed., *Mem. Geol. Surv.*, p. 63.

[4] First called the Oxford Oolite by Buckland (1818, Table in W. Phillips's *Geol. England & Wales*) where it was said to be worked as a freestone at Headington, and marked as overlying the Coral Rag; but in other quarries identical rock underlies coral rag, and the two facies undoubtedly alternate (see Arkell, 1927, pp. 132–3). Apart from the fact that oolitic structure is very rare, it seems undesirable to retain in its original restricted sense a term that has been so widely used with very different meanings (see above, p. 7). Buckman called the Wheatley Limestones Holton Beds (*T.A.*, vol. v, p. 53).

field-work, led Buckman a few years before his death to subdivide them into several zones. His misunderstanding of the deposition-dip is shown by a statement concerning the principal quarry at Headington (Magdalen Quarry, fig. 70) that 'there is a non-sequence—stratal failure—of about 6 feet in the face of the pit on the E. as compared with the W.'.[1] In reality such an inference is no more justifiable from these beds than from the Forest Marble or the Triassic sandstones, or any other formation in which false-bedding is manifested on a large scale. The true meaning of the false dip was explained by Blake and Hudleston in 1877.[2]

Unbroken fossils are rare, but occasionally they include ammonites, the most frequent being *Perisphinctes antecedens* Salf., though in the Lye Hill Quarry, near Wheatley, some badly-preserved giants of the *P. parandieri* style, like forms in the Berkshire Oolites, are found. Doubtless these floated in from outside the coralline area. Some of the echinoderms, such as *Nucleolites scutatus* and *Pygaster semisulcatus*, lived among the accumulating debris, for their tests are found perfectly preserved in thin argillaceous seams, although all the shells, with the exception of *Exogyra nana*, are finely comminuted.

South of Oxford, in the Thames Valley about Littlemore, Sandford and Kennington, the Osmington Oolite Series takes on the facies of the LITTLEMORE CLAY BEDS, of which this is the type-locality. The clay facies is well displayed in the railway-cutting at Littlemore, consisting of 20 bands of clay separated by as many of nodular, grey, white-weathering argillaceous limestone, the thickness seen being about 17 ft. (fig. 71). A few small fragmentary and crumbly casts of Perisphinctids have been found, but they do not suffice for specific identification and appear to be the young of common *antecedens*-like forms.[3] The other fossils are of common, undiagnostic, Osmington and Berkshire Oolite species, the commonest being *Exogyra nana*, massed together with *Serpulæ* in the form of shoal-like banks which interrupt the otherwise regular bedding. In their lithic and palaeontological characters the beds in every way resemble those at Hilmarton.

Mr. E. S. Cobbold first suggested that the lateral passage of the coral rag into the Littlemore Clay Beds might best be explained by supposing that the muddy waters of a river or stream flowing from the London landmass here found their way through a channel between the reefs to the open sea.[4] This suggestion best fulfils all the conditions, for mud is well known to inhibit coral growth, and the area occupied by the argillaceous beds is always narrow.[5] Moreover, it receives confirmation from a quarry on the side of the Thames Valley near North Hinksey; this seems to show us a deposit formed on the edge of the mud-bearing currents, for it comprises about 10 ft. of impure clay with an admixture of rubbly limestone, enclosing huge disconnected blocks of Isastræan and Thamnastræan corals, all of them encrusted with *Serpulæ* and *Exogyræ*.[6] The section is unique and when freshly worked it suggests very forcibly a reef that has been continually smothered by pollution of the water with muddy sediment.

[1] S. S. Buckman, 1925, *T.A.*, vol. v, p. 50.
[2] Blake and Hudleston, 1877, loc. cit., p. 311, and see Arkell, 1927, loc. cit., pp. 122–8.
[3] For Buckman's identification of these and criticism, see Arkell, 1927, loc. cit., p. 143.
[4] E. S. Cobbold, 1880, *Q.J.G.S.*, vol. xxxvi, p. 319.
[5] Here the width cannot be more than two miles, and at the other occurrences it is probably less.
[6] W. J. Arkell, 1927, loc. cit., p. 144.

The breaking down of the hard limestones into soft clays has enabled the modern drainage to find an easy passage through the Corallian ridge; and so, if Mr. Cobbold's suggestion is correct, as seems probable, the Jurassic river has here determined the course of the Thames.

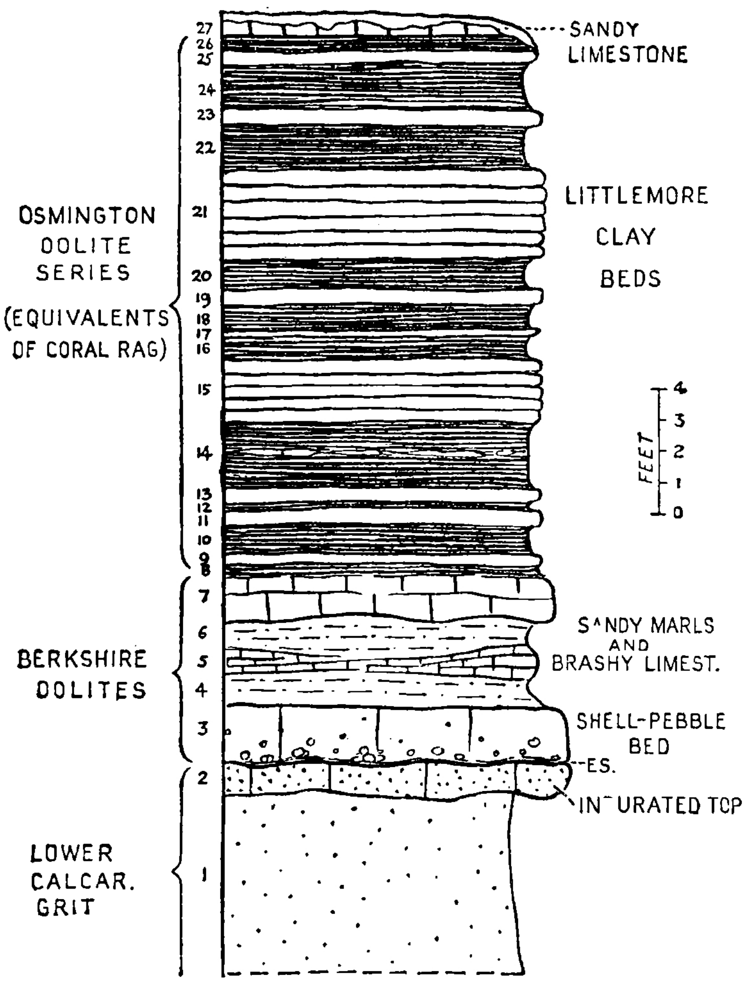


FIG. 71. The type-section of the Littlemore Clay Beds (which pass laterally into coral rag) at Littlemore railway-cutting, near Oxford. (From Arkell, 1927, *Phil. Trans.*, vol. ccxvi B, p. 141, fig. 14.)

The Berkshire Oolite Series, as has been stated, grows much thinner as it approaches the Thames south of Oxford, while the various subdivisions so clearly differentiated for 20 miles to the west are no longer recognizable.

It has already been remarked that the sections at Cumnor, Cothill and Marcham show that before its disappearance under the Kimeridge Clay of the Boar's Hill ridge the Berkshire Oolite Series becomes highly charged with sand. On the beds emerging upon the other side, the same feature is conspicuous in the more southerly of the sections, at Bagley Wood, Littlemore, Cowley and Horsepath. At these places the series consists of some 5–7 ft. of shelly sand and sandy, shelly limestone, variously interbedded, and at the base is the ubiquitous Pebble Bed. The sandy layers contain perfectly-preserved shells of *Pseudomonotis ovalis*, *Chlamys fibrosa*, *Oxytoma expansa*, *Exogyra nana*, &c. The harder bands are often shell-beds, crowded with the common lamellibranchs and ammonites of the *Trigonia hudlestoni* Limestones.

Owing to the high proportion of sand in all the strata below the coral rag in these sections it is often difficult to draw the boundary-line between the Berkshire Oolite Series and the Lower Calcareous Grit. Generally, however, the Pebble Bed provides the required datum.

It has been suggested that the continued influx of sand into the district south of Oxford may be explained as due to a survival of the activity of the river that brought down the Lower Calcareous Grit. Perhaps it was the same river that, when nearing the completion of its cycle, introduced into the district the mud to form the Littlemore Clay Beds.

Towards the north and east, in a short distance, all the quarries about Headington, and also those on the other side of the Thames at North Hinksey, show that the Berkshire Oolite Series has once more been reduced to the Shell-cum-Pebble Bed, only 1–2 ft. thick (see fig. 70). It is a bluish-grey, tough, oolitic limestone, locally dark-centred, largely made up of fossils. Like the shell-beds of the Inferior Oolite, it is the repository of a rich and varied fauna and undoubtedly owes its formation to gradual accumulation on a bottom kept free of sediment by currents. The large and fragile valves (often 4–5 in. in length) of *Lima*, *Chlamys*, *Trigonia*, *Gervillia*, &c. are generally unworn and unbroken, a condition in which they would never have survived had they been subjected to wave-action on a beach or to re-derivation from one deposit to another. The ammonites belong to a score or more of species of the genera *Perisphinctes*, *Aspidoceras* and *Cardioceras*, and include many giants of the *parandieri* and *cloroolithicus* types. Most of them can be matched among the ammonites of the *Trigonia hudlestoni* Limestones of Highworth and Kingston Bagpuize, but there are also new elements. Buckman formerly identified them with the species of foreign authors, such as Siemiradski and de Riaz,[1] but more recently he had begun to give them all new names and to found for them new genera based on differences of detail in the septal sutures. A revision of this rich ammonite assemblage still remains to be undertaken. A start has been made by Dr. Spath, who places most of the species either in *Perisphinctes sensu stricto* (as represented by *P. martelli* and its allies), or in the closely allied *Dichotomosphinctes* (the *antecedens-plicatilis* group), and affirms that most of Buckman's genera may be ignored.[2]

The Lower Calcareous Grit is composed, as usual, of a mass of yellow sands having all the characters of a sandbank, irregularly piled by currents. The thickness varies from a maximum of about 50 ft. to 12 ft. (or possibly less) in short distances. Except for the uppermost layers, which are seen in

[1] A case full, arranged and named by Buckman, is exhibited in the Oxford University Museum.

[2] L. F. Spath, 1931, *Pal. Indica*, N.S., vol. ix, pp. 401–2.

the bottom of nearly all the quarries and are worked at Littlemore for a moulding-sand to a depth of 15 ft., they are palaeontologically a *terra incognita*. As elsewhere, the highest 1–2 ft. is often indurated, and has the Pebble Bed cemented firmly to it. *Pachyteuthis abbreviatus* and casts of *Cardioceras cordatum* are sometimes found, but most of the ammonites recorded from the Lower Calcareous Grit of Cowley and Horsepath by Buckman and others came in reality from the sandy facies of the Berkshire Oolite Series. The immense hemeral table put forward by Buckman for these beds is purely fictitious.[1]

III. THE AMPTHILL CLAY REGION

(a) Oxford to the Fens

Five miles east of Oxford, close to the great limestone quarries of Wheatley and Lye Hill, the Corallian formation seems to come abruptly to an end. Looking eastward one beholds a broad clay vale, and on consulting the Survey maps (even the latest colour-printed edition) it appears that with the exception of a diminishing outcrop of Corallian Beds from Wheatley to Quainton (12 miles) and a small patch at Upware near Cambridge, the Oxford and Kimeridge Clays are in contact from here to the Yorkshire Basin.

The Upware patch represents an isolated reef, which will be described in the next subsection. The intervening area has received considerable attention in the past forty years from the late Thomas Roberts, Mr. C. B. Wedd, and Prof. A. Morley Davies, who have shown that except for a stretch of 30 miles north-east of Leighton Buzzard where the Lower Greensand oversteps on to the Oxford Clay, there is a continuous outcrop of beds of Corallian age; but they are developed in an entirely different facies.

The most complete section in this area was a railway-cutting at Ampthill, Bedfordshire (long since overgrown), where the Corallian Beds had a total thickness of 61 ft. After this exposure, and on account of their predominantly argillaceous facies, Seeley called the beds the AMPTHILL CLAY.[2]

The name Ampthill Clay has been commonly used by Woodward and others for the whole of the equivalents of the Corallian, but more recently it has been found necessary to exclude a basal portion, 6–20 ft. thick, which contains oolitic limestone and marl, often ironshot, with derived fossils and a great many oysters and *Serpulæ* and other shells. This basal division, called the Oakley Clay, or better OAKLEY BEDS, in Oxon. and Bucks., and ELSWORTH ROCK or Elsworth Rock Series about Cambridge, is the equivalent of the 'Upper Corallian' of the Oxford district (the Berkshire and Osmington Oolite Series or *martelli* and *antecedens* zone). From this it follows that the true Ampthill Clay as restricted is younger than any of the Corallian Beds preserved on the Oxford Axis or for a considerable distance farther west.

The Ampthill Clay.

For our knowledge of the Ampthill Clay we are indebted chiefly to Thomas Roberts, who in the latter part of the last century undertook a systematic examination of the numerous small clay-pits on the borders of Huntingdon

[1] S. S. Buckman, 1925, *T.A.*, vol. v, pp. 67–8; see Arkell, 1929, 'Mon. Corall. Lamell.', *Pal. Soc.*, p. 7.

[2] He earlier suggested and abandoned first Bluntisham Clay and then Tetworth Clay. See bibliography.

and Cambridge. Since many of these pits are now abandoned and are unlikely to yield any further information, his careful records are invaluable.

Roberts showed that the Ampthill Clay can readily be distinguished, both lithologically and palaeontologically, from the clays above and below it. It is dark and tenaceous, often black, and contains abundant selenite. Wherever the junction with the Kimeridge Clay is seen it is marked by a band of phosphatic nodules, regarded as the basement-bed of the Kimeridge. The fossils differ markedly from those in the Oxford Clay by their state of preservation, for they are never pyritized, while the ammonites and some other shells in the Oxford Clay are nearly always pyritized; moreover Wedd remarked that while the oysters and other shells in the Oxford Clay are freshly preserved, those in the Ampthill Clay are generally bored and encrusted, both inside and out, with *Serpulæ*. There are several thin bands of limestone, usually hard, nodular and argillaceous, never oolitic.

Roberts described a number of pits from Everton and Gamlingay on the Bedfordshire border eastwards along the outcrop at Great Gransden, Elsworth, Boxworth, St. Ives and Bluntisham to Fenton, where the clay disappears beneath the alluvium of the Fens. Records of Cardiocerates and Perisphinctids recur repeatedly; especially '*Ammonites plicatilis*' or '*A. biplex*', '*A. excavatus*', '*A. vertebralis*' and '*A. cawtonensis*'. The '*A. excavatus*' probably signifies a *Prionodoceras* (e.g. *P. serratum*), as also does probably '*A. cawtonensis*', while the other names may include *Perisphinctes* and *Dichotomoceras*. A revision of old material and any new that can be collected in existing exposures is needed before detailed correlations can be established. Meanwhile, however, it is evident from the presence of *Ostrea delta* that beds as high as the Glos Oolite Series are represented in the Ampthill Clay. One of the most fossiliferous horizons described by Roberts is a double band of hard, compact, grey limestone, 2–3 ft. thick, called the Boxworth Rock.[1] Besides '*A. plicatilis*' and '*A. excavatus*' this yielded to Roberts *Trigonia clavellata*, *Nucula menkei* and *Alaria bispinosa*—three species highly suggestive of the *Trigonia clavellata* Beds.[2]

The type-section at Ampthill was unfortunately never described with the care that it would have received had it lain within Roberts's area, and little information can now be gained from the record of the cutting. The old lists of fossils[3] are useless, for they include the rich fauna of the underlying Oakley Beds. This has given rise to an idea that the Ampthill Clay contains a mixed Oxford Clay and Kimeridge Clay assemblage.

A more useful section was described by Prof. Morley Davies in a cutting made in 1907 on the Great Western Railway from Princes Risborough to Banbury, between Ashendon Junction and Rushbeds Wood Tunnel.[4] Here 50 ft. of Ampthill Clay was exposed, and also the Oakley Beds below. The highest 30 ft. consisted of the usual selenitiferous clay, while the lowest 20 ft. was more varied, with some thin stone-bands. The highest and thickest stone-band, 20 ft. from the base, yielded narrow-whorled fine-ribbed Perisphinctids with forward sweep on the periphery, indicating the *wartæ* zone

[1] T. Roberts, 1892, *Jurass. Rocks Neighb. Cambridge*, p. 43.
[2] Though the identification of the *Trigonia* needs verifying.
[3] e.g. as given by H. B. Woodward, 1895, *J.R.B.*, p. 137.
[4] A. M. Davies, 1927, in Arkell, loc. cit., p. 152.

and correlating with strata at least no lower than the *Trigonia clavellata* Beds of Dorset. This showed that the bulk of the Ampthill Clay—that portion lying above the stone-band (=the Boxworth Rock?)—was to be assigned to the upper part of the Glos Oolite Series and Upper Calcareous Grit, or even higher beds. The 40 ft. of the Sandsfoot Clay in Dorset, with *Ostrea delta*, affords a suggestive comparison.

Simultaneously with my publication of this correlation, and independently of it, Buckman set down a brief note in *Type Ammonites* to the effect that 'The Ampthill Clay . . . which contains *Dichotomoceras variocostatum* Buckland sp., is not Corallian as usually stated—that is to say, it is later than Perisphinctean Age. It is of Prionodoceratan Age—towards the lower part of the Kimeridgian as generally understood.'[1] But Buckman apparently had not seen the Perisphinctids of *wartæ* style found by Prof. Davies 20 ft. above the base of the Ampthill Clay; moreover the necessarily Kimeridgian age of the genus *Prionodoceras* is highly questionable, since *P. serratum* signalizes the *decipens* zone of Salfeld's classification (= Upper Calcareous Grit, *pars*) and '*Dichotomoceras*' *variocostatum* (Buckland) seems to be a true *Perisphinctes sensu stricto*. But Buckman's suggestion is valuable in so far as it draws attention to the fact that the bulk of the Ampthill Clay occupies a higher stratigraphical position than was usually supposed.

The Oakley Beds and Elsworth Rock.

On the edge of the coralline area, at Stanton St. John, Woodperry and Stow Wood, the Wheatley Limestones are seen, with increasing distance from the reefs, to become diluted with marl and clay. A type of rock develops which at first sight resembles the Littlemore Clay Beds in its alternation of hard and soft bands, but a closer examination reveals that it is largely composed of detrital materials and small oysters (*Exogyra nana*). This interesting change did not escape Blake and Hudleston. They described a quarry behind the school at Stanton St. John as 'a very remarkable quarry . . . composed of alternate layers of hard doggery bands and marl . . . a perfect nest of echinoderms.' 'We see here', they wrote, 'the spot where the corals did *not* grow, as at Headington we saw where they did. Here we have the débris of the ground-up, variably hardened reef, along with the echinoderms that lived in the neighbourhood; and we thus have a natural termination of the Coral Rag in this direction.'[2]

An argillaceous deposit crowded with the shells of *Exogyra nana* was long ago mapped by the Survey across the country east of Stanton St. John and Wheatley, towards Quainton, but no good sections were known before the making of the railway-cutting near Ashendon Junction. Below the true Ampthill Clay in that cutting Prof. Davies found 6–10 ft. of beds full of *Exogyra nana*, varying in lithological composition from bluish clay to white limestone and marls, full of brown ooliths, like the Elsworth Rock (presently to be described) but unconsolidated. They contained also some masses of *Serpulæ* and oysters suggestive of the Elsworth Rock of Gamlingay and other places in Cambridgeshire. Prof. Davies remarked that the abundance of *Exogyra nana* and *Cidaris* spines linked these beds with the 'Upper Corallian'

[1] S. S. Buckman, 1927, *T.A.*, vol. vi, p. 49; compare Arkell, 1927, loc. cit., p. 153.
[2] Blake and Hudleston, 1877, *Q.J.G.S.*, vol. xxxiii, p. 310.

around Oxford (the Osmington Oolite Series).[1] The recognition in his collection of *Chlamys nattheimensis*, a mollusc of the coral fauna, seldom if ever found dissociated from corals, indicated that reefs were not, in fact, far distant.[2] But among the fossils collected by Prof. Davies from the *Exogyra nana* Beds, or as Buckman called them, Oakley Clay,[3] there are also some fragmentary Perisphinctids identical with specimens from the Shell-cum-Pebble Bed of the Oxford district. The Berkshire Oolite Series, therefore, is also represented.

Prof. Davies determined that in the Ashendon cutting the Oakley Beds rest directly upon the upper *præcordatum* zone of the Oxford Clay. In the 8 miles from the edge of the escarpment at Stanton St. John, therefore, the Lower Calcareous Grit has been entirely overstepped. He further proved that this overstep continues and increases towards the north-east, for he recognized the Oakley Beds at Quainton apparently resting on the lower *præcordatum* zone, and farther still, at Sandy, upon the *renggeri* or *lamberti* zone[4] (fig. 62, p. 348). A source is thus provided for the great spread of Oxford Clay pebbles, 40 miles in length, comprising the Pebble Bed; especially if we suppose a similar overstep to have taken place towards the south-east or south.

The recognition of the Oakley Beds as far away as Sandy, beyond Ampthill, brings into line the basal beds with many fossils in the Ampthill cutting, described by Woodward as a 'rubbly rock-bed like the basement-bed at Gamlingay'.[5] It also leads to the threshold of another area, where the deposits have been studied independently by Cambridge geologists—the area of the Elsworth and St. Ives Rock.

The basement-beds of the Corallian in Huntingdon and Cambridgeshire consist everywhere of some 10–15 ft. of highly fossiliferous strata known as the Elsworth Rock or Elsworth Rock Series; and, as in Buckinghamshire and Bedfordshire, they rest directly upon the Upper Oxford Clay. The beds consist of two rock-bands, the lower 3–7 ft. and the upper 1–1½ ft. thick, separated by about 5 ft. of clay. The rock composing both bands is, when fresh, a hard, grey, ironshot, shelly limestone, but it weathers readily to a yellowish-brown colour and disintegrates to a yellow, calcareous marl, full of dark-brown ooliths. The upper band is usually more decomposed than the lower, but otherwise they appear to be identical, lithologically and palaeontologically.

Mr. C. B. Wedd mapped the outcrop continuously for about 5 miles from Houghton Hall eastwards, past St. Ives to Holywell. On the south side of the Ouse Valley he mapped it again for over 6 miles past Elsworth to beyond Croxton, thus establishing what Roberts contended on palaeontological grounds, that the Elsworth Rock and St. Ives Rock are one and the same stratum.[6] As Croxton lies only 7 miles from Sandy, where Prof. Davies recognized the Oakley Beds, and as both Prof. Davies at Ashendon and Woodward at Ampthill likened the Oakley Beds to the Elsworth Rock, there cannot be much doubt that the two are in stratigraphical continuity—

[1] A. M. Davies, 1916, *Geol. Mag.*, vol. liii, p. 398.
[2] W. J. Arkell, 1927, loc. cit., p. 153.
[3] 1927, *T.A.*, vol. vi, p. 49.
[4] A. M. Davies, 1916, loc. cit., p. 399.
[5] H. B. Woodward, 1895, *J.R.B.*, p. 136.
[6] C. B. Wedd, 1901, *Q.J.G.S.*, vol. lvii, pp. 73–85.

though it does not follow that they are necessarily of precisely the same age throughout.

The Sedgwick Museum, Cambridge, contains a large collection of fossils from the Elsworth Rock (the greater number from the lower band) of Elsworth, St. Ives, Holywell and other places. The lamellibranchs comprise the same assemblage as the *Trigonia hudlestoni* Beds of the Berkshire Oolite Series, with additional species of earlier date.[1] The commonest are such familiar forms as *Trigonia hudlestoni* (resembling those found in Yorkshire more closely than the typical Berkshire and Oxfordshire forms), *T. reticulata*, *Astarte ovata*, *Cucullæa contracta*, *Chlamys fibrosa*, *C. splendens*, *Camptonectes lens*, *Velata anglica*, *Oxytoma expansa*, *Lima mutabilis*, *L. subantiquata* and many more. Earlier elements are *Nucula oxfordiana* de Lor., *Parallelodon* (*Beushausenia*) *keyserlingii* (d'Orb.), *Astarte cordati* Trautsch. and *Pinna lanceolata* Sow. Since the deposit must be dated by its latest fossils, there seems no alternative but to correlate it with the Berkshire Oolite Series. The ammonites comprise Perisphinctids of the *martelli* zone mixed with Cardiocerates of the *cordatum* zone; and there are in addition a number of forms, including some Oppelids, not known elsewhere in the British Isles.

This correlation was already advocated by Mr. Wedd, who wrote in 1901 that he would place the Elsworth Rock 'on a somewhat higher horizon than the Lower Calcareous Grit'.[2] In the discussion which followed the reading of Wedd's paper Hudleston remarked that, judging by the fossils, 'it was impossible to avoid the conclusion that the rock at Elsworth occupies a very low position in the Corallian Series'. H. B. Woodward made the ambiguous suggestion that 'the occurrence in the Elsworth Rock of the Lower Corallian *Ammonites perarmatus* and the Upper Corallian *A. plicatilis* might be taken to indicate a local blending of the two zones'—an explanation which seems to be certainly the right one, although not in the sense in which Woodward doubtless intended it.

Wedd noted that, all along the outcrop of the Elsworth Rock, even as far away as Gamlingay and Upware, there is a hard blue rock crowded with *Serpulæ* and *Exogyra nana*, which he took to indicate slow deposition. Further, he observed that the Elsworth Rock abounds in casts of ammonites to which, after the complete removal of the shell, *Serpulæ* have attached themselves. Thus penecontemporaneous erosion has undoubtedly taken place, and the 'blending of the two zones' is explained. Sedimentation may have been so slow that no appreciable thickness of rock separated the two faunas, which could then become mingled with very little disturbance or reworking of the strata.

Lower Calcareous Grit: The Arngrove Stone.

In the area between the Corallian escarpment at Stanton St. John and the projecting Portlandian spur of Brill and Muswell Hills, before the overstep of the Osmington and Berkshire Oolite Series on to the Oxford Clay is complete, a thin representative of the Lower Calcareous Grit survives, and has been named by Prof. Davies the ARNGROVE STONE. Lapping round the south of Otmoor, it forms an escarpment which, although subdued, is noticeable in

[1] W. J. Arkell, 1929, 'Mon. Corall. Lamell.', *Pal. Soc.*, p. 11.
[2] C. B. Wedd, 1901, loc. cit., p. 83.

an area otherwise composed of clays. The rock, which is worked as a 'gravel' in some shallow pits near Arngrove, is peculiarly light and absorbent.

Prof. Davies discovered that the Arngrove Stone is composed of spicules of the siliceous sponge, *Rhaxella perforata* Hinde, thus resembling *Rhaxella* cherts in the Lower Calcareous Grit of Yorkshire.[1] It also resembles the chert at Purton except that it lacks the large, scattered, brown ooliths. The rest of the fauna is composed of lamellibranchs of Lower Calcareous Grit species and small Cardiocerates of *cordatum* and *vertebrale* styles. It is a much richer assemblage than any found in the neighbouring sand-bank, but it is considered to correspond only to the lowest, unexposed, portion of the Lower Calcareous Grit (see fig. 62, p. 348).

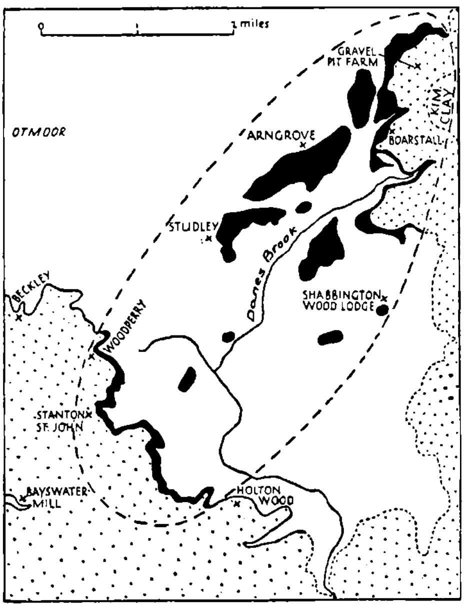


FIG. 72. Sketch-map of the outcrop of the Arngrove stone, by Prof. A. Morley Davies, 1931. (Based on the Oxford Special sheet Geol. Survey Map of 1908.) Oxford Clay, white; Arngrove Stone, black; later Corallian Beds, dotted.

The outcrop of the Arngrove Stone is restricted to an ellipse about 7 miles in greatest length (SW.–NE.) and 2¼ miles in width, extending from the slopes of the hills around Stanton St. John and Woodperry to about a mile beyond Boarstall (see fig. 72). Prof. Davies believes that this corresponds with the original area of deposition. Down the dip-slope to the south-east it was believed by Buckman to pass into a white clay, seen in the fields about Oakley and noted by him at Worminghall in a well. In the well the white clay was underlain by a 6-in. band of fossiliferous, yellow, marly sandstone, which Buckman named the WORMINGHALL ROCK, recording from it *Cardioceras* cf. *zenaidæ*, *Miticardioceras mite*, *Perisphinctes* cf. *intercendens*, 'immense *Gryphææ* and numerous lamellibranchs'. Beneath were 26½ ft. of blue Oxford Clay.[2]

The base of the Arngrove Stone was also seen by Prof. Davies in a well at Studley, but there no fossiliferous representative of the Worminghall Rock was found.

The relations of the deposit to the overlying beds have never been clearly exposed and the only place where they could be studied would be on the flanks of the hill for a short distance on either side of Stanton St. John. Prof. Davies noted a considerable thickness of calcareous sandstone above the Arngrove Stone in a road-cutting at Woodperry,[3] but at Stanton Great Wood he found indications of a clay occupying the same position.[4]

[1] A. M. Davies, 1907, *Q.J.G.S.*, vol. lxiii, pp. 37–43.
[2] S. S. Buckman, 1925, *T.A.*, vol. v, p. 54.
[3] A. M. Davies, 1907, *Q.J.G.S.*, vol. lxiii, p. 42. [4] Idem, 1909, *P.G.A.*, vol. xxi, p. 235.

(b) The Upware Reef

At Upware, 10 miles north-east of Cambridge, is a small reef, entirely isolated among the Fens and seventy miles from the nearest coral-bearing rocks at Wheatley. It rises above the level alluvium as a low hill, 3 miles long and less than a mile wide. As it produces the only limestone in the district, it has been opened up in two large quarries at the north and south ends of the hill, and in addition in several minor excavations. Concerning these openings and their interpretation as bearing upon the structure of the hill and the succession of the strata, an extensive literature has grown up. The locality has naturally always attracted the attention of Cambridge geologists: Sedgwick, Seeley, Bonney, Roberts and Keeping each made contributions to the stratigraphy. After a full description had been published by Blake and Hudleston in 1877 there followed an acrimonious discussion between them

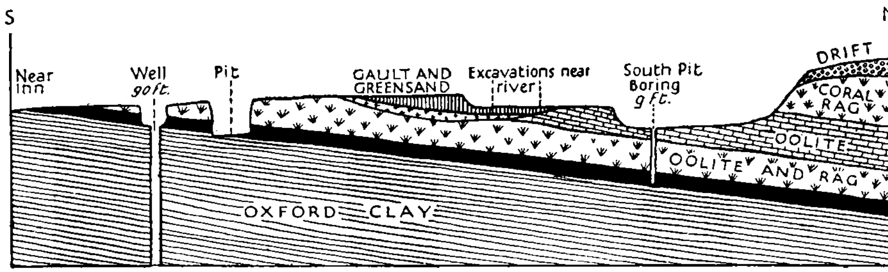


FIG. 73. Diagrammatic section through the Corallian Beds on the south side of the hill at Upware. The coral rag and oolite facies probably interdigitate more than shown. After P. Rigby, in R. H. Rastall, 1909, *Geol. in the Field*, p. 137, fig. 26 (re-drawn).

and Bonney; but Blake and Hudleston's palaeontological conclusions were in the main upheld by Wedd, who collected much new information and published an exhaustive account in 1898. Finally, in 1901 certain remaining difficulties were cleared up by Prof. W. G. Fearnsides, by means of a special excavation made through the floor of the south pit, and the results were published by him in 1904 and summarized in an account by Dr. R. H. Rastall in 1909.[1]

A brief description of the rock-succession suffices for present purposes, without entering into the history of the various controversies. At the same time the opportunity is taken to offer some further suggestions as to the correlation of the component strata.

The highest rock on the hill is a typical coral rag, composed of fine reef-building corals. It is exposed in the upper part of the north end of the south pit to a depth of about 10 ft., dipping gently north into the hill (see fig. 73). The rag is chiefly built up of layers of *Isastræa explanata* and *Thamnastræa arachnoides*, with which are associated *T. concinna*, *Montlivaltia dispar*, *Stylina tubulifera*, and numerous mollusca. It forms a creamy white limestone, the crystalline masses of coral alternating with pockets of whole and broken shells in an earthy matrix. In some of the beds the shells have been

[1] For the numerous earlier references see the Bibliography; the two principal accounts are by C. B. Wedd, 1898, *Q.J.G.S.*, vol. liv, pp. 601–9; and R. H. Rastall, 1909, *Geol. in the Field*, pp. 133–8.

dissolved away, leaving hollow moulds and casts. Blake and Hudleston wrote that, 'It is not so rubbly as many of the rags are, but compares well in some portions with that which occurs in Yorkshire, at North Grimston. It has, however, a peculiar creaminess about it that is hard to match elsewhere. ... The irregularity of the bedding is an indication of its reef-like character.'[1]

The fauna is remarkable, for, although the typical coral-dwelling assemblage is present, it is mingled with a large number of mollusca not usually found in any abundance in the coral rag, but more characteristic of the shell beds. In addition there are several peculiar species not found at any other English locality, or only very rarely in Yorkshire, but described from the Continent: these are *Isoarca texata* Quenst., *Isoarca multistriata* Étall., *Opis* (*Cœlopis*) *arduennensis* Buv. and *Opis* (*Trigonopis*) *virdunensis* Buv.[2] The absence of *Thecosmilia annularis*, the commonest coral in the Wilts.–Berks.–Oxon. ridge, is also striking.

Besides these forms there are two species which are highly significant because they are abundant in the *Trigonia clavellata* Beds of Dorset, but have never been found in the long outcrops of the Wilts.–Berks.–Oxon. ridge, where those beds are absent: *Mytilus* (*Arcomytilus*) *pectinatus* Sow. and *Prorokia problematica* (Buv.).

Below the coral rag, and exposed over the southern three-quarters of the south pit, is an oolite, locally loose and pisolitic and very shelly, but becoming less fossiliferous towards the bottom. The thickness seen is probably over 20 ft. The upper portions of this oolite contain most of the shells found in the overlying coral rag. The following lamellibranchs are most prominent in both: *Chlamys nattheimensis*, *Plicatula weymouthiana*, *Mytilus ungulatus*; and also *Chlamys intertexta*, *C. inæquicostata*, *C. fibrosa* (rare), *Navicula quadrisulcata*, *Velata anglica*, *Lima rigida*, *L. læviuscula*, *Trigonia reticulata*, *Myoconcha texta* and many others, as well as an unusually rich assemblage of echinoderms. The typical *Perisphinctes martelli* also occurs.[3]

A trial hole dug through the floor at the south end of the south pit, made during Prof. Fearnsides's investigations in 1901, passed through 4 ft. more of the oolite (making nearly 30 ft. in all) into a hard band of coral rag. Below this it penetrated another 5 ft. of variable rock, composed of a mixture of coral and marl, until, at a depth of 9 ft. it struck a hard oolitic rock stained with iron, which was considered to be undoubtedly the Elsworth Rock.[4] The boring was not carried any farther, but a continuation of the sequence was seen some years previously during the sinking of a well near the inn at Upware, to the south of the quarry, and nearby in another small opening recorded by Wedd. Here coral rock rested on ferruginous oolite with corals (2 ft. 3 in. thick) taken to be the top of the Elsworth Rock, which was completely penetrated in the well. Beneath the band of ironshot oolite were 9 ft. 9 in. of clay, the lower part full of *Exogyra nana*, below which again was a lower and thicker ironshot rock-band, as at Elsworth, here 4 ft. thick. The lower rock-band, which rested directly on Oxford Clay with *Cardioceras*,

[1] Blake and Hudleston, 1877, *Q.J.G.S.*, vol. xxxiii, p. 314.
[2] See Arkell, 1929, 'Mon. Corall. Lamell.', pp. 11, 47.
[3] Sedgwick Museum.
[4] W. G. Fearnsides, 1904, in Marr and Shipley, *Geol. Cambridgeshire*, p. 16; and Rastall, 1909, loc. cit., p. 136.

Peltoceras athleta (?), *P. eugenii*, and '*Ammonites hecticus*', contained the fauna of the Elsworth Rock, the ammonites recorded being *C. cordatum*, *C. vertebrale*, *C. mariæ* and *Peltoceras eugenii*.[1] If the last two were correctly identified they must have been derived, and they would prove that the unconformable overstep of the Oxford Clay by the basement-bed of the Corallian, as determined by Prof. Davies in Buckinghamshire and Bedfordshire, is here still more pronounced and has penetrated down to the *athleta* zone.

However this may be, the presence of *Cardioceras cordatum* and *C. vertebrale* and the absence of the plicatiloid Perisphinctids so abundant, in fact preponderant, in the more westerly exposures, suggests that the Elsworth Rock may be not an isochronous deposit—that it may here be earlier in date than at St. Ives and Elsworth, in spite of the close lithic resemblance.

The white oolite is again exposed in the north quarry, where the total thickness was estimated by Wedd to be 40 ft. or more. The coralline facies of the basal portion does not appear here, and the rock is less fossiliferous. Blake and Hudleston long ago placed it, purely on palaeontological grounds, below the main or topmost coral rag, which was at that time the only rock exposed in the south pit.

The upper, more fossiliferous portion, of the oolite, at any rate of the south pit, and the superincumbent coral rag may be regarded as later in date than any of the coral rag of Oxon., Berks. and Wilts. excepting only the reef at Steeple Ashton (above, p. 390). This conclusion is warranted by the peculiarities of its fauna as well as by its general appearance—both features remarked on by Blake and Hudleston. It would thus probably be about equivalent to the Steeple Ashton coral rag and the *Trigonia clavellata* Beds of Dorset (perhaps including the uppermost or rubbly portion of the Osmington Oolite Series and/or a part of the Sandsfoot Clay); and so to the lower part of the Ampthill Clay of Ashendon cutting.

(c) From the Fens to the Market Weighton Axis

The isolation of the Upware reef with its shallow-water coralline facies has long been known from borings at March, Wicken and other places in the Fens, which penetrated from Kimeridge Clay into Oxford Clay without meeting with any Corallian Beds as developed at Upware. The Survey maps show nothing more of the formation south of the Yorkshire Basin, denoting again from their colouring that throughout the long county of Lincolnshire the Oxford Clay and Kimeridge Clay are in contact. This is entirely misleading, however, for Roberts demonstrated in 1889 that the Ampthill Clay is continued through a large part of North Lincolnshire, and there is every reason to suppose that it extends from Upware at least as far as the Humber (see fig. 74, p. 418).

In common with the Oxford and Kimeridge Clays, the Ampthill Clay would seem to diminish in thickness northward along the Lincolnshire outcrop as it approaches the Market Weighton Axis. In two borings at Southery, in the Fens 14 miles north of the Upware reef and just over the Norfolk border, Dr. J. Pringle assigns about 50 ft. of clays to the Ampthill Clay.[2] In the lower portion were encountered several thin bands of argillaceous

[1] C. B. Wedd, 1901, loc. cit.
[2] J. Pringle, 1923, *Sum. Prog. Geol. Surv.* for 1922, pp. 126–39.

limestone, but none of them bore any resemblance to the Elsworth Rock. Below the lowest band was a small Cardiocerate, suggestive of the *præcordatum* zone. In the lower parts of the Ampthill Clay no fossils were found. The upper limit was drawn below a bed of clay containing fragments of large smooth ammonites identified as probably *Pictoniæ* and so indicating the basal zone of the Kimeridge Clay. At a level 23 ft. below this in one boring and 16 ft. below it in the other, specimens of *Prionodoceras serratum* (Sow.) were found.

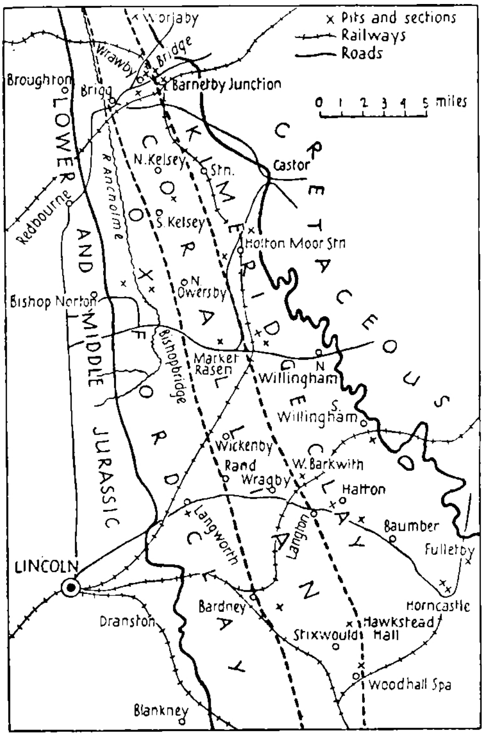


FIG. 74. Sketch-map of part of Lincolnshire to show the approximate position of the outcrop of the clays of Corallian date as determined by Roberts. (After T. Roberts, 1889, *Q.J.G.S.*, vol. xlv, p. 546.)

The work of Roberts was carried out in North Lincolnshire, between Bardney, on the latitude of Lincoln, and Brigg, a distance of about 25 miles.[1] By the same careful methods as those which he had followed in the Cambridge district, examining all the small brickyards now for the most part abandoned, and helped by several railway-cuttings, he established that a continuous belt of Corallian clays could be traced, differing both lithologically and palaeontologically from those above and below (fig. 74). As in the Cambridge district, he found that the ammonites in the Oxford Clay are pyritized, while those in the Ampthill Clay are never pyritized; the Ampthill Clay, moreover, can be readily recognized by its black colour and the abundance of selenite crystals.

The deepest continuous section of Ampthill Clay recorded was one of 17 ft. seen in a brickyard west of Hawkstead Hall. Other sections were described at Bardney, South and North Kelsey and Wrawby, in the railway-cutting.

Roberts found that the black selenitiferous clay contained Corallian fossils, and out of 23 species he recognized 16 that occur in the Ampthill Clay. The ammonites recorded are such typically Corallian names as '*A. cordatus*, *A. vertebralis*, *A. excavatus*, *A. cawtonensis*, *A. plicatilis*, *A. achilles* and *A. decipiens*', but further material and more detailed identifications would be necessary before their significance could be assessed. The records of '*A. excavatus*' and '*A. cawtonensis*' may both refer to *Prionodoceras*. Again there appears to be the same admixture of *Gryphæa dilatata* and *Ostrea delta*, but here Roberts states that *G. dilatata* is commonest in the lower part of the clay, while *O. delta* is more abundant in the upper part. *Alaria bispinosa* also

[1] T. Roberts, 1889, *Q.J.G.S.*, vol. xlv, pp. 545–60.

appears in the lists, but so do such typical Lower Calcareous Grit and Berkshire Oolite fossils as *Chlamys fibrosa* and *Pachyteuthis abbreviata*.

There is thus insufficient evidence for stating which subdivisions of the Corallian formation are represented, and it is unknown how thick the deposits may be. On the whole, however, there seems no reason to doubt that the bulk of the clay is of the same age as the bulk of the Ampthill Clay between Oxford and Cambridge, belonging high in the Corallian Series. No hard basement-beds comparable with those that are such a conspicuous feature in the more southerly area have been detected, but the junction with the Oxford Clay has nowhere been seen.

IV. THE MARKET WEIGHTON AXIS

Between the Humber and the Market Weighton Axis evidence of Corallian Beds has been recognized only in a well at Melton, near North Ferriby, close to the Humber.[1] They are still clays and they must be very thin and imperfect, for the total thickness from the base of the Oxford Clay to the top of the Kimeridge does not exceed 100 ft. It is probable that as they approach the axis they wedge out altogether.

We have to pass at least six miles to the north of the Market Weighton Axis before we find any Upper Jurassic rocks preserved beneath the Chalk, and by that time the normal limestone and sandstone facies of the greater part of the series has already returned. The transition from the one facies to the other, or the thinning out of both against a dividing ridge of older rocks, will never be seen by geologists, for over the critical region the overstep of the Chalk has obliterated all the evidence. Nevertheless, the country immediately to the north holds the key to the region on the axis and enables us to tell what becomes of the Corallian Beds as well as if we could see them.

The first trace of the beds is found above Ley Field, near Garrowby, where a small pocket of normal Lower Calcareous Grit has been quarried beneath the Chalk.[2] North of this, about Kirby Underdale, there is another considerable gap, owing partly to obscuring talus fallen from the Chalk, but principally to minor pre-Cretaceous folds, from the summits of which the Upper Jurassic rocks were eroded before the Chalk was deposited. In the valley of the Gilder Beck, south-east of Acklam, the Chalk rests again on Lower Lias, and on the crest of another sharp anticline between Acklam and Leavening it reposes on the Estuarine Series. These minor axes recall those parallel to and north of the main Mendip Axis, about Keynsham and Radstock.

Farther north, the Corallian Beds emerge fully from the Cretaceous covering and it becomes possible to discern the movements that took place during the Corallian period. The rocks are at first very incomplete. They thicken to the north and north-west into the Yorkshire Basin, not only by increments to every member of the series, but also by the incoming of some new and important subdivisions, of which at least one is not met with anywhere in the South of England.

Until almost as far north as Birdsall Kimeridge Clay rests unconformably on the Lower Calcareous Grit. The first subdivision to appear beneath it is

[1] P. F. Kendall and H. E. Wroot, 1924, *Geol. Yorkshire*, p. 332.
[2] To end of subsection based on C. Fox Strangways, 1892, *J.R.B.*, pp. 300–70.

the Upper Calcareous Grit, with what is probably the upper part of the Glos Oolite Series represented by an argillaceous rock, to be described in the next section, the North Grimston Cementstone. At Toft House 'a little impure limestone with oolitic grains' makes its appearance and thickens rapidly towards North Grimston, gradually coming to represent the whole of the great limestone divisions of the Yorkshire Corallian.

Thus the country between the Chalk Wolds and the Derwent gives us a fairly accurate idea of what became of the Corallian Beds over the Market Weighton Axis along the line of the present outcrop. It is clear that no part of the formation except the Lower Calcareous Grit reached so far south as the region where the Chalk overstep would have removed it, all the rest of the subdivisions having already disappeared, both by diminution in thickness —'wedging out'—and by being overlapped by the Kimeridge Clay.

V. THE YORKSHIRE BASIN

The thickening of the Corallian Beds, by the incoming of new subdivisions and the expansion of the old ones, continues north-westward across the Derwent and along the Howardian Hills to beyond the Gilling Gap. In the Hambleton Hills and eastward through the Tubular Range to the sea the formation attains a grander development than in any other part of the British Isles. It wraps around three sides of the Vale of Pickering, its dip-slopes along the north and west margins rising into flat-topped moorland, untamed and heather-covered, and offering as marked a contrast with the gentle hills of the Berkshire and Wiltshire range as do the moors of the Lower Oolites with their contemporary formations in the South of England. The strongest features of all are the lofty escarpments of the Hambleton Hills. For a considerable distance these rise above an average height of 1,000 ft., built of the hard gritstones of the Lower Calcareous Grit, much thicker and more massive than in the South and presenting precipitous faces westward, visible from far away over the Vale of Mowbray, like the Northern Pennines seen from the Vale of Eden.

Between the strata containing the fauna of the Berkshire Oolite Series and the true Lower Calcareous Grit are developed some 120 ft. of limestones and grits, belonging to the upper part of the *cordatum* zone. These beds, which are unknown in the South of England and may be represented in time by the gap below the Pebble Bed, are called the Hambleton Oolite Series, or the Lower Limestones and Passage Beds. Farther down the dip-slopes, forming an inner circle around the Vale of Pickering, follow the Osmington Oolite Series and succeeding beds, with a variable representation of the Upper Calcareous Grit. Coralline formations are widespread in the Osmington Oolites and probably also in the Glos Oolites, on the horizon of the *Trigonia clavellata* Beds. The earliest coral reef in England is found in the Hambleton Oolite Series of Hackness.

To attempt an adequate description of these rocks in any way commensurate with their importance and interest would involve extending this chapter far beyond its already swollen proportions. No other formation in Yorkshire maintains such continuous variety and so rich a fauna, or stimulates inquiry with so many exposures, as the Corallian. Its many-sided interest has attracted also a disproportionate amount of research, and we have exhaustive accounts of the rocks from the stratigrapher's point of view by Fox-Strangways and from the palaeontologist's point of view both by Hudleston and by Blake and Hudleston jointly. Yet even still a vast amount remains to be discovered, as is being proved by the researches of Dr. Vernon Wilson.

It is customary for purposes of description to divide the outcrop into a number of sections, each of which would have an importance equal to that of one of the earlier sections of this chapter. But in view of the essential continuity of the rocks, we will consider the Yorkshire Basin as a whole, confining ourselves to a brief summary of the succession, and noting the localities where each subdivision is best developed.

SUMMARY OF THE SUCCESSION AROUND THE YORKSHIRE BASIN [1]

Upper Calcareous Grit + Upper Glos Oolite Series: 80 ft. east of the Derwent and perhaps in the Howardian Hills; not more than 45 ft. elsewhere.

The second subdivision of the Corallian formation to appear beneath the Kimeridge Clay on the north side of the Market Weighton Axis (the first being the Lower Calcareous Grit) is a thick argillaceous series called the NORTH GRIMSTON CEMENTSTONE. It consists of bands of grey argillaceous limestone, like Blue Lias and used for making 'Blue Lias Cement', separated by and passing down in the lower half of the series into calcareous shales. The total thickness locally may exceed 80 ft.

The Cementstone Series is markedly unconformable with the coral rag and underlying oolite, which it overlaps southward on to the Lower Calcareous Grit, before being in turn overlapped by the Kimeridge Clay.[2] The well-known quarries near North Grimston show the character of the rock well. Fossils are rather scarce and always difficult to extract. The commonest are large specimens of *Gryphæa dilatàta* Sow. of several common varieties, including var. *discoidea* Seeley,[3] also *Lucina aspera* Buv. (abundant in the Upper Calcareous Grit) and such undiagnostic forms as *Thracia* and *Goniomya*. Some ammonites have been found, recorded by Blake and Hudleston as '*A biplex-variocostatus*' and '*A*. cf. *alternans* and *A*. cf. *serratus*' (*Prionodoceras* or *Amœboceras*).

The Cementstone Series crosses the Derwent and probably persists throughout the Howardian Hills, but no exposure has been seen for the whole length of 15 miles beyond Hildenley (near Malton). At the extreme west end of the Howardians, at Snape Hill Quarry, the upper part of the series is seen to have become more arenaceous. The total thickness is here still more than 50 ft. At the top are 5–6 ft. (formerly 10 ft.) of ferruginous sandstone—typical Upper Calcareous Grit—overlying 12½–13 ft. of alternating hard,

[1] Based on C. Fox-Strangways (1892, *J.R.B.*, pp. 300–70), W. H. Hudleston (1876–8, *P.G.A.*, vol. iv, pp. 353–410, and vol. v, pp. 407–94), and Blake and Hudleston (1877, *Q.J.G.S.*, vol. xxxiii, pp. 315–91), with alterations to nomenclature and some additions from personal observation and the researches of Dr. V. Wilson. See map, fig. 27, p. 138.

[2] Dr. Vernon Wilson informs me that he considers the Cementstone passes gradually up into the Kimeridge Clay.

[3] The *Gryphæa* was given a new name, *G. subgibbosa*, by Blake and Hudleston, but a number which Dr. Wilson has kindly shown me cannot be distinguished from *G. dilatata*. The varieties like var. *discoidea* were recorded by authors as *Ostrea bullata* Sow., the type of which came from the Kimeridge Clay. See Arkell, 'Mon. Corall. Lamell.', Part IV, p. 162.

blue-centred sandstones and softer shaly sandstones, then shales and cementstones to a thickness of 36 ft., resembling the North Grimston Cementstone but darker and harder; the whole resting on coral rag.[1] This section seems to show that the upper part of the Cementstone Series alternates with and passes laterally into sandstones, which on the north side of the Gilling Gap constitute the Upper Calcareous Grit; though it is not improbable that some of the sandstone here is younger than any of the beds seen about North Grimston.

The UPPER CALCAREOUS GRIT in its more typical development encircles the north-west and north sides of the Vale of Pickering, its outcrop generally in contact with the alluvium, or separated from it only by scattered patches of Kimeridge Clay. The first good section is seen in the railway-cutting midway between Nunnington and Oswaldkirk. Here and all around the west end of the Vale, about Helmsley and onward to Kirkby Moorside, the rock is a massive blue-hearted sandstone, frequently containing lines of large doggers of still harder rock. It is separated from the coral rag by shaly beds which are seldom seen, but they have been reported as full of *Gryphæa dilatata* var. *discoidea* ('*Ostrea bullata*'). The ammonites recorded from the Upper Calcareous Grit include '*A. achilles* d'Orb.', '*A. decipiens* Sow.', '*A. berryeri* Leseur', '*A. serratus* Sow.', '*A. alternans* von Buch.', and '*A. biplex* (small interior whorls)', all suggestive of the *Ringsteadiæ* and associated forms of Wilts. and Dorset. This correlation is confirmed by the presence of *Chlamys midas* (d'Orb.), which in Dorset and the South of England abounds in and is restricted to the Upper Calcareous Grit. The shales below thus fall into line with the Sandsfoot Clay, and so with at least a part of the Ampthill Clay. The southward passage of the Upper Calcareous Grit and underlying shales into the North Grimston Cementstone strengthens our correlation of the Ampthill Clay.

Excepting traces on the Hackness outlier, the Upper Calcareous Grit is not exposed at the surface east of Thornton Dale, 2 miles beyond Pickering. Hereabouts it is usually a soft, brownish-red, ferruginous sandstone, locally crowded with *Lucina aspera*, *Pseudomonotis ovalis*, *Chlamys midas*, &c. Below are shale and a claystone of variable thickness, which in the Pickering quarries is called the Throstler. The Upper Calcareous Grit was proved to extend underground to the sea, however, for it was penetrated by borings at Irton, near Scarborough, and at Filey. The thickness was 45–46½ ft., and most of the underlying shale seems to have passed into sandstone.

Osmington Oolite Series (? + **Lower Glos Oolite Series**) (CORALLINE OOLITE AND CORAL RAG, OR UPPER LIMESTONE), average 50–60 ft.

The Osmington Oolites and probably also some strata contemporaneous with the *Trigonia clavellata* Beds constitute the main mass of the 'Upper Corallian' of Yorkshire, usually known as the Coralline Oolite and Coral Rag, or Upper Limestone. They comprise a highly variable and complex set of strata, the detailed examination of which is beyond the scope of this work. The stratigraphy is as usual greatly complicated by coral growth and, as was realized by Hudleston, the spreads of coral rag in different places were not

[1] C. Fox-Strangways, 1892, p. 367; revised measurements and description from Dr. Wilson, 1931.

all formed at the same time. As a general rule, however, the main mass of rag is found at the top of the division, immediately below the shale or clay just described, and this gave rise to the introduction of the term 'The Coral Rag' as a stratigraphical term, which, as we have seen, is not permissible. Below are many variable beds, the commonest and thickest type being white oolite. The combination of the white oolite and the coralline facies forcibly recalls the Calne district, where the coralline province of Oxon.–Berks.–North Wilts. meets the non-coralline white oolite province of Dorset.

It is highly probable that some of the Yorkshire coral rag is younger than the Osmington Oolites and contemporaneous with the Steeple Ashton and Upware reefs, which we correlated with the *Trigonia clavellata* Beds. The shelly facies of these beds, so conspicuous in Dorset, seems to be wanting entirely in Yorkshire, but locally some of the characteristic shells are found in the highest part of the rag: e.g. *Mytilus pectinatus*, *Lopha solitaria*, *Lima spectabilis* Contejean (a species of the Lower Kimeridgian about Montbéliard), and *Opis virdunensis*, only known in France and in the late rag of Upware.[1] The localities where these fossils were found are all situated around Malton, Hildenley and North Grimston, on the south side of the basin, where also the series is thicker than elsewhere.

At North Grimston is the thickest development of coral rag known in the British Isles, amounting to 37 ft. Blake and Hudleston called it the North Grimston Limestone, and its peculiar characters may be considered to justify a separate name. Besides corals and the usual mollusca and *Cidaris* spines, it contains in places many bands of pale flinty chert. The only other localities where any considerable quantity of chert seems to be known in the coral rag are a quarry beside the road to the south of Helmsley, and at Slingsby, Hildenley and East Ness, near Nunnington.[2] Nowhere else, however, is there more than half this thickness of coral rag, and it would seem that coral growth proceeded here, at the southern edge of the basin, more continuously than anywhere farther north. Within a mile or two towards the south the entire division disappears against the Market Weighton Axis. This suggests that, if the wedging out is even partly original and not due entirely to unconformable overstep of the Cementstone, the water may have been shallow here for a longer period of time than elsewhere, and we may be seeing something of a true fringing reef that grew against the southern margin of the basin.

The strata below the rag are difficult to correlate with certainty with the succession in other parts of Yorkshire. Immediately under the rag are 25 ft. of drab-coloured, marly oolites with an occasional band of hard limestone and corals, called by Blake and Hudleston the MAMILLATED URCHIN SERIES. It is crowded with *Diplopodia hemisphærica*, *Hemicidaris intermedia*, *Cidaris florigemma*, *C. smithii* and *Nucleolites scutatus*. The Urchin Marls of the Wiltshire–Berkshire range are similar, but here the assemblage of urchins is much more varied.

Below the Mamillated Urchin Series Blake and Hudleston described a further 30 ft. of oolites, which have been taken to represent the 'Coralline

[1] W. J. Arkell, 1929, 'Mon. Corall. Lamell.', *Pal. Soc.*, pp. 8, 11.

[2] Information from Dr. Wilson; the only place where chert was previously noted was Helmsley, by Blake and Hudleston.

Oolite' below the coral rag of other districts; but if this correlation were altogether correct, the thickness of the series here would be little short of 100 ft., or nearly twice the thickness elsewhere. It seems probable that some of the Lower Limestones are represented, especially as the oolites are said to rest directly upon the Passage Beds, which separate the Hambleton Oolite Series from the Lower Calcareous Grit.

At Malton and the neighbouring village of Hildenley, across the Derwent Valley, the thickness is still great, and there is the same difficulty about the lower beds. The best section is shown by a large quarry at the cross-roads on the north side of Malton, exposing 30–40 ft. of rock. At the top is seen up to 7 ft. of coral rag, resting upon 13 ft. of white oolites which seem to correspond to part of the rag elsewhere, as they have 'a fauna somewhat approaching that of the rag'; 'and', observe Blake and Hudleston, 'this may partly serve to account for the very mixed character of the fossils which come from the Malton district in an undoubtedly oolite matrix'.[1] The more typical Coralline Oolites come in below, to the base of the quarry. Blake and Hudleston named these last the CHEMNITZIA LIMESTONES, owing to the abundance all over the western side of the Yorkshire Basin of *Pseudomelania* [*Chemnitzia*] *heddingtonensis* (Sow.). From them came the bulk of the wonderfully preserved shells for which Malton was famous. The collections of Strickland, Leckenby, Bean and others, which now enrich the museums all over the country, were made at a time when the quarries were more actively worked than now. They contain many perfect specimens of such large shells as *Chlamys splendens*, *C. intertexta*, *Lima mutabilis*, *L. læviuscula*, *Corbis ampliata* (Phil.), *C. decussata* Buv., *C. umbonata* Buv. Some of these species are not found in any other part of England, while others are known elsewhere only very rarely. The common *Chlamys qualicosta*, however, occurs on this horizon and appears to be restricted to it all over England.

Limestones high in the series, like those immediately under the rag at Malton, and containing some fossils more characteristic of the Upper Calcareous Grit, such as *Lucina aspera*, were also described by Blake and Hudleston at Hildenley. Here they recorded '*Ammonites variocostatus*'.

More or less typical Osmington Oolite, of the type called '*Chemnitzia*' Limestone, with 10–15 ft. of coral rag above, is continuous along the Howardian Hills past Hovingham and Cawton to Gilling, and again on the opposite side of the Coxwold–Gilling Gap in the long spur about Oswaldkirk and Nunnington, and so on to the north side of the basin. The total thickness of the division hereabouts maintains an average of 50–60 ft., which is the same as the thickness of the Osmington Oolite Series in Dorset. The Urchin *Glypticus hieroglyphicus*, usually rare, but common at Calne, is recorded from Wath, near Hovingham. About Oswaldkirk Blake and Hudleston noted a finer profusion of corals than at any other point in Yorkshire, especially of *Montlivaltia dispar* and *Stylina tubulifera*; and here, too, the spines of the sea-urchins are unusually large.

Along the north side of the basin the outcrop is continuous past Helmsley, Kirkby Moorside and Pickering to Thornton Dale, beyond which there is a gap of 5½ miles to the Brompton, Ayton and Seamer district. There are fine sections in the sides of Hutton Beck and also in the gorge of the River

[1] Blake and Hudleston, 1877, loc. cit., p. 365.

Seven at Sinnington. The best of all are afforded by the extensive quarries at Pickering, where the Osmington Oolite is still obtained for a flux in the Cleveland ironworks.

In the country north of Pickering the coral rag dies out locally and gives place to flaggy detrital deposits like the Wheatley Limestones. No true rag is present in the Pickering quarries, which show the complete succession well up into the Upper Calcareous Grit. Instead, the '*Chemnitzia*' Limestones are succeeded by 15 ft. of impure, earthy and flaggy limestones without corals. The same type of rock has a considerable extension along the northern outcrop, although locally, and more especially in the lower ground towards the alluvium, the rag is luxuriantly developed. The actual passage from rag into Wheatley Limestone, such as may be seen about Headington and Purton, has been described by Fox-Strangways near the valley of the Hutton Beck, north-west of Sinnington. In a quarry he describes about 12 ft. of 'irregular ragged limestone with *Cidaris florigemma* and branching corals . . . surrounded, or nearly surrounded, with these impure flaggy limestones; which, as we have suggested, may have been formed from the denudation of the purer beds [of coral]'.[1]

The Sinnington Gorge and the quarries at Pickering (fig. 75) show that the '*Chemnitzia*' Limestones portion of the Osmington Oolite Series is hereabouts 18–20 ft. thick; below are 13 ft. of variable limestones with shell-beds and occasional nests of corals, forming a passage downward into beds that are proclaimed by their fauna to belong to the Berkshire Oolite Series.

The isolated area inland of Scarborough, some 6–7 miles in length, from Brompton past East and West Ayton to Seamer, and its continuation in the Hackness outlier, contains beds of coral rag which Hudleston believed to occupy a lower horizon than the rag on the west and north-west sides of the basin.[2] The principal reasons for this opinion were the abundance of certain species of mollusca, such as *Nerinea visurgis* and *Astarte subdepressa* Blake and Hudleston (*A. duboisiana* auct., non d'Orb.) which are characteristic of the base of the Coralline Oolite at Pickering; and the absence of *Cidaris florigemma*, which abounds in the coral rag of all other parts of Yorkshire, but is here replaced by *C. smithii*. Dr. Wilson does not agree with Hudleston, however.

The best clean section at present worked is at the eastern extremity of the outcrop, in the Crossgates Quarry, Seamer, which shows 25 ft. of beds. At the top are 12 ft. of alternating oolites, Wheatley Limestones and coral beds, and below 13 ft. of oolites. At the base of the higher division with corals is a 2 ft. band of coral rock crowded with shells, called by Blake and Hudleston the Coral-Shell-Bed. They recognized the same bed, or another identical with it, on the Hackness outlier at Bell Heads Quarry, Silpho.

In Forge Valley, the gorge of the Derwent above Ayton, a complete section shows about 14 ft. of coral rag resting on about 25 ft. of oolites. In the neighbouring Yedmandale the rag is 20 ft. thick. The causes of the variability of these beds was made clear by Fox-Strangways in the following passage:

'Although there may be 20 ft. of coral rag in some of the sections, it is doubtful whether it does not thin out altogether in other places; in fact, the coral rag appears

[1] C. Fox-Strangways, 1892, *J.R.B.*, p. 351.
[2] W. H. Hudleston, 1878, loc. cit., p. 420.

to stand up in irregular lumps or bosses between the oolitic brash and dense pasty limestones which were formed around them, in the same manner that coral reefs at the present day are surrounded by deposits formed from their own destruction.' [1]

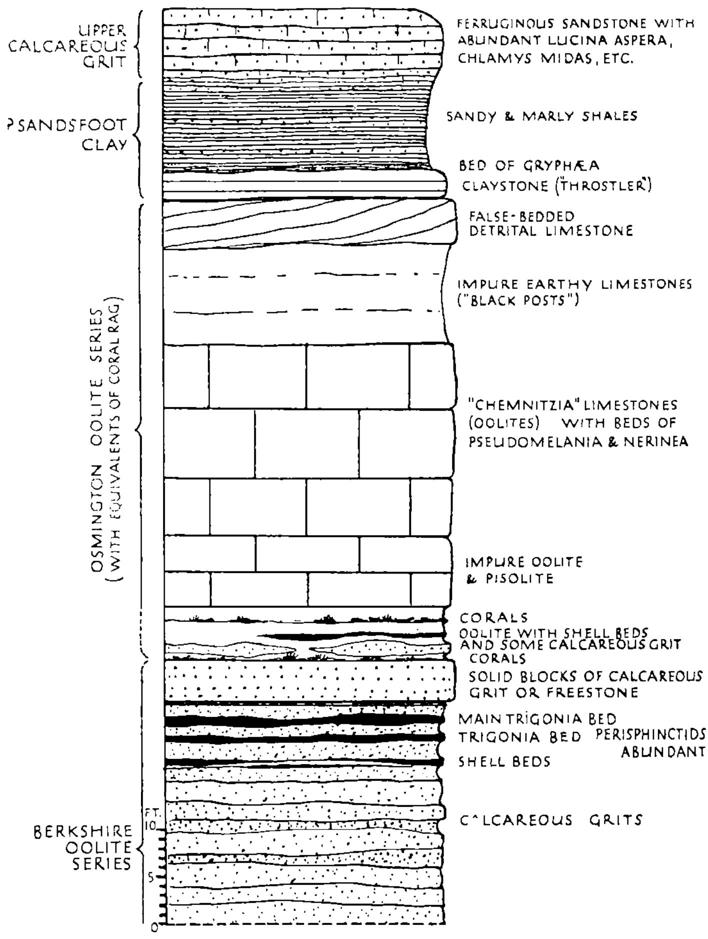


FIG. 75. Generalized section at Pickering. Based on Blake and Hudleston, *Q.J.G.S.*, vol. xxxiii, pp. 334–6, and personal observation, with correlation as suggested in the text.

On the coast, only the very base of the Osmington Oolite is seen at the point of Filey Brigg, where it is poorly fossiliferous and is overlain by thick Boulder Clay.

Berkshire Oolite Series (MIDDLE CALCAREOUS GRIT WITH TRIGONIA HUDLESTONI BEDS), average 10–45 ft., maximum 80 ft.

One of the best datum-lines for correlating the Corallian Beds of Yorkshire with those of the South of England is the *Trigonia hudlestoni* Beds. Shell-banks, crowded with this highly characteristic species and with many

[1] C. Fox-Strangways, 1892, *J.R.B.*, p. 346.

of its associates farther south, such as *T. reticulata*, *Cucullæa contracta*, *Gervillia aviculoides*, and many others, immediately underlie and inosculate with the basal layers of the '*Chemnitzia*' Limestones and the white oolites under them, which we recognize as the Osmington Oolite Series.

The *Trigonia hudlestoni* Beds form part of a predominantly sandy series, called the Middle Calcareous Grit, and mapped separately by the Survey. It extends continuously along the northern and north-western sides of the basin, attaining its greatest development in the north-west, between Helmsley and the Coxwold–Gilling Gap at Ampleforth. Its thickness is as much as 80 ft. in the banks of the Rye between Helmsley and Rievaulx, and it forms a great surface-spread on Wass and Ampleforth Moors, from the Rye to the Coxwold valley.

The clearest sections are in the Pickering Quarries and Hutton Beck, where the thickness is about 20–40 ft.; the rock is exposed in Hutton Beck for nearly a mile. The greater part of the series consists of poorly-fossiliferous sandstones, but locally freestones are developed, and here and there, especially towards the top, some of the slabs are studded with *Trigoniæ* and other shells, forming almost a solid mass. Perisphinctids similar to those in the South are abundant, though they still remain to be figured and identified. A start was made by Buckman, who refigured the type-specimens of three species named by Young and Bird, but unhappily all under redundant new generic names.[1] There are also Cardiocerates of *excavatum* type[2] and Aspidocerates (*A. perarmatum* in the old records), just as in the *T. hudlestoni* Beds in the South of England.

Towards both the east and the south-east the series becomes thinner. On the coast it is represented by 6 ft. of alternating shelly beds and sandstones, overlying 10 ft. of more massive sandstones, called the Filey Brigg Calcareous Grit. In the Howardians it thins down in the same way, until at the eastern end, about Malton, it is doubtfully represented by 10 ft. of gritty limestone containing large lamellibranchs, formerly exposed at Middle Cave. South of Malton it cannot be detected at all.

In view of the unconformable relations of the Berkshire Oolite Series to the beds underneath in so much of the South of England, a quarry described by Fox-Strangways on Wass Moor, north-west of Ampleforth, acquires a special interest.[3] It showed the base of the Middle Calcareous Grit resting on the Hambleton Oolite Series (Lower Limestone), in the top of which a large channel had been excavated and filled with sandstone before the grits were deposited. Erosion therefore preceded the deposition of the *Trigonia hudlestoni* Beds, at least locally, in Yorkshire also.

Hambleton Oolite Series (LOWER LIMESTONE AND PASSAGE BEDS), maximum 90 ft.

The next beds, the Hambleton Oolites of Blake and Hudleston and the Lower Limestone and Passage Beds of the Survey, are altogether peculiar to

[1] *Perisphinctes maximus* (Young and Bird) (refigured *T.A.*, 1924, pl. DXII), *P. ingens* (Y. & B.) (*T.A.*, 1920, pl. CLXXXIV) and *P. pickeringius* (Y. & B.) (*T.A.*, 1923, pl. CDXLVIII), all from Pickering.

[2] Including '*Chalcedoniceras*' *chalcedonicum* (Y. & B.) (*T.A.*, 1922, pl. CCXCV, A & B) from Thornton.

[3] C. Fox-Strangways, 1892, *J.R.B.*, p. 341, fig. 17.

Yorkshire, where they are, however, of great stratigraphical importance. Like the Middle Calcareous Grit, the beds are lenticular in shape, the thickest part of the lens being situated over the north-western end of the Vale of Pickering, away from which they thin out in all directions. Fox-Strangways thought that this distribution was determined by the original circumstances of deposition rather than by subsequent erosion, and the same view is taken by Dr. Versey.[1]

Over most of the north-eastern part of the area the Survey were able to map two distinct subdivisions, the Lower Limestone or Hambleton Oolite proper above, and a more gritty series below, called the Passage Beds. The two subdivisions grade imperceptibly one into the other, not only vertically, but also horizontally. On the coast, at Filey, the whole is developed in the gritty facies of Passage Beds, while at the west end of the Vale of Pickering all is limestones.

As remarked above, the lower portion of the great thickness of oolites at North Grimston, usually all grouped as 'Upper Limestone', may probably represent the Hambleton Oolite Series; the Middle Calcareous Grit, which usually separates the two, having wedged out. If this surmise be correct, the Hambleton Oolite Series has not such a localized distribution as has been supposed.

The best section of the Hambleton Oolite Series in the Howardian district is seen in the Brows Quarry, Malton, now unfortunately abandoned. It still shows a mural face of peculiar buff-coloured, fine-grained, gritty, sparsely-oolitic limestone, from which such early forms as *Rhynchonelloidea thurmanni*, *Millericrinus echinatus* and Cardiocerates recorded as '*A. cordatum*' have been obtained. Fossils, however, are always rather scarce in these beds.

Beyond the Coxwold–Gilling Gap the limestone thickens rapidly, and in the country at the west end of the Vale of Pickering and on the dip-slope of the Hambletons it has an average thickness of 50–60 ft., with a maximum of perhaps 90 ft. between Hawnby and Kepwick.[2] Up the dip-slope, however, it thins to 16 ft. on the edge of the western escarpment. In this district the rock is poorly fossiliferous and much silicified. In extensive quarries at Kepwick Blake and Hudleston recorded *Cardioceras cordatum*, *Rhynchonelloidea thurmanni*, *Oxytoma expansa*, *Pseudomonotis ovalis*, *P. lævis* and a few other fossils, all of Lower Calcareous Grit aspect.

'The fact is,' wrote Fox-Strangways, 'in this region the base of the [Lower] Limestone [Hambleton Oolite Series] and the top of the Lower Calcareous Grit are dovetailed together, producing an alternating series of sandstones and limestones, which to the north develop into one thick bed of limestone, while to the south first the lower band of limestone dies out and then the upper, so that in the south-east of this range of hills there is only one thick mass of arenaceous strata to represent the whole of these limestones.'[3]

It is only east of Kirk Dale (north-west of Kirkby Moorside) that the lower part of the Hambleton Oolite Series becomes permanently gritty enough to map separately as the Passage Beds. Along the rest of the Tabular Range the

[1] H. C. Versey, 1929, *Proc. Yorks. Geol. Soc.*, N.S., vol. xxi, p. 210.

[2] Fox-Strangways stated that the maximum was 80 ft., but Dr. Wilson informs me that at least 90 ft. are visible above Arden Hall, near Hawnby.

[3] 1892, *J.R.B.*, p. 331.

Photo. *Godfrey Bingley.*

Gristhorpe Cliff, near Filey, Yorks.

The overhanging bluffs are of Lower Calcareous Grit with some Lower Limestone, capped with Boulder Clay; the cliff below is of Oxford Clay.

Photo. *W. J. A.*

The Carr Naze, north side of Filey Brigg.

Cliffs of Filey Brigg Calcareous Grit, Lower Limestone and Passage Beds, with thick covering of Boulder Clay.

two divisions are then well distinguished, the limestones, 30–50 ft. thick, above, and the Passage Beds, up to 20 ft. thick or more, below. Above Staindale the Passage Beds have been locally cemented by silica, and the hardened portions, having resisted the action of the weather, stand up on the moor as the famous Bride Stones—some as much as 16 ft. high.

The two divisions are still distinguishable on the coast in Scarborough Castle Hill, where the limestone contains an abundance of very large shells of *Gervillia aviculoides*; but farther south, at Filey Brigg, they have coalesced, leaving some 35 ft. of strata, all in the gritty facies like the Passage Beds, but still with the large *Gervilliæ*.

On the Hackness outlier the Hambleton Oolite Series provides evidence of the earliest coral growth of the Corallian period in Britain. At the base of some 35 ft. of limestone are about 6–8 ft. of typical coral rag, which is best seen at Suffield and Silpho, but may extend as far south as Seamer Moor and as far west as Bickley or even Thornton Dale. In this early rag was already gathered together the well-known assemblage of corals, *Isastræa explanata*, *Thamnastræa concinna*, *Thecosmilia annularis* and *Rhabdophyllia phillipsi*, with their inevitable molluscan associates, *Lithophaga inclusa*, *Lima zonata*, *Chlamys nattheimensis*, *Exogyra nana*, *Lopha gregarea* and the ubiquitous *Cidaris smithii* (but not *C. florigemma*); and in addition a rich fauna of sponges and small brachiopods. Immediately above follow oolites with the typical giant *Gervillia aviculoides*, and *Cardioceras* recorded as *C. cordatum*. There can therefore be no doubt, either on stratigraphical or on palaeontological grounds, of the antiquity of this reef—or rather of the reef of which we see the broken fragments, with corals that have taken root amongst the debris. The only feature at all peculiar is the greater abundance than usual of small brachiopods and sponges. Nearly all the Corallian Calcispongiæ figured by Hinde in his monograph were recorded from here.

The determination of the stratigraphical position of the Hambleton Oolite Series in relation to the Corallian rocks of the South of England presents difficulties. The series is evidently to be regarded as a subdivision of the *cordatum* zone, for *Cardioceras cordatum* has been repeatedly recorded from it; and the passage just quoted from Fox-Strangways indicates the manner in which the limestone alternates with the normal sandstones of the Lower Calcareous Grit. On the other hand, such a development of limestones in the *cordatum* zone is known nowhere else in Britain. Some elements in the shell-bed fauna also are unique; in particular the highly characteristic *Gervillia aviculoides* of gigantic dimensions, and two species of *Trigonia*, *T. spinifera* d'Orb. and *T. blakei* Hudleston.

It is suggestive that from Calne, in Wiltshire, throughout North Wilts., Berks., Oxon., Bucks. and Beds., to at least as far as Upware, Cambridgeshire, the Berkshire Oolite Series rests non-sequentially and even unconformably upon the underlying *cordatum* and *præcordatum* zones; and that for forty miles it has at the base a pebble bed giving incontestable proof of erosion. I suggested in 1927 that in the South of England the *cordatum* zone is nowhere complete, and that the Hambleton Oolite Series may represent the missing strata. Until some more satisfactory correlation is put forward, it seems reasonable to suppose that the Yorkshire beds were laid down during the time-interval represented in the South of England by the Pebble Bed.

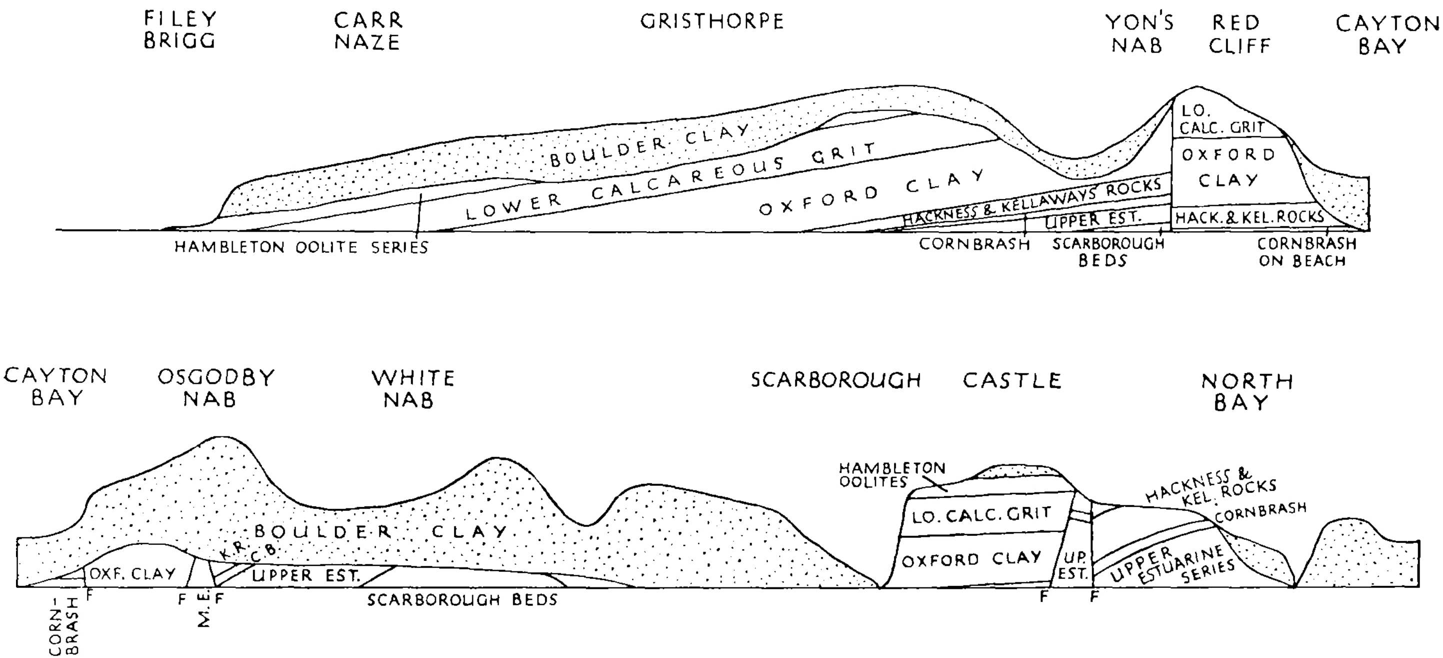


FIG. 76. Diagrammatic section along the cliffs from Filey to North Bay, Scarborough. Total distance 8 miles. The right-hand end of the lower section is separated from the left-hand end of the upper section in fig. 41 by about a mile of cliff composed of Boulder Clay. Vertical scale exaggerated. (After J. F. Blake, 1891, *P.G.A.*, vol. xii, p. 116.) (Included to show the general lie of the strata; the detail requires revision.)

Lower Calcareous Grit, 50–150 ft.

The Lower Calcareous Grit of Yorkshire is officially described as

'a yellow calcareous sandstone with doggers and cherty-bands passing down into softer sandstones, which become more shaly towards the base and gradually pass into the sandy shales of the Oxford Clay. Although the term "Grit" is applied to this rock, there is very little of it that would be called a grit among older formations, in fact many of the sandstones even of the Lower Oolite are harder and firmer and far more gritty.'[1]

This description, although perfectly accurate, conjures up a formation differing little from the Lower Calcareous Grit of the South of England. But in reality the Yorkshire rocks, as may be seen by reference to Pl. XVIII, are on the whole far harder and more massive, almost devoid of loose sand. The strongest bands of blue-hearted or blackish gritstone have few parallels in the South, excepting only in the Lower Calcareous Grit of the Weymouth district, where, however, the formation is so much thinner that the resemblance is not very striking.

In the Yorkshire Basin the Lower Calcareous Grit, as has been stated, is the first part of the Corallian Series to reappear on the north side of the Market Weighton Axis. Thence it is the most persistent member of the formation all round the basin. It attains its greatest development in the Hambleton Hills, where it caps the highest ridge of the escarpment, reaching a maximum height of 1,309 ft. above the sea in Black Hambleton. It also has a wide outcrop through the Tabular Range, extending as long tongues northward along the water-partings between the becks, far into the North York Moors. On the coast it is the only portion of the Corallian Series well exposed in the cliffs, under Scarborough Castle, in Red Cliff, Cayton Bay, and southward from Gristhorpe Cliff to Filey Brigg (fig. 76). Its great hardness and resistance to atmospheric weathering are directly responsible for the magnificent overhanging ramparts of Red Cliff and the jagged and vertical coast fronting the north side of the Carr Naze at Filey—some of the finest coastal scenery in Yorkshire.

Much of the Lower Calcareous Grit in Yorkshire is built up of sponge spicules, which are locally so abundant at certain horizons that they give rise to beds of chert. The species is *Rhaxella perforata* Hinde,[2] the same as that which builds up a large part of the Arngrove Stone and the similar cherty stone of Purton.

Measurements of the thickness vary greatly, from 60 ft. at the south end of the Howardian Hills and on the coast at Filey and Scarborough, to 150 ft. along the Tabular Hills and as much as 200 ft. at the north end of the Hambletons. It will be evident, however, from what has been said of the Passage Beds above and of the Oxford Clay below, that these figures include an indefinite amount of both older and younger strata in different places. In the Hambleton Hills, about Kepwick, as much as 45 ft. of limestones belonging to the Hambleton Oolite Series pass laterally into sandstones, which cannot be distinguished from the Lower Calcareous Grit. At Roulston Scar supposed Lower Calcareous Grit, resting directly on Hackness Rock, has

[1] C. Fox-Strangways, 1892, *J.R.B.*, p. 304.
[2] G. J. Hinde, 1890, *Q.J.G.S.*, vol. xlvi, pp. 54–61.

yielded a *Kosmoceras* of the *athleta* zone (see p. 360). Along most of the inland outcrop the boundaries, both above and below, are quite indefinite. The coast-sections alone present a clearly-defined Lower Calcareous Grit; but even there the collections of the earlier geologists show that at least a part of the grit is in the *præcordatum* zone of the Upper Oxford Clay. *C. præcordatum* identical with specimens found at Studley (Plate XXXVII, fig. 2) are represented in the old collections, in hard gritstone matrix.

In the cliffs below Scarborough Castle and from Cayton Bay to Filey Brigg the thickness is about 60–70 ft., and three fairly-well-marked divisions may be recognized. The highest 10–18 ft. consist of soft sandstone, weathering to a sand, with lines of huge, intensely hard doggers like cannon-balls. These 'Ball Beds' are especially conspicuous in the cliff of Scarborough Castle Hill, and some of the smaller balls closely resemble those in the Lower Calcareous Grit of Redcliff Point, near Weymouth, which Buckman mistook for derived blocks. Inside they sometimes contain nests of fossils, the commonest being *Chlamys fibrosa*, *Rhynchonelloidea thurmanni* and *Pinna lanceolata* Sow. (of which the type-specimen came from Oliver's Mount, Scarborough). On the platforms north-west of Filey Brigg, large double-valved shells of *Trigonia triquetra* Seebach may also be seen.

Under the Ball Beds is a 3–7 ft. block of very hard cherty calcareous gritstone, which is not only a conspicuous feature along the cliffs, jutting out abruptly beyond the softer strata above and below, but also caps many miles of the inland escarpment through the Tabular Hills, forming surface-spreads wide out of all proportion to its thickness.

The main mass of the Lower Calcareous Grit below consists of rough reddish or yellowish-brown grits and gritstones, with siliceous cement concentrated in bands and nodules. The whole weathers with a very irregular and jagged surface.

The fauna of the Lower Calcareous Grit seldom seems rich. *Cardioceras* and *Aspidoceras* are frequently quoted, but it is now difficult to obtain specimens adequate for specific determination. The commonest fossil, besides *Chlamys fibrosa*, is *Rhynchonelloidea thurmanni*, which is crowded in certain bands. It is curious that this Rhynchonellid has been recorded in the South of England at only two places—an old quarry at Catcombe, south of Lyneham, Wilts., now entirely obscured,[1] and in one of the borings in Kent.[2]

VI. EAST SCOTLAND

(a) **The Brora District of Sutherland**[3]

In Scotland the Corallian rocks are unfortunately not continuously exposed and little is known of any but the lowest portions. In the coastal plain north of Brora, where the bulk of the formation is presumed to occur, there are no exposures and much of the ground is covered with raised beach material and peat. There is an outlier south of the River Brora, in Dunrobin and Uppat Woods, but the surface is densely wooded and largely obscured by Drift (map, fig. 63, p. 366).

Where the low cliffs begin near Kintradwell, 2 miles north of Brora,

[1] Blake and Hudleston, 1877, loc. cit., p. 294. [2] See p. 439.

[3] Based on G. W. Lee, 1925, 'Geol. Golspie', *Mem. Geol. Surv.*, pp. 95–9, and personal observations.

Kimeridge Clay has already come in, but still farther north a gentle anticline near Loth brings up a series of sandstones which certainly belong mainly to the base of the Kimeridge formation, but may also in part represent the highest beds of the Corallian. Their position has been debated by several geologists. H. B. Woodward originally mapped them as Upper Corallian, but G. W. Lee considered them to be Kimeridgian and his conclusion was supported by Buckman tentatively identifying ammonites in Lee's collection as *Rasenia* and *Pictonia*. More recently, Dr. J. Pringle and Dr. M. Macgregor [1] have found between tide-marks a fossiliferous ledge which was previously overlooked, and from this they have collected a lamellibranch fauna (still unpublished) which they consider to have more affinities with the Corallian than with the Kimeridge Clay. This ledge lies off the mouth of a stream known as Allt na Cuile, about 1 mile south-west of Loth Railway Station, and it is only visible at low tide. Hitherto it is the only known exposure of beds that may represent the higher part of the Corallian formation.

The Lower Calcareous Grit is better known, from several exposures, but although the fauna is fairly abundant near the top, the downward limit within the Brora Sandstone (see p. 367) is purely a matter of conjecture.

The best exposure of the Lower Calcareous Grit in Sutherlandshire is at Ardassie Point, near the golf links, on the north side of the mouth of Brora River. No cliff-section exists, and a geologist first arriving there at high tide is disappointed to see only blown sand. The rocks emerge at low tide as several ledges running out to sea. They consist of seven bands of hard dark limestone separated by beds of carbonaceous shaly sandstone, the whole known as the ARDASSIE LIMESTONES. A total thickness of about 16 ft. is exposed. When the rock is broken up with a heavy hammer it is found to be highly fossiliferous, the most conspicuous members of the fauna being Cardiocerates and lamellibranchs. The Survey have recorded *Cardioceras* cf. *cordatum* (three forms), *C.* cf. *cawtonense*, *C.* cf. *excavatum*, *C.* cf. *maltonense*, *C.* cf. *rouilleri*, *C.* cf. *suessi*, and six unnamed forms, one figured by Buckman as '*Scoticardioceras*' *scoticum*;[2] also *Klematosphinctes vernoni* (?), a Perisphinctid of *biplex* type, and numerous lamellibranchs. The lamellibranchs belong almost entirely to common Corallian species, such as *Chlamys splendens*, *C. fibrosa*, *Camptonectes giganteus*, *Lima mutabilis*, *Oxytoma expansa*, &c., but there are a few unfamiliar elements, especially an abundant small *Grammatodon*.

The Ardassie Limestones strike inland in a westerly direction, and from the fossils found in surface rubble they are believed to cap Braambury Hill (see map, p. 366).

Another fossiliferous section in the Lower Calcareous Grit is afforded by a small road-metal quarry 320 yards south-west of Uppat House, on the wooded outlier south of the Brora River. About 8 ft. of sandstone are exposed, from which numerous impressions of more or less flattened Cardiocerates may be obtained, together with moulds of typical Corallian lamellibranchs. The bed is distinguished as the UPPAT CARDIOCERAS BED, and both by its fossils and by their state of preservation, it bears rather a striking resemblance to the Arngrove Stone. Among the many species common to the two is a small clavellate *Trigonia*.

The species of *Cardioceras*, of which the Survey record eight, are the

[1] 1930, *P.G.A.*, vol. xli, p. 81.

[2] *T.A.* 1925, pl. DXCIX.

same as those in the Ardassie Limestones, and the two deposits cannot be of very different dates. The lamellibranchs constitute a poorer assemblage, however, and the lithology is quite different. Lee considered that the Uppat *Cardioceras* Bed was probably rather earlier in date of formation, and suggested that it might lie on the horizon of a fossil bed in the upper part of the Brora Sandstone east of the bridges at Brora, mentioned by Judd but no longer open to view.

The absence of fossils in the bulk of the Brora Sandstone, below these *Cardioceras* horizons, precludes the drawing of any boundary line between the Lower Calcareous Grit and the Oxford Clay. The sandstone was described in the previous chapter because it forms a part of the Brora Arenaceous Series, of which the lower divisions are certainly of the age of the Oxford Clay; but the upper portions of the Brora Sandstone in the restricted sense are just as likely to correspond with some of the little-known basal portion of the English Lower Calcareous Grit.

A feature of the Sutherland Lower Calcareous Grit which should be mentioned is the lack of exact agreement between the ammonite species and their English prototypes. 'Ardassie', wrote Buckman, 'reveals little correspondence with the fauna of the Yorkshire beds. Its species, with few exceptions, appear to be new to English strata, but they have a likeness to Russian forms figured by Ilovaïsky.'[1]

(b) **Ross-shire**[2]

At Port-an-Righ, Ross-shire, both of the shore-sections between tidemarks, already referred to in connexion with the Oxford Clay (above, p. 369), are continued up into Corallian Beds, and they show (although obscurely) strata higher in the sequence than any that can be definitely ascribed to the Corallian in Sutherland. The northern section shows the highest beds, those near the top in the southern (Cadh-an-Righ) locality being nearly vertical and unfavourably displayed for fossil-collecting.

The highest Jurassic rocks seen are the PORT-AN-RIGH SANDSTONE, about 60 ft. of dark, shaly-weathering sandstones, with some hard bands and occasional small doggers. Fossils are sparsely distributed, but the Survey succeeded in collecting, besides a few indeterminative lamellibranchs and a Cardiocerate, three highly important Perisphinctids. Buckman identified them as *Perisphinctes antecedens*, *P. martelli* ('cf. *biplex*') and *P.* cf. *stenocycloides* (Neum.),[3] which indicate a date at least as late as the Berkshire Oolite Series.

The beds in which the *Cardioceras cordatum* fauna has been found consist of 7 ft. of soft, dark sandstone with nodules and nodular ribs of ironstone, called by Buckman the PORT-AN-RIGH IRONSTONES. From them the Survey collected the true *Cardioceras cordatum* (Sow.), *C. excavatum* (Sow.), and three other Cardiocerates, with another ammonite referred tentatively to *Klematosphinctes vernoni* (Bean-Phil.). Below are the thick shales of the *præcordatum* zone of the Oxford Clay. It is not justifiable to assume, however, that the Lower Calcareous Grit is reduced to 7 ft. in thickness, for it may also include an indefinite quantity of the Port-an-Righ Sandstones, below the level (not stated) at which the Perisphinctids were found.

[1] S. S. Buckman, 1925, *T.A.*, vol. v, p. 49. [2] G. W. Lee, 1925, loc. cit., pp. 100–3.
[3] S. S. Buckman, 1925, *T.A.*, vol. v, p. 49.

VII. THE HEBRIDEAN AREA[1]

The impossibility of drawing a definite boundary between the equivalents of the southern Lower Calcareous Grit and Oxford Clay within the Cardioceratan deposits is as manifest in the Inner Hebrides as in Sutherland. The *cordatum* fauna of the Lower Calcareous Grit occurs in three places, in the promontories of Strathaird and Trotternish, Skye, and in the Isle of Eigg. In Strathaird it is succeeded by an assemblage of Perisphinctids correlating with the Berkshire Oolite Series, and the beds containing these are overlain unconformably by Upper Cretaceous sediments and Tertiary basalts; in Trotternish, however, a complete sequence of Corallian and Lower Kimeridgian shales may be expected, even though not fully exposed.[2] Sufficient detailed collecting has not yet been undertaken to show where the *præcordatum* fauna of the Upper Oxford Clay gives place to the true *cordatum* and *excavatum* fauna of the Lower Calcareous Grit, and the Survey have found it impracticable to separate the equivalents of the two formations, either on their maps or in their descriptive memoirs.

The Skye and Eigg occurrences were described in the previous chapter in connexion with the Oxford Clay (p. 371). In Strathaird, Skye, the beds usually called Oxford Clay, which consist of some 200 ft. or more of dark sandy or micaceous shales, passing down into 80 ft. of sandstones, occur in a syncline running along the centre of the promontory. Owing to the overstep of the basalts across the syncline the highest sedimentary horizons preserved come to the surface along the sides of the central valley of Abhuinn Cille Mhairè. Here Wedd found a number of ammonites of obvious Berkshire Oolite affinities, identified as *Perisphinctes* ? *variocostatus* (Buckl.), *P.* ? *pickeringius* (Y. & B.), ? *P. suevicus* Siem., *P.* ? *mogosensis* Choffat, and *Cardioceras* cf. *quadratum* (Sow.).

At lower levels, in the cliffs north of Elgol, a *Cardioceras* fauna similar to that of the Ardassie Limestones and the Uppat *Cardioceras* Bed is said to occur to the base of the series. The forms recorded by Messrs. Wedd and Kitchin are as follows: *Cardioceras cordatum* (Sow.), *C. cordatum* (d'Orb.) *pars*, *C. excavatum* (Sow.), *C.* ? *funiferum* (Phil.), *C.* ? *nikitinianum* Lahusen, *C. quadratoides* (Nikitin), *C.* ? *quadratum* (Sow.), *C.* cf. *rotundatum* (Nikitin), *C. rouilleri* Lahusen, *C. suessi* Siem., *C. tenuicostatum* (Nikitin), *C. vertebrale* (Nikitin): an assemblage which appears to be a mixture of forms of the *cordatum* and *præcordatum* zones.

At Laig Bay in the Isle of Eigg, in a section exposed on the foreshore at low tide, described in the preceding chapter with the Oxford Clay (p. 372), a definite Lower Calcareous Grit fauna occurs in the dark-grey shales of Oxford Clay facies. Here Barrow found *Cardioceras cordatum* (two forms, coarsely and finely ribbed), *C. excavatum* and *Aspidoceras perarmatum*, associated with some typical Corallian lamellibranchs, the assemblage being very much the same as that of the Ardassie Limestones. No higher strata comparable with the *Perisphinctes* beds of Strathaird appear to be exposed.

An indication of the highest ammonite horizons of the Corallian (Upper

[1] Based on C. B. Wedd, 1910, 'Geol. Glenelg, Lochalsh and S.E. Skye', pp. 128–31; and G. Barrow, 1908, 'Geol. Small Isles of Inverness', pp. 26–8; *Mems. Geol. Surv.*

[2] See Mr. M. MacGregor's find of Lower Kimeridge Clay at Kildorais, NW. of Staffin, mentioned in the next chapter, p. 478.

Calcareous Grit), with *Prionodoceras* and *Dichotomoceras*, has recently been found in North Trotternish, Skye, by Mr. Malcolm MacGregor. The downward relations of the beds have not been seen, but upward they are continuous with a series of shales containing *Pictonia* and *Rasenia*, and so the occurrence is described in Chapter XIV, in connexion with the Kimeridge Clay (p. 478).

VIII. KENT[1]

The concealed province of Corallian rocks beneath the Weald is one of the most important in Britain. In it there is an exceptionally thick development of the upper divisions—Upper Calcareous Grit, Glos Oolite and Osmington Oolite Series. The lower divisions, the Berkshire Oolite Series and the Lower Calcareous Grit, on the other hand, are poorly developed and it is difficult to bring them into line with the thick Dorset sequence. This part of the succession is more comparable with the Lower Corallian Beds on the north of the Paris Basin, in Normandy and the Boulonnais, than with those of any other English district.

The complete succession was penetrated in four borings at Dover, at Brabourne, 4 miles east of Ashford, at Elham, and at Folkestone, but of these only the first two yielded complete information. Several borings entered the Corallian Beds but did not reach the base, while a number of others penetrated them in the district where they are incomplete, the upper portions having been removed by the Cretaceous denudations.

The average width of the buried outcrop is 3 miles. It runs from the coast under Dover to Chatham and Rochester, maintaining for the greater part of the distance a nearly straight course. The easterly attenuation against the London landmass is not nearly so marked as in the other formations, the total thickness being over 300 ft. at Brabourne and still 270–80 ft. at Dover.[2] These thicknesses are rivalled nowhere else in England outside the Yorkshire Basin.

The most conspicuous and constant feature of the Kentish Corallian Beds is a 125–35 ft. mass of white coralline limestones. In general it doubtless corresponds with the great central block of white coralline or oolitic limestones elsewhere, the Osmington Oolite Series; but it is twice as thick as the Osmington Oolite Series at its thickest in Dorset or in Yorkshire, excepting only at North Grimston. Other features suggestive of North Grimston are remarkably thick masses of coral rag—one as much as 33 ft. thick at Dover—and the rag facies recurs at all levels throughout.

It is interesting that this exceptional development of coralline limestones should be found close to the margin of the London landmass, against which all the other formations of the Jurassic thin out, while in Dorset, far from any shore-line, the oolites are only half as thick and contain no coral rag. It will be remembered that the great development of rag at North Grimston occupies an analogous position, close to the Market Weighton Axis; and that it and the superjacent portions of the Corallian Series, alone of all the Jurassic rocks, thicken towards the axis before being finally overstepped. The circumstances

[1] Based on G. W. Lamplugh and F. L. Kitchin, 1911, loc. cit., and Lamplugh, Kitchin and Pringle, 1923, loc. cit.

[2] The figures do not include the ironshot marls of the *præcordatum* zone, which the Survey classed as Lower Corallian.

therefore suggest that at both places we are dealing with actual fringing reefs that grew close to the shore.

It was remarked that the expansion of the coralline oolite and rag at North Grimston might be in part accounted for by the Berkshire and Hambleton Oolite Series taking on a coralline facies as they approach the land. The same explanation probably applies in Kent, where there is a poor show of rock that can be definitely assigned to those beds, and nothing at all comparable with the thick Nothe Clay and Bencliff Grit of Dorset.

Another analogy with North Grimston is provided by the thickness of the strata above the main mass of limestones—amounting at North Grimston to 80 ft. At Dover there were 96 ft. of such beds, while at Brabourne they reached the astonishing thickness of 162 ft. No such development of Upper Calcareous Grit and Glos Oolite Series is known elsewhere in the British Isles, but better parallels can be found on the Continent. All the principal types of rock in other parts of England are represented, however, the most characteristic being the ironshot oolite or Westbury Iron Ore, with its fauna of *Ringsteadiæ*.

It will be seen that the detailed correlation of the Kentish Corallian Beds with those of other parts of England presents special difficulties. The difficulties might not be insuperable were the rocks exposed in continuous cliff-sections like those in Dorset, but with no more information than could be obtained from bore-holes to work upon, no very detailed correlation is possible.

SUMMARY OF THE CORALLIAN ROCKS IN KENT

Upper Calcareous Grit and **Glos Oolite Series,** max. 162 ft.

The top of the Corallian Beds at Brabourne was taken above a 4–6 ft. band of 'greenish-grey glauconitic sandy mudstone with black specks', below which were about 14 ft. of 'blue-grey marly clay' and then ironshot oolite like the Westbury Iron Ore. The ore at Brabourne was only 3 ft. thick, all the rest of the succession down to the top of the main coralline limestones consisting of marls and marlstone or smooth argillaceous limestone, like a vastly expanded Sandsfoot Clay. In this were presumably included not only argillaceous equivalents of the Sandsfoot Grits, but also, judging by the fossils, strata of the age of the *Trigonia clavellata* Beds; for although little is known of the fauna of the Sandsfoot Clay, it is certainly not as rich as this would appear from the lists to be. The only possible correlation of the lower part of these upper beds is with the *T. clavellata* Beds, or the slightly later fossiliferous beds of Glos, in Normandy.

At Dover the succession was somewhat more varied and the lower portions were lithologically more suggestive of the *Trigonia clavellata* Beds. Here the Westbury Iron Ore—'millet-seed ore . . . small shining brown globules of iron carbonate crowded in a slightly clayey or loamy matrix'—was 16 ft. thick and yielded a specimen of *Ringsteadia*. Seven feet of clay above it also contained the ironshot grains, and above that were 26 ft. of alternating 'oolitic limestone, calcareous claystone, muddy grit, bands of marly clay and layers of pisolitic rubble'. These highest beds seem to have no counterparts in other regions in England; but the equivalent of the Westbury Iron Ore in the Boulonnais, the Oolithe d'Hesdin-l'Abbé, is 33 ft. thick and is succeeded by some 16 ft. of hard marly limestones called the Caillasses d'Hesdigneul, which in the valley of the Liane are replaced by calcareous sandstone (the Grès de Wirwignes).[1]

Trigonia clavellata Beds? (Pars.), **Osmington Oolite Series, Berkshire Oolite Series** (Pars.), 125–35 ft.

The highest 20 ft. of the beds grouped together as 'Corallian Limestones' by the Survey were described at Dover as 'creamy or greyish, soft, sandy limestone, with occasional layers of flaggy calcareous sandstone and incoherent sandy shale; and with rubbly bands mainly composed of rolled bits of shell and ooliths and containing many gasteropods, and *Pecten*, *Lima*, *Ostrea*, &c.'. Below this came 33 ft. of coral rag in 'irregular tabular masses', then 12 ft. of 'creamy-grey soft calcareous stone of sandy texture, containing few corals, but many shells and *Cidaris* spines', separating the upper coral rag from another 60 ft. of 'coral-limestone in hard tabular masses set in a softer calcareous matrix, with bluish-grey partings of calcareous silt': this last contained abundant Terebratulids.

At Brabourne corals were more or less common through the whole thickness of the limestones—134 ft. As already remarked, no such extensive development of coral rag as this is known elsewhere in England, for it exceeds even that at North Grimston; nor is there anything at all comparable with it either in the Boulonnais or in Normandy. If there were cliff-sections in Kent we might be able to trace out the coral rags at various levels into their contemporaneous shell-beds, or normal, non-coralline deposits, and so date them. But since coral rag of whatever age within the Corallian Series carries with it the same facies-assemblage, it is, as we have seen in Wiltshire and in Yorkshire, impossible to assign a date to any particular coral rag from internal evidence alone. The most we can hope to do is to fix limits to the period during which locally the coral régime endured.

Even if we are right in assigning some of the argillaceous shelly beds above the coral rag to the *Trigonia clavellata* Beds, there is still no reason why a considerable portion of the coral rag should not also be developed on the horizon of part of the *T. clavellata* Beds; for in Dorset they have every appearance of being condensed. It seems improbable that coral growth would have stopped short in Kent while the Steeple Ashton reef was growing in Wiltshire, and when, as we have shown reason to believe, rag was still being formed in the south of the Yorkshire Basin. The less coralliferous uppermost 20 ft. of the limestones at Dover, in fact, seems from the description more like *T. clavellata* Beds than like any part of the Osmington Oolite Series in other parts of England.

Berkshire Oolite Series (Pars.), **Lower Calcareous Grit.**

The lower limit of the Berkshire Oolite Series (the important plane of transgression at the base of the *martelli* zone) can be fixed with more confidence. This lower part of the succession seems to bear a strong resemblance to that on the coast of Normandy. There the Osmington Oolite Series (Oolithe de Trouville) rests directly on a thin representative of the Berkshire Oolite Series, in the form of 10 ft. of shelly *Trigonia hudlestoni* Beds (lime-

[1] P. Pruvost and J. Pringle, 1924, *P.G.A.*, vol. xxxv, pp. 34–5.

stones and marls) crowded with the usual lamellibranchs and Perisphinctids, and recalling very forcibly the *T. hudlestoni* Beds of England. In addition the shelly limestones are locally ironshot, thus resembling in appearance the Elsworth Rock, on approximately the same horizon.[1]

In Kent, the two most complete records (Dover and Brabourne) are rather obscure in this part of the section, but some of the more recently described borings are highly suggestive. At Dover the coralline oolite was immediately underlain by 11 ft. of 'dark blue clay with massive marly structure, in places indurated to marlstone, with bands of black rather sandy clay; and containing large crushed plicatiloid ammonites, casts of *Trigonia* and other lamellibranchs'. This is suggestive of the Nothe Clay; but 27 ft. of clay and claystone followed below before the ironshot oolite elsewhere at the top of the Oxford Clay was reached, and these beds did not yield sufficient fossils to enable their age to be settled.

At Fredville the Wealden Beds rest directly on strata below the main coralline limestones: 8 ft. of 'irregularly indurated pisolitic marlstone, passing down into 6 ft. of dingy, grey, impure, oolitic limestone with soft rubbly bands'; and below that were 12 ft. of 'compact blue-grey limestone, sparsely oolitic, with marly bands, *Gryphæa*, &c.'. These beds are suggestive of the Urchin Marls and *Trigonia hudlestoni* Limestones of Highworth, which, where they are thickest, do not contain the characteristic *Trigoniæ*; in fact the description of the Fredville strata applies exactly to some of those passed through in depth in the Red Down Boring, Highworth. Unfortunately these beds (like the Nothe Clay) were poorly fossiliferous and they can only be correlated with the Berkshire Oolite Series on stratigraphical and lithological grounds. They rested upon a bed which, by reason of its peculiar appearance, was easily recognized in a number of borings and served as a very useful datum-line—it was encountered at Fredville, Snowdown Colliery, Bere Farm, Brabourne, Chilham, Chilton and probably also at Guildford. This has already been described, in the preceding chapter, as forming the top of the Oxford Clay. It consisted of hard grey marlstone, packed with conspicuous dark-coated fossils, and its rich Cardiocerate and Peltocerate fauna proclaimed it to belong to the *præcordatum* zone. Above it no Cardiocerates of any kind were found, but in it and below it they were abundant.

No trace of the *cordatum* fauna was detected, though the presence of *C.* cf. *excavatum* (Sow.) and *Rhynchonelloidea thurmanni* (Voltz) in the dark-coated-fossil bed, and of *Perisphinctes* cf. *variocostatum* (Buckland) with abundant *Chlamys fibrosa* immediately below it, suggests that it may have been accumulated during a long period of time, perhaps spanning the *præcordatum*, *cordatum* and *martelli* hemeræ. In the absence of ammonites of the *cordatum* zone we must suppose that there is a non-sequence comparable with that at Quainton, Bucks., but no pebble-bed or other signs of erosion were found at the base of the presumed equivalents of the *martelli* zone.

[1] W. J. Arkell, 1930, *P.G.A.*, vol. xli, p. 401.

CHAPTER XIV

KIMERIDGE CLAY

Zones (Plates XXXIX, XL).	*Dorset Strata.*	*South Midlands.*
(Zonally unclassified)	Hounstout Marls Hounstout Clay *Rhynchonella* Marls and *Lingula* Shales	absent
Pavlovia pallasioides [1]		Swindon and Hartwell Clays with Lower Lydite Bed at base
Pavlovia rotunda [2]	*Rotunda* Nodules Crushed Amm. Shales	
Pectinatites pectinatus	400 ft. of clays with stone bands; Oil Shale 150 ft. from base	Shotover Grit Sand
Virgatosphinctoides nodiferus [3]		*Wheatleyensis* Nodules
Virgatosphinctoides wheatleyensis [4]		
Subplanites spp.[5]		absent
	YELLOW LEDGE	
Gravesia irius [6]	Lower clays of Hen Cliff 60 ft.	Generally absent
Gravesia gravesiana [7]		
Aulacostephanus pseudomutabilis	MAPLE LEDGE Clays above and below The Flats, 120 ft.	Clays with *Exogyra virgula*[9] and vertebrates
Aulacostephanus yo [8]		
Pararasenia mutabilis	Clays with layers of *Ostrea delta* towards base	Clays with layers of *Ostrea delta* towards base
Rasenia cymodoce		
Pictonia baylei	*Rh. inconstans* Clay	clay (absent from Oxford)

[1, 2] The *pallasianus* zone of Chatwin and Pringle (1922), divided by Kitchin and Pringle (1923) into the zones of *Pallasiceras pallasianus* above and *P. lomonossovi* below; revised by Neaverson in 1924 and 1925. *Pavlovia* Ilovaïsky, 1917, includes *Pallasiceras* and *Holcosphinctes*, according to Ilovaïsky (1923, *Bull. Soc. Nat. Moscou*, vol. ii, p. 342) and Spath (1931, *Pal. Indica*, N.S., vol. ix, pp. 470–1).

[3, 4] The *Virgatites* zone of Salfeld (1913) and later writers until Neaverson showed (1924–5) that the true Russian Virgatitids are unrepresented at this level. According to Dr. Spath, the *Virgatites* zones are at a higher horizon than the *Pavlovia* zones; and, in fact, *Provirgatites scythicus* (Michalski, plate XL, fig. 3) occurs in the basal Portland Sand of Hounstout Cliff. Dr. Spath informs me that he considers *Virgatosphinctoides* synonymous with *Subplanites*, but until a further study of these extremely perplexing ammonites has been published, I retain the names current hitherto.

[5] *Subplanites* Spath, 1925, *Mon. Hunt. Mus. Glasgow*, No. 1, p. 120; type '*Virgatosphinctes*' *reisi* Schneid (see T. Schneid, 1915, *Geol. u. Pal. Abhandl.*, vol. xvii, pp. 305–414).

[6, 7] Introduced by Salfeld (1913). Involute *Gravesiæ* of the *gravesiana* and *irius* groups appear to be unrepresented in any collections from this country, but crushed forms more evolute than these occur in the lower part of Hen Cliff, Kimeridge (two specimens found, 1932, by Dr. Spath, one in the writer's company; Salfeld stated that he found 'numerous examples').

[8] Apparently never yet found in this country, but retained in accordance with Salfeld's zonal scheme.

[9] Mr. L. R. Cox (1930, *Ann. Mag. Nat. Hist.* [10], vol. vi, p. 298) has pointed out that the name *Exogyra virgula* (Defrance, 1821–31) should lapse as a synonym of *E. striata* (William Smith, 1817); but as there is no other *E. virgula* having prior claim to the name, and as it has become so firmly established in the literature of more than a century, I propose to sacrifice precision for intelligibility and retain it here. The case for *Ostrea delta* Smith is different, because *O. deltoidea* Lamarck is a Cretaceous species.

I. DORSET

(a) The Isle of Purbeck: Chapman's Pool and Kimeridge[1]

THE structural backbone of both the Isle of Wight and the so-called Isle of Purbeck is the anticlinal flexure described in Chapter III, which strikes east and west and plunges gently to the east. In the Isle of Wight the lowest strata are the Wealden Beds of Brixton Bay on the west coast. From beneath these, somewhere under the intervening sea, rise the Purbeck and Portland Beds of Purbeck; and on the west coast of the peninsula is seen the lowest stratum brought to the surface by the anticline, the Kimeridge Clay (map, fig. 77, p. 442).

The Kimeridge Clay of the classic area of Purbeck crops out along the south-west side of the promontory as a narrow strip, measuring about 6 miles in length and never much exceeding 1 mile in width. It gives rise to a small but characteristic oasis of green clay-land, encircled behind by the lofty, steep-fronted escarpment of the Portland Stone, which rises well above the 500 ft. contour and effectively shuts off the coastal lowland from the rest of the 'island'.

The sea frontage from Chapman's Pool in the east to Kimeridge and Brandy Bays in the west consists of low cliffs of grey and black, shaly clay with thin mudstone bands. While in general the erosion of the sea is rapid, keeping the cliffs vertical and free from talus, the mudstone or cementstone bands offer a stubborn resistance, the harder ones, often repeated by small faults, running out to sea as treacherous ledges for more than a mile from the shore. Among mariners, the Kimeridge Ledges have justly deserved an evil reputation.

More famous than the ledges, however, is the 'Kimeridge Coal', a bituminous oil-shale, which for centuries has been dug along the cliffs and put to diverse uses.

In the south-east corner of the semicircular bay of Kimeridge the surface of the fields is scarred by a number of irregular mounds, overgrown with brambles. Near by a curious round building known as Clavell's Tower stands on the summit of Hen Cliff overlooking the eastern entrance to the bay, while on the beach beneath a pile of shaped stones is to be seen at the point marked 'pier' on the map (Pl. XX). These are the last vestiges of the Kimeridge alum industry, started at the beginning of the eighteenth century by Sir William Clavell, who built the neighbouring Smedmore House. Coker records [2] that that gentleman 'being ingenious in diverse faculties, put in tryall the makeing of allom, which hee had noe sooner, by much cost and travell, brought to a reasonable perfection, but the farmers of the allom workes seized to the king's use; and, being not soe skillfull or fortunate as himselfe, were forced with losses to leave it offe, and soe nowe it rests allmost ruined'. But 'Sir William Clavile, who[m] one disaster dismayed not' instead set up

[1] The spelling KIMERIDGE was used by H. B. Woodward in *The Jurassic Rocks of Britain*, by Damon in *The Geology of Weymouth and the Coast of Dorset*, and by most earlier authorities. The new form KIMMERIDGE was not heard of before Webster and Buckland introduced it in the nineteenth century and seems to have no justification. According to Hutchins (who in his great work on Dorset never deviated from KIMERIDGE) the spelling was KYMERICH in 1293 and CAMERIC in Domesday Book (Hutchins, *History of Dorset*, 2nd ed., 1774, p. 193).

[2] Rev. Coker, 1732, *A Survey of Dorsetshire*, p. 46, London.

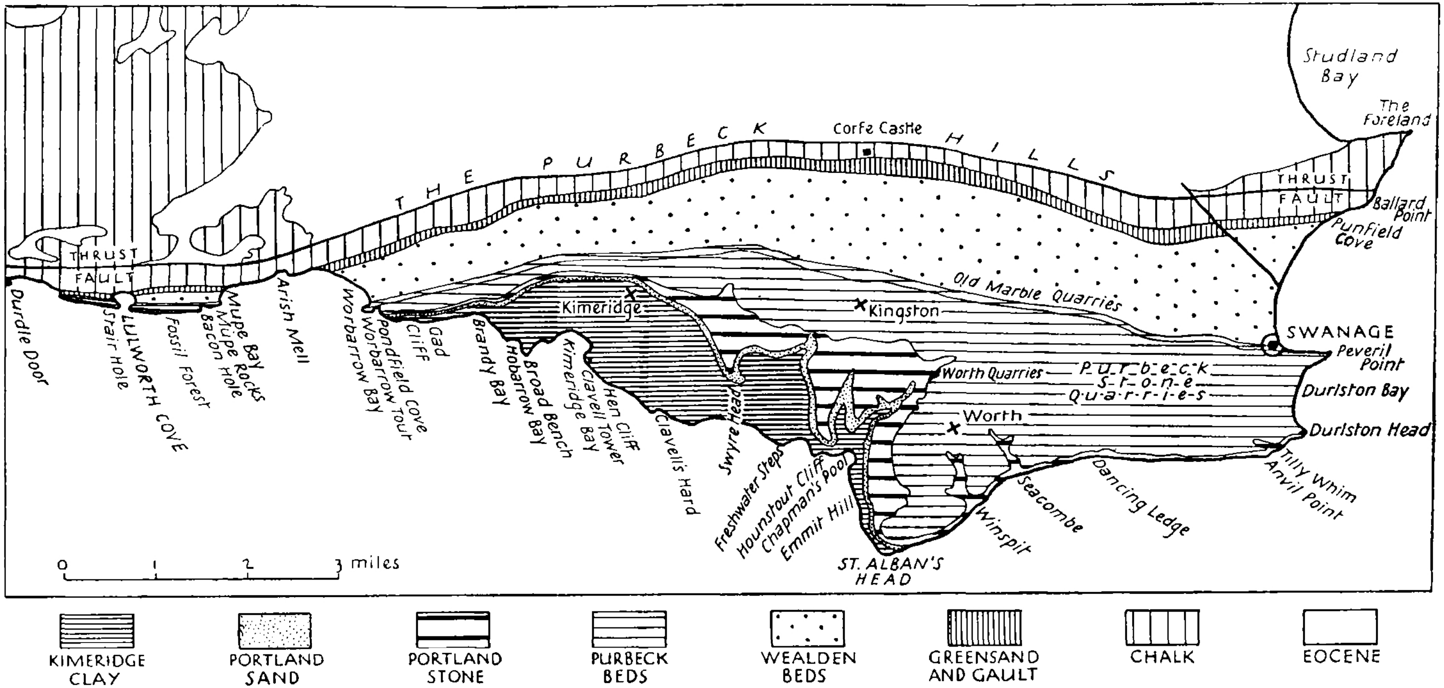


FIG. 77. Sketch map of the 'Isle' of Purbeck, to show the positions of the type-sections of the Kimeridge Clay, Portland Sand and Purbeck Beds.

works for making glass and for boiling the sea-water to extract salt, using the Kimeridge oil-shale as fuel. This earned for it the name 'coal', but Coker records that 'in burning it yields such an offensive savoure and extraordinarie blacknesse, that the people labouring about those fires are more like furies than men'. Notwithstanding, it is still used as a substitute for coal in the cottages round about, constant familiarity apparently enabling the local nose to accustom itself to the strong fumes of sulphuretted hydrogen given off during combustion.

By the middle of the eighteenth century ruins of buildings and heaps of ashes were all that remained of Sir William Clavell's projects, but in the latter half of the nineteenth century the bituminous shale was again exploited for the extraction of oil. The residual matter left after distillation of the oil and gas was sold as a deodorizer, decolorizer, disinfectant and manure. A ton of the shale was supposed to produce 7½ gallons of naphtha, 10 gallons of lubricating oil, 1 cwt. of pitch, and some fine white paraffin wax and gas.[1]

Owing to the high content of sulphur (6–7 per cent.) and to the thinness of the workable seam, however, the cost of extraction has always been too heavy to allow the projects to become an economic success, and no satisfactory method of extracting the sulphur having yet been found, the present century has seen the works totally abandoned.

The coal was described by Sir A. Strahan as 'a highly bituminous layer of shaly stone, about 2 ft. 10 in. thick with its partings, and of a dark brown colour, whence its local name of "blackstone". It breaks with a conchoidal fracture and readily ignites, burning with a bright flame and an offensive smell, and leaving a copious grey ash.' In 1917–18 the Government sank a series of test holes around Kimeridge in order to estimate the total yield of the field should exploitation become necessary owing to the shortage of other oils.

The thickness of Kimeridge Clay visible between Chapman's Pool and Brandy Bay west of Kimeridge is about 700 ft.,[2] although the three lowest zones, those of *Pictonia baylei*, *Rasenia cymodoce* and *Pararasenia mutabilis*, are not exposed. The total thickness of clay present, therefore, may amount to more than 800 ft.

The upper zones rise from beneath the Portland Stone and Sand along the west side of St. Alban's Head, where they are, however, largely concealed by extensive landslips (fig. 80). After a temporary incursion inland, along two deep valleys at Chapman's Pool, they strike the coast once more in the magnificent Hounstout Cliff, which rises 501 ft. above the sea (Pl. XIX). As the Portland Stone forms only a capping, 50 ft. thick, to this cliff, the lower slopes are relatively free from slipped masses, and provide the best section of the uppermost zones of the clay in Dorset.

The level at which the top of the Kimeridge Clay should be drawn is debatable, and a question analogous with the upper boundary of the Oxford Clay. Just as by time-honoured usage the Lower Calcareous Grit is classed as a part of the Corallian, although palaeontologically it is no more than a sandy upper part of the Oxford Clay, and the arenaceous facies undoubtedly begins at different horizons in different places, so the Portland Sands grade down imperceptibly into the Kimeridge Clay, from which there

[1] A. Strahan, 1918, 'Spec. Repts. Min. Resources', vol. vii, p. 27, *Mem. Geol. Surv.*

[2] As much as 930 ft. has been estimated by some authors, but this is certainly excessive.

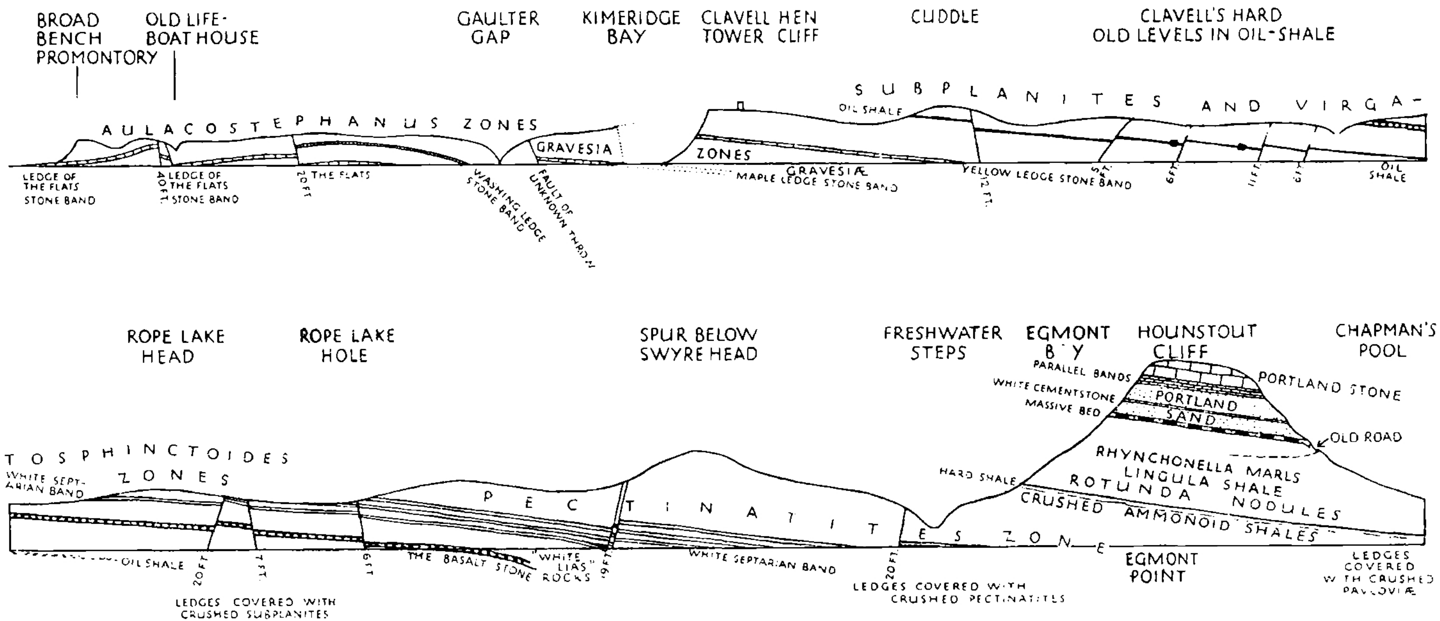


FIG. 78. Section along the cliffs of Kimeridge Clay from Broad Bench Promontory, near Kimeridge, to Chapman's Pool. Total distance 4⅓ miles. Horizontal scale 3·4 in. = 1 mile, vertical scale just under 1 inch = 500 ft. (Outline, stone bands and faults after Strahan, 1898, 'Geol. Isle of Purbeck and Weymouth', *Mem. Geol. Surv.*, pl. x; faults with a throw of less than 5 ft. omitted. The two faults near the lifeboat house have a combined throw of 40 ft.).

is usually little or nothing to distinguish them palaeontologically. The only comparatively constant datum is the base of the Portland Stone.

Fitton originally placed the top of the Kimeridge Clay 120 to 140 ft. below the Portland Stone, assigning the intervening beds to the Portland Sand,[1] and this plan was adopted by Sir A. Strahan in his Memoir on the Geology of the Isle of Purbeck.[2] Blake chose a datum about 100 ft. lower, giving the Portland Sand 244 ft.,[3] while H. B. Woodward preferred 179 ft., grouping the lowest 40–50 ft. as 'Passage Beds'.[4] Then when the deep borings in Kent proved Portland Stone resting directly on clay, it was believed that the Portland Sands of Dorset were there represented by clay. Although no direct palaeontological evidence of this was obtained, the idea gained credence to such an extent that in 1925 Dr. Neaverson wrote:

'There seems to be no doubt that the use of the term "Portland Sands" must be discontinued so far as the sandy beds below the Portland Stone Series of Dorset are concerned, since their faunal affinities are Kimeridgian rather than Portlandian and the sandy facies of Dorset and Bucks is represented by clays in the Kent borings. The ammonites from this horizon are, however, practically unknown . . .'[5]

The following summer, three years before his death, S. S. Buckman visited Chapman's Pool and, with the help of Mr. C. H. Waddington, began a study of Hounstout Cliff. He published a description of the beds below the Portland Stone, recording the fossils obtained *in situ*, and the result was to restore the Portland Sands to their original status, given them by Fitton and the early surveyors.[6]

In a band of white argillaceous cementstone, about 60–65 ft. from the top of the Portland Sands, specimens of *Leucopetrites* were found, a genus characterizing the lower levels of the Portland Stone (Behemothan Age) at Long Crendon, Bucks. Thus at least the upper half of the Sand (the St. Alban's Head Marl) belongs properly with the Portland Beds.

Below the level at which *Leucopetrites* was found are about 30–40 ft. of sandy marls (the Emmit Hill Marls, see below, p. 491), and below them again the most prominent band in Hounstout Cliff—a 5 ft. block of massive yellow and blue-grey sandstone, which Buckman named the Massive Bed. Fallen blocks can be easily recognized, and Buckman found in them ammonites with quadruplicate ribbing which he identified with the Russian *Virgatites scythicus* and *V. pallasi* (Michalski).[7] This was unexpected, since the Russian *Virgatites* zone was originally believed by Salfeld and others to be represented in England by what have been known since Neaverson's revision as the *Virgatosphinctoides* zones. Of the two specimens figured by Buckman, there seems no doubt of the identity of at least '*V.*' *scythicus* with the Russian form; but this group (as may be seen from Michalski's figures) has a different ontogeny from the true *Virgatites*, and it has for some years been separated under the generic name *Provirgatites*. True *Virgatites* still remains to be found.

[1] W. H. Fitton, 1836, *Trans. Geol. Soc.* [2], vol. iv, p. 212.
[2] A. Strahan, 1898, 'Geol. Isle of Purbeck', p. 60, *Mem. Geol. Surv.*
[3] J. F. Blake, 1880, *Q.J.G.S.*, vol. xxxvi, p. 195.
[4] H. B. Woodward, 1895, *J.R.B.*, p. 192.
[5] E. Neaverson, 1925, *Ammonites of the Upper Kim. Clay*, p. 43.
[6] S. S. Buckman, 1926, *T.A.*, vol. vi, p. 30.
[7] *T.A.*, pl. DCLXXV: and see Michalski, 1890–4, *Mém. Comité géol. Russie*, vol. viii, pl. v, figs. 6, 7.

The Massive Bed was the datum selected by Sir A. Strahan in his Memoir on the Isle of Purbeck at which to draw the arbitrary line of separation between the Portland Sands and Kimeridge Clay, and since it corresponds best with the base of the vague division established by Fitton, the originator of the term Portland Sand, there seem good historical reasons for following suit. Although Buckman and H. B. Woodward preferred a still more arbitrary invisible line 40–50 ft. lower, the Massive Bed has been adopted as the basement bed both by Mr. L. R. Cox in his palaeontological studies[1] and by Mr. M. P. Latter in his petrological account[2] of the Portland Beds, and its claims are accepted here.

SUMMARY OF THE SUCCESSION IN THE CLIFFS FROM CHAPMAN'S POOL TO KIMERIDGE[3]

Pavlovia Zones (+ ?).

The highest 120–130 ft. of the Kimeridge Clay according to this definition have so far yielded only a few ill-preserved ammonites, badly crushed. Dr. Neaverson recorded 'ammonites similar to *H. pallasioides* (though in a poor state of preservation)',[4] and the lower portions of the beds contain a number of other fossils, especially brachiopods. Buckman recognized four subdivisions (of which he included the highest in the Portland Sand). For the purposes of recording fossils it is essential that these should have names. Since the beds are best exposed in the face of Hounstout Cliff, I name the upper two divisions the Hounstout Marl and Hounstout Clay (see Pl. XIX and fig. 78). The succession is as follows:

[Massive Bed above]

4. HOUNSTOUT MARL, 40–50 ft.: blue sandy marl with thin bands of 'stinkstone' (sandy cementstone giving off a strong odour when struck with a hammer); it extends down to the old road round the face of Hounstout.
3. HOUNSTOUT CLAY: about 30 ft. of dark clay, apparently devoid of fossils.
2. RHYNCHONELLA MARLS, about 20 ft.: grey marls with numerous *Rhynchonella* cf. *subvariabilis* Dav., a small *Oxytoma*, numerous small belemnites, and *Cidaris* spines; well seen at Pier Bottom on the west side of St. Alban's Head, where they first rise from the sea.
1. LINGULA SHALES, 35–40 ft.: dark shales with *Lingula ovalis* auct. non Sow.

[*Rotunda* Nodules below.]

The highest beds yielding well-preserved ammonites belong to the *rotunda* zone. Where they are first seen, at the east end of Chapman's Pool, near the boat-house, they occupy the lowest 10–15 ft. of the vertical cliffs of black shale. The strongly-ribbed ammonites of the type that were long styled '*biplex*' can be seen from a distance, standing out in hundreds as hard claystone casts covered with a white chalky coating. Near the top they can be obtained more or less whole, often embedded in small nodules, and this bed is therefore known as the ROTUNDA NODULES. They have recently been collected carefully by Dr. Pringle and studied by Dr. Neaverson and Buckman, and were referred to the genera *Pallasiceras* and *Lydistratites*, which

[1] L. R. Cox, 1925–30, loc. infra cit. [2] M. P. Latter, 1926, loc. infra cit.
[3] The ledges after A. Strahan, 1898, 'Geol. Isle of Purbeck', *Mem. Geol. Surv.*, pp. 51–6.
[4] E. Neaverson, 1924, *Geol. Mag.*, vol. lxi, p. 149.

Photo. *W. J. A.*

Hounstout Cliff, Dorset.

The finest section of the Upper Kimeridge Clay and Portland Sand in Europe. The capping is of Portland Stone. The arrow on the right denotes the position of the Massive Bed, here chosen as the base of the Portland Sand. RN = *Rotunda* Nodules, which dip steadily towards sea-level at the right-hand end of the picture.

PLATE XIX

Dr. Spath regards as synonymous with *Pavlovia*.[1] *P. rotunda* is abundant, and Sowerby's holotype almost certainty came from here. Beneath the Nodules, at the foot of the cliff, the ammonites, though still white, are crushed flat. Most of them belong to the same species, but some are much larger, and Buckman thought that they might belong to *Paravirgatites*.[2] Other abundant fossils flattened in the bedding planes are *Lucina minuscula* and *Orbiculoidea latissima*. From the boat-house to the stream at the head of Chapman's Pool these beds form a hard slippery platform, on which the waves break. Westward they rise gently, providing a conspicuous datum easily followed below Hounstout until they rise to the top of the cliff some distance before reaching Freshwater Steps.

Pectinatites, Virgatosphinctoides and Subplanites Zones.

From the point where the conspicuous, hard, Crushed Ammonoid Shale rises to the top of the cliff in Egmont Bay, east of Freshwater Steps (Plate XIX), the next convenient datum is a thin stone band (1 ft.), which forms the base of the little cascade at Freshwater Steps, at a level estimated at 110 ft. below the top of the Crushed Ammonoid Shale.

In 1931, after heavy gales, I had the good fortune to see a large part of the lowest 40 ft. of these clays exposed as smooth ledges, swept clear of shingle, in Egmont Bay. They were covered with flattened white ammonites, mainly of fine-ribbed forms resembling *Pectinatites*, and some identical with '*Keratinites*' *naso* S. Buck. and '*K.*' *nasutus* S. Buck.,[3] which seem to be, and have been stated by Dr. Spath to be, generically identical with *Pectinatites*. During the winter 1931–2 the shingle returned and completely covered these exposures; but the crumbling cliffs yield numerous fragments of crushed, small, fine-ribbed, involute ammonites, which can only be identified as *Pectinatites*. Specimens may also be seen upon the shale ledges about 100 yds. west of Freshwater Steps, at a level about 6–10 ft. above the Steps stone band.[4]

West of Freshwater Steps a continuous exposure of Kimeridge Clay extends for 1½ miles to Clavell's Hard, where the Blackstone or 'coal' was quarried, and this stretch of cliffs has remained until almost the time of going to press virtually a *terra incognita*. It is inaccessible from either end except at low tide, and the cliffs are unscalable from above.

It was known that immediately above the Blackstone numerous small, crushed, fine-ribbed ammonites, very similar to those in Egmont Bay and at Freshwater Steps, abound on the ledges, and they have been generally identified as *Pectinatites pectinatus* and allied species.[5] The identification was first made by W. H. Hudleston as long ago as 1896, when reporting on an excursion of the Geologists' Association which he directed in that year:

'Pyritized specimens of *Ammonites pectinatus* Phil. are abundant in the Kimeridge Coal—a fact not hitherto noticed, though very important by way of correlation. It serves to show that the Kimeridge Coal is on the horizon of the well-known and richly fossiliferous "Lower Portland Sands" of Swindon. Consequently we have

[1] See figures by Neaverson, 1925, loc. cit., pl. 1, figs. 6–10, and Buckman, *T.A.*, 1926, pls. DXC (A–C), CCCLIII (C, D), DCXXXIX.

[2] S. S. Buckman, 1926, *T.A.*, vol. vi, p. 33.

[3] *T.A.*, pls. DCLII, DCLXIV.

[4] These I have recently photographed *in situ*.

[5] Two have been so figured by Neaverson, 1925, loc. cit., pl. 1, figs. 4, 5.

no difficulty in believing that the Kimeridge Clay of Chapman's Pool is on the horizon of the Hartwell and Swindon clays, at least, approximately.' [1]

For the time at which it was written, this was a remarkable observation, and after having been overlooked for a quarter of a century it seemed to have been vindicated by the independent work of the Survey and Dr. Neaverson.

The bed which yields these (pyritized) specimens identified as *P. pectinatus* and allied species most abundantly is the roof of the 'coal' seam. With them are found little radial plates, also pyritized, of the pelagic crinoid *Saccocoma*,[2] which have such a restricted vertical and such a widespread lateral range (having been encountered on the same horizon in the Kent and Norfolk borings) that Messrs. Kitchin and Pringle have suggested making of them a separate subzone; at Kimeridge they have a total vertical range of 13 ft.,[3] and are most abundant just below the Blackstone.

The ammonites, however, range up very much higher; in fact they may be found at intervals, with little apparent change, almost up to the stone band that sinks to the beach at Freshwater Steps, a measured distance of 155 ft. above the Blackstone.[4] Numbers are well shown upon the ledges on the east side of Rope Lake Head, where I have recently photographed them as they lie, since they invariably break if extraction is attempted. This level, where they seem to attain their acme, is between 20 ft. and 30 ft. above the Blackstone.

To those who have not made a very detailed and comprehensive study of these 'pectiniform' ammonites, the conclusion seems unavoidable that between the Blackstone and the Crushed Ammonoid Shales (*rotunda* zone) all the clays, shales and thin stone bands must be assigned to an extended *Pectinatites* zone, 250 ft. thick. Ammonites which seem indistinguishable in the field from *Pectinatites* abound throughout this great thickness; and I had therefore determined on this course. Dr. L. F. Spath assures me, however, that the only true *Pectinatites* occur above the stone band at Freshwater Steps—namely in the highest 100 ft.—and that all the rest, although they are barely (if at all) distinguishable from *Pectinatites* in the young stages which are by far the most commonly represented, develop later along different lines. These abundant earlier forms he assigns to the genus *Subplanites*, and he considers that the small ammonites found at and about the level of the Blackstone, and identified by Hudleston and by Neaverson as *Pectinatites*, belong to the homœomorphous genus *Lithacoceras* (Hyatt, 1920). It is therefore interesting to note that Buckman also gave them a separate name (*Pectiniformites*, 1925, *T.A.*, pl. DLXVII) and placed *pectinatus* considerably higher.

The 150 ft. of clays below and including the coal seam constitute the *Virgatosphinctoides* zones of Neaverson.

The ammonites of these zones have given rise to much controversy, owing to their general similarity to Russian forms, which Dr. Neaverson showed, however, to be unrelated. Salfeld in 1913 stated that the beds were equivalent to the Russian *Virgatites* zone, although he admitted that he had never found in them a true specimen of *Virgatites*.[5] The Geological Survey at first accepted Salfeld's statement and believed that they had detected the Russian

[1] W. H. Hudleston, 1896, *P.G.A.*, vol. xiv, p. 322.
[2] F. A. Bather, 1911, *Sum. Prog. Geol. Surv.* for 1910, pp. 78–9.
[3] Tested in 6 borings (J. Pringle, *in lit.*).
[4] Field-notes and measurements, 1932.
[5] H. Salfeld, 1913, *Q.J.G.S.*, vol. lxix, p. 425.

genus in a number of specimens recovered from the horizon of the oil-shale in borings at Corton, near Abbotsbury. With them were some large ammonites which were identified with another foreign genus, *Pseudovirgatites*, and this they made the index of a new zone to include the oil-shale.[1]

In 1925 Dr. Neaverson published his monograph upon these and other Upper Kimeridge Clay ammonites, showing that the similarity which the English forms bore to the foreign was due to homœomorphy, and the Corton and Kimeridge species previously regarded as *Pseudovirgatites* he named *Virgatosphinctoides grandis*, *V.* cf. *nodiferus* and *V. delicatulus*.[2] The stratigraphical position of the species was first determined inland, at Shotover and Wheatley, where they immediately underlie the thin *pectinatus* zone, but their position in the type-section in Dorset is by no means so certainly fixed. They have been recorded at and below the level of the oil-shale; but if Dr. Spath is right they should be sought at a considerably higher horizon. (For further notes on the ammonites see footnotes on p. 440.)

SUMMARY OF THE SUCCESSION FROM FRESHWATER STEPS TO CLAVELL'S HARD

	Ft.
Clays with crushed *Pectinatites*; some nodules about 25–30 ft. from base	100
THE THREE STONE BANDS, drawn in Strahan's section (loc. cit.) . .	35
The highest is the Freshwater Steps Stone Band.	
The lowest is the ill-named White Septarian Band, so called by Strahan in Brandy Bay. It is not septarian, but consists of hard white limestone with numerous paper-thin interlaminated clay-seams, giving it locally the appearance of tourmalinized slate. It forms the conspicuous white rocks east of Rope Lake Head, known by the fishermen as the Lias Rocks. Saurian vertebrae occur.[3]	
Clays and shales with crushed *Subplanites*, &c., more or less hardened . .	35
THE BASALT STONE BAND: hard black stone with conchoidal fracture; looks like a basalt sill; forms ledge bounding east side of Rope Lake Hole, and reaches beach level in W. corner of Brandy Bay	3
Soft shaly clay, many crushed *Subplanites*	70
ROPE LAKE HEAD STONE BAND: forms prominent ledge on W. side of extremity of Rope Lake Head	1½
Clays and shales with crushed *Subplanites*, about	10
THE BLACKSTONE	1
Clays and shales with crushed *Subplanites*, &c., and two conspicuous bands of cementstone, formerly worked for cement	140 to 150
THE YELLOW LEDGE STONE BAND	2

About 140–150 ft. below the 'coal' seam is a prominent band of hard mudstone known as the Yellow Ledge Stone Band. It rises at the ledge from which it takes its name (fig. 78) and, after running along the middle of Hen Cliff, reaches the top a hundred yards west of the Clavell Tower. This marks the line of division between Upper and Lower Kimeridge Clays, and it is the highest level at which *Exogyra virgula* has been found.

[1] Lamplugh, Kitchin and Pringle, 1923, 'Concealed Mesozoic Rocks in Kent', pp. 222–5 and pl. II, *Mem. Geol. Surv.*

[2] E. Neaverson, 1925, *Ammonites from the Upper Kim. Clay*, Liverpool.

[3] No ammonites or traces of ammonites have been found for certain in this band, and it could not possibly have been the source of the *Pavlovia* figured by Damon as 'Am. *biplex*' and renamed *A. Kimmeridiensis* by von Seebach, as supposed by Buckman.—*T.A.* 1926, vol. vi, p. 38, and pl. DCLXXIII. From its state of preservation that specimen can only have come from the *Rotunda* Nodules.

Gravesia Zones.

In the clays below the Yellow Ledge Stone Band, to the foot of Hen Cliff, the presence of flattened ammonites of the genus *Gravesia* was announced by Salfeld in 1913. He recorded the group of *G. irius* (d'Orb.) in the higher parts and the group of *G. gravesiana* (d'Orb.) below, thus (assuming his identification to be correct) providing an important link with the French and German succession.[1] Repeated search in more recent years, however, has only resulted in the discovery of two badly crushed specimens resembling the more evolute group of *G. gigas*.[2]

The downward limit of the *Gravesia* zones was defined by Salfeld as the Maple Ledge Stone Band,[3] which rises on the north side of the old pier, about 60 ft. below the Yellow Ledge Stone Band.

One hundred yards east of Gaulter Gap the Maple Ledge Stone Band is faulted up above the top of the cliff, and there is no other datum by which to determine the displacement of the fault. Sir A. Strahan wrote:[4] 'There is no reason, however, to suspect a large throw, and we may assume that the strata on the west side of the fault, while certainly below, are not far underneath the lowest seen on its east side.'

Aulacostephanus Zones.

On the other side of the fault, and below the Maple Ledge Stone Band, the ammonite fauna again changes; and, as Salfeld found, down to the lowest levels exposed the clays yield abundant *Aulacostephanus eudoxus*, *A. pseudomutabilis*, and other species of the same genus, with *Aptychi* and small *Aspidoceras*. The total thickness of the *Aulacostephanus* zones exposed is about 120 ft.

The axis of the Purbeck Anticline passes out to sea close to the Broad Bench Promontory, which forms the western horn of Kimeridge Bay. At the point, lying mainly between tide-marks, is a large flat shelf known as the Broad Bench, up which the muddy waves rush with spectacular fury in rough weather. It is formed by the lowest of the stone bands, which on account of repetition by small faults, gives rise to two similar benches nearer Kimeridge called The Flats, and so bears the name of The Flats Stone Band (Pl. XX).

On the west side of Broad Bench Promontory, in Hobarrow and Brandy Bays, the strata dip rather steeply below sea-level once more in the northern limb of the anticline, and all the zones are repeated in the space of less than a mile to the commencement of Gad Cliff. Farther west, beneath the precipitous walls of Portland Stone the highest zones are largely obscured by talus and wild undercliff like that beneath St. Alban's Head.

The lowest beds exposed in the Isle of Purbeck, still belonging to the zone of *Aulacostephanus yo*, are seen for a short distance in Hobarrow Bay, northwest of the axis. Here The Flats Stone Band is thrown about 50 ft. up in the cliff by a fault, so that below it are seen lower beds than are visible in the crest of the anticline on the other side of Broad Bench Promontory.

[1] H. Salfeld, 1913, loc. cit., p. 425.
[2] Found by Dr. Spath in 1932.
[3] Inquiries among the fishermen at Kimeridge in 1931 showed that the ledges called Maple and Washing Ledges in Sir A. Strahan's time are no longer known by name.
[4] 1898, loc. cit., p. 55.

Photo. W. J. A.

Hen Cliff, Kimeridge.

From the site of the old 'coal' pier. The Yellow Ledge Stone Band can be seen rather above the middle of the cliff, which is here formed mainly of the *Gravesia* zones. Note the muddy sea, and talus slopes continually being removed by the waves.

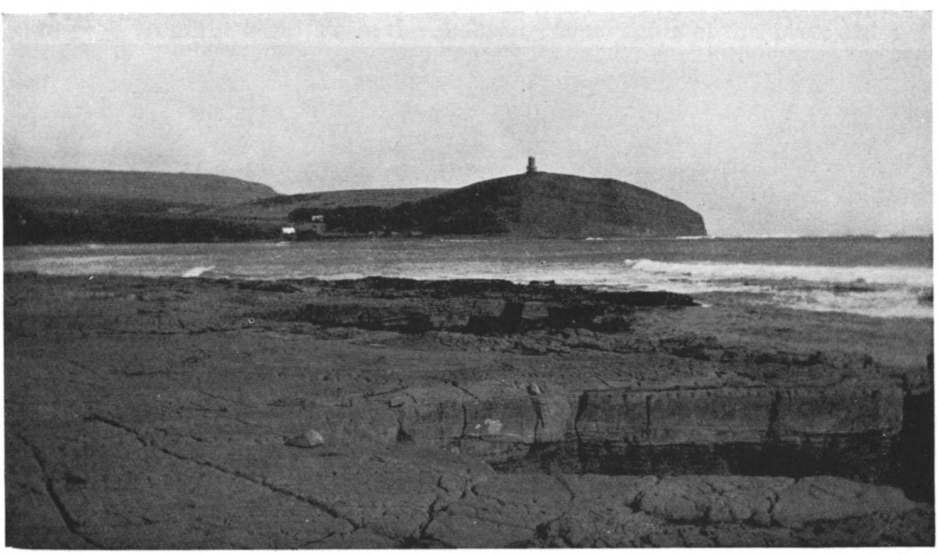


Photo. W. J. A.

Kimeridge Bay from The Flats.

Hen Cliff and Clavell's Tower on right of centre. Smedmore House among the trees in the distance on left, with Swyre Head behind. In the distance on right, waves are breaking on the mudstone ledges.

PLATE XXI

Photo. *W. J. A.*

Ringstead Bay and White Nothe Head.

The headland is of Chalk, resting on thin Upper Greensand and Gault, which cut unconformably across the Kimeridge Clay. Holworth House near top of cliff on left, with two masses of Portland Beds and Purbeck Beds below (showing white) brought down by pre-Albian faults.

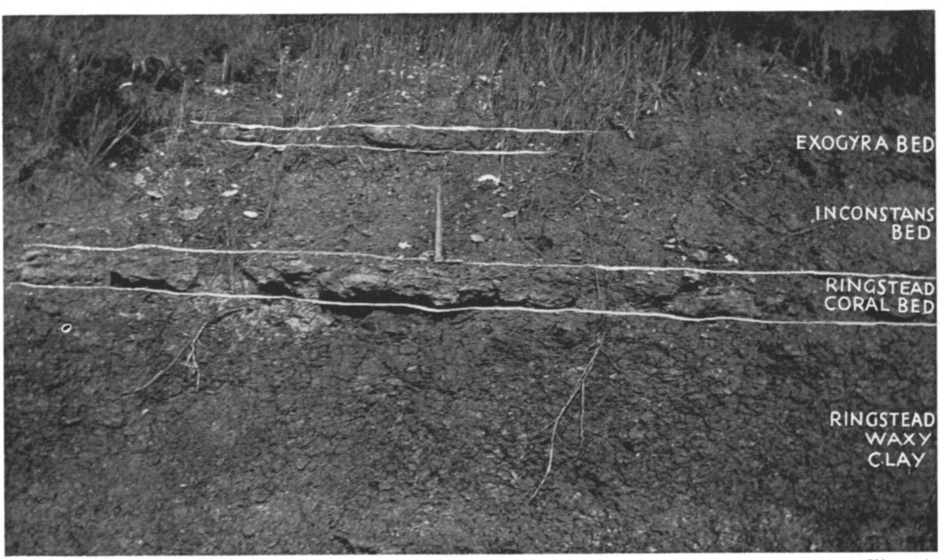


Photo. *W. J. A.*

Junction of Kimeridge Clay and Corallian Beds, Ringstead Bay.

For explanation see pp. 379 and 451.

It was probably from the *Aulacostephanus* zones that the type specimens of *Steneosaurus manselii* Hulke and *Ichthyosaurus enthekiodon* Hulke were obtained; they were embedded in reefs exposed at low water in Kimeridge Bay. A jaw of a *Teleosaurus* was found by Mansel-Pleydell and figured by Hulke, which had fallen from the cliff during the winter, probably from the same zones.[1]

(b) Northern Limb of the Weymouth Anticline: Ringstead to Abbotsbury

After a gap of 7 miles the Kimeridge Clay again appears in the cliffs of Ringstead Bay, where it is overlain by a small patch of faulted Portland and Purbeck Beds, and all are transgressed unconformably by the Gault (Pl. XXI). The exposures have deteriorated considerably in recent years and fossils are now somewhat scarce. Sir A. Strahan considered it probable that the middle zones are cut out by the faults, but both the highest and the lowest zones are visible. A detailed lithological description was made by Waagen in 1865,[2] and Salfeld in his paper of 1914 identified some of the ammonites collected by Waagen and endeavoured to assign them to their proper beds,[3] but no modern palaeontological work has been published.

The clays at the east end of the bay, which are partly succeeded by the Portland Sand and partly by the Gault, are poorly fossiliferous and all seem to lie above the *rotunda* zone. In the centre of the bay Waagen obtained abundant ammonites of the *Aulacostephanus* zones, below which, and passing westward into the lowest 100–140 ft. of the clay, Salfeld recognized evidences of both the *Rasenia* zones. From the presence of numerous flattened specimens of the typical *Pararasenia mutabilis* (Sow.) he assigned the higher parts of the lowest 140 ft. to the *mutabilis* zone; the *cymodoce* zone he recognized about 10 to 13 ft. from the base. From the *Aulacostephanus* zones of this place came the type-material of *Cardioceras anglicum* Salf. and *C. krausei* Salf.[4]

The *cymodoce* and *Pictonia* zones can be conveniently studied in the low cliffs for about a mile along the west side of the bay (Pl. XXI, lower figure). They contain many layers of large and well-preserved specimens of *Ostrea delta*, which weather out in hundreds on the beach. About 3½ ft. above the base of the Kimeridge Clay is a 6-in. band of marl, partly indurated to form a hard limestone, almost entirely composed of *Exogyra nana* (Sow.), with occasionally *E. prævirgula* Jourdy. The band of pale clay beneath contains abundant *Rhactorhynchia inconstans* and imperfect casts of *Pictoniæ*.[5] Waagen and subsequent writers have taken this by common consent as the basal bed of the Kimeridge Clay, and it is the lowest level at which *Pictoniæ* seem to occur (if not the only level). Immediately below is the Ringstead Coral Bed, the topmost member of the Corallian, in the equivalent of which *Ringsteadiæ* are found farther west.

[1] J. W. Hulke, 1869–80; see bibliography.
[2] W. Waagen, 1865, *Versuch einer allgemeinen Classifikation*, p. 4.
[3] H. Salfeld, 1914, loc. cit., pp. 204–6.
[4] H. Salfeld, 1915, 'Monographie der Gattung *Cardioceras* Neum. u. Uhlig, I', *Zeitschr. Deutsch. geol. Gesellsch.*, vol. lxvii, pl. xx, figs 1–9.
[5] Proved by personal observation, which is not in accord with Salfeld's record of *Ringsteadiæ* from the *Rh. inconstans* Bed. Waagen's specimens of *Ringsteadiæ* probably came from the clays with ironstone nodules immediately *below* the Ringstead Coral Bed, where they may still be found *in situ*.

The high cliff west of Holworth House, at the east end of the bay, is still known as Burning Cliff from a spontaneous ignition of the bituminous shale which took place in 1826 and continued for four years. The heat that caused the shale to ignite was supposed to have been produced by the decomposition of iron pyrites. The fire was in progress when Buckland and De la Beche visited the district for the preparation of their paper 'On the Geology of the Neighbourhood of Weymouth', read in 1830. They state that it originally gave off flames for many months, but by the time of their visit it had considerably abated, there being no flame, only 'small fumaroles that exhale bituminous and sulphureous vapours, and some of which are lined with a thin sublimation of sulphur'. 'Much of the shale near the central parts', they wrote, 'has undergone a perfect fusion and is converted to a cellular slag. . . . Where the effect of the fire has been less intense, the shale is simply baked and reduced to the condition of red tiles.' [1]

If the oil-shale is on the same horizon as that at Kimeridge, several other zones must be present that have not been proved palaeontologically.

At Black Head, west of Osmington, faults again bring down the base of the formation nearly to sea-level, and the *Pictonia* zone, with *Rhactorhynchia inconstans* and *Ostrea delta*, and the Ringstead Coral Bed at the bottom, can be traced close above the beach. Most of the Upper Kimeridge Clay is here cut out by the Cretaceous unconformity. Close to Osmington Mills, the Upper Greensand rests directly on the *Rasenia* zones, but higher zones succeed farther west, up to and above the oil-shale. The strata dip into the cliff at 40 to 60°, and where springs are given off at the base of the Chalk the clays have foundered, letting down enormous blocks of chalk, clay and greensand, and forming remarkable mud rivers, which flow slowly from the top of the cliff into the sea, after the manner of lava streams.

Beyond Black Head the Kimeridge Clay strikes inland, passing in a west-north-westerly direction along the north side of the Weymouth Anticline, giving rise to a deep valley parallel to that of the Oxford Clay, but separated from it by the Corallian ridge. It is not cut by the coast at the west end, but terminates at Abbotsbury faulted against Forest Marble.

Little was known of the major portion of the clay along this outcrop before 1917, when the boring of a number of test-holes for oil was commenced simultaneously at Kimeridge and at Corton, between Abbotsbury and Upway. The investigation was undertaken by the Department for the Development of Mineral Resources, oil-shale having been discovered at Portisham in 1856. The borings struck a moderately rich seam of oil-shale up to 2½ ft. thick, but it proved of no commercial value, for it shared the same disadvantage as the Kimeridge shale, namely the excessively high content of sulphur.[2]

Palaeontologically the borings were more profitable, the level of the oil-shale yielding *Saccocoma*, as at Clavell's Hard, associated with crushed ammonites identified as *Virgatosphinctoides* (*Subplanites*?).

The district is chiefly remarkable for another economic product, a thick deposit of iron ore which is locally developed in the *Rasenia* zones at Abbotsbury. The average thickness of the ore is about 20 ft., but in the best section, in the sides of the lane leading from Abbotsbury to Gorwell, the total develop-

[1] Buckland and De la Beche, 1835, *Trans. Geol. Soc.* [2], vol. iv, p. 23.
[2] A. Strahan, 1918, 'Spec. Repts. Min. Resources', vol. vii, pp. 24–40, *Mem. Geol. Surv.*

ment of ferruginous and sandy rock amounts to 45 ft. The main ore consists of 20 ft. of 'crumbling reddish-brown oolitic rock, full of shining pellets of ore in a matrix of fine quartz sand . . . traversed by numerous long thin seams of concretionary iron', with thick beds of sand, more or less ferruginous, above and below. Not much attempt has been made to work the ore, probably on account of its being too siliceous.[1]

A remarkable brachiopod assemblage occurs in the ore bed, the commonest being *Rhynchonella corallina* Leym. and *Ornithella lampas* (Sow.), with which is associated *Rh. inconstans*. From this association Blake and Hudleston inferred the stratigraphical position with tolerable accuracy, giving it as their opinion in 1877 that the beds were 'at least on the horizon of the passage-beds to the Kimmeridge Clay', and definitely above the Sandsfoot Grits.[2] Later Douvillé and then Salfeld showed that the ore contains such ammonites as *Rasenia uralensis* (d'Orb.) and *R. thurmanni* (Oppel), indicative of the *Rasenia* zones of the Kimeridge Clay.

The small size of the area over which the ore and sand deposits are developed is remarkable. Nothing similar is known at this horizon in any other part of England.

(c) Southern Limb of the Weymouth Anticline: Weymouth and Portland

The small area of Kimeridge Clay preserved on the southern limb of the Weymouth Anticline could scarcely be better described than in the words of Buckland and De la Beche, written in 1830:[3]

'The southern belt of Kimeridge Clay near Weymouth occupies a very small portion of the surface, constituting a triangular area, the base of which extends about a mile from Sandsfoot Castle westward to the Chesil Bank, whilst its apex is at Portland Ferry: but although so small a portion of this belt of clay is here visible on the surface, we have evidence of its submarine continuation from hence to Portland Island, in the clay bottom of the excellent anchorage of Portland Road, beyond which also it appears above the level of the sea in the base of the escarpment at the north extremity of the Isle of Portland, and along its west shore almost immediately south of the village of Chesilton. Hence it is clear that the Kimeridge Clay forms the fundamental stratum of the whole island, separated, as we have shown, from the Portland Stone by the Portland Sand and Sandstone. The rapid dip of all these strata towards the south causes the Kimeridge formations to sink below the level of the sea in the southern portion of the island; whilst that part of its western coast, whose base is composed of these perishable sands and clays, is defended from the tremendous south-western waves by a natural breakwater of enormous masses of Portland Stone that have fallen from the summit, and form a barrier against any further encroachments.'

In the top of the Portland Sands on the west side of the island Salfeld found a specimen of '*Perisphinctes gorei*', showing that at least the upper part of the sands here, as at Hounstout, should be classed with the Portland Sand. The same author recorded ammonites of the '*pallasianus*' group (i.e. *pallasioides* or *rotunda* zones) in septaria in the clays below, and in flattened

[1] J. Pringle, 1920, 'Spec. Repts. Min. Resources', vol. xii, p. 222, *Mem. Geol. Surv.*
[2] J. F. Blake and W. H. Hudleston, 1877, *Q.J.G.S.*, vol. xxxiii, pp. 273–4.
[3] 1836, loc. cit., p. 22.

condition in shaly clays in the railway-cutting.[1] The lowest horizon of the Kimeridge Clay outcropping at the surface on Portland Island is the oil-shale with *Saccocoma*. Between the island and the mainland is a gap, the highest beds exposed in the cliffs south of Sandsfoot Castle belonging to the *Pararasenia mutabilis* zone. An indication of the nature of the intervening clays that occupy this gap is afforded by a number of septaria washed up on the shore of Portland Roads. These have yielded some seven species of *Aulacostephanus*, together with other ammonites, and they indicate a development similar to that at Ringstead Bay.

The low cliffs extending to the north towards Sandsfoot Castle, at the southern extremity of the mainland, begin with the lowest beds of the *mutabilis* zone and show a good section of the *cymodoce* and *baylei* zones. The junction of the latter with the top of the Corallian is not so easy to find here as in Ringstead Bay, but the Ringstead Coral Bed is represented by a thin band of oolitic ironstone, reminiscent of the Westbury Iron Ore, and this should certainly be regarded as the highest bed of the Corallian. The *Exogyra nana* Bed[2] is also conspicuous.

(d) **North Dorset and the Vale of Wardour**

After reappearing from beneath the Chalk of the Dorset Downs the Kimeridge Clay outcrops for about 20 miles through North Dorset, until it is cut off abruptly by the E.–W. fault along the north side of the Vale of Wardour. On the downthrown (north) side of this fault the Cretaceous rocks still overstep the Kimeridge Clay and Corallian, the edge of the Chalk and Greensand scarp resting upon the Oxford Clay. On the upthrown (south) side of the fault they have been stripped off.[3]

Concerning the Kimeridge Clay of this tract very little is known. The highest zones reach the surface only in a narrow belt within the Vale of Wardour, south of which the Cretaceous scarp, running westward to Shaftesbury and then south-westward, oversteps on to progressively lower zones. Evidence was obtained by the Survey from a well-shaft between Okeford Fitzpaine and Shillingstone that in the south the Gault rests upon some part of the *Virgatosphinctoides* zones. They also proved the *Aulacostephanus pseudomutabilis* zone near Okeford Fitzpaine Church, in a brookside. The only clear section in the district is a large clay-pit south of the railway station at Gillingham, which exposes 25 ft. of clays falling entirely within the *Rasenia* zones. The clays are black and selenitic, and contain abundant *Exogyra virgula*, with *Lingula ovalis*, *Ostrea delta* and other shells, and bones of *Ophthalmosaurus pleydelli* Lyd. Dr. Pringle has recorded *Rasenia* cf. *stephanoides* (Oppel), *R.* cf. *trimerus* (Oppel) and numerous specimens of [*Pararasenia*] *desmonota* (Oppel).[4]

[1] H. Salfeld, 1914, loc. cit., p. 203.

[2] Salfeld's Bed 19, loc. cit., p. 202. Salfeld here places *Pictoniæ* below the *Exogyra nana* Bed, just as I have found them (in fragments) at Ringstead (see footnote on p. 451).

[3] Once the hard Chalk and Greensand had been removed, erosion of the Kimeridge Clay proceeded rapidly, so that now the Chalk on the downthrown side of the fault towers several hundred feet above the clay vale on the upthrown side.

[4] J. Pringle, 1923, 'Geol. Shaftesbury', *Mem. Geol. Surv.*, pp. 40–1; and *Sum. Prog.* for 1921, p. 112.

II. WILTSHIRE, BERKSHIRE, OXON. AND BUCKS

(a) Wiltshire

North of the Vale of Wardour the Kimeridge Clay is concealed for 11 miles beneath the extension of Salisbury Plain, formed by the overstepping of the Chalk westward to Mere, Warminster and Westbury. North of this the clay reappears for a few miles at the mouth of the Vale of Pewsey, where the *Pavlovia* zones have been worked in small brickyards, and where there are also (badly exposed) Portland rocks, as in the Vale of Wardour.[1] It is soon overstepped once more by Lower Greensand and Gault for 5 miles nearly to Calne. From Calne onwards the outcrop is uninterrupted until beyond the border of Berkshire; then at Faringdon a narrow tongue of Lower Greensand extends again on to the Corallian.

Throughout most of this tract, excepting the short distance in the Vale of Pewsey, the Kimeridge Clay is incomplete, being unconformably overlain by the Lower Greensand. Swindon, however, lies on a synclinal trough in which are preserved not only the higher Kimeridge zones but also the Portland and Purbeck Beds. The limestones form the capping of the hill on which the Old Town is built, while in the steep slopes below numerous brick-pits, opened to provide building materials during the rapid growth of the new railway town in the plain to the north, have at one time exposed almost the whole succession of the Kimeridge Clay. These pits, some of them of great size, yielded a rich harvest of vertebrate skeletons, belonging to *Ichthyosaurus*, *Ceteosaurus*, *Omosaurus* and rare Chelonia, some of which were described by Owen in his monographs of the Mesozoic Reptilia. Most of the vertebrate remains came out of the lower beds, especially the *Rasenia* and *Aulacostephanus* zones, as at Kimeridge.[2] The pits from which they came have for many years been abandoned.

Evidence has been obtained at Swindon for the presence of all the known zones of the Kimeridge Clay except that of *Subplanites*, up to and including that of *Pavlovia rotunda*, and less certainly that of *P. pallasioides*. Upon this the Portland Beds (*gorei* zone) rest non-sequentially, with a phosphatic pebble-bed at the base, containing derived fossils of *rotunda* and doubtfully *pallasioides* dates (the Upper Lydite Bed). Notwithstanding this apparently almost complete representation of its component parts, the formation reaches only some 300 ft. in thickness, or less than one-third of the total on the Dorset coast. This is in large measure due to the fact that the 400 ft. of the Dorset *pectinatus* and *Subplanites* zones are only represented by some 35–45 ft. of beds.

The most remarkable feature of the Kimeridge Clay at Swindon, a feature common also to the district about Oxford, is the development of the *pectinatus* zone in an arenaceous facies. Although all the other zones are represented by normal clays, the *pectinatus* zone consists of thick beds of sand with large doggers of hard calcareous gritstone. These have been called the Shotover Grit Sands, on account of their good development, with abundant

[1] A. J. Jukes-Browne, 1905, 'Geol. Country S. and E. of Devizes', *Mem. Geol. Surv.*, p. 5 (*Ammonites pallasianus* is said to have been 'one of the commonest fossils').

[2] *Tholemys passmorei* Andrews, found by Mr. A. D. Passmore in a temporary excavation and presented to the British Museum, was described as the most perfectly-preserved turtle ever found in the English Kimeridge Clay: C. W. Andrews, 1921, *Ann. Mag. Nat. Hist.* [9], vol. vii, pp. 145–53.

fossils, on Shotover Hill, Oxford. Their equivalence to a part of the Kimeridge Clay as low down as the oil-shale of Kimeridge was suggested in 1896 (see above, p. 447) by W. H. Hudleston, on the ground of the occurrence of *P. pectinatus* (Phil.), but the correlation was overlooked for twenty-five years. The true position was misunderstood by Salfeld, who correlated the Shotover Grit Sands at Swindon and Oxford with a part of the Portland Sands of Dorset above the *pallasioides* zone, and at the same time placed them above the Hartwell Clay (and the Atherfield Clay!).[1] Messrs. Chatwin and Pringle, of the Geological Survey, arrived independently, in 1921, at the same conclusion as Hudleston, and they, with the help of Hudleston's collection, gave the first accurate description of the sequence on Swindon hill.

SUMMARY OF THE SEQUENCE AT SWINDON [2]

Pavlovia Zones (SWINDON CLAY AND LOWER LYDITE BED).

On the floor of Okus Quarry, on the top of the west end of the hill, where the Portland Limestones are still actively quarried, a thin band crowded with dark phosphatic pellets and small lydite pebbles separates the glauconitic base of the Portland Stone (or strictly speaking the stony Portland Sand) from the clay below. Among the pebbles are commonly found rolled and phosphatized fragments of small ammonites belonging to the *rotunda* and possibly *pallasioides* zones, and it is concluded that these have been washed out of the

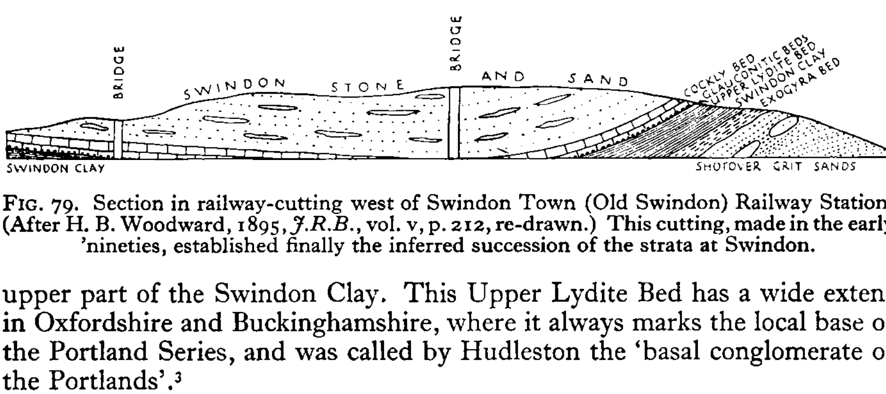


FIG. 79. Section in railway-cutting west of Swindon Town (Old Swindon) Railway Station. (After H. B. Woodward, 1895, *J.R.B.*, vol. v, p. 212, re-drawn.) This cutting, made in the early 'nineties, established finally the inferred succession of the strata at Swindon.

upper part of the Swindon Clay. This Upper Lydite Bed has a wide extent in Oxfordshire and Buckinghamshire, where it always marks the local base of the Portland Series, and was called by Hudleston the 'basal conglomerate of the Portlands'.[3]

The highest surviving Kimeridge stratum is the Swindon Clay, a blue clay, weathering brown, 15–20 ft. thick. The top forms the floor of Okus Quarry, but the lower parts, which are more sandy, are not now exposed, except occasionally in graves in the cemetery. The whole is very poorly fossiliferous, but Dr. Neaverson writes: 'The basal portion . . . consisting of a hard, greenish marl, contains fragments of ammonites which appear to be referable to *Pallasiceras* [= *Pavlovia*], and poorly preserved specimens are occasionally found in the blue clay which forms the mass of the Swindon Clay.' [4] Dr.

[1] Loc. cit., 1913, and 1914; see especially, 1914, p. 128, Table I.

[2] Based on C. P. Chatwin and J. Pringle, 1922, *Sum. Prog. Geol. Surv.* for 1921, pp. 162–8 (with emendations).

[3] W. H. Hudleston, 1880, *P.G.A.*, vol. vi, p. 345.

[4] E. Neaverson, 1924, *Geol. Mag.*, vol. lxi, p. 148.

Kitchin has more recently recorded that an excavation lately made in the top of the clay yielded ammonites indistinguishable from *Pavlovia pallasioides*.[1]

At the base is another 8-in. pebble-bed, the Lower Lydite Bed, resting on the

Pectinatus Zone (SHOTOVER GRIT SANDS).

The Shotover Grit Sands, 35–45 ft. thick, consist for the most part of yellow calcareous sands with enormous spherical doggers of hard gritstone, their old name being 'Lower Portland Sands'. Fossils are uncommon in all but the highest 6–8 ft., which consist of green and red marly sandstones, sands and clays, with abundant *Exogyra nana* and a rich fauna of other mollusca, including *Pectinatites pectinatus* (Phil.)[2] and *P. eastlecottensis* (Salf.).[3] Hudleston collected a fine series of fossils from a cutting during the construction of the M.S.W.J.Railway (fig. 79), but little below the Portland Beds can now be seen there. According to Messrs. Chatwin and Pringle:

> 'These upper beds were at one time (1887) well exposed in the road-cutting below Victoria Street, and the section was recorded by H. B. Woodward. A similar section was visible in May 1921 in a disused clay-pit south of Stafford Street; this pit has now been filled in, but from time to time the beds are exposed when graves are dug in the old cemetery, in the slope overlooking Clifton Street. Many fine uncrushed ammonites have been found in the material thrown out in grave-digging.'[4]

There is now a fine section showing sands with enormous doggers, overlain by the *Exogyra* Bed and Lower Lydite Bed, at the north-west end of the hill, above Hill's brickyard.

Virgatosphinctoides Zones.

The Grit Sands pass down gradually into clays, the junction having been exposed in Turner's upper brick-pit, west of Drove Road, on the north-east side of the hill, and a better section of the clays also in Hill's brickyard, below Okus Quarry. From these beds a number of ammonites with semi-virgatotome ribbing have been collected, which were formerly identified as *Virgatites*, but would now be called *Virgatosphinctoides*. There appears to be no indication of a separate *Subplanites* zone either here or in Oxfordshire. More detailed study of the ammonites is needed, however.

Gravesia Zones.

Messrs. Chatwin and Pringle record that a specimen of *Gravesia* exists in the Hudleston collection from Swindon, but the zone has never been identified *in situ*, and there is no longer any exposure likely to show it.

Aulacostephanus Zones.

In Turner's lower pit, known also as Bazzard's pit (now filled up with

[1] F. L. Kitchin, 1926, *Ann. Mag. Nat. Hist.* [9], vol. xviii, p. 452.

[2] A topotype of *A. pectinatus* Phil. (from Shotover Hill, Oxford) in the Oxford University Museum, has been figured by Buckman, *T.A.*, pl. CCCLIV; and another is figured here (pl. XXXIX).

[3] The type, figured *Q.J.G.S.*, 1913, vol. lxix, p. 430, pls. XLI, XLII, was believed by Salfeld to have come from the Upper Lydite Bed, and he made it the index of a separate zone above the Swindon Clay. Chatwin and Pringle proved that it came out of the upper part of the Shotover Grit Sands (loc. cit., p. 166). Buckman assigned it to a new genus, *Wheatleyites*, which Dr. Spath considers synonymous with *Pectinatites* (1931, loc. cit., p. 468).

[4] C. P. Chatwin and J. Pringle, 1922, loc. cit., p. 166.

rubbish and water, and having allotments over a large part of its floor), there were formerly exposed leathery bituminous shales, in which Salfeld recorded numerous crushed specimens of *Aulacostephanus pseudomutabilis* and *A. eudoxus*, together with *Aptychi*.

Rasenia and Pictonia Zones.

The presence of the *Rasenia* zones at Swindon is proved by some specimens collected by Hudleston from The Wharf, while Salfeld recorded that a fragment of *Pictonia baylei* had been found in Turner's lower pit (Bazzard's). At the base of an old clay pit in Telford Road he collected abundant *Prionodoceras serratum* (Sow.), which may have come from the base of the *baylei* zone or from the highest layers of the Corallian, though no *Ringsteadiæ* were found (see p. 395).[1] At the time work in Turner's lower pit was in active progress, a section was probably seen displaying clays of the *Pictonia*, *Rasenia* and *Aulacostephanus* zones, the two last yielding the vertebrate remains. The *Rasenia* and *Pictonia* zones are still visible in the brickyard at Stratton St. Margaret, north-west of the bridge where Ermine St. crosses the railway. They consist of brick-clays with *Ostrea delta* and some lines of septarian crackers containing the zonal ammonites well-preserved. The same zones, and the junction with the Upper Calcareous Grit, were formerly to be seen in an old brickyard at Wootton Bassett.[2]

During the construction of the Great Western Railway some of the longest and finest sections of the Kimeridge Clay in the country must have been seen in the vicinity of Swindon. Deep cuttings pass through the lower beds for several miles between Swindon and Wootton Bassett, and also near Stratton St. Margaret and South Marston; while near Bourton the upper beds were laid bare, and a small portion of them has recently been reopened in making a siding. Unfortunately no accounts of these cuttings were published.

Beneath the small Portlandian outlier of Bourton, near Shrivenham, the Upper Kimeridgian Beds are essentially the same as at Swindon, except that the top part of the Swindon Clay is sandy (see p. 508). A temporary excavation made in 1931 near Bourton End showed 3 ft. of Swindon Clay, greenish and sandy, with the Lower Lydite Bed at the base, resting on blue sands with large doggers, pierced to a depth of 4 ft. The lydite pebbles were exceedingly abundant.[3]

(b) Berkshire Vale and Oxford

Except for a momentary interruption near Faringdon, where a narrow strip of Lower Greensand, marked by high sandy ground, oversteps across the Kimeridge Clay on to the edge of the Corallian escarpment, the outcrop of the clay forms a continuous low-lying vale from Swindon to the Thames at Abingdon. This is the Vale of the White Horse in the narrower sense: the vale of the Gault and Kimeridge Clays, bounded on the north by the Corallian ridge, beyond which lies the wider but separate valley of the Thames.

Along the greater part of the Vale of the White Horse, the Gault and

[1] H. Salfeld, 1914, loc. cit., p. 196.

[2] The holotype of *Pictonia costigera* was collected here; see *T.A.*, 1927, pl. DCCXVI.

[3] Record kindly forwarded by my brother, Mr. J. O. A. Arkell, of Bourton End. I inspected the tip-heap, but found no fossils, only abundant lydite pebbles.

Kimeridge Clays are in contact, possibly because, as explained on p. 77, the outcrop obliquely crosses the continuation of the Birdlip Axis. The relations of the two are well seen at Culham brickyard, near Abingdon, where the *Douvilleiceras mammillatum* zone of the Gault (Middle Albian),[1] with a basal sandy pebble-bed, rests on grey sandy Kimeridge Clay, possibly of *pectinatus* date, or rather earlier. There are now very few other sections, though in days gone by the base of the Kimeridge Clay was to be seen in a brick-pit at Stanford in the Vale and a small exposure of the upper portion is still provided by another brick-pit at Drayton, near Abingdon.

On either side of the Thames south of Oxford, the outcrop extends northward for several miles up the dip-slope of the Corallian limestones, as long spurs with sides rising steeply from the plateau and capped by Lower Cretaceous sands. The western spur forms Boar's Hill and Cumnor Hurst; the eastern spur forms the lofty ridge that runs from Garsington to Shotover, and carries, in addition to the Cretaceous sands, a thick layer of Portland Beds with traces of Purbecks. At the end of each ridge there is a large brick-pit, the one at Shotover giving a nearly complete exposure of the Kimeridge Clay.

Eastward, around the south of Otmoor, the boundaries are obscurely defined owing to the dwindling of the Corallian limestones, but beyond the valley of the River Thame a third spur reaches northward to Brill and Muswell Hills. Here there are again exposures.

Still farther east the relics of a fourth spur, capped by outliers of Portland and Purbeck Beds and Cretaceous sands, survive as the hills at Quainton and Oving. The intervening country is dotted with a broken covering of Portland Beds, dissected by the Thame and its tributaries, and it presents in consequence an undulating scenery quite different from any to be found in other parts of the inland outcrop.

Seven miles north-east of Aylesbury the Kimeridge Clay is completely overstepped by the Gault and Greensand, and disappears under the Dunstable Downs, not to reappear for 32 miles.

Within this tract the best exposures are the brick-pits at the extremities of the two spurs on either side of Oxford, at Cumnor Hurst and Shotover, and a third brickyard on the eastern face of the Shotover ridge, at Littleworth, close to Wheatley. On the eastern side of Brill Hill, Prof. Morley Davies has described a valuable section of the lower beds at Rids Hill Brickyard, while the uppermost beds are or have been seen in other small brickfields at Long Crendon, Thame, Hartwell and Aylesbury. These exposures will be mentioned in connexion with the Hartwell Clay, a consideration of which is best left until the succession near Oxford has been described.

In the vicinity of Oxford the total thickness of the Kimeridge Clay is about 150 ft., although in places, as at Cumnor Hurst, it is still more reduced by pre-Cretaceous denudation.[2] This is only half the thickness at Swindon, but nevertheless the chief features of the Swindon succession, such as the Swindon Clay and the Shotover Grit Sands, are present, and the only zones which appear to be generally missing are those of *Pictonia*, *Gravesiæ*, and *Sub-*

[1] See Spath, 1923, 'Mon. Ammon. Gault', *Pal. Soc.*, part i, p. 4.

[2] Such denudation probably accounts for the low records of 94 ft. obtained in borings at Wantage and Culham [see 'Water Supply of Berks.', p. 89, and 'Water Supply of Oxon.', p. 42, *Mems. Geol. Surv.*].

planites. A substantial proportion of the total gap is probably represented, as at Swindon, by the Lower Lydite Bed.

At Chawley Brickworks, Cumnor Hurst, the Lower Greensand is seen resting on deeply channelled clays of the *Virgatosphinctoides* zone, about 20 ft. thick. In the past some relic of the *pectinatus* zone must have been encountered, for specimens of the zonal index fossil from this locality are preserved in the Oxford University Museum. The rest of the pit shows the upper *Aulacostephanus* zone, with *A. eudoxus*, *Exogyra virgula* and Saurian bones.[1]

The sections at Shotover and Wheatley Brickyards are much more complete and either here or at Brill the whole of the Kimeridge Clay has at one time or another been described.

SUMMARY OF THE SEQUENCE NEAR OXFORD, AT SHOTOVER, CUMNOR, WHEATLEY AND BRILL [2]

Pavlovia Zones (SWINDON CLAY AND LOWER LYDITE BED).

During 1930 and 1931 a sand-pit above the Shotover Brickyard has been worked farther back into the hill so that it now exposes not only the Swindon Clay but also the Upper Lydite Bed and the basal portion of the green Glauconitic Beds of the Portland Stone Series. The Upper Lydite Bed is about a foot thick and very conspicuous.

The SWINDON CLAY is a greenish-grey sandy clay and has at the base, as at Swindon and Bourton, the LOWER LYDITE BED. The full thickness of the clay is difficult to estimate, for it has acted as a slide-plane upon which the superincumbent Portland Stone has slipped down the hill-side, and it is in consequence much disturbed. The two lydite beds are only some 5 ft. apart, but an unknown thickness of the clay at the point where it is seen may have been squeezed out, since the beds are inclined at a high angle, in places approaching the vertical.

At Wheatley 12 ft. of the Swindon Clay[3] are exposed, but the top is not seen. Here small brown nodules occur in the clay, not uncommonly yielding fragmentary ammonites of the type of *Pavlovia rotunda* (Sow.). Fossils seem to be no longer found at Shotover, but Dr. Douglas observed in 1910 that 'a number of Kimeridge fossils, including the species usually termed *A. biplex*, were obtained from this clay-band'.[4] The species usually termed *A. biplex* at that time comprised the 'genera' *Pallasiceras*, *Lydistratites*, *Holcosphinctes* and *Aposphinctoceras*, all of which Dr. Spath considers synonymous with *Pavlovia* Ilovaïsky.[5]

Pectinatus Zone (SHOTOVER GRIT SANDS).

At the type-locality, the sand-pit above the brickworks on Shotover Hill, these consist of 16 ft. of yellow and whitish coarse sand with large doggers,

[1] J. Pringle, 1926, 'Geol. Oxford', 2nd ed., *Mem. Geol. Surv.*, p. 68.
[2] Based on J. Pringle, 1926, loc. cit., pp. 66–75.
[3] Buckman's name for the Swindon Clay here was Littleworth Lydite Clay.
[4] J. A. Douglas, 1910, *Geol. in the Field*, p. 206.
[5] The type of *Aposphinctoceras decipiens* Neaverson was figured by Miss M. Healey as '*Olcostephanus pallasianus* (d'Orb.)', *Q.J.G.S.*, 1904, vol. lx, p. 60, pl. XII, figs. 1 and 2, and came from Chippinghurst, Oxon., apparently from the Swindon Clay. This was previously known as *A. biplex*.

some of them resembling enormous cannon-balls. The sands and doggers, especially towards the top, contain abundant small lydite pebbles. The doggers are crowded with shells, of which the commonest are large Pernas (*Isognomon bouchardi* and another species), *Ostrea expansa* Sow., *Exogyra thurmanni*, a *Quenstedtia*, and various other bivalves. Among ammonites it suffices to mention those species of which this is the type-locality: *Pectinatites pectinatus* (Phil.),[1] *Paravirgatites pringlei* Buck.,[2] *Paravirgatites paravirgatus* Buck.,[3] and the horned *Pectinatites* ('*Keratinites*') *naso* Buck.[4] The name Shotover Grit Sands serves to distinguish them from the prior-named Shotover Sands of Lower Cretaceous (Wealden) age, which cap the hill.[5] Buckman also distinguished a Shotover Fine Sand, but this is probably no more than a local variant of the Shotover Grit Sands, which are here understood as including all the sands between the Swindon Clay and the *Virgatosphinctoides* zones.

At Wheatley brick-pit the Shotover Grit Sands are only 9½ ft. thick, consisting of 4 ft. of friable brown sandstone, crowded with shells, overlying 5½ ft. of lilac sandy clay. From the soft sandstone the fossils fall out in perfect condition, making the collection of specimens a much easier task than from the iron-hard doggers at Shotover. Very perfect *Trigoniæ* and other fossils may be obtained, forming a noticeably different assemblage from that at Shotover, but containing the same ammonites with numerous additions. From this bed were obtained the type specimens of seven species of *Pectinatites* (figured by Buckman as '*Wheatleyites*' and '*Keratinites*').

Virgatosphinctoides Zones.

Beneath the sands at Shotover about 10 ft. of blue-black clay is dug for bricks, and out of this come large irregular nodules or crackers, containing white-coated fossils of the *Virgatosphinctoides wheatleyensis* zone.

At Wheatley, the two *Virgatosphinctoides* zones together consist of some 18 ft. of dark clays, with layers of septarian nodules or cementstone crackers, from which Dr. Neaverson has obtained numerous ammonites. These nodules at Wheatley are the source of the types of the following:

Virgatosphinctoides wheatleyensis Neav., 1925, pl. I, fig. 1.
V. delicatulus Neav., pl. I, fig. 2.
Sphinctoceras crassum Neav., pl. II, fig. 1.
Allovirgatites tutcheri Neav., pl. III, fig. 2.
A. robustus Neav., pl. III, fig. 3.
A. versicostatus Neav., pl. III, fig. 4.

while at Shotover were obtained the types of *Virgatosphinctoides nodiferus* Neav. (pl. IV, fig. 1), *Sphinctoceras distans* Neav. (pl. IV, fig. 3), *Allovirgatites woodwardi* Neav. (pl. III, fig. 1). The *V. nodiferus* came from the clay above the nodule band, immediately below the Shotover Grit Sands, and on the strength of this Dr. Neaverson recognizes a separate zone of *V. nodiferus*; but it remains to be shown whether it can be recognized elsewhere.

At Chawley Brickworks, Cumnor Hurst, the clays on which the Lower Greensand is now seen to rest belong to the *Virgatosphinctoides* zones, which may be about 22 ft. thick. They contain the same cementstone crackers,

[1–4] See *T.A.*, pls. CCCLIV, DLXII, CCCVIII, DCLII. Dr. Spath considers Buckman's genus *Shotoverites* (type *S. pringlei*) identical with *Paravirgatites* (loc. cit., 1931, p. 472).

[5] The freshwater Wealden sands were so named by Prestwich and other early writers; the alienation of the name for the Kimeridgian dates from Blake (1880, pl. VIII). (See G. W. Lamplugh, 1908, 'Geol. Oxford', *Mem. Geol. Surv*, p. 68; and 2nd ed., p. 87.)

with *V. wheatleyensis*, *Allovirgatites tutcheri*, *Modiola* (*Musculus*) *autissiodorensis*, &c. The zones are also exposed at Rids Hill, Brill, where they are the highest seen in the old brick-pit.

Gravesia Zones.

No evidence for the presence of either fauna or strata of *Gravesiæ* date has been found in the Oxford district, and there seems no doubt that the zones are wanting.

Aulacostephanus Zones.

At Wheatley, Cumnor and Rids Hill Brickyards the *Virgatosphinctoides* clays rest directly upon dark shaly clays of the *Aulacostephanus* zones, with *Exogyra virgula* and *Aptychus latus*. To the base of the pit at Wheatley 8 ft. are seen, most of which belongs to the *pseudomutabilis* subzone, since *A. eudoxus* abounds; but Dr. Pringle has recorded *Physodoceras acanthicum* and *Ph. karpinskii*, from which he concludes that the top of the subzone of *A. yo* is also exposed.

At Cumnor 10 ft. of the same dark, shaly clays with *E. virgula* and *Aptychus* have been seen in the north end of the pit, but they are not visible on the main face to the south, being there thrown down below the floor by a fault. The zone at this place yields numerous Saurian bones, just as at Swindon and at Kimeridge. Remains of *Pliosaurus*, *Plesiosaurus*, *Dacosaurus* (also found at Shotover) and *Ichthyosaurus* have been obtained, and also the type-specimen of *Camptosaurus prestwichi* Hulke. *A. eudoxus* and allied ammonites are tolerably abundant.

At Rids Hill Brickyard, again, in the same clays, Dr. Pringle has obtained the characteristic fossils, *A. eudoxus*, *Aptychus latus* and *Exogyra virgula*.

Rasenia and **Pictonia Zones.**

The only section of the basal clays below the *Aulacostephanus* zones now open seems to be the old brickyard at Rids Hill, which is becoming obscure since being abandoned in 1911. The section was described by Prof. Morley Davies in 1907 and again by Dr. Pringle in 1924.[1] Immediately below the *Aulacostephanus* zone are two 1 ft. bands of creamy-weathering cement-stone with fragments of *Rasenia*, enclosing 2 ft. of creamy, calcareous clay; below this are 8 ft. of dark grey selenitiferous clay with *Rasenia stephanoides* (Oppel), *Ostrea delta*, and ancestral forms of *Exogyra virgula*.

At the base is what Prof. Morley Davies described as the most fossiliferous bed in the pit—the BRILL SERPULITE BED. It consists of an impersistent band of limestones or flattened doggers, up to 6 in. thick, largely composed of *Serpulæ* and shells. The stone is so tough that while the smaller bivalves such as Cyprinids and *Astarte* usually spring out perfect when it is broken, the larger belemnites and oysters generally shiver to pieces. When the masses are weathered, however, a better idea of the fauna can be obtained. *Serpula tetragona* (Sow.) and the little '*Cyprina*' cf. *cyreniformis* Blake predominate, but *Ostrea delta* and other lamellibranchs also abound,[2] and Buckman has figured from the bed a specimen of *Prionodoceras superstes*.[3] Since this ammonite

[1] 1926, loc. cit., p. 74.
[2] A. M. Davies, 1907, *Q.J.G.S.*, vol. lxiii, p. 34.
[3] *T.A.*, 1923, pl. CDXXII.

has been found in association with *Pictoniæ* in Scotland,[1] Dr. Pringle suggests that the Brill Serpulite Bed may possibly be a representative of the *Pictonia baylei* zone. He detected the bed *in situ* for the first time in 1924, at the base of the *Rasenia* zones, and he therefore considered the Serpulite Bed the basal bed of the Kimeridge Clay. Below were exposed 14 ft. of black selenitiferous clay probably belonging to the upper part of the Ampthill Clay (Upper Calcareous Grit-equivalent).

In no other exposure near Oxford has so much as a suggestion of the *Pictonia* zone been found. As mentioned in the last chapter, during the reconstruction of the London road in 1925, Dr. Pringle saw a deep trench east of Shotover Lodge, in which clays belonging to the zone of *Rasenia cymodoce* rested directly on a markedly eroded surface of the Corallian limestone. In the old quarry below the brickyard at the foot of Shotover Hill a similar section has only lately become overgrown. Phillips noted that about 15 ft. from the base of the clay there was a band of septaria yielding *Rhactorhynchia inconstans*, while below were layers of *Ostrea delta*, *Exogyra nana* and *E. virgula* (Sowerby's type specimens of the first two oysters came from here). At the base was a layer of coprolites.[2]

The non-sequence in the Oxford district denoted by this hiatus is very considerable, for not only is the *Pictonia baylei* zone missing, but also all the Upper Calcareous Grit and Glos Oolite Series of the Corallian (see p. 403).

The difference between the Shotover Grit Sands or *pectinatus* zone at Shotover and at Wheatley indicates that lateral variation is likely to be considerable. In the Horsepath tunnel, by which the railway passes under Shotover Hill, and in the adjacent cuttings, the sands seem to be much thicker and they have at their base two bands of shelly limestone, $1\frac{1}{2}$ to 2 ft. thick and 4 ft. apart, which run all through the cuttings. No Swindon Clay seems to be present.[3] A comparable section was made out by Prof. Morley Davies in a long field trench dug down the side of the hill near Garsington.[4] The sands were seen to be about 33 ft. thick and to become argillaceous towards the base. They were capped by a well-marked Lydite Bed, which was directly overlain by the green Glauconitic Series of the Portland Beds. The increased thickness of the sands suggests that the Swindon Clay has in this direction passed into sand.

Exactly comparable sections, where the green Glauconitic Beds with their basal Lydite Bed rest directly on some 30 ft. of sands (the Thame Sands of Buckman), had been described by Fitton farther east, at Long Crendon and at Barley Hill, east of Thame[5] (see below).

(c) The Thame and Aylesbury District (Hartwell Clay Area).

In the district about Thame and Aylesbury the best sections to be obtained are afforded by shallow brickyards, most of which are opened in a sandy, greenish clay, usually more or less micaceous and glauconitic—the HARTWELL CLAY.

[1] S. S. Buckman, 1923, *T.A.*, vol. iv, p. 42.
[2] J. Phillips, 1871, *Geol. Oxford*, p. 413.
[3] J. Pringle, 1926, loc. cit., p. 71.
[4] A. M. Davies, 1899, *P.G.A*, vol. xvi, p. 20.
[5] W. H. Fitton, 1836, *Trans. Geol. Soc.* [2], vol. iv, pp. 281–3.

The type-section is Locke's Brickyard, Hartwell, about a mile south-west of Aylesbury, beside the Thame road. Almost a duplicate section was formerly to be seen at Webster and Cannon's (Hill's) Brickyard, on the Bierton Road, north-east of Aylesbury, and in Ward and Cannon's Brickyard at Bierton. At these places the Hartwell Clay is or was exposed to a depth of about 10 ft., and is directly overlain by the Upper Lydite Bed and Glauconitic Series of the Portland Beds.[1] As early as 1880 Hudleston called this lydite bed the 'basal conglomerate of the Portlands' and correlated it with the similar stratum at Swindon; and in the passage already quoted (on p. 448) written in 1896, he definitely correlated the Hartwell Clay with the Swindon Clay. There was at that time no certainty on this point, however, for the fauna had not been properly studied, and the strata below the Hartwell Clay were, and still remain to-day, virtually unknown. Hudleston mentioned a report that a sandy stratum lay between the Hartwell Clay and the lower shaly clays on Aylesbury Hill, but he said that the information was unreliable. There is thus at least an indication that the Shotover Grit Sands may have some representation as far east as Aylesbury.

Concerning the stratigraphical position of the Hartwell Clay there have been widely divergent opinions: Blake in his paper on the Kimeridge Clay of England (1875) first placed it in the Lower Kimeridge, but five years later, probably under the influence of Hudleston, who in that year (1880) conducted an excursion to the district, he admitted his mistake and ascribed it to the Upper Kimeridge. H. B. Woodward in 1895 went to the other extreme and described the Hartwell Clay as part of the Portland Beds. In this he was probably misled by the then recent discovery that the Middle and Upper Kimeridge Clay of England were to be correlated with the Lower and Middle Portlandien of French geologists, but it is plain that he used the term Portland Beds in the English sense, not in the Continental. Apart from matters of nomenclature, he agreed with Hudleston, for he wrote:[2]

'There can be no question that the clay below the Portland Stone at Swindon is homotaxial with the Hartwell Clay, for although the Swindon Clay is not so fossiliferous as that at Hartwell, yet it has yielded some species, and the beds immediately below the Swindon Clay have yielded many fossils identical with those of the Hartwell Clay.'

In recent years Dr. Neaverson has collected many ammonites from the Hartwell Clay and has studied them and the collections in the Aylesbury Museum and elsewhere, with the result that the date of the deposit has been settled beyond much doubt as principally *pallasioides*, the lower parts including also deposits of *rotunda* date. In the monograph, already mentioned, on the ammonites from the Aylesbury–Oxford district (1925), he has described and figured the following forms from the Hartwell Clay:

[3] '*Aposphinctoceras*' *ailesburiense* Neav., pl. II, fig. 3.
[3] '*A.*' *hartwellense* Neav., pl. II, fig. 4.
[3] '*A.*' *variabile* Neav., pl. II, fig. 5.
'*Holcosphinctes*' *pallasioides* Neav., pl. III, fig. 5.
'*H.*' *flexicostatus* Neav., pl. III, fig. 6.

[1] See W. H. Hudleston, 1880, *P.G.A.*, vol. vi, pp. 344–52; and 1888, ibid., vol. x, pp. 166–72.
[2] 1895, *J.R.B.*, p. 223.
[3] Buckman did not consider these species congeneric with the genotype, which was chosen

while from the lower parts of the clay, obtained at a time when the brickyards were worked to a deeper level, he has described two representatives of the *rotunda* fauna: *P. ultima* (pl. I, fig. 2) and *P. inflata* (pl. II, fig. 2).

Since the discovery, announced by Dr. F. L. Kitchin, of *P. pallasioides* in the upper part of the Swindon Clay,[1] it is evident that the Swindon Clay and Hartwell Clay can be closely correlated, although the greater part of the Swindon Clay is probably of *rotunda* date and represents that portion of the Hartwell Clay lying below the usual floor of the brickyards. At Wheatley and Shotover, on the other hand, the upper or *pallasioides* portion of the clay seems to have been removed in early Portland times, before the formation of the Upper Lydite Bed.

Much additional information of interest might be obtained from a study of the lamellibranch faunas of these uppermost clays; for instance Dr. Kitchin finds that the most characteristic Hartwell species, *Hartwellia hartwellensis* (Sow.), recently described by him as the type of a new genus, is absolutely restricted to this level, although other allied species have been wrongly recorded under the same name from the *pectinatus* and even the *Virgatosphinctoides* zones at Swindon and Shotover.

Before leaving the subject of the Hartwell Clay, reference must be made to an opinion persistently held by Buckman, that the *pallasioides* fauna of the Hartwell Clay should be sought *below* the Shotover Grit Sands of the Oxford district and of Swindon. To the last he maintained that the Survey and Dr. Neaverson were wrong in their correlations.

> 'There is no objection taken', he wrote in August 1926,[2] 'to the correlation of the *rotunda* zone of Chapman's Pool with the Swindon Clay and with the Littleworth Lydite Clay; but when they also correlate these deposits with the Hartwell Clay of Hartwell, near Aylesbury, serious protest must be made; because the stratigraphical sequence of the beds is quite opposed to it. . . . The likeness of the Ammonoids of the Hartwell Clay and of Chapman's Pool is admitted; but it is a deceptive likeness.'

Again, in December 1926,[3] he wrote:

> 'There are at Swindon, below the *pectinatus* beds, a thick series of sands (Lower Cemetery Beds) above some feet of clay, whose ammonoid faunas are unknown: these beds are where the Hartwell Clay faunas should be sought. . . . There is little to be gained in reiterating statements of correlation without figuring the ammonoid evidence. I have figured such evidence for the correlations of the beds concerned.'

Any one reading these passages without knowing the history of the controversy might be led to believe that the weight of evidence was on Buckman's side. In 1926, however, at the meeting of the British Association at Oxford, Buckman read a paper upon the position of the Hartwell Clay. The paper was never published and so, in the interests of truth, a word of explanation may be timely.

Cross-questioning by Dr. Pringle elicited the information that the critical ammonites from Long Crendon, upon which the correlations depended, had

by Neaverson as *A. decipiens*, *nom. nov.* for the specimen figured by Miss Healey as *Olcostephanus pallasianus* in 1904, from the Swindon Clay of Chippinghurst, near Chiselhampton, Oxon. See *T.A.*, vol. vi, 1926, p. 25 (where references are given). Dr. Spath, on the other hand, considers not only all these but also the allied genera *Holcosphinctes* and *Episphinctoceras* Neaverson synonymous with *Pavlovia* (1931, loc. cit., pp. 470–1).

[1] F. L. Kitchin, 1926, *Ann. Mag. Nat. Hist.* [9], vol. xviii, p. 452.

[2] *T.A.*, vol. vi, p. 27.

[3] Ibid., p. 40.

not been dug up either by Buckman or in his sight, but had been purchased long afterwards from workmen, who had also worked in the pits at Hartwell and Brill. They had, therefore, probably never come from Crendon at all, but from the Hartwell Clay of Hartwell.

The sections at Long Crendon, on the hill leading down towards Thame (Barrel Hill), were described by Fitton in his classic memoir on the Strata below the Chalk,[1] and were re-examined in 1898 by Prof. Morley Davies, who confirmed Fitton's sequence.[2] Underlying the typical Portland Limestones are the usual Glauconitic Beds, with the Upper Lydite Bed at the base. Below come 30 ft.[3] of predominantly sandy strata 'with much clayey material in some of the beds' according to Morley Davies, and these rest in turn upon clay, which was formerly dug in the old brickyard near the foot of the hill. Nothing is now visible in the brickyard, the adjoining sand-pit has been filled up with rubbish, and the road-cutting is overgrown.

Similar conditions—Lydite Bed resting directly on sands, as at Garsington—were proved by Morley Davies in drainage excavations in Thame, and Fitton described the Glauconitic Beds resting directly on 30 ft. of sands at Barley Hill, east of Thame. Here the sand (Buckman called it Thame Sands) contained 'nodules of great size scattered in it irregularly', and they reminded Fitton of the doggers in the Shotover Grit Sands at Shotover.[4]

Buckman admitted the approximate contemporaneity of at least a part of the Thame Sands and the Shotover Grit Sands, but his point of divergence from the view accepted by all other recent investigators lay in the belief that the clay below the Thame Sands in the old brickyard at Long Crendon was Hartwell Clay. Blake referred to it as Hartwell Clay when leading an excursion of the Geologists' Association to the brickyard in 1893, but his contribution to Kimeridgian stratigraphy was never profound, and he gave no reasons for the opinion. Prof. Morley Davies also visited the brickyard while it was still in work, but he found no fossils, and a workman 'although he certainly knew what fossils were' informed him that none were found.

To settle the matter an excavation was made in the floor of the old brickyard at Long Crendon, and in the presence of Messrs. Buckman, Pringle and Chatwin, Dr. Pringle informs me, the workmen unearthed some ammonites typical of the *Virgatosphinctoides* zones, but nothing at all suggestive of Hartwell Clay. About 6 ft. below the floor of the pit appeared the *Exogyra virgula* clays.

The true explanation may be that, northward and eastward from Garsington to Shotover Brickyard and Wheatley, the upper part of the sands below the Upper Lydite Bed passes into the sandy Swindon Clay, and again that northward and eastward from Thame and Long Crendon to Brill and Hartwell it passes into the sandy Hartwell Clay. H. B. Woodward appears to have been believed in such a change of facies, for he wrote:[5]

'It is evident that the "sands of the Lower Portland Beds" [i.e. Thame Sands] are gradually replaced by clay as we proceed northwards [from Long Crendon]. At Brill, beneath the lydite-bed, there is 3 ft. of brown and greenish sand, which passes

[1] 1836, *Trans. Geol. Soc.* [2], vol. iv, pp. 281–2.
[2] A. M. Davies, 1899, *P.G.A.*, vol. xvi, p. 21.
[3] Buckman's measurements make the sands 80 ft. (*T.A.*, vol. vi, p. 36), but this thickness is improbable.
[4] W. H. Fitton, 1836, loc. cit., p. 283.
[5] 1895, *J.R.B.*, p. 225.

down gradually into stiff blue clay, yielding *Ammonites biplex*, *Thracia*, &c., and is not separable from the Kimeridge Clay.'

Prof. Davies expressed the same view somewhat differently, as follows: 'If we consider the . . . beds below the Pebble Bed [Upper Lydite Bed] we can trace a gradual transition, the clayey facies gradually rising from west to east. From the 39 ft. of pure sands with limestone at Garsington, we pass through the 26 ft. of more or less clayey sands of Long Crendon [Thame Sands] to the sandy clay of Dadbrook Hill and Hartwell [Hartwell Clay].'[1]

An alternative explanation, suggested and preferred by Dr. Kitchin, is that at Garsington, Thame and Long Crendon the non-sequence below the Upper Lydite Bed is greater than at the other places, and the Hartwell Clay has been removed by erosion, leaving the Upper Lydite Bed resting on Shotover Grit Sands.[2] If this view is correct the whole of the Thame Sands should one day be found to contain the *pectinatus* fauna.

III. THE FENS: CAMBRIDGE AND NORFOLK

After a gap of about 32 miles the Kimeridge Clay gradually emerges once more from beneath the Lower Greensand at Great Gransden, 10 miles west of Cambridge.[3] The outcrop remains narrow until due north of Cambridge, where it spreads out to a great width and is lost beneath the Fens. The eastern half of the Fens is floored by the Kimeridge Clay, which rises through the superficial deposits here and there as low, straggling 'islands'. The largest is the Isle of Ely, with its cappings of Lower Greensand, and other large islands have determined the sites of Chatteris and March. In Norman times the artificial causeways were the only means of communication between these isolated tracts and the mainland.

The area was studied principally by T. Roberts of Cambridge, previous to the year 1886,[4] but much additional information has been obtained from borings made during and since the Great War.

The maximum thickness of the Kimeridge Clay was estimated by Roberts to be 142 ft., this figure being arrived at by piecing together a composite section from the principal brick-pits in Cambridgeshire. He was in doubt, however, about 20 ft. of clays, which he considered he might have included twice, at Haddenham and at Littleport. In 1920 three boreholes were drilled in the Fens east of Southery, just over the border of Norfolk, and the results were published by Dr. J. Pringle.[5] The whole of the Kimeridge Clay was pierced in two of the borings, capped by Lower Greensand, and the total thickness was 121 ft. in one boring and 125 ft. in the other.

Pleistocene or Lower Cretaceous deposits rest unconformably on the clay. The Sandringham Sands of the Lower Greensand have at their junction with it a pebble-bed containing phosphatic nodules. The thinness of the Kimeridge Clay, however, is not due primarily to truncation of its upper zones by

[1] 1899, *P.G.A.*, vol. xvi, p. 25. [2] F. L. Kitchin, 1932, *in lit.*

[3] The *Pictonia* zone may appear sporadically much earlier, especially about Ampthill, where *Perisphinctes variocostatus* (Buckland) is said to have been found in clay grouped as Ampthill Clay, and according to Buckman indicates basal Kimeridgian. At Sandy, however, the Kimeridge Clay is entirely overstepped and Lower Greensand rests on basal Corallian.

[4] T. Roberts, 1892, *Jurassic Rocks of Cambridge*, pp. 61–76.

[5] J. Pringle, 1923, *Sum. Prog. Geol. Surv.* for 1922, pp. 126–39.

the pre-Cretaceous denudation, but to piecemeal attenuation of its component parts, as in Oxfordshire. In the Southery borings all the main zones were detected. The formation consists of dark clays with occasional thin bands of cementstone and some brown and greenish-brown oil-shales, just as in the South of England. The thinness would seem, therefore, to be due mainly to slow deposition.

According to Dr. Pringle, the basement-bed of the Sandringham Sands rests upon some part of the *rotunda* zone, for within 4 ft. of the top of the clay fragments of an ammonite were found which compare with some of those abounding in the *rotunda* zone at Chapman's Pool. Some better-preserved examples were found in another boring at King's Lynn.

Only 13 ft. below this horizon at Southery was encountered a shale, 8 in. to 1 ft. thick, crowded with the pyritized radial plates of *Saccocoma*, associated with fish teeth. These crinoid remains occur in Dorset, as has been stated, on the horizon of the Kimeridge Oil-Shale. Twelve feet below the *Saccocoma* band was a cementstone, which, since it marked the lower limit of *Modiola autissiodorensis* and the upper limit of *Exogyra virgula*, Dr. Pringle correlated with the Yellow Ledge Stone Band of Kimeridge.

The *Gravesia* zones were not proved palaeontologically, but there was room for them in the borings, for 30 ft. below the cementstone the *Aulacostephanus pseudomutabilis* zone was proved by a layer of *Amœboceras krausei* (Salf.).

The *Pararasenia mutabilis* fauna was represented by *Pararasenia desmonota* (Oppel), about 18 ft. above the base of the Kimeridge Clay at Southery, while *Rasenia stephanoides* was obtained from several borings near King's Lynn. At the base were 6 ft. of grey limy clay with fragments of smooth-whorled ammonites, identified with some hesitation as *Pictoniæ*.

Thus the bulk of the formation from the *rotunda* zone downwards seems to be represented in the Fenland, and a re-examination of the brickyards of Cambridgeshire on modern palaeontological lines might yield much new information about the several zones, their thicknesses and faunas.

The interpretation of Roberts's descriptions in the light of the borings is a task which could only be undertaken after a study of his fossils and other material, and detailed collecting from the pits.

In the first place it is evident that nearly all the sections described by him fall in the Lower Kimeridge Clay, below the level of the Yellow Ledge Stone Band. The opinion formerly held, that at the Roslyn (or Roswell) Pit, 1 mile north-east of Ely, some 8 ft. of paper-shales and clays with *Orbiculoidea latissima* are above the limit of *Exogyra virgula*, is not sustained by recent work. Dr. Kitchin and Dr. Pringle inform me that they have carefully examined the highest beds there and have found that their position is not above the zone of *Aulacostephanus pseudomutabilis*. The principal *Exogyra virgula* beds, which (Roberts noted) are also characterized by abundance of *Aptychus latus* at a certain level, we may identify with little hesitation as belonging to the *Aulacostephanus* zones. At the Roslyn Pit these beds occupy about 26 ft., and the main *E. virgula* bed is within 3 ft. of the top. Roberts used as zonal index of these *Aptychus* and *virgula* beds the comprehensive '*Ammonites alternans*'.

The lowest 4 ft. of clay and shale exposed from time to time in the Roslyn Pit are marked by a band crowded with *Astarte supracorallina*, and from this level Dr. Pringle has recorded *Pararasenia desmonota* (Oppel), characteristic of the *mutabilis* zone.[1] Normally the floor of the pit is under water.

The downward continuation was believed by Roberts to be represented in three clay-pits at Littleport. If these three pits do not overlap more than Roberts supposed, the *Astarte supracorallina* level is underlain by some 40 ft. of clay; but this needs substantiating by more intensive collecting.

The basement-beds were described in a brick-field half a mile west of Haddenham Railway Station, and in several temporary exposures near the west side of the outcrop. They always contain layers of *Ostrea delta*, and at the base a band of phosphatic nodules, thought to be coprolites. Where the base of the Kimeridge Clay rests upon the coral rag of Upware there is reported to be at the junction a layer of broken and rolled fragments of coral, but the clay is there unfossiliferous. The abundance of *Ostrea delta* and the layer of phosphatic nodules are said to be otherwise of widespread occurrence and to provide an easily recognized guide in mapping the junction of Kimeridge and Ampthill Clays. They recall the Corallian-Kimeridge junction at Shotover, Oxford.

IV. LINCOLNSHIRE: FROM THE WASH TO THE HUMBER

Beneath the Wash and the lowest tract of the surrounding Fens the Kimeridge Clay is totally concealed for 30 miles. On reappearing in Lincolnshire it has more than doubled in thickness, the accepted estimate from a number of borings in the south and middle of the county being 300–320 ft.[2] The most recent boring, at Donnington on Bain, which was undertaken in 1917 in search of oil-shale, stopped short after passing through 245 ft. of Kimeridge Clay, without reaching the bottom.[3] The lowest zone for which any fossil evidence was obtained was that of *Aulacostephanus pseudomutabilis*, at a level 66 ft. above that at which the boring was stopped. In an older boring at the same place the Kimeridge Clay was said to have been penetrated for 309 ft.

In the north of the county the Lower Cretaceous rocks gradually overstep on to successively lower levels within the clay, but the overstep has never been investigated quantitatively. Owing both to the poverty of exposures and to the difficulty of drawing a lower boundary between the Kimeridge and the Ampthill Clays in the north of the county, the extent to which the various zones may individually or collectively attenuate is unknown. All that can at present be said is that the Kimeridge Clay, like the Oxford, becomes much thinner towards the Humber.

The highest beds passed through beneath the Spilsby Sandstone in the Donnington boring were unrepresented by cores; but at 30 ft. from the top Dr. Pringle recognized several specimens of a finely-ribbed Perisphinctid identical with some which characterize the oil-shale at Kimeridge (*Subplanites*?). Two bands of brown bituminous shale were in fact encountered at 21 and 30 ft. from the top. The same forms of ammonite were also recorded at Acre House Mine, north of Claxby.

Perhaps to some part of the Upper Kimeridge, if not to the *Aulacostephanus*

[1] J. Pringle, 1923, loc. cit., p. 135.
[2] H. B. Woodward, 1904, 'Water Supply of Lincs.', p. 10, *Mem. Geol. Surv.*
[3] J. Pringle, 1919, *Sum. Prog. Geol. Surv.* for 1918, pp. 50–2.

zones, also belong about 15 ft. of paper-shales exposed in a brickyard about a mile west of Fulletby.[1] The bedding-planes of the shale are here crowded with white shells of *Orbiculoidea latissima* and *Lucina minuscula*, recalling the paper-shales at Ely, formerly thought to be of Upper Kimeridge date but now assigned to the *Aulacostephanus* zones.

Certainly the majority of the sections in Lincolnshire fall within the Lower Kimeridge Clay. The general succession seems to be normal, consisting of the usual dark clays with some cementstone bands, but much work still remains to be done on the palaeontology. An extremely interesting feature is the representation of the *Gravesia* zones, indicated by the raising of specimens of supposed *Gravesia* in the Donnington boring from a depth of 70 ft. below the top of the Kimeridge Clay. At 179 ft. from the top was found *Aulacostephanus eudoxus*. The absence of *Exogyra virgula* is remarkable, and seems to be a characteristic feature of the tracts north of the Wash. Bands of brown bituminous shale, on the other hand, occur more frequently and at much lower horizons than in any other part of England. They closely resemble the 'Kimeridge Coal' and give a similar yield of oil and other products, all strongly contaminated with sulphur. The lowest bands fall within the zone of *Aulacostephanus pseudomutabilis*.

The beds below the *Aulacostephanus* zones are best known from the renowned brickyards of Market Rasen, the type-locality of the genus *Rasenia* where the ammonites are in beautiful iridiscent and pyritic preservation. The commonest species here is *Rasenia cymodoce*. The zone has also been worked at Brigg and at Horncastle, where in addition *Pictoniæ* are recorded. Roberts noted that *Astarte supracorallina* has a longer range in Lincolnshire than in Cambridgeshire, occurring throughout the Lower Kimeridge; and that '*Ammonites alternans*', which he used as a zone fossil, attains its acme at a lower level. (It would include *C. kitchini*, *C. pingue*, and *C. cricki* of Salfeld.)[2]

The basement-beds of the Kimeridge Clay were recognized by Roberts at Woodhall Spa, West Barkwith and North Kelsey, crowded as usual with *Ostrea delta*.

V. THE MARKET WEIGHTON AXIS

It is certain that the Kimeridge Clay, like the Oxford and Corallian Clays, becomes extremely thin on approaching the Market Weighton Axis, for in South Yorkshire the three together measure little more than 100 ft. in thickness. Owing to the lack of exposures no boundaries have been drawn between the three formations, but 'in a general way, the Oxford Clay may be taken as occupying the flatter part of the ground just above the Kellaways Rock, while the Kimeridge Clay forms the steep slopes beneath the Chalk escarpment'.[3] Definite evidence for the presence of Kimeridge Clay is scanty, and it is improbable that any is present north of Drewton. Between the Humber and Drewton the Cretaceous rocks probably overstep all but the lowest zones,[4] so that the full thickness is nowhere present and the effects of the Market

[1] J. F. Blake, 1875, *Q.J.G.S.*, vol. xxxi, p. 201.

[2] Ibid., pp. 206–9; T. Roberts, 1889, *Q.J.G.S.*, vol. xlv, pp. 551–8; H. B. Woodward, 1895, *J.R.B.*, pp. 173–7; H. Salfeld, 1914, loc. cit., Table I, 1915, loc. cit., pl. XIX, figs. 1–17.

[3] C. Fox-Strangways, 1892, *J.R.B.*, p. 299.

[4] In a boring at Ferriby, near Hull, Red Chalk was found to rest either on the basal part of the Kimeridge Clay or on clays of Corallian age: J. Pringle, 1921, *Sum. Prog. Geol. Surv.* for 1920, p. 63.

Weighton Axis upon sedimentation in Kimeridgian times will never be known quantitatively.

On the north side of the Chalk Wolds the Kimeridge Clay does not appear at the surface until Acklam and North Grimston, a considerable distance from the axis, and by then the northerly thickening has already set in.

VI. THE YORKSHIRE BASIN

In the Yorkshire Basin the Kimeridge Clay floors the Vale of Pickering, bounded on the north by the rising dip-slope of the Corallian Moors and on the south mainly by the steep escarpment of the Chalk Wolds. Along the eastern part of the Vale, where the southern boundary is so formed by the overstepping Chalk and subjacent Speeton Clay, the structure is in essential features the same as that of the Vale of the White Horse, where the Gault protruding from the foot of the Downs is in contact with the Kimeridge Clay. In the western part of the Vale of Pickering the clay area is bounded on the south by the Corallian rocks of the Howardian Hills, the junction being largely faulted (see map, p. 138).

The greater part of the outcrop of the Kimeridge Clay, forming as it does the lowest tracts of the vale, is thickly covered by the alluvial deposits of the Pleistocene Lake Pickering, and exposures are scarce. Along the south side the alluvium laps up to the foot of the Wolds and the Corallian hills, covering the 'solid' formations to an average thickness of 90 ft. Only for a short distance where the Chalk escarpment turns southward, from Wintringham to Grimston, Birdsall and Acklam, does the Kimeridge Clay break through, and it is repeated in a faulted inlier south-west of Malton. Along the north side of the Vale outcrops are more numerous, but the consequent streams running down from the moors have dissected a once continuous rim of clay into a series of tongues and outliers. East of Brompton the clay becomes entirely hidden beneath the superficial deposits.

The east end of the Vale of Pickering, where good coast-sections might have been expected, is completely blocked with Drift. Under Filey the surface of the Kimeridge Clay is below sea-level, but towards the south end of the bay it rises sporadically above low-tide mark and towards Speeton it forms the base of the cliff, beneath the slipped masses of Cretaceous clays and Chalk. The dip, however, is southerly and soon brings the Cretaceous rocks down to beach-level.

The Speeton cliffs present at first sight a hopeless spectacle, a jumbled mass of slips, largely covered with mud. In the course of a century, however, geologists, chief among whom was the late G. W. Lamplugh, have watched the sections and, by piecing together the information obtained at different times when opportunities were favourable, after the beach has been swept clear by a storm, have succeeded in reconstructing the succession and collecting numerous fossils *in situ*. The state of the cliffs is always slowly but surely changing, and passes through cycles alternately favourable and unfavourable for collecting. The present century has so far been an unfavourable period, but two favourable occasions occurred in the thirties and again in the seventies and eighties of the last century. Of the later of these Lamplugh, who lived near at hand, was able to take full advantage.[1]

[1] G. W. Lamplugh, 1896, *Q.J.G.S.*, vol. lii, pp. 179–220; and 1924, *Proc. Yorks. Geol. Soc.*, N.S., vol. xx, pp. 1–31.

The stratigraphical work accomplished by Lamplugh provided a sure foundation for palaeontological researches, which culminated a few years ago in the application of Dr. L. F. Spath's wide experience of Cretaceous cephalopods to the ammonites collected at Speeton during the past century.[1] He was able to dispel finally the idea, already refuted two years previously by Dr. Kitchin and Dr. Pringle,[2] but still embodied in nearly all text-books, that there are at Speeton argillaceous representatives of the Portland Beds and 'passage-beds' between the Jurassic and Cretaceous. He found the '*Belemnites lateralis* zone', containing the earliest ammonitiferous beds above definite Kimeridge Clay, to be well up in the Valanginian (Lower Neocomian). At the base of the Cretaceous is a layer of phosphatic nodules (the Coprolite Bed), in which are embedded derived Kimeridge ammonites, and this Lamplugh correlated with the similar phosphatic nodule-bed at the base of the Spilsby Sandstone in Lincolnshire; both beds rest non-sequentially on the Kimeridge Clay. Lamplugh's correlation still stands, but over the whole region the strata immediately above the nodule-bed are now known to be of Neocomian date, and to be separated from the Jurassic rocks beneath by a long time-interval. At Speeton, according to Dr. Spath, 'there is a complete absence of the uppermost Kimeridgian, the whole of the Portlandian, the Tithonian (= Purbeckian), the Infra-Valanginian (= 'Upper Berriasian'), and the lowest Valanginian formations' [3]—an enormous non-sequence, but detected solely as the result of modern discrimination in ammonite identification.

The Coprolite Bed, or basal conglomerate of the Cretaceous, contains, among other rolled ammonites, species recorded as '*Olcostephanus*' and '*Virgatites*'[4] (? *Virgatosphinctoides*). Beneath have been seen some 40 ft. of dark shaly clays with compressed fossils and large septaria, but no detailed study of the ammonites has yet been published. Lamplugh recorded *Virgatites* sp. [? *Virgatosphinctoides*]. According to Danford 80 per cent. of the Belemnites belong to *Cylindroteuthis porrectus* (Phil.), as identified by Pavlow (? *C. tornatilis* Phil. sp.).[5] The beds are much contorted, probably as the result of squeezing by large masses of Drift or even by ice. The lowest levels exposed may sometimes be seen at low tide on the shore near Butcher Haven, 1¾ miles south of Filey. They consist of pale blue shaly clay with pyritous nodules, overlain by dark shales with large septaria, in which Lamplugh collected species of *Aulacostephanus*. Salfeld stated that *Aulacostephanus pseudomutabilis*, *A.* ? *yo*, and also *Pictonia* occurred in Filey Bay, but the last was probably from the Drift.[6]

The middle and lower portions of the Kimeridge Clay have been exposed inland in some small brickyards scattered round the rim of the western end of the Vale of Pickering. Since the old records of ammonites when accepted without revision are often misleading, little can usefully be said regarding the

[1] L. F. Spath, 1924, *Geol. Mag.*, vol. lxi, pp. 73–89.
[2] F. L. Kitchin and J. Pringle, 1922, *Geol. Mag.*, vol. lix, p. 197.
[3] L. F. Spath, 1924, loc. cit., p. 80.
[4] H. Salfeld, 1914, loc. cit., Table I.
[5] C. G. Danford, 1906, *Trans. Hull Geol. Soc.*, vol. vi, pt. i, pp. 1–14; and M. Lissajous, 1925, *Répertoire alph. Bélemnites jurass.*
[6] Isolated outcrops of shale appear from time to time in the cliffs nearer Filey, but their fossils prove them to be transported masses of Lias.

representation of the various zones. The lower layers of the shales are usually characterized, as in other parts of England, by large numbers of *Ostrea delta*. In the Coxwold rift valley Fox-Strangways mentions that '*Ammonites biplex* is rather abundant, and a *Discina* [*Orbiculoidea*] occurs'. In a brickyard at Hildenley, Hudleston records the basement-beds with *Ostrea delta*, *Exogyra nana*, &c., and '*Ammonites mutabilis*', suggesting the *Rasenia* zones. The same beds were also to be seen in the brickyard at North Grimston.[1]

The total thickness of the Kimeridge Clay in the Yorkshire basin has never been accurately determined. Borings along the northern and western rims of the Vale of Pickering pass through only the lower beds. On the south a boring at Knapton, close under the Chalk Wolds, penetrated 500 ft. of clay without reaching the bottom. The cores were not critically examined, however, and besides the probability that some of the clays were Cretaceous, there is a possibility that part of the Corallian formation is there represented by an argillaceous development, and that the boring came to an end in a representative of the Ampthill Clay. South of Wass, in the Coxwold fault-valley, a boring proved a thickness of 400 ft. of blue shales, and there are other records from different parts of the county indicating from 200 to 320 ft. A conservative estimate of the maximum thickness could safely be made at 400 ft.

VII. EAST SCOTLAND

(a) The Brora and Helmsdale District, Sutherland

The evidence for another basin of deposition off Eastern Scotland in Kimeridgian times is limited to a strip of rocks along the coast, now nowhere more than half a mile wide. But although forming a mere selvage, they occupy the foreshore and low cliffs beneath the raised beaches for a distance of over 11 miles and provide some of the most interesting and instructive Mesozoic sections in all Scotland (map, p. 151).

The outcrop is widest at the south end, where the basal zones first succeed the Corallian formation near Kintradwell, 2 miles north of Brora, and gradually dwindles northward, finally running out to sea near Dun Glas, north-east of Helmsdale. With the disappearance of the Jurassic rocks near Helmsdale the railway, which has been able to follow the coast from Golspie, is obliged once more to turn inland. With this sign that the coastal platform has come to an end, the last occurrences of Kimeridgian rocks become mere excrescences, hanging, as it were, from the steep wall of the Helmsdale Granite.

Not the least interesting features on this coast are several fine sections across the Ord Fault, by which the Jurassic rocks have been lowered into their present position. On the small headland of Dun Glas the downthrown rock can be seen dipping seaward at a high angle from the fault-plane, and in Navidale Bay a mass of sandstone belonging to the base of the Kimeridge series is caught up in the fault, and deceived Judd into thinking that it was in position above the local Kimeridgian—here probably of *Gravesiæ* date. At this point a throw of at least 700 ft. is therefore proved; but the fact that the Kimeridge Clay is now in contact with the granite suggests that the total throw is somewhere about 2,000 ft.

[1] C. Fox-Strangways, 1892, *J.R.B.*, pp. 375–6.

Owing to almost endless repetition by small fractures and folds, and to the highly variable lithology of the deposits, it is well nigh impossible to describe a continuous section or to arrive at the total thickness by direct measurements. The Survey estimated at least 700 ft., but Prof. Bailey and Dr. Weir measured over 1,000 ft. in unbroken succession and consider the total thickness to be at least 1,500 ft. Even if the whole of the formation were represented, these figures would be great, but modern zonal study by the Survey has proved that the highest strata present cannot be younger than *Gravesiæ* date.[1] The whole of the beds therefore fall within the Lower Kimeridge Clay, below the Yellow Ledge Stone Band of Kimeridge Bay.

The most remarkable feature of the sections is the presence of Boulder Beds intercalated in the series through almost the entire length of the outcrop (Pl. XXII).[2] The boulders are of all sizes up to huge masses many yards in circumference, and most of them are sharply angular, though some are more or less rounded. Here and there they are intermingled with smaller well-waterworn pebbles. Hugh Miller was the first to point out that the boulders contain fish-remains, such as *Gyroptychius* and *Osteolepis*, proving them to have been derived from the Old Red Sandstone.

The boulders usually lie along definite levels, where they protrude as numerous ledges averaging 5 or 6 ft., but sometimes up to 50 ft., in thickness, separated by dark shales. The shales are puckered and squeezed down under them, as if the boulders had fallen on them before they became consolidated. Occasionally, as at Dun Glas, little or no shaly matrix separates the boulders, which then form great thicknesses of breccia.

The largest of all the boulders is a huge mass of Old Red Sandstone popularly known as the 'Fallen Stack', measuring 150 ft. in length, 90 ft. in width and about 30 ft. in height. It lies on the shore, almost covered at high tide, a quarter of a mile south of Portgower, where it is a well-known landmark from the railway (see Pl. XXII). As it lies on its side the bedding-planes in the sandstone stand vertically, giving the impression very strongly of a fallen erosion-pinnacle or stack, such as are common round the coasts of Caithness at the present day. Yet it is only the largest of many blocks in a boulder-bed 50 ft. thick, underlain by shales and other boulder-beds for hundreds of feet.

Many theories have been put forward to account for these extraordinary beds. Nearly all the explanations suggested during last century involved, in some way or another, glacial action, whether by floating ice, glaciers, rain, snow and frost, or an ice-sheet. But, as Dr. Macgregor has pointed out, a glacial origin is discountenanced by the absence of Drift or striæ, by the fact that the boulders are too angular and too constant in their composition, and finally by the fauna and flora of the intercalated shales; both are of decidedly warm-temperate aspect, in no way incongruous with the fauna and flora of the rest of the British province at that time.

Thus we are bound to conclude that the boulders fell from a cliff, and moreover, a cliff composed exclusively of Old Red Sandstone; for the boulder-

[1] Part of a large ammonite found by H. B. Woodward and taken for '*A. giganteus*' and therefore as indicative of Portland Beds (*Q.J.G.S.*, 1902, vol. lviii, p. 310) is now considered to be a *Gravesia*.

[2] For the best account of these beds see G. W. Lee, 1925, 'Geol. Golspie', pp. 103–13, *Mem. Geol. Surv.*

Photo. *W. J. A.*

'The Fallen Stack', Portgower, near Helmsdale.

The bedding-planes of the Old Red Sandstone stand vertically. The scale is shown by a cormorant standing on the right hand end.

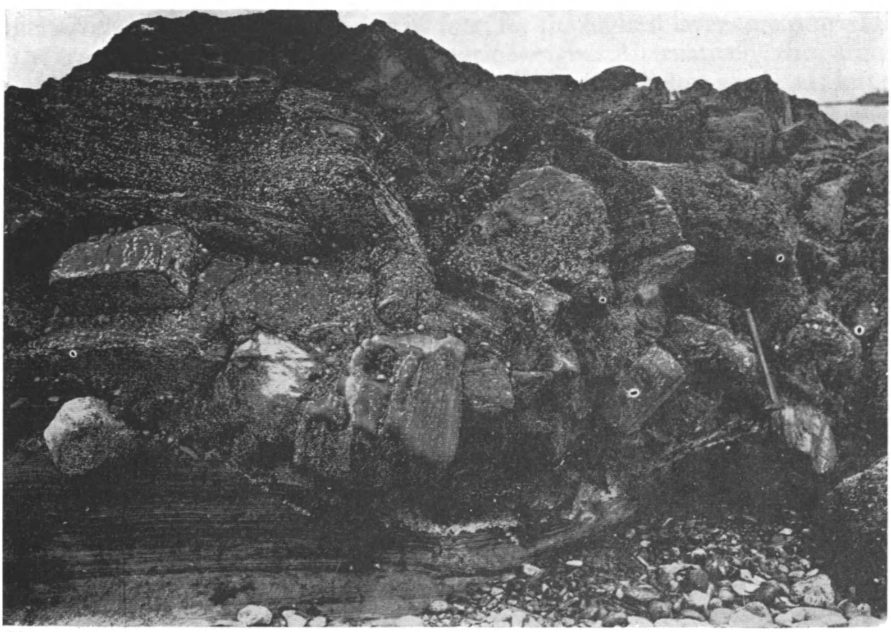


Photo. *Geol. Survey.*

Kimeridgian Boulder Bed, near Portgower, Sutherland.

Tumbled blocks of Old Red Sandstone interbedded in Lower Kimeridge shales of the *Aulacostephanus* zones.

beds contain no other material, although for several miles they now abut against granite. That part of the movements which brought up the granite into its present position along the Ord Fault must, therefore, have been mainly subsequent to the formation of the beds.

The explanation of the boulder-beds as under-water and shore talus fallen from a cliff was first arrived at by H. B. Woodward in about the year 1891, but his conclusions remained in manuscript until 1902,[1] and it was not until 1910 that a condensed account was published in Prof. Seward's monograph on the Jurassic Flora of Sutherland. The theory has been more recently elaborated by Dr. Macgregor in a paper entitled 'A Jurassic Shore Line', in which the history of previous investigation is usefully summarized.[2] It is implicit in this theory that, by an almost miraculous chance, modern coast-erosion and the Ord Fault have interacted in such a way that they have brought about a coincidence of the present shore with a shore of Lower Kimeridge date; and further, that both shores chanced to coincide with the line of the Ord Fault.

To such a chain of coincidences there are obvious objections, and Prof. Bailey and Dr. Weir deny the possibility that the boulders could have fallen from any ordinary sea-cliff.[3] They point out in the first place that there is at the foot of every cliff a platform of erosion upon which the talus falls, but that nowhere along these eleven miles of continuous exposures has any sign of the necessary platform been found; instead, boulder-beds and shales alternate for a thickness of at least 1,000 ft., until the Corallian strata rise conformably from beneath. Even the 'Fallen Stack', they remark, cannot have fallen on its side and remained there ever since, as its popular name implies, for it has no base. Below it are hundreds of feet of shales and other boulder-beds, proving that it must have been transported. In the second place, the cliff would need to have been at least 1,000 ft. high and to have been sinking progressively as the talus collected at its foot, for the highest layers are proved by the associated fossils to be still of submarine origin. Alternatively, they argue, it was much higher and 1,000 ft. of it was all the time below sea-level; but at such a depth, whence came the many large blocks of reef-corals lying loose among the debris?

The facts are ingeniously explained by Prof. Bailey and Dr. Weir in a theory elaborated at the centenary meeting of the British Association in 1931. The proximity of the boulder-beds to the Ord Fault for so many miles they hold to be no chance coincidence, but rather an indication that the cliff from which the blocks fell was none other than the fault-scarp. They explain the absence of a platform of erosion at the foot of the cliff, and the great thickness of the boulder-beds and shales, by supposing that movement was already taking place along the fault, as it was along the Peak Fault. It is visualized as having lain beneath the sea, not far from the shore. On the upthrown side, towards the land, grew the massive corals and shallow-water lamellibranchs; on the downthrown side was tranquil, deep water, in which ammonites and drifted plant-remains became entombed in fine, muddy sediment.

Sporadically, differential movement was renewed and the sea-bed on the outer side of the fault sank a step deeper, causing a seismic wave. At the same

[1] H. B. Woodward, 1902, *Q.J.G.S.*, vol. lviii, p. 205, and p. 310.
[2] M. Macgregor, 1916, *Trans. Geol. Soc. Glasgow*, vol. xvi, pp. 75–85.
[3] E. B. Bailey and J. Weir, 1932, *Rept. Brit. Assoc.* for 1931, pp. 375–6.

time blocks of Old Red Sandstone of all sizes would break away from the submarine cliff and slide down into the muds collecting below, followed by a debris of corals, shells and sand torn from the upper platform by the force of the wave. Then all would lapse into temporary quiescence once more, until the next earthquake.[1]

In recent years the work of the Scottish Geological Survey has thrown much new light on the fauna associated with these remarkable Kimeridgian beds. In places they are very shelly, though usually it is difficult to obtain even passably unbroken specimens. The commonest fossils are oysters and belemnites, while Pectens, Limas, &c., abound at several horizons, with more or less crushed ammonites.

The highest part of the sequence, at Navidale, north of Helmsdale, yielded fragmentary specimens of a large Perisphinctid, which Messrs. Kitchin and Pringle compare with forms occurring in the *Gravesia* zones. The zone having the widest extent of all is that of *A. pseudomutabilis*, and it is from this that most of the fossils have been procured. The commonest forms from this and the underlying zones are *Lima concentrica* (Sow.), *Ctenostreon proboscideum* (Sow.), *Chlamys* cf. *quenstedti* (Blake), *Ostrea delta* Smith, *Exogyra nana*, *E. virgula*, and various belemnites. Fragments of *Ichthyosaurus* and *Pliosaurus* skeletons have also been found.

Among the most interesting components of the fauna are the large loose blocks of reef-coral, *Isastræa oblonga* (Flem.) and rarely *Stylina alveolata* (Goldf.),[2] which are sometimes so numerous after having been torn up during storms that they are collected from the beach by the inhabitants for lime-burning. They appear to be as foreign to the muddy shales in which they are found as the blocks of Old Red Sandstone, and Prof. Bailey's suggestion that they have been swept down from a shallow-water platform on the upthrown side of the fault is the only explanation yet offered to account for them. This was the most northerly station of reef-building corals in Mesozoic Europe.

Other conspicuous fossils, not uncommon in certain places, are *Terebratula joassi* Dav. and *Rhynchonella sutherlandi* Dav., neither of which has been found outside Sutherland. The *Rhynchonella* is one of the largest species known. Its restriction to this locality is reminiscent of the local distribution of several other large brachiopods in the earlier formations in England.

The *Rasenia* zones both rise to the surface in the southern part of the outcrop, about Loth and West Garty. They consist of a hundred feet of shales, interlaminated with thin seams of hard fine-grained sandstone, and Buckman has named them the LOTH RIVER SHALES. They stand in marked contrast with the *Aulacostephanus* shales above, owing to the absence of boulders. The best section is to be seen in the left bank of the Loth River, beneath the railway bridge and in the railway cutting north of it. The Survey have obtained fragmentary ammonites identified by Buckman as *Rasenia* cf. *stephanoides*, *R.* cf. *cymodoce*, *R.* cf. *uralensis*, *R.* cf. *circumplicatus* and *Amœboceras* sp.; *Lima concentrica* is also common.[3]

[1] The first statement of this theory, with a fuller discussion of earlier analogues, appeared in E. B. Bailey and others, 1928, *Journ. Geol.*, vol. xxxvi, pp. 577–614.

[2] J. Pringle, &c., 1930, *P.G.A.*, vol. xli, p. 78.

[3] S. S. Buckman, 1923, *T.A.*, vol. iv, pp. 40–4; the ammonites are so fragmentary, however, that the identifications are doubtful.

Under the railway bridge the base of the Loth River Shales is seen resting on thick beds of white sandstone separated by black carbonaceous layers. The sandstone becomes less divided by black partings towards the sea, where it forms conspicuous buttresses of white rock beside the Loth River estuary. Here it seems to be entirely unfossiliferous, but a mile farther south, in the gorge cut by a stream named Allt na Cuile (where nearly 100 ft. are seen), some of the beds of sandstone are crowded with casts of fossils.

The position of the ALLT NA CUILE SANDSTONE in the zonal table still remains to be settled. H. B. Woodward originally mapped it as Corallian, but Buckman identified *Rasenia* and *Pictonia* in it and concluded that it belongs to the Kimeridge Clay, and Lee accepted his conclusion.[1] More recently the Scottish Survey officers have reverted to Woodward's classification.[2] The ammonites are all small and in the form of casts, not fit for specific determination, but if Buckman's identifications are right there can be no question as to the correct position of at any rate the highest part of the sandstone, in which the principal fossil-bed occurs (8 to 12 ft. from the top). Lee considered, indeed, that part of the sandstone replaced part of the Loth River Shales laterally.[3] The principal members of the fauna are Rhynchonellids, which, in the condition of casts showing the muscle-scars, offer a field for minute investigation which might settle the question. The lamellibranchs, though principally of Corallian species, are inconclusive; more Corallian species occur in the Clynelish Quarry Sandstone, which is dated by its ammonites to the Upper Oxford Clay. Moreover, a fragment of a large *Velata* from near the base of the Allt na Cuile section, preserved in the Scottish Geological Survey office, Edinburgh, is definitely not of any Corallian species known in England. The occurrence of spines of *Cidaris smithi* near the base cannot be regarded as of any great significance, for in Dorset the spines abound on the borderland of the highest Upper Calcareous Grit and the lowest Kimeridge Clay, in the Ringstead Coral Bed (see above, p. 379).

Not the least interesting feature of the remarkable Kimeridgian deposits of Sutherland is a rich and varied fossil flora. Petrified wood is found in the Boulder Beds and shales, and leaves and fronds occur in the shales and sandstones. They have been made the subject of two monographs by Prof. Seward, who recorded sixty-five species of plants, comprising Wealden or Upper Jurassic, Middle, and Lower Jurassic species.[4]

The abundance of land plants in the Kimeridge Clay of Sutherland testifies to the proximity of a shore-line during the time they were deposited, but there is no evidence to justify calling the deposits estuarine, as has often been done.

(b) **Ross-shire**[5]

The sections showing Corallian Beds at Port-an-Righ (above, p. 434) do not extend above that formation, but the presence of submerged Kimeridge Clay off-shore is proved by fossiliferous nodules which are washed up on the beach. From these have been obtained ammonites of several genera

1 S. S. Buckman, 1923, *T.A.*, vol. iv, p. 40.
2 1930, *P.G.A.*, vol. xli, pp. 76–7.
3 G. W. Lee, 1925, loc. cit., p. 106.
4 A. C. Seward, 1911–13, see bibliography.
5 G. W. Lee, 1925, loc. cit., pp. 114–15.

characteristic of the zone of *Pictonia baylei—Pictonia*, *Prionodoceras* (several) and *Dichotomoceras*.

Some 6 miles farther south, on the opposite side of the Cromarty Firth, a minute exposure of Kimeridge Clay is visible at low tide on the foreshore at Ethie. The beds, which are much disrupted owing to proximity to the boundary fault, consist of carbonaceous shales, sandstones, grits, bituminous shales and limestones, with fossils of the *Rasenia cymodoce* zone and plant-remains. Some of the fossils are exceptionally well preserved. From this locality were obtained the type-specimens of *Lima concentrica* (Sow.), *Amœboceras kitchini* (Salf.), *A. pingue* (Salf.), *Cylindroteuthis obeliscus* (Phil.)[1] and *C. spicularis* (Phil.),[1] as well as the types of several plants.

VIII. THE HEBRIDEAN AREA

The valuable researches of Mr. Malcolm MacGregor in North-east Skye, already referred to in Chapters XII and XIII, have revealed that Kimeridge Clay is present at the north end of the peninsula of Trotternish. I am indebted to Mr. MacGregor for very kindly communicating for this book an advance account of his discoveries.

The best section is on the foreshore at Kildorais, 2 miles north-west of Staffin, where about 100 ft. of shales are seen between tide-marks, tilted almost vertically. From the lower part of the shales Mr. MacGregor obtained specimens of *Prionodoceras* and *Dichotomoceras*, and from the upper part numerous *Pictoniæ* and occasional *Raseniæ*; and in addition a form which was identified in London as ? *Aulacostephanus pseudomutabilis*. The lower parts of this succession were again discovered in a quarry in the grounds of Flodigarry House, and also not far from the Oxford Clay exposure on the foreshore on the north side of Staffin Bay.

Kimeridge Clay has also been detected by Dr. Spath, he kindly allows me to state in advance of publication, in the Island of Mull. He has recognized the presence of numerous *Raseniæ* and Amœbocerates among a collection made there by the Survey and assigned by Buckman to the '*Reineckeia* zone' (= *kœnigi* zone), or Kellaways Beds (see p. 371 for further particulars).[2]

The importance of these discoveries is obviously great, for they prove that marine deposition continued normally in the Hebridean Area as long as in East Scotland, and the community of fossils indicates that the two areas were in connexion.

IX. KENT[3]

The concealed outcrop of the Kimeridge Clay beneath the Cretaceous rocks of Kent is rather wider than that of any of other Jurassic formations. It underlies the coast from a little south of Dover to Folkestone, at which place it is succeeded by the Portland Beds; maintaining a constant width of about 5 miles it then strikes inland in a north-westerly direction, which soon changes to west north-westerly. West of the railway from Canterbury to Ashford its boundaries have not been determined.

The thickness increases from east to west, and the study to which the fossils

[1] Not Oxfordian species as generally supposed (e.g. in Lissajous's catalogue).

[2] L. F. Spath, 1932, *Med. om Grønland*, vol. lxxxvii, no. 7, p. 149 (now published).

[3] Based on Lamplugh and Kitchin, 1911, loc. cit.; and Lamplugh, Kitchin and Pringle, 1923, loc. cit.

from the borings were subjected by the Survey led them to the conclusion that the 44 ft. of Kimeridge Clay at Dover might be represented by 138 ft. at Brabourne and by a still greater thickness at Pluckley, west of Ashford. The separation of this thickening from the effects of pre-Cretaceous erosion was only made possible by close attention to palaeontological zones.

At Penshurst 622 ft. of Upper Kimeridge Clay and Portland Sand-equivalents were proved, although the boring was stopped before it reached the base of the *Virgatosphinctoides* zones. At Pluckley the Lower Clays exceeded 300 ft. up to the top of the *Gravesia* zones, and may have been 350 ft. thick, so that the total maximum thickness of the Kimeridge Clay in Kent (including perforce the equivalents of the Portland Sand) must be close on 1,000 ft., or rather more than the development in Dorset.

The highest beds were penetrated in the most westerly boring at Penshurst, south-west of Tonbridge, where about 250 ft. of sandy clay overlies the *pallasioides* zone. Of this about 100 ft. is believed to represent the Portland Sands of Dorset (including the *gorei* zone).[1] Palaeontological evidence as to the exact stratigraphical position of these highest beds is meagre. Some unidentified ammonites were found, likened to some from the beds above the *pallasioides* zone of Hounstout Cliff, and there were also a species of *Grammatodon* and two or three other lamellibranchs of doubtful correlative value, but the exact positions of these in the Hounstout sequence (p. 446) has not been shown. More will be said on this subject in the next chapter on the Portland Beds.

At Ottinge and Brabourne the Portland Stone rests non-sequentially upon clays yielding ammonites believed to indicate an horizon about 300 ft. lower than those immediately below the stone-beds at Penshurst and Pluckley, namely the *pallasioides* or even the *rotunda* zone—an unconformity comparable with that in Wiltshire, Oxfordshire and Bucks.

The *pectinatus* and *Virgatosphinctoides* zones (as then understood, now including the *Subplanites* zones) were proved at Pluckley and were probably penetrated at Brabourne and Ottinge. They consist of shaly clays as in Dorset, with flattened ammonites, which have been discussed at length by Messrs. Kitchin and Pringle, for the most part under the name '*Pseudovirgatites*'. Associated with them, also, were numerous pyritized radial plates of *Saccocoma*, which were taken to correlate with the oil-shale of Kimeridge. According to Messrs. Kitchin and Pringle, *Modiola* (*Musculus*) *autissiodorensis* (Cott.) makes its appearance near the base of the zones and ranges up into the Portland Sand, being one of the commonest bivalves of the Upper Clays in Kent. Other common shells are *Protocardia morinica* (de Lor.), *Astarte* cf. *mysis* d'Orb. and *Aporrhais* cf. *piettei* (Buv.).

The Lower Kimeridge Clay was penetrated at Brabourne, Pluckley, Lower Standen, Abbotscliff and Dover. Wherever it was seen, it proved to be more sandy and calcareous than the Upper Clay. Palaeontologically it was separable with equal ease by the presence of *Exogyra virgula* and the absence of *Modiola autissiodorensis*.

Near the top of the Lower Clay a fragment of Perisphinctid was found agreeing with *P. bleicheri* (de Lor.), an ammonite of the *Gravesia irius* zone near Boulogne, and other fragments have been described as possibly repre-

[1] Lamplugh, Kitchin and Pringle, 1923, loc. cit., p. 228.

senting species of *Gravesia*. A notable feature of this zone was a *Trigonia* bed containing abundant *T. pellati* Mun.-Chalm., identical with a bed in the *Gravesia irius* zone at Boulogne.

The *Aulacostephanus* zones, although probably developed normally, yielded no ammonites, but their presence was thought to be indicated by the occurrence of *Protocardia morinica* at a considerable distance above beds with *Rasenia*. In Dorset this *Protocardia* makes its appearance in the Upper *Aulacostephanus* zone, that of *A. pseudomutabilis*, below Maple Ledge. Another bivalve of the same zone which occurred abundantly at Brabourne and Abbotscliff was *Astarte ingenua* de Lor.

The *Rasenia* zones proved more fossiliferous, yielding at levels 10 ft.–30 ft. above the base of the Kimeridge Clay such species as *Rasenia* cf. *stephanoides* (Oppel), *R.* (?*Prorasenia*) *witteana* (Oppel), *Pararasenia desmonota* (Oppel), ?*Involuticeras trimerus* (Oppel), *Physodoceras orthocera* (d'Orb.), recalling the upper part of the Abbotsbury Iron Ore and the clay of the type-locality of Market Rasen. At Dover a specimen of *Rasenia* was found only 12 ft. below the Cretaceous.

The *Pictonia baylei* zone cannot be more than 10–20 ft. thick and is probably less, since no ammonites that would prove its presence have been found. As in other parts of England, however, the lowest part of the Kimeridge Clay is full of *Ostrea delta* and *Exogyra nana*.

Postscript Note:—On the eve of going to press an important paper has come to hand by E. B. Bailey and J. Weir on 'Submarine Faulting in Kimmeridgian Times in East Sutherland', *Trans. Roy. Soc. Edinburgh*, vol. lvii, Dec. 1932, pp. 429–67. The authors elaborate their theory referred to above, pp. 475–6, and claim to have established the following facts: During Kimeridgian times a submarine fault-scarp was maintained by intermittent movement of the sea-floor of the Helmsdale district, while dry land existed a little to the north-west. The aggregate movement of the fault much exceeded 2,000 ft. The fault-scarp separated a comparatively shallow-water facies from a comparatively deep-water facies. Frequent earthquakes caused landslips along the scarp and spread out the debris of Old Red Sandstone in graded boulder-beds in a manner indicating the co-operation of tunamis ('tidal waves'); the movements also opened fissures in the Kimeridgian and produced a chasm-breccia along the fault. Analogues are pointed to in Britain, Switzerland, Canada, and the United States. In addition, the *Gravesia* zones are established at several localities, and the *Subplanites* zone is believed to exist at the northern extremity of the Kimeridgian outcrop.

CHAPTER XV
PORTLAND BEDS

Zones (Plate XL).		STRATA.		
		Dorset.	*Swindon.*	*Bucks.*
Titanites titan and *T. giganteus* [1]	PORTLAND STONE.	Freestone Series 40–50 ft.	Creamy Limestones 10 ft.	Creamy Limestones 7–12 ft.
Kerberites kerberus [2] and *K. okusensis* [3]	PORTLAND STONE.	Cherty Series 60–70 ft. Basal Shell Bed 8 ft.	Swindon Sand and Stone 25 ft. Cockly Bed 4 ft.	Crendon Sand 5–6 ft. Rubbly Limestones 6–12 ft.
Glaucolithites gorei [4] and *G. glaucolithus* [5]	PORTLAND SAND.	Portland Sand 100–20 ft.	Glauconitic Beds $3\frac{1}{2}$ ft. Upper Lydite Bed	Glauconitic Beds 5–10 ft. Upper Lydite Bed.
Provirgatites scythicus [6]	PORTLAND SAND.		—	—

I. THE DORSET COAST

(a) The Isle of Purbeck

THE Isle of Purbeck owes to the Portland Beds some of the grandest coastal scenery in the South of England. From Durlston Head, south of Swanage, westward for 6 miles to St. Alban's (or more correctly St. Aldhelm's) Head, the Stone Beds ascend sheer from the sea in a perpendicular wall of rock, unscalable, and inaccessible except by boat. Above the cliffs, the home of the sea-aster, the sea-campion, the samphyre and the thrift, the Purbeck Beds rise as grassy slopes to a level of 400 ft.

Here the strike coincides with the coast-line and the rocks appear horizontal, but in reality there is a slight seaward dip from the axial anticline of the Isle of Purbeck. At St. Alban's Head, where the coast-line changes its direction to the north, the Portland Beds rise to 500 ft. and cap the precipices of Emmit Hill and Hounstout, their tumbled blocks forming a wild undercliff upon the Kimeridge Clay beneath. From Hounstout they strike inland round the Golden Bowl, just failing to reach the sea in the prominent hill of Swyre

[1] Genotype of *Gigantites* Buckman, but, according to Dr. Spath, Buckman's genera *Gigantites*, *Briareites*, and *Galbanites* are all synonyms of *Titanites* Buckman, 1921. (See Spath, 1931, *Pal. Indica*, N.S., vol. ix, p. 472.)

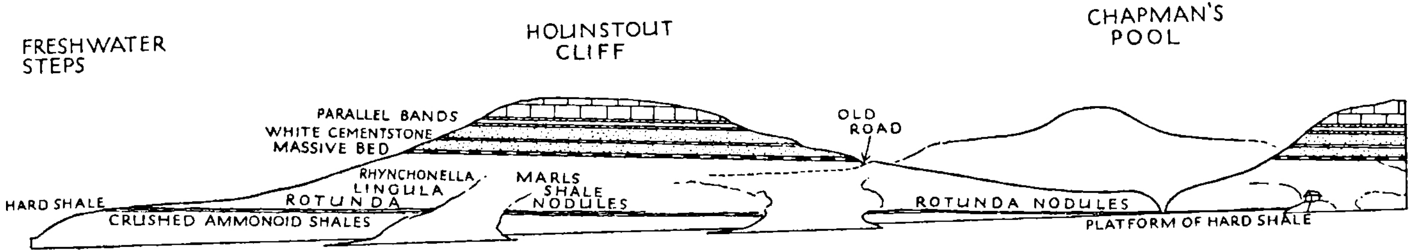
[2] Formerly known as the zone of *Ammonites pseudogigas* Blake, but replaced by Buckman (1926, *T.A.*, vol. vi, p. 26) owing to his selection of a later species of the *Titanites* zone as neotype (*Trophonites pseudogigas* Blake sp., *T.A.*, 1923, pl. CCCLXXXV).

[3] Named by Salfeld (1914, *Neues Jahrb.*, Beil.-Bd. xxxvii, pp. 130, 198–200) and since retained by all writers as alternative zonal index. Made genotype of *Kerberites* by Buckman (*T.A.*, 1925, pl. DLXX).

[4] Name given by Salfeld (loc. cit.) to *Ammonites biplex* de Loriol non Sow. (1867, pl. II, figs. 3–4) and subsequently used by all writers as zonal index. (Not placed generically by Buckman; but see Spath 1931, loc. cit., p. 472.)

[5] Used as hemeral index by Buckman (*T.A.*, 1922, vol. iv, p. 26) for part of the Glauconitic Beds of the Thame–Aylesbury district and figured, loc. cit., pl. CCCVI.

[6] See p. 491



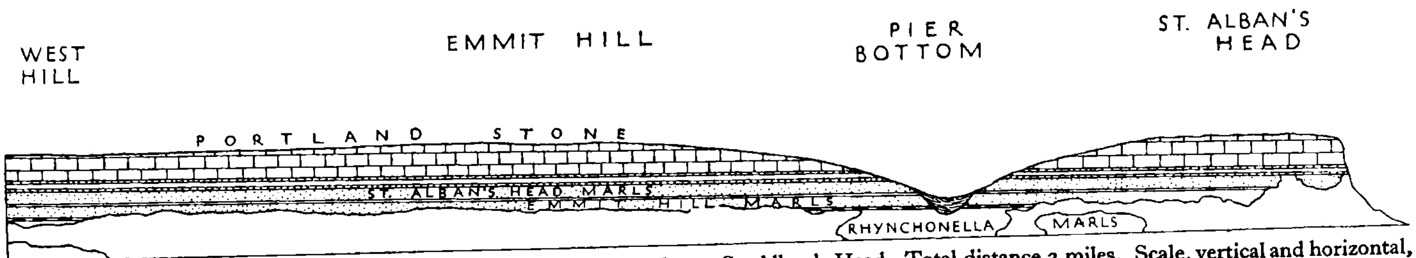


FIG. 80. Section along the cliffs from Freshwater Steps, below Encombe, to St. Alban's Head. Total distance 2 miles. Scale, vertical and horizontal, 7·2 in. = 1 mile. (Outline based on Strahan, 1898, 'Geol. Isle of Purbeck and Weymouth', *Mem. Geol. Surv.*, plates X and XI.)

Head (653 ft.), and after encircling the clay tract about Kimeridge with a bold escarpment, fall rapidly in overhanging crags into the sea at Gad Cliff. Here the dip is steeply to the north, towards the thrust-fault in the Chalk, and it is the predominant dip throughout Purbeck (see Pl. XXV and fig. 77, p. 442). Farther west smaller tracts of Portland Beds rise to the surface on either side of Lulworth Cove, forming the Mupe Rocks, the Man o' War in Man o' War Cove, and the base of the promontory and the famous arch at Durdle Door (Pl. XXVIII). These last fragments are close to the thrust-fault and they are tilted almost vertically.

The maximum thickness of the formation along this coast is about 220 ft., consisting of Portland Stone 110–20 ft. and Portland Sand about 100–20 ft. Since the beds are far more continuously and more extensively exposed than in the island from which they take their name, it is preferable to describe Purbeck first.

The Portland freestone was probably quarried in Purbeck long before the fame of the Portland quarries became known, and it is still wrought under the name of Purbeck-Portland. Its powers of resisting the weather are superior to those of the freestone from the island. The many ancient galleries driven into the cliffs east of St. Alban's Head bear witness to the activities of the past. Most of them have been abandoned for centuries and provided safe retreats for smugglers. The old quarries of Tilly Whim (generally called 'caves') are supposed to have supplied the stone for the building of Corfe Castle, and there is no doubt that some of the forgotten shafts and galleries were being worked in the early Middle Ages, when Swanage was exporting Purbeck Marble for churches, not only all over England, but to all parts of Europe.[1]

The Portland Stone is divisible in Dorset into two, the Freestone Series above and the Cherty Series below, corresponding roughly with the *Titanites* and the *Kerberites* zones.

SUMMARY OF THE PORTLAND BEDS OF PURBECK

The cliffs between Durlston and St. Alban's Heads provide a continuous exposure of almost the whole of the Portland Stone Series, and it is again magnificently exposed in Gad Cliff, Tyneham. In spite of this, the vertical (and in Gad Cliff, overhanging) precipices can be studied only at a few points, such as Tilly Whim, Dancing Ledge, Seacombe and Winspit, where quarrying operations have removed the Upper or Freestone Series, leaving the worthless Cherty Series beneath. At the end of the last century the quarries at Winspit (Pl. XXIII) were still in work, but they have now been deserted for some years. After the Great War there was a revival with modern equipment at the old quarries at Seacombe and St. Alban's Head, but about 1930 both of these ventures became derelict. Now the only locality at which work is being actively carried on is inland, at the Sheepsleights Quarry of the Worth Stone Company, in Coombe Bottom, 1 mile north-west of Worth (fig. 82). No waste occurs, for the principal service to which the stone is put is the making of macadam, and the Cherty Series is used as well as the caps and overburden

[1] In Grabau's *Textbook of Geology*, 1920, pp. 812–13, two photographs of Tilly Whim are given with the inscription 'Tilly Whim Caves: Elevated sea-caves cut by waves in horizontal (Jurassic) strata'. The engraving here reproduced, from Englefield's *Isle of Wight* (see fig. 81), drawn by Thomas Webster in 1811, showing the 'caves' in the making, may be of interest to users of that excellent text-book.

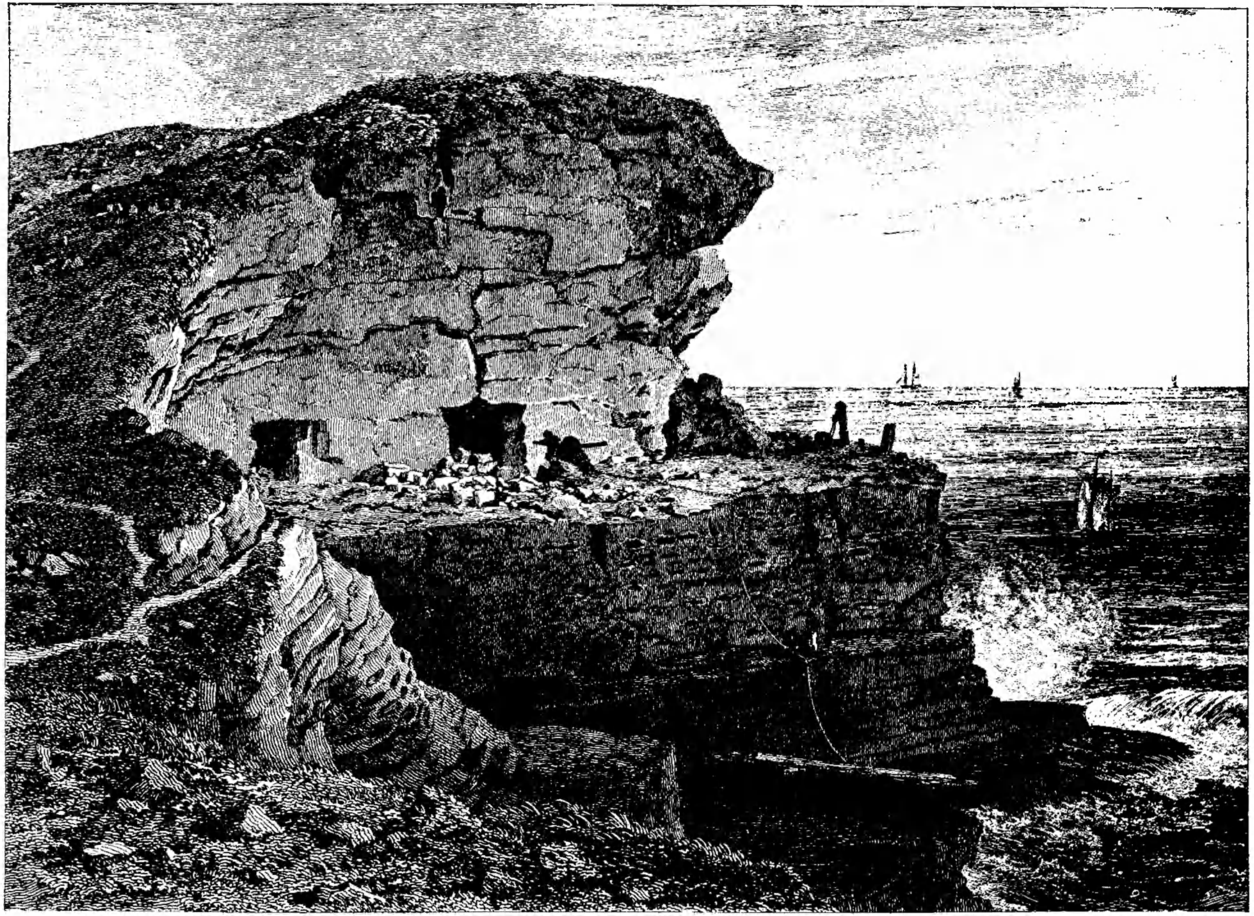


FIG. 81. Tilly Whim Caves in 1811, drawn by Thomas Webster; showing galleries being driven into the Purbeck-Portland Freestones, with the Cherty Series left as a ledge below. (From Englefield's *Description of the . . . Isle of Wight*, 1816, pl. 33.)

of the freestone. The best freestone is cut and sold for building, but only as a side-line.

This extensive new quarry provides the most valuable exposure of the Freestone Series in Purbeck. Being worked in four stages, it affords abundant access to all the beds *in situ*, a facility never enjoyed by geologists in the old cliffside quarries.[1]

No detailed investigation of the fossils of the numerous individual beds of the Portland Stone has yet been attempted. Mollusca, especially lamellibranchs, are abundant at almost all horizons, but owing to the hardness of the matrix they make unattractive material for the collector. The best-preserved fossils are the ammonites, but they are so large and heavy that they present difficulties of their own. It is essential for the investigator of the Portland Beds to have sufficient previous knowledge of the palaeontology to enable him to make identifications with accuracy in the field (though with the ammonites this is impossible). In the Freestone Series the ammonites seem almost restricted to a level near the top, where they abound, while the lamellibranchs, at least the common species, range through the whole Freestone Series and Cherty Series in about equal abundance. It is doubtful, therefore, whether satisfactory small palaeontological subdivisions of the Portland Beds will ever be established. For the present it is necessary to retain the terminology of the quarrymen. It has at least the merits of being applicable to all the Purbeck quarries and of being readily understood by all who deal with the stone, while it can also claim the dignity of a high antiquity.

Titanites Zone: Freestone Series, 50 ft.

SHRIMP BED, 8–10 ft. (reaching 16 ft. on St. Alban's Head).

White, fine-grained sublithographic limestone, like the Cream Cheese Bed of the Great Oolite. It derives its name from the carapaces and claws of a small shrimp-like Crustacean, probably of the genus *Callianassa*, found in it.[2] Casts of *Protocardia dissimilis*, *Chlamys* (*Camptochlamys*) *lamellosa* and some other species are also common, and occasionally there appear fragmentary casts of coarsely-ribbed triplicate ammonites (? perhaps *Glottoptychinites* Buckman gen.). The change to the overlying Purbeck Beds is everywhere abrupt, though conformable, but the downward passage to the underlying Spangle is gradual.

TITANITES BED (PERNA BED, BLUE BED or SPANGLE), 10 ft.

Greyish shelly limestone, crowded with *Trigonia gibbosa*, *T. incurva*, *Isognomon* [*Perna*] *bouchardi*, *Chlamys lamellosa*, *Protocardia dissimilis* and many other shells, and the source of all the ammonites obtained in the Worth quarry except the fragments mentioned above, in the Shrimp Bed. The ammonites, which are all giants, were identified with a query by Buckman as *Briareites*,[3]

[1] Through the kindness of the management, I was personally conducted over the excavations by Foreman W. J. Bower, who had spent his life in the Winspit and Seacombe Quarries before the present opening was begun, and whose knowledge of the stone-beds of all the quarries in Purbeck is unrivalled. He was able to give me the correct names for the different beds, together with interesting information as to their qualities, uses, fossil-contents and development in the coastal sections.

[2] Identification kindly supplied by Mr. H. Woods from fragmentary carapace and claw submitted to him from Seacombe and Worth.

[3] S. S. Buckman, 1926, *T.A.*, vol. vi, p. 35.

which Dr. Spath considers synonymous with *Titanites*.[1] The previous naming of this important fossil-bed is so unsatisfactory that I propose to call it the *Titanites* Bed. It was explained to me in the quarry, by the undisputed authority, the foreman mentioned above, that the whole bed may be called Spangle in one place and Blue Bed in another, but that in the Worth quarry the highest 8 ft. is Blue Bed and the rest Spangle; but it was almost immediately admitted that there was little or no perceptible difference. The word Spangle seems to refer to the glint of the fractured surface, due to calcite or shells; it is purely a descriptive lithological term, used equally for the House Cap lower down, and it should not therefore be applied to one particular bed as it has been by Buckman.[2] The foreman at Worth considered this bed the equivalent of the Roach at Portland, in which he was in unconscious agreement with J. F. Blake. Blake split up the bed at St. Alban's Head into 'Roach' above and 'Oolite with *Perna*' below.[3] Hudleston and Monckton called the whole bed the *Perna* Bed at Winspit,[4] but this designation is unsatisfactory for two reasons: first because the genus usually known as *Perna* should correctly be called *Isognomon*, and secondly because the species, *I. bouchardi*, is equally common in the lower bed of Spangle, the House Cap, and also abounds in the Cherty Series at much lower levels. H. B. Woodward[5] called the whole bed the Blue Stone, but this term is again misleading because the stone is never at all blue, becoming at its darkest no more than a mauvish-grey; further, in quarrymen's terminology there is a nice distinction between Blue Stone and Spangle, and the whole course is not always Blue Stone.

In the east, at Tilly Whim, a lenticular oyster-bed develops on this horizon. Locally about 8 ft. of the rock is almost entirely composed of oysters, cemented in an intensely hard matrix but weathering out in perfect condition. The principal constituents are *Exogyra nana* (Sow.), *E. thurmanni* Étall., *Ostrea expansa* Sow. and *Isognomon bouchardi* (Oppel), with a smaller proportion of *Lima rustica* (Sow.) and *Plicatula boisdini* de Lor.

PON OR POND FREESTONE, 7–7½ ft.

Good oolitic freestone, showing some false-bedding. Fossils rare. The origin of the name seems to have been lost, unless it is an abbreviation of Upon [the Chert Vein].

CHERT VEIN, 2–4 ft.

This, the most easily recognized datum in all the quarries, is usually called the Flint Vein or Flint Stone. Blake raised the boundary of the Cherty Series to include it, an undesirable course which has not been followed by any subsequent writer.

LISTY BED, 6–9 in.

So called 'because it breaks easily'. Present in the cliffs but absent in the Worth quarry. A soft freestone.[6]

[1] L. F. Spath, 1931, *Pal. Indica*, N.S., vol. ix, p. 472.
[2] 1926, *T.A.*, vol. vi, p. 35, misspelt Spengel.
[3] J. F. Blake, 1880, *Q.J.G.S.*, vol. xxxvi, p. 194.
[4] 1910, *P.G.A.*, vol. xxi, p. 514 and several earlier excursions.
[5] 1895, *J.R.B.*, p. 190.
[6] Misspelt Lisky Bed by Buckman, loc. cit., p. 35. Apparently the Nist Bed of H. B. Woodward, 1895, *J.R.B.*, p. 190, perhaps so recorded in error, as the Worth foreman and his

HOUSE CAP, 8 ft.

Greyish coarse limestone, like the *Titanites* Bed and also called a Spangle, but on the whole less shelly. A 6-in. shelly vein runs through it at Worth about 2½ ft. from the top, and the lower part is conspicuously shelly at Tilly Whim. The fossils seem to be the same, except that at Worth ammonites are absent; but at Winspit Woodward recorded '*Ammonites giganteus*'. *Trigoniæ* predominate.

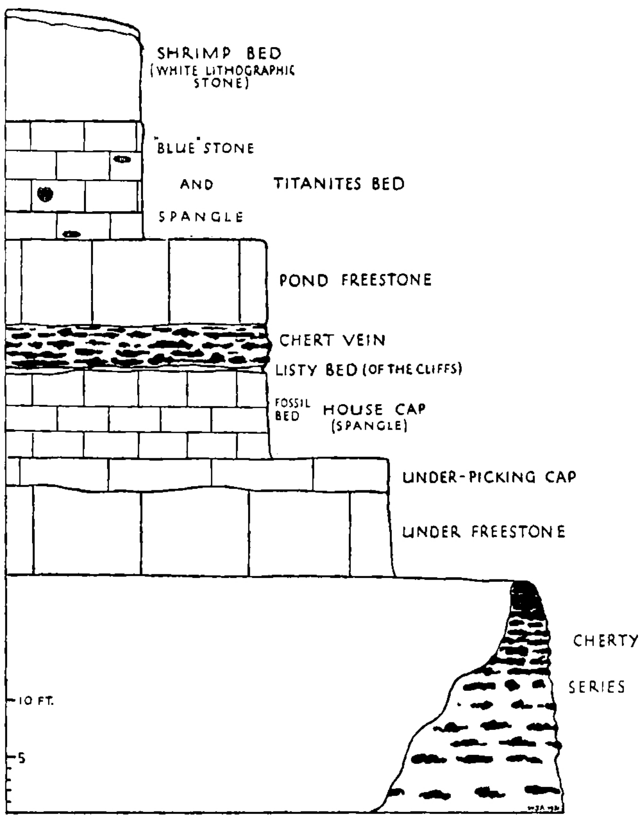


FIG. 82. Section of the Portland Freestone Series at Sheep-sleights Quarry, Worth Stone Quarries, 1 mile north-west of Worth Matravers.

UNDER PICKING CAP, 2–3 ft.

Hard freestone, which had to be blasted in the old cliff quarries, locally called Spangle. Rarely large ammonites were found in it at Winspit, but not at Worth.

UNDER OR BOTTOM FREESTONE, 8–11 ft.

Fine cream-coloured oolite, an easily-worked freestone of excellent quality,

men had never heard the name. At least as early as 1863 the bed immediately underlying the Chert Vein was called the Listy Bed (see a section at Seacombe in Hutchins's *History of Dorset*, 3rd ed., vol. i, p. 687).

with few fossils. This is the bed which was principally mined at all the quarries from Tilly Whim to St. Alban's Head. The numerous 'caves' are adit galleries driven into it, the 'caps' forming the roofs and the Cherty Series the floors (see fig. 81, and footnote on p. 483).

Towards the west most of the Freestone Series dies out. Hudleston pointed out that in Gad Cliff and Worbarrow Tout the Shrimp Bed and *Titanites* Bed are well developed, but that they rest directly upon the Cherty Series.[1] It remains to be proved whether the Pond and Under Freestones and intervening Cap disappear or merely lose their character and become cherty.

Kerberites Zone: Cherty Series, 60–70 ft.

The Cherty Series forms the lower part of the cliffs east of St. Alban's Head and the vertical capping to the higher cliffs to the west, at Emmit Hill and Hounstout. So far it has defied subdivision and it has the distinction of being one of the thickest masses of unsubdivided rock remaining in the English Jurassic System. It consists throughout of intensely hard brown limestone with numerous impersistent veins and nodules of dark chert. It can be easily studied at Tilly Whim, Dancing Ledge, Seacombe, Winspit and St. Alban's Head. At Dancing Ledge one of the thick courses of hard stone forms the ledge up which the waves dance, and the surface is studded with giant ammonites.

The upper part of the series is poorly fossiliferous, but the middle and lower parts are often quite shelly, and some of the courses are largely composed of *Serpula gordialis*. The limestone is so hard that collecting is difficult, but *Isognomon bouchardi*, *Chlamys lamellosa* and some of the other familiar shells may usually be seen. Blake recognized in 1880 that the ammonites differed from those found in the Freestone Series, signifying the difference by calling them '*A. boloniensis* de Lor.' Although they abound on the surface of some of the ledges washed by the sea and upon the fallen blocks beneath the cliffs west of St. Alban's Head and under Hounstout, their characters are still but little known. The reason for this is that the beds have never been quarried and in the natural exposures it is almost impossible to detach specimens from their matrix, while those visible *in situ* are always too much weathered for certain identification. In 1931, however, the Worth Stone Co. started quarrying the Cherty Series at Worth for breaking up to make macadam, and so it may be hoped that some of the ammonites will be obtained. At present our knowledge is restricted almost entirely to a few specimens collected in the Basal Shell Bed of the Isle of Portland (to be described later, below, p. 496).

Although Blake spoke of a Basal Shell Bed in his record of the section of St. Alban's Head,[2] no such bed has been detected by subsequent investigators, or seems to exist at this horizon in Purbeck; the shells are rather distributed through the lower portions of the Cherty Series instead of being concentrated in one particular bed as at Portland. In consequence the boundary between the Cherty Series and the Portland Sands beneath is less easy to define. The best accessible section is at the point of St. Alban's Head: here there is a perfect gradation downward through sandy and cherty

[1] W. H. Hudleston, 1896, *P.G.A.*, vol. xiv, p. 319.
[2] J. F. Blake, 1880, loc. cit., p. 194.

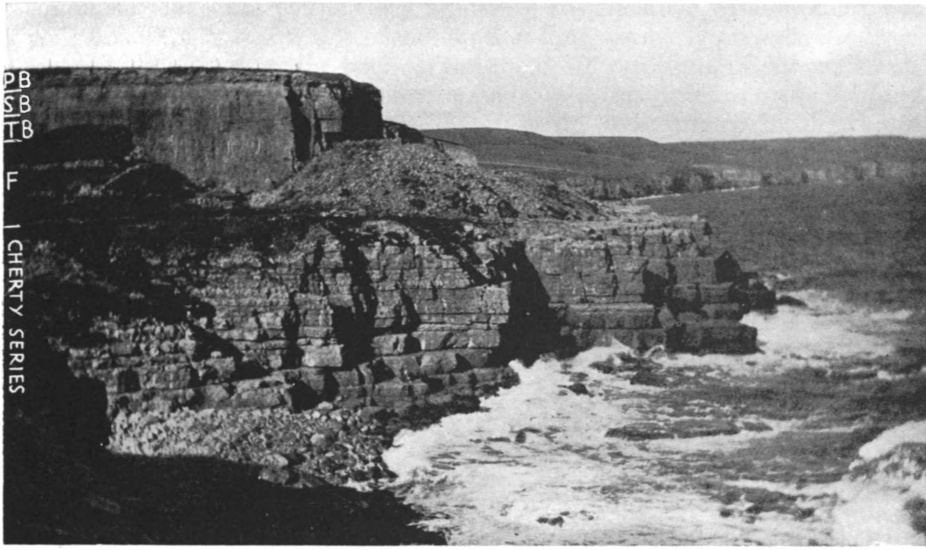


Photo. W. J. A.

Winspit Quarry, near Worth Matravers, Dorset.

Portland Freestones in upper part of cliff quarried back, and Cherty Series left in lower part of cliff. PB = Purbeck Beds; SB = Shrimp Bed; TB = *Titanites* Bed; F = Portland Freestones and Chert Vein. The vertical cliffs of Portland Stone are continued in the distance, surmounted by a slope of Lower and Middle Purbeck Beds.

Photo. W. J. A.

Dancing Ledge Quarry, near Langton Matravers.

Galleries have been driven into the Freestone behind, at a lower level.

PLATE XXIV

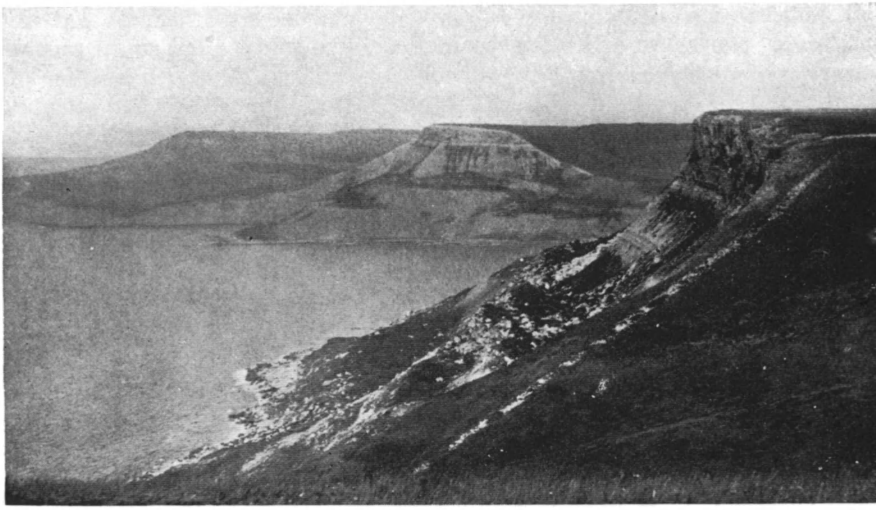


Photo. *W. J. A.*

Swyre Head, Hounstout Cliff and Emmit Hill, seen from St. Alban's Head.

The dip in the foreground is Pier Bottom, the next Chapman's Pool, the next Egmont Bay, below Encombe, with Freshwater Steps at the point where the grass almost reaches the sea.

Photo. *W. J. A.*

Hounstout Cliff and Emmit Hill.

On Emmit Hill PB = The Parallel Bands; St.AHM = St. Alban's Head Marls; WCB = The White Cementstone; EHM = Emmit Hill Marls. The Massive Bed (base of the Portland Sand) crops out at the foot of the bank, below the photographer.

limestone and calcareous cherty sandstone to sandstone without chert but with honeycomb weathering, denoting that lime, formerly present, has been leached out. To draw the boundary at the downward limit of either lime or chert is unsatisfactory, and at present evidence is insufficient for the marking of any palaeontological division. The difficulty is illustrated by the recent petrological study of the Portland Sands by Mr. M. P. Latter, who fixed no definite upper boundary to the Sands and began his descriptions of sections at different levels in localities so close together as St. Alban's Head and Emmit Hill.[1] In short, wherever we choose our boundary, we cannot avoid grouping either sandy beds with the Cherty Series or cherty beds with the Sands. At the junction are 24 ft. of grey and yellow sandstone, weathering with honeycomb structure, the upper half very cherty and sandy, the lower half free from chert (see fig. 83). I follow Hudleston[2] and Sir A. Strahan[3] in grouping these beds with the Cherty Series of the Portland Stone rather than with the Portland Sand.

Glaucolithites Zone: Portland Sand, 100–20 ft.

The Portland Sand was first so named by Fitton,[4] who described Emmit Hill, the steep cliff on the west side of St. Alban's Head (Pl. XXIV) as the typical section. There is hereabouts a complete and almost continuous exposure from the point of St. Alban's Head to Chapman's Pool and again in Hounstout Cliff (fig. 80). At first sight 'Sand' seems a misnomer, for the series consists rather of grey and black sandy marls, with bands of sandstone and sandy cementstone. The same applies to the Isle of Portland. North of Weymouth, however, the proportion of sand is much higher, and there are in places up to 40 ft. of yellow sand; but even in Purbeck and Portland there is more than is at first sight apparent, for owing to its black colour and the admixture with marl, the sand escapes notice.

In the cliffs of the type-locality the beds fall into several well-defined subdivisions, marked off by prominent bands of cementstone or sandstone, distinctly traceable from end to end of the exposures. To provide a framework for palaeontological investigations in the future it is essential that these thick subdivisions should have names, and accordingly some of them are here named for the first time.

Buckman introduced two major subdivisions, a Cementstone Series above and a Sandy Series below,[5] but his interpretation of the lower boundary of the formation was different from that accepted here, and his Cementstone Series is almost exactly synonymous with the Portland Sand as now understood. All but the highest 5 ft. (the Massive Bed) of his Sandy Series is here classed as Kimeridge Clay, following Strahan, Cox, Latter and probably Fitton (see above, p. 446, where it is named the Hounstout Marl).

THE PARALLEL BANDS, 23 ft.

The most conspicuous strata in Hounstout, Emmit Hill and St. Alban's Head cliffs, remarked on by all observers, are two parallel thick bands of

[1] M. P. Latter, 1926, *P.G.A.*, vol. xxxvii, pp. 76–7.
[2] W. H. Hudleston, 1882, *P.G.A.*, vol. vii, p. 385.
[3] A. Strahan, 1898, 'Geol. Isle of Purbeck', p. 67, *Mem. Geol. Surv.*
[4] W. H. Fitton, 1836, *Trans. Geol. Soc.* [2], vol. iv, pp. 211–12.
[5] S. S. Buckman, 1926, *T.A.*, vol. vi, p. 34.

sandstone or sandy cementstone, which run from one end of the sections to the other without perceptible change. Both Blake and Buckman (and Hudleston and Strahan by implication)[1] took these bands as marking the top of the Portland Sand, and since here, at the type-locality, they provide the only obvious summit to a division admittedly of arbitrary boundaries, it is as well to make use of them. Buckman and Strahan gave no thickness, but according to my own measurements and to those of Mr. Latter they measure in all about 23 ft.[2]—Upper 6½–7 ft.; Lower 10 ft.; intervening beds 5–6 ft.

Under St. Alban's Head, 9 in. below the top of the Upper Parallel Band, there is a noticeably even and persistent parting, which may indicate a physical break. The highest 9 in. form a separate bed of hard sandstone, above which is a dark shaly layer, merging up into the grey sandstones. A convenient position at which to draw the top of the Portland Sand would be at this persistent parting or eroded surface (fig. 83).

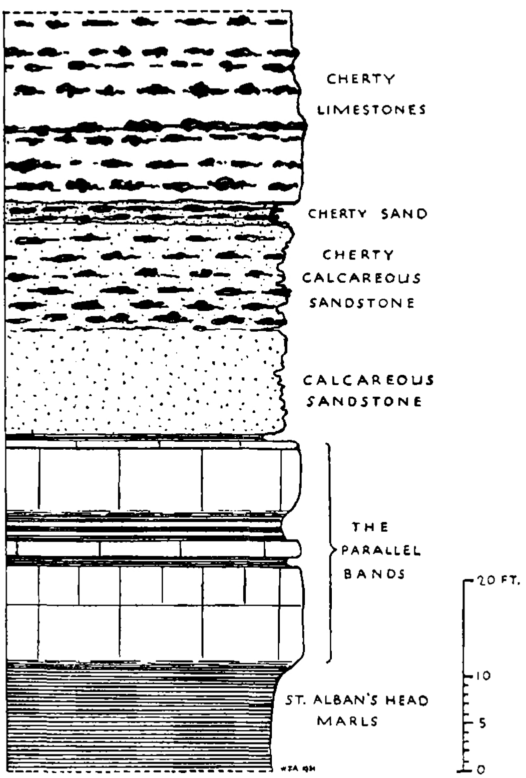


FIG. 83. Section in the cliff under the west side of St. Alban's Head, at the junction of the Cherty Series with the Portland Sand. The arbitrary boundary is taken at the top of the Parallel Bands.

The two chief Parallel Bands are separated by light chalky shales with two white layers, and in the lower part of the chalky shales there is a thinner hard band (1 ft. 6 in.) as persistent as the other two and forming a Middle Parallel Band, conspicuous from St. Alban's Head to Hounstout (fig. 83 and Pl. XXIV).

Concerning the palaeontology of the Parallel Bands everything still remains to be discovered. Blake speaks of '*Ammonites biplex*' as abundant, a record that has not so far been interpreted.

[1] 'The base of the Portland Stone, however, can be seen round nearly the whole headland [St. Alban's] and under Emmit Hill also; it contains not only an abundance of chert-nodules, but so much sand that it may be described as a calcareous sandstone' (Strahan, 1898, loc. cit., p. 67). See also Hudleston (1882, *P.G.A.*, vol. vii, p. 385), 'the bare slopes of Portland Sand are seen to be surmounted by the cherty calcgrits which form the base of the Portland Stone capping the precipices of Emmit Hill'. The 'cherty calcgrits' and 'calcareous sandstone' are the sandy base of the Cherty Series immediately above the Parallel Bands, referred to on p. 489.

[2] Blake gave a thickness of 39 ft., but how this was arrived at is not clear. My own measurements and Mr. Latter's, although made quite independently, agreed within 1 ft. See M. P. Latter, 1926, loc. cit., pp. 76–7.

ST. ALBAN'S HEAD MARLS, 40–45 ft.

Below the Parallel Bands are 40–45 ft. of grey sandy marls and marly sands with thin bands and nodules of cementstone, all poorly fossiliferous. These and the underlying marly and sandy beds have not hitherto been named.

THE WHITE CEMENTSTONE BAND, 2 ft.

A conspicuous band of light-grey to whitish cementstone, 2 ft. thick, is persistent in all the cliffs, and Buckman named it the White Cementstone, recording and figuring from it the Behemothan ammonite *Leucopetrites cæmentarius*, found by Mr. C. H. Waddington.[1] The bed breaks with a conchoidal fracture and the broken surfaces often show red staining. It contains casts of *Thracia depressa* (Sow.), *Pleuromya tellina* Ag. and '*Arca*' *fœtida* Cox., in places abundantly, especially in the lower part.[2]

EMMIT HILL MARLS, 30–40 ft.

Below the White Cementstone are three ill-defined bands of partly indurated, blackish, shaly marl or sandy shale, in all 12 ft. thick, containing abundant crushed casts of *Thracia*, *Pleuromya*, &c. Below this again, and distinguished only by being less indurated, are some 25 ft. of blue or blue-black sandy and partly shaly marls, with numerous thin bands of cementstone. Since all these are still in need of a name I propose to call them the Emmit Hill Marls, after the type-locality of the Portland Sand, where they are well exposed and thickest. According to Mr. Latter's measurements they are 39 ft. thick at Emmit Hill, 38 ft. at St. Alban's Head, and 30 ft. at Hounstout.[3] Dr. Spath informs me that he believes a number of the fragments of *Provirgatites* of the *scythicus* group collected by him to have fallen from these beds.

THE MASSIVE BED, 5–6 ft.

The Massive Bed, so named by Buckman,[4] has already been referred to at some length (above, pp. 445–6). It is a prominent band of hard, blue-centred, brown-weathering, shaly to rubbly, calcareous sandstone, which forms an easily-recognized feature about 50 ft. above the old road leading round the face of Hounstout Cliff. Palaeontologically it has proved, owing to the researches of Messrs. Waddington and Buckman, of great interest. It contains in places an abundance of a small rugose variety of *Exogyra nana*, recalling the *Exogyra* Bed of the Isle of Portland, associated with crushed specimens of *Rhynchonella portlandica* Blake. Of paramount importance, however, are the ammonites. Buckman[5] was the first to identify some of these with the Russian *Provirgatites scythicus* (Michalski) (see above, p. 445); and since a fairly large number of fragments have since been found, it seems to be indicated that we place the Massive Bed and Emmit Hill Marls in the *scythicus* zone, already recognized in Germany (Pl. XL, fig. 3).

The Massive Bed was selected by Sir A. Strahan [6] as the arbitrary base of

[1] S. S. Buckman, 1926, *T.A.*, p. 35, pl. DCLXXVII.

[2] It seems likely that this is Blake's Bed 13 (cementstone with abundant *Thracia*, 2 ft.) (*Q.J.G.S.*, 1880, p. 195). It is Latter's Bed 6 at St. Alban's Head and Emmit Hill and Bed 4 at Hounstout (*P.G.A.*, 1926, pp. 76–8).

[3] Latter's Beds 3, 4, 5 (loc. cit., pp. 76–7) and 3 (p. 78); Blake's Bed 12 (thickness 30 ft.).

[4] 1926, *T.A.*, pp. 31–3.

[5] Ibid., pp. 32–3, pls. DCLXXV, DCXCIII.

[6] 1898, loc. cit., p. 62.

the Portland Sand, a selection accepted by Messrs. Kitchin and Pringle, by Latter [1] and by Cox.[2] The thickness thus assigned to the Portland Sand, if the Parallel Bands are taken as the top, is about 100 ft., whereas Fitton's original estimate was 120–140 ft. It seems likely, however, that Fitton included in the sands the 24 ft. of sandstone above the Parallel Bands, the upper part of which, as mentioned above (p. 489) contains chert. Sir A. Strahan's estimate of the thickness of the Portland Sand was 100–120 ft., with which the classification here adopted agrees, and he certainly included the sandstones in question with the Cherty Series of the Portland Stone.[3]

The Geological Survey of 1855 mapped an indefinite line in the sandy clays about 40–50 ft. below the Massive Bed, and in this they were followed by H. B. Woodward, who estimated the thickness of the Portland Sand at 170 ft. or 130–70 ft.; [4] and more recently Buckman also has followed suit. Blake preferred a line 70 ft. lower still, giving the Portland Sands 244 ft.,[5] but with this no authors have agreed.

(b) The Isle of Portland

The Portland Beds of the Isle of Portland bear a greater resemblance to those of Eastern Purbeck than to those of Western Purbeck anywhere west of Kimeridge, or to their continuation north of Weymouth. The Stone Beds are divisible into a Freestone Series above and a Cherty Series below, and the Sands consist predominantly of argillaceous sands and cementstones rather than true sands. The details, however, differ considerably, rendering refined correlations uncertain.

The Isle of Portland represents but a small fragment of the southern limb of the Weymouth Anticline. It provides a sample of the great tract of country which formerly lay beyond the present coast-line of Dorset—a limestone upland of grassy downs like the Cotswolds, useful for sheep-grazing and corn-growing had it not nearly all been destroyed by the inroads of the sea. The island is a gently-tilted plateau, completely surrounded by cliffs of Portland Stone, the surface 'so destitute of Wood and Fuell that the inhabitants are glad to burne their Cowe Dung, being first dried against the Stone Walls, with which their Grounds are enclosed altogether', as Coker tells us.[6] At the north end the cliffs rise to 495 ft., above a tumbled undercliff of fallen blocks lodged on the Kimeridge Clay, as at Hounstout and St. Alban's Head; towards the south end or Bill they sink gently into the sea. So extensive have been the quarrying operations of the last two centuries, however, that most of the Freestone Series has been removed from the cliffs, while vast tips of debris have built up a curtain round the greater part of the north, east and west sides of the island. The east side has in addition been much obscured by landslips, due to the heavy stone-beds foundering upon the clay slopes beneath. It is only the magnificent West Weare Cliffs that give tolerably clear and accessible sections of the Portland Sand and Cherty Series at the present day (Frontispiece and Plate XXV, opposite; also map, p. 342).

The quarrying of the Portland Freestone was carried on only for local

[1] 1926, loc. cit., p. 76.
[2] 1929, loc. infra cit., p. 133.
[3] A. Strahan, 1898, loc. cit., p. 60; and see footnote above, on p. 490.
[4] 1895, *J.R.B.*, p. 192.
[5] 1880, loc. cit., p. 194.
[6] Rev. Coker, 1732, *Survey of Dorsetshire*, p. 38.

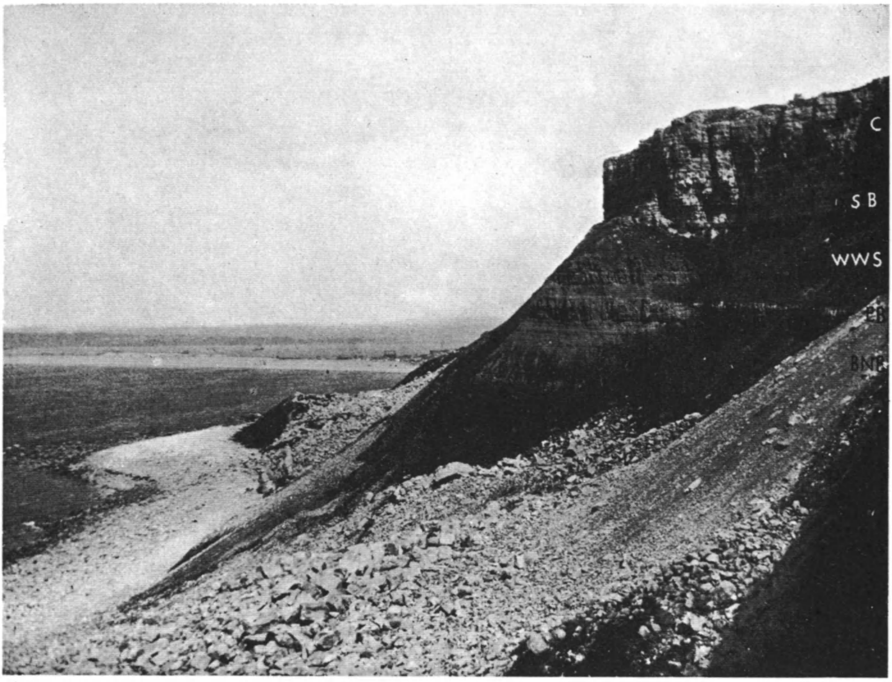


Photo. *W. J. A.*

West Weare Cliff, Portland.

C = Cherty Series of Portland Stone, with SB = Basal Shell Bed; WWS = West Weare Sandstones; EB = *Exogyra* Bed; BNB = Black Nore Beds. Chesil Beach, Portland Roads and Weymouth are seen in the distance.

Photo. *W. J. A.*

Gad Cliff from Worbarrow Tout, Dorset.

Overhanging cliff of Portland Stone and Lower Purbeck Beds. Undercliff of fallen blocks on Kimeridge Clay. Swyre Head in the distance.

Photo. *W. J. A.*

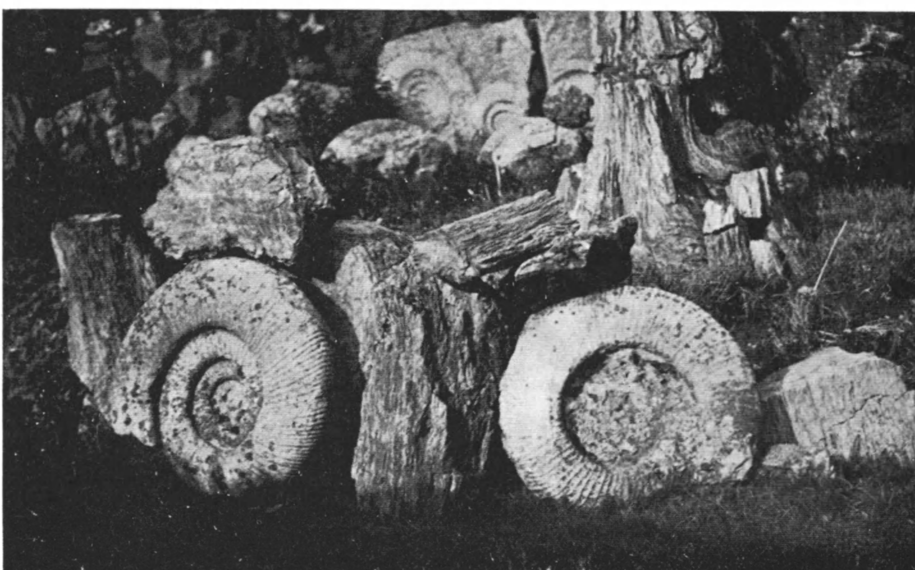


Photo. *W. J. A.*

'Divers of those Snake or Snail Stones, as they call them, whereof great varieties are found in Portland, dug out of the very midst of the Quarry, of a prodigious bigness.' (Dr. Robert Hooke, *Lectures and Discourses of Earthquakes*, 1668 (1705), p. 327.)

Specimens of *Titanites* from the Portland Stone and silicified tree-trunks from the Great Dirt Bed of the quarries where the stone was got for rebuilding St. Paul's Cathedral; photographed on Portland Island.

purposes until the seventeenth century. The fame and great reputation of the stone dates mainly from its selection by Sir Christopher Wren for the rebuilding of St. Paul's Cathedral after the Fire of London, though it was already chosen in 1610 for rebuilding the Banqueting Hall at Whitehall. Since that time it has been used for well-known buildings all over the country, and especially in London, where its resistance to the corroding agencies in the atmosphere renders it particularly valuable. Among the buildings constructed with it are the British Museum (1753), Somerset House (1776–92), the General Post Office (1829), the Horseguards, the Foreign Office, and the Record Office; and the parts of the stone not shipped as a freestone were used in enormous quantities for the great breakwaters of Portland Harbour, one of the largest undertakings of its kind in the world, completed by convict labour in 1864.

As the result of all these activities, most of the north and central parts of the island have been removed bodily, leaving vast expanses of rubbish tips, now overgrown, traversed here and there by walls and strips of unquarried rock. The scene has been graphically described by Sir Frederick Treves:

> 'Here is a garden of stones with roads deep in dust or deep in mud: the grass is grey with dust, the horses, that in teams of eight or ten drag stone-laden trolleys through the waste, are grey too with the powder of stone. A faded traction-engine rumbles by crunching the stones and blackening the air, driven by earth-coloured men, who are shaken as they pass by the fearful vibrations of the machine. There are deep pits of stone, tanks of oolite, walls of white masonry laid bare by the pick, terrific slopes of loose rubble sliding down into the cool sea.
>
> 'Over a wide chasm, with sides as clean-cut as those of a graving-dock, fantastic cranes rise up into the air. They wave titanic arms against the sky, which might be the tentacles of some leviathan insect, or weave threads of wire over the abyss like the strands of some unearthly spider's-web; smoke rises from the gasping engines, while now and then a block of stone glides hissing across the void like a fearsome bird. All round are heaps of litter, piles of wind-blown dust, patches of scarred earth, and deserted pits which are becoming covered with a green mould.' [1]

Since the Great War most of the north end of the island, once the centre of this scene, the nucleus of one of the world's most famous quarrying localities, has been abandoned, and instead smaller pits are being worked farther south. The horse-teams, too, have gone, superseded by files of 'faded traction-engines', which invade the roads, sometimes ten at a time, laden with their huge cubes of stone.

SUMMARY OF THE PORTLAND BEDS OF PORTLAND [2]

Titanites Zone: Freestone Series, 25 ft.

THE ROACH, 1½–4 ft., usually about 3 ft.

White oolitic limestone, a porous mass of hollow moulds and casts from which the shells have been entirely dissolved away. The commonest species are *Aptyxiella* [*Cerithium*] *portlandica* (the 'Portland Screw'), *Trigonia gibbosa* and *Plicatula lamellosa* Cox. The 'Screw' is entirely confined to this horizon. Locally in a thin layer at the top some of the fossils are silicified.

[1] *Highways and Byways in Dorset*, 2nd ed., 1906, p. 229.

[2] The best account of the Portland Stone Series is by H. B. Woodward, 1895, *J.R.B.*, pp. 198–201.

WHIT BED, 7 ft. (in places up to 15 ft.).

Buff to white oolite, with comminuted shells, the best freestone on the island. In Fitton's time this was the only bed worked. Locally an irregular cherty band with 'sand holes' yields, according to H. B. Woodward, a micromorphic fauna of gastropods and marks off an additional 3 ft. to 3 ft. 9 in. of buff oolite below, called the Bottom Whit Bed. The Whit Bed is the principal source of the gigantic ammonites for which Portland is famous. According to Blake '*Ammonites giganteus*' is confined to this horizon, but Woodward also records it from the Curf. Some huge specimens are preserved in the garden of the Portland Stone Firm's Office on the island (see Pl. XXVI). Blake noted a plane of erosion at the base of the Whit Bed, in places cutting out the Curf, which is said by Woodward to be absent south of Weston.

CURF AND CHERT, 3–6½ ft.

Oolitic shelly limestone with numerous chert nodules. According to Woodward '*Ammonites giganteus* is abundant'.

LITTLE ROACH, 0–1½ ft.

Oolitic limestone with hollow moulds and casts of *Trigonia* and other shells, resembling the true Roach above; not always present.

BASE BED, 10 ft. (5–10 ft.).

Fine-grained, buff, oolitic freestone, comparatively unfossiliferous. Some of the old quarries from which the Whit Bed was formerly removed are now being reopened to get at the Base Bed, which may be almost as good a freestone as the Whit Bed.

No detailed correlation of these subdivisions with the thicker Freestone Series of Purbeck has yet been established. It is noteworthy that the peculiar white sublithographic stone, the Shrimp Bed, so constant a feature at the top of the formation in Purbeck, is not to be seen in Portland. Instead the top is formed by the equally peculiar Roach, not found in Purbeck. It is believed by the Worth Foreman, Mr. W. J. Bower (above, p. 485), and was suggested by Blake, that the Roach is equivalent to the *Titanites* Bed of Purbeck. This view is probably based on the tempting supposition that the Whit Bed freestone equals the Pond Freestone and that the cherty Curf is represented by the Chert Vein. But it must not be forgotten that the Curf and the Whit Bed of Portland are the home of the giant ammonites, while in Purbeck ammonites never seem to be found in the Chert Vein or in the Pond Freestone but occur in abundance in the *Titanites* Bed above. Until more detailed work on the specific identity of the ammonites in the two areas has been accomplished, the correlations must remain a matter of surmise.

Kerberites Zone: Cherty Series, 60–70 ft.

The Cherty Series is of about the same thickness in Portland as in Purbeck and of much the same appearance, but there is no proof that its upper limit is on exactly the same horizon in the two localities; the assumption is founded only upon the supposed equivalence of the Under Freestone to the Base Bed Freestone, neither of which has yielded diagnostic fossils. The Cherty Series is well exposed in the high crags forming the summit of West Weare Cliffs and

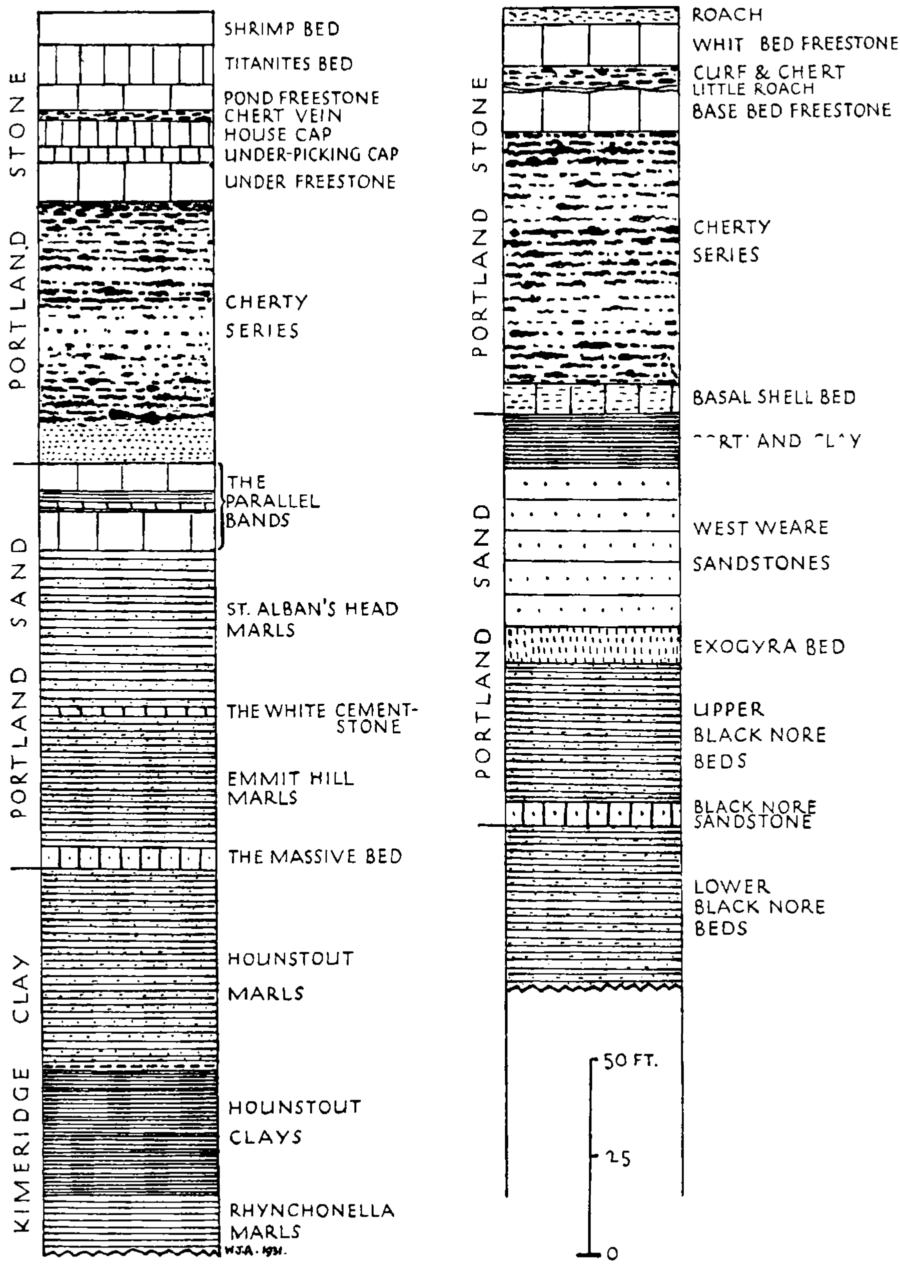


FIG. 84. Tables representing the Portland and subjacent rocks at Purbeck (left) and Portland (right).

Clay Hope, on the north-west side of the island (Pl. XXV). The hard limestones contain bands and nodules of chert throughout, and in places at various levels may be seen lenticles of cellular rock full of hollow moulds of fossils like the Roach. These represent *Trigonia incurva* and *Protocardia dissimilis*, not found in the true Roach, and also the large Behemothan ammonites distinguished collectively as '*Ammonites boloniensis*' by the earlier writers, as in Purbeck. *Serpula gordialis* is in places so abundant that Blake called a band near the top a serpulite.

BASAL SHELL BED, 7–8 ft.

By far the most interesting feature of the series in Portland, and the richest palaeontological horizon in the British Portland strata, is the Basal Shell Bed. It forms a clearly demarcated base to the stone beds, offering a marked contrast to the gradual transition from cherty stone to sand in Purbeck. Until recently the Basal Shell Bed was comparatively little known, but in 1925 an extensive collection of fossils made by Col. R. H. Cunnington was described in a valuable monograph by Mr. L. R. Cox.[1] This has enriched our knowledge of the fauna of the English Portland Beds by nine new species of gastropods, eighteen new species of lamellibranchs, and several new ammonites, echinoids and polyzoa.

The thickness of the bed is 7–8 ft. It consists largely of shells compacted together in a matrix of very hard limestone crowded with the tubes of *Serpula gordialis*. The whole has been almost entirely recrystallized as calcite, which breaks along its characteristic cleavage-planes, irrespective of the boundaries between shells and matrix. It is consequently impossible to separate the shells from the stone, except where they stand out in relief upon the weathered surfaces, whence they can be removed with a hammer and chisel. The fauna consists principally of lamellibranchs, of which Mr. Cox records over 50 species. The commonest forms are those most frequently met with in the middle and lower parts of the Cherty Series in Purbeck, such as *Isognomon bouchardi*, *Chlamys lamellosa*, &c. The ammonites, although scarce, sufficed for Buckman to pronounce them as fairly evidently of late Behemothan date; they include the usual large forms of '*bononiensis*' style, the type-specimen and other material of *Kerberites portlandensis* Cox, and forms resembling *Glaucolithites gorei* (Salf.).

Glaucolithites Zone: Portland Sand, about 100 ft.

The Portland Sand of Portland still remains palaeontologically almost unknown. Its general lithic character is much like that of Eastern Purbeck, but the details are entirely different.

At the north end of the island, under the Verne Fort, the highest member is a 10 ft.–14 ft. band of stiff blue marl, called by Damon the PORTLAND CLAY.[2] This is not present in the other sections; in the clearest of all, at West Weare Cliff, the Basal Shell Bed of the Portland Stone is immediately underlain by 30 ft. of brown and grey marly sandstones and sandy cementstones of varying degrees of hardness. From these Salfeld recorded *Glaucolithites gorei*,[3] and other records by Blake show the desirability of further collecting.

[1] L. R. Cox, 1925, *Proc. Dorset N.F.C.*, vol. xlvi, pp. 113–72.
[2] R. Damon, 1860, *Geol. Weymouth*, p. 82.
[3] H. Salfeld, 1914, *Neues Jahrb. für Min.*, B.-B. xxxvii, p. 191.

Towards the north end of the island, according to the measurements of Mr. Latter, these sandstones thicken considerably. It is convenient to distinguish them by the name WEST WEARE SANDSTONES.

Beneath is the most conspicuous band in the series, the EXOGYRA BED. It consists of 6–8 ft. of stiff marl packed with almost a solid mass of *Exogyra nana* (Sow.),[1] and it weathers to a prominent massive band easily recognized in the cliff (Frontispiece and Pl. XXV). According to Latter the top of the *Exogyra* Bed is 31 ft. below the Shell Bed in West Weare Cliff and 57 ft. below it at the north end of the island.

The lower beds are imperfectly exposed, but a considerable thickness of sandy beds is present at West Weare Cliff, below Black Nore Gorge, and they may be appropriately referred to as the BLACK NORE BEDS. The Upper Black Nore Beds consist of black sands with lines of light grey nodules, 35 ft. thick according to Latter.[2] They are separated from the Lower Black Nore Beds by a 6 ft. band of hard, black, argillaceous sandstone with large intensely hard concretions.[3] The Lower Black Nore Beds[4] consist of blue-black sandy clays, extending as far as the foot of the visible section, 40 ft. below the Black Nore Sandstone.

The Portland Sand of Portland may therefore be summarized as follows:

TABLE OF THE PORTLAND SAND OF PORTLAND

	ft.
Portland Clay (north end of island only)	14
West Weare Sandstones . . . 30 ft. to about	40
Exogyra Bed	8
Upper Black Nore Beds	35
Black Nore Sandstone	6
Lower Black Nore Beds . . . seen to	40
Total about	140

In the present state of palaeontological knowledge it would be rash to attempt any correlations with Purbeck. If we assume that the upper limit is drawn on the same horizon as in Purbeck (itself an unsafe assumption) then there is a close agreement in aggregate thickness if we take the base at the bottom of the Black Nore Sandstone, and moreover the Black Nore Sandstone falls into line with the Massive Bed of Purbeck. The presence in the Massive Bed in one locality at Chapman's Pool of a considerable quantity of *Exogyra nana* suggests correlation rather with the *Exogyra* Bed; but *Rhynchonella portlandica*, which is associated with it, has not been found in the *Exogyra* Bed, and the futility of placing any reliance on the oyster is demonstrated by the much later oyster-bed near the top of the Freestone Series at Tilly Whim (above, p. 486). Aggregate thicknesses are here likely to be a safer guide for a working hypothesis, and it seems likely that the sandy clays constituting the Lower Black Nore Beds will one day prove to be the Hounstout Marl, regarded here as belonging to the Kimeridge Clay (above, p. 446).

[1] Usually known by the synonym, *E. bruntrutana* Thurm., see Jourdy, 1924, 'Hist. nat. des Exogyres', *Ann. Pal.*, vol. xiii.

[2] Latter's Bed 3 at Black Nore Gorge, 1926, loc. cit., p. 82. Latter calls all the nodules and concretions, both here and in Purbeck, septaria, but very few are septarian.

[3] Latter's Bed 2, loc. cit., p. 82.

[4] Latter's Bed 1.

(c) The Northern Limb of the Weymouth Anticline

The Portland Beds in the northern limb of the Weymouth Anticline are distant from Portland Island only 5 miles across the bay, but they differ profoundly from their equivalents on the island. They also differ as much from the Portland Beds of Purbeck, and the change from the Purbeck and Portland type of development can be traced north-westwards through the numerous small connecting outcrops along the sea-coast, at Lulworth, Durdle Door and the Cow and Calf Rocks. Beyond the last outlying rock there is a gap of 2 miles to the faulted mass below Holworth House, Ringstead Bay, whence the outcrop is continuous, except for minor interruptions, to Portisham. The Portland Beds, capped by Purbecks, form a lower escarpment and spurs jutting out below the main cuesta of the Chalk Downs. Where they enter into the Chaldon Anticline they surround and floor an elongate inlier, giving rise to a striking amphitheatre known as Poxwell Circus.

It was remarked that even so far east as Gad Cliff great changes were to be seen in both the Portland Stone and the Portland Sand. There Hudleston noted that the Shrimp Bed and *Titanites* Bed seem to rest directly on the Cherty Series, while the Portland Sands are both sandier and thinner, and the divisions established farther east cannot be recognized. In the main outcrop from Ringstead Bay westward the differences are intensified, the whole formation dwindling to less than 80 ft. at Portisham.

The **Titanites Zone** or **Freestone Series** presents a curious blend of the various beds developed in Portland and Purbeck. A close study of their local changes might provide a key to the correlation of the two better-known areas, but no such investigation has yet been undertaken. In Ringstead Bay the series is represented by variable, oolitic, shelly and chalky limestones, 12 to 18 ft. thick, containing Roach as at Portland, in the upper and lower parts. Roach is also present at Sutton Poyntz, in the neighbourhood of which '*Ammonites giganteus*' is described as abundant. At Greenhill Barton there is an oyster-bed like that at Tilly Whim.[1]

The greatest attenuation seems to take place in the middle of the outcrop, at Upway, where only 3 ft. of Roach intervenes between the Purbeck Caps and the Cherty Series. The thickness at Portisham is 5 ft., but the roach has there given place to a hard limestone. We are warned by the presence of the Chert Vein in the centre of the Freestone Series of Purbeck against assuming that the chert nodules terminate everywhere on one and the same horizon.

The **Kerberites Zone** or **Cherty Series,** however, is hardly likely to embrace representatives of much of the overlying strata, for it is itself greatly reduced in thickness, measuring only 30 ft. at Portisham. Its most noticeable feature is an extreme whiteness of the limestone, which renders the series hard to distinguish from Chalk-with-flints. The Basal Shell Bed is represented at Portisham, where the lowest 6 ft. of the series consists of limestone crowded with *Serpula gordialis* and shells. Farther east, however, the bed does not seem to have been recognized, and there is nothing that could be said to represent it in the cliff-section below Holworth House in Ringstead Bay.

The **Portland Sand** has recently been the object of petrological investigation by Mr. M. P. Latter, who emphasized the much higher proportion of

[1] A. Strahan, 1898, loc. cit., p. 69.

true sand here as compared with Purbeck or Portland. Commensurate with the increase of sand, an increase in the quantities of heavy minerals was noticed, especially garnet, tourmaline, zircon and rutile, accompanied by kyanite, staurolite, muscovite and glauconite.[1] These facts he rightly considered to indicate that the shore-line lay to the north-west. Concerning the origin of the heavy minerals, however, his results are diametrically opposed to those of Dr. A. W. Groves. While Mr. Latter concluded that the heavy minerals 'point to the granite massifs of Devon and Cornwall as being the main source of origin for the Portland Sand', Dr. Groves asserts 'No indication whatever has been found of direct derivation of detritus from Dartmoor in the Jurassic rocks of Dorset, nor inland as far as the Oxford district . . . in the Portland Sand detritus resembling Dartmoor material is referred with more certainty to the granites of Normandy and Brittany.'[2]

The best section of the Portland Sand is to be seen in the faulted block below Holworth House, in Ringstead Bay. It has been described by Woodward, Strahan, Latter and Buckman, but the descriptions vary so greatly that it is almost impossible to discern a single feature in common. Woodward's total thickness adds up to 69 ft., Strahan's to 57 ft., Latter's to 121 ft., and Buckman's to 48 ft. 2 in.! Buckman, however, stated that his thicknesses were 'only guess-work',[3] while Latter evidently included in the Portland Sand most, if not the whole, of the Cherty Series. The downward passage from Cherty Series to Sands is, in fact, quite gradual, as at St. Alban's Head, but here there are no Parallel Bands to guide us in our arbitrary selection of a junction.

Buckman found, somewhere near the base of the section, a 2-in. seam of marly clay containing *Rhynchonella portlandica* Blake, *Lingula ovalis* auctt., and two minute species of *Orbiculoidea* no bigger than a large pin's head. On account of the *Rhynchonella* he was inclined to correlate this seam with the Massive Bed of Purbeck.[4]

Woodward noted, about 20 ft. from the top selected by him, 10 ft. of calcareous sandstone with *Exogyra*, *Ostrea* and *Trigonia*, which suggests a possible correlation with the *Exogyra* Bed of Portland; he also recorded *Exogyra* in about the same position at Portisham.[5]

The presence of glauconite grains in the Portland Sands of this district is of great interest in view of the important part that they play in rocks placed on palaeontological grounds on the same horizon farther inland. The chalky condition of the Cherty Series is also of considerable assistance in correlating with the next district to the north—the Vale of Wardour.

II. THE WESTERN RIM OF THE WILTSHIRE DOWNS

Owing to the unconformable overstep of the Cretaceous rocks, the Portland Beds are almost entirely concealed inland. Only two glimpses of the main outcrop are obtained under the western rim of the Wiltshire Downs, where deep notches have been cut back into the Chalk to form the Vales of Wardour and of Pewsey; and farther north two small outliers have been preserved in synclines on the Kimeridge Clay at Swindon and Bourton. The fact that the

[1] M. P. Latter, 1926, loc. cit., pp. 89–90.
[2] A. W. Groves, 1930, *Q.J.G.S.*, vol. lxxxvii, pp. 86, 70.
[3] *T.A.*, vol. vi, p. 37.
[4] Ibid.
[5] H. B. Woodward, 1895, *J.R.B.*, p. 194.

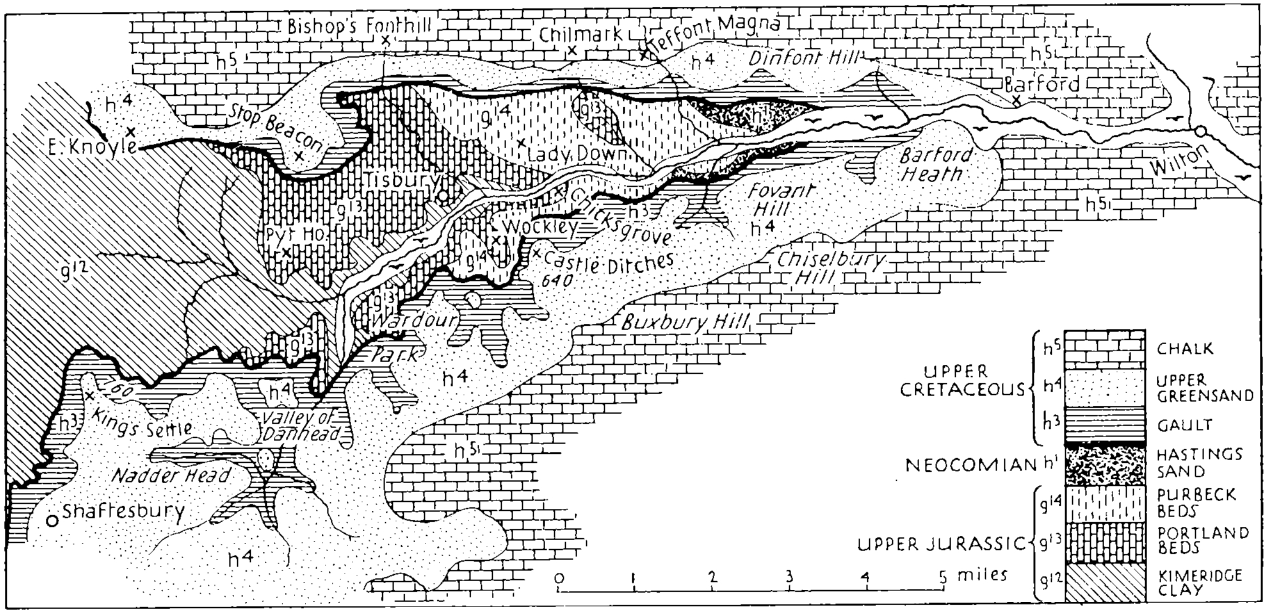


FIG. 85. Sketch-map of the Vale of Wardour, to show the outcrop of the Portland and Purbeck Beds. The thick black line represents the unconformity at the base of the Upper Cretaceous (Albian). (Based on W. H. Hudleston, 1881, *Proc. Geol. Assoc.*, vol. vii, p. 163; re-drawn.)

only two recessions in the Downs disclose Portland Beds in normal superposition above the Kimeridge Clay, while the larger, the Vale of Wardour, shows Purbeck Beds and Wealden Sands also, suggests strongly that the outcrop of these beds is continuous beneath the Cretaceous covering. The covering is so thick that it has never been penetrated by wells.

In a series so variable, the discontinuity of the visible outcrops renders detailed correlation from place to place exceedingly difficult. The total area of Portland rocks exposed at the surface in Wiltshire does not exceed 4 miles square. On the other hand, the distance of the Vale of Wardour from the nearest outcrop to the south, the Isle of Purbeck, is 30 miles; while another 14 miles intervenes between the Isle of Wardour and the Vale of Pewsey, which is separated by a further 18 miles from the outlier at Swindon. From such fragmentary evidence we cannot hope to piece together more than a very incomplete picture of the inland Portland Beds.

(a) The Vale of Wardour

By far the largest and most important surface-outcrop is that of the Vale of Wardour, lying in the extreme south-west corner of Wiltshire, 10 miles west of Salisbury. The remarkable geological features of the Vale have been described by many writers. The River Nadder gathers the surface water from the Kimeridge Clay north of Shaftesbury and carries it eastward across the strike of both the Jurassic and the Cretaceous formations into the heart of the Chalk Downs, to join the Avon at Salisbury. In the apex of the narrowing valley, before the river passes on to the Chalk, the Portland, Purbeck and Wealden Beds are laid bare in a trough 8 miles long and 2 miles wide at the widest end. They strike N.–S. across the floor of the valley and disappear on both sides beneath the walls of Gault, Upper Greensand and Chalk (map, opposite).

The main outcrop of the Portland Beds occupies a dissected upland plateau within the Vale, surrounding the town of Tisbury. A number of quarries have been exploited for building-stone in the past, and one or two are still working. The principal exposures, however, lie about a mile to the east of the main outcrop, in the sides of a valley known as the Chilmark Ravine, where a roll brings the Portland Beds to the surface through the Purbeck Beds in an outcrop about a mile long and a few hundred yards wide. This picturesque ravine, thickly wooded, and scarred beneath the vegetation by numberless ancient quarries and tip-heaps, has for hundreds of years yielded the Chilmark Stone, which was well known long before the Portland Stone was heard of. It was employed in many important buildings in the South of England, among them the cathedrals of Salisbury, Chichester and Rochester, the Chapter Houses of Westminster Abbey, Christchurch Priory, Wardour Castle, Lulworth Castle, and Fonthill Abbey.

The Chilmark Stone is at present worked only in one locality, by means of an underground gallery in the west side of the ravine. In the past it was obtained in large open quarries as well as underground galleries, and some still afford good exposures, especially the largest quarry at the north-west end of the ravine.

The main building-stones are about 18 ft. in thickness and consist of peculiar glauconitic and sandy limestones, very different in appearance from the Portland and Purbeck-Portland freestones. Moreover, they form the base of the local Portland Stone, while above them follow thick chalky limestones with veins and nodules of chert, identical with the Cherty Series of the Upway-Portisham district; and these are in turn succeeded by an upper series of freestones more like those of Dorset.

There seems little doubt on stratigraphical grounds that the main building-stones of the Vale of Wardour correspond with the upper part of the Portland Sands of Dorset, which become glauconitic in the northern limb of the Weymouth Anticline (p. 499). They are probably to be correlated with the West Weare Sandstones of Portland, and so with the upper part of the *Glaucolithites* or '*gorei*' zone. Beneath are some 38 ft. of sandy strata corresponding with the rest of the zone. So far as I am aware this correlation has not been put forward previously, and the study of the ammonites is not yet sufficiently advanced to establish it on a palaeontological basis. But since it seems to be the only one by which the Portland Beds of the Vale of Wardour can be brought into line with those in Dorset, it is tentatively adopted here.

The succession has been very thoroughly elucidated by Hudleston, Blake, and H. B. Woodward. They built on foundations laid by Fitton, W. R. Andrews of Teffont Evias, and Miss Etheldred Benett, one of the earliest of lady geologists, who in the early part of the nineteenth century resided at the stately Pyt House, west of Tisbury. In the following summary the succession established by these geologists is fitted into the classification used throughout this chapter.

SUMMARY OF THE PORTLAND BEDS OF THE VALE OF WARDOUR [1]

Titanites Zone: Upper Building Stones, 0–16 ft.

The Upper Building Stones consist of fine-grained, white or buff, siliceous, oolitic limestones, locally passing into Roach, full of cavities whence the fossils have been dissolved out. The better quality stone takes fine carving and, being very durable, was used in the elaborately carved west front of Salisbury Cathedral. The principal fossils are *Aptyxiella portlandica* (confined to this horizon as at Portland), *Trigonia gibbosa*, *Neomiodon cuneatum* (Sow.) [= *Cyrena* or *Cytherea rugosa* auctt.], *Eodonax dukei* (Mor. and Lyc.), *Protocardia dissimilis*, *Chlamys lamellosa*, *Neritoma sinuosa*, *Ampullina ceres*, and *Lucina portlandica*. There are occasional chert veins in the lower part of the series.

Locally in the south of the area, as at Chicksgrove Mill Quarry, the Upper Building Stones are absent, owing either to attenuation or to the unconformable overlap of the Purbeck Beds, thus recalling the wedging out of the Freestone Series in Gad Cliff.

Kerberites Zone: Cherty Series and Ragstone Beds, 30–5 ft.

CHALKY OR CHERTY SERIES, 24 ft.

The Cherty Series is identical with that in the northern limb of the Weymouth Anticline, consisting of soft, white, chalky limestone, burnt for lime,

[1] Based on J. F. Blake, 1880, loc. cit., pp. 199–203; W. H. Hudleston, 1883, 'The Geology of the Vale of Wardour', *P.G.A.*, vol. vii, pp. 161–85; H. B. Woodward, 1895, *J.R.B.*, pp. 203–9.

with many veins and nodules of black flinty chert. The fossils are mainly of large size and include many big ammonites recorded as '*A. boloniensis*', like those abounding on the slabs at Dancing Ledge and Winspit, but as yet unstudied (Buckman figured one specimen from Chilmark as '*Galbanites*' *cretarius*).[1] The other fossils are principally *Chlamys lamellosa*, *Ostrea expansa*, *Protocardia dissimilis* and *Trigonia gibbosa*; the last forms locally a bed of Roach at the base, comparable with the roach-beds in the Cherty Series of Portland. According to Hudleston the upper part of the series is missing at Chicksgrove Mill. A local chert vein near Tisbury formerly yielded silicified specimens of the coral, *Isastræa oblonga*, which were cut and polished and were famed as long ago as 1729 under the name of 'Starr'd Agates'.[2]

THE RAGSTONE BEDS, 8–10 ft. [= BASAL SHELL BED?].

At the base of the Cherty Series are 8–10 ft. of strongly-bedded, very shelly limestone, containing quartz grains but no glauconite, and divided by marly partings. In the state of preservation of their fossils as well as in their stratigraphical position these Ragstones resemble the Basal Shell Bed of the Isle of Portland. Before the wonderful fauna of the Portland stratum was made known by Mr. Cox, Hudleston declared that no Portland rock in England contained such well-preserved fossils as the Ragstones of Chilmark. The fauna, however, has received relatively little study, and no ammonites are known. The most abundant species is *Neomiodon cuneatum* (Sow.), a small lamellibranch that has given rise to more discussion and misconceptions than any other in the Upper Jurassic.[3] It is in appearance like a strongly-ribbed *Astarte*, but the hinge bears the dentition of *Neomiodon*, to which belongs the freshwater Cyprinid shells common in the Purbeck Beds and formerly known as *Cyrena*. On this account Hudleston called the Ragstones the *Cyrena* Beds and the Upper Building Stones the Upper *Cyrena* Beds, even going so far as to say that they had an estuarine or fluvio-marine origin. But of this *Neomiodon cuneatum* is no evidence, for although it has not been found in the Basal Shell Bed (or any other part of the Portland Series) of Portland, it ranges on the Continent throughout the Kimeridgian and Portlandian stages, where it certainly lived under purely marine conditions. It differs from the Purbeck species in being strongly ribbed like an *Astarte*, whereas they are smooth, and its generic affinities are still somewhat doubtful.

Other common fossils in the Ragstones are '*Cerithium*' *concavum* Sow., a number of other gastropods, and such familiar marine forms as *Protocardia dissimilis* and *Lucina portlandica*.

Glaucolithites Zone: Portland Sand, 50–60 ft.

MAIN BUILDING STONES, 18 ft.

The main building stones of Chilmark and Tisbury consist of glauconitic and sandy limestones varying from green to brownish-buff in colour. They are of generally uniform appearance, but the quarrymen detect slight differences and give to each bed a distinguishing name. The names vary in different

[1] *T.A.*, 1925, pl. DCXXI.
[2] H. B. Woodward, 1895, *J.R.B.*, p. 208.
[3] L. R. Cox, 1929, *Proc. Dorset N.F.C.*, vol. l, pp. 175–6.

parts of the district and they are now for the most part dying out; Woodward listed the following:

	ft.	in.	
Trough Bed with *T. gibbosa*	2	8	18 ft. 0 in.
Green Bed	5	0	
Slant Bed	1	0	
Pinney Bed	2	0	
Cleaving or Hard Bed	1	0	
Fretting Bed	3	4	
Under Beds	3	0	

Fossils are generally scarce, but *Trigonia gibbosa* is not uncommon in the Trough Bed, and the Pinney Bed receives its name from an abundance of *Serpulæ*. Some ammonites occur, recorded by Blake as '*A. boloniensis*' and '*A. biplex*'. The latter is suggestive of *Glaucolithites*, but the forms have not been worked out according to modern standards. One, however, has been figured by Buckman from the Green Bed as *Gyromegalites polygyralis*.[1]

BASEMENT BEDS WITH UPPER LYDITE BED, 30–40 ft.

Woodward records that a well was sunk at the base of the Chilmark (Teffont) Quarry beneath the Building Stones to a depth of 38 ft., through clays and calcareous sandy bands to black Kimeridge Clay. These sandy strata, called the Basement Beds by Hudleston, seem to have been seen only twice in temporary excavations. In the railway-cutting (now overgrown) west of Chicksgrove Mill, east of Tisbury, Woodward described 15–20 ft. of 'brown and greenish-brown sand with clay seams and bands of indurated sand, containing casts of shells here and there and thin beds of stone near the top'. These beds seemed to merge up gradually into sandy, shelly and glauconitic limestone, presumably representing the base of the Building Stones.[2]

A more interesting section was described by Blake and by Hudleston, exposed in a road-cutting near Hazelton, between Tisbury and Wardour.[3] Beneath the Building Stones were 7 ft. of loose sands with doggers, underlain by 3 ft. of greenish concretionary gritstone, and below all, sands and clays seen to 21 ft. The chief centre of interest was the 3 ft. of gritstone, which contained not only badly-preserved *Trigoniæ*, *Isognomon bouchardi*, *Chlamys lamellosa*, *Protocardia dissimilis*, *Exogyra nana*, &c., but also occasional lydite pebbles.

This is the most southerly known occurrence of lydite pebbles. They become a constant feature in the more northerly areas, at Swindon and in Oxfordshire and Buckinghamshire, where they occur always on the same horizon and form the Upper Lydite Bed.

(b) The Vale of Pewsey

A small area of Portland Beds peeps out from beneath the Cretaceous rocks at the mouth of the Vale of Pewsey, between Potterne and Coulston, near Devizes, but exposures are too meagre for the succession to be made out. Woodward described diminutive exposures of several types of rock: cherty

[1] *T.A.*, pl. DCXX, c, d. [2] H. B. Woodward, 1895, *J.R.B.*, pp. 206, 204.
[3] W. H. Hudleston, 1883, *P.G.A.*, vol. vii, p. 172.

beds, fossiliferous gritty limestone, gritty and glauconitic limestone with an occasional lydite pebble, and glauconitic sands with concretions.[1] Not for another 18 miles, until Swindon is reached, 32 miles from the Vale of Wardour, do the Portland Beds again come to the surface.

(c) The Swindon Outlier

The hill upon which Old Swindon is built is capped with Portland and Purbeck Beds. They probably owe their preservation to being situated in a synclinal depression on the outskirts of the area where the Cretaceous rocks normally would overstep on to Kimeridge Clay, for they seem to be an outlier: no trace of them was found in a boring carried through the Cretaceous rocks at Burdrop, between Wroughton and Chiseldon, on the south.

Thanks to two extensive quarries on the summit of the hill, described in detail by Blake, and to a railway-cutting opened subsequently to Blake's work and described by H. B. Woodward (fig. 79, p. 456), the succession is known in considerable detail. The zonal positions of the subdivisions were established by the palaeontological work of Dr. Salfeld, whose results were later corrected and amplified by Messrs. Pringle and Chatwin.

The highest part of the Portland Stone (the *Titanites* zone) and the Purbeck Beds are seen only in the Town Gardens Quarry, long ago abandoned and now rapidly deteriorating. The lower zones and the junction with the Kimeridge Clay, which were also exposed in the railway-cutting near Old Town Railway Station, are well displayed in Okus Quarry, on the western end of the hill. Here work is still carried on apace and many gigantic ammonites may be obtained. Although some of them reach almost the dimensions of the giants of Portland and Purbeck, they are of different genera, characteristic of the earlier Behemothan Age, and they are associated with species of *Kerberites*.

There are several new features not met with farther south, but perhaps the most important is the extremely thin representation of the Portland Sand, which is reduced, both here and in the more north-easterly areas, to a few feet of Glauconitic Beds with the Upper Lydite Bed at the base.

SUMMARY OF THE PORTLAND BEDS OF SWINDON [2] (fig. 86)

Titanites Zone: The Creamy Limestones, about 10 ft.

As elsewhere, the beds of the *Titanites* zone are highly variable in short distances, a fact which has given rise to considerable discrepancies in the accounts of the succession seen in the old Town Gardens Quarry. In places the whole zone is absent and the beds beneath are overlain directly by Purbeck Beds.

Where they are preserved, there is at the top up to 6 ft. of pale, cream-coloured marly limestone, suggestive of some of the Purbeck Beds, but containing, rarely, shells of *Trigonia*. Beneath comes 4 or 5 ft. of Roach like that at Portland, riddled with hollow moulds of *Aptyxiella portlandica*, here associated with an equal abundance of *Neomiodon cuneatum*, and the usual *Trigonia*

[1] H. B. Woodward, 1895, *J.R.B.*, p. 210.

[2] J. F. Blake 1880, loc. cit., pp. 203–13; H. B. Woodward, 1895, *J.R.B.*, pp. 210–15; Chatwin and Pringle, 1922, *Sum. Prog. Geol. Surv.* for 1921, pp. 162–8 (see also 1922, *P.G.A.*, vol. xxxiii, pp. 152–5).

gibbosa, *Chlamys lamellosa* and *Protocardia dissimilis*. Apparently no ammonites have been found in these beds.

According to Blake there is at the base a distinct discordance.

Kerberites Zone: Swindon Sand and Cockly Bed, 30 ft.

THE SWINDON SAND AND STONE.

This is the thickest part of the Portland Beds of Swindon, consisting of

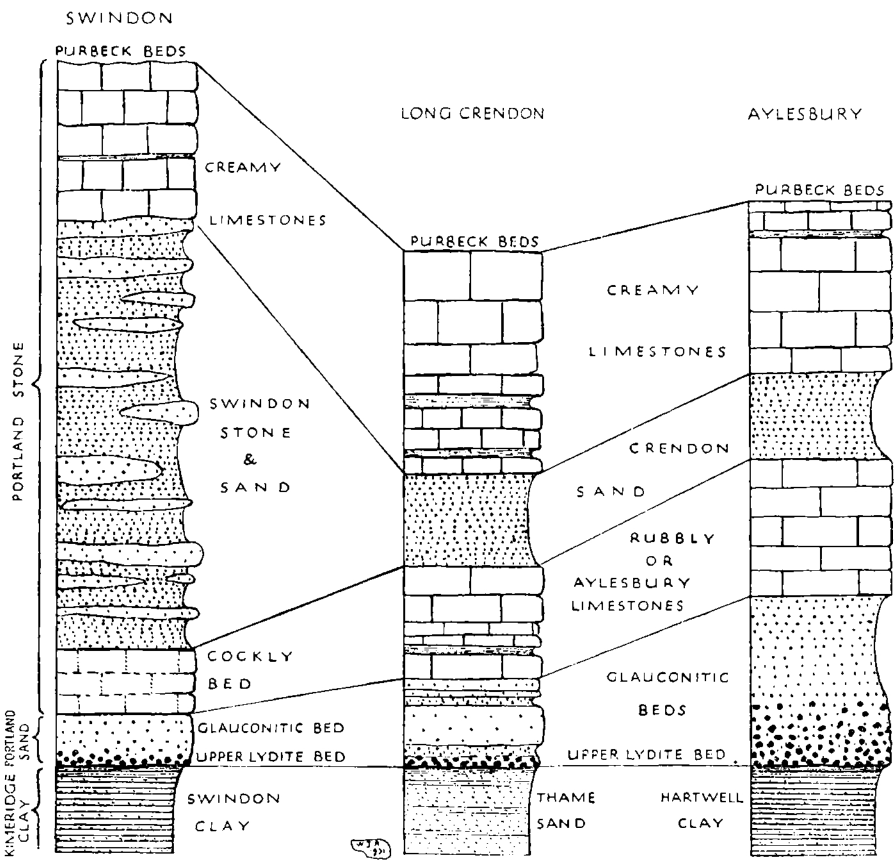


FIG. 86. Comparative sections showing the Portland Beds of Swindon, Long Crendon (after Buckman) and Aylesbury (after Woodward and Hudleston).

25 ft. of buff and white false-bedded sands with bands and lenticles of calcareous sandstone. Locally the sands are largely made up of comminuted oysters and Pectens, and they also contain some lignite; but on the whole they are very poorly fossiliferous, and ammonites seem to be unknown. The Swindon Sand forms the lower part of the section in the Town Gardens Quarry and the upper part of that in Okus Quarry, and it is still well exposed in the railway-cutting (fig. 79). Blake correlated the beds with the Cherty Series of Portland, a view which still seems probably correct.

THE COCKLY BED.

At the base of the Swindon Sand in Okus Quarry is a 4 ft. bed of creamy limestone crowded with fossils, for the most part in the form of moulds and casts, named the Cockly Bed to distinguish it from the Roach of higher horizons. The Cockly Bed is the source of nearly all the ammonites found in the Portland Stone of Swindon, and some are of gigantic size, but they still remain to be adequately described and figured. Salfeld and subsequent writers identified the commonest form as '*Perisphinctes*' *pseudogigas* Blake, but more recently Buckman has chosen a neotype of Blake's species from the *Titanites* zone of Buckinghamshire. A number of the Swindon forms will probably fall into the genus *Behemoth* of Buckman. The other common type of ammonite is the genus with heavy triplicate ribbing now known as *Kerberites*, of which the Cockly Bed of Okus Quarry is the source of the types of *K. trikranus* Buck.[1] and *K. okusensis* (Salfeld).[2] *K. kerberus* Buck. is also common; the holotype came from Chicksgrove near Tisbury, but from exactly which horizon is uncertain.[3]

Other common fossils of the Cockly Bed, approximately in order of abundance, are *Protocardia dissimilis*, *Trigonia incurva*, *T. gibbosa*, *Isognomon bouchardi*, *Pleurotomaria rugata*, *Pleuromya tellina*, *Mytilus suprajurensis* Cox. The bed is simulated in appearance by the lenticles of Roach in the Cherty Series of Portland.

Glaucolithites Zone: Glauconitic Beds and Upper Lydite Bed, 3½ ft.

The Portland Sand is very greatly reduced, consisting of only 3½ ft. of glauconitic, sandy limestone, with at the base a well-marked layer of lydite and phosphatic pebbles—the Upper Lydite Bed, so called to distinguish it from the Lower Lydite Bed at the base of the Swindon Clay (see p. 457).

The glauconitic limestone contains *Glaucolithites gorei* (Salf.) which is found in the upper part of the Portland Sand of Dorset (the West Weare Sandstone), and a number of similar forms, some of which have been figured and named by Buckman; e.g. *Polymegalites polypreon*[4] and *Gyromegalites polygyralis*.[5] The last was also figured from the Green Bed of the Main Building Stones of Chilmark.[6] The Upper Lydite Bed, aptly styled many years ago by Hudleston 'the basal conglomerate of the Portlands', contains rolled and phosphatized fragments of small ammonites derived from the *Pavlovia* zones of the Kimeridge Clay, upon which it reposes non-sequentially. If we correlate it with the Lydite Bed in the Vale of Wardour (as seems reasonable) it is evident that the bulk of the Portland Sands of that locality are missing at Swindon. Assuming that the portion of the Portland Sands above the Lydite Bed in the Vale of Wardour (the Main Building Stones and 7 ft. of sands) is approximately equivalent to the West Weare Sandstone of Portland and the St. Alban's Head Marl of Purbeck, then it emerges also that some 130 ft. of Dorset strata are wanting in this position at Swindon. The *scythicus* zone has nowhere been detected inland.

[1] *T.A.*, 1924, pl. DXXXV.
[2] *T.A.*, 1925, pl. DLXX.
[3] *T.A.*, 1924, pl. DXX and 1926, pl. DXX, a–b.
[4] *T.A.*, 1925, pl. DXCI.
[5] *T.A.*, 1925, pl. DCXX, a and b.
[6] *T.A.*, 1927, pl. DCXX, c and d.

(d) The Bourton Outlier

Five miles east of Swindon, just over the Berkshire border, a tiny outlier of Portland Beds, only half a mile in diameter, forms the hill on which the village of Bourton stands. The stone was formerly quarried in a large pit on the south of the village, at Bourton End, but the sides are now sloped and overgrown, and the excavation is full of water. The complete succession on the hill was made out by Godwin-Austen in 1850,[1] and the quarry was again described by Sir Andrew Ramsay in 1858.[2] The succession is essentially the same as at Swindon, except that there are a few feet (7 ft.?) of sands below the Lydite Bed. It is possible that this represents some portion of the Portland Sand, preserved here below the Lydite Bed, but it is more probable that it is a sandy development of the upper part of the Swindon Clay, equivalent to the Thame Sand of Oxfordshire (see above, p. 458). A recent excavation already referred to (p. 458), lower down the hill south-east of the old quarry, has proved that the lower part of the Swindon Clay is present in normal development, with the Lower Lydite Bed at the base, resting on the Shotover Grit Sands or *pectinatus* zone.

Combining Godwin-Austen's and Ramsay's description with this new information, it is possible to piece together the full succession at Bourton, as follows:

SUCCESSION AT BOURTON

	Interpretation.	*Record* (*Godwin-Austen*).	*Ft.*
	CREAMY LIMESTONE	Stratified earthy oolite: Ammonites and casts of *Trigonia*	8?
	SWINDON SAND	Buff and yellow sand; no fossils	12
		Flat-bedded white oolitic sand	8
	COCKLY BED	Rubbly oolite: large *Pleurotomariæ* . . .	1
		Ostrea and *Perna* bed	?
	GLAUCONITIC BEDS AND UPPER LYDITE BED	Pebbles in calcareous beds: fossils numerous (Ramsay calls the base of this 'a bed of hard bluish fossiliferous limestone with pebbles of Lydian stone and white quartz')	10
KIM. CLAY	? THAME SAND	Fine sands	7?
	SWINDON CLAY	Kimeridge Clay below. (Swindon Clay, base greenish, sandy)	
	LOWER LYDITE BED	(Lower Lydite Bed, lydites abundant, ½ ft.)	Seen in 1930
	SHOTOVER GRIT SANDS	(Sands with large doggers, seen to 4 ft.)	

III. THE OXFORDSHIRE AND BUCKINGHAMSHIRE AREA

The most northerly area of Portland Beds exposed at the surface in Britain, and also the largest, extends from Nuneham Courtenay, on the east bank of the Thames, in a north-easterly direction for 25 miles past Thame and Aylesbury to Whitchurch and Stewkley, on the watershed of the Ouse. It is now dissected by the River Thame and its tributaries into scattered groups of outliers, but the original area covered by the Portland Beds now exposed must

[1] R. A. C. Godwin-Austen, 1850, *Q.J.G.S.*, vol. vi, p. 462.
[2] A. Ramsay, 1858, 'Geol. Parts of Wilts. & Gloster', p. 27, *Mem. Geol. Surv.*

have been at least 25 miles long and more than 8 miles wide. The south-western edge of the area is 21 miles from Bourton.

The principal outlier, usually designated the main outcrop, lies between Thame and Aylesbury, and, with the many others to the north and west, forms a pleasant country of small hills, often capped by Purbeck Beds, Lower Greensand or Gault, and separated by valleys of Kimeridge Clay.

The Cretaceous rocks overstep from the south and south-east in such a way that the Portland Beds seem to have been isolated like those at Swindon. In consequence also of this overstep, especially on the southern and south-eastern margins of the area, the sequence is often incomplete. The effect is most marked in Oxfordshire, about Haseley, the Baldons, the Miltons, and the long ridge of Shotover Hill, running from Garsington and Cuddesdon to Headington, where the *Titanites* zone is often absent. In the parallel ridge running from Thame to Long Crendon and Chilton and terminating in the outliers of Brill and Muswell Hills, and also in the central area about Haddenham, Cuddington and Hartwell, higher beds are present. From here many giant ammonites of the *Titanites* zone, like those at Portland, have been obtained. Down the dip-slope, about Thame, on the contrary, the Portland Stone Series seems to have been in places entirely removed by the Cretaceous denudation.

In the most northerly outliers, about Quainton, Oving, Whitchurch and Stewkley, exposures are now meagre, but the succession was accurately described by Fitton, and it is evident that it is complete. North-east of Aylesbury, the Gault cuts out the Portland Beds entirely, coming to rest on the Kimeridge Clay and finally on the Oxford Clay.

Although this area is so large in comparison with the Wiltshire outcrops, it will suffice for our present purpose to summarize its features as a whole, in a single generalized succession. The same subdivisions as at Swindon may be recognized; in particular there is almost the same reduction of the Portland Sands to a few feet of Glauconitic Beds, with the Upper Lydite Bed at the base.

The sequence has been elucidated by a number of distinguished geologists. The groundwork was as usual laid by Fitton,[1] who described in detail many sections long since abandoned and too often completely obliterated. His careful work, which has preserved for our benefit many valuable and irretrievable records, provides an outstanding example of the importance of recording every exposure before economic vicissitudes render it too late and the information is lost. Blake in 1880 summarized the succession,[2] introducing the four main subdivisions used at the present day. At the top he divided off beds of 'compacted shell brash' and 'creamy limestones' (now grouped together as the Creamy Limestones), separated by sands (the Crendon Sands of Buckman forty-five years later) from a lower set of highly fossiliferous 'Rubbly Limestones'. Below these he recognized the Glauconitic Beds and the Lydite Bed at the base. Blake's correlation of these subdivisions with those at Swindon, however, was somewhat wild.

Between 1880 and 1890 Hudleston led several excursions of the Geologists' Association over the ground in the neighbourhood of Aylesbury, publishing detailed accounts of the succession at the Bugle Pit, Hartwell, and at Aylesbury

[1] W. H. Fitton, 1836, *Trans. Geol. Soc.* [2], vol. iv, pp. 269–95.
[2] J. F. Blake, 1880, loc. cit., pp. 213–21.

and Bierton.[1] The whole area was revised by H. B. Woodward in 1895 and Blake's correlation was criticized. In particular Woodward emphasized the stratigraphical continuity of the Lydite Bed with that at Swindon.[2]

By far the most detailed investigation was made by Prof. A. Morley Davies and published in 1899.[3] He described a number of new exposures and above all was able to establish three complete vertical sections in the west and central parts of the area, at Garsington, Long Crendon and Haddenham, to compare with that published by Hudleston for the Aylesbury district in the east. The stratal succession was thus established on a sure foundation, and in certain localities it was now known in considerable detail.

Finally S. S. Buckman settled in the district. He made his home at Southfield, on the road between Thame and Long Crendon, and so began in earnest his incursions into Upper Jurassic stratigraphy. He soon collected a number of large ammonites from the pits at Long Crendon, especially one now already nearly filled up at Barrel Hill,[4] south of the village, and others north-west of the village beside the road to Oakley. In 1922 he published a table of hemeræ, which was corrected and enlarged in 1926.[5] The quarrymen's terms for the beds were listed and almost every bed was assigned a zonal index; in all, the Portland Beds of Long Crendon were divided into 23 beds, for which 16 zonal indices were provided, covering his two Behemothan and Gigantitan Ages. At the same time photographs of the ammonites were published in *Type Ammonites*, most of them under not only new specific but also new generic names. Buckman explained that this was to be considered, not so much a splitting up of previously-existing zones, as an amplification of the known zonal sequence.

In his treatment of the Portland Beds of Long Crendon Buckman displayed as clearly as in any part of his work the limitations of the principles which he followed, and the illogical results inevitably obtained (both in systematy and in stratigraphy) by pursuing them beyond their reasonable capacity. In his more cautious youth he would never have pressed sound principles to so outrageous a conclusion, but in his old age he seemed to become reckless. Every bed that yielded an ammonite became for him a zone, every new thread discerned in the mighty tangle of ammonite phylogeny, however slightly different it might be from the rest, was for him a new genus. The ordinary cautions proclaimed by ecology went unheeded, and the absence of an expected ammonite was hailed as infallibly indicating stratal failure.

A different view has been taken by the most recent reviser of the families of ammonites to which those from Long Crendon belong. Dr. L. F. Spath, in his monumental work on the Indian and English Cephalopods, states that most of Buckman's Portlandian genera are quite unjustifiable, and he believes that the diversity of types upon which they are founded constitute a purely local English fauna without chronological value.[6] Nevertheless this fauna,

[1] W. H. Hudleston, see bibliography.
[2] H. B. Woodward, 1895, *J.R.B.*, pp. 216–28.
[3] A. M. Davies, 1899, *P.G.A.*, vol. xvi, pp. 15–58.
[4] Not to be confused with Barley Hill, east of Thame, one of Fitton's localities (1836, p. 282) now entirely obliterated, which Prof. Davies believes to be located at the rising ground north of Kingsey Road, Thame (1899, p. 31).
[5] S. S. Buckman, 1922, *T.A.*, vol. iv, p. 26; and 1926, vol. vi, p. 35.
[6] L. F. Spath, 1931, *Pal. Indica*, N.S., vol. ix, p. 472.

local or not, would well repay detailed examination. An interesting work awaits any palaeontologist who will undertake to describe and figure it systematically (the Portland and Purbeck specimens as well as those from Buckinghamshire), for it not only represents the expiring effort in the evolution of that almost incredibly diverse family, the Perisphinctidæ, but also their acme in diversity of form and immensity of size.

Moreover it must be recognized that Buckman, by his work at Long Crendon and by means of his refinement in ammonite identification, achieved the correlation of the Oxon.-Bucks. Portland Beds with those of Wilts. and Dorset. He showed that the Creamy Limestones contain the same assemblage of *Titanites* ammonites as the Freestone Series of the Isle of Portland; that the Rubbly Limestones contain *Kerberites kerberus*, which characterizes the Cockly Bed at Swindon; and that the Glauconitic Beds contain the *gorei* forms (*Glaucolithites*, &c.) found on the same horizon at Swindon and in the top of the Portland Sands of Dorset.

Thus we are enabled for the first time to give a summary of the Portland Beds of Oxfordshire and Bucks. fitted into the classification adopted in the type-locality.

SUMMARY OF THE PORTLAND BEDS IN OXON. AND BUCKS.[1] (fig. 86, p. 506)

Titanites Zone: Creamy Limestones, 7–12 ft.

The highest rock in all the quarries was described by Blake as several beds of a compacted shell brash, 3–4 ft. thick, having at the bottom of the topmost block a number of *Trigoniæ* (*T. gibbosa*). From these beds Buckman figured some peculiar ammonites which he did not find at lower horizons. The highest 3 ft. at Barrel Hill, Long Crendon, in the quarry now in process of being filled up, consisted of four beds with Cadicone Gigantids and was called by the quarrymen the Upper Witchett. Beneath was a 2 ft. 6 in. shell-bed with massive Gigantids called the Osses Ed.[2] From these beds Buckman figured the genotypes and holotypes of the following ammonites: *Hippostratites hippocephaliticus*,[3] *H. rhedarius*,[4] *Glottoptychinites glottodes*,[5] *G. audax*,[6] the first from Scotsgrove near Haddenham, the second and third from Barrel Hill, and the last from Coney Hill near Over Winchendon. He remarked that he had seen nothing comparable with these ammonites among the giants from Portland and suggested that the beds yielding them were younger than any Portland Beds preserved in Dorset. Perhaps they correspond with the Shrimp Bed of Purbeck, in which unidentified ammonites of similar style occur (see p. 485).

The true Creamy Limestones, as originally so-called by Blake, consist of some 5 ft.–9 ft. of white, chalky, non-oolitic and highly fossiliferous limestone, crowded with *Ostrea expansa*, *Trigonia gibbosa*, *Protocardia dissimilis* *Ampullina ceres*, &c., and with the usual giant ammonites of the *Titanites* zone. Blake stated that he found *Aptyxiella portlandica* at one locality, but he omitted to mention where.[7]

[1] Based on Blake, Hudleston, Woodward, Morley Davies and Buckman, loc. cit.

[2] Horses' Heads is the name given by quarrymen in many parts of England to the casts of *Trigoniæ*. Plot adopted the name as *Hippocephaloides* (*Nat. Hist. Oxfordshire*, 1676, p. 128, pl. VII, fig. 1).

[3] *T.A.*, 1924, pl. CDXCV. [4] *T.A.*, 1924, pl. DXIV. [5] *T.A.*, 1923, pl. CDIII.

[6] *T.A.*, 1927, pl. DCCXVII. [7] 1880, loc. cit., p. 217.

According to Buckman certain forms of ammonites at Barrel Hill, Long Crendon, are restricted to definite beds, and he lists the workmen's terms for the beds and the ammonites derived from them as follows (the Roman numerals refer to plates in *Type Ammonites* in which the forms are figured):

Sandstone	1 ft. 7 in. with *Briareites polymeles* (CCLVII).
[Supposed position of bed at Haddenham with *Titanites titan*] (CCXXXI).	
Hard Lime	1 ft. 3 in. with *Gigantites giganteus* (CCLVI).
Soft Rock	9 in. with *Trophonites trophon* (CCCXXV and CCCXLIII).
Lower Witchett .	1 ft. 0 in. with *Galbanites fasciger* (CDLI) and *Pleuromegalites forticosta* (DXIII).
Hard Stone	1 ft. 3 in.
Waste	7 in.
Bottom Bed or Hard Brown .	1 ft. 2 in. with *Vaumegalites vau* (DXXXVI).

It was from this district that the types of the familiar species *A. giganteus* Sowerby and *A. pseudogigas* Blake came, and Buckman has figured chorotypes.[1] The new genus *Gigantites*, which he created for *A. giganteus*, is according to Dr. Spath synonymous with the earlier-named *Titanites*, and the genus *Trophonites*, to which he assigned *A. pseudogigas*, Dr. Spath thinks may be the same as the earlier-named *Kerberites*. It is to be noted that between 1922 and 1925 Buckman reversed the order of the *Titanites* and *Briareites* hemeræ without explanation.[2] Dr. Spath considers that *Galbanites* as well as the other three genera can be considered synonymous with *Titanites*.[3]

Kerberites Zone: Crendon Sand and Aylesbury Limestone, *c.* 12–15 ft.

THE CRENDON SAND, 5–17 ft.

At the base of the Barrel Hill Quarry, Long Crendon, were 5 ft. of non-glauconitic, unfossiliferous, yellowish-brown sands, called by Buckman the Crendon Sand. Blake noticed that they are continuous throughout the district and occur 'within the limits which we must assign to the Portland Stone as distinguished from the Portland Sand'. Hudleston and Woodward noted them, still 5 ft. thick, at Aylesbury, at the other end of the district (see fig. 86), and Fitton described them on the outlier of Stewkley (7 ft. thick). In a recent excavation for a new reservoir at the northern extremity of Shotover Hill they were considerably thicker and were directly overlain by the Shotover Ironsands (Cretaceous). Here they also contained bands of hard calcareous, unfossiliferous sandstone, recalling unmistakably the Swindon Sand and Stone, with which they are beyond much doubt to be correlated. Dr. Pringle noted a similar section in a well at Coombe Wood, on the Shotover ridge, and here the thickness of the sand and stone bands (Swindon Stone) was 17 ft. He noted them also at the City Farm, where their thickness was 12–15 ft.[4]

[1] *T.A.*, 1921, pl. CCLVI, and 1923, pl. CCCLXXXV.
[2] Compare *T.A.*, iv, 1922, p. 26; vol. v, 1925, p. 71; and vol. vi, 1926, p. 35.
[3] L. F. Spath, 1931, loc. cit., p. 472.
[4] J. Pringle, 1926, 'Geol. Oxford', 2nd ed., *Mem. Geol. Surv.*, pp. 80–1.

THE RUBBLY LIMESTONES OR AYLESBURY LIMESTONE,[1] 6–12 ft.

Blake described the Rubbly Limestones as well displayed in several excavations now almost disappeared, at Coney Hill, Quainton, Brill, Lodge Hill and Aylesbury railway-cutting. They are still to be seen in the small quarries north-west of Long Crendon, beside the road to Oakley, where they were described under the quarrymen's terms by Buckman; the thickness here is about 7 ft. In 1922 he recorded '*P. gorei*' from about the middle, but later (1925–6) he omitted this record and inserted *Kerberites kerberus* at the base and '*Crendonites*' *leptolobatus* near the top. But Dr. Spath thinks '*Crendonites*' is probably synonymous with *Glaucolithites*, and Buckman's specimen was picked up on a heap of quarried stone and has a slightly glauconitic matrix, and so it may have come from the Glauconitic Beds.[2]

In the recent excavation for the reservoir on Shotover Hill a large quantity of the Rubbly Limestones was thrown out. The material, in the identity and state of preservation of its fossils as well as in its lithic appearance, bore a striking resemblance to the Cockly Bed of Swindon. Dr. J. A. Douglas and Mr. C. J. Bayzand obtained a number of the large ammonites comparable with those from the Cockly Bed, and it is hoped that a publication will soon appear on the subject. A similar fauna was collected by Hudleston from material thrown up during drainage operations near the George Hotel, Aylesbury.

Blake noticed that at Coney Hill many of the fossils seemed to have been derived, for their matrix differed from that of the surrounding Rubbly Limestone.

Glaucolithites Zone: Glauconitic Beds and Upper Lydite Bed, 5–10 ft.

Over the whole area the base of the Portland Beds consists of 5–10 ft. of highly glauconitic, green, rubbly, sandy limestone and sand, with the Upper Lydite Bed at the bottom, resting upon the *Pavlovia* zones of the Kimeridge Clay (or the Thame Sands; see p. 466). Two of the best sections, described by Hudleston, were the pits in the Hartwell Clay at Hartwell and Bierton, near Aylesbury, where the Lydite Bed is unusually thick and fossiliferous. A cutting on the Metropolitan Railway at Walton proved the sand and Lydite Bed to be 10 ft. thick.[3] Another good section may now be seen on Shotover Hill, since the large quarry in the Shotover Grit Sands has recently been enlarged farther into the hill and displays the Swindon Clay with the lower Lydite Bed below and the Upper Lydite Bed above, overlain by the Glauconitic Beds.

Buckman has investigated the ammonite fauna of the Glauconitic Beds in the quarries north-west of Long Crendon and he records the following succession, using again the quarrymen's terms and introducing a number of new genera. As these have not yet been revised, I give the original names.

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(Rubbly Limestones above.)	
Green Specked Bed . .	9 in. with *Polymegalites polypreon* (cf. DXCI).
Brown layer . . .	3 in.
Green marl (ammonites in white matrix)	8 in. with *Leucopetrites leucus* (CCCVII a–c).
Building Stone (glauconitic) .	3 ft. 0 in. with *Glaucolithites glaucolithus* (CCCVI).
Waterstone . . .	10 in. with *Aquistratites aquator* (DXXXIV) and *Hydrostratites bifurcus* (DCLXXVI).
Lydite Bed .	5 in. with '*Lydistratites*' *lyditicus* (= derived Pavlovids).
(Thame Sands below.)	

In addition to these ammonites he figured from the Glauconitic Beds of Haddenham the genoholotype of *Behemoth megasthenes*[1] and from Thame *B. lapideus*.[2]

The Upper Lydite Bed provides one of the most constant and most useful datum lines for the correlation of the Portland Beds from Aylesbury to the Vale of Wardour. Its essential contemporaneity was insisted upon first by Hudleston, then by Woodward, and more recently by Prof. Davies.

'There are certain general reasons', wrote the last, 'why a pebble-bed of this kind should be a more trustworthy indication of a definite horizon than a line of lithological change.... Such a bed, especially when continuous over a large area, betokens most probably an interruption of normal sedimentation for a time by the action of a current—some of the fine material previously deposited being probably swept away at the beginning of the current-phase, while at the end of that phase the first slackening in the current would cause a deposition of pebbles previously swept to and fro, and then the deposit of fine material would be resumed.'[3]

Prof. Davies found among the usual fragments of black chert constituting the bulk of the 'lydites' at Garsington several pebbles of spherulitic felsite and one of phosphatized bone. Later he recorded also a fragment of a phosphatized ammonite at Dadbrook Hill near Haddenham.[4] More recently a detailed study has been devoted to the bed by Dr. Neaverson.[5] He divides the pebbles into two sorts, those of local origin, and those which are far-travelled. The pebbles of the first category are highly phosphatic, containing as much as 56 per cent. of calcium phosphate; they comprise phosphatic casts of lamellibranchs and Pavlovid ammonites, dull black in colour, composed of clear quartz grains, with occasional grains of glauconite, set in a brown matrix. The ammonites have for the most part been washed out of the underlying Hartwell or Swindon Clay and are thus derived, though not in the sense of Dr. Neaverson's more distantly derived pebbles of the other category.

The pebbles brought into the district from a distant source consist mainly of black chert, and in some of them Dr. Neaverson found spicules of *Hyalostelia*, a sponge found in the Lower Carboniferous Beds of Scotland, Yorkshire, North Wales and Ireland. Besides the cherts, there are a number of fragments of vein quartz and some, of especial interest, of silicified oolite. These may also be regarded as a chert, with ooliths which have been nearly

[1] *T.A.*, 1922, p. CCCV.
[2] *T.A.*, 1922, pl. CCCXLII a–c.
[3] A. M. Davies, 1899, loc. cit., p. 25.
[4] Ibid., pp. 20, 158.
[5] E. Neaverson, 1925, *P.G.A.*, vol. xxxvi, pp. 245–6.

obliterated during silicification. Similar pebbles occur in the Lower Greensand of Faringdon, and in boulders derived from the Lower Greensand in Glacial deposits near Quainton. Their origin is problematic, but again the existing occurrences of silicified oolite, like those of spicular chert, are in the North-West Highlands of Scotland (Torridonian and Cambrian) and South Wales (Carboniferous).

These considerations, taken in conjunction with the failure of the lydites in Dorset, lead Dr. Neaverson to postulate a northerly origin for the pebbles. That they were derived originally from some part of the Caledonian mountain chain seems highly probable, but they may have come from a part of the chain lying to the east of the British Islands; and they may have travelled south in late Palaeozoic or Triassic times and have been rederived during the Jurassic period from the London–Ardennes landmass or its extension under the North Sea.[1]

IV. KENT[2]

No Portland Beds are known to exist in the British Isles north of the last faulted outlier at Stewkley, near Leighton Buzzard. An idea formerly prevalent (introduced by Pavlow), and reiterated even in certain recent textbooks, that equivalents of the Portland Beds exist in the Speeton Clay of Yorkshire, has been dispelled by recent work (see above, p. 472). Another basin of deposition, however, or more probably a continuation of the Dorset trough, has been proved by the borings beneath the Weald of Kent. The Portland Beds were penetrated in at least six places, four of them in a straight line running nearly west to east from Tonbridge towards Dover, and the rest near Battle, on the south of the Weald.

Lithologically the rocks are markedly different from those in Dorset and accurate correlation of the subdivisions, with the limited palaeontological evidence supplied by the cores, was impossible. The Portland Stone was found to be much more sandy than in Dorset and there was no suggestion of a Freestone Series or a Cherty Series. The Portland Sand, on the other hand, was more argillaceous and graded down so imperceptibly into the Kimeridge Clay that for convenience it had to be classed with the Upper Kimeridge Clay, no separation being practicable. For these reasons the over-all thickness of the Portland Beds as defined in this chapter cannot be ascertained from the records.

It was found that the stone-beds were thickest in the west, at Penshurst boring, south-west of Tonbridge, where they attained a thickness of 131 ft., and at Battle, where supposedly the same beds reached 141 ft. Eastward they thinned rapidly. At Pluckley and Brabourne, two borings nine miles apart, west and east of Ashford, proved thicknesses of 70 ft. and 30 ft., while at Ottinge, midway between Ashford and Dover, only 17 ft. were left. At the first four places Purbeck Beds capped the Portlands, but at Ottinge the Purbecks had been cut out by an unconformable overstep of the Wealden Beds, and an unknown thickness of Portland Stone may also have been missing. In a boring still farther east, at Dover, the Wealden Sands had crossed both

[1] See W. J. Arkell, 1927, *Phil. Trans. Roy. Soc.*, vol. ccxvi B, pp. 80–2, where this problem is discussed in connexion with the similar lydite pebbles in the Lower Calcareous Grit.

[2] Based on Lamplugh and Kitchin, 1911, loc. cit.; and Lamplugh, Kitchin and Pringle, 1923, loc. cit.

Purbeck and Portland Beds and had come to rest on the Lower Kimeridge Clay.

The borings at Penshurst and Battle, which penetrated the fullest sequence, provide the best illustration of the development in Kent. The Lower Purbeck Beds at Penshurst, consisting here of gypsiferous marlstone, were separated from the Portland Beds, the top composed of a calcareous sandstone full of marine fossils, by a sharp line of demarcation, wanting, however, in any signs of erosion. Only the highest 6 ft. of the Portland Stone contained sufficient calcareous matter to be entitled a sandy limestone. It abounded in such fossils as *Chlamys lamellosa*, *Trigonia gibbosa* and *Isognomon bouchardi*. The sandstone below this, according to Lamplugh,

'for the next 60 ft. . . . was much less limy and yielded comparatively few fossils, being a massive homogeneous rock with the bedding planes very feebly developed. At lower depths the bedding became more pronounced again, being often accentuated by clayey streaks; and the sandstone also (as at Pluckley) included hard calcareous bands containing many fossils. These beds merged gradually downward into sandy shale, which formed an unbroken passage into the Kimmeridge Clay.'[1]

The lowest 6 ft. of strata grouped with the Portland Beds were described as 'dark grey, sandy, calcareous shale with a few obscure fossils, chiefly *Ostrea*, *Pecten*, &c., passing down gradually into dark blue clay of Kimmeridge type'.[2] Beneath this were 185 ft. of dark blue and paler grey clay with bands of calcareous claystone at intervals, some of them nodular, and containing *Lingula ovalis*, *Modiola autissiodorensis*, &c., before really shaly and black clays were reached. Evidently a great part of this, if not all of it (Messrs. Kitchin and Pringle have suggested 100 ft.), corresponds to the Portland Sand of Dorset as defined above, but it is quite impossible to say where the line of separation should be drawn. Ammonites suggestive of the *Pavlovia* zones were met with about 215 ft. below the base of the stone.

In the Pluckley boring, about 5 miles west of Ashford, the succession was identical, except that the Portland Stone was only 70 ft. thick, and an ammonite, which may indicate the *Pavlovia* zones, was met with only 131 ft. below the stone.

At Brabourne, about the same distance east of Ashford, great changes had set in. Here the stone-beds were only 31 ft. thick, although the Purbeck Beds were still present above. They could be roughly divided into three blocks. At the top were 11 ft. of greyish-yellow sandy limestone with many *Serpulæ* and casts of bivalves, and a fragment of a large ammonite. The fossils were the same as in the upper portion at Penshurst and Pluckley. Below came 16 ft. of greenish-grey sandy mudstone and semi-indurated calcareous sandstone, again with *Serpulæ* and casts of bivalves. At the base, 4 ft. of hard conglomeratic rock rested abruptly on dark, highly fossiliferous shaly clay with ammonites of the *Pavlovia* zones.

At Ottinge, still farther east, where the Wealden Beds had cut down unconformably upon them, only 17 ft. of the Portland Beds were left. The whole of this consisted of glauconitic sand and sandstone, and it rested abruptly on hard dark Kimeridge Clay, evidently with an even more pronounced non-sequence than that revealed at Brabourne.

[1] G. W. Lamplugh, 1911, loc. cit., p. 76.

[2] Ibid., p. 75.

Messrs. Lamplugh, Kitchin and Pringle considered that the non-sequence here excluded not only the greater part of the *pallasioides* zone and the overlying 'passage-beds' but also the whole of the equivalents of the Portland Sand of Dorset, and in addition some basal portion of the Portland Stone (about 300 ft. of strata at Penshurst). No lydite pebbles were reported from any of the borings, but in view of the 'conglomeratic or brecciated appearance'[1] of the basement-bed at Brabourne and the presence of glauconite, so conspicuous at Ottinge, it is tempting to suppose that the transgressive stratum is on the horizon of the Upper Lydite Bed and Glauconitic Beds of Wiltshire, Oxon. and Bucks. If this is so, then there was on both sides of the London–Ardennes ridge an overstep at about the same time, and a simultaneous appearance of glauconite in the sediment. By such a correlation, the magnitude of the non-sequence in Kent is somewhat reduced, for the Glauconitic Beds and Upper Lydite Bed of the Midlands undoubtedly represent an upper portion of the Portland Sand of Dorset.

A feature of the Portland Stone in Kent, possibly of secondary origin, but none the less remarkable, was the impregnation of the stone with bitumen. In some of the borings it was so abundant that it had collected in the joints and other crevices in thick drops. In North-West Germany, also, the presumed equivalent of the Portland Beds, the 100 ft.-thick Eimbeckhäuser Plattenkalk Series, is highly bituminous. Although shales are often bituminous, it is a rare feature in limestones and sandstones.

[1] Ibid., p. 44.

CHAPTER XVI

PURBECK BEDS

Divisions.	*Ostracod Zones* (Pl. XLI).	*Strata in Durlston Bay.*	*Thickness.*	
UPPER	*Cypridea punctata* and *C. ventrosa*	*Viviparus* Clays	11′ (+?)	72′(+)
		Marble Beds and Ostracod Shales	46′	
		Unio Beds	5′	
		Broken Shell Limestone	10′	
MIDDLE	*Subzone.* *Cypridea granulosa* var. *fasciculata* and *Metacypris forbesii*	Chief Beef Beds	30′	157′
		Corbula Beds	34′	
		Upper Building Stones	50′	
		Cinder Bed	8½′	
		Lower Building Stones	34′	
		Mammal Bed	1′	
LOWER	*Cypris purbeckensis* and *Candona ansata.*	Marls with Gypsum and Insect Beds	135′	170′
		Broken Beds	15′	
		Caps and Dirt Beds	19′	

THE last phase of the Jurassic period, represented by the Tithonian Stage in Southern Europe where normal marine sedimentation continued, saw a profound change over the British area. The sea retreated, leaving swamps and lakes, in which a freshwater fauna flourished from Dorset to Buckinghamshire and Kent. Ammonites became extinct in the area, not to reappear until brought in with the Cretaceous transgressions.

Minor oscillations lifted the surface temporarily into dry land, on which Coniferous and Cycadean forests took root and flourished, providing a habitat for insects and, most important of all, for small mammals and reptiles, whose bones became interred in the land soils and lacustrine muds. The sea remained not far distant, however, for periodically the fresh and brackish-water fauna or land flora was replaced by a marine assemblage comprising such familiar genera as *Ostrea*, *Trigonia*, *Modiola*, *Thracia*, *Isognomon* and *Hemicidaris*. The most important of these transgressions left evidence that it affected Dorset, Sussex, Kent and South Wiltshire. In Dorset and in the Vale of Wardour was formed an oyster-bank like those in the Portland Beds, locally 8½ ft. thick, composed of *Ostrea distorta* Sow. The other marine invasions were relatively minor episodes in a long period of lacustrine or mud-flat and swamp conditions, under which great accumulations of banded shales, clays and thin-bedded limestones were built up, often crowded with Ostracods and small freshwater molluscs, such as *Viviparus* and *Unio*.

These deposits together form the Purbeck Beds, which in the type-locality in Dorset attain a maximum thickness of 400 ft. and under the Weald of Kent reach no less than 560 ft. Superficially, as noted by several geologists, they bear an unmistakable resemblance to the Rhætic Series: banded clays and shales, fine-grained white limestone like White Lias, laminated insect-beds and even arborescent stone resembling Cotham Marble, all are found in the Purbeck Beds. It would thus appear that the sedimentary conditions under which the Jurassic period in the British area opened were to some extent repeated in its closing phase.

It is not easy to subdivide the Purbeck Beds, or to correlate the subdivisions in different parts of England. Lithologically there is little by which to be guided, for the many types of rock alternate rapidly in short distances. This is not surprising in view of the probable mode of formation of the deposits, in changing and often separate basins covered by shallow water, now open to the sea, now cut off from it by shifting sand or mud bars. The palaeontology at first sight likewise affords few criteria, for the freshwater mollusca are the same from base to summit, the assemblages at successive levels differing only in the relative abundance of certain species—differences of no use in making correlations over any but small areas.

The deficiency left by the macroscopic fauna, however, is made good by the Ostracoda. The study of these minute Crustacea *in situ* in the cliffs of Dorset was begun by Edward Forbes, who based on them a tripartite subdivision of the beds, which he published in 1850.[1] The subdivisions were at the same time accurately defined by Bristow, who mapped the Isle of Purbeck and measured the sections in great detail.[2] Unfortunately Forbes did not live to fulfil his intention of monographing the Purbeck invertebrate fauna, but the study of the Ostracods was taken up, with important results, by the late Prof. T. Rupert Jones.

Prof. Jones described and figured all the known Ostracods from the English Purbecks and determined as accurately as possible their range. He concluded as follows:

> 'There are fourteen species of Ostracoda in E. Forbes' three divisions of the Purbeck series of deposits. Five of them occur only in the Lower Purbeck. Of the others, six occur in both the Middle and the Upper. . . . *Cypridea punctata* for the Upper, *C. granulosa* (*fasciculata*) for the Middle, and *Cypris purbeckensis* for the Lower Purbeck, are especially characteristic.'[3]

Since this passage was written some authors have promoted several of Jones's varieties to new species, but his general conclusions as to their range have been found to hold, not only for Dorset, but also for the inland localities. Andrews and Jukes-Browne early applied Forbes's and Jones's classification to the Vale of Wardour Purbecks, with marked success, the Ostracods enabling them to prove that all three subdivisions are there represented. Detailed collecting by Prof. Morley Davies and still more recently by Mr. E. A. Merrett has shown that two zones of Ostracods can be recognized also in Buckinghamshire, although the strata are greatly reduced in thickness; the lower zone there represents the Lower Purbeck Beds and the higher zone the Middle and perhaps also the Upper Purbeck of Dorset. In N.W. Germany, 550 miles away, Koert has proved the same succession and established all three divisions (see next chapter, p. 551).

So much work has now been successfully done on the Purbeck Ostracods

[1] E. Forbes, 1850, *Edinburgh Phil. Journ.*, vol. xlix, pp. 311–13, 391; and 1851, *Rept. Brit. Assoc.* for 1850, pp. 79–81.

[2] H. W. Bristow, Vertical Sections Geol. Survey, sheet 22, No. 1.

[3] T. R. Jones, 1885, *Q.J.G.S.*, vol. xli, p. 331.

that it seems justifiable to accept their chronological value as established. It does not seem practicable, however, to distinguish more than two major zones. The upper corresponds with the range of *Cypridea punctata* (Forbes) and *C. ventrosa* Jones, embracing the Upper and Middle Purbeck of Forbes.[1] The lower zone is defined by the range of the five species enumerated by Jones, and of them may be chosen as zonal indices the two most typical and abundant, *Cypris purbeckensis* Forbes and one of the two common species of *Candona*, *C. ansata* Jones or *C. bononiensis* Jones (see Pl. XLI).

Two species seem to be confined to the Middle Purbeck, *Cypridea granulosa* (Sow.) (especially its more common variety, var. *fasciculata* Forbes) and *Metacypris forbesii* Jones. But since both of these occur within the range of *Cypridea punctata* and *C. ventrosa*, they do not indicate more than a subzone.

In contrast to the advanced state of our knowledge of the Ostracoda, the rest of the invertebrate palaeontology remains in much the same position as seventy years ago. A revision of the mollusca is badly needed, but the continued neglect of the subject is fostered by the unattractive condition of the material. Much patience would be required to procure specimens of all the species fit for photography and description.

The vertebrate fauna has fared better, as its extreme importance to palaeontology (but not to stratigraphy) merited. The mammals, reptiles and fishes are known the world over, and a voluminous literature has grown up about them. Even since the Great War revisionary monographs have appeared upon the fishes by Sir Arthur Smith Woodward and upon the mammals by Dr. G. G. Simpson. The vertebrate fossils will be noticed in the following pages when the type localities are described.

I. DORSET

(a) The Isle of Purbeck

The Purbeck Beds of the Isle of Purbeck give rise to a grassy upland, partitioned by stone walls, and simulating an outlying fragment of the Cotswold Hills. The outcrop is widest in the east, about the quarrying centres of Swanage, Langton and Worth, where the Portland Stone lies deep underground, only appearing above the surface along the south coast of the peninsula. Above the vertical cliffs of Portland Stone described in the last chapter the softer Purbecks rise in steep grassy and flowery slopes to a general height of 400 ft., clad during the summer in scabius, rest-harrow, pyramid orchis and bee orchis, and the closer turf at the top carpeted with thyme and blue, pink, and white veronica.

The hills are scarred with innumerable old quarries and the tip-heaps from abandoned shafts, which, with the remains of ancient quarrymen's shelters overgrown with brambles, suggest to a new-comer to the district the site of some ruined town of remote antiquity.

These relics scattered all over Purbeck mark the site of one of the oldest stone-quarrying industries in the country. Purbeck Stone, together with the Portland Stone mined in the cliffs and now called Purbeck-Portland, were transported far and wide as building materials long before the stone of Port-

[1] *C. dunkeri* Jones is unsuitable as a zonal index, for it ranges up into and abounds in the Wealden Beds in Kent.

land Island had acquired fame through Wren's selecting it for the rebuilding of St. Paul's. Purbeck Marble also, which is a freshwater limestone made up of myriads of *Viviparus* [*Paludina*] shells, was transported to Scotland, Ireland and the Continent for church decoration in the Middle Ages. The causes of its demand were its green (and occasionally red) mottled colouring and its property of taking a high polish. The most striking and extensive use to which it has been put is probably in the interior decoration of Salisbury Cathedral, where the dark green, slender detached shafts of the columns and windows are of marble, contrasting strongly with the white background of freestone. This building testifies to an active quarrying industry in Purbeck at least as early as 1258. After a life of some 700 years, or more, the industry seems at last to have died out, killed by the importation of more varied and more durable true marbles from Italy.[1]

The quarrying of the Purbeck Stone still continues, and is still largely in the control of the closed guild who have handed down the tradition from father to son from time immemorial. To the stone industry has been directly due the growth of Swanage. More recently, however, since the exploits of George the Third at Weymouth introduced the cult of sea bathing, the little stone-mining village has found in its golden sands a new and more valuable asset, and the austerities of its earlier development are becoming so thoroughly masked that they will soon be forgotten.

Several complete sections of the Purbeck Beds are afforded by the cliffs from Swanage to beyond Lulworth. The finest is that in Durlston Bay (fig. 87) to the south of Swanage, where the formation attains its maximum thickness in Dorset of 400 ft.; most of the sequence is repeated by a fault in the centre of the bay. Westward from Durlston Head, past Dancing Ledge, Seacombe and Winspit to St. Alban's Head, the basement-beds and the abrupt junction with the Portland Stone are seen discontinuously in the brow of the cliffs, while inland along the same length of outcrop many small sections of the middle and upper parts of the series are afforded by the quarries and stone mines. The next complete section is seen on the south side of Worbarrow Bay, in the small peninsula of Worbarrow Tout and the adjoining Pondfield Cove (Pl. XXVII); here the total thickness has shrunk by more than a quarter to 290 ft. Towards the west the strata become more and more steeply inclined as they approach nearer to the Purbeck Thrust Fault, and this contributes even more than the diminution in thickness to the narrowing of the outcrop.

West of Worbarrow Tout the outcrop lies for the most part beneath the sea, but several disconnected stretches remain on either side of Lulworth, protected on their seaward side by bulwarks of Portland Stone. The longest runs from the south side of Mupe Bay, where outliers cap the stacks of Portland Stone called the Mupe Rocks, to Lulworth Cove. Here are some of the best of all the sections of the Purbeck Beds, especially in Bacon Hole, a cove immediately west of the Mupe Rocks, and at the famous Fossil Forest between Bacon Hole and Lulworth (Pl. XXVII). The total thickness still further diminishes, from 250 ft. at Mupe Bay to 176 ft. at Lulworth Cove (map, p. 442).

[1] The last building in which any extensive use was made of the marble was the Eldon Memorial Church at Kingston, near Corfe Castle, opened in 1880; large quantities were employed for facing the columns of the colonnades in the nave, for the chancel screen and the window pillars, and the result is extremely pleasing. The pits were opened in a field at Blashenwell Farm, north of the village.

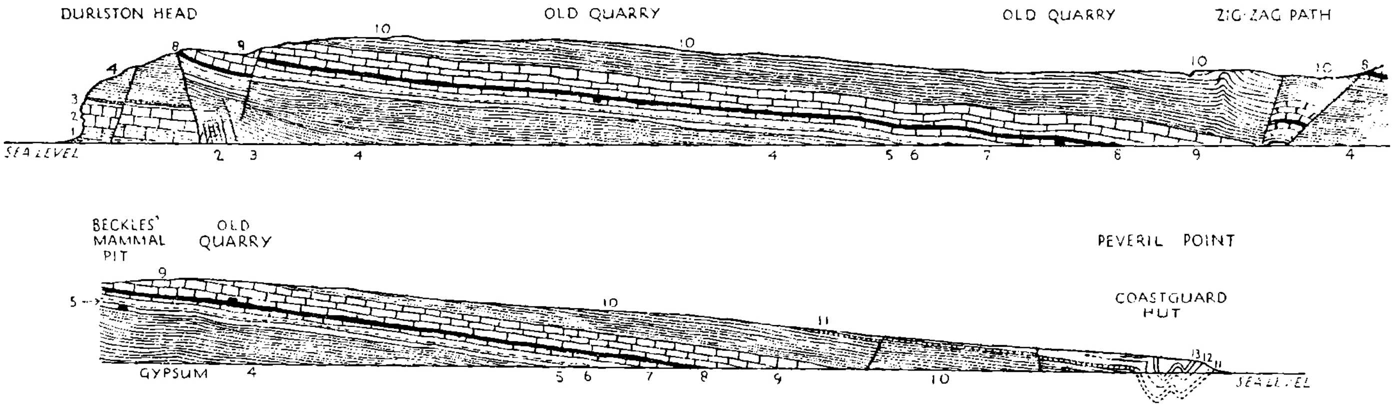

FIG. 87. Type-section of the Purbeck Beds in Durlston Bay, Swanage. Distance 1 mile. (After A. Strahan.)

Upper Purbeck:
- 13 Purbeck Marble Beds and Ostracod Shales
- 12 *Unio* Beds
- 11 Broken Shell Limestone

Middle Purbeck:
- 10 *Corbula* and Beef Beds
- 9 Upper Building Stone
- 8 Cinder Bed

Middle Purbeck:
- 7 Lower Building Stones, with flint at base (6)
- 5 Mammal Bed

Lower Purbeck:
- 4 Marls with Gypsum and Insect Beds
- 3 Broken Beds and Caps

Portland Beds:
- 2 Freestone Series
- 1 Cherty Series

West of Lulworth Cove the beds are much contorted, as is shown in the well-known section in Stair Hole, so often portrayed by pen and camera. The last remaining fragment forms the neck of the Promontory of Durdle Door, where the beds, being close beneath the Thrust Fault, seen in the Chalk cliff of the adjoining mainland, stand vertically (Pl. XXVIII). The extreme thinness of the formation here, and to a lesser extent also at Stair Hole, is due to the squeezing out of the clays, for much of the Gault also is missing.

SUMMARY OF THE PURBECK BEDS OF PURBECK [1]

Zone of Cypridea punctata and C. ventrosa: Upper Purbeck, 27–70 ft.+

VIVIPARUS CLAYS, 1 ft.–11 ft.?

The highest beds of all consist of blue, green, grey and purple marls and sandy shale with fish-remains, *Viviparus* and Ostracods. These beds are not seen at Swanage, where the junction with the Wealden Series is concealed by the harbour and town, as well as by alluvium. At Worbarrow also it is obscured by the stream that enters the sea near the boat-house. At Mupe Bay it can be clearly studied, however, and the passage to the Wealden is perfectly conformable and gradual; the thickness of the *Viviparus* Clays there is 11 ft.

MARBLE BEDS AND OSTRACOD SHALES [Upper *Cypris* Shales], 17–46 ft.

Near the top of this division are the two chief bands of Purbeck Marble, one red and the other green, composed of *Viviparus cariniferus* and *V. elongatus*. A short distance below is a tough bed of greenish sandy limestone with *Unio* (the *Unio* Bed). These hard bands crop out at Peveril Point, where they run for a mile out to sea and form some of the ledges upon which the Danish fleet is supposed to have been wrecked in the year 877. Inland they run along the High St., and outside the town they can be traced at the junction of the vale and the hills by a line of old marble workings, overgrown with woods and thickets. Below and between the limestones are clays, shales with 'beef', red and green marls, and thin seams of limestone, some of which are made up almost entirely of the minute valves of Ostracods. A piece of one of the Ostracod-limestones has been figured by Chapman,[2] who states that the species, in order of abundance, are *Cypridea punctata* (Forbes), *C. posticalis* Jones and *C. ventrosa* Jones; *Darwinula leguminella*, fish-remains and coprolites are also found.

UNIO BEDS, 5 ft. 9 in.–4 ft. 9 in.

The name *Unio* Beds is given to a thin series of clays with occasional beef and bands of greenish limestone containing *Unio*, but not so conspicuously as in the *Unio* Bed higher up. One band of carbonaceous limestone has yielded crocodilian remains in Durlston Bay and has been called the Crocodile Bed. Other fossils are remains of fish and turtles, coprolites, *Cypridea punctata*, *Viviparus*, and the freshwater bivalve *Neomiodon* ['*Cyrena*' auct.]. One of the best sections of the *Unio* Beds is to be seen on the north side of Worbarrow Tout, close to the beach, near the boat-house.

[1] Based on H. B. Woodward, 1895, *J.R.B.*, pp. 243–56; and A. Strahan, 1898, 'Geol. Isle of Purbeck and Weymouth', pp. 91–103, *Mem. Geol. Surv.*; thicknesses by H. W. Bristow. Alterations have been introduced in nomenclature.

[2] F. Chapman, 1906, *P.G.A.*, vol. xix, pl. v, p. 283.

BROKEN SHELL LIMESTONE OR BURR, 3 ft. 9 in.–10 ft.

This limestone, largely made up of comminuted shells of *Neomiodon* and *Unio*, with *Limnæa*, *Viviparus* and fish-remains, is 10 ft. thick at Peveril Point, where it forms the most northerly of the reefs. It also forms the shelving platform along the shore below the Grosvenor Hotel, where it contains curious round depressions noticed a hundred years ago by Fitton, but not yet satisfactorily explained.[1]

Subzone of Cypridea granulosa and Metacypris forbesii: Middle Purbeck, 55–157 ft.

CHIEF BEEF BEDS, 8–30 ft.

Dark shales with much 'beef' and selenite, with beds of limestone and layers of perished shells of *Neomiodon*; also *Cypridea*.

CORBULA BEDS, 16–34 ft.

Layers of shelly limestone, shale and marl, with beef and selenite, and marine molluscs: *Corbula* spp., *Modiola*, *Ostrea*, '*Pecten*', *Isognomon*, *Thracia*, *Protocardia*; also *Melanopsis harpæformis*, *Neomiodon*, turtle- and fish-remains, insects and Ostracods. The *Corbula* Beds contain more limestone than the Chief Beef Beds, but otherwise there is no essential difference in the lithology. The species recorded from the Middle Purbeck of Swanage by Koert are *Corbula alata* Sow., *C. forbesi* De Lor., *C. inflexa* Roemer and *C. durlstonensis* Maillard.[2]

UPPER BUILDING STONES, 8½–50 ft.

The Purbeck building-stones are not a strictly-defined stratigraphical unit, for towards the west end of the promontory they are in part replaced by marl and clay; this may be seen at Worbarrow Tout, where the great reduction in their thickness is not wholly due to the general westerly attenuation.

The stone mines lie entirely east of Kingston, and are thickest in the district between Worth, Langton and Durlston, where the downs are almost covered with tip-heaps and depressions. Many of the mines are still worked by the ancient methods, an inclined shaft following the chosen rock-band underground, the dip being generally steep.

The stone is a more or less shelly, pale limestone, occurring in rather thin beds separated by shale partings with *Cypridea punctata*. The highest 4½ ft. at Durlston, called the White Roach, and by Forbes the Pecten Bed, contains a marine fauna, including '*Pecten*', *Ostrea*, *Gervillia obtusa* Roem., *Corbula* spp. and *Protocardia*. The same assemblage (less the unidentified '*Pecten*') is met with at several horizons, separated by beds in which only freshwater or estuarine forms are found—*Viviparus*, *Limnæa*, *Hydrobia chopardi* de Lor., *Valvata helicoides* Forbes, &c.[3]

Of the greatest importance, however, is the vertebrate fauna of the Building Stones, which is large and varied, and has provided science with a number of unique forms of fishes, turtles and crocodilians. Even on a casual visit to

[1] See A. Strahan, 1898, loc. cit., p. 91.

[2] W. Koert, 1898, Inaugural-Dissertation, Göttingen, pp. 52–3.

[3] Koert, 1898, loc. cit., pp. 52–3, gives a list of mollusca from the Middle Purbeck of Swanage which he says are preserved in Göttingen Museum and are identical with forms from North-West Germany.

a mine it is usually possible to obtain from the quarrymen fin-spines of sharks ('ichthyodorulites') or bones or plates of the curious turtle, *Pleurosternum*, intermediate in structure between the later Cryptodira and Pleurodira, and so relegated to a separate sub-order, the Amphichelydia. The rich fish fauna of the Purbeck Beds, which has been monographed by Sir Arthur Smith Woodward,[1] comes almost entirely from the Upper and Lower Building Stones; the list is now as follows (compiled from his monograph):

Hybodus strictus Ag.
Asteracanthus verrucosus Eg.
A. semiverrucosus Eg.
Undina purbeckensis Smith Woodw.
Lepidotus minor Ag.
L. notopterus Ag.
Mesodon daviesi Smith Woodw.
Eomesodon depressus Smith Woodw.
Microdon radiatus Ag.
Cœlodus lævidens Smith Woodw.
C. arcuatus Smith Woodw.
Ophiopsis dorsalis Ag.
Histionotus angularis Eg.
Caturus purbeckensis Smith Woodw.
C. tenuidens Smith Woodw.
Amiopsis austeni (Eg.)
Aspidorhynchus fischeri Eg.
Pholidophorus ornatus Ag.
P. granulatus Eg.
P. purbeckensis Davies
Pleuropholis crassicauda Eg.
P. longicauda Eg.
Pachythrissops lævis Smith Woodw.
Thrissops molossus Smith Woodw.

CINDER BED, 4 ft.–8 ft. 6 in.

The Cinder Bed derives its name from its black scoriaceous appearance where weathered on the shore. It is the most conspicuous and the most constant bed in the whole Purbeck Series and marks a marine invasion of widespread importance. The mass of the rock is made up of the compacted shells of *Ostrea distorta* Sow., but in addition there are occasionally found other marine forms, such as *Trigonia*, *Isognomon*, *Protocardia purbeckensis* (de Loriol) *Serpula coacervata* Blumb., and above all the significant echinoid, *Hemicidaris purbeckensis* Forbes.[2] Unlike the oyster-banks in the Portland Series, with their restricted distribution, this bed is found on the same horizon all along the outcrop as far west as Portisham, and even in the Vale of Wardour. The marine episode to which it bears witness seems also to be marked by the presence of the same molluscan assemblage in the Weald. *Cypridea granulosa* var. *fasciculata* is recorded in the Cinder Bed by Jones.

LOWER BUILDING STONES, 5 ft. 9 in.–34 ft.[3]

The fauna of the Lower Building Stones is mainly freshwater. The top course (2 ft. 2 in. thick) immediately below the Cinder Bed is known to the quarrymen as the Feather Bed. From it was obtained the first jaw (the type-specimen) of the mammal *Trioracodon major* (Owen) and another jaw of *T. ferox* (Owen) came from immediately below.[4]

Sixteen feet below the top of the Feather Bed is a conspicuous 3 ft. band of white limestone with nodules of black chert. From this band Bristow recorded *Viviparus*, *Valvata*, *Physa*, *Planorbis* and *Neomiodon.*

From the chert vein to the Mammal Bed at the base of the Middle Purbeck,

[1] 1916–19, *Pal. Soc.*
[2] Usually rare, but Prof. Hawkins found 35 tests at Durlston: *Q.J.G.S.*, vol. lxxxi, p. cxxviii.
[3] Bristow's measurement, quoted by Woodward (1895, p. 244), was 43 ft., but according to Strahan's figures it is only 34 ft. (1898, p. 94).
[4] *Teste* Simpson. It should be noted, however, that Owen sometimes referred to the Mammal Bed as the Feather Bed.

shales predominate. Mr. F. W. Anderson has recently made a microscopic study of this part of the sequence and has discovered three rhythmic or phasal changes in the salt-content of the shales and in the Ostracod fauna. He attributes these changes to the periodic influx of fresh water into basins which were otherwise becoming steadily more saline.

'The increase in salinity had a marked influence on the Ostracod fauna. The fresh-water deposits at the commencement of each phase contain *Darwinula leguminella* (Forbes) and *Cyprione bristovii* (Jones); these are followed by an early form of *Cypridea dunkeri* (Jones) and *Cypridea punctata* (Forbes), which are later in the phase replaced by *Cypridea granulosa* (Sow.), these latter becoming more abundant as the water became more brackish.'

The third phase, according to Mr. Anderson, was terminated by the marine invasion marked by the Cinder Bed.[1]

MAMMAL BED, 0–1 ft.

The bed chosen as the base of the Middle Purbeck division is a brown or grey-brown, carbonaceous, earthy layer or 'dirt bed', suggesting an ancient soil, and filling inequalities in the hard marl below. The wonderful vertebrate fauna obtained from this bed in the nineteenth century has made Durlston Bay world-famous. Except for the few mammalian remains found in the Stonesfield Slate and the Rhætic Beds, the fauna is unique in Europe; it correlates, however, with an assemblage entombed in somewhat similar beds in the Morrison formation of North America. Most of the Purbeck specimens were found in a special excavation known as Beckles's Mammal Pit, near the top of the cliff a short distance north of Belle Vue restaurant. An exceptionally rich pocket was struck, for a large excavation made subsequently led to the discovery of only a single additional specimen. Beckles's collection, described by Owen, was purchased by the British Museum, where it can now be seen.

The revision completed in 1928 by G. G. Simpson[2] has made it clear that the time-honoured belief that these early mammals belonged to the marsupials has no foundation in fact. Simpson ranges them in four orders, *Multituberculata*, *Triconodonta*, *Symmetrodonta* and *Pantotheria*, and he regards these as derived independently from the Cynodont reptiles. The last two orders may, he thinks, have diverged from the same stock as all the living mammals, but they branched off long before the marsupials and the placentals became differentiated.

Since this bed is to the vertebrate palaeontologist perhaps the most important in the Jurassic System, it may be useful to give the complete list of the mammals found in it, as revised by Simpson—in all 19 species.

LIST OF MAMMALIA FROM THE MAMMAL BED OF DURLSTON BAY

MULTITUBERCULATA; PLAGIAULACOIDEA.

Plagiaulax becklesii Falconer.
Ctenacodon minor (Falconer).
C. falconeri (Owen).
Bolodon crassidens Owen.
B. osborni Simpson.
B. elongatus Simpson.

TRICONODONTA; TRICONODONTIDÆ.

Triconodon mordax Owen.
Trioracodon ferox (Owen).
T. oweni Simpson.
T. major (Owen).

[1] F. W. Anderson, 1932, *Rept. Brit. Assoc.* for 1931, p. 380.
[2] G. G. Simpson, 1928, *Cat. Mesozoic Mammalia Brit. Mus.*

SYMMETRODONTA; SPALACOTHERIIDÆ.
Spalacotherium tricuspidens Owen.
Peralestes longirostris Owen.

PANTOTHERIA; PAURODONTIDÆ.
Peramus tenuirostris Owen.

DICROCYNODONTIDÆ.
Peraiocynodon inexpectatus Simpson.

PANTOTHERIA (contd.)

DRYOLESTIDÆ.
Amblotherium pusillum (Owen).
A. nanum (Owen).
Kurtodon pusillus Osborn.
Peraspalax talpoides Owen.
Phascolestes mustelula (Owen).

Only second in interest to the mammals are the unique dwarf crocodiles found in this bed and at some other horizons. Most of them were described by Owen, and they have been more recently revised by Sir Arthur Smith Woodward.[1] The Teleosauridæ are represented by the genus *Petrosuchus*; but the majority belong to the Goniopholidæ, a family much more akin to the marsh-loving forms of the present day. The genus *Goniopholis* is full-sized; the rest, *Nannosuchus*, *Theriasuchus* and *Oweniasuchus*, are dwarfed.

Zone of Cypris purbeckensis and Candona ansata: Lower Purbeck, 93½–170 ft.

MARLS WITH GYPSUM AND INSECT BEDS, 87–135 ft.

The thick marls and clays forming the greater part of the Lower Purbeck Beds contain irregular masses of gypsum, some so large that they were formerly worked in the cliff of Durlston Bay for making Plaster of Paris. In the upper part there are also pseudomorphs in mud of crystals of rock-salt, the cavities filled with carbonate of lime, and other salts also have been detected: the deposits seem to have formed in muddy evaporating basins or salterns. Mollusca are rare, but insects were apparently blown or washed into the water in abundance. Two levels of insect-beds were recognized by Fisher and Bristow, who divided the series into six subdivisions, but the details are so inconstant that they are not worth noting; Bristow's sequence (quoted by H. B. Woodward) does not tally with Fisher's and was not adopted by Strahan. The insects include butterflies, beetles, dragon flies, locusts, grasshoppers, ants and aphides, an assemblage indicative of a temperate climate.

Ostracods are, as usual, abundant at certain levels, but the species are not the same as those found in the higher divisions; the most characteristic are *Candona ansata* Jones, *Candona bononiensis* Jones and *Cypris purbeckensis* Forbes. The marine bivalve *Protocardia purbeckensis* is not uncommon but badly preserved, and gave rise to the somewhat inappropriate name Cockle Beds for the bulk of the Lower Purbecks. Occasionally *Neomiodon*, *Planorbis*, *Corbula*, &c. may be found, and also the Isopod, *Archæoniscus brodiei*. At the base are numerous bands of freestone interbedded with the marls and shales to a thickness of 36 ft. in Durlston Bay and 22 ft. at Lulworth. Bristow called this basal portion the *Cypris* Freestone, from the occurrence of *Cypris purbeckensis*.

BROKEN BEDS, 10–15 ft.

Towards the base of the Lower Purbeck Beds limestones predominate, the lowest of all, the Caps, simulating at a distance the Portland Stone. Above the Caps all over Purbeck (perhaps the best section being at the Fossil Forest,

[1] A. Smith Woodward, 1886, *P.G.A.*, vol. ix, pp. 318–26.

near Lulworth) are remarkable shattered limestones known as the Broken Beds, the formation of which has given rise to a controversy of long standing. They consist of fragments of limestone set at all angles in an earthy rubble, like a crush-breccia. The Rev. O. Fisher first suggested in 1854[1] that the brecciation might be due to the sediments having been deposited over a mass of vegetation, which subsequently decayed and allowed the covering rock to fall in. But H. B. Woodward considered that the fact that the disturbance affects higher beds in some places than in others proved the shattering to have been subsequent to Purbeck times. He believed that the Broken Beds represent a gigantic slide-plane, upon which the whole of the Purbeck Beds above have been moved forward by pressures set up during the formation of the Purbeck Anticline and the Thrust Fault.[2] Sir A. Strahan, however, reverted to Fisher's view. He pointed out that the Broken Beds follow approximately the same stratigraphical horizon, not only from Durlston Head to the Isle of Portland, but also in the Vale of Wardour, and that they everywhere overlie a forest-grown land surface; moreover, that the nearest approach to the Broken Beds in other formations is a brecciated clay found above the Cromer Forest Bed.[3]

CAPS AND DIRT BEDS, with FOSSIL FOREST, 9–19 ft.

The junction with the Portland Stone is obscured by faulting at the south end of the Durlston Bay section, in Durlston Head, but numerous exposures of the junction and the basal Purbeck Caps are to be seen in the quarries along the cliffs westward to St. Alban's Head. The finest sections of all are at the Fossil Forest near Lulworth, and in Pondfield Cove, Worbarrow. Everywhere the junction of the two formations, though sharply defined, is perfectly conformable.

THE CAPS consist of two bands, a Soft Cap above (4½–7½ ft.) and a Hard Cap below (4½–11 ft.), with thin impersistent fossil soils and limestone gravel, called DIRT BEDS, at the base of either or both. The stone composing the Caps is a peculiar, porous, tufaceous and botryoidal limestone, occasionally enclosing such mixed fossils as fish-remains, *Viviparus*, Ostracods and *Archæoniscus*.

The section of these beds at the Fossil Forest, midway between Bacon Hole and Lulworth, is a highly instructive and vivid sight. The cliff there rises to a height of about 100 ft. above the sea, and the lower part, formed by the Portland Stone, is vertical or even overhanging; but the upper part, formed by the softer Purbecks, is weathered back in a gentler slope down which it is easy to scramble. Midway down, the Caps form a broad ledge upon which the famous 'forest' is displayed (Pl. XXVII).

By looking over the edge of the ledge it is possible to see that the Hard Cap, which is very thick, rests directly on the Portland Stone with the usual sharp but conformable junction. Between the Caps is the principal Dirt Bed of this part of the district, a seam of black earth 6–18 in. thick, so full of pebbles of limestone that it resembles a gravel. The Soft Cap above, 2–4 ft. thick, here also a hard tufaceous limestone, encloses the silicified trees, and the standing

[1] O. Fisher, 1856, *Trans. Cambr. Phil. Soc.*, vol. ix, p. 566.
[2] H. B. Woodward, 1895, *J.R.B.*, p. 248.
[3] A. Strahan, 1898, loc. cit., pp. 80–2.

Photo. *W. J. A.*

Bacon Hole and the Mupe Rocks, looking across to Worbarrow Bay and Gad Cliff.

Rocks of Portland Stone and cliff of Purbeck Beds, tilted in the Purbeck Anticline. Chalk cliffs of Arish Mell behind on left.

Photo. *W. J. A.*

The Fossil Forest, Lulworth.

Silicified boles of conifers encased in 'burrs' of tufa, in position of growth in the dirt bed, basal Purbeck Beds.

PLATE XXVIII

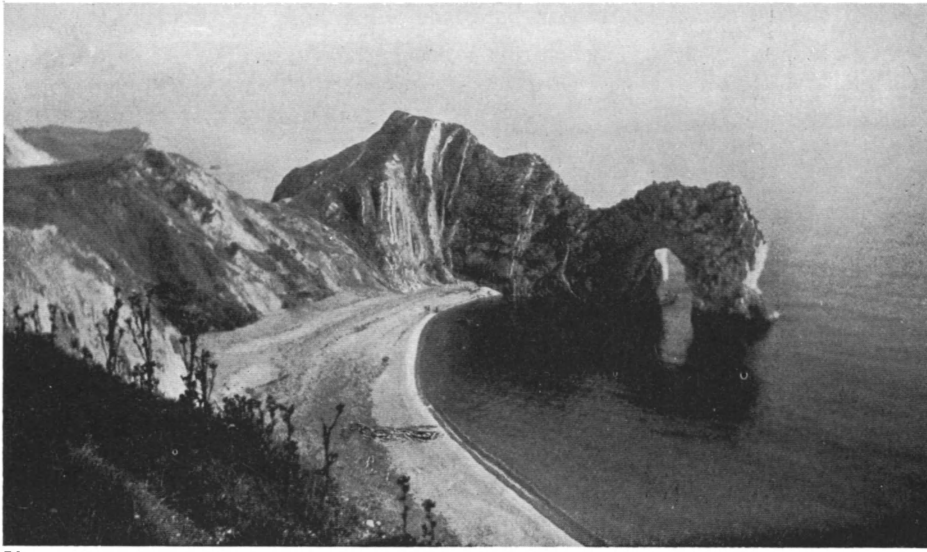

Photo. *W. J. A.*

Durdle Door, near Lulworth.

The arch is of Portland Stone and the highest part of the promontory is of Purbeck Beds. The soft Wealden Beds form the neck as far as the conspicuous band of dark Gault Clay, in front of which is the Chalk.

Photo. *W. J. A.*

Vertical Purbeck Beds, Durdle Cove, Lulworth.

The whole Purbeck formation is seen, with the Wealden Beds on left, all greatly reduced in thickness (partly by squeezing out of the clays).

stumps, enveloped in tufa, protrude on the upper surface as huge round bosses (called 'burrs'), their centres sometimes hollowed out to form cup-shaped depressions. Beside them lie the prostrate trunks, broken off once close to the root and again some 8–10 ft. higher up, and likewise enclosed in sheaths of tufa, although the trees within are silicified.

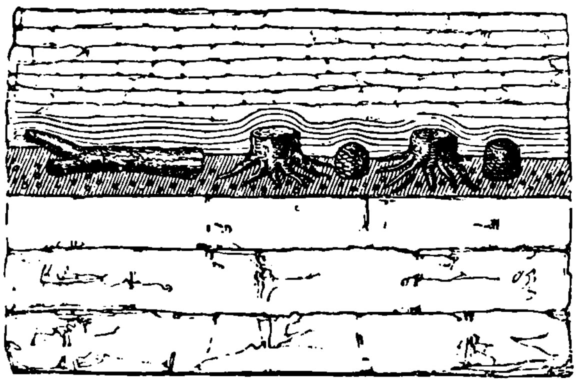

FIG. 88. The Great Dirt Bed of the Isle of Portland, showing boles of trees with roots, cycads, and pebbles of Portland Limestone. The Dirt Bed rests on the tufaceous Top Cap limestone and is overlain by the Aish. (After Buckland and De la Beche, 1836, *Trans. Geol. Soc.* [2], vol. iv, p. 13.)

(b) The Isle of Portland

Only Lower Purbeck Beds remain on the Isle of Portland. The greatest thickness survives north and west of Southwell, where little less than 100 ft. are exposed in the cliff. An old geological map by Buckland and De la Beche[1] shows that a century ago Purbeck Beds also overspread much of the northern part of the island, whence they have since been completely quarried away.

The essential features of the basement-beds, the tufaceous Caps with silicified trees and Dirt Beds, are present, but the details differ considerably in adjoining parts of the island and there is nowhere an exact replica of the development on the mainland. Little is to be gained by following out the changes of detail, and a typical section will suffice to illustrate the succession (fig. 89, p. 530).

The bulk of the beds consists of marls with bands of white fissile limestone, up to 3 ft. thick but splitting into thin laminæ; these bands are called by the quarrymen 'Slatt' (slate). The chief interest, however, is centred in the basement-beds. Below the lowest slatt is a hard streaky limestone with layers of sand, graphically called the Bacon Tier (about 2 ft.), below which, and often joined on to it, is another 2 ft. band of soft argillaceous limestone called the Aish. This rests on a tufaceous limestone called the Burr Bed or Soft Burr, which probably corresponds with the Soft Cap of Purbeck. It contains silicified tree-stumps and trunks enveloped in tufa (the 'burrs' of the quarrymen); Woodward records that one was found so large that people came from

[1] *Trans. Geol. Soc.* [2], vol. iv, pl. 1.

far and wide to view the 'fossil elephant'. The Soft Burr rests on the Upper or Great Dirt Bed, a blackish layer in places up to 1 ft. thick, with rolled limestone pebbles and well-preserved silicified trees and *Cycadeoideæ*. The trees are much more perfectly preserved than in Purbeck, some having been obtained as much as 23 ft. in length and from 2 to 4 ft. in diameter (see fig. 90 and Pl. XXVI). At the base are two massive blocks of tufaceous limestone called the Top Cap (10 ft.) and the Skull Cap (2–3 ft.), easily mistaken at first sight for Portland Stone. Between them, however, is in places an impersistent Dirt Bed, thinner than that above, and in the Top Cap may be seen many hollow casts of tree-trunks. The lower Dirt Bed has yielded some of the best specimens of Cycads known.

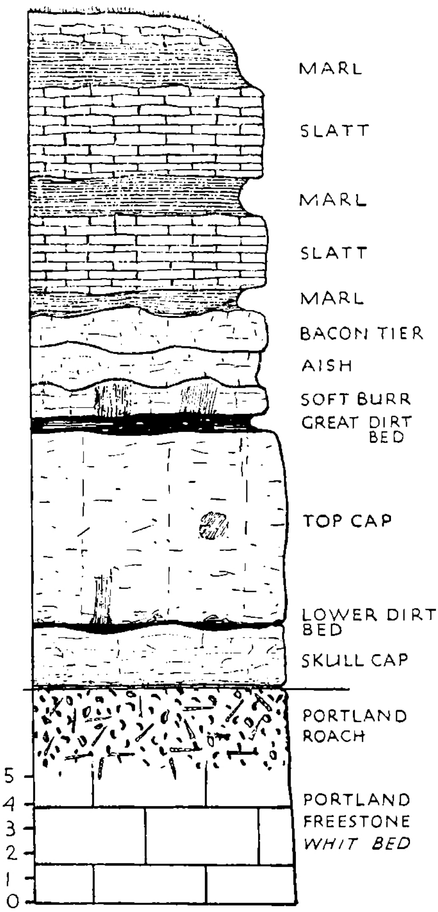

FIG. 89. Section of the basement-beds of the Lower Purbeck in the quarries at the south end of the West Weare Cliff, north of Black Nore, Isle of Portland.

At the south end of the island the Top Cap, Upper Dirt Bed and Soft Burr are not represented.

The basement-beds of the Purbeck rest everywhere upon the Roach of the Portland Stone and the junction is perfectly even and conformable. Nevertheless, some of the pebbles in the Dirt Bed have been identified as derived from the Portland Stone,[1] thus proving that there was erosion somewhere in the vicinity, possibly over the crest of the Weymouth Anticline.

(c) The Northern Limb of the Weymouth Anticline from Ringstead to Portisham, and the Chaldon Anticline.

The Purbeck Beds follow the Portland feature along the outcrop in the northern limb of the Weymouth Anticline and round the Poxwell Circus, but there are now only small sections. About 12 ft. of the Lower Division is also seen in the faulted block below Holworth House, in Ringstead Bay. The details again differ from those noted elsewhere.

A complete section (total thickness 190 ft.) was formerly seen in the railway-cutting near the entrance to the Bincombe Tunnel,[2] and building-stones in the Lower Purbeck, on the horizon of the *Cypris* Freestone, are still

[1] H. B. Woodward, 1895, *J.R.B.*, p. 265.
[2] Described by C. H. Weston, 1852, *Q.J.G.S.*, vol. viii, p. 116.

from time to time quarried near by, close to Upway. These exposures were studied in great detail by the Rev. O. Fisher, who described Upper and Lower Insect Beds and obtained many specimens from them, and also noted the chert-beds in the same position as at Durlston, and the Cinder Bed.[1] The Lower Purbeck has yielded two fish not known at Swanage—*Ophiopsis penicillata* Ag. and *Amiopsis damoni* (Eg.).[2] It is interesting to notice that the Upper Purbeck Beds here were said to be coarser and sandier than in the Isle of Purbeck and to contain a larger proportion of the spoils of the land, such as lignite and plants. This evidence agrees with that provided by the Portland Sand in pointing to a land-area in the west.

II. THE VALE OF WARDOUR

In the Vale of Wardour a considerable area of Purbeck Beds occupies the surface on the east of the Portlandian outcrop about Tisbury and surrounds the inlier in the Chilmark Ravine (see map, p. 500). The total maximum thickness is not accurately known, but it was estimated by Woodward to be about 85 ft., and, by Andrews and Jukes-Browne, 110 ft.

The general aspect of the beds and the fossils are the same as on the Dorset coast, and all three divisions have been recognized by their Ostracod faunas. The Middle Division bears witness, as in Dorset, to an important marine invasion, in which the Cinder Bed was formed, composed of *Ostrea distorta* and its associated marine molluscs and Hemicidarid.

Numerous sections, especially of the Lower Division, have been described in detail by Fitton, the Rev. P. B. Brodie, the Rev. O. Fisher, the Rev. J. F. Blake, the Rev. W. R. Andrews, A. J. Jukes-Browne, W. H. Hudleston, and H. B. Woodward. To Messrs. Andrews and

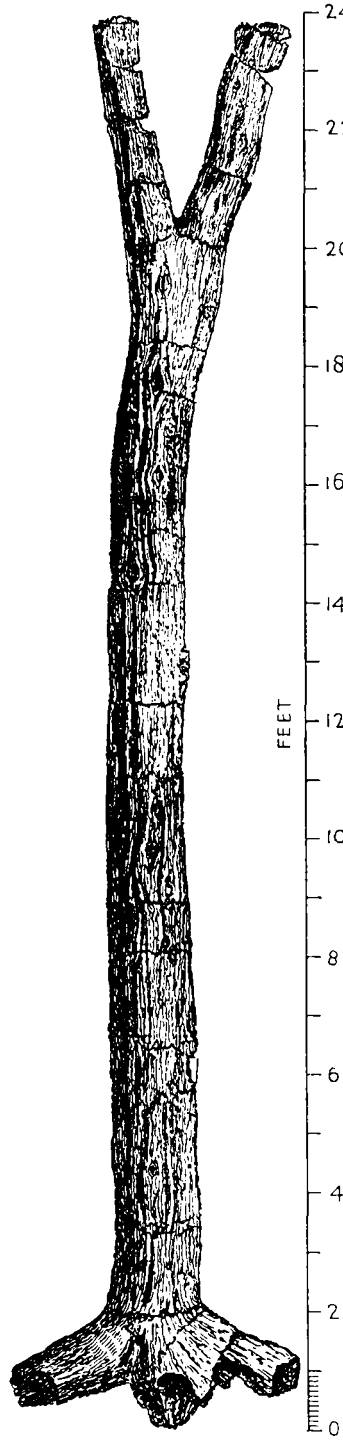

FIG. 90. Silicified trunk of a coniferous tree from the Great Dirt Bed, Isle of Portland, 'from a drawing made by Mr. Sowerby, after careful admeasurement, as it lay horizontally'. (After Fitton, 1836, *Trans. Geol. Soc.* [2], vol. iv, p. 221.)

[1] O. Fisher, 1856, loc. cit.
[2] A. Smith Woodward, 1916–19, loc. cit.

Jukes-Browne, however, belongs the credit for deciphering the Ostracod succession and thus establishing the correlation of the beds on a palaeontological basis. They were able to show, by careful collecting *in situ*, that the attenuated Purbeck Beds of the Vale of Wardour contain representatives of all the three divisions of Dorset, and at the same time to set bounds to the divisions. It was thus established that the feeble representation of the formation in the Vale was not due to removal of the major portion of the beds by pre-Cretaceous denudation, but to a piecemeal thinning out of its component parts.

SUMMARY OF THE PURBECK BEDS OF THE VALE OF WARDOUR[1]

Zone of Cypridea punctata and C. ventrosa: Upper Purbeck, 20 ft.

Only one good section of the Upper Purbeck Beds has been described, a complete one in the railway-cuttings west of Dinton Railway Station, first studied by Messrs. Andrews and Jukes-Browne, and later by H. B. Woodward in company with Sir A. Strahan. There was some difference of opinion regarding the horizon at which the boundary between the Wealden and the Purbeck Beds should be drawn, and in spite of the opinion of the earlier authors that there were signs of discordance between the two formations, H. B. Woodward and Sir A. Strahan showed that the passage was in reality perfectly conformable. At the same time they assigned to the base of the Wealden some considerable thickness of white clays and sands regarded by the earlier writers as part of the Purbeck.

The Upper Purbeck Beds at Dinton as so restricted comprise 20 ft. of highly variable strata, ranging from blue clay and white or blue marl to brown sandstone and blue-hearted shelly limestone—all types of rock common in the same division in Dorset. Woodward regarded the highest 'lithological Purbeck' bed, a band of stiff white marl, as the top of the formation. At the base were about 6 ft. of blue clay. Messrs. Andrews and Jukes-Browne collected *Cypridea punctata* from three levels and at one horizon they also obtained *Cyprione bristovii*. About the middle of the division *Unio*, *Neomiodon* and *Viviparus* were collected from a shelly limestone which they considered to be probably equivalent to the *Unio* Beds of Durlston Bay.

Subzone of Cypridea granulosa and Metacypris forbesii: Middle Purbeck, 22 ft.[2] (20–5 ft.).

The Middle Purbeck Beds also were completely exposed in the Dinton railway-cuttings, as well as in several quarries, especially at Teffont Evias, described by Andrews and Jukes-Browne.

The topmost bed grouped with this division was a band of hard white marl, its upper surface eroded and the hollows filled with clay. Below this were about 6 ft. of shales and sandstones with occasional *Neomiodon*, and then a remarkable 3-in. layer of hard marly limestone in places crowded with the Isopod *Archæoniscus brodiei*.

About 2 ft. below the *Archæoniscus* Bed is the most easily recognized horizon of all, the Cinder Bed, 1 ft. 3 in. thick at Dinton, 2 ft. 6 in. thick at

[1] W. R. Andrews and A. J. Jukes-Browne, 1894, *Q.J.G.S.*, vol. l, pp. 44–69; H. B. Woodward, 1895, *J.R.B.*, pp. 267–75.

[2] Woodward's estimate plus a portion of his Lower Purbeck which contains Ostracods belonging to the Middle Division. Andrews and Jukes-Browne estimated at least 32 ft.

Teffont Evias railway-cutting, and 1 ft. 6 in. thick at Teffont quarry (near the church); as in Dorset, this bed is largely made up of *Ostrea distorta* Sow. Although it would usually be rash to consider oyster-beds contemporaneous at places so distant as the Vale of Wardour and the Dorset coast, the correlation in this instance is supported by several other marine forms—occasional spines of *Hemicidaris purbeckensis* and two species of *Trigonia*, one likened to the Portlandian *T. gibbosa* Sow., the other a new species, *T. densinoda* Etheridge.

Below the Cinder Bed are more alternations of compact marlstone, shelly limestone and shale, for the most part indistinguishable lithologically from the local Lower Purbecks. The best section of these beds was described by Andrews and Jukes-Browne in the large quarry west of Teffont Evias Church. Here they found, by carefully collecting the Ostracoda *in situ*, that *Cypridea punctata* extended to 7 ft. 10 in. and *C. granulosa* var. *fasciculata* to 11 ft. below the Cinder Bed, while at lower levels only *Cypris purbeckensis* was found; they therefore drew the line between the Middle and Lower Purbecks 11 ft. below the Cinder Bed. In the lowest bed of their Middle Purbeck *Cypris purbeckensis* and *Cypridea granulosa* both occurred plentifully, but they justifiably selected 'the point where *Cypridea fasciculata* first makes its appearance'. 'It is true', they wrote, 'that *Cypris purbeckensis* is still the most abundant form, so that the bed might be grouped with either division, but we prefer to regard the incoming of *Cypridea fasciculata* as marking the base of the Middle Purbeck Beds.'[1]

Although this careful work showed that the classification of the Purbeck Beds by means of the Ostracods could be applied in the Vale of Wardour as well as in Dorset, H. B. Woodward remained unconvinced of the zonal value of Ostracods, and having declared his scepticism in the discussion following the reading of Andrews's and Jukes-Browne's paper, he ignored their results when compiling *The Jurassic Rocks of Britain*. In describing the Teffont Evias quarry he was guided by the lithology, and in order to group all the main bands of limestone together, he carried the top of the Lower Purbeck up to within 4 ft. 7 in. of the Cinder Bed (and to within 1 ft. 5 in. of it in the Dinton railway-cutting). At the same time, Andrews's and Jukes-Browne's records of Ostracods appear in his account merely as 'Cyprides'.[2]

Zone of Cypris purbeckensis and Candona ansata: Lower Purbeck, about 45 ft.[3]

The Lower Purbeck Beds have been exposed in numerous quarries. The highest portions, best seen in the base of the quarry south-west of Teffont Evias Church, contain white limestone bands locally known as Lias and bearing a resemblance to true Lower Lias limestones. Lithologically they are indistinguishable from the basal portion of the Middle Purbeck, but they may be recognized by the characteristic *Cypris purbeckensis*. Fish-remains also are numerous, some as fine as any obtained in Dorset in the Middle Division. From the Lower or Middle Purbeck of Teffont came the types of *Coccolepis*

[1] R. W. Andrews and A. J. Jukes-Browne, 1894, loc. cit., p. 54.

[2] 1895, *J.R.B.*, pp. 271, 274.

[3] Woodward's estimate, less that portion of his Lower Purbeck which is here assigned to the Middle Division. See, however, Andrews and Jukes-Browne, 1894, p. 63, who estimate the thickness of the division to be 70 ft.

andrewsi Smith Woodw., *Mesodon parvus* Smith Woodw., *Pholidophorus purbeckensis* Davies and *Pleuropholis formosa* Smith Woodw.; while from the Vale of Wardour, but less localized, came the types of *Ophiopsis breviceps* Egerton (a common species), *Enchelyolepis andrewsi* Smith Woodw., *Ceramurus macrocephalus* Egerton and *Leptolepis brodiei* Agassiz.[1]

The basement-beds have been described in the Chilmark Ravine and at Chicksgrove, Wockley and other places near Tisbury, the details differing in every exposure; on the whole, however, they are strikingly like their counterparts in Dorset. At Chilmark the base is formed by a 6 ft. block of tufaceous 'cap' with seams of chert, and a little higher up there are two Dirt Beds with gravelly stones, fossil wood and *Cycadeoidea*. In the basal bed at Wockley Messrs. Andrews and Jukes-Browne found the characteristic Ostracods *Candona ansata* and *C. bononiensis*, but as these were supposed to be estuarine forms, they were led to include the bed with the Portland Stone. Woodward, however, maintained that it unquestionably belonged to the Purbeck and that there was nowhere in the Vale of Wardour any difficulty in determining the junction between the two formations. Subsequent work on the Ostracods has brought the palaeontology into line with Woodward's opinion, for *Candona ansata* and *C. bononiensis* have now been listed as definitely freshwater forms.[2]

Hudleston considered, from the way in which the Purbeck Beds rest upon different subdivisions of the Portland Stone, that there is undoubtedly an unconformity between the two.[3] But this view was contested by Woodward.[4]

> 'No doubt', he wrote, 'there are abrupt changes here and there between the formations, as there sometimes are between individual beds in the Portland series. There is, however, no discordance such as would imply upheaval and denudation of the strata. The phenomena may be attributed in part to contemporaneous erosion, in part to the attenuation and local deposition of certain [Portlandian] sediments; while again the variations in the lithological characters of different layers serve to render the results of minute correlation very difficult and uncertain.'

III. THE SWINDON OUTLIER

A small patch of both zones of the Purbeck Beds, with a maximum thickness of 19 or 20 ft., caps the Portlandian outlier on Swindon hill. The only exposure described is the old Town Gardens Quarry, but the condition of the section is now so bad that we have to rely almost entirely on the published accounts of the last century.

The beds comprise a varied series of marls, clays and hard white marly limestone, from which *Viviparus*, *Unio*, *Planorbis* and the Ostracods *Candona ansata*, *C. bononiensis*, *Cypris purbeckensis*, *Cypridea dunkeri*, *C. punctata* and *Cythere retirugata* have been recorded. But of any Dirt Beds or tufaceous limestones suggestive of the Caps farther south, there is no sign.

At Swindon there is no doubt about the relations of the Purbeck to the Portland Beds: they are distinctly unconformable. The uneven base of the Purbecks was seen in the west face of the quarry to cut down across the *Titanites* zone or Creamy Limestones on to the Swindon Sand and Stone

[1] A. Smith Woodward, 1916–19, op. cit.
[2] F. Chapman, 1899, *P.G.A.*, vol. xvi, p. 43.
[3] W. H. Hudleston, 1883, *P.G.A.*, vol. vii, pp. 170–4.
[4] H. B. Woodward, 1895, *J.R.B.*, p. 208.

(*Kerberites* zone), and in the base of the Purbeck both Blake and Woodward found derived blocks of Swindon Stone and pebbles of Creamy Limestone containing *Aptyxiella portlandica*. To Woodward it appeared also that there was a certain amount of overlap of the lower layers of the Purbeck Beds by the higher.[1]

Blake somehow became obsessed with a belief that the beds here were older than those farther south, and were to be correlated with a part of the Portland Beds of Dorset.[2] But Woodward remarked 'such a view seems to me purely hypothetical'.[3] It would seem more probable, if the overlap suggested by Woodward be a fact, that the beds seen at Swindon are not even so old as the lowest Purbeck Beds in the type-locality. In this way might be explained the absence of tufaceous Caps or Dirt Beds and the unconformity. The records of *Cypridea punctata* and *C. dunkeri* point to the presence of Middle or Upper as well as Lower Purbeck Beds. Although the summit is not seen at Swindon, these Ostracods give an indication of great attenuation in the formation between South and North Wiltshire.

IV. THE OXON.-BUCKS. AREA

No Purbeck Beds are known on the Portlandian outlier at Bourton, but in the large tract in Bucks. and on the borders of Oxford they are scattered over almost as wide an area as the Portland Beds. They are reduced to a number of small outliers capping hills of Portland Stone and inliers showing through the Gault, or to small outcrops protruding from beneath Lower Cretaceous sands. At the best these are merely fragments, left over by the accidents of denudations, not only of the subaerial denudation of the recent period which has dissected the country into scattered hills, but also of three subaqueous denudations in Lower and Upper Cretaceous times. As explained in the last chapter, the Portland sequence is not everywhere complete, owing to the overstep of the Cretaceous rocks, and from this it follows that in places the Purbeck Beds were either entirely removed or never deposited.

In the ridge of Shotover Hill, near Oxford, a small patch of Purbeck Beds occurs at the south end, about Garsington, but towards the north the Lower Cretaceous sands rest on the *Kerberites* zone of the Portland Stone. This is of especial interest because the sands, called the Shotover Sands or Shotover Ironsands, have from time to time yielded freshwater fossils (of which a collection is preserved in the Oxford University Museum) denoting that they are of Wealden date. They seem to be overlapped or overstepped in turn by the marine Lower Greensand. Lamplugh investigated the age of the Shotover Sands (including those of Brill); and after revising the stratigraphy of the district of their occurrence and summarizing the palaeontological evidence, he agreed with the opinion reached by Strickland, and later by Phillips and by Prestwich, that they are entirely of freshwater origin and that 'they represent the lowermost part of the Wealden Series of Kent and Sussex, and may be correlated with the Hastings Beds'.[4]

Thus there is in the Oxford district the first unequivocal evidence of overlap

[1] J. F. Blake, 1880, *Q.J.G.S.*, vol. xxxvi, pp. 203, 207; H. B. Woodward, 1895, *J.R.B.*, p. 277.

[2] 1880, loc. cit., pp. 203–13, and repeated in 1885, *Q.J.G.S.*, vol. xli, p. 352.

[3] 1895, *J.R.B.*, p. 278.

[4] G. W. Lamplugh, 1908, in Pocock, 'Geol. Oxford', p. 66, *Mem. Geol. Surv.*

of the Purbeck by the Wealden Beds. No such overlap is apparent in the west; but under the north and east of Kent, where the formations approach nearer to the London–Ardennes landmass than at Oxford, it is proportionately more strongly marked.

The relics of Purbeck Beds that survive in Oxon. and Bucks. are now only poorly exposed, but Fitton described numerous sections, since for the most part obscured.[1] A general survey of the area was published in 1899 by Prof. A. Morley Davies, who described most of the exposures then extant.[2] He enumerated eighteen patches of Purbeck Beds, at the following localities: Garsington, Long Crendon, Brill, Towersey, Haddenham and district, Stone, Bishopstone, Aylesbury, Coney Hill, Quainton Hill, Oving Hill, Weedon and Stewkley. Since then the part of the area around Aylesbury has been again covered by Mr. E. A. Merrett, who searched especially for Ostracoda *in situ*.[3]

The most complete sections that have been described are the well-known Bugle Pit at Stone (Hartwell), where 12 ft. of Purbeck Beds can still be seen, and a quarry west of the cross-roads (King's Cross) north of Haddenham. This quarry, which was described by Prof. Davies and yielded interesting Ostracods, showed 8 ft. of Purbeck Beds without reaching the top, but it is now filled up with tins. The other exposures are all considerably smaller.

Lithologically the beds are highly variable, as in the other localities, consisting chiefly of green or grey clays and marls, with thin seams of hard whitish limestone, occasionally botryoidal or showing obscure oolitic structure. Some of the bands are shelly, and the genera *Viviparus*, *Planorbis*, *Neomiodon*, *Modiola* and *Mytilus* have been recorded, but nearly always too badly preserved for specific identification. Fish teeth and scales, too, are not uncommon: *Pleuropholis serrata* Egerton and *Arthrodon intermedius* Smith Woodw. have been collected from the Bugle Pit, Hartwell, and near Aylesbury.

Of greatest importance, however, are the Ostracoda, which Messrs. Chapman and Merrett have turned to good account in correlating with other areas. Mr. Merrett's collecting in those pits which are still open, and Prof. Davies's in some others now closed, have established that Middle or possibly even Upper Purbeck Beds are present in some of the localities in the Aylesbury district. At the Bugle Pit near Hartwell, at Haddenham near Ford, and at Creslow Farm near Whitchurch, they have found that the uppermost portion of the sequence contains only the Middle or Upper Purbeck forms *Cypridea punctata*, *C. dunkeri*, *C. granulosa* and *Cyprione bristovii*, while the rest of the sequence is characterized by the Lower Purbeck forms *Candona ansata*, *C. bononiensis*, *Cypris purbeckensis*, *Cythere transiens* and *C. retirugata*. In the Bugle Pit, Mr. Merrett describes the junction of the two divisions as clearly visible in the form of an uneven line running through a thick bed of unstratified marl, from 2 ft. 10 in. to 3 ft. 3 in. below the top of the pit. He speaks of the relations of the two divisions, from the upper of which he obtained only the Middle or Upper Purbeck Ostracods, as being unconformable and proclaiming erosion within the Purbeck formation. At this pit and

[1] W. H. Fitton, 1836, *Trans. Geol. Soc.* [2], vol. iv, pp. 269–92.
[2] A. M. Davies, 1899, *P.G.A.*, vol. xvi, pp. 15–58.
[3] E. A. Merrett, 1924, *Geol. Mag.*, vol. lxi, pp. 233–8.

at two other places in the district, namely Brill and the railway-cutting ¼ mile west of Haddenham, seams of peculiar earthy breccia have been noticed, consisting of angular fragments of pale mudstone and bits of lignite scattered in a muddy loam. Similar rock was found in Kent.[1]

At some localities, such as the pit now filled in, at King's Cross, north of Haddenham, and again between Bishopstone and Walton, Prof. Davies collected from the Lower Purbeck Beds a mixture of species of different habitat, apparently indicating a gradual transition from marine to freshwater conditions, but probably only of minor and local importance, like the phases in the Middle Purbecks of Durlston Bay, detected by Mr. Anderson. There is never any difficulty in separating the Purbeck Beds from the purely marine Portland Stone with its highly characteristic fauna of large mollusca. The dividing line is as usual sharp, although there are no signs of unconformity.

The types of basement-beds so characteristic of Dorset and the Vale of Wardour are generally entirely absent. Silicified wood has been noted at Garsington, however, and Buckland recorded traces of a dirt-bed above the Portland Stone about 2 miles north of Thame—probably at Long Crendon.[2]

The recent studies in the Ostracods enable us to obtain a far truer conception of the meaning of the Purbeck Beds of this area than was possible before. We may now visualize a thin formation made up of both the Lower and the Middle and perhaps also the Upper Divisions of Dorset, and therefore as truly representative of the fully developed sequence as are the greatly reduced but composite Portland Beds beneath.

V. KENT AND SUSSEX[3]

The part of the trough in which the Purbeck Beds attain their greatest thickness in Britain is that underlying the Weald of Kent. It may be presumed that the underground extension is continuous from Dorset, but on this point there is no evidence. The beds crop out at the surface over a small area in the crest of the Wealden Anticline, north and north-west of Battle. The total length of the outcrop does not exceed 10 miles and the breadth is nowhere so much as 1 mile; and it is separated into three portions, of which the two easterly are due to faulting.

The beds have been worked at many places on the outcrop. The general development is closely comparable with that in Dorset, the succession consisting of shales and clays with subordinate thin limestones, wrought in open quarries and in shafts, and the fauna comprising the familiar molluscs *Viviparus*, *Unio*, *Corbula*, *Neomiodon*, *Melanopsis* and *Ostrea distorta*, with insect remains, Purbeck Ostracods and fish and reptile bones. Conybeare and Phillips in 1822 and Webster and Fitton in 1824 recognized the similarity between these oldest strata exposed in the Weald and the Purbeck Beds. From surface indications the thickness was estimated at about 400 ft., as in Dorset.

In the present century a flood of new light has been thrown on these beds by the borings for coal. The formation was penetrated from top to bottom

[1] G. W. Lamplugh, 1908, in Pocock, 'Geol. Oxford', p. 63; and 1911, 'Mesoz. Rocks in Coal Expl. in Kent', p. 40 (with photograph); *Mems. Geol. Surv.*

[2] H. B. Woodward, 1895, *J.R.B.*, p. 279.

[3] Based on Lamplugh and Kitchin, 1911, loc. cit.; and Lamplugh, Kitchin and Pringle, 1923, loc. cit.; also H. B. Woodward, 1895, *J.R.B.*, pp. 280–6.

by five borings: one was on the south side of the Weald at Battle, near the outcrop but started on Wealden Beds; the others farther north, at Penshurst south-west of Tonbridge, and at Pluckley, Hothfield and Brabourne, in the Ashford district.

The Battle site was 2¾ miles east-south-east of the old sub-Wealden borings of 1874–5, but they had started on Purbeck Beds and therefore did not penetrate the full thickness. The new sinking of 1907–09 first passed through 424 ft. of Wealden Beds and proved the total thickness of the Purbecks (according to the grouping adopted by Lamplugh) to be 387 ft. The greatest thickness known in Britain was proved at Penshurst, the most westerly of the borings, where 562 ft. of strata were grouped with the Purbeck Beds.

The more easterly borings showed great attenuation: at Pluckley, 23 miles east of Penshurst, the thickness was 100 ft., at Hothfield it was 68 ft., and at Brabourne only 60 ft. Finally, in the numerous borings in the country farther east and north, the formation was altogether absent.

An interesting fact in connexion with this easterly and northerly attenuation is the overlap of the Purbeck Beds by the Wealden, already noticed at Oxford. In the westerly borings, those in which Purbecks were present, the boundary could only be fixed with difficulty and arbitrarily, owing to the perfect gradation from the one formation to the other. Farther east, however, the Wealden Beds were proved to pass on after the disappearance of the Purbecks and they were met with in numerous other borings, resting upon the lower formations. At Dover and Folkstone the Wealden Beds (themselves attenuated) rested upon an eroded surface of the Kimeridge Clay; at Guildford, Chilton, Fredville and Harmansole they had descended on to Corallian Beds; at Oxney on to Kellaways Beds; and at several other more remote places they were in contact with Great Oolite or the Palaeozoic platform.

In the Penshurst section, where the beds were most fully developed, the succession consisted almost entirely of clays and shales with subordinate mudstones or thin sandstones, with only very occasionally minor bands of limestone; in the more easterly sections limestones became somewhat more prominent. In all the borings the palaeontological succession was much the same. The fauna was predominantly a freshwater one, except in a band about the middle, which denoted a marine invasion probably to be correlated with that of the Middle Purbeck Beds of Dorset and the Vale of Wardour.

The commonest fossil in the highest 130 ft. of shales at Penshurst was *Viviparus*, recalling the *Viviparus* Clays and Purbeck Marble of Dorset. The marine invasion, with the usual *Ostrea distorta*, *Protocardia* and *Isognomon*, was detected between 268 ft. and 278 ft. from the top. The same assemblage occurred also about the middle of the section at Brabourne, where some more specific identifications were possible: Dr. Kitchin was able to recognize *Protocardia purbeckensis* (de Lor.), also an undescribed species of *Protocardia* and *Corbula alata* Sow. Throughout most of the rest of the succession the fauna was found to be essentially freshwater. In the upper part, but below the maximum of *Viviparus*, bivalves, principally *Neomiodon* and *Unio*, were so numerous that at intervals they formed flaggy layers of shelly limestone.

In the Lower Division fossils were as usual rare, consisting principally of fish-remains and Ostracods. On the whole the use that could be made of the

Ostracods in correlating was disappointing when compared with the results obtained in Buckinghamshire and abroad. However, the two zones are definitely recognizable from the records: *Cypris purbeckensis* was restricted to the lower beds, below the marine horizon, and *Cypridea punctata* was recorded from a number of levels in the upper part of the series, the lowest record being 17 ft. below the marine band. Several additional Ostracods were found in both Upper and Lower Divisions but could not be identified.

The lowest 200 ft. of the beds at Penshurst (and lesser thicknesses at the base of all the other sections) were found to be highly charged with gypsum. The mineral is also present at the outcrop in Sussex, where it is about 60 ft. thick, and it is extensively mined near Netherfield. This provides another link with the Purbecks of Dorset, where it will be remembered gypsum was formerly worked for making plaster of Paris from the Lower Purbeck Beds of Durlston Bay.

The junction with the Portland Beds wherever seen in the Kent borings was abrupt but devoid of any signs of erosion or unconformity.

CHAPTER XVII

THE END OF JURASSIC TIME AND THE CRETACEOUS BOUNDARY

I. THE TRANSITION FROM JURASSIC TO CRETACEOUS IN THE BRITISH ISLES

OVER all the northern part of the British Isles evidence bearing on the events in the closing phases of the Jurassic period is entirely lacking. In Scotland and in Northern and Central England as far south as Bedfordshire the record is cut off abruptly in the Kimeridge Clay, and it is unprofitable to speculate on what may have taken place in the interval between the deposition of the Kimeridge Clay and its truncation by the transgressive Lower Cretaceous (Neocomian and Aptian) seas. Some rolled pebbles and fossils incorporated in the basement-beds of the Cretaceous in this area have been identified with Portlandian forms and have been taken to indicate a former extension of Portland Beds far beyond the present outcrop; but the identifications have been seriously questioned, and it seems probable that all the species not derived from the Kimeridge Clay are Cretaceous.[1]

We will therefore abandon the north for a time and concentrate our attention on the tract south of Leighton Buzzard in an endeavour to trace out the concluding events of Jurassic time in Britain. The quest is not a new one, but we can embark on it equipped with a great deal more accurate information than was at the disposal of our predecessors.

We now know, thanks to Buckman's researches on the ammonites, that the marine Upper Portland Beds of Oxfordshire and Buckinghamshire are complete, and that there are therefore no grounds for a supposition at one time entertained, that the Purbeck Beds of that area and of Swindon were laid down while Portland Stone was forming in Dorset.[2] Moreover, a knowledge of the Ostracods enables us to state that both of the zones recognizable in the Purbeck Beds of Dorset are present in these northerly outcrops. We must therefore picture the peculiar conditions of the Purbeck period, the low-lying swamps and lakes, now elevated into dry land, now depressed beneath the sea, as extending from the English Channel between East Kent and West Dorset at least as far inland as Swindon, Oxford, Aylesbury and Leighton Buzzard. A number of facts point to these most northerly existing outcrops having lain near the fringe of the area of deposition: the extreme thinness of the beds, the overlapping of successive members one over another at Swindon, and their local unconformity to the Portland Beds, the discordance between the two Purbeck zones at Hartwell, and the fact that the marine advance of the Middle Purbeck left no trace and so presumably did not extend so far north. Similarly the rapid attenuation of the Dorset Purbecks towards the west, commensurate with an increase in the coarseness of the sediment, points to permanent land not far away in that direction. In North and East Kent we

[1] G. W. Lamplugh, 1896, *Q.J.G.S.*, vol. lii, pp. 195–8.

[2] J. F. Blake, 1880, loc. cit., and 1885, loc. cit.; and A. J. Jukes-Browne, 1892, *Build. Brit. Isles*, 2nd ed., p. 240.

have seen that the attenuation is even more rapid against the London–Ardennes landmass.

The area from South-West Kent and Sussex to East Dorset experienced the maximum amount of subsidence and deposition, through the Purbeck as through the preceding Portland and Kimeridge periods. Here too, in the central region of the depression, was subsequently accumulated the greatest thickness (more than 2,000 ft.) of materials, still perfectly conformable with the Purbecks and of freshwater origin—the Wealden Formation.

Like the Purbecks, the Wealden Beds thin out rapidly towards the east, west and north. Although more than 2,000 ft. thick at Swanage, they are reduced at Mupe Bay to 750 ft. and north of Weymouth to little more than 350 ft.—a rate of diminution at which they would disappear when they reached Bridport. At the same time there is a marked westerly increase in the coarseness of the sediments, sands replacing clays and pebbly grits taking the place of sands.

Similarly, in the Weald, although the beds in Sussex are as thick as at Swanage, the numerous borings in Kent have shown that between Dover and Canterbury they nowhere exceed 85 ft., and beyond this, towards the north-east and north, soon after overlapping the Purbecks on to the Palaeozoic platform, they die out altogether. In the Vale of Wardour the thickness is much reduced, and in the most northerly outcrops of all, on the hills of Shotover and Brill, east of Oxford, it does not exceed 50–60 ft.

It will thus be seen that, although the Wealden Beds are everywhere four or five times as thick as the Purbeck Beds, the two behave as one in regard to their changes of thickness and their distribution.

The Wealden Beds are too well known to need describing in detail. In the region of greatest thickness, from West Kent and Sussex to East Purbeck, they comprise two main divisions, a predominantly sandy series below, called the Hastings Beds (maximum thickness about 1,000 ft.) and a predominantly argillaceous series above, known as the Weald Clay (maximum thickness 1,200 ft.). At the outcrop in the Weald a number of subdivisions have been established; in particular the Hastings Beds are divided into Ashdown Sand below and Tunbridge Wells Sand above, separated by the Wadhurst Clay (with a maximum thickness of 180 ft.). But these subdivisions are not constant even at the outcrop, both of the sandy divisions being liable to replacement by clay (the Fairlight Clays, up to 350 ft. thick, at the base of the Ashdown Sand near Eastbourne, and the Grinstead Clay, up to 50 ft. thick, at any horizon in the Tunbridge Wells Sand). Away from the outcrop, as in the borings in North and East Kent and in the equally-well-developed succession at Swanage, the subdivisions cannot be identified, and only a broad grouping of the series into Weald Clay above and Hastings Beds below is possible, the details varying considerably from place to place.[1]

In view of this inconstancy, the lithology of the Wealden Beds can only be described in general terms. The coarser sediments vary from fine sand to coarse quartz sand with pebbly seams, and wedge-bedding is frequent, testifying to the action of changing currents. Some of the pebbles in the Weald have been identified as derived from the Palaeozoic rocks of the

[1] G. W. Lamplugh, 1911, 'Mesoz. Rocks in Coal Expl. in Kent', p. 85; and A. Strahan, 1898, 'Geol. Purbeck and Weymouth', pp. 122–32; *Mems. Geol. Surv.*

London–Ardennes landmass, but in Purbeck the quartz pebbles increase westward and obviously came from the west. In the Upper Wealden of Purbeck and the Weald have been found the first heavy minerals derived from the Dartmoor granite, now freshly laid bare of its thick sedimentary covering.[1]

The clays are sometimes soft and soapy, sometimes shaly and interbedded with lenticular and irregular limestone bands, crowded with freshwater shells and closely resembling some of the Purbeck Beds. Locally there are deposits of drift-wood, of which the classic example is the well-known 'Pine Raft' on the west coast of the Isle of Wight.

'The character of the greater part of the formation', wrote Sir A. Strahan, 'suggests the action of a river distributing clay, sand and gravel irregularly and locally on a subsiding area.'[2] The nature of the subsiding area has long been visualized as a great lake-basin: 'The essentially lacustrine character of the Wealden deposits is now generally admitted,' writes Jukes-Browne.[3]

> 'By some geologists they have been regarded as the delta of a great river, comparable to that of the Nile or the Mississippi; but as a matter of fact the deposits do not resemble those of a single delta, but rather those of several rivers or streams pouring their sediment from different directions into a large freshwater lake. This view was held by Searles V. Wood and by Godwin-Austen, and was strongly advocated by Meyer in 1872.'[4]

De Lapparent rightly remarks that the area drained by these rivers must have been far greater than all the existing mountainous regions of the British Isles.

The conception of a lake filled by rivers is not radically different from the picture of the flat and swampy landscape in Purbeck times. All the differences would be accounted for by increased subsidence of the floor of the basin, compensated, as is usual in similar changes of level, by increased elevation of the surrounding land. This would set in motion the normal forces of denudation accompanying a cycle of activity: revival of the rivers and accelerated sedimentation; in fact a repetition of the processes involved in the filling up of the Old Red Sandstone lakes, but on a modified scale. From time to time in the Wealden lake, conditions locally simulated those in which the freshwater portions of the Purbecks were formed, as may be seen by the repetition even in late Wealden times of Ostracod-shales interbedded with *Viviparus*-limestones ('Sussex Marble') in Sussex and Kent.

In view of this essential continuity of conditions between the Purbeck and Wealden periods, it is interesting to examine more closely the junction of the two formations—'the convenient plane for the base of the Cretaceous' which, according to the most recent text-book, is 'marked by the lithological change from limestones and marls to sands and clays'.[5]

The best sections are undoubtedly those exposed on the coast of the Isle of Purbeck, especially at Worbarrow and Mupe Bays, and at Lulworth and Durdle Door. No one knew these sections better than Sir A. Strahan, who of all men might be expected to provide us with an exact level at which to draw so important a boundary-line. Instead, he summarized his conclusions by

[1] A. W. Groves, 1931, *Q.J.G.S.*, vol. lxxxvii, pp. 70–2.
[2] A. Strahan, 1898, loc. cit., p. 122.
[3] 1911, *Building Brit. Isles*, 3rd ed., p. 302.
[4] 1872, *Q.J.G.S.*, vol. xxviii, p. 247.
[5] 1929, *Handbook to the Geol. of Gr. Britain*, p. 388.

saying that 'no line can be drawn which does not either include beds of Purbeck type in the Wealden or beds of Wealden type in the Purbeck, the two formations being absolutely inseparable'.[1] In the most favoured locality for studying the junction of the Jurassic and Cretaceous Systems, then, there is clearly no 'convenient plane' of separation at all, and any one familiar with the sections knows that any line is purely arbitrary.

In the Vale of Wardour, again, the passage is so gradual that many feet of argillaceous strata have been grouped with the Wealden by some authorities (Woodward and Strahan)[2] and with the Purbeck by others (Andrews and Jukes-Browne).[3]

The same difficulty was met with in the more complete of the borings in Kent and Sussex, where it had to be admitted that, when Purbeck and Wealden Beds were both present, the position at which the boundary between the two should be placed was a matter of opinion.

'At Penshurst the lowest beds [of the part of the core grouped as Wealden] were dark laminated shales and greenish clays with bands of ironstone and hard sandstone, hardly differing from the underlying Purbecks and containing the same abundance of fresh-water fossils. By gradual upward transition and alternation these beds became more sandy and less fossiliferous, containing for the most part the remains of plants and fish only, until in the upper 225 feet of the boring there was a predominance of soft yellowish sandstone, with subsidiary beds of clay.'[4]

Upon this evidence it may be considered established that in the central parts of the trough, where the Purbeck and Wealden Beds are most fully developed, the formations grade imperceptibly one into the other and form a perfectly continuous and conformable series.

But, as might be expected, the earth-movements which failed to interrupt the essential continuity of sedimentation in the central parts of the trough made themselves felt at the margins, especially in the vicinity of the London–Ardennes landmass, a traditionally unstable region. The Kentish borings proved that the greatly attenuated Wealden formation oversteps all the Jurassic formations and comes to rest on the Palaeozoic platform, before being in turn overstepped by the Lower Greensand. Close to the same Palaeozoic platform in the Boulonnais, also, it can be seen overstepping on to rocks as old as the Bathonian.[5] There is nothing by which to correlate these reduced representatives of the Wealden with the fuller sequence that is conformable with the Purbecks, and they may represent only the uppermost part of the formation. The highest beds would be expected to cover a wider area than the lowest and to overlap them as the result of the continued subsidence. This was appreciated by the authors of the Memoir on the 'Concealed Mesozoic Rocks in Kent', who, although they noted that even where the Wealden Beds are thinnest they are still argillaceous and shaly in the upper portion and sandy and silty in the lower, considered that these subdivisions do not truly represent the thick Weald Clay and Hastings Beds of the fuller sequence.[6]

Again, in the northerly outcrop on Shotover Hill, east of Oxford, the thin

[1] A. Strahan, 1898, loc. cit., p. 126.
[2] H. B. Woodward, 1895, *J.R.B.*, pp. 267, 273.
[3] 1894, *Q.J.G.S.*, vol. l, pp. 59–63 and 66–8.
[4] G. W. Lamplugh, in Lamplugh and Kitchin, 1911, loc. cit., p. 85.
[5] M. Parent, *Ann. Soc. géol. Nord*, vol. xxxii, p. 17.
[6] Lamplugh, Kitchin and Pringle, 1923, loc. cit., p. 17.

representatives of the Wealden Beds (the Shotover Sands) overlap the Purbecks and come to rest on the Portland Stone; but on the neighbouring Brill Hill, a few miles to the east, there seems to be no such overlap (fig. 91).[1]

The evidence of the palaeontology in England is entirely in favour of assigning the Wealden as well as the Purbeck formation to the Jurassic, and

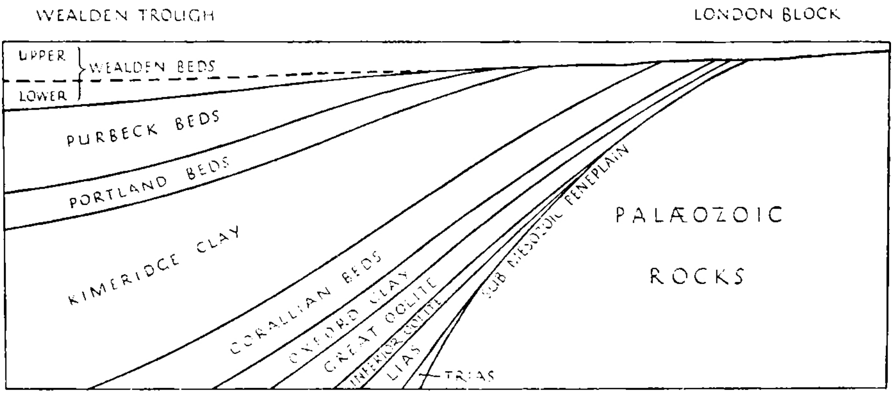

FIG. 91. Diagrammatic section across the margin of the Wealden trough of deposition, where the strata abut against the London landmass; the top of the Wealden Beds restored to horizontality. Note that in the centre of the trough the whole series from Trias to Wealden is perfectly conformable but that towards the edge overlaps and oversteps develop. In particular the Upper Wealden overlaps the Lower, and oversteps the whole Jurassic System unconformably. Towards the centre of the trough, however, it is progressively difficult to distinguish overlap from overstep. (Relative thicknesses approximately correct, but vertical scale greatly exaggerated for the sake of clearness.)

that they should be divided between the two systems seems wholly irrational if we consider only the English fauna and flora.

The most recent revisers only endorse opinions arrived at before the middle of the last century.

'So far as known', writes Sir Arthur Smith Woodward in 1919, 'the fishes of the Wealden and Purbeck formations are essentially Jurassic, and not mingled with any typically Cretaceous forms. Most of them are, indeed, the specialised and evidently final representatives of the Jurassic families to which they belong, and very few can be regarded as possible ancestors of fishes which followed in Cretaceous and later times.'[2]

Sir Richard Owen stated the same thing of the Wealden Reptilia in 1850, when he brought it forward as an objection to Forbes's proposal to sever the Wealden from the Purbeck Beds and to place one in the Cretaceous and the other in the Jurassic System. Now lastly comes Dr. Simpson's verdict upon the Purbeck mammals, some of which have been found also in the Wealden Beds. He finds (1928) that they are unrelated to any Cretaceous or more recent stocks, but that some belong to the same orders as those represented in the Stonesfield Slate.[3]

Among invertebrates the testimony of the Ostracods is the most important.

[1] See above, p. 535.
[2] 1919, 'Mon. Purbeck and Wealden Fishes', *Pal. Soc.*, p. 141.
[3] 1928, *Cat. Mesozoic Mammals in Brit. Mus.* See above, pp. 526–7.

T. R. Jones showed that of the six species of Ostracods which he recognized in the Middle and Upper Purbeck Beds, five range up into the Wealden, where some of them become more abundant.[1] The Middle and Upper Purbecks are therefore much more closely linked by their Ostracod fauna to the Wealden than they are to the Lower Purbecks.

The freshwater molluscs of the two formations are largely identical, but like all freshwater molluscan faunas, they are somewhat featureless for dating purposes. It has often been remarked that, taken from their context, they have a Tertiary or even Recent appearance. The marine mollusca (which occur only in the Purbecks) are all of typical Jurassic genera; but of even more significance than these is the Jurassic echinoid, *Hemicidaris purbeckensis*, found in the Cinder Bed, and also in the Portland Beds in the North of France.

The plant life of the period tells the same story. The greatest authority, Prof. Seward, wrote in 1895, 'The evidence of palaeo-botany certainly favours the inclusion of the Wealden rocks in the Jurassic series.'[2] In 1931 he is still of the same opinion: 'Whether or not we include the Wealden series in the Jurassic period is a matter of secondary importance,' he writes, but, 'of greater importance from our point of view is the general agreement of the plants preserved in Wealden deposits with those of the older Jurassic floras.'[3]

In face of this consensus of opinion that the Wealden and Purbeck Beds cannot be separated on palaeontological or on stratigraphical grounds, it is important to understand the stratigraphical relations of the Wealden Beds to the strata of undisputed Cretaceous date in other countries, as well as in England.

So far as the South of England is concerned, the facts are once more abundantly clear in the coast-sections of the Isle of Wight and the Isle of Purbeck, especially at Atherfield in the Isle of Wight and at Punfield in Swanage Bay. At Atherfield the basement-bed of the marine Lower Greensand (the base of the Atherfield Clay) is the *Perna* Bed (so called from the occurrence of *Isognomon* [*Perna*] *mulleti*). It consists of

'a brown calcareous grit, highly fossiliferous, and always contains scattered pebbles, some of which are rolled ammonites or other marine fossils; and it rests upon a slightly eroded surface of the Wealden Shales. At Punfield a highly fossiliferous grit, displaying the conglomeratic character of the *Perna* Bed, occupies a corresponding position at the base of the Atherfield Clay, and also rests upon a disturbed surface of Wealden Shales.'[4]

The Atherfield Clay yields ammonites (*Parahoplitoides*) which belong to an horizon 'well above the base of the Aptian', and the ferruginous sands immediately above at Punfield (formerly known as the 'Punfield Beds') have yielded forms of the same genus pointing to a slightly later date, but still to the Lower Aptian or Bedoulian.[5]

Westward through Purbeck the Lower Greensand (Aptian) oversteps steadily on to lower horizons in the Wealden Beds.[6] Similarly, in the exposures about Oxford the two formations are unconformable: the marine Aptian

[1] T. R. Jones, 1885, *Q.J.G.S.*, vol. xli, p. 331.
[2] 1895, *Cat. Plants Brit. Mus.*, *Wealden Flora*, part 2, p. 240.
[3] 1931, *Plant Life through the Ages*, p. 340.
[4] A. Strahan, 1898, loc. cit., p. 136.
[5] L. F. Spath, 1923, *Sum. Prog. Geol. Surv.* for 1922, p. 148.
[6] A. Strahan, 1898, loc. cit., p. 122.

TABLE ILLUSTRATING THE RELATIONS OF THE STRATA ON THE JURASSIC-CRETACEOUS BORDERLINE

Ages of Neocomian and Tithonian and correlations of Neocomian after Spath, 1923 and 1924 (ages of the Tithonian and their correspondence with the three divisions of the Purbeck rather hypothetical)

Stages.	*Ages.* (*Marine Sequence*)	*S. France and Jura.*	*NW. Germany.*	*Speeton.*	*Lincs. and Norfolk.*	*S. England.*	
APTIAN		APTIAN	APTIAN	APTIAN	APTIAN (CARSTONE)	APTIAN (ATHERFIELD CLAY)	
BARREMIAN	Heteroceratan	MARINE NEOCOMIAN.	MARINE NEOCOMIAN.	SPEETON CLAY. Cement Beds		(Aptian pebble-bed rests on Wealden)	NEOCOMIAN. CRETACEOUS.
	Paracrioceratan			Zone of *B. brunsvicensis* (B)	Snettisham Clay Tealby Limestone Tealby Clay		
HAUTERIVIAN	Hoplocrioceratan						
	Simbirskitan			Zone of *B. jaculum* (C)			
	Crioceratan				(gap)		
	Lyticoceratan			Zone of *B. lateris* pars. (D)	Claxby Ironstone		
VALANGINIAN	Hoplitidan			(gap)	(gap)		
	Polyptychitan			Zone of *B. lateris* pars. (D)	Hundleby Clay		
	Platylenticeratan			(?)	(gap)		
INFRAVALANGINIAN	Subcraspeditan		Wealden	Coprolite Bed on Kim. Clay	Spilsby Sandstone Phosphatic Pebble Bed on Kim. Clay	Wealden	
	Spiticeratan						
TITHONIAN or PURBECKIAN	Berriasellidan	Absent or much reduced and inosculating with above.	Freshwater Limestones Zone of *Cypridea punctata*			Upper Purbeck Zone of *Cypridea punctata*	JURASSIC.
	Kossmatian	? Middle Purbeck	Serpulite Sub-Zone of *Metacypris forbesii*			Middle Purbeck Sub-Zone of *Metacypris forbesii*	
	Aulacosphinctoidean	Lower Purbeck Zone of *Cypris purbeckensis*	Munder Marls Zone of *Cypris purbeckensis*			Lower Purbeck Zone of *Cypris purbeckensis*	
PORTLANDIAN	Titanitan	Marine Portland (chiefly dolomites)	Partly represented by the Plattenkalk (mainly marine)			Marine Portland	
	Behemothan						

sands come to rest at numerous places inland upon Kimeridge Clay, and over the Charnwood and Nuneaton Axes they extend on to Oxford Clay. In the Weald the discordance is less marked, but even there the Aptian eventually oversteps the Wealden and passes on to the Palaeozoic platform.[1]

And so, as Sir A. Strahan wrote in 1898, 'there is not only in the Isle of Wight and in the Isle of Purbeck, but in the South of England generally, a well-defined base to the Lower Greensand, above which, and nowhere below it, occur the characteristic and purely marine species of that formation, while the brackish and freshwater fauna is confined . . . to the Wealden group'.[2]

Were we dealing only with the South of England there could be no question of drawing the dividing line between the Jurassic and Cretaceous Systems anywhere but at this major transgression, which marked the invasion of the area covered by the freshwater lake-deposits, containing a purely Jurassic fauna and flora, by the Aptian sea with its purely Cretaceous and marine assemblage. But when we take a wider area into account the matter assumes an entirely different aspect. For in Yorkshire, Lincolnshire and North Germany there were two Lower Cretaceous transgressions, the Aptian invasion being preceded by a Neocomian one, which left no traces in, and so probably did not extend over, the country occupied by our Wealden lake.

The Neocomian deposits of Yorkshire, Lincolnshire and Norfolk were fruitfully studied for many years by Lamplugh, but it is only recently that Dr. Spath's elucidation of the ammonites has enabled them to be effectively brought into line with the Continental sequence. Everywhere the Neocomian deposits rest upon an eroded surface of the Kimeridge Clay and contain at their base a bed of phosphatic pebbles, among which are rolled Kimeridgian ammonites and other fossils. In Yorkshire the phosphatic pebble-bed (called the Coprolite Bed) is succeeded by the Speeton Clay, containing ammonites belonging to all the three subdivisions of the Neocomian—the Valanginian, Hauterivian and Barremian (though with a number of gaps in their faunas)—and overlain by the Aptian. In Lincolnshire and Norfolk the sequence is somewhat different, but a similar general succession of ammonite faunas has been made out, ascending from the Spilsby Sandstone through the Hundleby Clay, Claxby Ironstone, Tealby Clay, Tealby Limestone and Snettisham Clay to the Aptian Carstone. Here the earliest ammonites found, in the Spilsby Sandstone, are of slightly earlier date than those in the lowest ammonite-bearing horizon of the Speeton Clay (the Upper part of the Infravalanginian or Upper Berriasian);[3] but, as pointed out by Lamplugh, the phosphatic pebble-bed at the base of the Spilsby Sandstone can without much doubt be correlated with the so-called Coprolite Bed at the base of the Speeton Clay.[4] The two denote but a single transgression of the Jurassic plains by the Neocomian sea.

This northern Neocomian sea was completely excluded from the area of the Wealden lake by the London–Ardennes landmass: no sign of marine Neocomian deposits exists anywhere on the south of the barrier in England or in Northern France. If, however, we follow along the north of the land-barrier

[1] Lamplugh, Kitchin and Pringle, 1923, loc. cit., p. 16.
[2] A. Strahan, 1898, loc. cit., p. 135.
[3] L. F. Spath, 1924, *Geol. Mag.*, vol. lxi, p. 80, Table.
[4] G. W. Lamplugh, 1896, *Q.J.G.S.*, vol. lii, p. 159 and Table.

eastward and cross into Germany, we find to the south of Hanover an extensive tract of richly ammonitiferous Neocomian clays, evidently a continuation of those in Yorkshire and Lincolnshire, and beneath them other freshwater beds resembling our Wealden and Purbeck formations.

Before we can profitably discuss any further the vexed question of the upper limit of the Jurassic System, therefore, we must abandon the insular outlook which we have maintained hitherto in this book and consider the relations of the formations in the classic region around Hanover and Hildesheim.

II. THE TRANSITION FROM JURASSIC TO CRETACEOUS TIMES IN NORTH-WEST GERMANY, AND ON THE JURASSIC-CRETACEOUS BOUNDARY IN GENERAL

The Jurassic and Lower Cretaceous rocks of the neighbourhood of Hanover were long ago described in memoirs by Struckmann, Roemer, Brauns and von Seebach, and more recently they have received attention at the hands of Koert, von Koenen, Salfeld and other geologists. By far the most important modern contribution to an understanding of the uppermost part of the Jurassic series was made by Koert, who carefully collected the Ostracods from the various levels.

The general succession from the Neocomian to the Kimeridgian is as follows:

SUMMARY OF THE SUCCESSION NEAR HANOVER

Hils Clays. The Hils Clays, studied with minute care by von Koenen in numerous brickyards, especially in the Hilsmulde, contain a full suite of Neocomian ammonite faunas, with which Dr. Spath has been able to correlate the ammonite succession of the Speeton Clay and its equivalents in Lincolnshire. Since the clays are undisputedly of Cretaceous date they only concern us here in so far as they provide us with a datum-line.

Unlike the Neocomian of Lincolnshire and Yorkshire, the Hils Clays do not rest non-sequentially upon much older Jurassic beds, with a basal pebble-bed, but pass down conformably into a thick series of strata like our Wealden. The lowest ammonite-bearing marine horizon is the *Platylenticeras* zone of the Lower Valanginian, which is unrepresented in England, but which Dr. Spath places between the faunas of the Hundleby Clay and the Spilsby Sandstone (see table on p. 546). Immediately above it is the *Polyptychinites* zone or Middle Valanginian, equivalent to the Hundleby Clay.[1] At Hils the *Platylenticeras* fauna has not been found, and the *Polyptychinites* zone seems to rest directly on the Wealden Beds. At other places the basal portion of the *Platylenticeras* zone or marine Lower Valanginian inosculates with the freshwater Wealden, so that there are several alternations of marine and freshwater strata.[2] On the evidence of this inosculation of the uppermost beds of the Wealden with strata slightly older than the Hundleby Clay (which rests on the Spilsby Sandstone), Dr. Spath correlates the Wealden of North-West Germany with the Spilsby Sandstone and the Infravalanginian of other regions.[3]

Wealden. The German Wealden, like the English, is a highly variable

[1] L. F. Spath, 1924, loc. cit., p. 80, Table.
[2] C. Gagel, 1893, *Jahrb. Preuss. Geol. Landesanst.*, vol. xiv, pp. 158–79.
[3] L. F. Spath, 1924, loc. cit.

series of freshwater, lacustrine and deltaic deposits, and reaches a maximum thickness not far short of 1,000 ft. Some authors have divided it into Wealdenthon above and Wealdensandstein below, suggesting our Weald Clay and Hastings Sands, while others have considered it divisible into three, a predominantly sandstone division between two clays—the differences depending on the place. The sandstones make good building-stones and have been used in Cologne Cathedral. Interbedded with them are bituminous, pyritous or carbonaceous shales and seams of coal. The flora, like that of our Wealden, is purely Jurassic, and so is the vertebrate fauna. The clays are grey or black, rarely sandy, with thin-bedded limestones made up of *Neomiodon*, *Unio waldensis*, *Melania strombiformis*, *Viviparus fluviorum*, *Cypris waldensis*, &c. The same fossils occur more rarely in the sandstones; and saurian footprints have also been found.

Freshwater Limestones. Locally at Hilsmulde, Little Deister, Osterwald and Nesselberg there are up to 185 ft. of marly, freshwater limestones and marls; but they seem to fail near Hanover, at Deister, at Süntel and in the Teutoburger Wald, where various writers have described the Wealden sandstones resting directly on the next stratum beneath, the Serpulite. Koert showed that these limestones yield *Cypridea punctata* Forbes in almost every exposure, and also *Physa bristovii* Forbes, *Hydrobia*, *Bythinia*, *Valvata*, *Planorbis* and *Chara*. Some of the beds are described by Koert as crowded with *C. punctata*, like the Ostracod Shales of the Upper Purbeck, and the species is found throughout the sections, especially with *Planorbis* and *Chara*-remains.[1]

Serpulite. The freshwater limestones pass down, without any sharp line of demarcation, into a series of some 50–150 ft. of mixed marine and freshwater beds, mainly massive grey limestones in the upper part, and grey clays with subordinate limestones in the lower part. This series has long borne the name of Serpulite on account of the abundance of *Serpula coacervata* Blumb., which largely composes some of the limestones. The marine fauna predominates, but there are many freshwater fossils, including *Physa bristovii* Forbes, *Neomiodon angulatam* (Sow.), *Valvata helicoides* Forbes. Of greatest significance are the Ostracoda, carefully collected by Koert, which include *Metacypris forbesii* Jones, *Cypridea punctata* and *C. dunkeri* Jones,[2] clearly a Middle Purbeck assemblage. The marine genera recorded are *Ostrea*, *Exogyra*, '*Pecten*', *Gervillia*, *Corbula* and *Actæonina*. Other fossils stated by Koert to be represented in the collection at Göttingen from both the Serpulite and the Middle Purbeck of Swanage are *Melanopsis harpæformis* Dunk. & K., *M. attenuata* Sow., *Nerita valdensis* Roem., *Litorinella elongata* (Sow.), *Turritella minuta* Dunk. & K., *Corbula durlstonensis* Maillard and other *Corbulæ*, &c.

The Serpulite transgresses the underlying beds down to the Lias and Trias, but where the Munder Marls are developed the passage is gradual and conformable.

Munder Marls. The Munder Mergel, often called Purbeck Mergel, consists of up to 1,000 ft. of red and green marls, containing much gypsum and

[1] W. Koert, 1898, *Geol. und Pal. Untersuch. der Grenzschichten zwischen Jura und Kreide auf der Südwestseite des Selter*', Inaug.-Dissertation, Göttingen, pp. 23–30.
[2] Ibid., pp. 17–23.

other salts. Fossils, except for *Cypris purbeckensis*, are rare, but certain beds yield such marine species as *Gervillia arenaria* Roem., *Corbula* and *Serpula coacervata*; while other layers, especially towards the top, contain some of the same lacustrine forms as the Serpulite—*Valvata helicoides* Forbes and *V. sabaudiensis* Maillard. The marls are in many respects comparable with the Lower Purbeck, with which they have long been correlated by authors, and with which Koert's discovery of abundant *Cypris purbeckensis* accords.[1] They have been likened to the marls of the Keuper, and seem to have had a similar mode of origin.

Eimbeckhäuser Plattenkalk. The Munder Marls pass down gradually and conformably into the Plattenkalk, which is a very widespread formation in North-West Germany. It consists of a variable series of peculiar platy, bituminous, marly or shaly limestones, some oolitic, separated by marly clays, in all up to more than 300 ft. thick. Some of the layers are highly impregnated with bitumen. The fossils recorded by various authors include *Eodonax pellati*, *Protocardia* cf. *dissimilis*, *Corbula alata*, *C. inflexa*, *C. autissiodorensis* and *Modiola autissiodorensis*, all rather abundant, and *Isognomon bouchardi*, *Trigonia variegata*, *Neomiodon cuneatum* and *N. angulatum*. With these are still occasionally found *Viviparus*, *Bythinia*, *Melania* and *Carychium*.

Gigas Beds. Below the Plattenkalk, and resting on Kimeridge Clay with *Exogyra virgula* (Lower Kimeridge Clay), are the fossiliferous *Gigas* Beds with large ammonites previously known as *Ammonites gigas* and *A. giganteus*, and supposed to represent the Portland Stone. Salfeld, however, recognized these forms as the Kimeridgian genus *Gravesia*. The beds consist of marls with bands of limestone. They also contain *Exogyra virgula*.

[Lower] Kimeridge Clay, with *Exogyra virgula*, below.

Until recently the correlation of this succession with that in Dorset was considered straightforward. The view held by the pioneers, Roemer, Struckmann and Seebach, and greatly strengthened by Koert, was that the *Gigas* Beds, with or without the Plattenkalk, represent the Portland Stone, and that the remaining strata up to the base of the Wealden are equivalent to the Purbeck Beds. This is the correlation set forth in all the text-books, such as the *Traités* of De Lapparent and Haug, and, so far as the strata above the *Gigas* Beds are concerned, there is much to be said in its defence.

In 1914 Dr. H. Salfeld introduced a revolutionary classification, based on his discovery that the large ammonites of the *Gigas* Beds belonged, not to the species of the Portland Stone, but to the superficially similar genus which he called *Gravesia*, characteristic of the Lower Kimeridge Clay in England. As a result of this correction, he sought to discover representatives of the higher Kimeridgian and Portlandian Beds amongst the overlying strata in Germany usually assigned to the Purbeck. Von Koenen had already suggested that the Serpulite might perhaps be correlated with the Portland Stone,[2] and Salfeld now took up the idea and proclaimed it as his opinion that the underlying Munder Marls and Plattenkalk probably bridged the zones of '*pallasianus*' [*Pavloviæ*], *pectinatus* and *gorei*.[3] As the solitary representative of the Purbeck

[1] W. Koert, 1898, loc. cit., pp. 16 and 17.
[2] Von Koenen, 1900, 'Ueber das Alter des norddeutschen Wälderthon's', *Nachrichten des K. Gesell. Göttingen*, aus 1899, pp. 311–14.
[3] H. Salfeld, 1914, loc. cit., p. 173.

Beds, he left the impersistent Freshwater Limestones (Koert's Upper Purbeck).

Salfeld's correlation seems to be based solely on the three following points:[1]

(1) in one place, in the conglomeratic and highly transgressive Serpulite, von Koenen found a single specimen of *Belemnites* cf. *absolutus* Fischer, a species which is also found in the *Titanites* (*giganteus*) zone (see von Koenen, 1900, p. 313).

(2) the abundant *Serpulæ* in the Serpulite recalled to Salfeld portions of the Cherty Series of the Isle of Portland, likewise crowded with *Serpulæ*.

(3) the Serpulite marks a period of marine transgression, whereas in England and North France, he states, the sea withdrew after *Titanites* (*giganteus*) times; therefore the Serpulite is unlikely to be later than the *Titanites* zone.

Against these considerations I would draw attention to the following: (1) The single belemnite found in the Serpulite (even if its identification were not beyond suspicion, but it is only *compared* with *B. absolutus* Fischer) could never be relied upon for dating purposes, for it might have been derived from an older formation; the associated pebbles are derived from all parts of the Jurassic and even the Trias.[2] Andrée has pointed out in another connexion that not much value can be attached to this single find.[3] (2) The *Serpula* of the Portland Cherty Series is *S. gordialis*, whereas that of the Hanoverian Serpulite is *S. coacervata*, a species which Koert identified in the Middle Purbeck of Swanage.[4] (3) The statement that the sea withdrew altogether after *Titanites* times is incorrect, for there was a widespread marine invasion in the Middle Purbeck (see above, pp. 518, 531, 538).

Against the slender arguments adduced by Salfeld must be set the resemblance of the whole of the fauna and most of the lithology of the Munder Marls, Serpulite, and Freshwater Limestones to the Purbecks. There is, in fact, definite evidence for believing that these three formations represent the Lower, Middle and Upper Divisions of the Purbeck Beds: (i) In the Munder Marls there is the zone fossil *Cypris purbeckensis*, which Koert says is abundant at certain horizons, as well as the general lithology and the masses of gypsum to suggest the Marls-with-Gypsum of the Lower Purbeck; the gypsum and other salts are in evidence not only in Dorset and the Weald[5] but also in the Charente and the Jura Mountains.[6] (2) In the Serpulite, Koert's discovery of the Ostracods *Metacypris forbesii*, *Cypridea punctata* and *C. dunkeri*, taken with the predominance of limestones and the evidence of a marine transgression, calls for correlation with the Middle Purbeck. (3) The Freshwater Limestones correspond well with the Upper Purbeck, even to the abundance of the zone-fossil, *Cypridea punctata*, to the exclusion of other Ostracods.

Von Seebach classed the Plattenkalk also with the Purbecks,[7] but the marine lamellibranch fauna is that of the Portland Beds. The abundance of

[1] H. Salfeld, 1914, loc. cit., pp. 158–9.

[2] H. Stille, 1905, 'Muschelkalkgerölle im Serpulit des nördlichen Teutoburger Waldes', *Zeitschr. deutsch. geol. Gesell.*, vol. lvii, p. 168.

[3] K. Andrée, 1908, *Neues Jahrb.*, Beilage Band, xxv, p. 389.

[4] W. Koert, 1898, loc. cit., p. 53.

[5] See above, p. 539.

[6] At la Rivière, south-west of Pontarlier, there is a gypsum works, where the Lower Purbeck gypsum is exploited as in the Weald and formerly in Durlston Bay. (Maillard, 1884, *Mém. Soc. pal. Suisse*, vol. xi, pp. 9–26 and map.)

[7] K. von Seebach, 1864, *Hannoversche Jura*, p. 59.

bitumen, also, it may be remembered, was one of the characters of the Portland Beds in the Kentish borings, where, especially at Brabourne, 'both the limestone and the muddy sandstone were strongly impregnated with bitumen, which had frequently exuded in brown pitchy drops and flakes along joints and other crevices'.[1]

When all things are considered, therefore, there seems good reason for supposing that, however imperfectly the Portland Beds and Upper Kimeridge Clay may be represented in Hanover (the latter perhaps cut out entirely by a major non-sequence represented in part by the very considerable ones below our two Midland Lydite Beds), the Purbeck and Wealden Beds are well developed, the Purbecks more than twice as thick and the Wealden not quite half as thick as in Southern England. So great a thickening of the Purbeck Beds would probably cause no surprise if the full sequence of marine equivalents in other parts of Europe were more properly understood. Dr. Spath, who has recently studied the question, states that 'recent researches indicate that there is room for a very long and important epoch between the Cretaceous and the Portlandian, an epoch for the widely-scattered marine equivalents of which the terms "Purbeckian" or "Aquilonian" seem inappropriate'.[2]

The reason for this long digression to inquire whether the North German Purbeck-Wealden sequence is homotaxial or contemporaneous with that of Southern England, although accumulated in a separate basin, will be evident: it provides us with a common factor for linking up the Wealden lake-deposits of Southern England with the marine Neocomian in Lincolnshire and Yorkshire. If the German Purbeck-Wealden can be correlated with the English, then at least the upper part of the Wealden Beds south of the London–Ardennes ridge is contemporaneous with the Spilsby Sandstone to the north of the ridge.

In view of this correlation a new interest attaches to the transgression of the attenuated upper part of the Wealden Beds as it approaches the London Palaeozoic rocks under the Weald of Kent, and again in the Boulonnais and in Belgium (where the famous Iguanodon deposits of Bernissart, near Mons, rest on a channelled surface of the older rocks). The same transgression of the upper part of the Wealden has been reported in Germany. The Weald Clay rests on Bajocian at Sehnde, near Hanover, and a boring at Borgloh-Ösede has been said to show it in contact with Sequanian; borings on the borders of Westphalia and Holland proved it again, much diminished in thickness, resting on Trias.[3] If these records have been rightly interpreted, the German Upper Wealden reaches out, as it were, to meet the Anglo-Franco-Belgian on the other side of the London–Ardennes ridge. Such a transgression on both sides of the ridge speaks eloquently in support of the palaeontological correlation with the Spilsby Sandstone and other basement-deposits of the highly transgressive Neocomian in Lincolnshire and Yorkshire. That some of the transgressive deposits are marine and others lacustrine is unimportant, since a general subsidence of the ridge would have the same

[1] G. W. Lamplugh, 1911, loc. cit., p. 43, and see other borings.

[2] L. F. Spath, 1923, *Q.J.G.S.*, vol. lxxix, p. 304. For the stage-name he uses Oppel's term Tithonian.

[3] De Lapparent, 1906, *Traité*, p. 1310, where references are given. See, however, K. Andrée, 1908, *Neues Jahrb. für Min. &c.*, Beilage Band, xxv, pp. 389–90, who throws doubt on some of these interpretations. He believes the marls with gypsum and anhydrite at Borgloh-Ösede, which Gagel called Weald Clay, to be the Munder Marls.

effect on both sides whether the water were fresh or salt; moreover the subsidence led, as we have seen, to a mingling of the fresh water and the sea in the neighbourhood of Hanover.

If this subsidence was not purely a local one affecting only the London–Ardennes ridge, then we begin to see some justification for De Lapparent's proposal to divide up the Wealden Beds so as to assign the Weald Clay to the Cretaceous and the Hastings Beds to the Jurassic.[1] But such a partition of a perfectly continuous series is a highly unnatural one, and all the arguments used against the separation of the Wealden from the Purbeck Beds apply again with equal force. Since the lack of fossils of any chronological value makes it impossible to determine which portions of the fully-developed sequence are represented in the attenuated and overstepping strata at the margins of the basin, no line could be drawn with any certainty in the Wealden Beds of the South of England. Salfeld has protested also against the attempt to draw any such line through the Hanoverian Wealden.[2] Further, it may be questioned whether any separation of the transgressive from the non-transgressive portions of the formation is justifiable on theoretical grounds; for the process of subsidence of the land was probably continuous and the overlap progressive throughout the life of the Wealden lakes. The accumulation of over 2,000 ft. of sediments proves the bed of the English lake to have sunk at least that amount during the Wealden period.

Once again we seem driven to look farther afield for relevant facts indicating where the dividing line between Jurassic and Cretaceous is to be drawn in the South of England. Comparison with Germany has shown us that our Wealden Beds are Neocomian, and therefore Cretaceous. It now remains to see what are the relations of the Neocomian formation, when fully developed in its marine facies, to the Purbeck or Portland Beds. For this we have to pass to the South of Europe.

In the Jura Mountains and the surrounding districts to the west and north-west, ammonite-bearing deposits, earlier than any found in the Neocomian of North-West Europe, and belonging to the Lower Infravalanginian, rest directly upon a thin but widespread representative of the freshwater Purbeck Beds. Locally they even inosculate with the upper portion of the Purbecks just as do the *Platylenticeras* deposits of the Lower Valanginian with the top of the Wealden in Germany.[3] So closely do the Purbeck Beds here resemble, in their lithic characters and their fauna, those of England, that the conclusion that they are at least homotaxial is unavoidable. Moreover, they rest upon apparently authentic Portland Beds (correlated by several authors with the Plattenkalk). Maillard, who monographed the freshwater fauna, concluded his résumé by stating emphatically 'the Purbeckian of the Jura, reduced to two subdivisions, corresponds exactly with the Purbeckian of Hanover as restricted to the Munder Marls and the Serpulite, and probably with the Lower and Middle Purbeckian of England. . . . There is no gap between the Purbeckian and the [Infra]valang[in]ian, which is the time-equivalent of the Wealden.'[4] In support of his conclusions he figured from the Jura a number of English and Hanoverian Purbeck fossils, including *Cypris purbeckensis* Forbes.

[1] De Lapparent, loc. cit., p. 1262.
[2] H. Salfeld, 1914, loc. cit., p. 161.
[3] G. Maillard, 1884, loc. cit., p. 136; stated to have been observed also by Benoît, Bertrand and Gilliéron.
[4] G. Maillard, 1884, p. 144.

Koert endorsed Maillard's statements after his careful study of the Purbeckian of the Selter in North-West Germany, and the table which he published, indicating the numerous species in common, leaves little doubt as to the equivalence of the Purbeck Beds in the three areas.[1]

In the Jura Mountains these beds are so insignificant in thickness that Maillard regarded them as merely a freshwater facies of the upper part of the Portland Stone, and this doubtless influenced Haug, who classed them in this text-book as a substage of the Portlandian.[2] The inosculation of the top of the Purbeck Beds with the base of the marine Neocomian then led to the fallacious conclusion that part of the Portlandian in some places might be contemporaneous with part of the Neocomian in others.

What really takes place is that the Purbeck Beds, when followed towards the Alps, pass laterally into marine strata, resembling and perfectly conformable with the Portland Beds—the Tithonian formation. As its name, derived from Greek mythology, implies,[3] this formation is not only conformable with, but also in some ways foreshadows the Cretaceous, although it is always classed with the Jurassic. Here in the deeper parts of Tethys we have, in fact, a continuous sequence of marine deposits linking the Jurassic System with the Cretaceous on the one hand and with the Triassic on the other. Here no earth-movements such as disturbed the shallower sea-bed of North-Western Europe were profound enough to cause great breaks in the sedimentation or to give rise to important unconformities. This is no region in which to establish convenient stratigraphical subdivisions or to set other than palaeontological boundaries to the formations.

The Tithonian is comparable (on a smaller scale) with the Tethyan Trias, in that both formations pass laterally over wide areas in North-Western Europe into freshwater and terrestrial formations. The continental episode represented by the Permo-Trias (or 'Epiric') formation marks one of the major interludes in the sedimentary history of North-Western Europe and is made use of to separate the Primary from the Secondary rocks.[4] The difficulties of correlating it with the marine strata and of deciding to which formation it should rightly be assigned are illustrated by the still lively controversy. The one point upon which all now seem agreed is that the Jurassic System should begin with the advance of the Rhætic sea from the shrunken Tethys across the desert plains and salt lakes of North Germany and Britain. This advance, which, as we have seen, reached to the North of Scotland, brought in a new era and with it we began this book. If we are to be consistent we must make use of the corresponding datum in choosing the base of the Cretaceous System. The succession in the Jura and the Rhone Basin in general shows us that the continental Purbeck episode, of which the lacustrine and terrestrial deposits extend from the borders of the Alps to North Germany and Central England, was brought to an end by the marine invasion of the Infravalanginian. This, and no other, should be the basal member of the Cretaceous.[5]

[1] W. Koert, 1898, loc. cit., pp. 52–3.
[2] E. Haug, 1911, *Traité de Géologie*, vol. ii, pp. 1075 et seq.
[3] Tithon was the spouse of Eos (Aurora), goddess of the dawn.
[4] See R. L. Sherlock, 'Correlation of the British Permo-Triassic Rocks', *P.G.A.*, 1926, vol. xxxvii, pp. 1–72, and 1928, vol. xxxix, pp. 49–94.
[5] For a convincing exposition of this principle of using widespread gaps in sedimentation

Complication arises from the fact that the Infravalanginian transgression did not affect the whole of the area covered by the Purbeck lakes and swamps. The regions where the Purbeck Beds were thickest—North Germany and Southern England—became isolated by land barriers, and, although they too were depressed at the same time as the sea found its way north of the London landmass and over the plains of Lincolnshire and Yorkshire, they did not sink beneath the sea but formed vast lakes. The lacustrine fauna of the Purbeck era there survived with but little modification, for it found itself in an environment differing little from that to which it was already adapted. The land, too, which supplied the flora washed into the Wealden lakes, was the same as that which surrounded the Purbeck swamps and lakes; and this in turn was nothing but an extension of the old Jurassic land-surface. Consequently the terrestrial fauna and flora still remained essentially Jurassic.

Thus we see that in the South of England (and in North Germany) we are in an abnormal area. We cannot judge of the events at the close of Jurassic and the dawn of Cretaceous times without travelling far afield, for we have none of the right kind of evidence, and the little that we have is misleading. Although palaeontologists and palaeobotanists affirm that the land and freshwater fauna and the flora of the Wealden Beds cannot be separated from those of the Purbecks, the Wealden Beds are contemporaneous with Cretaceous marine strata on the other side of the London landmass and in the Jura Mountains, while the Middle Purbeck incursion of marine animals proves that the Purbeck Beds were laid down at a time when the fauna in the neighbouring sea was still purely Jurassic.

Lacustrine mollusca are traditionally resistant to the forces of evolution, and their assemblages stable, while terrestrial faunas and floras also may be expected to survive unless wiped out by wholesale marine transgression or revolutionary changes of climate. If consideration of them, on their rare occurrences in the stratigraphical record, were allowed to outweigh the evidence of the normal marine succession, chaos would result. When Messrs. Topley and Jukes-Browne reported to the International Geological Congress in 1855 that 'the separation of Purbeck from Wealden is a mistake due only to the occurrence in Purbeck of one or two Oolitic forms of marine life, . . . is unnatural',[1] they were displaying an outlook anything but international. Further, they were disregarding the principles of correlation, for the 'one or two Oolitic forms of marine life' are worthy of more regard than all the rest of the fauna and flora together. No matter if Jurassic mammals and reptiles still peopled a Jurassic land-area, about lakes where an imprisoned assemblage of Jurassic fishes and freshwater mollusca still survived; once the Cretaceous sea with its teeming new population was already encroaching over the Continent, then Cretaceous times had begun. When Fitton and Webster, in the eighteen-twenties, united the Purbeck and Wealden series[2] they knew nothing of the marine provinces beyond our own islands, and more than twenty years were still to elapse before the discovery by Forbes of the few precious marine species in the Middle Purbecks.

over continental areas as guiding lines in stratigraphical classification see C. Diener, 1925, *Grundzüge der Biostratigraphie*, pp. 160–1.

[1] *Compte Rendu, Congrès géol. int.*, 3me Session, Berlin, 1885, p. 453.

[2] T. Webster, 1826, *Trans. Geol. Soc.* [2], vol. ii, p. 44; W. H. Fitton, 1827, ibid., vol. iv, pp. 105, 159.

The conclusion, therefore, seems to be that, since the *relatively* sudden change of sedimentation at the commencement of the Wealden Series may be due to the same earth movements as those which elsewhere caused the Neocomian transgression to begin, however unsatisfactory it may be in the abnormal Southern English area, it is the only available datum-line at which to draw the important boundary between the Jurassic and Cretaceous Systems.

PART IV

CHAPTER XVIII

PALAEOGEOGRAPHICAL CONCLUSIONS

HAVING now reviewed briefly the principal geological data, we are better qualified to approach the most fascinating but at the same time the most dangerous part of our subject, the palaeogeography. This entails leaving the comfortable society of ascertained facts and venturing into the alluring but treacherous realms of deduction, inference and speculation. It is to the guiding of such speculations, however, that the data set forth in the stratigraphical part of this book are directed, and to leave the mass of facts as they stand would be to abandon them as meaningless. As Prof. Watts has said: 'It is to the elucidation of Earth History that all branches of geology are contributory, and from a knowledge and interpretation of the details of this history that the applications of geology proceed. . . . We must be accurate in our geological facts; but we may, as Darwin advised us, speculate freely.'[1]

To do justice to the palaeogeography of the Jurassic period would require a second volume almost as large as this; for the subject is no longer a mere constructing of palaeogeographical maps, but a full-blown science, containing within it many -ologies. If we were to pursue it thoroughly, we should have to proceed systematically from the points of view of palaeorography, palaeohydrography, palaeoceanography, palaeobiogeography, palaeoclimatology, palaeoastronomy, and many others.[2] No such attempt is possible here, at the end of a single volume already swollen beyond its intended dimensions; and consequently the following brief remarks may appear superficial. But it should be observed that certain fundamental aspects of palaeogeography have already been dealt with at greater length in Part II. We have already pictured the trough sea that stretched across the British area between the western and the eastern landmasses, from Kent and Dorset north-eastward to Yorkshire and north-westward by way of Shropshire, the Irish Sea and Antrim to the Hebrides; and we have examined the stages by which the bed of the sea sank progressively deeper, keeping pace with the accumulation of sediment. Now it remains to review briefly certain other matters upon which light is shed by the stratigraphy: (1) the distribution of the more important marine organisms, which give some indication of the conditions of life in the seas—especially the depth (this comes under 'palaeobiogeography' or 'palaeoecology'); and (2) the probable extent of the Jurassic seas over regions where no trace of sediments is to be found; the height of the surrounding land; and the connexions between the British seas and those on the Continent or elsewhere (palaeogeography proper, or 'palaeocartography').

I. SOME ASPECTS OF PALAEOECOLOGY

(a) The Distribution of Corals

The reef-building corals are probably the most important of all marine organisms for the palaeogeographer. At the present day, although there is an

[1] W. W. Watts, 1911, Address to the Geological Society, *Q.J.G.S.*, vol. lxvii, p. lxiii.
[2] E. Dacqué, 1915, *Grundlagen und Methoden der Paläogeographie*, pp. 1–499.

almost boundless diversity of types and forms, they all live under the same conditions, within definite limits of depth, temperature, salinity and clarity of water; it is therefore reasonable to infer that where reef-building corals flourished in the past, similar conditions obtained. Since sheets of coral are intercalated at a number of horizons in the Jurassic System in various parts of the country, we are provided with a number of valuable (because definite) controls. We may not postulate abysmal depths for the deposition of sediments in which any coral growth took place. Further, it is improbable that there was a great depth of water during the formation of any part of a series in which coralline intercalations are so frequent as in the English Jurassic; otherwise we have to imagine an unlikely degree of activity of the sea-bed, alternately rising and sinking through prodigious distances, every time the bottom was brought within the necessary reach of the surface to enable coral growth to become established. Moreover, since thin and irregular sheets of coral sometimes completely overspread the troughs of deposition from side to side, we know that at those times the depth of water *even in the centres of the troughs* cannot have exceeded 120–50 ft. (see p. 53).

It is difficult to classify the Jurassic coral sheets or to find analogues in modern seas. They are neither barrier reefs nor atolls, for they seldom exceed 20 ft. in thickness, and no suggestion of atoll shape has been detected. On the other hand, although many of them evidently grew far from any shore, and so are hardly comparable with the best known and most typical fringing reefs (such as those along the steeply-shelving coasts of oceanic islands or the Red Sea), it would seem that they may be grouped with Fringing Reefs as understood in Darwin's classification; for the width of a fringing reef, as Darwin pointed out, depends entirely on the degree of inclination of the submarine slope, combined with the fact that the corals cannot grow below a certain depth. Thus when the sea is very shallow and the coast gently-shelving, there is nothing to prevent the fringing reefs spreading almost indefinitely. Then, as Darwin found in the shallows of the Persian Gulf and the East Indian Archipelago, 'the reefs lose their fringing character and appear as separate and irregularly scattered patches, often of considerable area' (see p. 394).

It is noteworthy that the only two localities where uninterrupted coral rock exceeding 20 ft. in thickness is known are at North Grimston (p. 423) and in Kent (especially in the borings at Brabourne and Dover; p. 438). North Grimston lies on the southern margin of the Yorkshire Basin, against the flank of the relatively-stable (non-subsiding) axis of Market Weighton; the Kent localities are on the margin of the Wealden trough, close to the flank of the London landmass. As these are the only truly fringing (marginal) reefs known, the idea suggests itself that the prevailing thinness of the coral sheets elsewhere may be due to frequent periodic subsidences having interrupted their growth, perhaps carrying them below the 150 ft. limit, or admitting muddy or sandy currents, before they had time to attain any greater thickness; and that it was only at the margins of the troughs and near the stable axes that coral growth was able to keep pace with subsidence. The borings through the Corallian rocks in Kent lead to the surmise that if the marginal Inferior Oolite deposits in the west had been preserved, between the Cotswold escarpment and the Welsh mainland, the thin and scattered bands of coral in the Cotswolds would have been found to join up as they were traced westward over the Vale of Gloucester and the Vale of Berkeley, until they passed into thick fringing reefs along the Palaeozoic land margin. There is, indeed, evidence of a thickening of the existing coral bands in this direction.

The history of coral growth in the British Jurassic seas is interesting. Very rarely, isolated fragments of [illegible] met with in the Rhætic Beds (e.g. p. 108), and scattered examples and seams, chiefly of *Montlivaltia*, occur in many places in the Lower Lias—even commonly enough to form an ornamental stone in one place in the *davœi* zone (Banbury Marble, p. 134)—but in general the Liassic sea was too muddy for coral growth to flourish. In two widely separated localities, however, in the neighbourhood of the Cowbridge Island, Glamorgan, and in Skye, corals became well established in early Lower Lias times (pp. 127, 146). Here there was apparently unusually clear water. It is possible, too, that the building of calcareous structures was facilitated in the neighbourhood of the Mendip Archipelago by the solution of the Carboniferous Limestone of which the islands were composed, and in Skye by th[illegible]ing outcrops of Durness Limestone. T[illegible]e coral fauna of [illegible]e Sutton Stone in Glamorgan is a rich one, but the area over which it occurs is small.

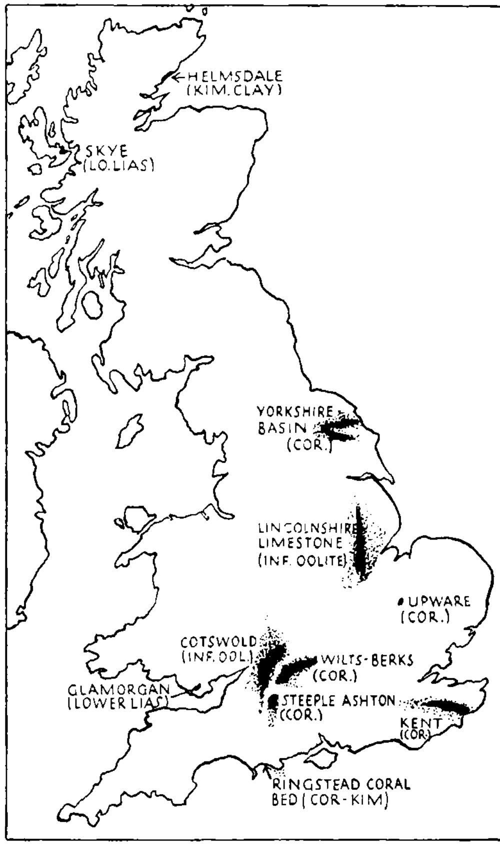

FIG. 92. Map showing the distribution of Jurassic coral reefs in Britain. Existing fossil coral reefs black; extensions for which there is more or less indirect or strong presumptive evidence dotted.

It was not until the Inferior Oolite period that coral growth covered large areas in England. It then became the most characteristic feature of the Cotswold and the Lincolnshire Limestone provinces. Although, as just mentioned, most of the Inferior Oolite reefs, of which so much of the Cotswold Hills are the detritus, probably lay in the main west of the present outcrop and were destroyed by the excavation of the Severn Valley, some true coral reefs remain. The earliest and perhaps the best-developed (15–20 ft. thick) is found between the Pea Grit and the Lower Freestone (*murchisonæ* zone) in the neighbourhood of Stroud, where the Oolite escarpment draws close to the Palaeozoic tract; and thence it can be traced for some miles along the escarpment, as far as Crickley Hill, Coberley and Cowley, but it dies out towards the north-east.[1] In the same district a Middle Coral Bed appears in the Oolite Marl (*bradfordensis* zone), and this can be traced to Leckhampton Hill;[2] but neither this nor the last extends south of the South Cotswolds, the region of the Mendips and the rest of Somerset and Dorset being a non-coralline province. Finally, in Upper Inferior Oolite times a new sheet of corals appears all along the South Cotswolds, comprising the same species as the two earlier reefs, but spreading over a wider area (p. 240). This, the Upper Coral Bed (*truellei* zone), for the first time encroaches on part of the previously non-coralline province to the south, for it continues through the Bath district and on to Dundry Hill, and corals were rolled round the east end of and beyond the Mendips, being found as far away as Bruton (p. 237).

In the eastern counties patches and straggling sheets of coral were formed all over the basin of deposition of the Lincolnshire Limestone, probably at several different dates or more or less continuously in different places (p. 210), but the stratigraphy of this district still remains to be worked out. It may be presumed that the two basins of Lincolnshire and the Cotswolds were in open communication north of the present outcrop, divided only by a belt of shallows over the Vale of Moreton Axis (p. 67).

In the Great Oolite period conditions in the Cotswolds–Lincolnshire province were similar to those of Lower Inferior Oolite times, at least during the deposition of the White Limestone and (in the Cotswolds) earlier. Corals are abundant in the White Limestone from the neighbourhood of Bath to mid-Lincolnshire; but there is nothing entitled to be called a reef, the coral beds rarely exceeding 2 or 3 ft. in thickness. There is no doubt, however, that the corals in these beds are often in the positions where they grew, for the beds are lenticular in shape and contain perfectly-preserved specimens of delicate branching varieties, standing erect. The coralline province was then coextensive with the area where the Great Oolite limestones were forming. In the Mendip district and farther south, as in Lower Inferior Oolite times, there were no corals; while north of the Market Weighton Axis, as before, deltaic conditions held sway. The species in the Great Oolite are for the most part new, but perhaps 10 per cent. are survivals from the Inferior Oolite. Although the coral beds are so thin, some of them can be traced intermittently over considerable areas on the same horizons, and, since there are a number of horizons, the Great Oolite limestones are on the average probably as richly coralliferous as those of the Inferior Oolite. Coral growth seems to have been extinguished by the disturbed conditions with strong currents which gave rise to the Forest Marble, when this facies, which may be regarded as a modified extension of the deltaic ('estuarine') type of Yorkshire and Scotland, spread south over both coralline and non-coralline provinces alike.

The next burst of coral growth was in the Corallian period. It was the greatest of all, and all the species were new. After the general shallowing and clarifying of the sea which heralded the second phase of the Oxford Clay cycle and is attested by the piling up of the Lower Calcareous Grit sandbanks, coral growth sprang up in widely separated parts of England. The earliest reef appeared in the Hackness Hills on the north side of the Yorkshire Basin (Hambleton Oolite Series) (p. 429). South of the Market Weighton Axis, the

[1] T. Wright, 1868, 'On Coral Reefs, Present and Past,' *Proc. Cots. N.F.C.*, vol. iv, p. 149.
[2] Ibid., p. 151.

earliest reefs preserved are in the lower part of the Berkshire Oolite Series in Wiltshire. They consist of small patches of true reef-coral, which were soon smothered by deposits of Nothe (or Highworth) Clay and Bencliff (or Highworth) Grit (p. 400 and fig. 69). The main burst of coral growth in this part of England came later, in the Osmington Oolite period, when more or less continuous reefs stretched for forty miles from the neighbourhood of Oxford to Calne, in Wiltshire (fig. 66) and again over a large area in Kent, where they probably continued into the succeeding period. At the same time an isolated reef appeared at Upware near Cambridge; but south of Calne, in Dorset, and in most parts of Yorkshire, oolites were deposited at this time.

Towards the end of the Osmington Oolite period, and in the succeeding Glos Oolite period, coral growth attained its maximum in Yorkshire and at Upware, while in Wiltshire it extended southward to Steeple Ashton, and coral debris even reached North Dorset (p. 388). At all of these places the reefs and coral debris overlie the main mass of the Osmington Oolite, into which those of the Oxford-Calne area pass laterally.

With the incoming of the Sandsfoot Clay (and in Yorkshire the Grimston Cementstone) at the beginning of the next cycle (p. 54) coral growth in England was almost extinguished for good, although on the Continent it continued through the Kimeridgian period. The thin Ringstead Coral Bed, at the top of the Upper Calcareous Grit, testifies to a recrudescence of coral growth somewhere in the vicinity, either off the Purbeck coast or under the Chalk Downs; but the exact location of the reef, if one existed, is unknown (p. 379). Still later, in Sutherland, considerable masses of reef-building coral grew in the peculiar conditions prevailing there during the time of the Lower Kimeridge Clay (*Aulacostephanus* zones) (p. 476).

The Portland Beds contain thin bands of corals in one or two localities, but usually they are wholly absent, and there is no sign of anything like true reef-formation having occurred at this period in any part of Britain.

One of the most important and suggestive aspects of coral reefs is their influence upon the rest of the fauna.

It has been shown how, in the only reefs that have been studied from this point of view—those in the Corallian Beds—a small assemblage of mollusca, comprising certain lamellibranchs and gastropods, not closely related to one another, are always found in association with the corals and seldom if ever away from them (p. 397). More important than this, however, are the much larger assemblages of mollusca which appear to have found the proximity of coral reefs uncongenial, since they have been shown to be seldom found in any quantity in association with them. Among the lamellibranchia this mutual exclusiveness between the coral-dwelling and other forms is especially noticeable in the genera *Trigonia*, *Lima*, *Gervillia*, *Isognomon*, *Pinna*, &c., of which the large and fragile species occur in great profusion in shell-banks in the non-coralline area, but are only found occasionally (and then usually in fragments) among the corals. There may or may not be a causal connexion, but it is evident that these large and brittle lamellibranchs are mechanically unsuited to a coral habitat, where they would have to withstand the pounding of surf and strong currents. The same applies still more forcibly to the floating ammonites, whose shells would be doomed to destruction if they wandered or were driven by winds or currents too close to the reefs. It is, therefore, interesting to notice that ammonites are not only scarcely ever found actually among the reefs, but that they are always rare in coralline provinces. This mutual exclusiveness on the part of ammonites and corals has hitherto been little appreciated; but the fact that either the conditions which favoured coral growth were unfavourable to ammonites, or else that the conditions produced in the vicinity of coral reefs provided an unfavourable habitat, explains many of the anomalies in the distribution of ammonites upon which altogether different constructions have been put.

(b) The Distribution of Ammonites

Buckman drew attention to the fact that in certain formations ammonites are abundant all over the British area, from Dorset to the North of Scotland; but that in other formations, notably the Oolites, they abound and are well preserved only in certain districts, while in other districts only a few miles away they may be unaccountably scarce. Moreover, he pointed out that in the districts in which ammonites are scarce, such few specimens as are found are more or less broken or worn and frequently have *Serpulæ* or oysters attached; in fact they bear signs of having been drifted into their present positions after death.[1] The abundant and well-preserved ammonites he called autochthonous,[2] or autochthones, as distinct from those which give evidence of having been drifted away from some district where they were autochthonous.

The changing history of ammonite distribution may be summarized as follows (the Ages and their equivalents are shown in Table IV, p. 24):

Ages.	*Ammonite Distribution.*[3]
Pre-Psiloceratan	During the deposition of the Rhætic and Pre-*planorbis* Beds ammonites seem to have been completely excluded from the British area.
Psiloceratan-Canavarinan	Autochthonous ammonites all over Britain.
Ludwigian-Sonninian	Autochthonous ammonites abundant in the Dorset–Somerset area, including Dundry Hill (north of the Mendip Axis), and also in the Hebrides; drifted in the Cotswolds and Lincs. areas; none in Yorkshire.
Stepheoceratan	As before, but in addition ammonites spread over the Yorkshire Basin (Scarborough Limestone).
Parkinsonian	Ammonites still common in the Hebrides and in Dorset, but retreated from Yorkshire, and from Somerset, as far south as the Yeovil–Sherborne district.
Zigzagiceratan and Tulitan	Ammonites common in the Normandy–Dorset–Somerset area; north of this, in the Cotswolds and Lincs. areas, rare and mostly drifted. None in the Hebrides or Yorkshire.
Early Clydoniceratan	Ammonites retreat altogether from the British area, while deposits somewhat similar to the 'estuarines', previously confined to the North, spread all over England (Forest Marble).

[1] S. S. Buckman, 1922, *T.A.*, vol. iv, pp. 19–20.
[2] *Oxford Dict.*: 'sprung from that land itself'; i.e. aboriginal.
[3] Compare a table by Buckman, 1922, loc. cit., p. 19, drawn up, however, to illustrate a

Ages.	*Ammonite Distribution.*
Late Clydoniceratan	Autochthonous ammonites again abundant, in the Lower Cornbrash, from Normandy as far north as the Market Weighton Axis; north of this, deltaic conditions or no deposition at all.
Macrocephalitan–Early Perisphinctean	Autochthonous ammonites all over Britain.
Late Perisphinctean	Autochthonous ammonites retreat from all parts of England with the general spread of coral reefs (Osmington and Glos Oolite Series); strata not exposed in Scotland.
Ringsteadian (or Prionodoceratan ?)–Gigantitan	Autochthonous ammonites all over Britain (except when the sea retreated from the North in Portlandian times).
Post-Gigantitan	During the Purbeck and Wealden periods ammonites appear to have been once more completely excluded from the British area.

Buckman explained these facts by postulating movements along axes of uplift, which he supposed cut off certain areas from free communication with the open ocean. Thus, to account for the abundance of autochthonous ammonites in the Dorset and Somerset area and on Dundry Hill in the Lower Inferior Oolite, and their absence from the Cotswolds, he wrote: 'The Mendip axis divided in the main, but it was breached between Somerset and South Wales, so that Dundry had autochthones like Dorset. Dundry was cut off from the non-autochthonous area of the Cotswolds by an elevation of the Malvern Axis.' Then, to account for the retreat of ammonites towards the south in the Upper Inferior Oolite period, he supposed 'the North Devon Axis divided'.[1]

This explanation led Buckman to some very extraordinary palaeogeographical restorations. Having assumed that communication between the Dorset-Somerset area and the Cotswolds was severed, he was faced with finding some other connexion between the southern area and the Hebrides, where the same ammonites swarmed as in Dorset and Somerset; and he provided it by means of a connecting channel round the west of Ireland.[2] On this view, which is opposed to all previous palaeogeographical restorations, Ireland, Wales, Lyonesse and Brittany were an island, which Buckman named Juroceltia. Both to the north-west and to the south of it (in the Paris Basin) were supposed to be freely-communicating reservoirs of autochthonous ammonites, from which the seas over England were supplied; and Buckman considered that during the time when the Mendip and Malvern Axes were supposed to have prevented communication across England, the drifted specimens in the Cotswolds and Midlands came from the northern reservoir, via the Hebrides.

A further difficulty was the presence of relatively numerous and well-preserved ammonites in the Yorkshire Basin in the Stepheoceratan Age (during the deposition of the Scarborough Limestone). To account for this

tectonic theory; the present table contains many amplifications and emendations and the tectonic bias is eliminated.

[1] S. S. Buckman, 1922, loc. cit., p. 19.

[2] 1922, loc. cit., p. 19; and 1923, map, p. 52.

another sea had to be postulated to the north-east, for in Buckman's view communication with the south and west was severed at that time by the Market Weighton Axis.[1]

To say the least of these palaeogeographical restorations, they seem extremely far-fetched. The Mendip and Malvern Axes, as was shown in Chapter III of this book, were probably regions of shallows and interrupted deposition and they certainly marked off two well-defined areas—a coralline and a non-coralline province—but there is nothing to warrant the supposition that throughout their whole length they stood above water, interrupting communication completely. There seems no reason to suppose that ammonites could not have floated from south to north across parts of the axes visible at the present outcrop, and concerning the much wider belt to eastward, hidden under the later rocks, there is almost no evidence at all. Deep borings farther east might reveal Inferior Oolite transitional between the two types—in fact the Westbury boring of 1921 yielded fragments of ammonites which Buckman himself identified as probably belonging to the *murchisonæ* zone (p. 200). But even if no such rocks were found, this would be no proof of interrupted communications; for over the axis region there was probably little deposition and there were certainly frequent erosions. It would be as legitimate to base a similar assertion on the absence of connecting deposits between the Cole Syncline and the Sherborne District.

Buckman's theory takes no account of the facts that of the lamellibranchs, gastropods, brachiopods and echinoderms of the Cotswolds, while a number of species are not found in the Dorset and Somerset province (and on these emphasis has been laid), yet a much larger number are common to the two provinces; and that they constitute an incomparably richer fauna than is found in the Hebrides. For these animals, migration via the Hebrides seems out of the question.

If the rest of the fauna was able to migrate across the axes of uplift, we cannot suppose that the ammonites were unable to do so. The only conclusion seems to be that the ammonites were able to enter the Cotswold province from the south, and did so, *but that they did not colonize it because it was an uncongenial or unsuitable habitat.*

A few that did enter died and were entombed in the rapidly-accumulating coral debris of the Cotswold basin; some floated in *discites* times as far as Lincoln, there to become interred in the Silver Bed; but the majority of those that crossed the axis passed on until they reached Western Scotland. There they found a favourable environment similar to that in the Dorset–Somerset area, and in it they settled and became truly autochthonous. The fact that the epiboles and faunizones succeed one another in the Hebrides almost exactly as in Dorset proves that migration was continuous, and moreover that, as Buckman frequently taught, the time taken to perform such a journey was negligible in relation to species-duration. Since the rare and non-autochthonous individuals in the Cotswolds compose an identical, though incomplete and not easily recognized, zonal succession, it seems reasonable to regard them as the chance casualties in a non-favourable area, through which the species migrated without staying to colonize it.

In Yorkshire, throughout most of Lower Oolite times, deltaic deposits were

[1] S. S. Buckman, 1923, loc. cit., p. 52.

accumulating and all forms of marine life, including ammonites, were absent. On several occasions, however (pp. 217–22), the deltaic type of deposition was temporarily arrested and a marine fauna entered the district, and on the last of these occasions—during the Stepheoceratan Age—ammonites tarried in fair numbers, their shells becoming embedded in the Scarborough Limestone.

In the Cotswold and Lincolnshire provinces it was not deltaic conditions that produced an inimical or unsuitable environment and prevented colonization by ammonites: it was either the concomitants of coral reefs—the heavy breakers and strong currents—or else something about the peculiar conditions that favoured the growth of coral reefs, but that was repellent to ammonites.

In the Upper Inferior Oolite period (Parkinsonian Age), Buckman notes, autochthonous ammonites retreated south from Dundry and most of Somerset, at the time when the Mendip Axis and the associated shallows to the north (the Malvern Axis?) became submerged. Buckman now shifts the role of barrier on to the North Devon Axis; it was this, he says, that in the Parkinsonian Age confined ammonites to the Sherborne and Yeovil district and the area to the south (as quoted above, p. 563). But if the Mendip and Malvern Axes previously prevented ammonites from advancing northward into the Cotswolds, as Buckman maintained, why should the breakdown of those axes cause the ammonites to retreat still farther to the south? With the removal of the barrier, if there were no other impediment, they might be expected to advance northward. Since they did not, Buckman can only have wished us to suppose that the North Devon Axis rose above water before the Mendips sank, so that the advance of the main body of autochthones was cut off before the northern barrier was removed, and then those that had been isolated between the two barriers were starved or otherwise extinguished before the Mendips sank.

This elaborate explanation (which Buckman did not put forward, but which seems to be necessarily implicit in his hypothesis) does not survive examination of the stratigraphy of the North Devon Axis. From the careful work of Richardson it is apparent that the Upper Inferior Oolite passes across the axis without interruption (p. 236), and the North Devon Axis therefore offered no resistance to the free passage of ammonites during the Parkinsonian Age.

Rather it would seem that some force, liberated by the further subsidence of the Mendip and Malvern Axes, repelled the ammonites southward at the very time when, on Buckman's hypothesis, they should have been free to spread northward. It can hardly be mere coincidence that the retreat of the ammonites corresponds both in time and in place with the southerly advance of corals from the Cotswold province. The spread of the coralline type of deposition was in turn probably conditioned by the subsidence of the Mendip Axis, which had previously been effective in separating two different basins of deposition, but it was only in this indirect manner that the axis influenced the ammonites. There is a very great difference between a barrier rising above water without a break, in such a way as to bar the passage of floating and swimming cephalopods (such as Buckman visualized), and a belt of shallows and strong currents, offering no bar to migration, but nevertheless sufficient to provide a boundary between two basins which, for some other reason, were

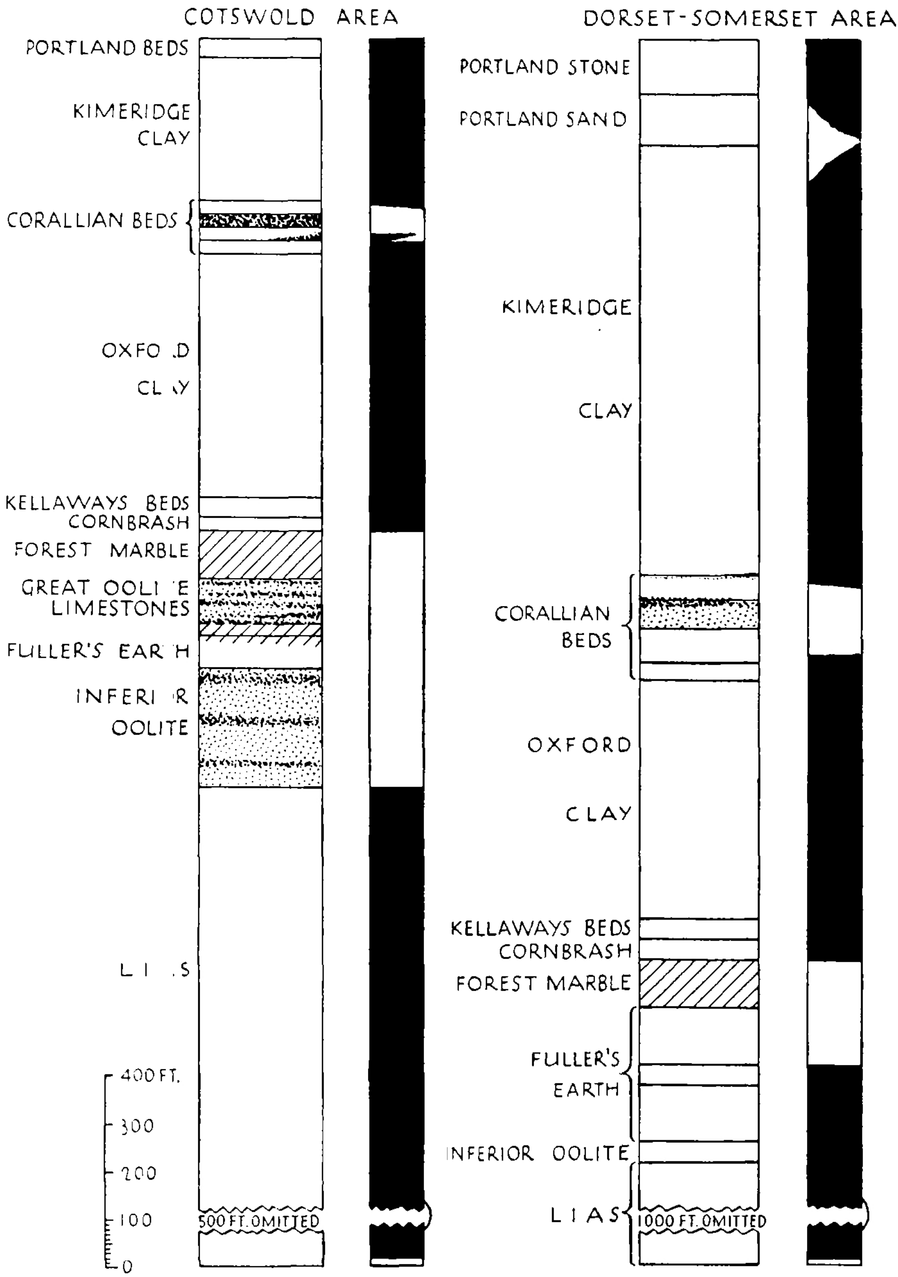

FIG. 93. Columns showing the relation between coralline deposits and autochthonous ammonites. In left column in each area, dotted = coralline deposits (coralline oolites and detrital limestones, &c.); thick dots = coral-beds; cross-hatched = 'Forest Marble' facies. In right columns, black denotes autochthonous ammonites.

characterized by different types of sedimentation and different environmental conditions.

Whenever we come to compare the distribution of ammonites and coral reefs the interdependence of the two is striking (fig. 93). Where the deltaic (or what is generally known as estuarine) type of deposition prevailed, neither corals nor ammonites existed; but in the districts where other types of deposit were being formed, either ammonites were autochthonous or corals, but never both. Moreover, at the phase of maximum growth of coral reefs (the Osmington–early Glos Oolite periods), when almost the whole of England was covered by coral seas, autochthonous ammonites disappeared altogether, their scattered shells being only very rarely found even in the areas where oolite or debris was accumulating although no actual coral growth was taking place (e.g. in South Dorset). The presence of even a few drifted ammonites or fragments of ammonites in such deposits, however, precludes their being placed in the same category as the Rhætic and Purbeck Beds, which were apparently formed in water definitely cut off by land barriers from all connexion with seas inhabited by ammonites, since no trace whatever of cephalopods is to be found in them.

It is just possible that there may be some more subtle reason why corals and ammonites should not have flourished in the same waters—perhaps connected with the food-supply of the adult ammonites or their free-swimming larvae. But since ammonites are extinct, this will always remain a matter of surmise.

II. PALAEOCARTOGRAPHY

Whether the resulting conclusions be accepted or rejected, the foregoing remarks will at least have served to illustrate the necessity for ecological studies as a prelude to attempting palaeocartographical reconstructions. Unhampered by the awkward land-barriers or isthmuses which Buckman thought it necessary to erect, we may more readily tackle the wider problems: the outer boundaries of the Jurassic seas, where they abutted on the ancient landmasses, and where they were connected with the continental seas and the Tethys. We now enter more deeply into the realms of surmise than at any previous stage of this book.

(a) The General Boundaries of the British Troughs in the West and North

All (with the exception of Buckman) who have attempted to construct palaeogeographical maps of the British region in Mesozoic times have agreed in one respect, namely, in the existence of a vast landmass, North Atlantis, to the west of these islands, over the site of the present Atlantic. Of this landmass the last relics are supposed to be the mountains of Wales and the West of Ireland, the peninsulas of Devon and Cornwall and Brittany, and perhaps the Outer Hebrides. The rest has foundered in the bed of the Atlantic or been eaten away by the waves.

How wide the landmass is likely to have been we do not know; but for all we can tell it may have been continuous with the Mesozoic continent which Canadian and United States geologists are accustomed to picture as they look eastward over the eastern part of North America and the Western

Atlantic—their Jurolaurentia.[1] Further speculations will be idle until the Wegener hypothesis that the continents have drifted apart has been either proved or disproved. Of more immediate concern is the extent to which the Jurassic seas overspread North Atlantis from the east, and upon this question many views have been expressed, supported by many different classes of argument. The relevant facts are briefly as follows:

At the present time three tongues of Jurassic rocks extend more or less intermittently westward into the Palaeozoic region and separate the ancient highlands of Brittany, Devon and Cornwall, Wales, and Scotland (see fig. 2, p. 38):

(i) The most southerly tongue occupies the site of the English Channel; the evidence for it being the dredging up of fragments of Liassic limestone 30–34 miles south-east and 45 miles south-south-east of the Lizard,[2] and of *Psiloceras planorbis* or an allied species 30 miles south of the Eddystone Lighthouse (above, p. 121).

(ii) The second coincides with the Bristol Channel: it is denoted by the westerly extensions of the Lower Lias and Rhætic Beds in South Glamorgan and near Minehead, and these unquestionably extended at one time still farther. That there has been Lower Lias in the vicinity of the Gower peninsula seems to be indicated by the presence of oysters allied to *O. irregularis* in stalactites in the Carboniferous Limestone at Mumbles near Swansea.[3]

(iii) The northern tongue, by far the most important of all, is denoted by the Liassic outliers at Prees in Shropshire (p. 135) and near Carlisle (p. 142), by the Lias and Rhætic Beds preserved beneath the basalt plateau of Antrim (pp. 112, 142), and in the Tertiary volcano of Arran (p. 115), and by the disconnected but important relics of Jurassic rocks in the Inner Hebrides (ranging in age, as we have seen, from Rhætic to Kimeridgian). A further outlier connecting the Shropshire and the Antrim areas is believed, from indirect evidence, to exist upon the floor of the Irish Sea, where Mr. E. Greenly maps an elliptical area of Jurassic rocks covered by Chalk, as shown in fig. 2 (p. 38). The evidence for this is the presence of pieces of a crumbly ferruginous oolite like that in the *jurensis* and *opalinum* zones and of 'Jurassic-looking boulders, chiefly of calcareous shale' in the Drift on the east side of Anglesey, associated with numerous Chalk flints, all of which seem to have come from the bed of the Irish Sea to the north-east.[4] Liassic boulders containing fossils have also been found in the Drift on the adjoining north coast of the mainland, at Penmaenmawr, Carnarvonshire.[5]

Upon the intervening projections of Palaeozoic rocks, the supposed salients of Atlantis, there are no traces of Mesozoic sediments, but there are conspicuous elevated peneplains at various levels and of uncertain dates.

The crux of the matter is to decide how far the present arrangement of the Jurassic rocks is original: whether they were laid down as they are found, in low-lying troughs separated by projecting masses of highland, or whether they owe their preservation in those areas to subsequent depression, while

[1] See a series of palaeogeographical maps of N. America by C. H. Crickmay, 1931, 'Jurassic History of North America', *Proc. Amer. Phil. Soc.*, vol. lxx, pp. 80–93.

[2] A. J. Jukes-Browne, 1911, *Building of the British Isles*, 3rd ed., p. 260.

[3] A. E. Trueman, 1922, *P.G.A.*, vol. xxxiii, p. 278.

[4] E. Greenly, 1919, 'Geol. Anglesey', vol. ii, pp. 777–8, *Mem. Geol. Surv.*

[5] *Summ. Prog. Geol. Surv.* for 1931, p. 38.

erosion has caused the removal of the rest of the strata in the intervening areas. Upon this question opinion has always been divided; but it is now becoming increasingly probable that neither view is altogether right: that some of the high Palaeozoic tracts were submerged and some were not, and that often they formed shallows—areas of retarded deposition alternating with contemporaneous erosion—rather than dry land. The two schools of thought are exemplified by Jukes-Browne and Judd, whose conflicting views we will have occasion to examine in the following pages.

(b) The Boundaries of the Jurassic Sea in Wales and the Bristol Channel

It was a favourite line of reasoning with Jukes-Browne that, although the Jurassic formations, if produced, would in places pass over tracts occupied by Palaeozoic rocks, the present relief of those tracts is only due to Tertiary and Quaternary denudation; therefore that they probably stood a great deal higher in Jurassic times, and the Jurassic sea would not have been able to cover them. The complementary inference, that if Tertiary and Quaternary denudation has been so potent, it has probably destroyed Jurassic rocks that may formerly have existed over those self-same areas, received scant consideration.

Thus Jukes-Browne wrote:

'This [1,010 ft.] is about the height of the escarpment [on the east side of the Forest of Dean] at the present day, and as it must have been very much higher in Jurassic times, the sea of the Upper Lias is not likely to have passed over the Forest of Dean.'[1] Again: 'We may assume that during the formation of the Lias the coast-line ran from the eastern border of Dean Forest to Malvern, the gaps which now intervene between the higher elevations being due to post-Jurassic erosion. Thence it probably trended north-westward through Shropshire and Denbighshire, and across the Irish Sea to the west coast of Ireland. . . . From Ireland the sea extended over the site of the western Scottish [Keuper] lake, and thence probably up the Great Glen to the north-eastern basin.'[2]

For this conservative view there is much to be said, and the distribution of land and water outlined by Jukes-Browne in the latter of these passages has been generally adopted in text-books and is implicitly accepted by most research workers in Jurassic stratigraphy. The great stumbling-block to the acceptance of the Malvern and Abberley Hills as the actual shore-line, however, has always been the Malvern Fault. This everywhere forms the western boundary of the Trias, which it throws down against the Palaeozoic and Archaean rocks of Wales. It is hinged in such a way that, although the throw is only perhaps 100 ft. near Newnham in the south, it increases to a maximum of 1,000 ft. near Malvern. It seems to be entirely post-Triassic, for the Trias adjoining it is of the thickness normal for the district and appears not to be banked up against it; moreover there seems to be no marginal change of facies. From these facts it is inferred that the Trias 'must have formerly extended well over the site of the Malvern and Abberley Hills on to the area of the Old Red Sandstone'.[3] How far the Trias may have extended no one has ventured to calculate; and the question has no certain bearing on the former extension of the Jurassic formations, since movement may have

[1] A. J. Jukes-Browne, 1911, loc. cit., p. 265. [2] Ibid., p. 266.
[3] T. Groom, 1910, *Geol. in the Field*, pp. 717 and 726.

begun along the fault immediately after the end of Triassic times. As we have seen, the Rhætic Beds of the Berrow Hill outlier and the western side of the Worcestershire outcrop, as well as the Inferior Oolite of the Cotswolds, show signs of a shore-line at no great distance (p. 108). It would not be surprising if the fault were a marginal fracture caused by unequal subsidence of the Jurassic trough, for it adjoins the deepest part of the trough, where the Lias and the Lower Oolites attain thicknesses far exceeding any developed in other parts of the South of England.

A reasoned attempt to ascertain to what extent the Mesozoic rocks, especially the Trias, may have encroached upon the Palaeozoic tract of Wales was made by Prof. O. T. Jones in 1930, in the course of a suggestive study of the Bristol Channel region.[1] His most important innovation is an endeavour to trace Tertiary folding from the Mesozoic region on the east into the Palaeozoic tract of the west, and he comes to some novel conclusions. He believes that Central and North Wales have been uplifted by a broad anticlinal axis extending east and west, probably a prolongation of that which gave rise to the major deflexion of the Chalk outcrop and strike in Fenland. Similarly, he considers the high elevation of Exmoor to be due, not so much to the superior hardness of the rocks of which it is composed, as to its being on the axis of uplift between the syncline of Central Devon and another centred along the Bristol Channel. The Bristol Channel he considers to be a broad E.–W. Miocene downfold, analogous with the syncline of the London Basin, but resembling it as a mirror image and pitching to the west.

These conclusions are reached along two lines of reasoning. The first is the drainage. As Strahan pointed out,[2] the rivers of South Wales bear no relation to the structures resulting from the Armorican and Charnian orogenic movements, but disregard them entirely, cutting through the highest escarpments by deep gorges. South Wales has, in fact, a superimposed drainage, which can only be explained by supposing it to have originated upon a blanket of Mesozoic strata sloping gently south-eastward, but now entirely removed. Strahan supposed that this blanket was composed of sediments of Upper Cretaceous date—an idea which was acclaimed by Jukes-Browne, for it fitted in with his view of the former wide extension of the Upper Chalk sea over all except the highest districts of North and Central Wales and the Brecon Beacons.[3] Quite apart from the question whether the sedimentary blanket was composed of Jurassic or Cretaceous strata, Strahan's theory, if correct, is held to involve a post-Cretaceous (presumably Miocene) uplift of North Wales relative to South Wales. Actually, however, it is conceivable that the drainage may have started upon an original slope of deposition, and so it does not seem absolutely necessary to invoke tilting.

The other line of reasoning by which Prof. Jones was led to the belief in a Miocene uplift of North Wales was a consideration of the slope of the sub-Mesozoic platform when traced beyond the region where Mesozoic deposits remain upon it. This subject is of such importance that we will proceed to a short independent examination of the data; for Prof. Jones considers it legitimate to assume that marine Rhætic and Liassic (if not later) strata were

[1] O. T. Jones, 1931, *Rept. Brit. Assoc.* for 1930, Presid. Add. Sect. C, pp. 57–82.
[2] A. Strahan, 1902, *Q.J.G.S.*, vol. lviii, pp. 207–25.
[3] A. J. Jukes-Browne, 1911, loc. cit., fig. 53, and p. 335.

deposited, not only over all parts of the platform where Trias is now found, but also over all those parts from which it has been removed by subsequent erosion.[1] But apart from this assumption being invalidated by the existence of a fault such as that at Malvern, which although post-Triassic, may be pre-Jurassic or at least intra-Jurassic, it is important that there should be absolute certainty that the sub-Mesozoic platform can be correctly identified. It is therefore to the identification of the platform that we will pay special attention.

Within the British Isles the ideal district for studying the sub-Mesozoic platform where it first begins to emerge from beneath its sedimentary covering is the area surrounding the head of the Bristol Channel, in Somerset, Monmouth and Glamorgan. Here recent denudation has so far stripped off the covering that it is possible to obtain a clear idea of the surface that lies beneath, while at the same time a sufficient amount remains still buried to leave no doubt as to the age of the feature.

A more or less unevenly sculptured surface of Palaeozoic rocks lies revealed, evidently an old landscape, formed by the wearing down of the Armorican mountains under subaerial agencies—probably in a desert climate. All the original tectonic features had been planed down, so that the Triassic deposits overstep rapidly across the basset edges of the various Palaeozoic formations; and in places, such as near Cardiff, where the Keuper rests on Silurian, at least 7,000–8,000 ft. of Upper Palaeozoic rocks were removed. Here and there, however, residual hills or 'monadnocks' were left standing above the general level of the undulating plain, and later these formed islands, first in the Keuper lake and then in the Rhætic and Liassic seas (as described on pp. 103–5 above). The most important of the smaller monadnocks were the Mendips, Quantocks, and Cowbridge Island (see fig. 17, p. 104). Beyond these the scarp of the South Wales Coalfield certainly rose to even higher elevations; but whether it merely formed the edge of a much larger manadnock, or was the fringe of a great tract of ground lying to westward at a higher level and worthy of the name of mainland, usually bestowed upon it, is a difficult problem.

The configuration of the sub-Mesozoic platform in the Bristol Channel district and the gradual submergence of the monadnocks by the marine transgressions of the Rhætic and Lias have been vividly described in the following passage by Strahan,[2] who elucidated the sequence of events in Glamorgan:

'The features of the old landscape were due primarily to the effects of denudation upon the sharply folded Palaeozoic rocks. Then, as now, the Carboniferous Limestone formed scarps and the Old Red Sandstone stood up as rounded hills. Around and between these features the marl was spread out, mixed at its margin with the debris that fell from their sides. As the subsidence continued the marl and breccias extended further up the slopes, but, though they had covered the small crags, they had failed to surmount the higher tracts when they were succeeded by the Tea Green Marls. Gradually diminishing in size, these same tracts can be easily recognized through the period of the Tea Green Marls, of the Rhætic, and of part of the Lias, but they all finally disappeared during the deposition of the Lower Lias.'

It might be thought that such a well-marked peneplain, with its residual monadnocks, would be easy to follow over wide areas in other parts of Britain.

[1] O. T. Jones, 1931, loc. cit., p. 64.

[2] A. Strahan, 1904, 'Geol. South Wales Coalfield, Part VI, Bridgend', p. 22, *Mem. Geol. Surv.*

But directly we leave the fringe of the surviving Triassic deposits we are faced with two difficulties: (i) uncertainty (or, rather, complete ignorance) of the level at which to look for it, and (ii) interference by other peneplains of much later date.

The first difficulty will be readily appreciated by considering the differences in level of the sub-Mesozoic peneplain or Palaeozoic platform beneath those parts of England that are still under the Mesozoic covering. As pointed out in Chapter II, it has been continually depressed beneath the Jurassic troughs of deposition, and to an increasing extent towards the centres of those troughs, throughout the Jurassic period; and as remarked on p. 50, it may have been still further depressed in the same places by the very Miocene movements that gave rise to anticlines in the Chalk covering above (for example under the Weald). The Palaeozoic platform is two or three thousand feet lower under Hampshire and Sussex than in Somerset, where it comes to the surface (see figs. 3–6). It plunges rapidly below sea-level again beneath the Bristol Channel. At what level, therefore, are we to look for it over Wales, and so how is it to be distinguished from other peneplains?

This brings us to the second difficulty. The sub-Mesozoic peneplain has been identified with the 400-ft. coastal platform of Carmarthen and Pembrokeshire. No Mesozoic strata are found *in situ* so far west, but the presence of red marls of Triassic appearance in gash-breccias, or the filling of collapsed caverns in the Carboniferous Limestone, and the local red staining of the limestone, have been taken to indicate the former presence of the Trias. Prof. Jones therefore suggests that the conspicuous monadnocks, such as the Prescelly Mountains and Carn Llidi and others, which dominate the Pembroke peninsula, are survivals of the Triassic landscape just as are those in Glamorgan and Somerset; in fact, that the coastal plain of Pembrokeshire is substantially the sub-Mesozoic peneplain.[1] Mr. E. E. L. Dixon, who has studied the peninsula in detail, also considers that 'though the Triassic floor has undergone some later planation, this has merely touched up the work of the earlier erosion'. Nevertheless he admits that 'parts of it show little trace of Triassic staining and none [shows any trace] of Triassic deposits; on the contrary it supports relics of post-Triassic sediments':[2] 'as though the surface of the original Triassic landscape had been considerably pared down', as he wrote a few years earlier.[3]

This coastal platform compares perfectly, in fact, with the Pliocene platform of Cornwall. From the Cornish platform rise the monadnocks of Carn Menellis, Carn Brea, Carn Marth, St. Agnes' Beacon, &c., for all the world like Carn Llidi and its companions across the Bristol Channel; and upon its surface, as proof of its age, lie the relict patches of Pliocene deposits at St. Erth and St. Agnes. There are upon parts of the Pembrokeshire platform also the same type of gravels as in Cornwall, probably dating from the slightly earlier period at which the peneplain began to be formed by subaerial agencies. In one place, too, not far from Pembroke, is a considerable patch of pipe-clay of uncertain Upper Tertiary age, and at least 45 ft. thick.[4]

[1] O. T. Jones, 1931, loc. cit., pp. 62–4.

[2] E. E. L. Dixon, 1921, 'Geol. South Wales Coalfield, Part XIII, Pembroke and Tenby', p. 162, *Mem. Geol. Surv.*

[3] E. E. L. Dixon, 1914, 'Geol. South Wales Coalfield, Part XI, Haverfordwest', p. 199, *Mem. Geol. Surv.*

[4] E. E. L. Dixon, 1921, loc. cit., pp. 166 et seq.

The Pliocene coastal platform occurs also in North Wales and Anglesey, varying within a hundred feet or more in height, and often separable into two or more stages. In Anglesey and the adjoining mainland Greenly has described three such platforms, at 550 ft., 430 ft., and 275 ft., all of which he considers probably of approximately Pliocene date; and since the highest has monadnocks rising out of it as in Pembroke and Cornwall, he calls it the Monadnocks Platform.[1] The point of interest about these platforms in our present context is not their precise heights, but their late Tertiary (conveniently generalized as Pliocene) date, and their widespread distribution. They enable it to be said with confidence that the existence of a platform at about 400 ft. with monadnocks in Pembrokeshire, even though there may be some places farther east along the coast where it coincides with the sub-Mesozoic peneplain, is no proof of the former existence of the Mesozoic base at anything like that level over the Pembrokeshire peninsula. The point is one of some importance, for if the Mesozoic base did extend at so low a level across the peninsula, it would seem to be shaping to pass round behind the highlands of Wales.

The question is precisely similar to that arising in the promontory formed farther north by the Isle of Anglesey. Near at hand under the Irish Sea, as under the Bristol Channel, the base of the Trias is well below sea-level (p. 568 and fig. 2, p. 38). The adjoining land is peneplaned, and from the peneplain rise monadnocks. But Greenly does not attribute the peneplain and the monadnocks to the Trias. Although he asserts that 'it is, of course, evident that the Mesozoic rocks must have extended over the tract that is now the Isle of Anglesey', he considers that the Mesozoic base over the island was probably more than 700 ft. above sea-level.[2]

Prof. Jones has endeavoured to trace the sub-Mesozoic peneplain farther into Central Wales. He describes how in North Pembrokeshire, Carmarthenshire and South Cardiganshire the coastal plateau at 400 ft. slopes upward inland and merges imperceptibly into the high plateau of Central and North Wales, at 1,900 or 2,000 ft.[3] The high plateau was noticed as early as 1846 by Ramsay (who attributed it, however, to marine erosion)[4] and it has been described also by Prof. Fearnsides[5] and others. It is a well-marked feature from which the highest mountains of the Snowdon group, Cader Idris, the Arenigs and Arans, Plynlimon, &c., stand out as monadnocks, like those on the lower plateau. Prof. Fearnsides also spoke of it as 'sloping gently away to the south-east across Merioneth and Cardiganshire', and Prof. Jones in an earlier paper described how it 'extends to the foot of the Upper Old Red Sandstone escarpment of Breconshire and Carmarthenshire, which overlooks it as a line of high cliffs overlooks a level foreshore'.[6] The continuous slope of the platform is taken by Prof. Jones to indicate that the whole of it is the sub-Mesozoic peneplain which has been warped up in Central Wales, as explained on p. 570. The logical conclusion at which he arrives is that 'it would be rash to assert that the Lias did not extend over the Palaeozoic

[1] E. Greenly, 1919, 'Geol. Anglesey', vol. ii, p. 783, *Mem. Geol. Surv.*; see also W. G. Fearnsides, 1916, *Q.J.G.S.*, vol. lxxii, p. 76 (platforms in Carnarvonshire).
[2] E. Greenly, 1919, loc. cit., p. 778.
[3] O. T. Jones, 1931, loc. cit.
[4] A. Ramsay, 1846, *Mem. Geol. Surv.*, vol. i, pp. 331, 333; and 1866, ibid., vol. iii, p. 236.
[5] W. G. Fearnsides, 1910, *Geol. in the Field*, pp. 820–1.
[6] O. T. Jones, 1924, *Q.J.G.S.*, vol. lxxx, p. 568.

area of Wales and the Welsh Borders; the formation may, indeed, have attained a thickness of several hundred feet over that area'.[1]

Before accepting so far-reaching a conclusion as this it is well to examine for comparison the ancient Palaeozoic tract under London, which, as already remarked (p. 52), offers unique opportunities for studying the relations of the Mesozoic rocks to the platform. Here all the evidence has been preserved and can be studied by means of borings, whereas around the western and northern landmasses the critical strata have been completely destroyed by erosion.

The first fact to strike the eye on referring to Lamplugh's sections is that, although the surface of the platform has a continuous slope, it is not all of the same age, in the sense that neither Trias nor Lias nor any other single formation of the Jurassic stretches or apparently ever stretched all over it. Owing to the peculiar combination of oversteps and overlaps occurring at the margins of the trough of deposition (as shown in fig. 91, p. 544) progressively later rocks transgress on to it at progressively higher levels. Therefore, although the lower part of the peneplain may have lain beneath the Liassic water-level, the higher parts were not inundated until the Upper Cretaceous. Yet, if the Mesozoic rocks were to be stripped entirely away, the peneplain would presumably look much the same as that of Wales. The points that must be emphasized are (1) that the slope of the peneplain was not imposed upon it by the Miocene earth-movement, but was slowly acquired, stage by stage, through the subsidence of the Jurassic trough around it; and (2) that the land-area was exposed to prolonged subaerial denudation, the highest parts for the longest time, before finally sinking beneath the sea and perhaps having a submarine peneplain superimposed upon the subaerial one.

By analogy, it is not unreasonable to suppose that by the end of Jurassic times the slope of Palaeozoic rocks in Central Wales was already tilted southward and eastward so steeply that, if there has been any Miocene uplift, its effects have been relatively trivial.[2]

The Miocene uplift of Exmoor, which, as Prof. Jones points out, produced a water-parting from which the streams flow southward into the syncline of Central Devon and northward into that of the Bristol Channel, was merely a revival of an earlier uplift. Prof. Jones calls Exmoor an analogue of the Wealden anticlinorium and the Bristol Channel an analogue of the London Basin synclinorium.[3] The Miocene movements, which conditioned the modern drainage, may, it is true, have had similar effects in the two areas; but it is the fundamental structure that concerns us here, and in this there is no analogy. Exmoor, as we saw in Chapter III (pp. 71–3), lies upon the North Devon Axis of uplift, which was a line of retarded deposition, indicating non-subsidence or relative elevation, in the Jurassic period. The Weald, on the contrary, was a region of depression and heavy sedimentation throughout the Jurassic period. Further, the Bristol Channel, as is shown by the surviving outcrops of Lias, was depressed early in Jurassic history, while the London Basin probably remained above water for most of the Jurassic period—at least it is the very region where the Palaeozoic platform rises nearest the surface and attains its maximum convexity. So far from being analogous,

[1] O. T. Jones, 1931, loc. cit., p. 66.

[2] I say 'if' because the drainage may have been initiated upon an original slope of deposition of the Cretaceous covering.

[3] O. T. Jones, 1931, loc. cit., p. 81.

therefore, the Weald and Exmoor, in their fundamental structure, are opposites. Yet both appear to have been elevated during the Miocene orogeny, while both the London Basin and the Bristol Channel, equally opposite, were depressed.

This is only one of several instances illustrating the apparent contradiction between Godwin-Austen's 'law' (p. 59) that the Miocene anticlines arose along the lines of earlier anticlines, traceable in the Jurassic and earlier rocks, and Lamplugh's 'law' (p. 47) that the greatest uplifts that occurred in the Miocene period were superimposed upon broad synclines in the Jurassic rocks beneath. At first sight the contradiction is puzzling, and seems to render both laws worthless. But the explanation is, I think, that Godwin-Austen and Lamplugh made their observations on two different types of uplift, both of Miocene date, but arising upon different foundations from different immediate causes (though both were due ultimately to pressure); and so both laws are true when applied to the type of phenomenon from which they were first deduced.

Godwin-Austen had in mind the type of anticline exemplified by the Vale of Pewsey and the Hog's Back—a long but relatively narrow fold or ripple in the strata, often consisting of strings of periclines. Such folds, of which the east–west axes are the best examples, are all based upon older folds of Armorican date, and their Miocene revival was only the last of many revivals of activity spanning all Mesozoic time (see Chapter III).

Lamplugh, on the other hand, studied the Weald, which is not a single anticline but an anticlinorium. Folds which replace those of the Vales of Pewsey and Wardour eastward pass on over the Wealden anticlinorium merely as ripples upon its surface. It is not one of the separate anticlines that is based upon a syncline, but the whole anticlinorium that is based upon a synclinorium in the Jurassic rocks underneath; and the synclinorium is the Jurassic trough of deposition. The supposed cause of the upfold of the Cretaceous rocks here, by compression of the Jurassic trough already filled with sediment, was explained on p. 50.

It so happens that in the Weald the Jurassic trough coincides in direction with the east–west or Armorican folds. But elsewhere (fig. 7, p. 48) the folds cut across it at all angles, and so give rise to 'axes of uplift' across the troughs. The Mendip and the North Devon Axes intersect the trough of deposition in Somerset and Wilts. roughly at right-angles (see map, fig. 15, p. 86). Therefore the elevations along these axes acted at right-angles to the broader bulging up of the Chalk over the deepest parts of the trough. But over the axes the trough was shallow and there was correspondingly little bulging up; therefore an anticline of east–west directrix was always the dominant result of the Miocene earth-pressures over the ancient axes of uplift, no matter what the direction of the trough thereabouts might be.

The bearing of this upon our present problem will be obvious. It explains why the uplift of the North Devon Axis was dominant, although the trough of deposition crossed it at right angles, and therefore how the east–west elevation of Exmoor came to condition the drainage, rather than any bulging up of the Cretaceous rocks over the Jurassic trough in a contrary direction. In this way came about the analogy between the drainage of Exmoor and that of the Weald, which proves so deceptive when used as the starting-point for inquiries into the tectonic history of Mesozoic times.

To summarize the conclusions to which a study of the ancient landmass under London leads us:

(1) The surface of the London landmass is a peneplain, which slopes gently under the Mesozoic covering. The covering is still intact owing to its having been carried for the most part below the reach of the forces of erosion by the south-easterly tilt to which the British Isles were subjected early in the Tertiary period. On the other side of the Jurassic trough the Welsh highlands rise similarly with a peneplaned surface, but they have been stripped bare in the Tertiary and Quaternary periods.

(2) If, as seems probable, the two landmasses on opposite sides of the Jurassic trough were analogous, none of the Triassic or Jurassic rocks is likely to have passed right over the top of the Welsh highland, although they may have encroached to an unknown extent round its margins, beyond their present outcrop.

(3) The slope of the Welsh peneplain was not acquired as the result of the Miocene orogeny, although it is possible that it was steepened at that time. The surface sagged gradually throughout the Jurassic period as the trough subsided. It is probable that the south-easterly slope would be considerably greater had not the stresses found relief in the Malvern Fault, whereby the subsidence of the trough was probably enabled to continue without dragging the margin of the adjoining highland with it.

(4) The depression of the Bristol Channel, where Trias and Lias still exist below present sea-level, represents a branch of the Jurassic trough of deposition, analogous with the Kentish Weald. The floors of these depressions sagged to their present low relative levels during the Jurassic period, not as the result of the Miocene folding.

(5) The highland of Exmoor lies upon an Armorican anticline, along which activity was repeatedly revived during the Mesozoic period, when it and its continuation eastward formed the North Devon Axis of uplift, crossing the Jurassic trough of deposition at right-angles. It was finally re-elevated during the Miocene orogeny, and this revival gave rise to the Vale of Wardour fold and initiated the present drainage of Exmoor.

(c) The Dartmoor Highland

Concerning the elevation of the Dartmoor highland in the Mesozoic period an altogether new line of inquiry has been opened up by the study of the mineral assemblage of the Dartmoor granite. Dr. A. W. Groves has carried out a series of investigations in the sediments of all ages in the South of England with the express object of detecting the earliest appearance of this assemblage of heavy minerals.[1]

Assuming that the batholith was intruded in Permo-Carboniferous times, and that its granitic structure proves it to have crystallized slowly under a thick covering (probably 5,000 ft.) of Palaeozoic rocks, the problem was to find at what period the covering first began to be removed so far as to expose the granite. Dr. Groves finds that the sought-for detritals first appear in the Wealden Beds, while the many Triassic and Jurassic sands contain not a trace. The inference is, therefore, that throughout Triassic and Jurassic times the

[1] A. W. Groves, 1931, 'The Unroofing of the Dartmoor Granite', *Q.J.G.S.*, vol. lxxxvii, pp. 62–96.

Dartmoor highlands were some thousands of feet higher than at present, relative to the sub-Mesozoic floor, the granite still lying buried beneath its covering of Palaeozoic strata and remaining untouched by denudation until the period of the Wealden lakes. This seems to vindicate Jukes-Browne's line of reasoning that the Palaeozoic land areas were much higher in the Jurassic period than now.

Striking evidence is available of the height and steepness of the mountain tract of Dartmoor during the formation of the earlier New Red rocks. The Triassic peneplain in Devonshire comes to an end abruptly against the high ground in a manner suggestive of its termination against the escarpment of the South Wales Coalfield. Beyond, buried valleys, filled with New Red rocks, run for considerable distances westward into the folded Carboniferous tract, out of which they were carved during the Epiric or New Red continental period. Although their excavation would date from an earlier stage of the erosion of the Armorican mountains than the formation of the desert peneplain of the Trias, the fact that they were not destroyed by the production of the peneplain testifies to the survival of high ground into the Jurassic period. The steep gradient of the valleys is remarkable. In the largest, which runs from Exeter westwards through Crediton to Hatherleigh, the floor lies more than 2,000 ft. lower than the top of the Dartmoor granite only 4 miles away; yet apparently erosion in the upper course of the valley had not reached the granite, for no detritus from it is found in the New Red filling below.[1]

In dealing with Wales we are hampered by the fact that not only has all trace of Jurassic rocks been swept away from the neighbourhood of the existing high ground, but all trace of the Cretaceous rocks also. It is therefore particularly instructive that in Devonshire, in one restricted area, we are afforded an opportunity of observing the relations of Cretaceous and Eocene strata to the Palaeozoics, within a few miles of the highland of Dartmoor.

The Upper Cretaceous rocks of the Blackdown Hills and the dissected plateau to the south, which themselves project many miles farther west than any other Cretaceous outcrops in England, are continued after a gap of about 15 miles by the diminutive outliers of the Haldon Hills, south of Exeter. Already at Seaton on the coast the cliff-sections show the Albian overstepping the Lias and Rhætic Beds and coming to rest on the Keuper Marls, and the discordance can be followed in the cliffs as far as the Peak Hills west of Sidmouth. The inland outcrops continue the overstep until on the Haldon Hills the Albian rests upon the Permian. But there is also an overlap within the Albian, for the lower part of the Upper Gault (in the arenaceous facies known as Blackdown Beds), present in the Blackdown Hills, is absent at Haldon.

> 'Not only is there this overlap westward, but the sands at Haldon have become in places coarse-grained, granitic, or even pebbly. The fauna they yield is also highly suggestive of shoal water, or even of a shore-line within a few miles. Compound corals resembling littoral forms, absent from Blackdown, are here abundant and varied; the mollusca are thick-shelled strong species, such as could stand much knocking about.'[2]

Within 3 miles to the west, in fact, is the present edge of the Dartmoor

[1] A. W. Groves, 1931, loc. cit., p. 69.
[2] C. Reid, 1913, 'Geol. Newton Abbot', p. 93, *Mem. Geol. Surv.*

granite, beyond which heights rise rapidly to 1,200 ft. and 1,500 ft. above sea-level, and eventually to about 2,000 ft. on the highest points of the moor. Since the base of the Cretaceous rocks on Haldon is only about 700–50 ft. above sea-level and there is no sign of folding or faulting on a comparable scale, it is evident that they abutted against a shore-line somewhere in the next few miles to the west, where a deep valley has since been excavated by the River Teign. The total thickness of the Albian rocks is about 65 ft. on Great Haldon and 90 ft. on Little Haldon. Upon them lies a sheet of gravel of presumably Eocene age, composed mainly of Chalk flints mixed with finer-grained detritus from Dartmoor. The fossils in the flints indicate the former existence of nearly all the zones of the English Chalk.

If a section be drawn from Dartmoor through the Haldon Hills to the main Mesozoic outcrop of Dorset, filling in the gaps caused by subsequent erosion (fig. 94), certain marked resemblances to the section through the eastern margin of the Mesozoic trough emerge. In the first place the Cretaceous rocks appear as a transgressive sheet, overstepping the Jurassic and Triassic strata outwards; secondly, the Cretaceous rocks show overlap within the series, the higher overlapping the lower. This is in principle exactly what occurs on the margin of the London landmass. But there are important differences. The principal are, that in Devon (1) the New Red rocks are vastly thicker and are not overlapped by the Jurassics before those are in turn overstepped by the Cretaceous; and (2) the Cretaceous oversteps regularly on to progressively older members of the Jurassic System westward, the last being the Lower Lias and Rhætic; whereas against the London landmass it jumps from Lower Oolites on to Palaeozoics, the Lias having been previously overlapped and overstepped by the Oolites (see fig. 8, p. 52). The second difference is accounted for by the fact that the Cretaceous overstep against Dartmoor is considerably steeper (previous tilting was greater) than against the London landmass, so that the edges of the higher Jurassic formations, which may once have spread beyond the boundaries of the Lias, would have been removed prior to the Cretaceous transgression (this is suggested diagrammatically in fig. 94). A comparison between the feather-edges of the Jurassic rocks in Devonshire with those around the London landmass is therefore legitimate. We may presume that a similar combination of overlaps and oversteps and paucity of sedimentation within the Jurassic Series took place towards the shore-line of Dartmoor, but we must imagine all the evidence as having lain at some unknown (but probably not very great) height above the present plane of discordance at the base of the Cretaceous. The marked westerly attenuation of the Green Ammonite Beds of the Lower Lias between Golden Cap and Black Ven may be significant in this connexion (p. 119).

The alternative explanation to the one here offered, namely that the Jurassic System (some 3,000 ft. thick in Dorset), or at least a substantial part of it, was laid down over the top of the Dartmoor highland, but has since been removed owing to Tertiary uplift of the highland, as Prof. Jones would have us believe of Wales and Exmoor, is here discountenanced by the existence of the Albian patches on the Haldon Hills. These patches prove that the necessary uplift and erosion must have taken place *before the Albian period* instead of in the Miocene as postulated for Wales and Exmoor; and although there certainly was pre-Albian and post-Jurassic uplift of the landmass relative to the adjoining trough, such colossal upheaval and stupendous erosion between the Jurassic and Cretaceous periods as would be required on this view seems altogether improbable.

Incidentally the low level of the Haldon Cretaceous and Eocene outliers relative to the adjacent granite mass throws interesting light on the age of the erosion features on the top of Dartmoor. If the granite was not submerged by the Cretaceous sea, it has been undergoing subaerial denudation for a very long period. Any one who is acquainted with the vast sheets of fresh and coarse granitic detritus, largely of Dartmoor origin, spread out over the Dorset–Hampshire Basin and constituting the Bagshot Beds, will readily ascribe the main roughing out of the existing features on the highest part of the moor to the Eocene period. Hence if there is anything in the suggestion of Travis[1] that the highest points on Dartmoor[2] and Exmoor[3] are part of a subaerial peneplain and continuous with the 1,900–2,000 ft. plain of North and Central Wales, sloping towards a base-level of erosion to the south or south-east, then the Eocene is at least a likely period for the formation of this peneplain. The Eocene gravels, granitic sand and pipe-clay of the Dorset and Hampshire heaths can only have reached their present positions across a continuous sheet of Chalk, stretching up to the flanks of Dartmoor over the sites of the modern valleys of the Teign, Exe and Otter. It is highly probable, and in accordance with Jukes-Browne's restoration of the Chalk sea, that the highest parts of the peneplain in North Wales, with the largest monadnocks rising from it, may likewise never have been submerged beneath any Mesozoic sea

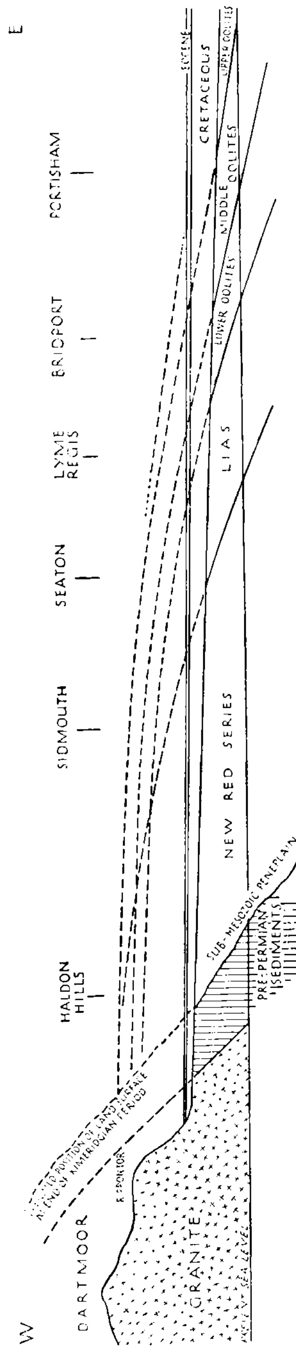

FIG. 94. Diagram to illustrate the supposed relationships of the Jurassic strata to the Dartmoor highland before the Cretaceous Transgression and erosion, assuming them to have been the same as on the margin of the London landmass, except for a deeper downcutting by the Cretaceous (here Upper instead of Lower). Supposed former positions of the Jurassic base-lines represented diagrammatically by broken lines. The highest and nearly horizontal line represents the level plain across which the Dartmoor detritus and Chalk flints from Devon were transported to the Hampshire Basin. Total distance 70 miles. Vertical scale greatly exaggerated.

[1] C. B. Travis, 1914, Pres. Add. *Liverpool Ge .S c.*, ol. x , p. 26.

[2] High Willhays, 2039 ft.; Cut Hill, 1981 ft.; White Horse Hill, 1,974 ft.; Lints Tor, 1,908 ft.

[3] Dunkery Beacon, 1,707 ft.

but may have been still undergoing subaerial erosion in the Eocene, when the Mesozoic rocks themselves formed the continuation of the same plain to eastward. This seems to have been the view of Prof. Fearnsides, who was the first in modern times to give a description of the feature in North Wales; he wrote: 'As to the age of the peneplain we have no evidence. . . . Probably it is an early Tertiary surface of subaerial denudation which, reduced to a condition of low relief, had its drainage rejuvenated by the further uplift of the Miocene.'[1]

(d) The Pennine Range and the Lake District

In considering the question of the possible extension of the Jurassic sea over the high Palaeozoic tracts of the North of England, and in particular the Pennine Range and the mountains of the Lake District, there are two lines of approach: (1) direct internal evidence for or against land to the west or north-west in the Jurassic sediments of Leicestershire and Lincolnshire, the Yorkshire Basin, and the Carlisle outlier; (2) evidence bearing on the date of upheaval of the high features beyond the present confines of the Jurassic outcrop, so that it may be judged whether it is probable that the Jurassic sea ever overspread them. These two classes of data will now be briefly considered.

INTERNAL EVIDENCE OF PROXIMITY TO LAND IN THE JURASSIC ROCKS OF NORTHERN ENGLAND AND THE MIDLANDS

Until very recently the microscope was not used for examining the sands of the Yorkshire Jurassic, and the data considered in inferring their source of origin were entirely macroscopic—false-bedding, thickening and increase in coarseness. On these grounds it was generally believed that the materials of the thick deltaic deposits of the Middle and Upper Jurassic were brought into Yorkshire from the north, or from rather west of north. Eighty years ago Sorby came to the conclusion, on taking the average of a large number of measurements, that the false-bedding indicates currents from about WNW.,[2] and more recently Mr. Black has ascertained that the washout channels also indicate a flow of water from north to south (p. 315). As a whole the 'Estuarine Series' thickens towards the north of the Yorkshire Basin and, as Fox-Strangways pointed out, the sand-grains become coarser towards the west, thus suggesting a source of supply in the north-west.[3]

Most of the other Jurassic formations of the Yorkshire Basin were considered by Fox-Strangways to show signs of having been formed off land lying in approximately the same direction, ranging from north to west, on account of their either thickening in that direction or becoming more arenaceous, or both. Thus the Middle Lias changes in facies towards the north-west from a deeper-water argillaceous deposit to a series of calcareo-arenaceous ironstones (pp. 160–1), suggesting to Fox-Strangways that land lay not far north-west of Eston Moor near Middlesborough.[4] The Scarborough Beds or Grey Limestone Series likewise become excessively coarse and arenaceous at Eston Moor, so that Fox-Strangways says: 'It is therefore probable that

[1] W. G. Fearnsides, 1910, *Geol. in the Field*, p. 821.
[2] H. C. Sorby, 1852, *Proc. Yorks. Phil. Soc.*, vol. i, pp. 111–13.
[3] C. Fox-Strangways, 1892, *J.R.B.*, p. 391.
[4] Ibid., pp. 387, 389.

a shore-line existed somewhere to the west, and not far from the present north-west outcrop; arenaceous beds were formed in the west, while calcareo-argillaceous strata were deposited in the east.'[1] The Kellaways Beds thicken in general towards the north, like the Estuarine Series, the constituents of which the sands resemble; and Fox-Strangways considers this 'incontestable proof that the sandy sediment must have been derived from the north'.[2] Mere increase of thickness, however, is no proof of approach towards a shore-line, since it may be caused by thinning in the opposite direction against an axis of uplift, where sedimentation was retarded. Fox-Strangways himself records on the next page that the Oxford Clay thickens to a maximum in the south-east, but he does not infer from this that land lay in that direction, but rather the deepest part of the sea, while uplift was going on in the north-west. The lenticular shape of the Hambleton Oolite Series and the westerly thickening of the Middle Calcareous Grit were likewise taken by the same author to indicate land in the west, and he suggested that the sub-oolitic limestone of the Hambleton Oolite might be composed of detritus from a coral reef 'extending along the flank of the old Palaeozoic land to the west, which we have every reason for believing existed during the whole of the period'.[3] Hudleston was equally convinced that land existed not far to the north-west of the Yorkshire Basin in the Oxfordian period.[4]

We cannot accuse Fox-Strangways of being biased and of interpreting all evidence in favour of a preconceived notion that there was land to the north and west; for he records of one formation—the Dogger—that a more calcareous development along the western escarpment seems to him to indicate 'somewhat deeper water' in that direction, and he is led to suggest that the channels of the Dogger (p. 224) may be 'a series of narrow inlets connected with a larger sea to the west'.[5] He makes no comment, however, on the inconsistency of this with the evidence derived from the other formations, and the reader is left to reconcile the opinions as best he may. The suggestion as to the Dogger channels has, in fact, little to recommend it. The increase in the calcareousness of the Middle Lias towards the NW. is taken by Fox-Strangways on another page to indicate approach to a shore, where presumably Carboniferous Limestone was undergoing solution.

All these inferences drawn by Fox-Strangways and his predecessors from the macroscopic data bear solely on the direction from which the sands were brought into Yorkshire; they suggest nothing as to the actual source of the materials. Upon this subject the microscopic investigation of the heavy minerals is now being brought to bear by Dr. Rastall, but the work is still in its infancy and unfortunately no very definite conclusions are yet available. It appears certain, however, from information which Dr. Rastall has kindly communicated to me, that the sands could not have come from any adjoining British source. The inference is that they were derived from the Fennoscandian mainland or Atlantis, probably from some part of the site of the present North Sea. They therefore have no bearing on the existence of land over the Pennines.

The clay formations, such as the Lias and the Kimeridge Clay, give no

[1] Ibid., p. 394. [2] Ibid., p. 396. [3] Ibid., pp. 399, 401.
[4] W. H. Hudleston, 1876, *P.G.A.*, vol. iv, p. 370.
[5] C. Fox-Strangways, 1892, loc. cit., p. 390.

indications of the source of their materials. It was suggested by Goodchild that the dark muddy sediment of the Lias might have been derived from the disintegration of Coal Measures, but it is stated that the mica flakes in the Lias are larger than those in the Coal Measures.[1]

South of the Market Weighton Axis all the formations thicken steadily and, as has been emphasized on earlier pages, the outcrops of the Jurassic formations cut obliquely across a trough of deposition, of which the opposite margin lay to the south-east. Only one definite instance is known of materials in the Jurassic strata of this trough having been derived from the north-west: at Leicester the base of the Rhætic Beds contains small pebbles of igneous rocks from the neighbouring Charnwood Forest (p. 111). On the Forest the Keuper Marls overlap the earlier New Red rocks and rest directly upon the Archæan, and the pebbles at Leicester indicate that, as with some of the islands in the Mendip Archipelago, the surface was not submerged until during or after Rhætic times. Of the later deposits, only the Northampton Sands have been investigated, and Mr. Skerl is of the opinion that their materials were derived from the south-east (p. 209).

The Lower Lias and Rhætic Beds of the Carlisle outlier show no abnormalities that could be ascribed to deposition particularly near to a shore-line; nor do the Liassic strata of the Shropshire outlier.

THE AGE OF THE PRESENT HIGH FEATURES OF THE PENNINE RANGE AND THE LAKE DISTRICT AND THE POSSIBILITIES OF THEIR HAVING BEEN COVERED BY THE JURASSIC SEA.

When we examine the surface upon which the New Red rocks rest as they approach the Pennines we find a peneplain similar to the sub-Mesozoic peneplain of the South-West of England. The Trias and the Permian together form a conformable series, which passes across the denuded edges of the structures formed during the Armorican orogeny and itself takes no part in them. There is the same proof of enormous erosion after or during the uplift of the Armorican mountains, before the New Red rocks were laid down. Along the flanks of the Pennines the coal-basins were already determined in their long N.–S. synclines and the Coal Measures had been entirely removed from the intervening anticlines before the earliest Permian strata were laid across their surfaces.[2] On the west side of the Pennines, in the Ribble Valley at Clitheroe, one of the most easterly patches of Permian rests upon Viséan limestone. This indicates that all the Coal Measures, the Millstone Grit and the Yoredale–Pendleside Series had previously been removed—amounting to 15,000 ft. of strata.[3]

Nevertheless, the central anticline of the South and Mid Pennines (the northern part of the range will be considered separately) still rises to an average height of 1,000–1,500 ft. above sea-level, with points over 2,000 ft. in Derbyshire, many hundreds of feet above any surviving New Red rocks. The patch at Clitheroe lies at an elevation of only some 200 ft., in a valley

[1] P. F. Kendall and H. E. Wroot, 1924, *Geol. Yorkshire*, p. 310.

[2] J. J. H. Teall and E. Wilson, 1880, *Geol. Mag.* [2], vol. vii, pp. 92–5; E. Wilson, ibid., 1879, vol. vi, pp. 500–4; G. V. Wilson, 1926, 'Concealed Coalfield of Yorks. and Notts.', 2nd ed., *Mem. Geol. Surv.*, p. 54.

[3] R. H. Tiddeman, 1875, in 'Geol. Burnley Coalfield', pp. 121–2, *Mem. Geol. Surv.*; and Kendall and Wroot, 1924, loc. cit., p. 262.

hollowed out of the crest of an anticline, and is surrounded by hills of Carboniferous strata ranging from 1,000 to nearly 2,000 ft. in height;[1] it is thus analogous with the Permian valleys which run westward into the Culm Measures towards the Dartmoor highland. This suggests strongly that the South and Central Pennines stood high above the Permian sea and have not been first removed by the peneplanation and later re-elevated to their present height. Moreover, the difference in the fauna of the marine Permian on the two sides demands a barrier with only a roundabout connexion.

That there has been re-elevation along the Pennine Axis from time to time can hardly be doubted. But, by analogy with comparable axes under the Jurassic covering, the movement is more likely to have been gradual, prolonged through the Mesozoic period and mostly relative to the sagging troughs of deposition on either side, rather than positive, paroxysmal, and restricted to the Tertiary period, as commonly stated. The line of the Derbyshire Pennines is continued accurately by the Vale of Moreton Axis, and if the two are truly connected, as seems probable from the relation of the Mendip, Malvern, North Devon and other axes to corresponding uplifts in the Mesozoic covering, then the Vale of Moreton Axis is a key to the history of the Pennine Chain.

The movements along the Vale of Moreton Axis were probably only faint tremors of the main disturbances farther north, for the Vale of Moreton lay near the extreme south end of the anticline, where it pitched underground and disappeared or joined the opposite side of the trough. Yet we have seen (Chapter III) that the movements were enough to control deposition through much of the Lower and Middle Jurassic period. If a continuation so remote, although below water, was sufficiently near the surface to cause retarded deposition and repeated contemporaneous erosions, it is difficult to believe that the main Pennine Axis was not in part above the sea like the Mendips in Jurassic times. The least we can suppose is that it constituted a broad hog's-back of shallows, sometimes above water, sometimes submerged, separating the eastern from the western trough of deposition. We must also not forget the evidence of an island at least as late as Rhætic times at Charwood Forest. The Charnwood range is only a small branch of the Pennines, and it is hardly likely to have stood above water while they were submerged, an island by itself in the middle of an extensive sea.

The many eminent geologists who have discussed the evolution, tectonic and physiographical, of the Pennines and Northern England have usually evaded the question of the former extent of the Jurassic sea, or have dismissed it in a few lines, including it, if at all, simply to complete their histories.

Goodchild wrote: 'I have no doubt in my own mind that all the rocks up to the Lias, and even all the Jurassic rocks, once overspread the whole district and were continuous with those of other parts of the kingdom.'[2] He gave no reasons, however. Prof. Marr reached the same conclusion at the end of an ingenious and interesting chain of reasoning.[3] Jukes-Browne wrote: 'When discussing the extension of the Keuper Marls across England we came to the conclusion that the whole of the southern and central parts of the Pennine

[1] Kendall and Wroot, 1924, loc. cit., p. 263.
[2] J. G. Goodchild, 1889, *P.G.A.*, vol. xi, p. 277.
[3] J. E. Marr, 1906, *Q.J.G.S.*, vol. xlii, pp. lxxxvii–lxxxviii.

Chain were submerged beneath the great inland sea of later Triassic time. From this it follows that the Liassic sea also spread over this part of England from Cheshire, Lancashire, and Westmoreland on the west to Yorkshire and Lincolnshire on the east, and thence across the whole breadth of the North Sea area'; and 'I strongly suspect that the Oxfordian sea spread completely over the greater part of the Pennine area, as the Liassic sea had done'.[1] Messrs. Kendall and Wroot 'are driven to the conclusion that . . . the general lowering of level had been carried sufficiently far to bring the waters of the Jurassic sea over all that remained of at any rate the South Pennines. In that case probably all the Jurassic series was deposited over the Pennine area, except perhaps the heights of the northern fault blocks.'[2] Lastly, Mr. J. S. Turner has published a similar opinion, though adding no new evidence.[3]

I should be placing myself in an extremely unenviable position if I openly expressed disagreement with such a consensus of opinion. Nevertheless no harm can be done by reviewing the evidence brought forward in support of these statements, calling attention to some of the objections. The arguments, so far as I have been able to discover them, may be ranged under the following headings:

(1) The base-lines of the Trias and the Rhætic, when produced, pass over the top of the Pennines and Lake District (Jukes-Browne and Marr).

(2) If the uplift of the present elevations was post-Triassic, as shown by (1), then it was probably Tertiary, because in the Mesozoic period 'there is no evidence of great movements in the British Area', such as would suffice for the task (Marr; and implied by others).

(3) If the amount of Permo-Trias present in West Lancashire were restored over the relict outlier of Permian in the Ingleton Coalfield, the top of the Keuper would be considerably higher than the Carboniferous rocks of the adjoining Pennines (Jukes-Browne).

(4) Denudation during and after the Armorican uplift was so drastic that all features were probably lowered to such an extent as to bring them below the Jurassic sea-level (Kendall and Wroot).

(5) To supply the Jurassic sediments of the Yorkshire Basin 'it seems likely that some land exposure of much greater area must have been drawn upon. The thick beds of grit at the Peak [of Yorkshire; i.e. Ravenscar] must have been brought by a larger river than could have been formed on so narrow a belt as the Pennine uplift' (Kendall and Wroot).

(6) 'If the Skye uplift can have been sculptured into its present condition in late Tertiary times, the same explanation applies to Lakeland, and if we suppose Lakeland to have existed as land since, say, the end of New Red Sandstone times, it would long ago have been reduced to a nearly level surface by denuding agencies.' On the contrary, the district is physiographically young, and erosion is still in progress (Marr).

(7) The south-easterly tilt is probably alone responsible for the preservation of Mesozoic rocks in the South-East of the British Isles; hence their absence from the North-West of England and Scotland is probably due to their having been removed by erosion (Marr).

[1] A. J. Jukes-Browne, 1911, *Building of the Brit. Isles*, pp. 266, 277.
[2] P. F. Kendall and H. E. Wroot, 1924, *Geol. Yorkshire*, p. 310.
[3] J. S. Turner, 1927, *P.G.A.*, vol. xxxviii, p. 372.

When we come to examine these arguments, we find that each one harbours a fallacy, which I will endeavour to the best of my ability to show up, since they are dangerous when allowed to remain latent.

(1) and (2) The production of base-lines was a favourite line of reasoning with Jukes-Browne, who employed it throughout his book. The assumption is that if the base-line of the Keuper or Rhætic passes over the top of any high ground separating two outcrops, the folding is subsequent to deposition, and therefore the sheet of sediment was originally continuous—was not banked up against the barrier. A good instance of the application of this argument is the following:[1] 'The broad Derbyshire anticline lies between two equally deep and broad synclines, and the manner in which both Trias and Lias come into these basins makes it almost certain that they both dipped off the intervening anticline; in other words, the final arching of the anticline was completed by *post-Jurassic* flexuring.' The two words that I have placed in italics imply the application of argument No. (2) above, and this leads to such statements as the following: 'if the Keuper passed across the Palaeozoic ridges [of the North Pennines] then the greater part of the Jurassic series must have done so, and the Palaeozoic floor would have been covered by some 3,000 to 4,000 feet of Trias, Lias and Oolites'.[2]

Now this line of argument is plausible, but it rests upon a misconception of the method of accumulation of the Jurassic sediments and upon a lack of appreciation of the tectonic movements which, as we have seen, were proceeding all through the Jurassic period. It is true there was no major orogeny in the Jurassic, comparable with the Alpine and capable of upheaving the Pennines and Lake District all in one spasm; but there was continual subsidence of the troughs of deposition, amounting altogether to 3,000–4,000 ft., compensated to an unknown extent by elevation of the adjacent more stable blocks. This subsidence was greatest in the centres of the troughs and decreased or changed into elevation towards the margins. Consequently the earlier strata to be formed (i.e. the Rhætics and Lias) were by the end of the epoch depressed into deep synclinals, although the latest stratum was still being laid down horizontally. When the later strata were then removed from the edges of the troughs (because that was where they were highest and thinnest), the earlier layers revealed underneath would be disposed in synclinal fashion without having undergone any 'post-Jurassic flexuring'. The two completely different interpretations that can therefore be put upon the same facts are illustrated by fig. 95, p. 586.[3]

(3) The third argument depends upon the first; for it assumes that the same thickness of Permo-Trias was deposited at Ingleton, on the flank of the Pennines, as farther west, over the syncline of West Lancashire. On the view put forward here, an equal thickness of Permo-Trias would certainly not have been formed at the edge of the trough in such a position, and still less an equal amount of Jurassics. There would, in fact, probably have been slow sedimentation interrupted by erosions. It is curious that Jukes-Browne himself should note, on the next page, that 'round Derby and Ashbourne, where the Pennine axis passes below the Trias, the Bunter is reduced to a small thickness (about 100 ft.), and the Keuper sandstones thin out entirely'. If there is this

[1] A. J. Jukes-Browne, 1911, loc. cit., p. 245. [2] Ibid., p. 244.

[3] For a further discussion of these principles see Chapter III.

attenuation of the Trias across the axis so far south, where it was pitching and dying out, how much more might both Trias and Jurassic have thinned out over and towards the principal part of the uplift farther north? Even at the Vale of Moreton much of the Jurassic is missing.

(4) and (5) Prof. Kendall's and Mr. Wroot's first suggestion seems to me to be robbed of much of its weight by the fact that the denudation did not remove the high Carboniferous ground surrounding the Permian valley at Clitheroe. Moreover, drastic as this denudation certainly was everywhere, it left high features in the South-West, such as Dartmoor and the South Wales Coalfield, across which the Jurassic sea was unable to spread. Their other suggestion (5) can be readily agreed to without prejudicing the existence of a Pennine ridge. It seems certain that whether the Pennines were high above the water or deep beneath the sea, a large tract of land lay to the north and north-east (Fennoscandia), and that this supplied the sediments, not the small and narrow Pennine ridge. Any such ridge, even if it was above water, was too small to provide a catchment area adequate to supply the huge mass of deltaic sediments in Yorkshire; , d k th heavy minerals being begun by Dr. R. H. Rastall shows that the sediments are of the wrong sort to have come from the rocks composing the Pennines. Yet the Pennines may have been land nevertheless, just as Cowbridge Island was above water while the thick mass of sandstones derived from the mainland were accumulating to northward of it in the Rhætic Period (p. 103; and compare fig. 97, p. 597).

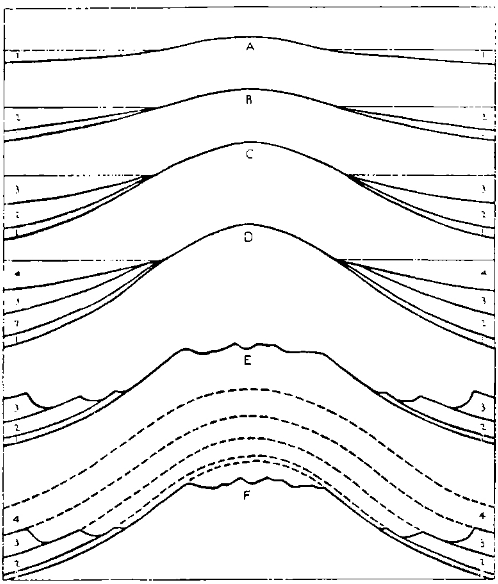

FIG. 95. A, B, C, D show stages in the subsidence and filling of two troughs of deposition, compensated by uprise of the intervening anticline. E shows the same after epeirogenic uplift of the whole area and consequent subaerial denudation, with relics of strata 1, 2, 3 dipping off the anticline. F represents the reconstruction inferred by producing the base-lines of the strata 1–4.

(6) Prof. Marr's comparison of the Lake District with the Skye uplift, where Tertiary rocks of an equal or greater hardness have been sculptured to about an equal extent, is a singularly apt reminder of the extreme length of geological time. No one could deny that the Lake District would have been converted to a nearly level plain had it been upheaved to its present position in relation to sea-level in New Red Sandstone times and had those relations remained the same ever since. But the present rate of erosion depends entirely on the relation of the ground to sea-level, a factor which cannot possibly have remained even approximately constant for so great a length of time. That the present state of erosion of the Lake District is the same as that of Skye only proves that the last major adjustment of sea-level took place at about the same

time (late Tertiary or early Quaternary) in the two regions. This has no bearing on the relations of the ancient rocks of the Lake District to the Jurassic sea. That there was upheaval over the site of the Lake District during the Armorican movements is proved by the overstep of the New Red rocks across Lower Palaeozoics along the present seaboard, between Whitehaven and Millom. And, as will be mentioned presently, there seems good reason for supposing that high ground survived and that the Carboniferous covering continued to be stripped off during the formation of the Permian of the Vale of Eden. Whether this high ground remained above water in Jurassic times or was only a region of shallows it is impossible to say; but the synclinal arrangement of the Lower Lias and Rhætic Beds of the Carlisle outlier does not imply that the Jurassic rocks were deposited in force all over the Lake District, but may even indicate the reverse (see (1) above, and fig. 95).

(7) It is in general true that the south-easterly tilt of the Tertiary epoch was responsible for the preservation of the Mesozoic rocks in the South-East of the British Isles; and that they have been removed from much of the North-West is a legitimate corollary. But Jurassic rocks were not deposited everywhere in the South-East (e.g. they are absent over the London–Ardennes landmass) and consequently they need not have been deposited everywhere in the North-West.

There is a direct bearing upon these problems in the new picture of the structure of the Northern Pennines that has begun to emerge as the result of recent work. The stratigraphical results achieved by Prof. Garwood and the illuminating investigations by Profs. Marr and Jones, Dr. Rastall, Mr. Turner, and Messrs. Trotter and Hollingworth depict the northern end of the Pennine Range east of the Craven, Dent and Pennine Faults as a stable block with a rigid foundation of Archæan rocks, more or less surrounded by geosynclinals filled with Lower Palaeozoic sediments.[1] In Lower Carboniferous times sedimentation began early over the geosynclinal troughs, but it was not until late in the S_2–D period that the Rigid Block was submerged.

The previous view has been that the great faults were initiated at latest in Carboniferous or Permo-Carboniferous times and had arrived at essentially their present positions by the Permian period; that the Rigid Block stood high above the subsided country of the Vale of Eden, where fans of torrent-breccia were spread out from the foot of the escarpment to form the Permian brockrams. Prof. Kendall explained the introduction of Lower Palaeozoic pebbles in the Upper Brockram and their absence from the Lower by supposing that in the interval between the formation of the two layers of breccia a movement took place along the faults, which brought up lower rocks within the influence of erosion. This view of the physiography of the Northern Pennines in New Red Sandstone times, of which Prof. Kendall was the champion,[2] seemed to be corroborated by Prof. Marr's conclusions as to the Tertiary date of upheaval of the Lake District dome.[3]

[1] J. E. Marr, 1921, 'The Rigidity of North-West Yorkshire', *The Naturalist*, pp. 63–72; and O. T. Jones, 1927, 'The Foundations of the Pennines', *Journ. Manchester Geol. Assoc.*, vol. i, part 1, pp. 5–14.

[2] P. F. Kendall, 1902, 'The Brockrams of the Vale of Eden . . .', *Geol. Mag.* [4], vol. ix, pp. 510–13; and 1924, *Geol. Yorkshire*, p. 261.

[3] J. E. Marr, 1906, loc. cit.; and 1919, *Geol. of the Lake District*, pp. 122–3.

Certain facts, however, make it seem possible that a complete revision of this view will be necessary. Messrs. Turner[1] and Trotter and Hollingworth[2] have brought forward evidence that in New Red times the Rigid Block actually lay at a lower level than its surroundings. Turner has observed that the Permian brockrams do not thicken and become coarser and more angular towards the Pennine Faults, but away from them, as if the materials had been derived from the south. He interprets the appearance of Lower Palaeozoic rocks in the Upper Brockram as a sign that between the formation of the two layers of brockram the Carboniferous covering over the high ground of the Howgill Fells and the Lake District, from which the materials were being derived, had begun to be worn through, so that Lower Palaeozoic rocks were exposed to erosion. Confirmation of this view is adduced by Trotter and Hollingworth. They point out that north of Armathwaite (9 miles SE. of Carlisle), where the adjoining Carboniferous rocks of the escarpment that overlooks the Vale of Eden are composed of sandstones of the Yoredale facies, there are lenticular beds of conglomerate in the Penrith (New Red) Sandstone made up almost entirely of limestone pebbles. If any pebbles in this position had been derived from the escarpment on the north-east they would have consisted mainly of sandstone: the inference is, therefore, that these came from high ground in the opposite direction, where the Carboniferous Limestone was being stripped off the Lake District.

Turner has shown, moreover, that the westerly downthrows along the Outer and Middle Pennine Faults, which lowered the present Vale of Eden, are post-Triassic, while along the Dent and Inner Pennine Faults, which downthrow eastwards, the movements were late Carboniferous and pre- or early-Permian, since they do not affect the New Red rocks. He also draws interesting corroborative conclusions from a study of the dolomitization, to which the Carboniferous Limestone was subjected below the floor of the magnesian sea or salt lake of the Permian period. The limestone of the Rigid Block, east of the faults, has not been dolomitized like that on the west, and from this he infers that in Permian times it was protected by a thick covering of Yoredales, Millstone Grit and Coal Measures, through which the dolomitizing waters were unable to percolate. This points again to considerable pre-Permian depression of the Rigid Block relative to its surroundings. The depression was apparently brought about by movements along the Dent and Inner Pennine Faults; the subsequent post-Triassic movements, which reversed the relative levels of the Rigid Block and the Vale of Eden, occurred along the parallel Outer and Middle Pennine Faults.

Along the E.–W. line of the Stublick Fault, which forms the abrupt northern edge of the Rigid Block, some of the protective covering of higher Yoredales, Millstone Grit and Coal Measures still survives as a string of faulted outliers extending from Midgeholme eastward to south of Hexham. North of the Stublick Fault region there ran in Lower Palaeozoic and Lower Carboniferous times a geosyncline, striking E.-W., where sedimentation began at a much earlier stage of the Carboniferous period than over the Rigid Block to the south of the fault. Over the site of this geosyncline arose during the Armorican orogeny the Bewcastle Anticline, the crest of which was

[1] J. S. Turner, 1927, *P.G.A.*, vol. xxxviii, pp. 358–72.
[2] F. M. Trotter and S. E. Hollingworth, 1928, *Geol. Mag.*, vol. lxv, pp. 433–47.

denuded down until in places (as at Kirkcambeck, 12 miles north-east of Carlisle) the Trias came to rest directly upon the Cementstones at the base of the Lower Carboniferous. Here we have proof that before the deposition of the Trias some 10,000 ft. of Carboniferous strata had been removed and therefore that the anticline had been elevated by that amount relative to the Rigid Block.[1]

Another geosynclinal trough of Carboniferous beds, with a pre-New Red anticline superimposed upon it, is traced by Messrs. Trotter and Hollingworth from east to west across the Rigid Block. Starting south of St. Bees Head and pitching east like the Bewcastle Anticline, it passes through the Howgill Fells and the Pass of Stainmore until lost beneath the main outcrop of the Magnesian Limestone at Middleton Tyas, between Richmond and Darlington. On this line there is an enormous overstep of the Carboniferous strata by the New Red rocks on both sides of the Pennines. The feature severs the northern end of the Rigid Block from the rest and makes of it a separate structural unit, which Trotter and Hollingworth term the Alston Block.

The Alston Block, it is interesting to note, is surrounded on three sides (north, south, and west) by broad anticlines, elevated during the Armorican movements over the sites of previous geosynclinal troughs, much as after the Alpine movements the London landmass was surrounded on the same three sides by upraised Chalk, arched over geosynclinal troughs filled with Jurassic rocks. The Carboniferous and the Cretaceous strata seem to have played an analogous role in the two places. We are reminded of the conclusion that the relatively low level of the Chalk under the London Basin is due not so much to its having been folded down as to the bulging up of the surroundings owing to the compression of the buried geosynclinal troughs beneath (p. 50).

The question of importance in our present context is: At what period was the Alston Block re-elevated relative to its surroundings, and when was the thick canopy of Millstone Grit, Coal Measures and Permo-Trias removed from its top? There is a certain amount of indirect evidence. Many years ago Goodchild[2] pointed out the existence of relics of a peneplain, passing from the level tops of the Lake District mountains and the Howgill Fells across the New Red country eastward, until it sloped down to the foot of the Pennine escarpment. He believed that this peneplain was formerly continuous with that which is a marked feature at about 2,000 ft. at the top of the Pennine Range, from which Cross Fell (2,930 ft.) and a few other high points protrude as monadnocks; and on his view its age was Cretaceous. To Goodchild, therefore, belongs the credit for noticing a peneplain of post-Triassic date *which has been displaced along the Pennine Faults.*

Goodchild's views, because often imaginatively expressed, have frequently been rejected or even treated with contempt. But other investigators, when they have become as familiar with the district as he was, have also come to recognize this peneplain.[3] It has now been accepted whole-heartedly by Trotter, who considers that it has not only been faulted along the Pennine and

[1] Trotter and Hollingworth, loc. cit.

[2] J. G. Goodchild, 1889, *P.G.A.*, vol. xi, p. 268 and fig. 8; and *Trans. Cumb. and West. Assoc.*, No. XIV, pp. 73–90.

[3] e.g. T. McK. Hughes, 1901, *Proc. Yorks. Geol. Soc.*, vol. xiv, p. 129.

Stublick Faults but also warped or gently folded, as well as having participated in the general south-easterly tilt of England.[1] He believes that the same peneplain is continued by the level top of the Chalk Wolds of East Yorkshire (at about 800 ft.) and therefore that the date is not Cretaceous as Goodchild supposed, but Tertiary—that it is, in fact, the Early Tertiary peneplain recognized in the Mesozoic areas of England by W. M. Davis.

By an able study of the drainage of the region, Trotter shows that the faulting and gentle folding of the peneplain are events 'so recent that their impress is still boldly stamped on the topography'; and while they are pre-Glacial, he considers that they are probably not earlier than Pliocene. This latest movement along the faults was only enough to give rise to the present main topographic features—to allow the Vale of Eden and Tyne Gap to subside to their present low levels relative to the top of the Alston Block. The amount of the throw is measurable by the present height of the escarpment—a maximum of about 1,500–2,000 ft. If we restore the two sides of the fault as they were before the displacement, so that the peneplain is continuous once more, it becomes evident that there was a much greater displacement before the formation of the peneplain; for by joining the faulted edges of the peneplain we only bring Trias against Lower Carboniferous. This means that if the Permian and Trias and all the intervening Carboniferous Beds originally passed across the Alston Block, some 8,000 ft. of strata had been removed from the block by the time the peneplain was completed. Had this mass of strata been already carried away by Jurassic times, or did it remain throughout the Jurassic period and act as a barrier separating the east from the west?

Mr. Trotter considers that, since the idea of the Northern Pennines towering above the surrounding country in Permian times has to be replaced by a conception of the Rigid Block depressed relatively to its surroundings by the Armorican movements, the idea that the Mesozoic formations may not have extended across the area from east to west must inevitably collapse. This conclusion, however, seems too hasty. There are still many uncertain factors. It cannot be assumed that because the Alston Block was depressed during the Armorican orogeny it remained a depression all through the Mesozoic era. We know, in fact, that it rose to such an extent that all the extra mass of sediments was removed by the time the Tertiary peneplanation was completed. The vital factor is the date (or dates) at which this elevation took place.

According to Turner, part of the post-Triassic movements along the great faults consisted of thrusting from the south or south-west. During this episode dolomitized limestone was brought into direct contact with undolomitized limestone and Silurian rocks were thrust over Carboniferous. Such pressures suggest the Miocene orogeny and were perhaps a prelude to the final (Miocene or Pliocene?) subsidence along the faults. But the main trend of the movement was in the opposite direction, resulting in elevation of the Alston Block or lowering of the surrounding country. Both Turner and Trotter assume that this elevation took place in early Tertiary times. The amount of the movement is so great, however, that it seems likely that it was spread out over a very long time—perhaps through the whole Jurassic and Lower Cretaceous periods—denudation perhaps keeping pace with elevation

[1] F. M. Trotter, 1929, *Proc. Yorks. Geol. Soc.*, vol. xxi, pp. 161–80.

as movement continued along the faults. There is an example of an intra-Jurassic fault close at hand, at Peak (Ravenscar) (p. 180). Moreover, we know that the work was brought to an end by the completion of the great peneplain; and by comparison with other areas the date of the peneplain is Eocene.

Another line of speculation as to the state of the Lake District in the Jurassic period is worth mentioning. We have seen that, even if Prof. Marr's evidence of the radial drainage demands a final doming up of the district in the Tertiary period, there was certainly an elevation as early as the end of Carboniferous times. Mr. Green considers that this earlier uplift took place along an anticline of NW.–SE. trend and pitch, which can be traced through the Ingleton and Horton-in-Ribblesdale inliers until, bending round W.–E., it is lost in the Pennines beyond Pateley Bridge in Nidderdale.[1] On this view the Lake District is nothing more than a periclinal enlargement of an anticline pitching to the SE. Now it is noteworthy that where this anticline loses itself in the centre of the Pennines it is replaced by several others having a W.–E. or NW.–SE. strike, which pass on eastward until they disappear beneath the Mesozoic covering. The most important is the Wharfe Anticline, which continues the earlier line of the Lake District—Horton Anticline; and this has been identified by Prof. Kendall with the Market Weighton Axis (p. 62). Therefore, if Green's view of the structure is correct, it is not unreasonable to suppose that in Mesozoic times the Lake District had a history similar to that of the Market Weighton Axis.

(e) The Scottish Highlands

It has been emphasized that the present occurrences of Jurassic rocks in the Hebrides bear no relation whatever to the original distribution of the sea which deposited them, but that their preservation has been determined entirely by faulting combined with the protective action of coverings of Tertiary lava. The surviving relics, in fact, represent fragments that were faulted down into safe positions in the solid sub-Mesozoic platform, out of reach of denuding agencies.[2]

Thus it would seem that, but for the faulting and the outpourings of basalt, there would be no trace at all of the Jurassic sediments. The most impressive demonstration is the occurrence of Rhætic rocks and fossils caught up in the neck of the Tertiary volcano on the Isle of Arran, many miles from any other vestige of Mesozoic strata. Yet the Arran and other Hebridean Jurassic rocks show no signs of having been deposited in a very restricted area; on the contrary, most of them closely resemble their counterparts in England.

Consequently, when in imagination we restore the landscape as it stood before the denudation, it seems that we cannot argue as Jukes-Browne was wont to do on the Welsh Border, that the surrounding ancient rocks were formerly so much higher that the Jurassics cannot have spread far beyond their present limits. Instead, we are bound to infer that from areas where mountainous tracts now form the surface, great thicknesses of Jurassic strata have been removed.

[1] J. F. N. Green, 1920, 'Geol. Structure of the Lake District', *P.G.A.*, vol. xxxi, p. 126.
[2] J. W. Judd, 1878, *Q.J.G.S.*, vol. xxxiv, p. 669; and G. W. Lee, 1920, 'Mesozoic Rocks of Applecross, Raasay and N.E. Skye', p. 1, *Mem. Geol. Surv.*

Judd, who made the first comprehensive study of the Jurassic rocks of Scotland, was so impressed by these indications that he found it

'impossible to avoid the conviction that these patches of Secondary strata, although now so minute in dimensions and isolated in position, once formed portions of a great series of connected deposits which covered the greater part of the vast area [of Scotland] and attained in places a thickness of from 4,000 to 5,000 ft. . . . that the whole of the north and north-western portions of the British archipelago—now sculptured by denudation into a rugged mountain land—were, like the south and south-eastern parts of the same islands, covered by sedimentary deposits, ranging in age from Carboniferous to Cretaceous inclusive.'[1]

This was an extreme view, and it was opposed by such authorities as Sir Andrew Ramsay and Professor Sollas. The latter justly remarked that 'to say from the present absence of Oolitic beds over large areas that such beds had never been was more philosophical than to deduce from it their former existence', and upheld the view that also 'all Wales, Devonshire, Cornwall and the Pennine chain have been above water since the time of the Lower Lias'.[2] Nevertheless, it cannot be denied that there has been colossal loss by denudation, and that a very considerable area of what is now high mountainous country in the Hebrides and along the west coast must have been at one time covered by Jurassic and Cretaceous strata.

Unfortunately there is no hope of gaining any idea of the former extent of these sediments by looking for the sub-Mesozoic peneplain, for all traces of it have been obliterated by two or more phases of Tertiary peneplanation.

The loftiest mountains in Scotland, such as Ben Nevis and the Cairngorms, rise as monadnocks from a High Plateau at 2,000–3,000 ft., which is the most conspicuous physiographical feature of the Highlands. W. M. Davis ascribed this plateau to subaerial denudation, and he considered that, by analogy with other peneplains, it can hardly have been exposed to dissection longer than since late Mesozoic times, and that the work of dissection probably commenced in the Tertiary era.[3] According to Peach and Horne, the arrangement of the Mesozoic rocks shows that 'they must have entered, largely into the structure of the High Plateau'[4], and if that is so the peneplanation cannot be earlier than Tertiary. This conclusion falls into line with Trotter's views as to the Tertiary date of the peneplain at 2,000 ft. in the North Pennines, and with Fearnsides's conjecture regarding the one at the same height in North and Central Wales; hence it becomes extremely unlikely that any information on Mesozoic water-levels is to be gained from the peneplains in any of the highlands of Western and Northern Britain.

Along most of the west coast of Scotland a still later plateau is conspicuous, with an upper limit at about 1,000 ft. This is partly cut in the Eocene volcanic and plutonic rocks and is presumably a shelf of marine erosion, like the 1,000 ft. and lower platforms in Cornwall. Where it is found there is still less possibility of tracing any sub-Mesozoic peneplain.[5] Clearly, if we are to

[1] J. W. Judd, 1878, loc. cit., pp. 668–9.
[2] W. J. Sollas, in discussion of Judd's paper, ibid., p. 743.
[3] W. M. Davis, 1896, *Geol. Mag.* [4], vol. iii, p. 526.
[4] B. N. Peach and J. Horne, 1930, *Chapters on the Geology of Scotland*, p. 7.
[5] Peach and Horne call the 1,000 ft. the Intermediate Plateau, the lowest being the Continental Shelf; 1930, loc. cit., p. 2.

arrive at any decision as to how much of the Highlands was covered by the Jurassic sea, we must approach the question from other directions.

When Judd came to the conclusion that all Scotland was submerged and had the full thickness of Jurassic sediments deposited over it, he seems to have been influenced by two principal considerations: (1) the fact that the rocks in the Hebrides are not of littoral facies any more than those in England; and (2) the fact that it is only owing to faulting and lava-flows that any fragments have been preserved at all; which prompts the question: 'How much more may have been lost entirely, leaving no trace behind?' Let us now examine the value of these considerations as arguments.

The first may be dismissed, since all the Jurassic rocks of the Hebrides could have been deposited sufficiently far from a shore-line for them to contain no littoral deposits, without the whole of Scotland being submerged. The shore may have lain 10 or even 20 miles east of the existing deposits.

The second line of argument implies that the faulting and the igneous activity to which the sediments owe their preservation were restricted to the area where the sediments are found. For if the sediments previously existed everywhere and their survival anywhere is directly due to these processes, then they should be preserved as a natural consequence wherever the faulting and the igneous activity have occurred.

This raises an interesting point, because to a certain extent it is true that the relics of Mesozoic strata are centred precisely in the part of Scotland where Tertiary igneous activity and faulting were most thickly concentrated. The igneous activity, indeed, *was* virtually confined to the western coast and islands. The faulting seems to have been at least most frequent in the same area. Prof. Gregory believed that the majority of the pre-Glacial fiord-like lochs and valleys were due primarily to faults,[1] and, although this view has been questioned, it is remarkable that the faulted relics of Mesozoic rocks survive just in the area in which most of the fiords occur.

But it is possible that all three phenomena—igneous activity, faulting, and the occurrence of Mesozoic sediments—are merely effects of some common cause. If the area was one of subsidence in Jurassic times, it is not improbable that the same crustal weakness that gave rise to the subsidence and consequent sedimentation was later responsible for the localization of the faulting and igneous outbreaks of the Eocene period.

At least it would be very rash to assert, as Judd seems to imply, that the absence of Mesozoic sediments in other parts of Scotland can be attributed solely to the absence of those causes which conditioned their survival in the Hebrides—namely, lava-sheets and faulting.

Some of the largest faults of all, which have lowered the whole surface of the country thousands of feet, cross Scotland from sea to sea. The most important examples are the great trough faults of the Central Lowland or Midland Valley and the Great Glen (Glenmore). It is said that there are traces still extant of the river-system which drained the country now occupied by the Central Lowland and the surrounding country before the faults came into

[1] J. W. Gregory, 1913, *Nature and Origin of Fiords*, pp. 172–5, and map on p. 144. All agree that faults often determined the sites of fiords even though the fiord form was not directly due to faulting; for even if we suppose fiords to be ice-deepened valleys, the pre-Glacial rivers which originally formed the valleys frequently selected the lines of faults as paths of least resistance.

existence, and that the faults are therefore (at least in the main) of Tertiary date; and other faults which belong to the same group cut some of the Eocene igneous dykes.[1] Consequently, if thick Mesozoic strata had covered the area, they would have been lowered by the faults and some would surely have survived—at least until the Pleistocene Ice Age, when the Boulder Clay would have been filled with their fragments. In the Great Glen it is still more noteworthy that Mesozoic rocks do survive also at the eastern end of the troughed belt (in the Brora and Ethie district), but they are to be found *at the ends only*. There is nothing to show that the faulting which gave rise to the Great Glen was more intense at the extremities than in the middle, and indeed such an idea is on theoretical grounds highly improbable. Why, then, should there be no traces of Mesozoic rocks throughout the central and longest part of the trough?

The only logical conclusion seems to be that the Jurassic strata were only deposited, at least in anything like their full thickness, on either side of the Highlands; that Scotland formed an island, a non-subsiding block, between two sinking troughs or geosynclinals. Hence, even though the Jurassic seas may have transgressed to an unknown extent around its edges, the general tendency of the area would have been one of elevation, and no great thickness of Jurassic sediments is likely to have been deposited upon it.

On the other hand, the Jurassic rocks and their faunas, from the Lower Lias to the Kimeridge Clay, are so nearly identical on the two sides of Scotland[2] that a direct sea-connexion is demanded. De Lapparent's maps show continuous sea across the North-West Highlands[3] from the time of the Lower Lias,[4] and Prof. Wills also submerges the North-West Highlands during the Oxfordian period.[5] But the present heights of the North-West Highlands are little short of those of the Grampians: there are large areas over 1,500 ft. high, and many points exceed 3,000 ft.; on the same latitude as the Jurassic area of Ross-shire Ben Dearg rises to 3,547 ft.; and there is a point of 3,040 ft. (Ben Hope) within a few miles of the north coast. All this country consists of ancient rocks, the relics of the Caledonian mountains, and there is no more reason for supposing that it was ever submerged beneath the Jurassic sea than for supposing that the Grampian Highlands or Snowdonia were submerged.

Another form of connexion that is often portrayed on palaeogeographical maps is a narrow strait through the Great Glen, where Jukes-Browne imagined a river to have existed as early as the Triassic period, linking up the main Keuper lake with an isolated lake over the Golspie district and the Moray Firth.[6] But apart from the fact that this unjustifiably presupposes the existence of a Triassic and Jurassic Great Glen, as we have already remarked, if Jurassic sediments had been deposited all along it, there seems no reason why none should have been preserved in the middle. The central reaches of

[1] E. B. Bailey, 1910, 'Geol. East Lothian', p. 9, *Mem. Geol. Surv.*; and J. W. Gregory, 1913, loc. cit., p. 175.

[2] Excepting local accidents, such as the boulder-beds in the Kimeridgian of Sutherland.

[3] The term North-West Highlands is here used as defined by Peach and Horne, to denote the part of Scotland north and west of the Great Glen (Glenmore); the mountain mass between the Great Glen and the Central Lowland or Midland Valley being the Grampian Highlands.

[4] De Lapparent, 1906, *Traité*, p. 1126.

[5] L. J. Wills, 1929, *Physiog. Evolution of Britain*, p. 150.

[6] A. J. Jukes-Browne, 1911, loc. cit., pp. 248, 274; and Wills, loc. cit., p. 134.

the Great Glen would have provided an ideal place for the survival of some fragments of faulted Mesozoic strata had any existed there.

In view of these difficulties in the way of supposing the Highlands or Lowlands to have been submerged in the Jurassic period, the simplest course seems to be to make the necessary connexion round the north of the North-West Highlands, over the low-lying tract mainly occupied by sea at the present day. From the lie of the Trias at Elgin, on the south side of the Moray

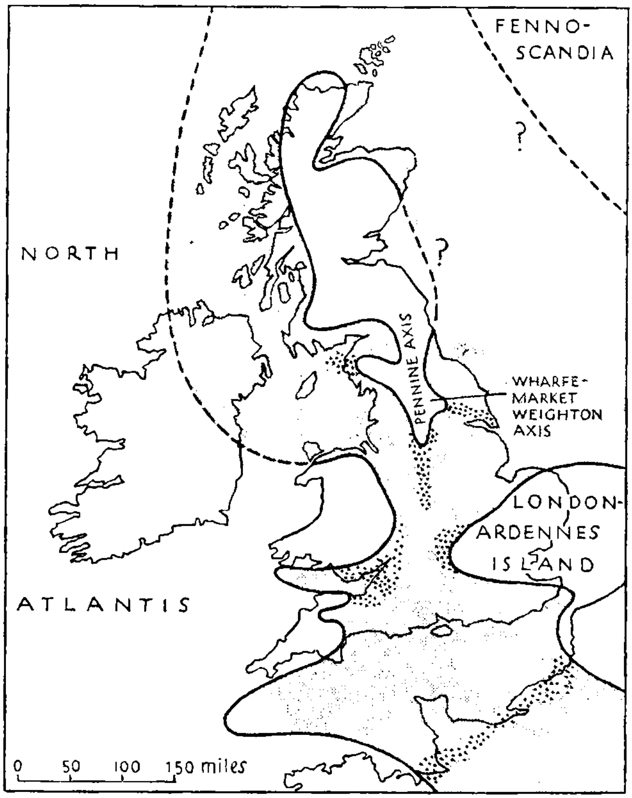

FIG. 96. Sketch-map to show the supposed distribution of land and sea over the British Isles during the deposition of the Lower Lias. Sea stippled; some special shallows dotted.

Firth, it is well-nigh certain that the Mesozoic rocks lapped round the Grampians across the low-lying promontory of North-East Aberdeenshire and Banff into the bay now occupied by the Moray, Cromarty and Dornoch Firths and the Coastal Lowland of Sutherland and Ross. It imposes no strain on probability if we imagine that they similarly lapped round the North-West Highlands, perhaps across part of Caithness and the Orkneys, into the Hebridean sea. The connexion that is demanded is one, not only from the Oxfordian period onward, but from the time of the Lower Lias and probably the Trias.

On this view the Grampians and the North-West Highlands, which, like the Northern Pennines, were considerably higher before the Tertiary peneplanation, would have stood above water in Mesozoic times. By analogy with other such massifs of elevated ancient rocks in Britain and on the Continent, upward movements would have been in excess of downward during Jurassic times, and there would never have accumulated those thousands of feet of sediments which Judd conjured up, but which only characterize geosynclinal regions.

(f) The North Sea Region and the Connexions with the Continental Troughs

De Lapparent[1] and most other palaeogeographers depict the greater part of the North Sea as submerged in Jurassic times beneath a broad channel leading to the Arctic Ocean. Fossils brought back in recent years from Spitsbergen and other Arctic islands prove that after the Triassic period there was a marine transgression in those regions at least as early as the time of the Upper Lias, and that shallow epeiric seas survived with sporadic interruptions until late in the Cretaceous period. The faunas of these far northern seas are of the same general facies as those which inhabited Europe, and they prove that the two areas lay within one and the same zoological province. There are many minor differences—in fact there is seldom specific identity—but this may be accounted for partly by the colder climate and partly by the fact that there was probably often emergence and loss of deposit in one area while there was submergence and deposition in the other, with the result that the faunas which appear most nearly comparable are not strictly synchronous.[2] However this may be, the correspondences are so close that there can be no doubt of the existence of a direct sea-connexion with North-Western Europe throughout most of the Mesozoic era.

A number of the Spitsbergen fossils are more closely allied to forms found only on the Continent than to British species. There must, therefore, have been some more direct connexion between the Continent and the Arctic than across England by way of the Hebrides.

These considerations make it probable that a channel or trough lay over at least a part of the North Sea, between the highlands of Scotland and Scandinavia (fig. 96). It is not by any means certain, however, that the channel remained always open. In the Bathonian period, for instance, when enormous quantities of sand were brought into the north of the British area, presumably by a large river or rivers from the Scandinavian highlands, so that deltaic and estuarine conditions prevailed on both sides of Scotland and in Yorkshire and Lincolnshire, it is difficult to see how any passage could have remained open. Probably deltaic material such as that which was carried southward on both sides of Scotland and all down Eastern England completely filled the narrow trough sea, cutting off communication with the Arctic (fig. 97).

Interesting light has been thrown on the south-westward extension of the ancient landmass of Fennoscandia, and the extent to which it supplied sediment to the adjoining Jurassic seas, by petrographical and stratigraphical

[1] 1906, *Traité*, maps on pp. 1126, 1189, 1211, 1225, 1239, 1245.

[2] H. Frebold, 1928, 'Strat. u. Paläog. des Jura u. der Kreide Spitzbergens', *Centralblatt für Min.* &c., Abt. B, p. 629, and *Skrifter om Svalbard og Ishavet*, 1929, no. 20, and 1930, no. 31, with numerous palaeogeographical maps. Spath rejects Frebold's explanation in favour of climatic races.

investigations in North Germany. Brinkmann[1] and Schott[2] have shown that at least from Vesulian to Kimeridgian times the bulk of the clastic sediment deposited in the North German sea was derived from the north. Every formation when followed from north to south passes from sand into clay. On the strength of a great deal of evidence brought together from an examination of outcrops, borings and Drift pebbles, it is concluded that at least from the

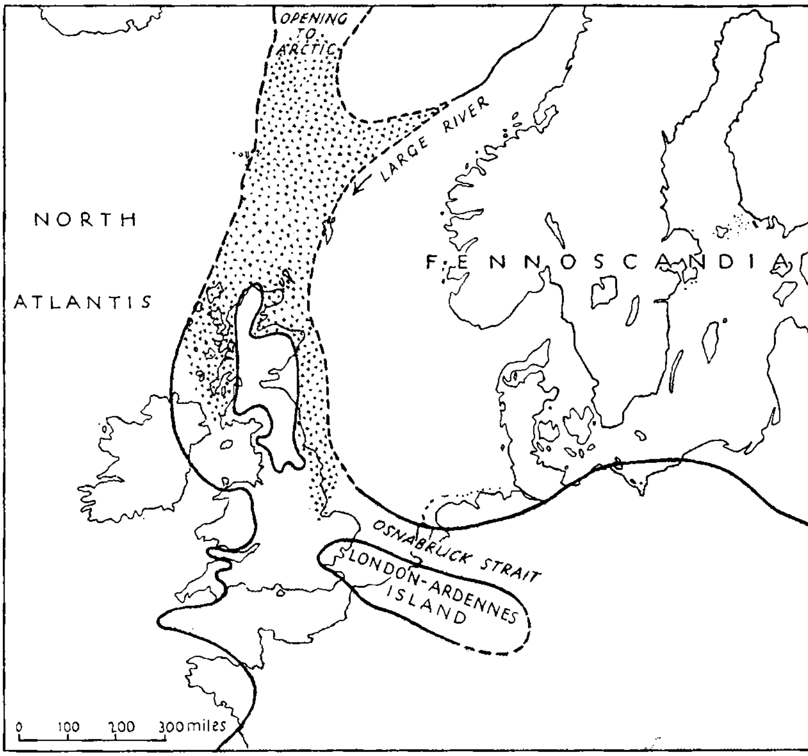

FIG. 97. Sketch-map to show the supposed distribution of land and sea during the Bathonian period (Tulitan Age). Deltaic deposits dotted. The boundary of Fennoscandia over Germany according to Schott.

Parkinsonian to the Perisphinctean Ages the coast-line ran roughly E.–W. across the South Baltic region from Riga towards Copenhagen, and thence, after encircling a gulf that lay over most of Denmark, on by way of Hamburg and the Zuider Zee in the direction of The Wash. On this view most of the North Sea was land, an extension of the continent of Fennoscandia.[3]

Somewhat farther south, as we have seen in Chapters II and III, lay the London–Ardennes landmass, and although this was negligible as a source of sediment in Germany according to Schott, its existence as a large island is

[1] R. Brinkmann, 1923, 'Dogger u. Oxford des Südbaltikums', *Jahrb. Preuss. Geol. Landesanst.*, vol. xliv, pp. 477–513.

[2] W. Schott, 1930, 'Paläogeographische Untersuchungen über den Oberon Braunen und Unteren Weissen Jura Nordwestdeutschlands': Inaugural-Dissert., Göttingen, *Abh. Preuss. Geol. Landesanst*, N.F., Heft 133, pp. 1–51.

[3] Schott uses the name Cimbria for the south-western peninsula separated by the Danish Gulf (which only came into existence with the Callovian (Macrocephalitan) transgression).

manifest in the thinning out of the formations towards its shores both in England and in North-West Germany, and in its contributions of sediment in England. Its northern shore-line, striking WNW.–ESE., is found by Schott to be constantly in evidence owing to the attenuation of the formations south-west of the Teutoburger Wald, which bounds the Jurassic region of Hanover, Bielefeld and Osnabrück.

Between the London–Ardennes landmass and the south-westerly extension of Fennoscandia the Jurassic rocks are arranged in a typical trough of deposition, which Schott has called the Osnabrück Strait. It strikes approximately SE.–NW., in the direction of East Anglia, and is crossed, like its English analogues, by axes of uplift running at right angles to the direction of the trough and causing local attenuation of the rocks.

There can be no doubt that the Osnabrück Strait made connexion with the English Midland trough in Lincolnshire and the district of The Wash. This connexion accounts for several facts, notably the occurrence in the Coral Rag of Upware and Yorkshire of a group of ammonites and lamellibranchs which have never been found in the South of England, but which were described on the Continent, especially in the Department of the Meuse (p. 416). It may also explain the resemblance of the Cardiocerates of Eastern Scotland to Russian species (p. 434); though, if a more critical study of the German Cardiocerates fails to reveal these species, it will have to be supposed that they migrated round the north of Fennoscandia by way of the Arctic. It was undoubtedly through the Osnabrück Strait that the Jurassic sea first invaded the British Isles from the Continent. The Rhætic Beds of Germany and their fauna are almost identical with our own, whereas the correspondence with those of France is much less close. In the Rhætic and Liassic periods the strait was probably wider than in Upper Jurassic times and may have covered a considerable area which later became part of Fennoscandia. Northward, as already mentioned, it seems highly probable that it was continued east of Scotland to the Arctic Sea.

The direct connexion between England and the Paris Basin seems to have been first opened at the time of the Lower Lias. Thenceforward there was always a wide sea channel between Normandy and the Boulonnais, perfectly continuous with that between Dorset and Kent.[1] M. Lemoine has shown that the deepest part of the trough lay along its north-eastern side, close to the London–Ardennes island, from the Pays de Bray eastward along the basins of the Marne and the Aisne, across that of the Meuse, towards the Vosges. Here in a broad belt the Lias is more than 1,000 ft. thick and the Palaeozoic floor reaches its greatest depths below the surface.[2] This deep zone is separated from that in Kent by a ridge of shallows which runs approximately under the French coast. It appears to be a typical 'axis of uplift' with Caledonian strike, like those which Schott has detected crossing the Osnabrück Strait, and upon it the whole of the Lias is exceptionally thin (105 ft. at Abbeville, probably less at Rouen, and said to be nil at Havre). Little has been learnt about this ridge, however, for the Cretaceous covering is thick and there

[1] See W. J. Arkell, 1930, 'A Comparison between the Jurassic Rocks of the Calvados Coast and those of Southern England', *P.G.A.*, vol. xli, pp. 396–411, esp. 396–7.

[2] P. Lemoine, 1930, 'Structure d'ensemble du bassin de Paris', *Livre jubilaire, Soc. géol. France*, vol. ii, pl. XLIX and L.

have been few borings. The attenuation of the Jurassic rocks westward in Normandy is due to their approaching the margin of the trough of deposition and has no bearing on the subject.

Back at the shores of the Celtic highland, we must bring our brief survey of British Jurassic palaeocartography to an end.

The picture of contemporary geography which we are led to draw differs from those extreme reconstructions which either conjure up land almost wherever no Jurassic sediments are found at the present day or extend the sea across the whole British area from horizon to horizon. It enables us to recognize the significance of the outliers in Ireland and the Hebrides without submerging the Scottish and Welsh Highlands beneath a sea with thousands of feet of sediment accumulating on its bed; it admits of a strait up the western part of the North Sea, connecting Germany with Eastern Britain and the Arctic, although most of the area was occupied by the Fennoscandian mainland. Our picture is of a landscape diversified with rather narrow and strait-like seas, occupying a subsiding cleft between the mainlands of Fennoscandia on the one side and North Atlantis on the other, and broken by two elongated islands—the London–Ardennes Island in the south-east, the Scottish–Pennine Island in the north.

Around the margins of the land the seas transgressed and regressed with an unceasing ebb and flow, as in one age subsidence exceeded elevation and in another elevation overcame subsidence. On the whole, however, the upward tendency prevailed on the land and the downward in the troughs, until in the end the centres of the troughs had subsided between 3,000 and 4,000 feet, and they had become filled with the richly-fossiliferous and inexhaustibly interesting series of varied sediments which we call the Jurassic System.

ILLUSTRATIONS OF THE PRINCIPAL SPECIES OF AMMONITES EMPLOYED AS ZONAL INDICES IN THE BRITISH JURASSIC

with the characteristic lamellibranchs of the Rhætic and Pre-*planorbis* Beds and the zonal ostracods of the Purbeck Beds.

Mainly from photographs by J. W. TUTCHER, Esq., M.Sc.

EXPLANATORY NOTES

DIMENSIONS.—After the name and particulars of each specimen the dimensions are given, following S. S. Buckman. The first figure represents the maximum diameter in millimetres, the second the height of the last whorl, the third the thickness of the last whorl, the fourth the width of the umbilicus. The last three dimensions are expressed as percentages of the diameter. At the end comes the amount of the reduction or enlargement of the figure.

TYPE SPECIMENS.—Types are designated as follows:

Holotype: the original specimen on which a species was founded.

Syntypes: the original specimens on which a species was founded, when two or more specimens were figured or described and no holotype was designated.

Paratypes: any other specimens figured or referred to by the author in his original description as belonging to his species in addition to a specified holotype.

Lectotype: a specimen selected as type by a subsequent author from among the original syntypes.

Topotypes: specimens from the same horizon and locality as the original types.

Chorotypes: specimens from the same district and horizon as the original types, but not from exactly the same locality.

Neotype: a specimen designated as type by a subsequent author when the original types are lost or destroyed or too fragmentary for recognition. A neotype may only be chosen from among paratypes, topotypes, or chorotypes.

Genotype: the original specimen on which a genus was founded. And so on for genosyntypes, genolectotype, &c.

PLATE XXIX

RHÆTIC BEDS AND PRE-PLANORBIS BEDS

PRE-PLANORBIS BEDS

1. *Oxytoma longicostata* (Strickland),
Montpelier, Bristol. J.W.T. coll. fig. ×0·6.
2. *Ostrea liassica* Strickland (= *O. irregularis* Schlotheim?),
Ostrea Beds, Stoke Gifford, nr. Bristol. J.W.T. coll. fig. ×1·0.
3. *Lima terquemi* Tate,
Shepton Mallet, Somerset. J.W.T. coll. fig. ×1·0.
4. *Modiola minima* Sowerby,
Ashley Hill, Bristol. J.W.T. coll. fig. ×1·5.
8. *Pleuromya tatei* Richardson & Tutcher,
Stapleton, Bristol. J.W.T. coll. fig. ×1·0.

LANGPORT BEDS OR WHITE LIAS

5. *Dimyodon intus-striatus* (Emmrich),
Cold Knap, Barry, Glamorgan. L. Richardson coll. fig. ×2·0.
6. *Modiola langportensis* (Richardson & Tutcher),
Langport, Somerset. J.W.T. coll. fig. ×1·0.

COTHAM BEDS

7. *Pseudomonotis fallax* (Pflücker),
Kilmersden, Somerset. J.W.T. coll. fig. ×1·0.

WESTBURY BEDS OR CONTORTA SHALES

9. *Pteromya crowcombeia* Moore,
Blue Anchor, nr. Watchet. L. Richardson coll. fig. ×2·0
(from Richardson & Tutcher, 1916, Proc. Yorks. G. S., xix, pl. VIII, fig. 1).
10. '*Schizodus*' *ewaldi* (Bornemann) (= '*Axinus*' *cloacinus* Quenst. sp. et Moore; = '*Isocyprina*' *ewaldi* Healey). Genus indet. Pending determination of the genus, *Schizodus* is retained here, as in the bulk of the previous literature, although it and all other generic determinations made hitherto are certainly wrong.
Beer Crowcombe, Somerset. J.W.T. coll., ex. Moore coll. fig. ×2·0.
11. *Chlamys valoniensis* (Defrance),
Stoke Gifford, Glos. J.W.T. coll. fig. ×1·0.
12. *Protocardia rhætica* (Mérian),
Charlton, near Bristol. J.W.T. coll. fig. ×1·75.
13. *Mytilus cloacinus* Tutcher,
Bone Bed, Aust Cliff. J.W.T. coll. fig. ×1·0.
14. '*Cardium*' *cloacinum* Quenstedt,
Blue Anchor, nr. Watchet. J.W.T. coll. fig. ×1·0.
15. *Pleurophorus elongatus* Moore,
Aust Cliff. J.W.T. coll. fig. ×1·0.
16. *Pteria contorta* (Portlock),
Charlton, near Bristol. J.W.T. coll. fig. ×1·3.

SULLY BEDS

17. *Ostrea bristovi* Etheridge,
St. Mary's Well Bay, Glamorgan. J.W.T. coll. fig. ×0·8.

PLATE XXIX

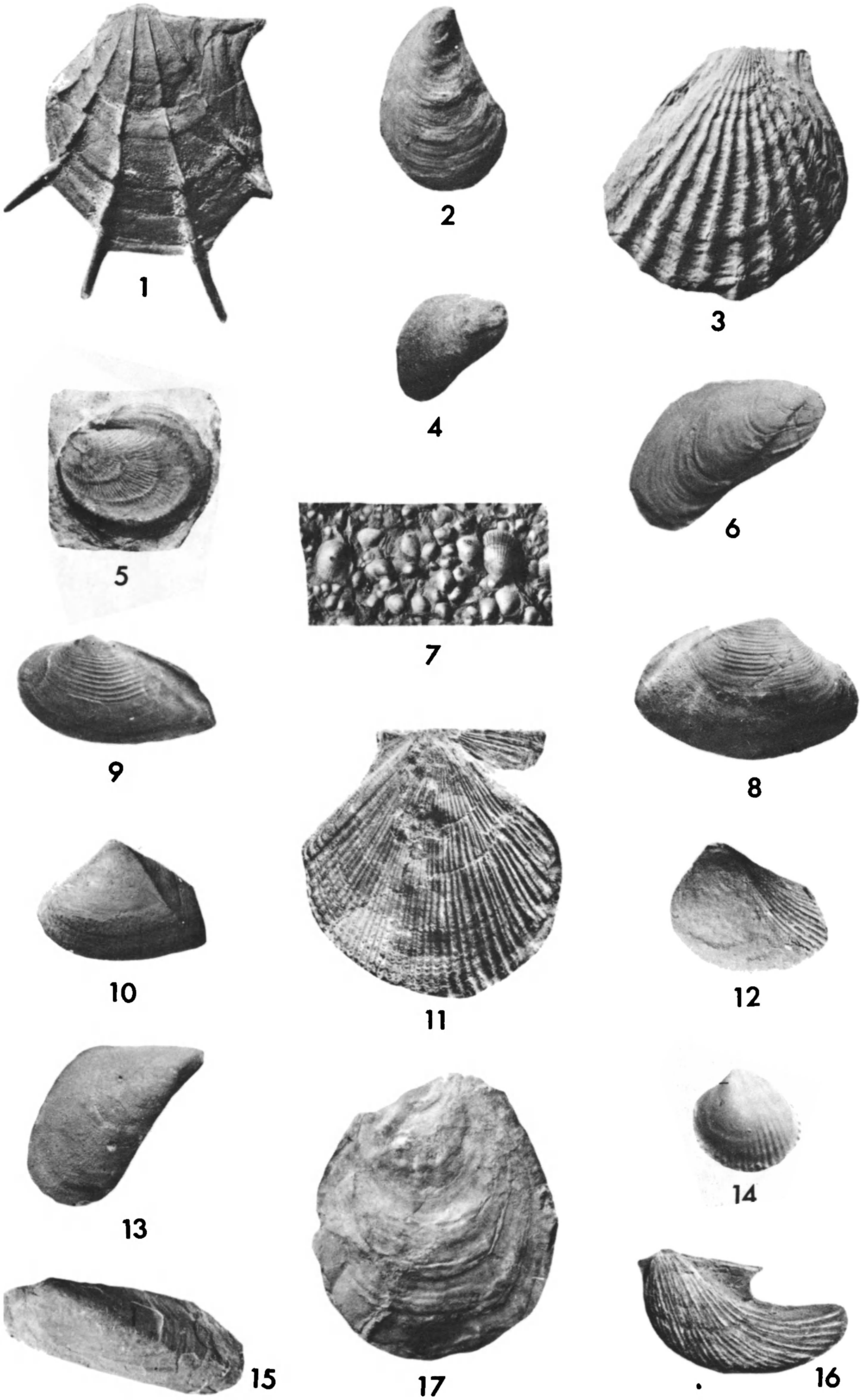

PLATE XXX

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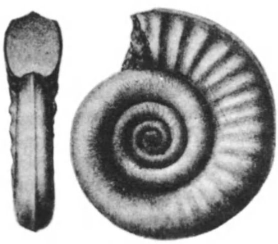

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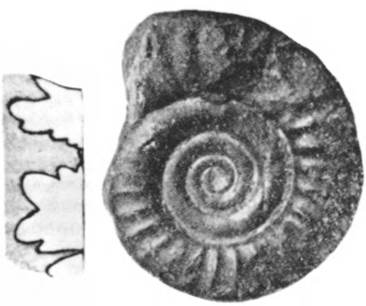

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PLATE XXX

LOWER LIAS

1. *Oxynoticeras oxynotum* (Quenstedt),
Stonehouse, near Stroud, Glos. J.W.T. coll.
48. 50.15.20. fig. ×1·29.

2. *Asteroceras obtusum* (Sowerby),
Charmouth, Dorset. Chorotype. J.W.T. coll.
70. 37.31/34.40. fig. ×0·8.

3, 4. *Arnioceras semicostatum* (Young & Bird),
3. Semur, Côte d'Or, France; from Hyatt, *Genesis of the Arietidae*, 1889, pl. 2, fig. 10. fig. ×1·0.
4. The holotype, Robin Hood's Bay, Yorkshire. Whitby Museum; from Buckman, *Type Ammonites*, vol. 2, pl. cxii.
38. 29.23.52. fig. ×1·0.

5. *Coroniceras bucklandi* (Sowerby),
Keynsham, Somerset. Chorotype. J.W.T. coll. (The whorl-section is drawn from another figure and is too quadrate.)
493. 26.32.55. fig. ×0·15.

6. *Scamnoceras angulatum* (Schlotheim),
Hanham, near Bristol. J.W.T. coll.
48. 35.25.34. fig. ×1·0.

7. *Psiloceras planorbis* (Sowerby),
Watchet, Somerset. Topotype. J.W.T. coll. (The crushed condition is typical.)
68. 32.?.42. fig. ×0·75.

PLATE XXXI

LOWER AND MIDDLE LIAS

1. *Paltopleuroceras spinatum* (Bruguière),
Stoke-sub-Hamdon, near Ilchester, Somerset. J.W.T. coll.
48. 34.30.40. fig. × 1·0.

2. *Amaltheus margaritatus* (Montfort),
South Petherton, Somerset. J.W.T. coll.
66. 43.20.28. fig. × 0·8.

3. *Prodactylioceras davœi* (Sowerby),
Charmouth, Dorset. Topotype. J.W.T. coll.
66. 25.27.56. fig. × 0·8.

4. *Tragophylloceras ibex* (d'Orbigny),
Branch Huish, near Radstock, Somerset. J.W.T. coll.
43. 43.23.26. fig. × 1·0.

5. *Echioceras raricostatum* auct. pars, *E. raricostatoides* Vadasz (= *E. raricostatum* Bayle non Zieten).
The true *E. raricostatum* Zieten, which is rare in Britain, has a somewhat less rounded whorl and rather more widely-spaced ribbing on the outer whorls: see Trueman & Williams, 1925, *Trans. Roy. Soc. Edinburgh*, vol. liii: there are, however, many closely comparable forms, doubtfully true species.
Grove Quarry, Radstock, Somerset. J.W.T. coll.
60. 20.19/23.62. fig. × 0·9.

6. *Uptonia jamesoni* (Sowerby),
Paulton, Somerset. J.W.T. coll.
96. 33.22.51. fig. × 0·78.

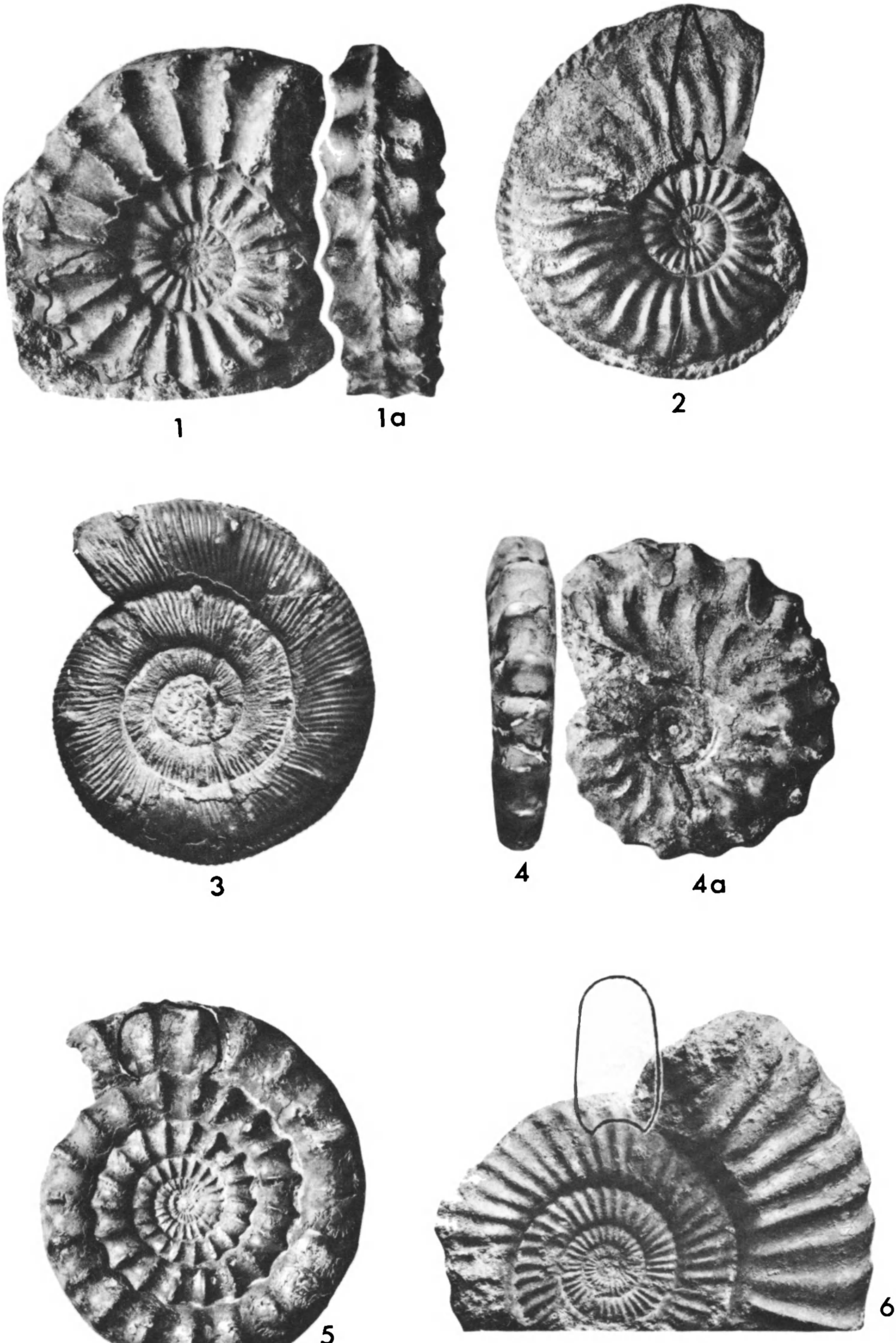
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PLATE XXXII

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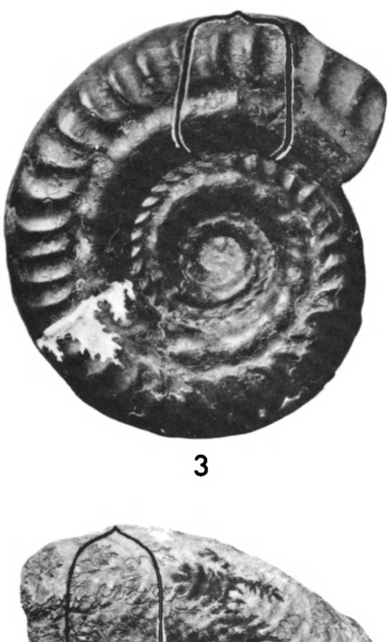

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PLATE XXXII

UPPER LIAS

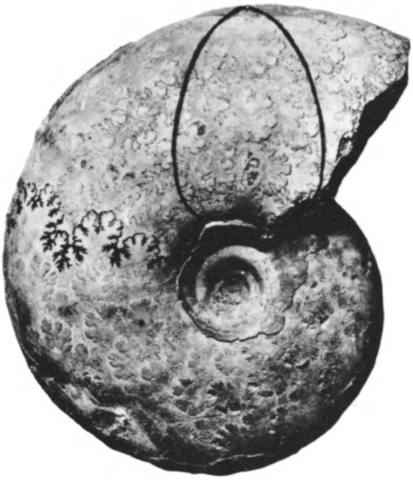
1. *Lioceras opalinum* (Reinecke),
Near Bridport, Dorset. J.W.T. coll.
55. 50.20.16. fig. ×1·0.
2. *Lytoceras jurensis* (Zieten),
Frocester Hill, Glos. J.W.T. coll.
101. 42.36.30. fig. ×0·65.
3. *Hildoceras bifrons* (Bruguière),
Whitby, Yorks. J.W.T. coll.
60. 32.30.41. fig. ×1·0.
4. *Dactylioceras commune* (Sowerby),
Whitby, Yorks. Topotype. J.W.T. coll.
53. 25.24.60. fig. ×1·0.
5. *Harpoceras falcifer* (Sowerby),
Moolham, near Ilminster, Somerset. J.W.T. coll.
107. 40.21½.31. fig. ×0·6.
6. *Dactylioceras tenuicostatum* (Young & Bird),
Whitby, Yorks. Chorotype. J.W.T. coll.
66. 22½.20.56. fig. ×0·8.

PLATE XXXIII

LOWER AND MIDDLE INFERIOR OOLITE

1. *Shirbuirnia stephani* Buckman,
Sandford Lane, near Sherborne, Dorset. Chorotype. J.W.T. coll.
117. 51.31.18. fig. ×0·55.
2. *Hyperlioceras discites* (Waagen) pars., *H. discitiforme* Buckman. The holotype of *H. discites* (Waagen) in the Berlin Museum has been figured by Buckman (1907, 'Mon. Ammonites Inf. Ool.', *Pal. Soc.*, p. cxxii, fig. 88), who says that all the British specimens differ slightly in either ribbing or proportions or both. He therefore regards them as distinct species.
Bradford Abbas, Dorset. Topotype. J.W.T. coll.
65. 50.20.13. fig. ×1·0.
3. *Ludwigella concava* (Sowerby),
Wyke, near Sherborne, Dorset. J.W.T. coll.
71. 52.21.15. fig. ×0·8.
4. *Tmetoceras scissum* (Benecke),
Burton Bradstock, Dorset. J.W.T. coll.
35. 33.28.45. fig. ×1·1.
5. *Brasilia bradfordensis* Buckman,
Barrofield, Beaminster, Dorset. J.W.T. coll.
123. 48.21.21. fig. ×0·45.
6. *Ludwigia murchisonæ* (Sowerby),
Bradford Abbas, Dorset. From Buckman, 'Mon. Ammonites Inf. Ool. Pl. III, fig. 1.
114. 41.26.32. fig. ×0·6.

PLATE XXXIII



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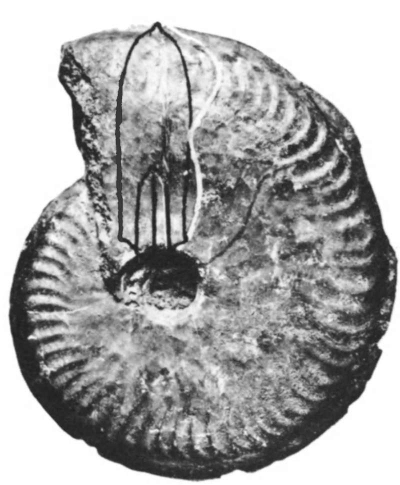

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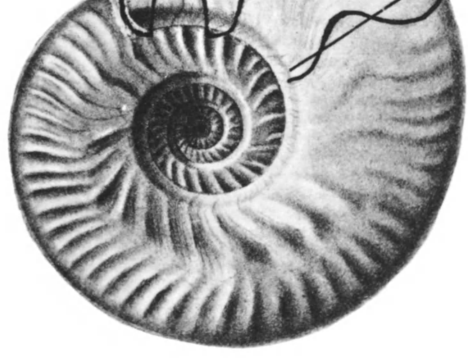

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PLATE XXXIV

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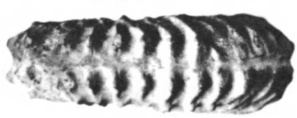

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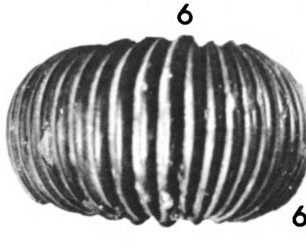


6a

5a

PLATE XXXIV

MIDDLE AND UPPER INFERIOR OOLITE

1. *Parkinsonia schlœnbachi* Schlippe,
Burton Bradstock, Dorset. G. A. Kellaway coll.
75. 34.33.44. fig. ×0·7.
2. *Garantiana garantiana* (d'Orbigny),
Near Sherborne, Dorset. J.W.T. coll.
76. 38.34.36. fig. ×0·75.
3. *Strigoceras truellei* (d'Orbigny),
Burton Bradstock, Dorset. J.W.T. coll.
79. 56.36.7. fig. ×0·7.
4. *Strenoceras niortensis* (d'Orbigny),
Oborne, Dorset. J.W.T. coll.
40. 35.30.41. fig. ×1·0.
5. *Teloceras blagdeni* (Sowerby),
Near Sherborne, Dorset. J.W.T. coll.
41. 29.71.47. fig. ×1·2.
6. *Otoites sauzei* (d'Orbigny),
Dundry Hill, Somerset. J.W.T. coll.
36. 42.50.23. fig. ×1·2.

PLATE XXXV

GREAT OOLITE SERIES AND CORNBRASH

1. *Macrocephalites macrocephalus* (Schlotheim),
Upper Cornbrash, Shorncote, Glos. W.J.A. coll.
Identified by L. F. Spath and mentioned Douglas & Arkell, *Q.J.G.S.*, vol. lxxxiv, p. 135.
151. 53.52½.12. fig. ×0·33.

2. *Clydoniceras discus* (Sowerby),
Lower Cornbrash, South Brewham, Somerset. J.A.D. & W.J.A. coll.
Identified by S. S. Buckman and figured *T.A.*, plate DVI B; mentioned Douglas & Arkell, *Q.J.G.S.*, vol. lxxxiv, p. 146.
60. 60.25.0 fig. ×1·0.

3. *Tulites subcontractus* (Morris & Lycett),
Great Oolite, Minchinhampton, Glos. Lectotype. Lycett coll.
Geol. Survey Engl., No. 25610. Figd. Buckman, *T.A.*, vol. 4, pl. CCLXX.
86. 35.51.35. fig. ×0·72.

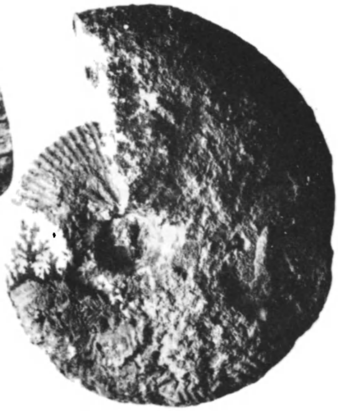
4. *Morrisiceras morrisi* (Lycett),
Great Oolite, Minchinhampton. Topotype. J.W.T. coll.
68. 50.64.15. fig. ×0·85.

5. *Oppelia fusca* (Quenstedt),
Basal Fuller's Earth, Broad Windsor, Dorset. J.W.T. coll.
Identified by S. S. Buckman.
38. 55.18.9. fig. ×1·24.

6. *Zigzagiceras zigzag* (d'Orbigny),
Zigzag Bed, Crewkerne, Somerset. J.W.T. coll.
37. 33.32.43. fig. ×1·0.

PLATE XXXV

1



1a

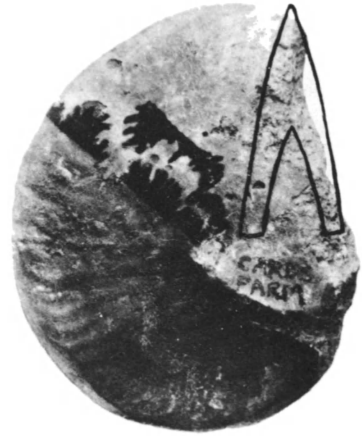


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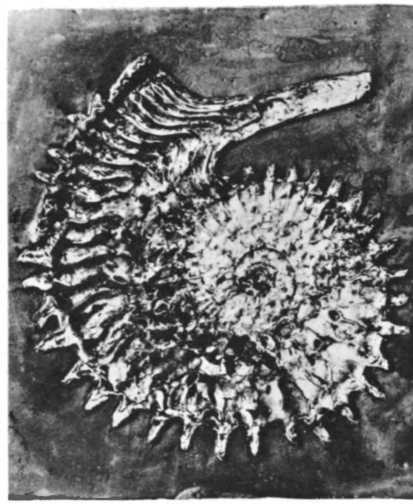
PLATE XXXVI


1


1a


2

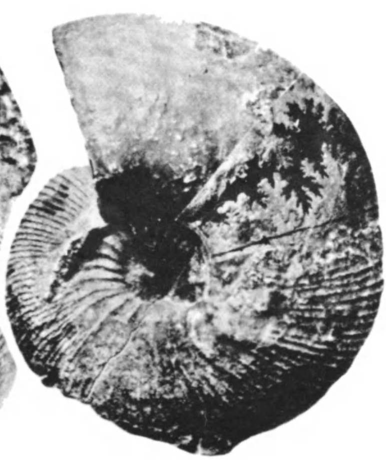

3


3a


4


4a


5


5a


6

PLATE XXXVI

KELLAWAYS BEDS AND LOWER OXFORD CLAY

1. *Erymnoceras reginaldi* (Morris),
Trowbridge, Wilts. Topotype. British Museum.
430. 38.36.36. fig. ×0·16.
2. *Kosmoceras* (*Spinikosmoceras*) *pollux* (Reinecke),
Christian Malford, Wilts. Brit. Mus., No. 62229. (The flattening is highly characteristic in England.)
60. 38½.—.32. fig. ×0·9.
3. *Kosmoceras* (*Gulielmites*) *jason* (Reinecke),
Gammelshäusen, Württemberg. Chorotype. Alte Akademie, Munich. After S. S. Buckman, *T.A.*, 1924, plate DIII.
24. 44.26.29. fig. ×1·0.
4. *Cadoceras sublæve* (Sowerby),
Kellaways Rock, Kellaways, Wilts. Topotype. J.W.T. coll. Figd. Buckman, *T.A.*, 1922, pl. CCLXXV.
65. 39.80.25½. fig. ×0·76.
5. *Sigaloceras calloviensis* (Sowerby),
Kellaways Rock, Kellaways, Wilts. Holotype, Sowerby coll., Brit. Mus. Photographed from plaster cast; suture from another specimen (chorotype, ?topotype) superimposed.
94. 47.41.22. fig. ×0·63.
6. *Proplanulites kœnigi* (Sowerby),
Kellaways Clay, near Chippenham, Wilts. Chorotype. J.W.T. coll. Suture from another specimen.
70. 40.30.29. fig. 1×·0.

PLATE XXXVII

MIDDLE AND UPPER OXFORD CLAY

1, 2. *Cardioceras præcordatum* R. Douvillé,
1. Marnes à *Creniceras renggeri*, Jura Mountains. Paratype; from R. Douvillé, 1912, *Mém. Soc. géol. France*, vol. xix, p. 62, pl. IV, fig. 21.
28. 45.33.29. fig. ×1·0.
2. Horton-cum-Studley, near Oxford. W.J.A. coll.
38. 42.32.31. fig. ×1·0.

3. *Quenstedtoceras lamberti* (Sowerby),
Tidmoor Point, Weymouth. Topotype. J.W.T. coll.
63. 40.25.32. fig. ×1·0.

4. *Creniceras renggeri* (Oppel) (*Ammonites cristatus* Sowerby non Defrance),
Ludgershall, Bucks. Geol Survey coll. No. 27791.
15. 49.22.24. fig. ×1·5.

5. *Kosmoceras proniæ* Teisseyre,
Summertown Brickyard, Oxford. J.W.T. coll.
41. 45.30.25. fig. ×1·0.

6. *Kosmoceras duncani* (Sowerby),[1]
Summertown Brickyard, Oxford. J.W.T. coll.
33. 42.29.29. fig. ×1·0.

7. *Peltoceras athleta* (Phillips),
Hackness Rock, Scarborough, Yorks. Topotype, Neotype. Brit. Mus., No. 89052. Identified and figured by L. F. Spath, 1931, *Mem. Geol. Survey India*, vol. ix, pl. CVI, fig. 3, and CVII, fig. 5.
70. 28.46.49. fig. ×1·0.

[1] This specimen compares as nearly as possible with Sowerby's figure of *Ammonites duncani*; the original, which came from the Oxford Clay of St. Neots, is lost. Brinkmann's so-called neotype, from Etrochey, Côte d'Or (*Abh. Ges. Wiss. Göttingen*, 1929, M-P. Kl., N.S., vol. xiii, pl. 1, fig. 7), should not be accepted, since it bears no resemblance to Sowerby's figure and was not chosen from among topotypes or even chorotypes.

PLATE XXXVII

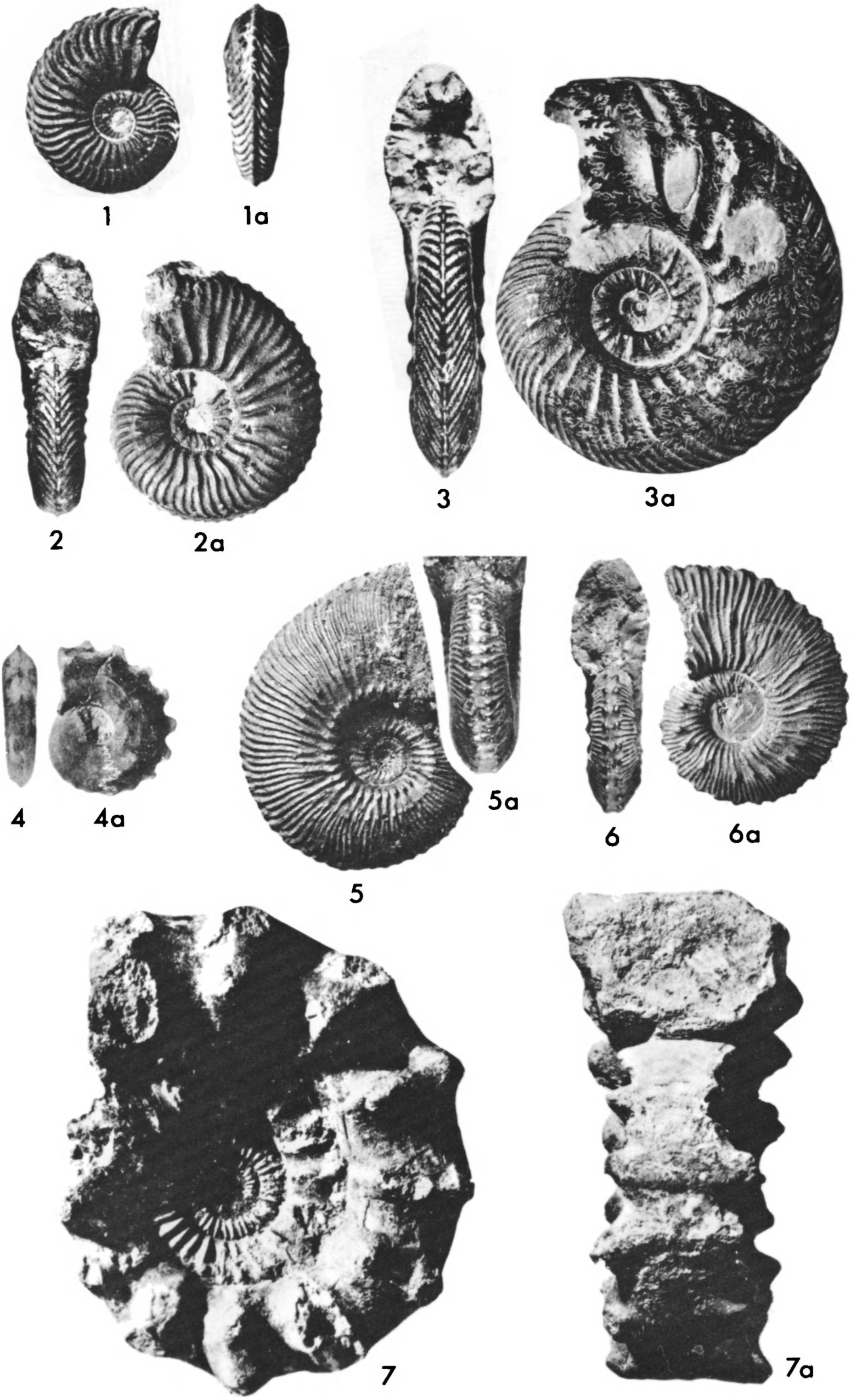
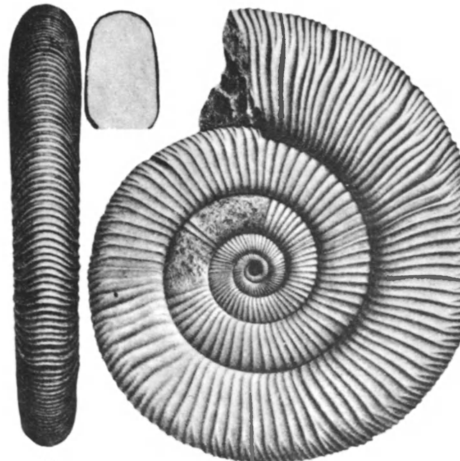


PLATE XXXVIII

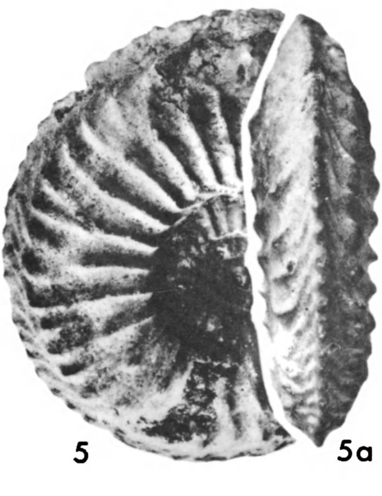
1



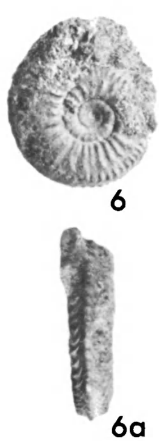
2 2a

3

4 4a



5 5a



6 6a

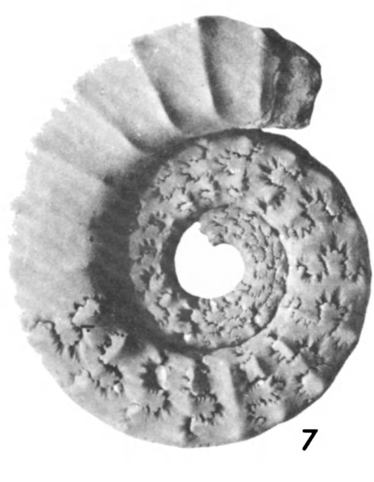


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PLATE XXXVIII

CORALLIAN BEDS

1. *Ringsteadia anglica* Salfeld,
Iron Ore, Westbury, Wilts. Topotype. Devizes Museum.
263. 34.19½.37. fig. ×0·25.

2. *Perisphinctes* (*Dichotomosphinctes*) *wartæ* Bukowski,
Weisser Oxfordkalk, Czenstochau, Poland. Copy of original figure, *Beitr. z. Geol. u. Pal. Österr.-Ungarns*, vol. v, 1887, pl. XXXVII, fig. 1.
156. 27.17.51. fig. ×0·35.

3. *Perisphinctes* (*Dichotomosphinctes*) *antecedens* Salfeld,
Junction of Heersumer Schichten and Korallenoolith, near Hildesheim, North-West Germany. Copy of original figure, 7e *Jahresber. d. Niedersäch. geol. Vereins z. Hannover*, 1914, fig. 3.
133. 27.24.55. fig. ×0·42.

4. *Perisphinctes* (*Perisphinctes*) *martelli* (Oppel),
Holotype (*Amm. biplex* d'Orbigny non Sow.); locality unknown. From *Palaeontologia Universalis*, no. 51.
268. 23.30.60. fig. ×0·2.

5, 6. *Cardioceras cordatum* (Sowerby),
5, 5 *a*. Lower Calcareous Grit, Marcham, Berks. Chorotype. Brit. Mus. No. 88978.
60. 40.28.33½. fig. ×1·0.
6, 6 *a*. Lower Calcareous Grit, Shotover, Oxon. Holotype. Brit. Mus. Sowerby coll.
20. 35.25.40. fig. ×1·0.

7. *Aspidoceras* (*Euaspidoceras*) *catena* (Sowerby),
Lower Calcareous Grit, Marcham, Berks. Topotype. Oxford University Museum.
272. 28.27.51½. fig. ×0·2.

PLATE XXXIX

KIMERIDGE CLAY

1. *Virgatosphinctoides wheatleyensis* Neaverson,
Kimeridge Clay, Wheatley, Oxon. Holotype. Brit. Mus. No. C. 26897. From Neaverson, *Amm. Up. Kim. Clay*, pl. 1, fig. 1.
122. 33.28.48. fig. ×0·6.

2. *Gravesia gravesiana* (d'Orbigny),
Near Auxerre, Yonne, France. Syntype, Geno-syntype. From *Palaeontologia Universalis*, No. 178, figs. T 1, T 1 *a*.
85. 34.76.42. fig. ×0·68.

3. *Aulacostephanus pseudomutabilis* (de Loriol),
Speeton, Yorkshire. Geol. Survey coll., No. 18150.
Specimen identified by Dr. F. L. Kitchin.
73. 41.26.27½. fig. ×0·93.

4. *Rasenia cymodoce* (d'Orbigny),
Lectotype, Genotype. Locality unknown. From *Palaeontologia Universalis*, No. 55.
81. 33.26½.45. fig. ×0·6.

5. *Pararasenia mutabilis* (Sowerby),
Horncastle, Lincolnshire. Holotype. British Museum, Sowerby coll.
70. 38½.28½.36. fig. ×1·0.

6. *Pictonia baylei* Salfeld,
Wootton Bassett, Wilts. J.W.T. coll.
135. 31.22.48. fig. ×0·5.

PLATE XXXIX

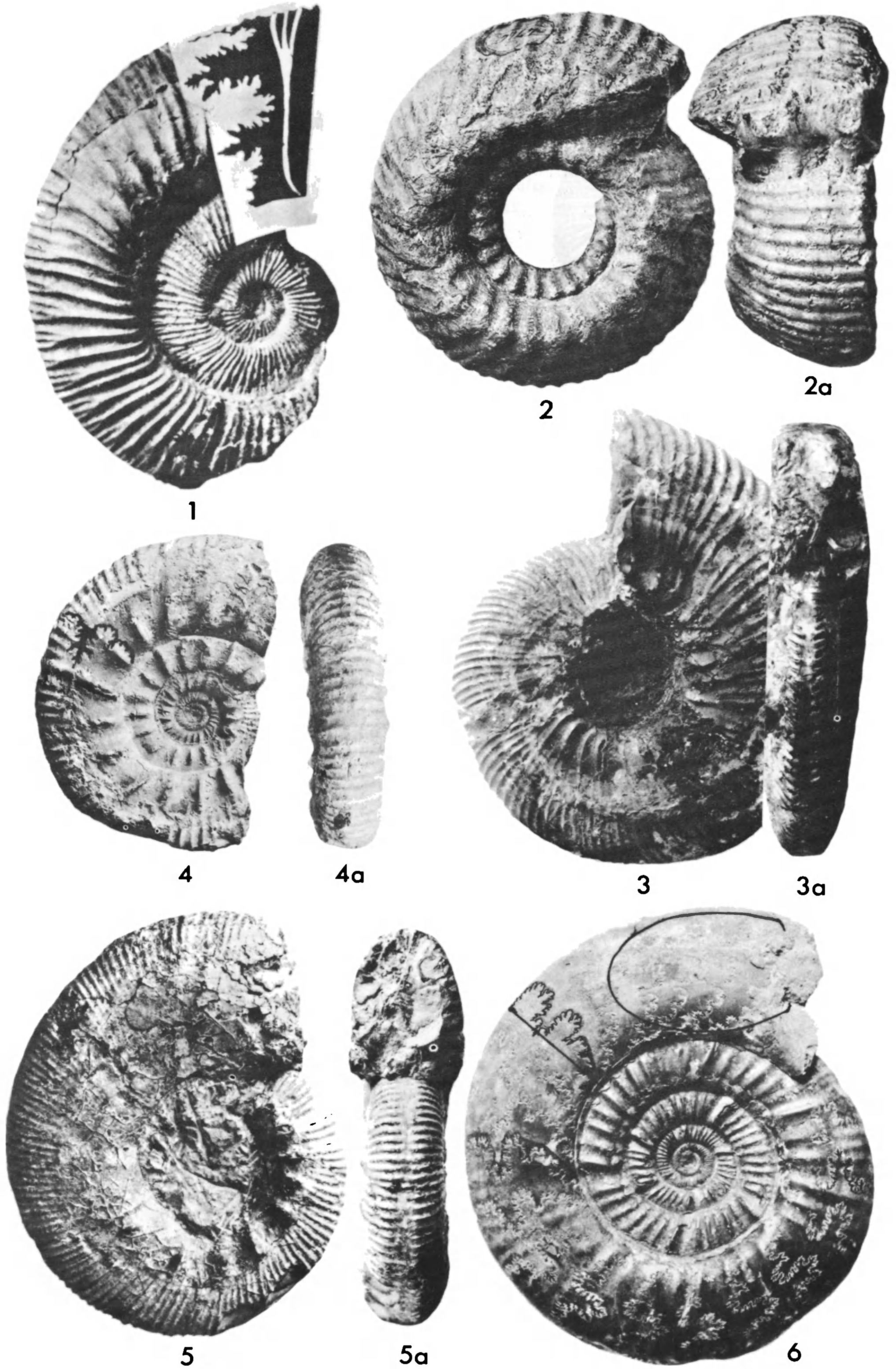


PLATE XL

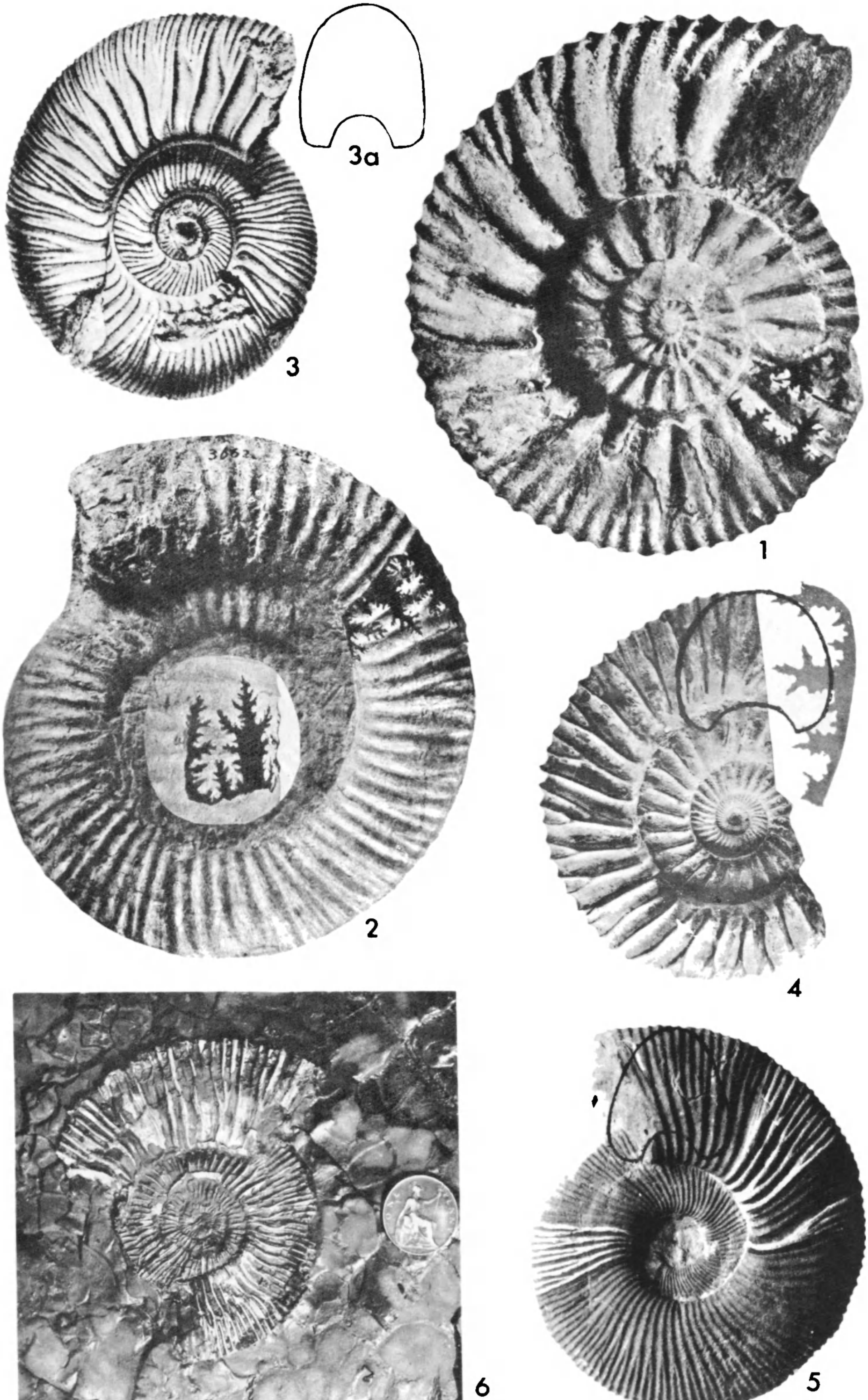


PLATE XL

PORTLAND BEDS AND UPPER KIMERIDGE CLAY

1. *Kerberites kerberus* Buckman,
Portland Stone, Chicksgrove, Tisbury, Wilts. Genotype, Holotype. J.W.T. coll. Figd. Buckman, *T.A.*, pl. DXX.
105. 33.41.40. fig. ×0·76.
2. *Glaucolithites glaucolithus* Buckman,
Glauconitic Beds, Portland Sand, Long Crendon, Bucks. Genotype, Holotype. S.S.B. coll. From *T.A.*, pl. CCCVI *a*, *b*.
271. 33.35.48. fig. ×0·3.
3. *Provirgatites scythicus* (Michalski),
'Kimeridge Clay', near Moscow. Original figure, from Michalski, *Mém. Comité géol. Russie*, 1894, vol. viii, pl. V, figs. 6*a* and *b*.
58. 34½.31.39. fig. × 1·0.
(Note that the ribbing on the early whorls is not virgatotome as in *Virgatites*.)
4. *Pavlovia rotunda* (Sowerby),
Rotunda Nodules, Chapman's Pool, Dorset. Topotype. Brit. Mus., No. C. 26903. From Neaverson, *Amm. Upp. Kim. Clay*, pl. 1, fig. 6.
96. 27.31.48. fig. ×0·6.
5. *Pectinatites pectinatus* (Phillips),
Shotover Grit Sands, Shotover Hill, Oxford. Topotype. Oxford University Museum.
114. 38.33½.35. fig. ×0·5.
6. *Subplanites* sp.,
Typical specimen in characteristic state of preservation, photographed by the author *in situ* on the foreshore, at a level 14 ft. above the Rope Lake Head Stone Band and about 25 ft. above the Blackstone, on the east side of Rope Lake Head, Dorset. (Identified by Dr. L. F. Spath.)
129. 33½.—.40. fig. ×0·37.

Specimens of *Titanites*, from the highest zone of the Portland Stone, are figured on pl. XXVI, p. 493.

PLATE XLI

PURBECK BEDS

All the figures are reproduced from T. Rupert Jones's paper 'On the Ostracoda of the Purbeck Formation', *Q.J.G.S.*, vol. xli, 1885, pp. 311–53, pls. VIII and IX.

1–8. *Cypridea punctata* (Forbes) and varieties,
Middle and Upper Purbeck: 1–3, Mupes Bay; 4, 5, Durlston Bay; 6–8, Ridgeway.

9, 10. *Cypridea ventrosa* Jones,
Upper Purbeck, Durlston Bay.

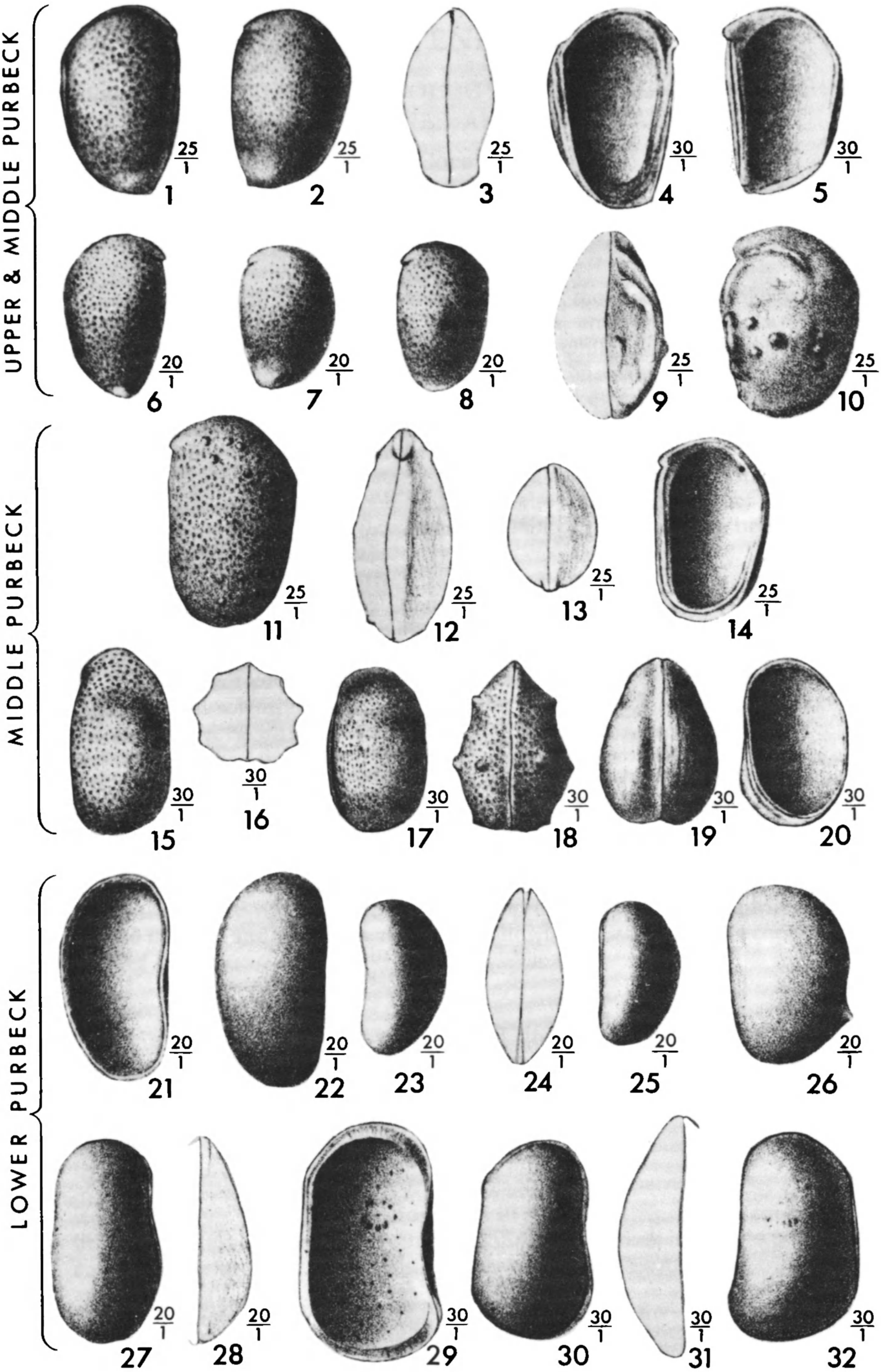
11–14. *Cypridea granulosa* (Sowerby), var. *paucigranulata* Jones,
Middle Purbeck, Whitchurch?

15–20. *Metacypris forbesii* Jones,
Middle Purbeck, Ridgeway.

21–6. *Cypris purbeckensis* Forbes,
Lower Purbeck: 23, 27, Hartwell; 25, Whitchurch; the rest from the Vale of Wardour.

27–8. *Candona bononiensis* Jones,
Lower Purbeck, Hartwell.

29–32. *Candona ansata* Jones,
Lower Purbeck, Hartwell; and Oving (30 only).


UPPER & MIDDLE PURBECK
MIDDLE PURBECK
LOWER PURBECK
1 2 3 4 5 6 7 8 9 10
11 12 13 14 15 16 17 18 19 20
21 22 23 24 25 26 27 28 29 30 31 32

APPENDIX I

NOTES ON THE TERMINOLOGY OF FOSSIL CORAL REEFS, GEOSYNCLINES AND PENEPLAINS

(a) Coral Reefs

WHEN the proofs of this book were nearly completed, a paper appeared advocating greater precision in the terminology of fossil coral reefs and cognate structures (E. R. Cumings, 1932, 'Reefs or Bioherms?', *Bull. Geol. Soc. America*, vol. xl, pp. 331–52).

The author urges that coral reefs and all 'reeflike, moundlike, lenslike or otherwise circumscribed structures of strictly organic origin, embedded in rocks of different lithology' should in future be called 'bioherms'; while 'purely bedded structures, such as shell beds, crinoid beds, coral beds, &c., consisting of and built mainly by sedentary organisms and not swelling into moundlike or lenslike forms' should be known as 'biostromes'. He then goes on to such suggestions as 'hermatolith' or 'hermatobiolith' for reef rock, and 'hermatopelago' for a group of coral islands. The reason adduced for these innovations is alleged ambiguity in existing usage of the terms coral reef, coral bed, shell bed, &c.; the definition of 'reef' quoted from Murray's Dictionary is 'A narrow ridge or chain of rocks, shingle or sand, lying at or near the surface of the water'.

Admittedly the word reef carries this meaning in nautical language; but as such it is purely a generic term. The definition quoted fits it only when it is used in its generic sense. It is difficult to see how there can be any confusion when it is accompanied by the customary specific qualification: e.g. coral reef, reef of rocks, shingle reef. Even without such qualifying words, the context usually renders the meaning unmistakable in scientific literature; moreover, no English scientist in the midst of a discourse on coral structures would court confusion by referring to a 'reef' if he meant a reef of rocks or shingle: he would surely call it a rock ledge (cf. the Kimeridge Ledges, above, p. 441) or a shingle spit or a sand bar. As to 'purely bedded structures, such as shell beds, crinoid beds, coral beds, &c.', any author who referred to these as reefs would not be competent to contribute to scientific knowledge and might safely be ignored.

The true test of such innovations in our terminology is their descriptive power: whether they make not only for the greater precision that they claim, but also for increased lucidity and vividness. The two following passages may be compared from this point of view:

1. *Ordinary English:*

   The sea floor was dotted with a small archipelago of coral islets, in which quarries show typical reef rock made up of corals in position of growth. When traced outwards from the reefs, the rock is seen to pass first into beds of rolled corals, then into bedded detrital deposits almost entirely made up of coral debris, and finally into limestones with shell beds.

2. *The same passage with the so-called ambiguous terms superseded:*

   The sea floor carried a hermatopelago, in which quarries show typical hermatolith. When traced outwards from the bioherms, the rock is seen to pass first into coral-biostromes and then into limestones with shell-biostromes.

It should be noted that, in order to express the grading of the detrital beds from rolled corals to coral debris by the method advocated, it would be necessary to add so much qualifying or descriptive matter to the word 'biostrome' that the word itself would become redundant.

I venture to suggest that Professor Cumings has fallen into the same error as did S. S. Buckman when he imagined that he was making himself clearer by referring to a 'colomorphic nomomorph' when he meant an ammonite of normal size reduced by the removal of the outer whorls; or by calling a deformity a 'plagiomorphic kakomorph'.[1]

As Dr. Seitz has remarked: 'The art of description does not consist in stringing a greater or lesser number of terms disjointedly together, but in bringing out in clear language the features that are essential and distinctive.' [2]

(b) Geosynclines

Followers of the Haug and Kober schools will take exception to the free use made in Chapter XVIII of the word geosyncline. I have not used it in this way in ignorance of what has been said in favour of restricting the term to the much deeper troughs out of which the folded mountains arose; but because, having read and studied *Der Bau der Erde*, I remain unconvinced. To those who are familiar with the sedimentary troughs of the extra-Alpine region of North-West Europe, their secular downsinking and the deformation which they have undergone during orogenic times, Kober's rigid distinction between orogen and kratogen seems artificial. The difference between the deformation of the kratogen and the deformation of the orogen (which Kober would have us believe is something fundamental) seems to me to be purely one of degree. Not only do the elongate troughs of deposition on the kratogen answer to the American definition of geosynclines—'all the greater long-continued down-flexured parts of the lithosphere'—but the folding to which they were subjected generally follows the lines laid down during past orogenies (as pointed out in Chapter III).

Admittedly there are different classes of geosynclines, and those which were deepest and subsequently broke forth into mountain ranges (probably as the direct result of their excessive depth) should rightly be placed in a different sub-class (the Alpine type) from those with less violent histories (as Stille calls them, the Germano-type). But there is nevertheless a gradation in depth which links them all together as fundamentally one class of phenomenon.[3] A consideration of the sedimentary systems of the world reveals a network of subsiding troughs of all different degrees of size and depth, and periodically the deepest buckled, bringing on an orogenic convulsion with the formation of a range of folded mountains. As Stille has aptly said, if we are to restrict the term geosyncline to those troughs which have given rise to mountains 'we might with as much justice deny the title of wife to a wife because she has not brought forth a family'.[4]

(c) Peneplains

The spelling of this word as 'peneplain' (almost a plain) or 'peneplane' (almost a plane surface) has now become nearly an infallible distinction between English and

[1] *T.A.*, vol. iii, pp. 6, 32.

[2] O. Seitz, 1929, *Jahrb. Preuss. Geol. Landesanst.*, vol. i, p. 154.

[3] The significant depth is, of course, not the depth of water, but the depth of water plus sediment. This gives a measure of the subsidence of the bottom.

[4] *Grundfragen*, p. 8. The conception of the geosyncline here given conforms with that in the two principal works on geosynclines by American authors—and it was in America that the expression was first used: see Ch. Schuchert, 1923, 'Sites and Nature of the North American Geosynclines', *Bull. Geol. Soc. America*, vol. xxxiv, pp. 151–230, and A. W. Grabau, 1924, 'Migration of Geosynclines', *Bull. Geol. Soc. China*, vol. iii, pp. 208–347. Grabau gives a map showing Asia covered with a network of geosynclinal troughs of different ages. It is very doubtful whether his distinction between geosynclines (in this broad sense) and oceanic deeps can be maintained. He calls the latter fore-deeps; but the Indo-Gangetic plain is a typical fore-deep in a tectonic sense, and because this is filled with sediment he calls it a geosyncline. The presence or absence of a plentiful supply of sediment is surely an extraneous factor.

American writings. It is not on this account, however, that I have adopted peneplain.

The question has been fully discussed by Professor D. W. Johnson in his *Shore Processes and Shoreline Development* (1919, pp. 164–9). He defines his use of certain terms as follows: '(1) The level erosion surface produced in the ultimate stage of any cycle will be called a *plane*. (2) The undulating erosion surface of moderate relief produced in the penultimate stage of any cycle will be called a *peneplane*. (3) A low-relief region of horizontal rocks will be called a *plain*.' And later he states: 'A peneplain is not "almost a plain" of horizontal sediments, but is almost a plane surface in the mathematical sense of the term; therefore, "peneplane" more nearly expresses the true meaning of the term than does the older and commoner spelling.'

The British reader will at once detect in these passages an unfamiliar element in the definition of a 'plain', which seems unwarrantably to be made to depend on the horizontality of the strata. In English the expression carries no such implications regarding the strata. The prototypes of plains, such as Salisbury Plain, the Plain of York, the Plain of Esdraelon, &c., were so called centuries before any idea of the stratification can have been present in the minds of those who conferred the names. Plain in English, in fact, simply means 'a level tract of country'[1] and nothing more. Therefore the peneplains referred to in Chapter XVIII, whether of marine or subaerial origin, are best described as 'almost plains'. It was certainly this meaning, rather than almost mathematically plane surfaces, that W. M. Davis expressed when he first introduced the word as 'peneplain'.

APPENDIX II

LIST OF 120 STAGE-NAMES HITHERTO PROPOSED FOR PARTS OF THE JURASSIC SYSTEM IN EUROPE, WITH REFERENCES.

Arranged approximately in descending stratigraphical order, synonyms in order of date.

May.-Eym., 1864, 1881, 1884, 1888, *refer to the four works by C. D. W. Mayer-Eymar, enumerated in the bibliography, p.* 624.

CLAVINIAN. Jukes-Browne, 1884. Geol. Mag. [3], vol. i, p. 526. Clavinium = Weymouth, Dorset. = Middle and Upper Oolites.

GLEVONIAN. Jukes-Browne, 1884. Geol. Mag. [3], vol. i, p. 526. Glevonium = Gloucester. = Lower Oolites up to Cornbrash incl.

PURBECKIEN. Brongniart, 1829. Tabl. terr. séd. = Purbeck Beds.

DUBISIEN. Desor, 1859. Étude Jura neuchat., p. 45. = Purbeckian of Doubs and the Jura Mts.

TITHONIAN. Oppel, 1865. Zeitschr. Deutsch Geol. Gesell., vol. xvii, p. 535 = Marine Purbeckian of the Alps. Tithon was spouse of Eos (Aurora), Goddess of the Dawn (ref. dawn of Cretaceous). Discussed Haug, 1898, Bull. Soc. géol. France, vol. xxvi, pp. 197–228. Restr. Spath, 1923, Q.J.G.S., vol. lxxix, p. 304.

AQUILONIAN. Pavlow, 1891. Bull. Soc. natur. Moscou, N.S., vol. v, p. 550; & 1896, Q.J.G.S., vol. lii, p. 542. Aquilo, Nord, France. = Marine Portland–Purbeck pars. Discussed Spath, 1923, Q.J.G.S., vol. lxxix, p. 304.

ALLOBROGIEN. Rollier, 1909. Compte rendu, 9e Congrès Assoc. franc-comtoise à

[1] *Oxford Dictionary.*

Pontarlier, pp. 13–30; and see Mém. Soc. pal. Suisse, 1917, vol. xlii, p. 624. = Purbeck and Portland Beds of the 'Rhodano-Swabian Province'.

PORTLANDIEN. Brongniart, 1829. Tabl. terr. séd. = Portland Beds.

FREIXIALIN. Choffat, 1887. Rech. terr. second. au sud du Sado, Secção dos Trabalhos Geologicos, vol. i, p. 307. Freixial, Portugal. = Portlandian of Portugal.

KIMMÉRIDIEN. Thurmann, 1833. Essai sur les soulèvemens jurassiques du Porrentruy. Mém. Soc. Hist. nat. Strasbourg, vol. i, 2 livr., p. 12.

KIMÉRIDGIEN. d'Orbigny, 1846–9. Pal. franç. terr. jurass., vol. i, p. 610. = Lower Kimeridge Clay.

BOULOGNIAN. Blake, 1880. Q.J.G.S., vol. xxxvi, p. 196. See Bolonian.

BOLONIAN. Blake, 1881. Q.J.G.S., vol. xxxvii, p. 581. Boulogne-sur-Mer, France. = Upper Kimeridge Clay, between the clays with *Exogyra virgula* and the Portland Beds. = Portlandien inférieur, *sensu gallico*.

BOLONIN. May.-Eym., 1888.

BOULONIEN. Pavlow, 1891. Bull. Soc. natur. Moscou, N.S., vol. v, p. 550.

BONONIAN. Pavlow, 1896, Q.J.G.S., vol. lii, p. 542. Bononia = Boulogne-sur-Mer. = Portland Beds *sensu stricto* by definition, though apparently only intended as a different spelling of Bolonian, Blake.

VOLGIEN. Nikitin? Defined as the 'Wolgaformation' by Nikitin, 1881, Jura-Ablag. zw. Rybinsk, Mologa u. Myschkin, Mem. Acad. Imp. Sci. St. Petersburg [7], vol. xxviii, p. 36. = Upper Kimeridgian of Russia (River Volga). Discussed Spath, 1923, Q.J.G.S., vol. lxxix, p. 304; and Haug, 1898, Bull. Soc. géol. France [3], vol. xxvi, pp. 197–228.

HÂVRIEN. Brongniart, 1829. Tabl. terr. séd. = Kimeridgian of Hâvre. = Lower Kimeridgian.

VIRGULIEN. Thurmann, 1852. Mitth. Bern. Naturf. Gesell., p. 217. = Lower Kimeridge Clay with *Exogyra virgula*.

SOLENHOFIN. May.-Eym., 1881. Solenhofen, Bavaria. = *nom. nov.* for Virgulien. =Lower Kimeridgian pars, above the Ptérocerian (Bannéin).

SALINIEN. Rollier, 1909. Compte rendu, 9e Congrès Assoc. franc-comtoise à Pontarlier, pp. 13–30; and see Mém. Soc. pal. Suisse, 1917, vol. xlii, p. 624. Salins, near Besançon, Jura. = Virgulien of France, = Solenhofin.

DANUBIEN. Rollier, 1909. Compte rendu 9e Congrès Assoc. franc-comtoise à Pontarlier, pp. 13–30; and see Mém. Soc. pal. Suisse, 1917, vol. xlii, p. 624. = Salinien of 'Rhodano-Swabian Province'; all between Elsgovian and Bononian.

PTÉROCERIEN. Thurmann, 1852. Mitth. Bern. Naturf. Gesell., p. 217. = Lowest Kimeridgian, zone of *Pteroceras oceani*, below the range of *Exogyra virgula*.

BANNÉIN. May.-Eym., 1881. = Marls of Banné, Jura salinois; see Marcou, 1848, Jura salinois, p. 104. = Lo. Kimeridgian (Ptérocerian) of Porrentruy, Jura bernois.

ELSGOVIEN. Rollier, 1909. Compte rendu, 9e Congrès Assoc. franc-comtoise à Pontarlier, pp. 13–30; and see Mém. Soc. pal. Suisse, 1917, vol. xlii, p. 624.= Marls of Banné. = Ptérocerian. = Bannéin.

CRUSSOLIEN. Rollier, 1909. idem; *Tenuilobatus* and *Aulacostephanus* zones and coral rag of Nattheim. = Elsgovien. = Bannéin of 'Rhodano-Swabian Province'.

SEQUANIEN. (Thurmann MS.), Marcou, 1848. Rech. géol. sur le Jura salinois; Mém. Soc. géol. France [2], iii, pp. 96, 102–3. Sequania = Franche-Comté (Jura). = *Astarte supracorallina* Beds = Astartien = Lower Kimeridgian, Thurmann. As used by De Loriol in the Boulonnais and thence by Arkell for Dorset, this includes the Upper Corallian, an extension that does not seem legitimate.

ASTARTIEN. Thurmann, 1852. Mitth. Bern. Naturf. Gesell., p. 217. = *Astarte supracorallina* Beds of Porrentruy, immediately below the Ptérocerian. = Sequanian.

DICÉRATIEN. Étallon, 1857. Esquisse Descr. géol. Haut-Jura; Annales Soc. agric. et indust. Lyon, vol. i, pp. 253, 292. = Reef facies of Sequanian with *Diceras arietina*.

RANDENIEN. Rollier, 1897. Le Malm du Jura et du Randen, Compte rendu, Congrès géol. internat., Sess. vi, Zurich, 1894 (1897), p. 337. Randen, Switzerland. = Ammonitiferous and spongiferous facies of the Sequanian.

CORALLINIEN. Étallon, 1861. Mém. Soc. Emul. Doubs, vol. vi, p. 53. = Reef facies of Upper Sequanian of the Jura.

VERDUNIN. May.-Eym., 1881. = Upper Sequanian of Verdun, Lorraine.

FRINGELIN. May.-Eym., 1881. = Lower Sequanian of Fringeli, Jura bernois.

CORALLIEN. Thurmann, 1833. Mém. Soc. Hist. nat. Strasbourg, vol. i, p. 14. D'Orbigny, 1845, Pal. franç. terr. jurass., vol. i, p. 609. = Sequanian (*not* Corallian *sensu anglico*, which is defined above, Chapter XIII, p. 376).

ARGOVIEN. Marcou, 1848. Rech. géol. sur le Jura salinois; Mém. Soc. géol. France [2], vol. iii, p. 88. Canton of Argovie, Switzerland. = Zones of *Pelt. transversarium* (? and *Cardioceras cordatum*; mentioned by Marcou). = Lower Corallian, *sensu anglico*.

LUSITANIEN. Choffat, 1885. Descr. Faune jurass. Portugal, Moll. Lamell.; Sect. Trav. géol. Portugal, p. 17. Lusitania = Portugal. = Argovian of Portugal. Adopted for whole Corallian by Haug.

RAURACIEN. Gressly, 1867. Essai sur le Jura, p. 72; and 1870, Mat. Carte géol. Suisse, 8^e livr., p. 75. Rauracia = district about Bâle, Jura Mts. = Corallian of the Swiss Jura. = Reef-facies of the Argovian, *teste* Rollier, 1897, Compte rendu, Congrès géol. int., Session vi (1894), p. 335.

GEISSBERGIN. May.-Eym., 1881. (?Moesch, 1857.) Geissberg, Argovian Jura. = Upper Argovien = Pholadomyen = Oltenin, Mayer-Eymar, 1888.

OLTENIN. May.-Eym., 1888. Olten, Soleure. = Upper Argovian = Pholadomyen = Geissbergin, May-Eym., 1881.

ZOANTHARIEN. Étallon, 1861. Mém. Soc. Emul. Doubs, vol. vi, p. 53. = Reef-facies of Upper Argovian of the Jura.

GLYPTICIEN. Étallon, 1861. Mém. Soc. Emul. Doubs, vol. vi, p. 53. = Argovien? or Lower Sequanien? with *Glypticus hieroglyphicus*.

PHOLADOMYEN. Étallon, 1861. Mém. Soc. Emul. Doubs, vol. vi, p. 53. = Upper Argovian with *Pholadomya*. = Geissbergin May.-Eym., 1881. = Oltenin, May.-Eym., 1888.

MIHIÉLIN. May.-Eym., 1881. St. Mihiel, Meuse. = Reef-facies of the Argovien.

EFFINGIN. May.-Eym., 1881. (?Moesch, 1857.) Effingen, Switzerland. = Middle Argovian, Effinger Schichten.

SPONGITIEN. Étallon, 1857. Esquisse Descr. géol. Haut-Jura, Ann. Soc. agric. et indust. Lyon, vol. i, pp. 253, 275. = Spongiferous Lower Argovian of the Jura.

BIRMENSTORFIN. May.-Eym., 1881. (?Stutz, 1859.) Birmenstorf, Switzerland. = Lower Argovian.

OXFORDIEN. Brongniart, 1829. = Middle Jurassic (so used also by Marcou, &c.). Emend. d'Orbigny, 1846–9, = Argovian + Divésian pars.

DIVÉSIEN. Renevier, 1874. Tabl. terr. séd., ed. 1. Dives, Normandy. = Middle Oxfordian, zones of *Kosmoceras ornatum* to *Cardioceras cordatum* inclusive.

NEUVISYEN. Lapparent, 1893. Traité de Géol., ed. 3, p. 1032. Neuvisy, Ardennes. = Upper Divésian, zone of *Cardioceras cordatum*.

VILLERSIN. May.-Eym., 1881. Villers-sur-Mer, Normandy. = Upper Callovian of Oppel, zone of *Peltoceras athleta*.

VILLERSIEN. Lapparent, 1893. Traité, ed. 3; emend. = Upper Divésian, = Upper Oxford Clay + Lower Calc. Grit.

KELLOVIEN. d'Orbigny, 1844.

CALLOVIEN. d'Orbigny, 1846. Pal. franç. terr. jurass., vol. i. Callovium = Kellaways, Wilts. = Kellaways Beds + Lower Oxford Clay, zones of *Proplanulites kœnigi* to *Kosmoceras jason*. Emend. Oppel, 1858, Die Juraformation, p. 506.

CHANASIAN. Parona and Bonarelli, 1895. Mém. Acad. Sci., &c., Savoie [4], vol. vi, p. 30. Chanaz, Savoy. = Kellaways Beds.

NIORTIN. May.-Eym., 1881. Niort, Deux-Sèvres, France. = Lower Callovian *sensu lato* (Upper Cornbrash), zone of *Macrocephalites macrocephalus*.

BEDFORDIN. May.-Eym., 1881. Bedford, England. = Cornbrash.

HANDTHORPIAN.
STALBRIDGIAN. } Buckman, 1927. Q.J.G.S., vol. lxxxiii, p. 7.
CLOSEWORTHIAN.

Handthorpe, Lincs.; Stalbridge and Closeworth, Somerset. = Cornbrash. For criticism see Douglas and Arkell, 1928, Q.J.G.S., vol. xxxiv, pp. 125–7.

HINTONIAN.
CORSHAMIAN. } Buckman, 1927. Q.J.G.S., vol. lxxxiii, p. 7.
WYCHWOODIAN.

Hinton Charterhouse and Corsham, Wilts.; Wychwood Forest, Oxon.; = Forest Marble. See Arkell, 1931, Q.J.G.S., vol. lxxxvii, p. 595.

BRADFORDIEN. Desor, 1859. Étude Jura neuchat., p. 85. = Bradford Clay of Bradford-on-Avon, Wilts. + Forest Marble.

BATHONIAN. D'Omalius d'Halloy, 1843. Précis élémentaire de Géologie, p. 470. = Dogger. Restr. d'Orb., Pal. franç. terr. jurass., vol. i, p. 607, to Great Oolite Series (+ Vesulian pars).

BATHIEN. May.-Eym., 1864. Bathonian + Bajocian. Restr. May.-Eym., 1884, to Cornbrash + Bradford Clay.

MANDUBIEN. Marcou, 1860. Lettres du Jura, p. 344. Mandubii = people of the Jura Mts. = Bathonian of the Jura.

FALAISIN. May.-Eym., 1881. Falaise, Normandy. = Middle Bathonian; Great Oolite with *Nerinea voltzi*.

VÉSULIEN. Marcou, 1848. Mém. Soc. géol. France [2], vol. iii, p. 73. Vesulum = Vésoul, Haute-Saône. Marls of Vésoul, with *Ostrea acuminata* and *O. knorri*. = Fuller's Earth + Bath Oolite (*pro parte*) by original definition. Emend. May.-Eym., 1881 = Cadomin + Stonesfieldin + Falaisin (i.e. Great Oolite Series less the Bradford Clay and higher beds).

STONESFIELDIN. May.-Eym., 1881. Stonesfield Slate Beds + Oolithe miliaire. Later (1884) included by Mayer-Eymar in his Cadomin.

CADOMIN. May.-Eym., 1881. Cadomum = Caen, Normandy. = Fuller's Earth, Lower Vesulian, marls with *Ostrea acuminata* + Caen Stone.

FULLONIAN. Woodward, 1894. Jurassic Rocks of Britain, vol. iv, p. 229. = Fuller's Earth of England.

EHNINGIN. May.-Eym., 1881. Ehningen, Württemberg. = Upper Inferior Oolite, zone of *Parkinsonia parkinsoni* (*sensu lato*).

BAJOCIAN. d'Orbigny, 1847. Pal. franç. terr. jurass., vol. i, p. 606. Bayeux, Normandy. = Inferior Oolite Series, from the zone of *Ludwigia murchisonæ* to that of *Zigzagiceras zigzag*. Restricted by the founding of the Aalenian.

LAEDONIEN. Marcou, 1848. Rech. géol. Jura salinois, Mém. Soc. géol. France [2], vol. iii, p. 70. Laedo = Lons-le-Saunier, Switzerland. = Bajocian, pars.

TORGONIEN. Rutot and Van den Broëck, 1885. Sketch Geol. Belgium; Geol. Assoc., London, p. 38 = Bajocian of the Ardennes.

SCARBOROUGHIN. May.-Eym., 1881. Scarborough, Yorks. = Bajocian, pars, zone of *Stephanoceras humphriesianum* (*sensu lato*).

MÂCONIN. May.-Eym., 1881. Mâcon, Saône et Loire. = Bajocian, pars, zone of *Sonninia sowerbyi.*

AALENIAN. May.-Eym., 1864. Aalen, Württemberg. = Zones of *Lioceras opalinum* and *Ludwigia murchisonæ* (*sensu lato*).

CHELTENHAMIN. May.-Eym., 1881. = Upper Aalenian. = Lower Inferior Oolite of Cheltenham.

GUNDERSHOFIN. May.-Eym., 1881. Gundershofen, Alsace. = Lower or Middle Aalenian = Gundershofen Schichten, limestones with *Trigonia navis.*

BOLLIN. May.-Eym., 1881. Boll, Baden, Germany. = Lower Aalenian.

OPALINIEN. Renevier, 1874. Tabl. terr. séd., ed. 1. = Lower Aalenian, zone of *Lioceras opalinum.*

TOARCIEN. d'Orbigny, 1849. Pal. franç. terr. jurass., vol. i, p. 106. Toarcium = Thouars, Deux-Sèvres, France. = Upper Lias.

THOUARSIEN. May.-Eym., 1864.

MUSSONIEN. Rutot and Van den Broëck, 1885. Sketch Geol. Belgium; Geol. Assoc., London, p. 38. Musson, Belgium. = Toarcian of the Ardennes.

ALFELDIN. May.-Eym., 1881. Alfeld, near Hanover, Prussia. = Upper Toarcian = Yeovilian.

YEOVILIAN. Buckman, 1910. Q.J.G.S., vol. lxvi, p. 88. Yeovil, Somerset. = Upper Toarcian, subzones of *Grammoceras striatulum* to *Dumortieria moorei.*

ALDORFIN. May.-Eym., 1881.

ALTDORFON. May.-Eym., 1888. Altdorf, nr. Nürnberg, Bavaria. = Lower Toarcian = Whitbian.

WHITBIAN. Buckman, 1910. Q.J.G.S., vol. lxvi, p. 88. Whitby, Yorkshire. = Lower Toarcian, subzones of *Dactylioceras tenuicostatum* to *Haugia variabilis.*

LIASIEN. d'Orbigny, 1849. Pal. franç. terr. jurass., vol. i, p. 605. = Middle and part of Lower Lias. Adopted for whole of the Lias by Jukes-Browne, 1884, Geol. Mag. [3], vol. i, p. 526.

PLIENSBACHIEN. Oppel, 1858. Die Juraformation, p. 815. Pliensbach, near Boll, Württemberg. = Liasien d'Orb.

CHARMOUTHIAN. May.-Eym., 1864. Charmouth, Dorset. = Pliensbachien.

VIRTONIEN. Rutot and Van den Broëck, 1885. Sketch Geol. Belgium; Geol. Assoc., London, p. 38. Sandstone of Virton, Belgium. = Pliensbachian.

CYMBIEN. Leymerie, 1872. Bull. Soc. géol. France, vol. xxix, p. 168. = Middle Lias with *Gryphæa cymbium.* = Upper Pliensbachian.

BANZIN. May.-Eym., 1881. Banz, near Coburg, Bavaria. = Upper Pliensbachian.

DOMERIEN. Bonarelli, 1894. Atti della R. Accad. delle Scienze di Torino, vol. xxx, p. 85; and 1895, Rendiconti Reale Istituto Lombardo, Ser. 2, vol. xvxiii, pp. 326, 415. Monte Domero (Domaro), Lombardy Alps. = Middle Lias = Upper Pliensbachian.

MENDIN. May.-Eym., 1881. Mende, Lozère, France. = Middle Pliensbachian, with *Lytoceras fimbriatum.*

ROTTORFIN. May.-Eym., 1881. Rottorf, Brunswick. = Lower Pliensbachien, zones of *Tragophylloceras ibex* and *Uptonia jamesoni.* = Carixian, pars.

CARIXIAN. Lang, 1913. Geol. Mag. [5], vol. x, p. 401. Carixa = Charmouth. = Lower Pliensbachian, zones of *Prodact. davœi*, *Trag. ibex* and *Uptonia jamesoni.*

ROBINIEN. Rollier, 1915. Eclogæ Geologicæ Helvetiæ, vol. xiii, p. 374. Robin Hood's Bay, Yorkshire. = Zones of *Prodactylioceras davœi*, *Uptonia jamesoni* and *Deroceras armatum*.

SINÉMURIEN. d'Orbigny, 1849. Pal. franç. terr. jurass., vol. i, p. 604. Sinemurum = Sémur, Côte d'Or. = Lower Lias pars.

SÉMURIEN. May.-Eym., 1864.

ARLONIAN. Rutot and Van den Broëck, 1885. Sketch Geol. Belgium; Geol. Assoc., London, p. 38. Marls of Arlon, Belgium = Lower Lias of Belgium.

LOTHARINGIEN. Haug, 1911. Traité de Géologie, p. 961. Lothringen = Lorraine. = Lower Lias above Hettangian.

BALINGIN. May.-Eym., 1881. Balingen, Württemberg. = Upper Sinemurian, zones of *Echioceras raricostatum*, *Oxynoticeras oxynotum* and *Asteroceras obtusum*.

LOURNANDIN. May.-Eym., 1888. Lournand, Saône-et-Loire. = Upper Sinemurian. = Balingin, May.-Eym., 1881.

FILDERIN. May.-Eym., 1881. Filder, near Stuttgart, Germany. = Lower Sinemurian, zones of *Arnioceras semicostatum* and *Coroniceras bucklandi*.

SUÉVIEN. Rollier, 1915. Eclog. Geol. Helvet., vol. xiii, p. 374. Suévie = fr. Swabia. = Zones of *Arnioceras semicostatum*, *Coroniceras bucklandi*, *Scamnoceras angulatum*, *Psiloceras planorbis* and *Pteria contorta* (outside the Mediterranean Province).

HWICCIAN. Hwiccas = people of Gloucester, Worcester and part of Warwick.
WESSEXIAN. Wessex = the kingdom of the West Saxons.
RAASAYAN. Raasay = island in the Hebrides.
DEIRAN. Deira = the kingdom embracing Yorkshire.
MERCIAN. Mercia = the kingdom embracing the Midlands.
LYMIAN. Lyme Regis, Dorset.
Buckman, 1917. Q.J.G.S., vol. lxxiii, pp. 263–77. = Sinemurian + Carixian.

HETTANGIEN. Renevier, 1864. Not. Alp. vaud., vol. i, p. 51. Hettange, Lorraine. = Sandstone with *Psiloceras planorbis*.

RHÉTIEN (RHÆTIEN). Guembel, 1861. Bay. Alp., p. 122; and Renevier, tabl. terr., ed. 1. Rhætia = Rhætic Alps (Grisons). Rhætic Beds.

SOMERSETIAN. Richardson, 1911. Q.J.G.S., vol. lxvii, p. 73. = Cotham Beds + Langport Beds + Watchet Beds of Somerset, England. = Upper Rhætic.

KŒSSENIN. May.-Eym., 1881. (?Suess, 1852.) Kœssen or Kössen, Tyrol. = *Pteria contorta* zone and Bone Bed. = Lower Rhætic.

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Note: District and Sheet Memoirs, sections and maps of the Geological Survey are not included, because a complete list is published and may be obtained cheaply from the Geological Survey Museum, London.

ABBREVIATIONS

The following contractions are used throughout the text, in footnotes, and in the bibliography:

Q.J.G.S. *Quarterly Journal of the Geological Society*, London.

P.G.A. *Proceedings of the Geologists' Association*, London.

J.R.B., 1892, 1893, 1894, 1895. *Jurassic Rocks of Britain*, vols. i–v, by C. Fox-Strangways (vol. i, 1892) and H. B. Woodward (vols. ii–v); *Memoirs of the Geological Survey of Great Britain*.

T.A. *Type Ammonites* (including *Yorkshire Type Ammonites*), by S. S. Buckman.

Proc. Cots. N.F.C. *Proceedings of the Cotteswold Naturalists' Field-Club.*

The other abbreviations used are self-explanatory.

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[1] I am indebted to Dr. C. D. Sherborne for the information that K. (or C.) Mayer and C. D. W. Mayer-Eymar, often indexed separately, were one and the same man.

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SUBJECT INDEX

Note: To keep the index within reasonable bounds, place-names are not included, but the page headings are intended to act as a geographical as well as a stratigraphical guide. The order of describing each formation is from south to north—from Dorset to Yorkshire and Scotland, and lastly the Weald of Kent.

The only personal names indexed are those of certain pioneers, whose work is specially dealt with in Part I.

INDEX OF STRATA

(Stage-names not indexed, *see* Appendix II, p. 617.)

CORRIGENDA

Pp. 390, 400. *Isognomon* [= *Perna*] *mytiloides* Lamk et auct. The name will have to be changed owing to its having been preoccupied for an Inferior Oolite species by Hermann (1781). Where mentioned the species is probably *I. subplana* (Étallon).

Pp. 468–70. The *Astarte supracorallina* of Blake, Roberts, Woodward, and others, is not *A. supracorallina* d'Orbigny but *A. mysis* d'Orbigny, which is probably synonymous with *A. extensa* Phillips. Both these matters will be dealt with in forthcoming instalments of 'A Monograph of the British Corallian Lamellibranchia'.

P. 613. Explanation of Plate XL, fig. 3. *Provirgatites scythicus* was first named and figured by Vischniakoff in 1882 ('Descr. des Planulati (Perisphinctes) jurass. de Moscou', pl. iii, figs. 1, 2). The types came from Mniovniki near Moscow. Michalski's specimens are at least chorotypes.