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# A comparison of the Hettangian to Bajocian successions of Dorset and Yorkshire

S. P. HESSELBO & H. C. JENKYNS

*Department of Earth Sciences, University of Oxford, Parks Road, Oxford OX1 3PR, UK*

**Abstract:** The Lower Jurassic successions exposed on the coasts of Dorset (Wessex Basin) and Yorkshire (Cleveland Basin) have been re-measured, integrating existing lithostratigraphical and biostratigraphical schemes. The resultant stratigraphical columns are presented for all units, and include intervals for which no detailed graphical logs have been published previously, such as the Bridport Sands of East Cliff and Burton Cliff in Dorset, and the Lower Lias of Robin Hood's Bay in Yorkshire. The relationships of the main exposures of Lower and Middle Jurassic rocks are illustrated and discussed with respect to synsedimentary faults that are located onshore and offshore. In addition to phenomena reported previously from Dorset, which can be interpreted in the context of fault movement (e.g. fissuring in limestones and sandstones adjacent to faults and the distribution of hiatus concretions), thickness changes in Middle Lias and Upper Lias sandstones can also be clearly related to horst and graben structures. Along the Dorset coast, N–S-oriented faults appear mostly to have had a Jurassic downthrow to the west and E–W-oriented faults downthrew mainly to the south. Many of these faults were inverted subsequently. Sedimentary cyclicity, expressed as compositional or grain-size variations, is a prominent feature of the Lower Jurassic succession at a number of different scales. The sedimentary cycles appear to have developed synchronously in both basins, particularly during the early Lias: in a bed-to-bed or member-to-member comparison, sandy mudstones in Yorkshire commonly correspond to marls in Dorset, whereas silty mudstones in Yorkshire commonly correspond to organic-rich mudstones in Dorset. At a larger scale of comparison (sedimentary packages approximately equivalent in time to ages) thick sections in Yorkshire are equivalent to condensed or missing section in Dorset and *vice versa*. This large-scale relationship derives from cyclic changes in relative sea-level. In general, the Dorset succession became expanded when shelfal or alluvial accommodation was reduced in Yorkshire, whereas the Dorset succession became condensed when there was excess creation of shelfal accommodation in Yorkshire.

The purpose of this field guide is to allow a detailed comparison of the coeval stratigraphical development in the Jurassic of Dorset and Yorkshire. At present, it is not possible to make such comparisons for the whole Jurassic section, due to a lack of exposure or poor biostratigraphical control in either one or both of the areas; thus, the intervals suitable for comparison are the Hettangian to Bajocian (this study) and Oxfordian stages (Coe, this volume). Most of the stratigraphical sections included in this guide have been remeasured, incorporating all previous published data, and are designed to enable future workers to key new data into a stable lithostratigraphical framework.

The text is structured so as to give a detailed explanation of the construction of each measured section including the origin of the lithostratigraphical and biostratigraphical schemes, followed by an indication of stratigraphical and sedimentological features of particular note. Comparative comments can generally be found under the Yorkshire headings. In an effort to avoid confusion, we have not revised or standardized the stratigraphical nomenclature, but instead have used those names that have found wide acceptance in the literature. However, where lithostratigraphical boundaries have not been fixed in a previous published measured section, we have done so herein. For comprehensive treatment of the geology of the Dorset and Yorkshire coasts, readers should refer to Arkell (1933), Hemingway (1974), House (1989) and Rawson & Wright (1992). Reviews of the biostratigraphy pertaining to these sections can be found in Cope *et al.* (1980*a*, *b*) and Cox (1990), and their context within the UK area is described by Hallam (1992) and Bradshaw *et al.* (1992). Please be aware that some of the localities mentioned in this guide are remote from points of access and/or escape routes and should be visited only on a falling tide: this is particularly relevant to the Yorkshire coast.

## Structure and geological setting of the Wessex and Cleveland Basins

The Wessex and Cleveland Basins (Fig. 1) are Mesozoic extensional basins formed during widespread post-Carboniferous subsidence of the northwest European continental area (Ziegler 1981, 1990*a*; Whittaker 1985; Bradshaw *et al.* 1992). The intervening region was less subsident but was, nonetheless, depositional during much of the Jurassic. Important influences on Jurassic sedimentation in the UK area were pre-Atlantic rifting (Hallam & Sellwood 1976) and uplift and volcanism in the mid-North Sea (Hallam & Sellwood 1976; Ziegler 1990*a*, *b*; Underhill & Partington 1993).

Sediment accumulation in the Wessex Basin (Fig. 1b) occurred from the Permian to Late Cretaceous (Kent 1949; Stoneley 1982; Chadwick 1986; Whittaker 1985; Sellwood *et al.* 1986; Lake & Karner 1987; Karner *et al.* 1987; Penn *et al.*

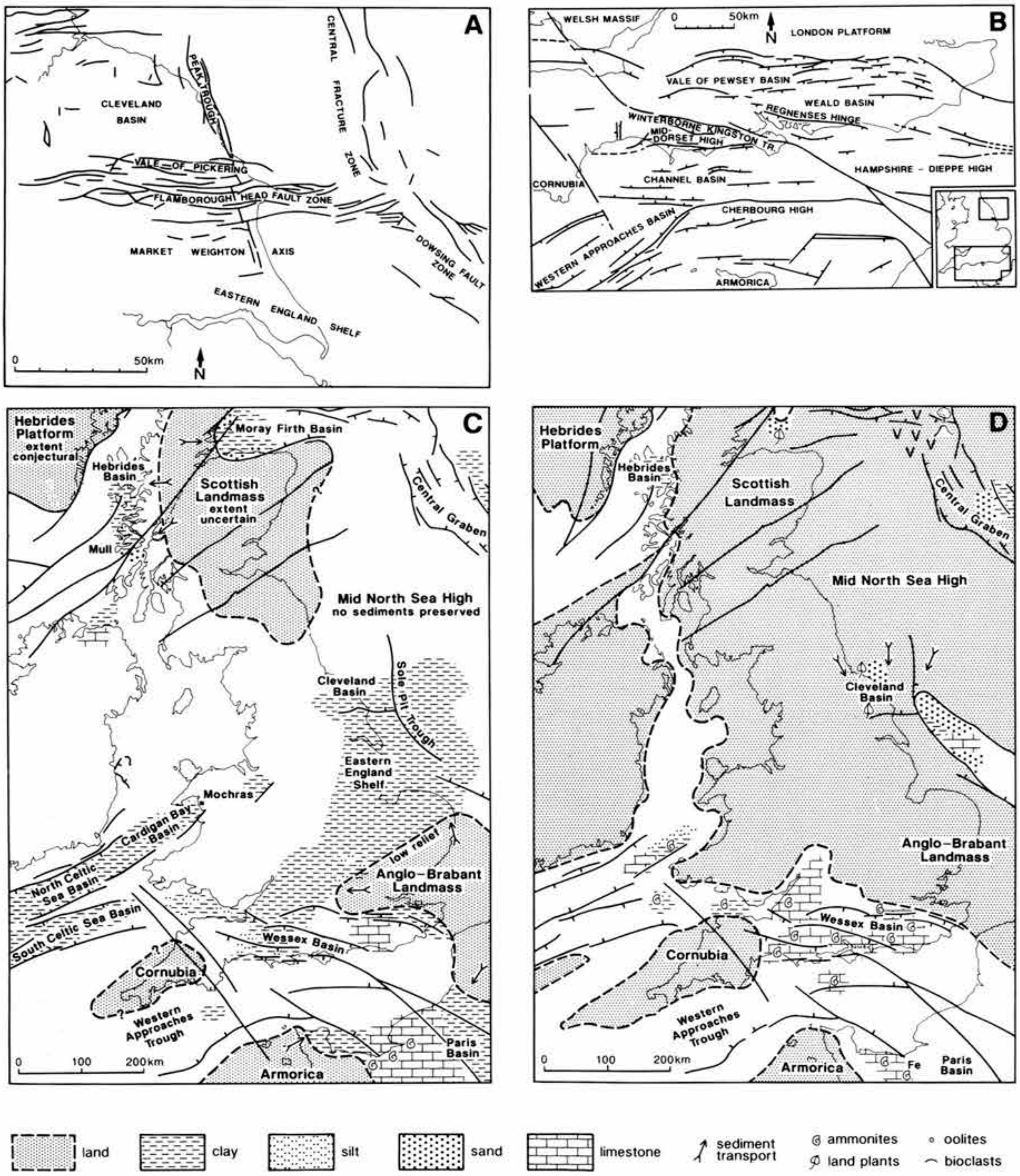



**Fig. 1.** Palaeogeographical and structural maps. (**a**) Major structural elements in the Cleveland Basin area, redrawn from Kirby & Swallow (1987) and Milsom & Rawson (1989). (**b**) Major structural elements in the Wessex Basin area, redrawn with modifications from Lake & Karner (1987). (**c**)–(**d**) Palaeogeographical maps simplified from Bradshaw *et al.* (1992); (**c**) Early Pliensbachian; (**d**) Late Bajocian.

1987; Selley & Stoneley 1987). The basin includes much of southern England and extends out southwards under the English Channel and is bounded to the north and east by the London–Brabant Massif, to the northwest by the Welsh Massif, to the west by the Cornubian Massif and to the south by the Armorican Massif (Bradshaw *et al.* 1992). Near neighbours are, westwards, the Bristol Channel and Western Approaches Basins and, to the southeast, the Paris Basin (Fig. 1).

The structural disposition of the Wessex Basin is thought to have been inherited from thrust and transfer faults in the Hercynian basement (Chadwick *et al.* 1983; Chadwick 1986; Karner *et al.* 1987; Lake & Karner 1987). The major tectonic lineaments affecting Mesozoic strata comprise deep-seated normal faults, oriented mainly east–west (Dewey 1982; Stoneley 1982). These faults delimit the northern edges of a number of sub-basins, typically developed as half-grabens, which stepped-down progressively towards the south in the Jurassic (e.g. Penn *et al.* 1987). A second, more widely spaced set of faults trends north–south to northwest–southeast; these probably had sinistral strike-slip and minor dip-slip components during the Jurassic (Stoneley 1982; Lake & Karner 1987). Based on both surface and subsurface data, Jurassic fault activity appears to have taken place principally from the Hettangian to Bajocian and from the late Oxfordian onwards, with a period of relative quiescence in the later Middle Jurassic and early Late Jurassic (Chadwick 1986; Jenkyns & Senior 1991).

Inversion of the Wessex Basin began in the Late Cretaceous to Palaeogene, culminating synchronously with the Helvetic phase of Alpine deformation in the Oligocene–Miocene (Lake & Karner 1987). Inversion is manifested as uplift of Mesozoic sub-basins and subsidence of Mesozoic highs; of more localized importance are the tight monoclinal flexures on the former downthrown sides of east–west-oriented faults and partial or total reversal of the throw (Chadwick 1993).

Subsidence in the Cleveland–eastern North Yorkshire area also occurred in the Permian, the deposits of which were laid down on eroded Carboniferous rocks, but a distinct Cleveland Basin was not developed until the late Triassic (Kent 1980). The basin is bounded to the west and northeast by less subsident or uplifted blocks which formed the Pennine and Mid-North Sea Highs (Fig. 1a). To the southeast, the Cleveland Basin extends into the Sole Pit Trough of the Southern North Sea Basin (Kent 1980; Hemingway & Riddler 1982). The southern limit of the Cleveland Basin is defined by the Market Weighton High, which greatly influenced Jurassic stratal thicknesses; it is thought now that the high is underlain by a granite (Sellwood & Jenkyns 1975; Bott *et al.* 1978; Gaunt *et al.* 1980; Kent 1980; Bott 1988; Donato 1993).

Less is known about the exact timing of fault movements in the Cleveland Basin compared with those in the Wessex Basin. North–south-oriented normal faulting occurred within the Cleveland Basin intermittently from Triassic to latest Cretaceous, e.g. along the margins of the Peak Trough and parallel structures (Alexander 1986; Milsom & Rawson 1989). East–west-oriented faults in the Vale of Pickering were active in the latest Jurassic and the Cretaceous (Kirby & Swallow 1987). Subsidence was terminated in a major phase of basin inversion which, as in the Wessex Basin, occurred in the late Cretaceous and early Tertiary (Kent 1980; Hemingway & Riddler 1982; Whittaker 1985; Kirby & Swallow 1987) and is expressed as broad uplift of the basin with associated sulphide mineralization.

## Early to Middle Jurassic depositional history

Lower Jurassic rocks of both the Wessex and Cleveland Basins are predominantly siliciclastic, typically fine-grained and were probably all laid down in fully marine environments. In all the British onshore basins the Triassic and Lower Jurassic topmost rocks are the first marine accumulations following a period of continental sedimentation during most of the Triassic. Middle Jurassic rocks of the northern British area, including Yorkshire, were deposited in proximal marine, coastal or non-marine settings (Fig. 1d). Middle Jurassic accumulation in the more southerly British area took place principally in marine, carbonate-producing environments, with or without the input of argillaceous sediment (Fig. 1d). The ammonite biostratigraphy and lithostratigraphy for the Lower and Middle Jurassic successions of Dorset and Yorkshire are summarized in Figs 2 & 3.

In general, the Lias in Dorset shows a progressive change in sediment grain size from clay through to fine sand (Day 1863; Arkell 1933; Wilson *et al.* 1958; House 1989). The Lower Lias is composed of shales, marls and limestones, whereas the Middle Lias and Upper Lias comprise alternating packages of siltstones, sandstones and thin limestones (subdivision of the Lias into lithostratigraphical Lower, Middle and Upper is still common practice for Dorset, but less so for Yorkshire where more recently formulated formation names exist). Middle Jurassic rocks mark a return to fine sediment deposition, and are developed as limestones and mudstones. Sediment accumulation rates in the Dorset area were highly variable, as is evident from the great variation in thicknesses of zones and subzones: a clear pattern exists of increasing variation in sedimentation rates up through the succession, with extreme condensation occurring in the late Pliensbachian to mid-Toarcian and in the late Aalenian to early Bathonian. In the Yorkshire Lias, a general upward increase in grain size is also evident, although it is less pronounced than in Dorset. The Middle Jurassic of Yorkshire, however, contrasts greatly in that it is developed as a thick succession of mainly non-marine siliciclastics, punctuated by a small number of marine units.

A striking feature of both the Dorset and Yorkshire successions, commented upon by many previous workers, is the lithological cyclicity which is evident at several scales (e.g. Arkell 1933, pp. 54–55; Hemingway 1951, 1974; Hallam 1967*a*, 1975; Sellwood & Jenkyns 1975) and has been related to relative sea-level fluctuations. Although relative sea level is clearly involved, particularly in the generation of the larger, formational-scale cycles, the precise relationship between the stratigraphy and phases of deepening or shallowing remains unresolved.

## Dorset

The coastline of south Dorset cuts an oblique section across a number of relatively small-scale fault blocks situated on the Mid-Dorset High, on the northern, footwall, side of the major Abbotsbury–Ridgeway fault system (Fig. 1b). A large body of evidence now exists to indicate that syndepositional movement occurred on these faults during the Jurassic. A geological map of the Lyme Bay area and a coastal cross-section are shown in Figs 4 and 5; these illustrate the main faults and their inferred sense of Early and/or Mid-, and probably Late Jurassic motion.

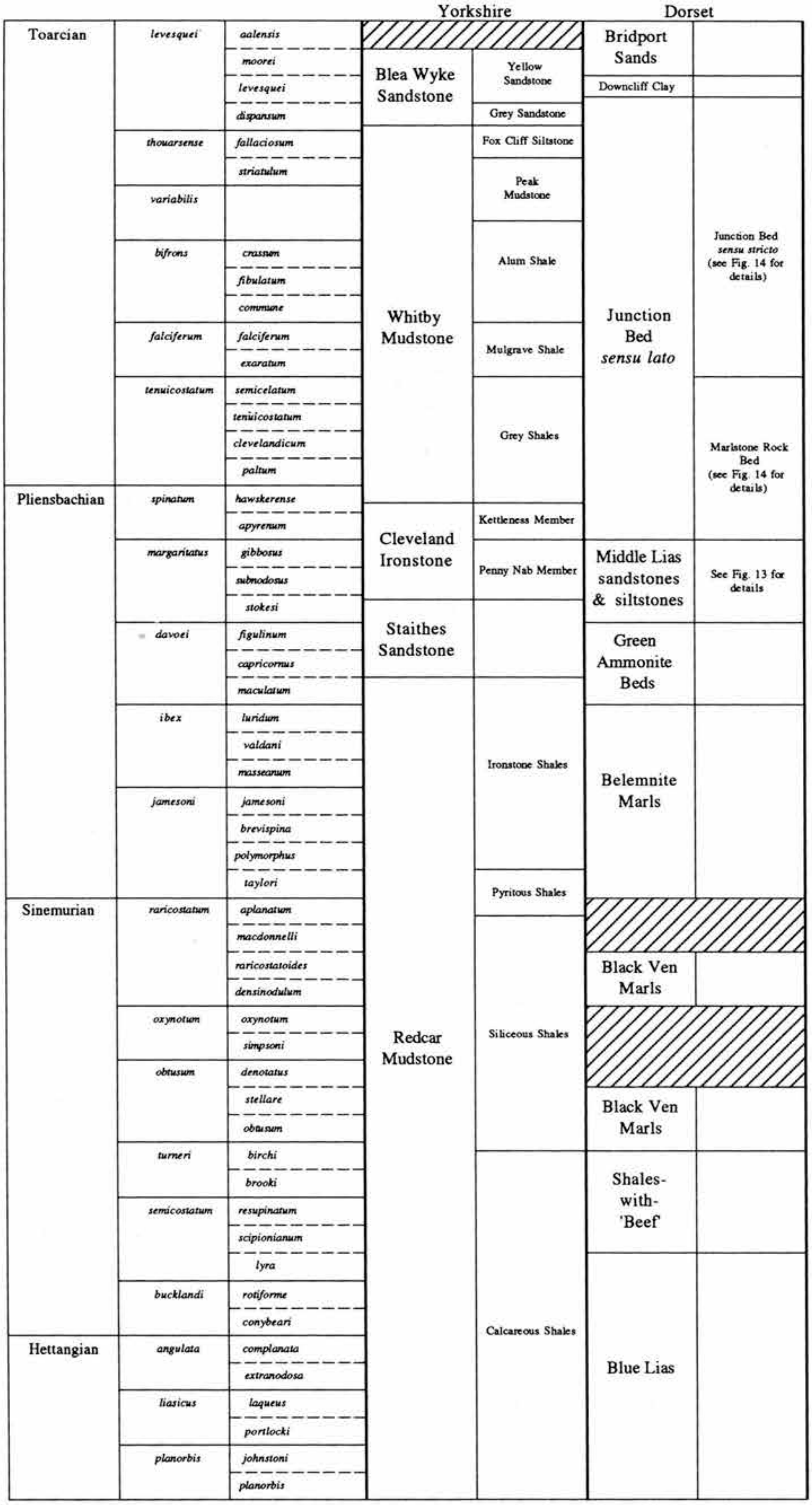



**Fig. 2.** Stratigraphical scheme for the Lower Jurassic of Yorkshire and Dorset. Compiled from Cope *et al.* (1980*a*), Ivimey-Cook & Donovan (1983), Knox (1984), Powell (1984), Howard (1985). Primary sources for the biostratigraphy and lithostratigraphy are discussed in detail in the text.

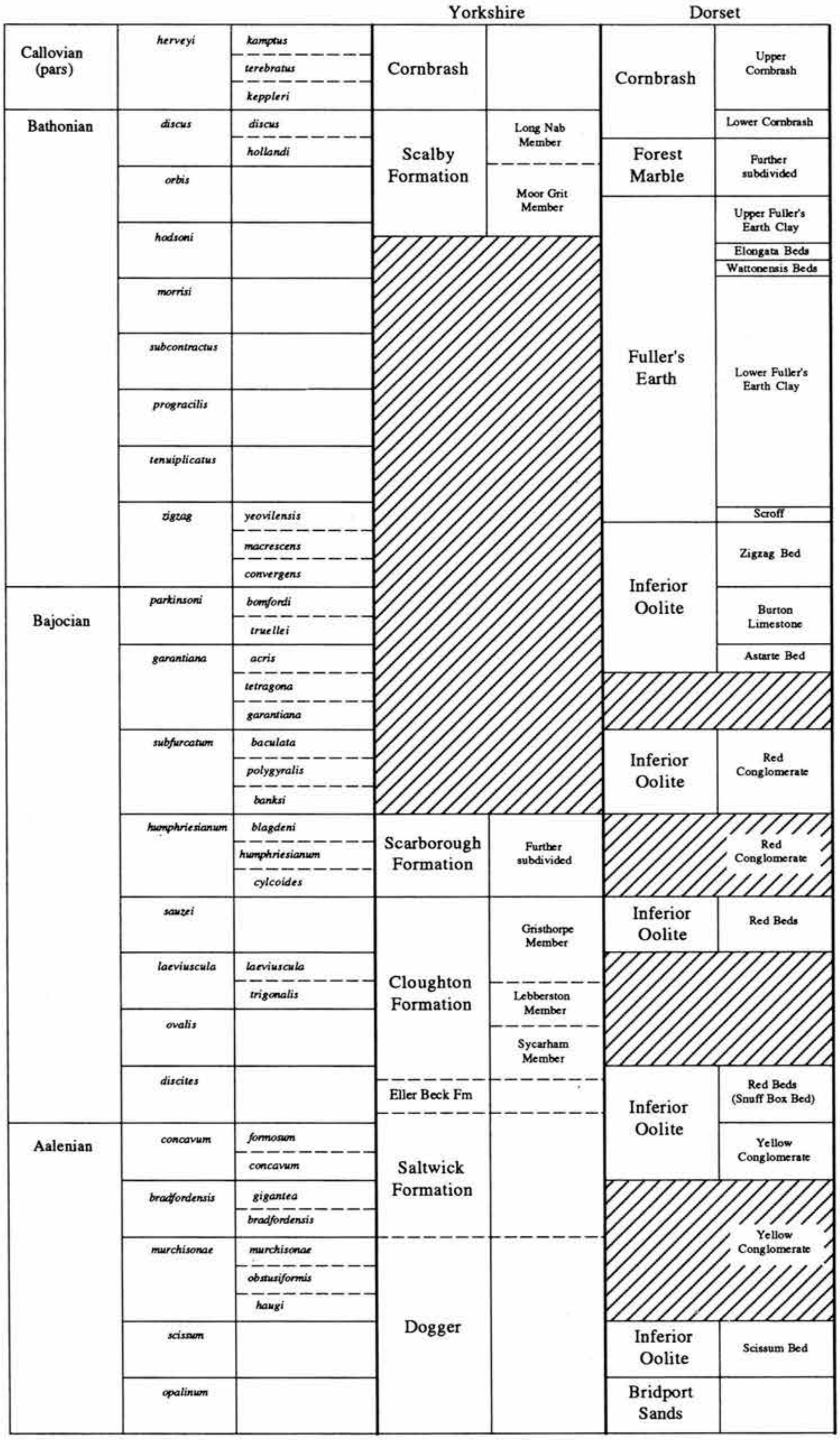



**Fig. 3.** Stratigraphical scheme for all but the upper part of the Middle Jurassic of Yorkshire and Dorset. Compiled from Hemingway & Knox (1973), Cope *et al.* (1980*b*), Callomon & Chandler (1990), Page (1989). Primary sources for the biostratigraphy and lithostratigraphy are discussed in more detail in the text.

Faults with an east–west orientation were mostly characterized by an Early to Mid–Late Jurassic downthrow to the south, an inference based on evidence of synsedimentary fissures in sandstones and limestones and changes in stratal thickness and facies (Jenkyns & Senior 1977, 1991). More rarely, some east–west faults had a downthrow to the north.

Faults with an approximate north–south orientation are also present and these generally had an Early to Mid Jurassic downthrow to the west, evidenced by stratal thinning and the development of hiatus-concretions on fault-block crests (e.g. Hesselbo & Palmer 1992): these faults have subsequently been inverted or may also have acted as strike-slip faults. Hence, the downthrows are presently to the east. The horizontal displacement was apparently of a much greater magnitude for the faults with an east-west orientation (Stoneley 1982).

### *Lyme Regis, Rhaetian to Sinemurian (the Langport Member (or White Lias) of the Penarth Group; the Blue Lias and basal Shales-with-'Beef' of the Lower Lias)*

The section across the Triassic–Jurassic boundary (Fig. 8) was measured in the area of Pinhay Bay [SY 318 908] and Seven Rock Point [SY 328 910], near Lyme Regis (Fig. 6). Thicknesses are taken mainly from the cliff exposures, supplemented with data from the foreshore where necessary. The construction of this section owes much to the careful work of Weedon (1987*a*) whose log of the Blue Lias, somewhat modified, forms the backbone of Fig. 8. There exists considerable lateral variability in bed thickness in the White Lias (Langport Member; Lilstock Formation; Penarth Group: Warrington *et al.* 1980). Beds 1–4 were measured *in situ*, beds 5–12 in a slipped block and bed 13 *in situ*. The bed numbers are those of Hallam (1960*a*).

Bed numbering for the Blue Lias and lower part of the Shales-with-'Beef' is from Lang (1924). The base of the Blue Lias follows Hallam (1960*b*). The biostratigraphy is as summarized by Getty (*in* Cope *et al.* 1980a), based mainly on the work of Lang (1924) and Dean *et al.* (1961), with the modifications of Ivimey-Cook & Donovan (1983, p. 130) who questioned the status of the Bucklandi Subzone and altered the definition of the subzones of the Semicostatum Zone. The base of the Jurassic is defined by the lowest occurrence of *Psiloceras planorbis*, although this practice is not universally accepted (see Torrens & Getty *in* Cope *et al.* 1980*a*; Donovan *et al.* 1989; Warrington & Ivimey-Cook 1990; Hallam 1990, 1991; Cope 1991). Useful marker horizons are provided by Intruder (bed H30), a very fine-grained clean tabular unit remarkably different in aspect from other Blue Lias limestones,

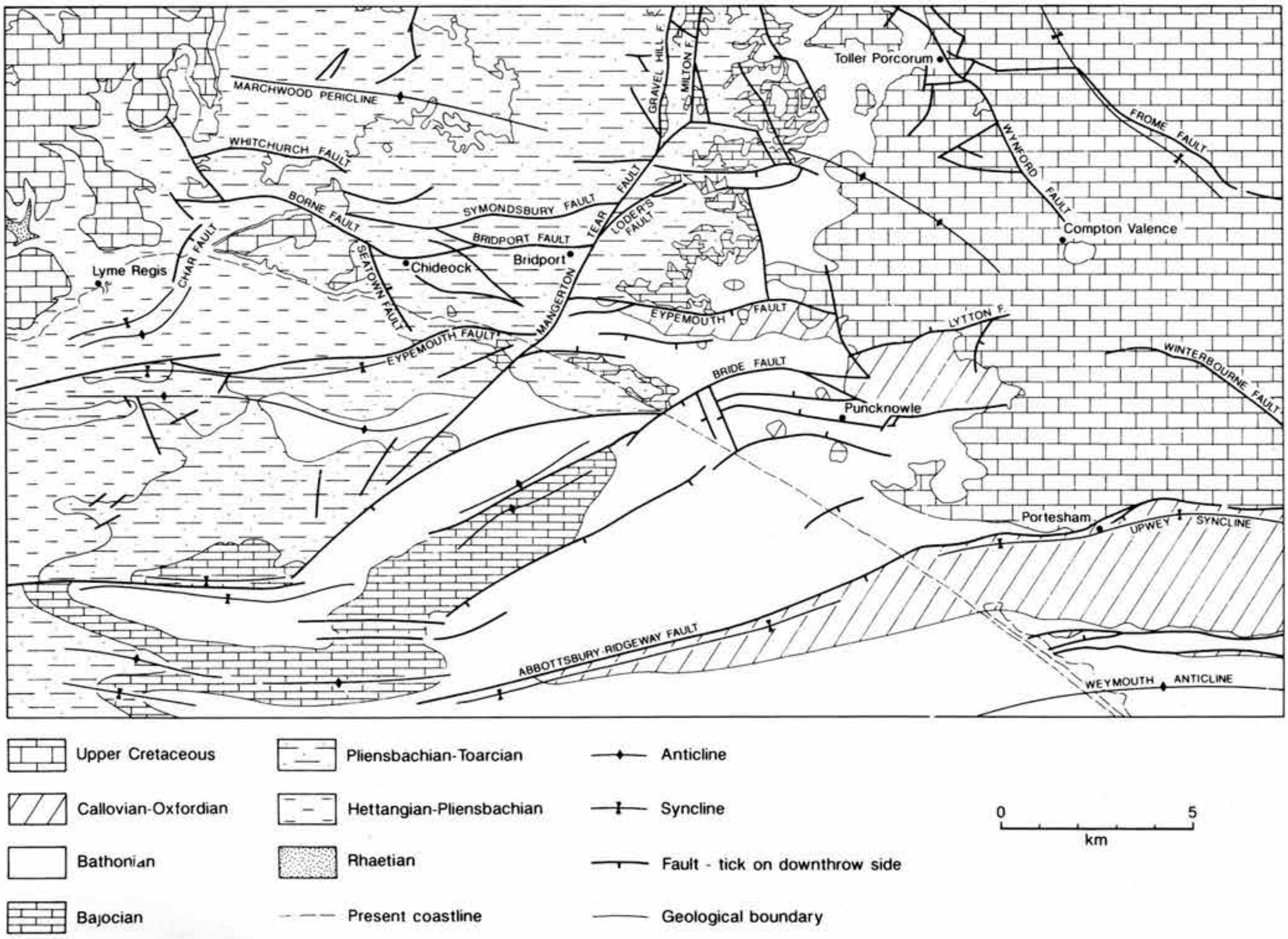



**Fig. 4.** Onshore and offshore geological map of the Lyme Bay area, simplified with slight modification from Darton *et al.* (1981).

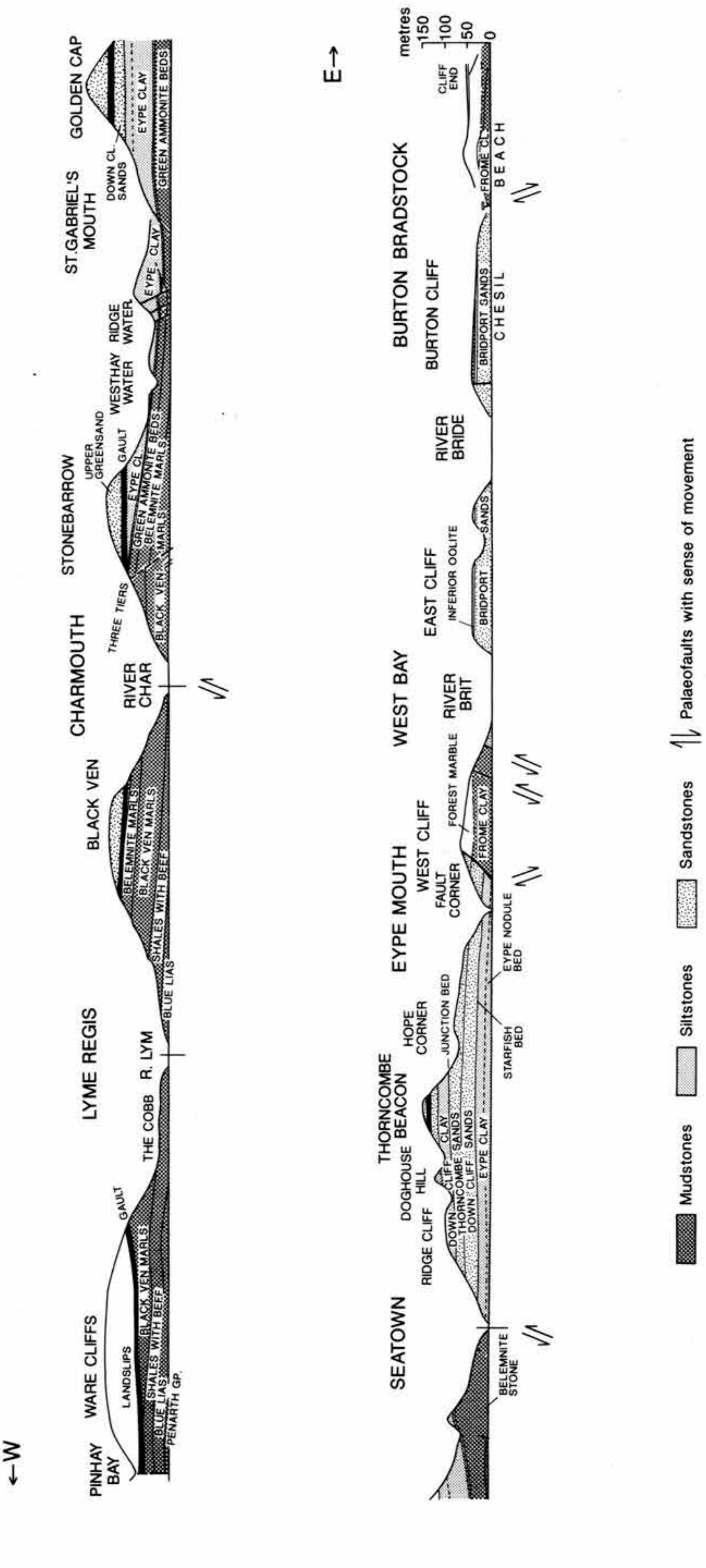



**Fig. 5.** Coastal exposures of the Lower Jurassic rocks around Lyme Bay, modified from Arkell (1933) and House (1989) by addition of probable Jurassic sense of motion on the faults.

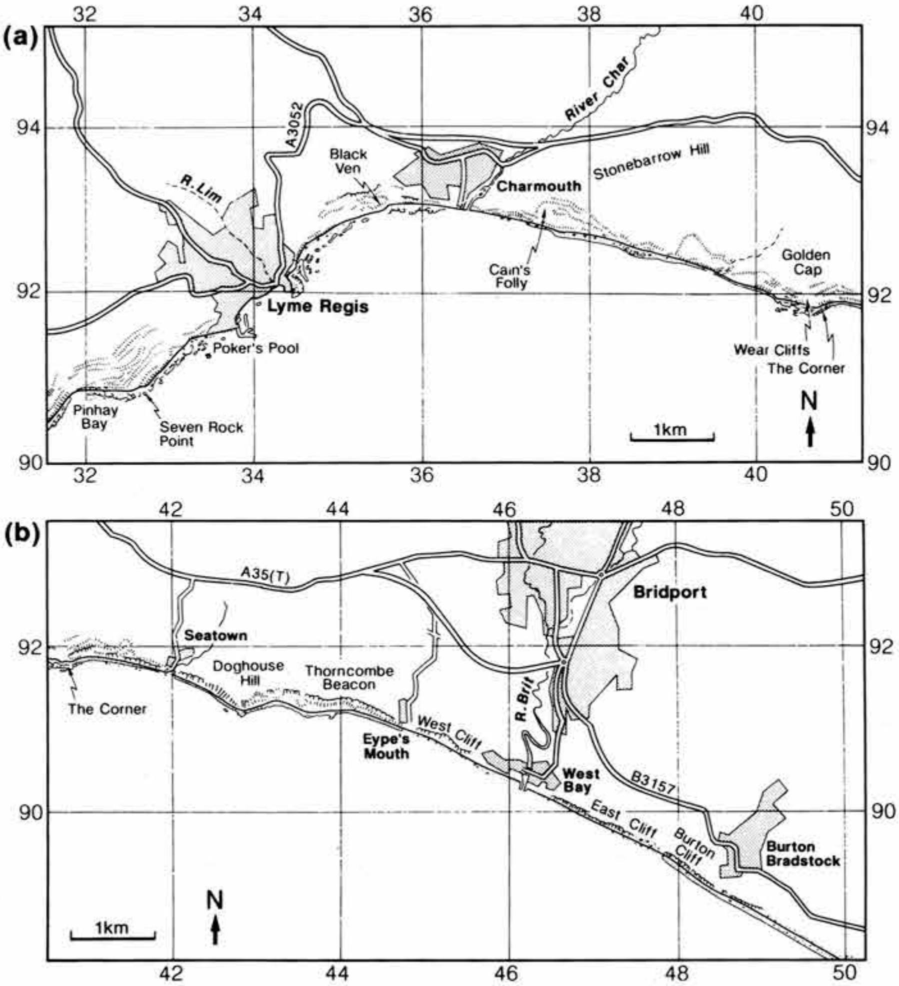



**Fig. 6.** Location map for the coastal area around Lyme Bay from Lyme Regis to Burton Bradstock: (**a**) west; (**b**) east. © Crown copyright.

which forms a prominent ledge on the foreshore; Brick Ledge (bed 1), a composite, highly nodular limestone; and Grey Ledge (bed 49), a complex condensed limestone which forms the top of the Blue Lias.

*White Lias.* Most, perhaps all of the beds in the White Lias were redeposited, either as carbonate-mud flows, or less commonly as slumps, as inferred from the matrix-supported conglomeratic (intraclastic) and retextured nature of most beds, the presence of slump folds in bed 8, and the disoriented nature of fossiliferous limestone cobbles in bed 5. Hallam (1960*a*) was the first to report these phenomena and give a detailed description of the lithologies, bedding relationships and fauna, although he underestimated the degree to which redeposition had taken place. Internally, the redeposited beds have generally been homogenized with a weakly contorted structure evident locally; beds 1–4 (some of which are compound) have particularly rubbly tops and contain macroscopic, inclusion-rich, euhedral celestine crystals.

The occurrence of celestine in the White Lias (an observation of I. M. West's reported by Hallam & El Shaarawy (1982)), explains the high strontium values found by Hallam (1960*a*) which he put down to an aragonite precursor to the calcite now forming the bulk of the rock. It appears likely that the celestine formed as a replacement of evaporitic gypsum, as had been suggested for other similar occurrences in the Upper Jurassic of Dorset (West 1964, 1973, 1979). Celestine in the Mercia Mudstone and Penarth Group near Bristol, on the northern edge of the Wessex Basin, is thought to be an early diagenetic replacement of gypsum and anhydrite, or a primary evaporite mineral, with the strontium sourced by the conversion of aragonite to calcite or dolomite in adjacent Carboniferous rocks (Nickless *et al.* 1976; Wood & Shaw 1976). Further petrographical work is required to give a clear indication of celestine paragenesis in the White Lias.

Although the Rhaetian strata are generally thought to have been deposited in normal-marine waters, abnormal salinities have been inferred for some parts of the succession (e.g. Anderson 1964; Hallam & El Shaarawy 1982; Copestake 1989); the depositional environment of the White Lias may have been hypersaline, at least episodically, on the basis of the occurrence of celestine. Analysis of oxygen-isotope values in these strata does not, however, indicate that the carbonate was precipitated from waters that had undergone evaporation.

The Sun Bed, which marks the top of the White Lias does not display unambiguous desiccation cracks as are suggested by its name; however, trace fossils are common and include

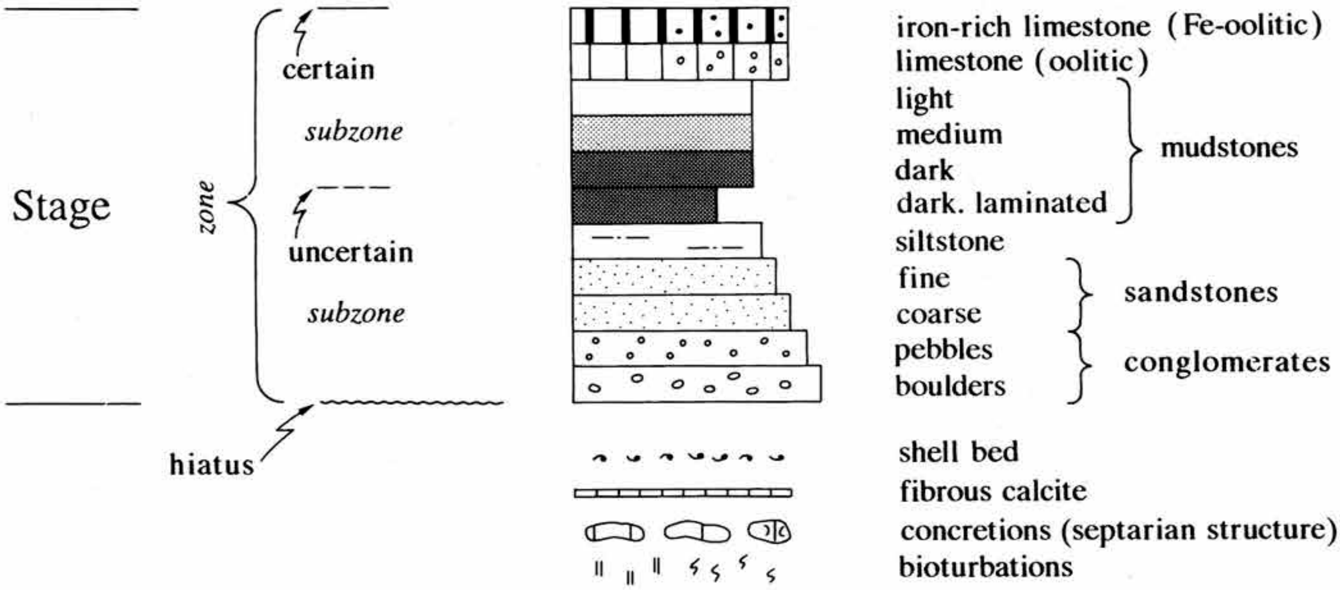



**Fig. 7.** Key for Lower and Middle Jurassic measured sections (Figs 8–13, 15, 19–29).

*Diplocraterion* (Hallam 1960*a*; Sellwood *et al.* 1970). The lithological change across the White Lias to Blue Lias boundary is essentially sharp, but some of the lowest limestones in the Blue Lias are lithologically similar to typical White Lias, as had been recognized early on by Richardson (1906, p. 407): the change in depositional environment represented by these rocks was probably more gradual in nature than is first apparent.

*Blue Lias.* The Blue Lias, although relatively thin, is typical of the same time-interval seen across much of the UK, comprising interbedded organic-rich millimetre-laminated shales, light and dark marls and massive limestones in tabular beds and concretions (Lang 1924; Hallam 1960*b*, 1964, 1986, 1987; Weedon 1986, 1987*b*; Bottrell & Raiswell 1989). Illite is the predominant clay mineral with minor kaolinite also occurring (Sellwood & Sladen 1981). The rocks are all of fully marine aspect and yield diverse macro- and microfossil assemblages and a nannoflora (Lang 1924; Barnard 1950; Hallam 1960*b*; Bown 1987; Chen & Wright 1987; Lord *et al.* 1987; Copestake & Johnson 1989). With a few exceptions, the limestones tend to be well burrowed whereas the millimetre-laminated organic-rich shales lack trace fossils. One unusual feature of some limestone beds (e.g. H30 and Under Copper) is the presence of centimetre-wide vertical fissures, part-filled with bioclastic limestone and presumably formed by early diagenetic shrinkage not unlike that occurring in septarian concretions.

It has been suggested that the interbedding of limestones and mudstones so apparent in the Blue Lias was produced by orbitally forced climatic oscillations (House 1985, 1986; Weedon 1986), with the proximal mechanism possibly being variation in runoff affecting surface productivity (Weedon 1986). Significant regular cyclicity is apparent despite overprinting of a primary lithological signal by diagenetic precipitation of calcite (see discussions in Hallam 1960*b*, 1964, 1986, 1987; Weedon 1986, 1987*b*).

Over intervals of tens of metres, limestones or shales may predominate in the succession although, because of its relatively condensed nature, the cycles are not as obvious in the Lyme Regis area as they are elsewhere in Britain. Limestones are important constituents of the Pre-Planorbis Beds and Planorbis Zone (together with laminated shales), the Angulata and basal Bucklandi Zones and, to a lesser extent, the latest Bucklandi Zone and the earliest Semicostatum Zone (Lyra Subzone). Shaly intervals occur within the Liasicus Zone, the mid-Bucklandi Zone and the remainder of the Semicostatum Zone. Recent work on the macrofossils in Jurassic mudrocks (Wignall & Hallam 1991) has defined oxygen-controlled biofacies, which are indicative of bottom-water oxygenation that varied from strongly anaerobic to weakly dysaerobic and which correlate well with the lithofacies. The least-oxygenated intervals, typically characterized by millimetre-laminated shales, do not necessarily correlate with the most argillaceous parts of the succession.

A package of strata appears to be missing in the Angulata Zone (Smith 1989) by comparison with the succession in Somerset. This was determined by correlating groups of metre-scale lithological cycles between the Dorset coast and Watchet coast and the Burton Row Borehole in Somerset. Some 30 m of strata present at the latter two localities are thought to be absent or dramatically condensed at Lyme Regis. The location of this possible gap in the Lyme Regis exposure cannot be determined with precision and has not been calibrated biostratigraphically. However, it may correspond to the bed-spacing minimum at or near Brick Ledge (Fig. 8, bed 1).

A second, more precisely defined, stratigraphical gap occurs at the top of the discontinuous tabular limestone, Grey Ledge (Fig. 8, bed 49), which is characterised by shell accumulations, glauconite, pyritized fossils, limestone intraclasts and phosphate nodules (Hallam 1960*b*, 1981). Several surfaces of erosion are evident from the truncation of large ammonites within Grey Ledge. This condensation and erosion occurs within the basal subzone of the Semicostatum Zone (the Lyra Subzone). In contrast to the possible Angulata Zone gap, this incomplete section is overlain by laminated shales with few limestones.

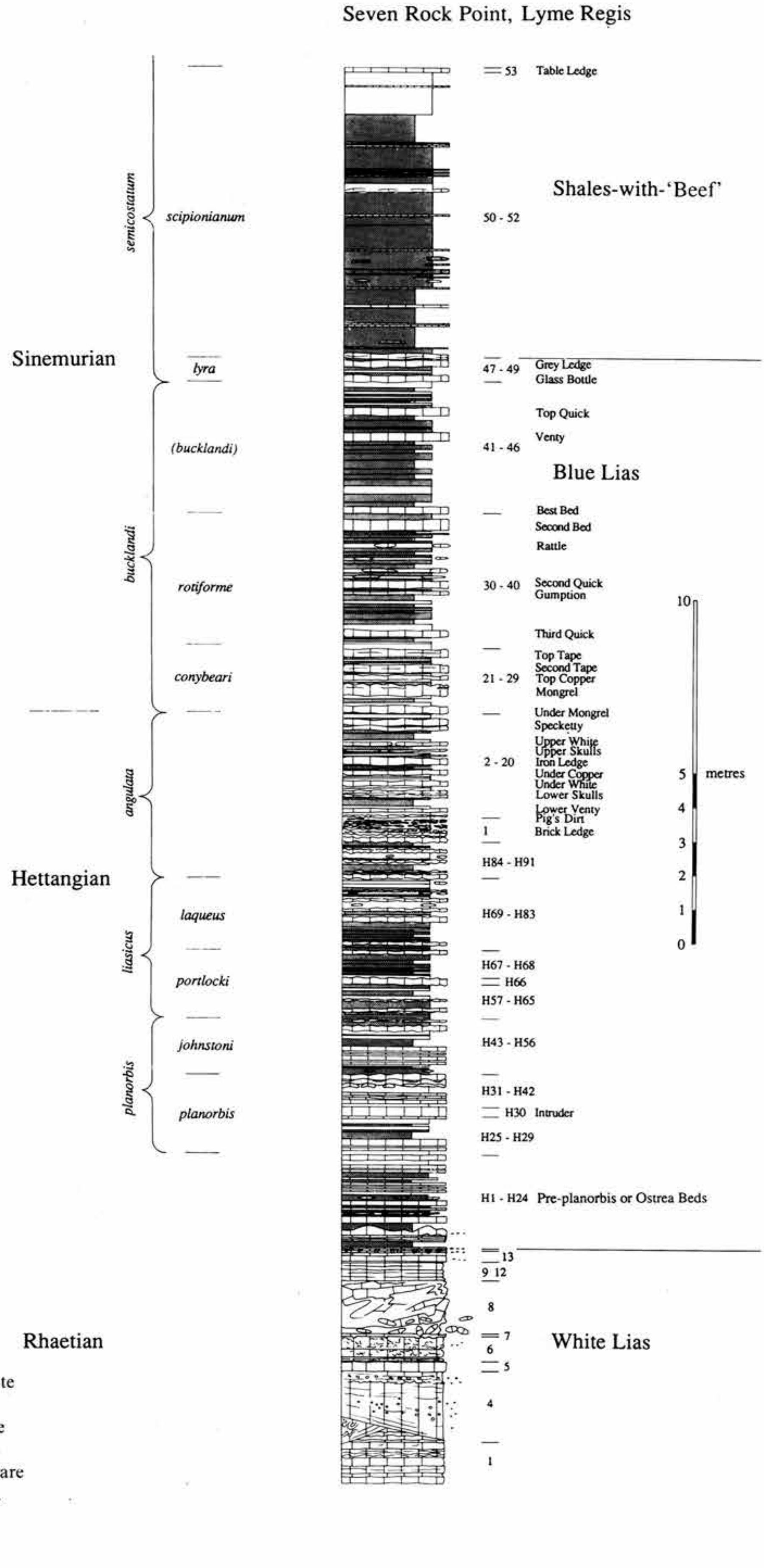



**Fig. 8.** Measured section from the White Lias to the basal Shales-with-'Beef', Pinhay Bay to Seven Rock Point, Lyme Regis. Precise locations and lithostratigraphical and biostratigraphical sources are discussed in the text. See Fig. 7 for key.

The shaly intervals of the Liasicus, Bucklandi and Semicostatum Zones have been interpreted as recording relative sea-level rises of at least regional extent (Donovan *et al.* 1979; Hallam 1981).

Some of the lower limestones of the Blue Lias, particularly in the Pre-Planorbis Beds and the Planorbis Zone, may be the products of redeposition, although the evidence for this is admittedly weak: bed H4, with a very irregular bedding style, locally contains small intraclastic limestone pebbles similar to those seen in the White Lias and suggesting that it too resulted from a mud flow; and bed H30 (Intruder), a homogeneous, exceptionally clean, very fine-grained limestone, sits uniquely with a razor-sharp junction on the underlying marly limestone, implying a sudden depositional event, possibly from a low-density turbidity current. Similar limestones, albeit slightly younger in age, occur in the Watchet section of Somerset (Whittaker & Green 1983).

### *Charmouth, Sinemurian (the Shales-with-'Beef' and Black Ven Marls of the Lower Lias)*

The upper Shales-with-'Beef' section (Fig. 9) was measured in the foreshore (beds 53–71) and cliff (beds 72–75) below Black Ven, west of Charmouth [SY 356 930 to SY 364 930]. Lithostratigraphy is taken from Lang *et al.* (1923). The biostratigraphy is as summarized by Getty (*in* Cope *et al.* 1980*a*), based mainly on the work of Lang *et al.* (1923), Dean *et al.* (1961) and Palmer (1972*a*, *b*), with the modifications to the zonal scheme of Ivimey-Cook & Donovan (1983, p. 130). Beds 53, 63, the base of 72 and the named beds, all form easily recognizable levels, although the concretions of the Black Arnioceras Bed are sparsely developed and may easily be missed. One limestone on the foreshore, recognized as bed 73g of Lang *et al.* (1923) by its resemblance to the 'stools of fossil trees', is also distinctive in containing reoriented, 10–20 cm, laminated limestone 'cobbles' apparently displaced by cone-in-cone calcite growth. This bed cannot be identified definitely as either of the lower two limestones of bed 73 shown in the measured section, possibly because of a change in the succession adjacent to the Char Fault.

Good exposures at the base of the cliff below Stonebarrow, east of Charmouth [SY 368 930 to SY 380 927] were used as the basis for the measured section of the Black Ven Marls (Fig. 10). Bed numbers are those of Lang & Spath (1926). The biostratigraphy is as summarized by Getty (*in* Cope *et al.* 1980*a*), based mainly on the work of Lang & Spath (1926), Dean *et al.* (1961) and Palmer (1972*a*, *b*). The positions of the bases of the Obtusum Zone and the Stellare Subzone are as indicated by Page (1992). Named concretionary limestone bands serve as unambiguous marker beds.

*Shales-with-'Beef' and Black Ven Marls.* The Shales-with-'Beef' (so-called because of their abundant vertically oriented fibrous calcite of diagenetic origin) and Black Ven Marls together comprise a package of predominantly dark laminated shales and dark marls with occasional concretionary and tabular limestone bands. Organic-rich 'paper shales' occur in the mid-Semicostatum Zone (Scipionianum Subzone), Turneri Zone (straddling the Brooki–Birchi subzonal boundary) and the Obtusum Zone (Obtusum Subzone). The fauna of these beds is similar to that of the Blue Lias in its general aspect. Additionally, fossil insects occur in the Birchi Nodular Bed and, particularly, in the Flatstones (Zeuner 1962; Whalley 1985). Illite is the predominant clay mineral, but smectite also occurs commonly and chlorite and kaolinite are minor constituents (Sellwood & Sladen 1981).

A small stratal gap may be present above the Pavior and near the base of the Obtusum Shales of the Black Ven Marls below Stonebarrow (Fig. 10). Evidence for this is in the form of a distinctive surface with prominent burrows (*Diplocraterion* and *Thalassinoides*) and a concentration of belemnites, unusual in this formation. Further, the Black Ven Marls are slightly expanded on Black Ven with respect to Stonebarrow and the first recorded *Asteroceras* (Lang & Spath 1926) occurs higher in the section in the former locality; this is compatible with synsedimentary activity on the intervening Char Fault inferred to have occurred during, or prior to, the late Sinemurian (Hesselbo & Palmer 1992).

Moving up the succession, still within the Black Ven Marls, a pronounced stratigraphical gap occurs at the horizon of the Coinstone, where three subzones are missing. The Coinstone was identified by Lang & Spath (1926) as being a surface of non-sequence on biostratigraphical, palaeoecological and lithological grounds. Further supporting evidence was furnished by Lang (1945), Hallam (1969) and Sellwood (1972) who detailed encrustation, boring and mineralization around the Coinstone concretions which had evidently been exhumed on the Jurassic sea floor. A mechanism of stratal erosion has been proposed recently in which burrowing is of central importance, and which does not necessitate vigorous bottom-current movement in the environment (Hesselbo & Palmer 1992). The burrowing organisms, which included crustaceans, are inferred to have caused resuspension and increased bed roughness, thus facilitating erosion by relatively weak bottom currents. The significance of horizons like the Coinstone in terms of sea-level change remains contentious and opposing views are given by Hallam (1988) and Haq *et al.* (1988).

### *Stonebarrow to Seatown, Pliensbachian (the Belemnite Marls of the Lower Lias)*

The Belemnite Marls section (Fig. 11) was constructed from a number of exposures along the coast from below Stonebarrow [SY 380 927] to Seatown [SY 416 917]. Beds 103–109 were measured in cliffs and fallen blocks below Stonebarrow, and the details of bed 110 were constructed from photographs of the vertical cliff at the same locality. Beds 111–115 were measured east of Westhay Water [SY 386 925–391 924]. Beds 116–121 were measured in the low cliffs between The Corner and Seatown [SY 410 918–416 917]. Bed numbers are taken from Lang *et al.* (1928). The biostratigraphy is as summarized by Getty (*in* Cope *et al.* 1980*a*), based mainly on the work of Lang *et al.* (1928), Dean *et al.* (1961) and Palmer (1972*a*, *b*).

We have placed the Sinemurian to Pliensbachian boundary (an erosional discontinuity at which the two highest subzones of the Raricostatum Zone are missing) at the base of Bed 103, the Hummocky Limestone. This is in contrast with the view of Spath (1956, p.149) who reports that 'Dr Lang has found fragments of coarse ('raricostate') species of *Echioceras* in the clays above 'Hummocky' as well as on the upper side of that limestone'. Spath concluded that the stratigraphical gap lay between beds 104 and 105. However, without doubt the *Echioceras* specimens found at the base of the Hummocky Limestone, and indicative of the Raricostatum Zone, are reworked since they are commonly present as serpulid-encrusted steinkerns. Furthermore, the bed is pervasively

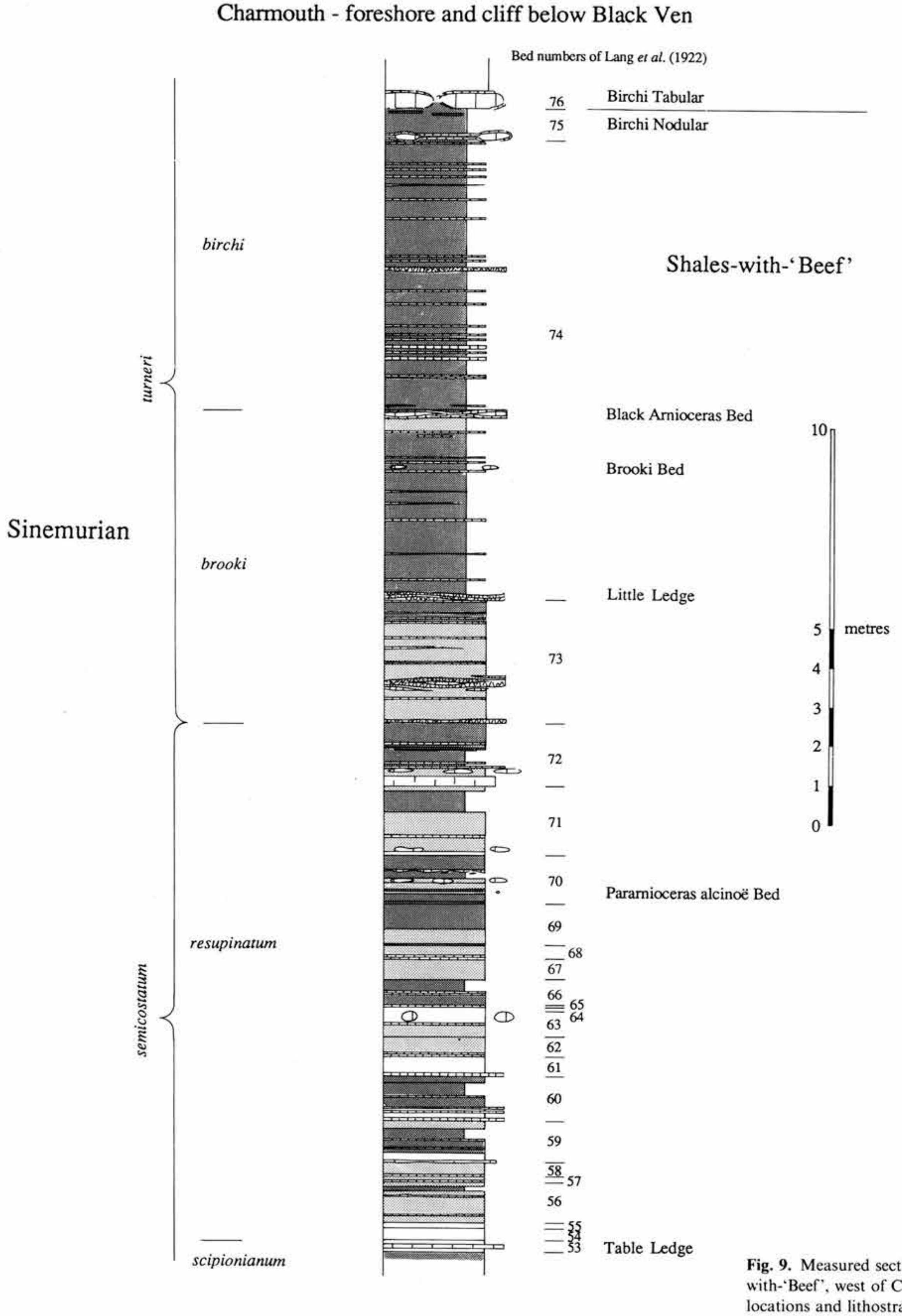



**Fig. 9.** Measured section for the Shales-with-'Beef', west of Charmouth. Precise locations and lithostratigraphical and biostratigraphical sources are discussed in the text. See Fig. 7 for key.

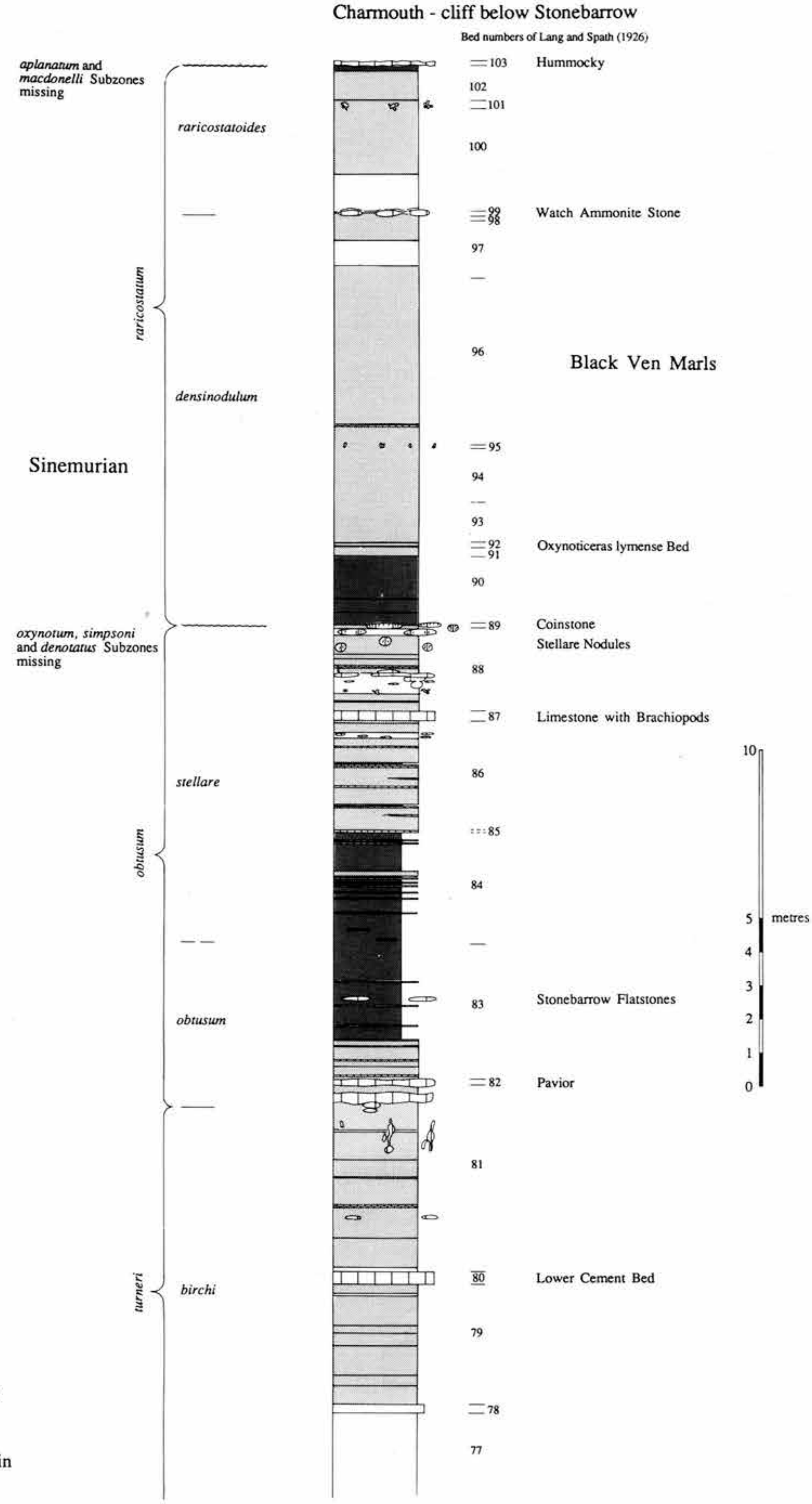



**Fig. 10.** Measured section for the Black Ven Marls, east of Charmouth. Precise locations and lithostratigraphical and biostratigraphical sources are discussed in the text. See Fig. 7 for key.

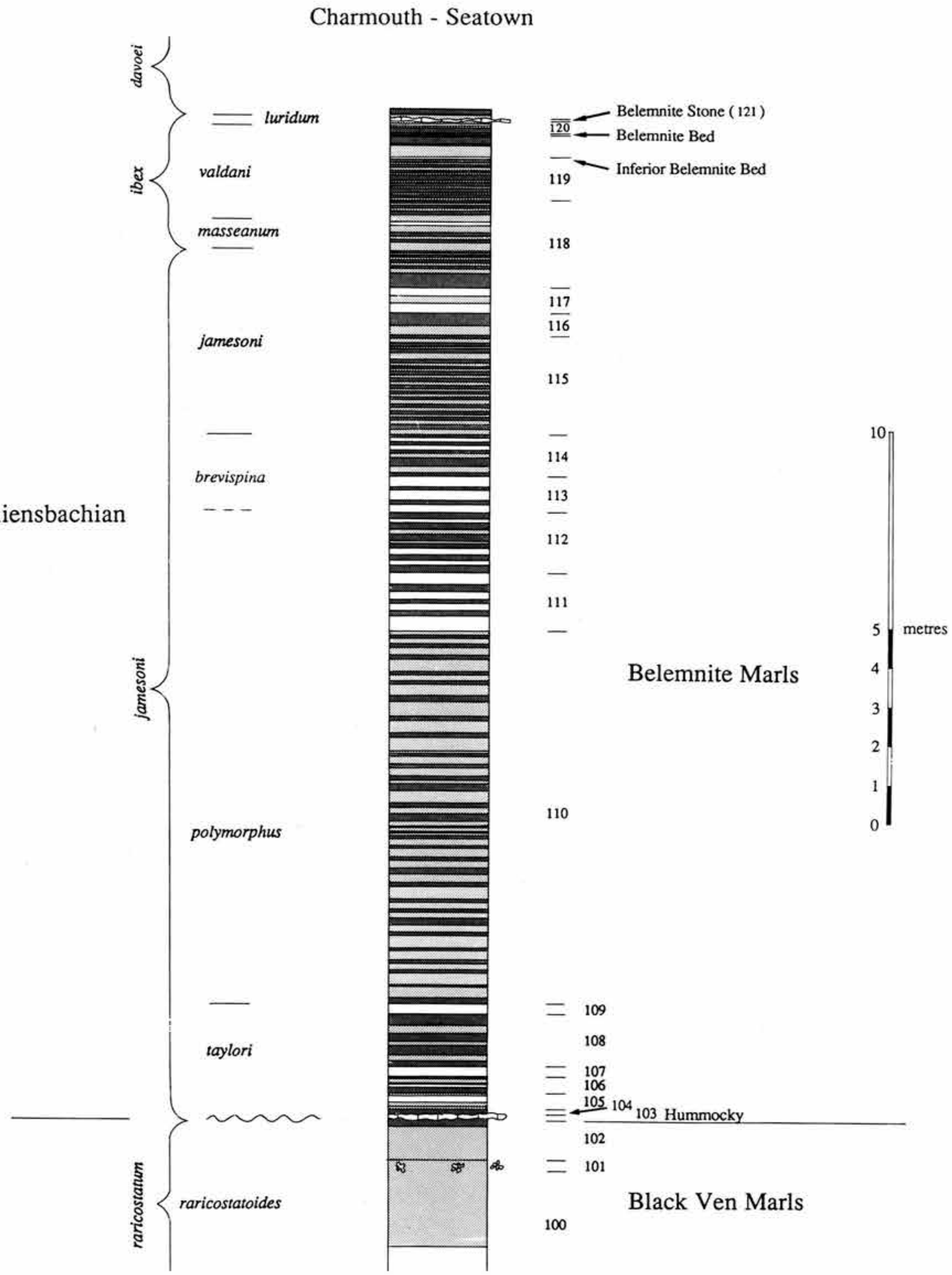



**Fig. 11.** Measured section for the Belemnite Marls, Charmouth to Seatown. Precise locations and lithostratigraphical and biostratigraphical sources are discussed in the text. See Fig. 7 for key.

bioturbated with pebble-sized fragments of concretions, also encrusted, dispersed throughout the bed; these limestone clasts and the tiered burrow systems have been described and illustrated by Sellwood (1972). Thus, it appears likely that the fragments of *Echioceras* found by Lang are also reworked and that the base of the Hummocky Limestone is the deepest level to which Pliensbachian burrowers penetrated, whereas the Pliensbachian sea-floor may not have been lower than the top of bed 104. We see the intervening interval as one of mixing and biogenic stratification (cf. Baird 1978; Meldahl 1987) and although the time of onset and the duration of erosion is unclear, the mechanism of erosion was probably biologically mediated as in the case of the Coinstone described above.

*Belemnite Marls.* The Belemnite Marls (Lang *et al.* 1928) comprise dark and light marls with minor millimetre-laminated carbon-rich shales and concretionary horizons. Cyclicity in the Belemnite Marls, like the Blue Lias, occurs at several scales but is much less strongly overprinted by diagenesis. Bed-by-bed couplets of light and dark marls and parallel changes in body and trace fossil assemblages (Lang *et al.* 1928; Simpson 1957) reflect different ambient oxygenation conditions which have been tentatively linked to water depth (Sellwood 1970, 1972), but may be more satisfactorily interpreted in terms of climatic variance affecting detrital input of clays and/or plankton productivity (Donovan *et al.* 1979; Weedon & Jenkyns 1990). The nature of the plankton may have changed from predominantly carbonate to predominantly organic-walled, depending on nutrient availability in near-surface waters. Spectral analysis through the Jamesoni Zone reveals a 300 cm bundle cycle in addition to the couplet cycle of 37.5 cm. The bundles may record irregular large-amplitude climatic variations and the couplets are best interpreted as precession cycles with a duration of 20 Ka (Weedon & Jenkyns 1990).

The Belemnite Marls as a whole (Fig. 11) can be considered as one sedimentary cycle of first increasing and then progressively decreasing bed-couplet and subzonal thicknesses with concomitant changes in belemnite concentrations, indicating first increase and then progressive decrease in net sedimentation rate. The top of the Belemnite Marls is greatly condensed with an ammonite sequence that is essentially complete (Lang *et al.* 1928; Phelps 1985). On the basis of subzone thickness (see Fig. 11), the most condensed horizon is the Belemnite Stone, of Luridum Subzone age, which is a light grey-brown concretionary horizon, some 4–5 cm thick, containing abundant belemnites, ammonites, bivalves and *Chondrites*. (Indeed, Callomon (*in* Callomon & Oates 1993) has argued that a minor stratigraphic gap lies above the Belemnite Stone by comparison with the more expanded succession at Blockley, Gloucestershire). On the basis of belemnite concentration, the most condensed horizon would be the Belemnite Bed, 34 cm below the Belemnite Stone and in the Valdani Subzone, which is a somewhat diffuse, dark grey pyritic and friable organic-rich mudstone, about 7–8 cm thick, characterized by a superabundance of belemnites and bivalves. A similar, but less marked, belemnite concentration (the Inferior Belemnite Bed of Fig. 11) occurs some 60 cm below the Belemnite Bed. Strontium-isotope stratigraphy suggests a small gap may be present within the Valdani Subzone at the Belemnite Bed (Jones *et al.* 1994).

Scours, with spans in the region of a metre and thicknesses in the order of a decimetre, are well displayed towards the top of the Belemnite Marls and in the base of the overlying Green Ammonite Beds and are ascribed a storm origin (Sellwood 1972). They occur in both the light and dark beds and are commonly filled with crinoid debris, belemnites, brachiopods and wood.

### *Seatown, Pliensbachian (the Green Ammonite Beds of the Lower Lias and the Three Tiers of the Middle Lias)*

The Green Ammonite Beds section (Fig. 12) was measured in the cliffs around Golden Cap, near Seatown (Fig. 5): beds 6–21 were measured around SY 413 918, beds 24–41 around SY 402 920 and the Three Tiers in a gully at SY 406 919. Bed numbers and biostratigraphy are from Phelps (1985) whose work largely supersedes the pioneering study of Lang (1936). The Red Band is a fairly distinctive level about the middle of the Green Ammonite Beds.

*Green Ammonite Beds.* This, the uppermost unit of the Lower Lias (Lang 1936), is a fully marine succession of mudrocks which is more silty and less calcareous upwards, in anticipation of the fundamental change to coarser siliciclastic deposits that characterize the Middle Lias. The name stems from the colour of the calcite in the chambers of the ammonite *Androgynoceras*. An unexplained peculiarity of the succession is the very pyritic nature of beds 40 and 41, at the top of the succession. A very marked westward thinning has been noted for the lower Green Ammonite Beds from below Golden Cap in the east to Black Ven in the west (Lang 1936). This pattern is compatible with a control on sedimentation being exercised by the Seatown Fault to the east (Figs 4–6), as is suggested also by other lines of evidence from the Middle Lias described below. However, if the Char Fault had any effect on sedimentary thicknesses at this time (which is doubtful), it would have been the reverse of that inferred for the earliest Jurassic.

### *Seatown to Eype's Mouth, Pliensbachian (the Three Tiers, Eype Clay, Down Cliff Sands, Thorncombe Sands and Marlstone of the Middle Lias and the Junction Bed* sensu stricto *of the Upper Lias)*

A different scale to that used for the other sections has been adopted to illustrate the Middle Lias and Junction Bed (Fig. 13). The measured section is a composite, the lower part up to and including the Eype Nodule Bed being taken from the cliffs of Golden Cap [SY 406 919] and the remainder from around Thorncombe Beacon [SY 430 914–435 914]. Lithostratigraphical and biostratigraphical data are taken from Howarth (1957; *in* Cope *et al.* 1980*a*). Details of the stratigraphy of the Middle Lias–Upper Lias transition (the Marlstone and Junction Bed *s.s.*) are shown in Fig.14.

The Middle Lias (closely approximating to the Upper Pliensbachian) succession (Fig. 13) comprises siltstones and very fine to fine sandstones with occasional minor limestones. This fully marine succession generally coarsens up, from the Eype Clay, through the Down Cliff Sands and into the Thorncombe Sands. However, this general pattern is complicated by relatively thin sandstones at the base (the Three Tiers) and erosion surfaces and condensed sections throughout, expressed as hiatus concretions and shell beds (the Eype Nodule Bed, Day's Shell Bed) or shelly flat-pebble conglomerates (the Margaritatus Stone, the Thorncombiensis Bed and the Marlstone, which also contains ferruginous ooids).

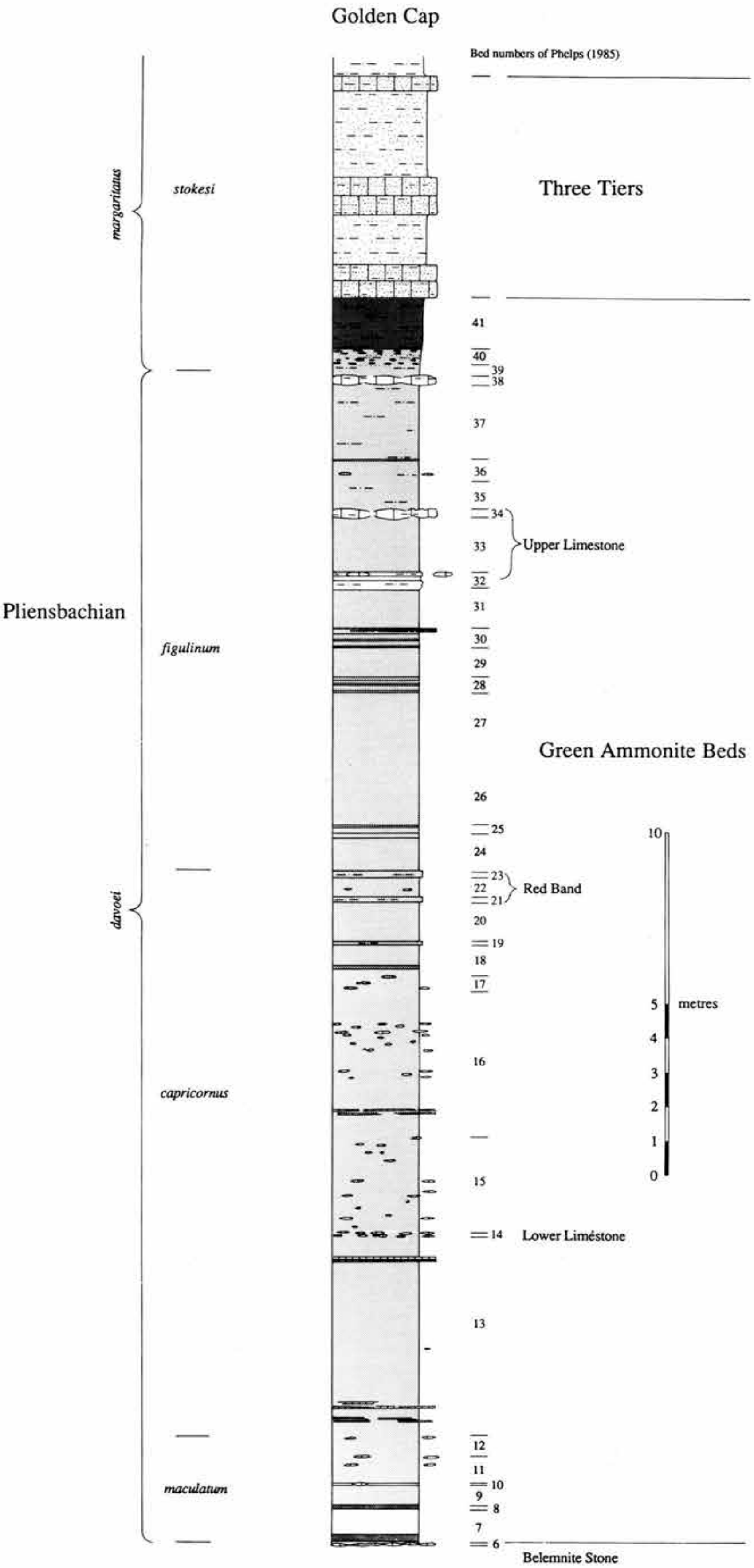



**Fig. 12.** Measured section for the Green Ammonite Beds, below Golden Cap, Seatown. Precise locations and lithostratigraphical and biostratigraphical sources are discussed in the text. See Fig. 7 for key.

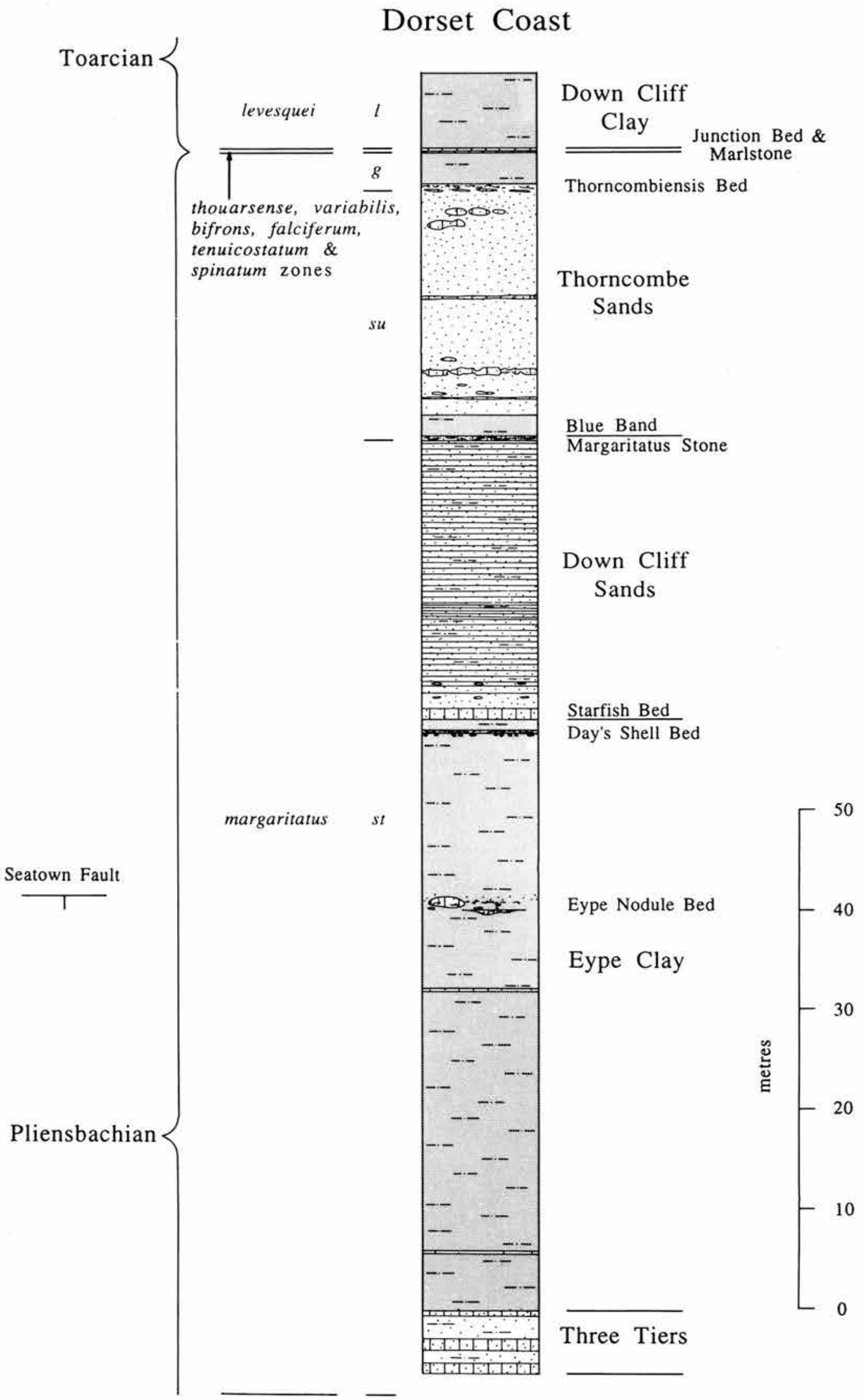



**Fig. 13.** Measured section for the Middle Lias, Seatown to Eype's Mouth. Precise locations and lithostratigraphical and biostratigraphical sources are discussed in the text. See Fig. 7 for key; detailed grain-size variations are not shown.

| BIOSTRATIGRAPHY | | LITHOSTRATIGRAPHY | | | LITHOLOGY |
|---|---|---|---|---|---|
| Zones | Subzones | Nomenclature from Jackson (1922,1926) | | | |
| *levesquei* | *aalensis* | | | | |
| | *moorei* | | | | |
| | *levesquei* | | | | |
| *thouarsense* | *dispansum* | I | Junction Bed *sensu stricto* | Junction Bed *sensu lato* | Pink and grey conglomeratic and nodular limestone |
| | *fallaciosum* | | | | |
| | *striatulum* | | | | |
| *variabilis* | | | | | |
| *bifrons* | *crassum* | | | | |
| | *fibulatum* | K | | | |
| | *commune* | L | | | |
| *falciferum* | *falciferum* | M | | | Grey, argillaceous nodular limestone and marl |
| | *exaratum* | O+N | | | |
| *tenuicostatum* | *semicelatum* | P | Marlstone | | Grey, pink and brown weakly Fe-oolitic and bioclastic limestone |
| | *tenuicostatum* | | | | |
| | *clevelandicum* | | | | |
| | *paltum* | | | | |
| *spinatum* | *hawskerense* | Px | | | |
| | *apyrenum* | R | | | Red-brown conglomeratic, Fe-oolitic limestone |
| *margaritatus* | *gibbosus* | | | | |
| | *subnodosus* | | | | |
| | *stokesi* | | | | |

**Fig. 14.** Lithostratigraphy and biostratigraphy of the Junction Bed, *sensu lato*, from Jackson (1922, 1926), Howarth (1957; in Cope *et al.* 1980*a*) and Jenkyns & Senior (1991).

Sandstone also immediately overlies the Eype Nodule Bed locally, whereas thin units of siltstone overlie the Margaritatus Stone and Thorncombiensis Bed. The vertical arrangement is thus one of highly assymetrical cycles of mudstones and/or sandstones and/or limestones. Although the limestones are volumetrically a minor component of the succession, they probably account for a significant proportion of the time represented; any hiatuses present are beyond the resolution of the ammonite biostratigraphy.

*Three Tiers and Eype Clay.* The Three Tiers is a unit containing three cemented beds, each 0.5–1 m thick and comprising very fine sandstone. Each bed has gradational upper and lower boundaries. There is a weakly defined planar lamination, but the predominant fabric is bioturbational, with common *Thalassinoides* (Sellwood *et al.* 1970). There is not a great difference in grain size between the cemented sandstone of each 'Tier' and the intervening less well-consolidated sediment. The base of the lowest 'Tier' is conventionally taken as the base of the Middle Lias and this does not correspond exactly with the base of the Margaritatus Zone (Figs 12 and 13). Ammonites have been found in the Three Tiers, the lowest 'Tier' being the most fossiliferous and yielding also some small gastropods (Wilson *et al.* 1958).

The Eype Clay (Fig 13) is a light grey micaceous and variably silty mudstone with many small siderite nodules. It is generally devoid of body fossils with the exception of small specimens of *Amaltheus*. Illite is the predominant clay mineral (Sellwood & Sladen 1981). There are few distinctive horizons within the succession, the most notable of these being the Eype Nodule Bed (Howarth 1957; Wilson *et al.* 1958; Ensom 1984*a, b*). Ammonite fossils and concretions collected from this bed near Eype's Mouth [SY 448 910] by Ensom (1984*a, b*) show abundant evidence for reworking on the sea floor in the form of a diverse range of encrusting organisms.

A somewhat similar horizon occurs at the top of the Eype Clay, but because of the great abundance of shelly debris it contains, it has been termed Day's Shell Bed (Day 1863; Wilson *et al.* 1958; Palmer 1966). Small carbonate concretions also occur within the shell bed and in the underlying strata, but they are less numerous than those in the Eype Nodule Bed. A striking feature of the diverse and abundant marine fauna in the shell bed is the general immaturity of the individuals represented, especially the gastropods, with only the bivalves *Pseudolimea*, *Gryphaea*, *Lucina* and *Astarte* preserved predominantly as adults (Palmer 1966).

*Down Cliff Sands to Thorncombe Sands.* The Starfish Bed, at the base of the Down Cliff Sands, is a composite unit with several decimetre-scale intervals of laminated sandstone, locally showing oscillation ripples and hummocky cross-stratification, alternating with bioturbated sandstones (see Goldring & Stephenson 1972). The eponymous 'starfish', the ophiuroid, *Palaeocoma egertoni*, is thought to have been killed through sudden smothering by storm-transported sand (Goldring & Stephenson 1972; Ensom 1983), a phenomenon likely to have occurred only in environments in which sand-sheet deposition would be unusual. Ophiuroids appear not to have been preserved once episodic sand deposition had become established, as in the case of higher levels in the Middle Lias. The bulk of the Down Cliff Sands comprise grey-brown muddy very fine sands and sandy mudstones, closely interbedded. More homogeneous are the yellow-weathering, silty, very fine sands of the Thorncombe Sands, higher in the section. Wave-washed fallen blocks of Thorncombe Sands exhibit interbedded hummocky cross-stratified and bioturbated horizons (cf. Sellwood *et al.* 1970), also suggesting a strongly storm-influenced sedimentary environment.

*Junction Bed* sensu lato. This is a highly condensed and lithologically diverse limestone (Fig. 14) which has been described by Jackson (1922, 1926), Howarth (1957, 1980; *in* Cope *et al.* 1980*a*), Hallam (1967*b*), Sellwood *et al.* (1970) and Jenkyns & Senior (1991). The lowest unit, the Marlstone, is a brown or pink, conglomeratic, more or less oolitic (berthierine and goethite) and crinoidal limestone assigned to the Spinatum and Tenuicostatum Zones, commonly piped down in large *Thalassinoides* into the underlying mudstone. The Marlstone is overlain, across a hardground, by Junction Bed *sensu stricto*, the basal portion of which is typically pink to buff, fine-grained, stromatolitic limestone and marl belonging to the Falciferum Zone. The upper part of the Junction Bed *s.s.* comprises light-coloured conglomeratic limestones of the Bifrons, Thouarsense and Variabilis Zones. Episodically rapid sedimentation rates have been inferred, because the abundant vertically oriented ammonites would not have been preserved had they lain for long periods on the sea-floor unprotected by a blanket of sediment (Hallam 1967*b*).

Typically only a few tens of centimetres in thickness at outcrop, the Junction Bed thickens and becomes more silty in the Winterborne Kingston Trough to the north (Fig. 1; Ivimey-Cook 1982; Rhys *et al.* 1982).

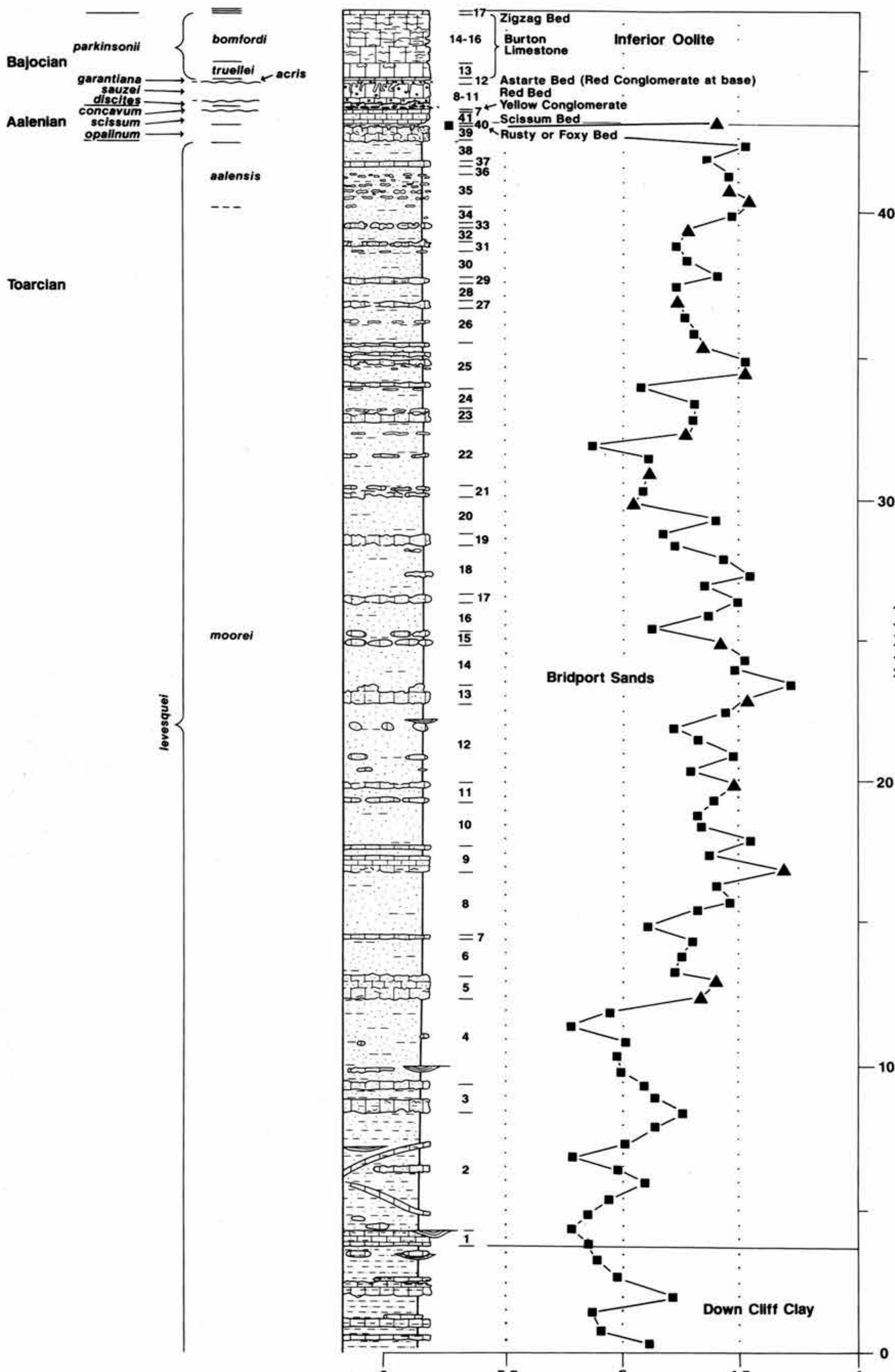
*Fault movement and Middle–Upper Lias sedimentation.* Subtle lateral variation occurs in the Middle Lias. Below Golden Cap (Figs 5 and 6), the Eype Nodule Bed is dispersed through some 40 cm of section, and is overlain by 75 cm of silty, very fine sandstone. About 2 km to the east, in Ridge Cliff (Fig. 6), the Eype Nodule Bed shows evidence for the early formation of carbonate concretions, some of which have been reworked by burrowing organisms and have pyritized rims. Just west of Eype's Mouth, the Eype Nodule Bed has a similar aspect to that at Ridge Cliff, except that some of the nodules are, in addition, bored and encrusted (Ensom 1984*b*). Strata of the upper part of the Middle Lias, the Margaritatus Stone to Junction Bed, measured in the cliffs by Howarth (1957), show a progressive thickening eastwards from just over 20 m at Ridge Cliff to just over 28 m on the eastern side of Thorncombe Beacon. East of Eype's Mouth [SY 451 909] the same interval is again reduced to 22 m, at least some of this being by truncation of the topmost beds below the Junction Bed. These observations may be explained by postulating synsedimentary movement on the NNW–SSE-trending Seatown Fault (which would have had a downthrow to the west in the late Pliensbachian, implying substantial inversion to give the present throw) and on the Eype's Mouth Fault (Figs 4 and 5).

The exposures near Eype's Mouth show further curious, but conclusive evidence for movement on the east–west-oriented Eype's Mouth Fault which intersects the coast spectacularly at 'Fault Corner', Watton Cliff (Buckman 1922; Jenkyns & Senior 1977, 1991). There, the Middle and Upper Lias outcrop on the northern side of the fault and are juxtaposed against Fuller's Earth and Forest Marble of Bathonian age on the south. The Junction Bed *s.l.* shows a dramatic, trumpet-like, thickening into the fault-plane, probably all of which is due to the presence of synsedimentary tectonic fissures filled with fine-grained, parallel and cross-laminated, buff to pale rose coloured calcilutites. Contacts between the fill and the matrix are generally sharp but locally are gradational and the fissures occur rarely as dykes or, much more commonly, sills. The dykes contain gastropods, brachiopods, crinoid and echinoid fragments, thin-shelled bivalves and foraminifera. Sills contain a similar fauna but have yielded additionally nautiloids and, importantly, ammonites indicative of the Falciferum, Bifrons, Thouarsense and Variabilis Zones. Thus, faunas belonging to the Toarcian have been inserted, out of sequence, into older Toarcian and Pliensbachian matrix, a relationship that caused considerable difficulties of interpretation for previous workers (Buckman 1922; Jackson 1922, 1926; Wilson *et al.* 1958). Multiple episodes of submarine faulting were envisaged by Jenkyns & Senior (1991) during which vacuum suction resulted in the deposition of the fissure fills within partially lithified sediment. Movement on the fault is very likely to have been down to the south. Sediment-filled dykes also occur in loose blocks of probable Starfish Bed in the vicinity of Eype's Mouth (Ensom 1987); in one example the dykes apparently cross-cut calcite veins, suggesting an origin connected with tectonic fracturing rather than soft sediment deformation and again indicative movement on the Eype's Mouth Fault.

The Eype's Mouth Fault is offset sinistrally by the NNE–SSW trending Mangerton Fault (Fig. 4) and it has been mapped, with a continuing east–west trend, some 1.5 km further inland from the coast (Wilson *et al.* 1958; Fig. 2). Fissure facies *in situ* and in field rubble at Bothenhampton [SY 478 916 and SY 483 916] and Shipton Gorge [SY 501 913], along the line of the Eype's Mouth Fault, indicate Toarcian (Thouarsense and Levesquei Zones) and Bajocian (Garantiana Zone, Acris Subzone) fault movement (Jenkyns & Senior 1991). The true stratigraphy of the Inferior Oolite in the area of Shipton Gorge is also indicative of early Bajocian movement on the Eype's Mouth Fault, since strata of this age are locally missing north of the fault (Senior *et al.* 1970; Jenkyns & Senior 1991). Thus, the evidence shows that activity on the Eype's Mouth Fault continued at least into the Middle Jurassic.

### *West Bay to Burton Bradstock, Toarcian (the Down Cliff Clay and Bridport Sands of the Upper Lias)*

The Down Cliff Clay and Bridport Sands (Fig. 15) up to and including bed 12 were measured from the foot of East Cliff [SY 465 902–474 897]; beds 13–31 from the foot of Burton Cliff between SY 478 895 and 490 888 (25–31 are from a large fallen block at about SY 485 891); beds 32–37 from a cutting behind the garage at SY 488 893; and beds 38–40 from the sunken lane at SY 487 892. Samples for grain-size analysis were collected from the same exposures but those for bed 32 upwards were all collected from the sunken lane [SY 487 892]. The Inferior Oolite is seen in fallen blocks at the western end of Burton Cliff and a detailed section is shown and discussed below. The base of the Bridport Sands is that taken by Davies (1967) and the top follows Arkell (1933) in excluding the Scissum Bed. The positions of the subzonal boundaries of the Levesquei Zone are uncertain because age-diagnostic fossils are uncommon through most of the succession. The Levesquei Subzone is represented in the Down Cliff Clay at Doghouse (Doghus) Cliff, on the basis that Buckman (1910) recorded ammonites now known to be typical of the Levesquei Subzone (Dean *et al.* 1961) at 12 ft (4 m) from the top and at lower horizons. Although almost all of the lower 30 m of Bridport Sands



Bajocian
parkinsonii
bomfordi
truellei
acris
garantiana
sauzei
discites
concavum
Aalenian
scissum
opalinum
aalensis
Toarcian
moorei
levesquei
17
Zigzag Bed
14-16
Burton Limestone
Inferior Oolite
13
12
Astarte Bed (Red Conglomerate at base)
8-11
Red Bed
7
Yellow Conglomerate
41
Scissum Bed
40
39
Rusty or Foxy Bed
38
37
36
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
Bridport Sands
Down Cliff Clay
Height (m)
0
10
20
30
40
6
5.5
5
4.5
4
Mean grain size (phi)

lack age-diagnostic fossils (Buckman 1910), specimens of *Dumortieria moorei* have been reported from the basal cemented bands at East Cliff, West Bay (Parsons 1975), suggesting that the Moorei Subzone extends down to the base of that unit. The highest subzone of the Levesquei Zone is somewhat better defined: Buckman (1910, p. 74) indicated only 1 ft 6 ins (0.45 m) of Bridport Sands containing Aalensis Subzone ammonites at Burton (3 ft 6 ins (1.1 m) if the 2 ft (0.6 m) of barren sandstone below the first appearance of *Leioceras opalinum* are included, as they are in Fig. 15). Richardson's section (1928–30, p. 64) implies that the whole of our bed 35 (Fig. 15) belongs to the Aalensis Subzone. These small thicknesses contrast with the 34 ft (10.4 m) of Aalensis Subzone in the vicinity of Chideock Hill, some 7–8 km to the west (Buckman 1910, Table III, facing p. 78) and also with the figure given by Arkell (1933, p. 166) who states an approximate thickness of 25 ft (7.6 m) for the Aalensis Subzone, but specifying neither source of information nor locality. Published evidence (Buckman 1910; Richardson 1928–30; Torrens in Cope *et al.* 1969; Callomon & Chandler 1990) suggests that the Opalinum Zone is only 1 ft 6 ins (*c.* 0.5 m) thick; the 2.0 m given by Parsons (*in* Cope *et al.* 1980*b*) is from an inland section, the Stoney Head Road Cutting (Parsons 1975).

*Down Cliff Clay and Bridport Sands.* The succession from the Junction Bed, through the Down Cliff Clays, to the Bridport Sands is one of broadly increasing grain-size. On the coast, the onset of deposition of large volumes of silt occurred during the Levesquei Subzone of the Levesquei Zone. The Bridport Sands and their inland equivalents, the Yeovil Sands, Midford Sands and Cotteswold Sands, were the subject of an important early study demonstrating diachroneity of identical facies (Buckman 1889). The locus of sand deposition moved southward, apparently in an episodic fashion, from the late Bifrons Zone to the late Levesquei Zone (Buckman 1889; Arkell 1933; Davies 1969; Torrens in Cope *et al.* 1969; Bryant *et al.* 1988); areas distal to the siliciclastic sediment supply continued to accumulate condensed limestones such as the Junction Bed. The Bridport Sands on the coast are composed of silt, very fine sand and fine sand (Fig. 15). Calcite-cemented bands weather out prominently in the cliff and these are thought to reflect slight primary differences in original sediment texture, possibly bioclast-rich storm deposits with characteristic burrow suites (Kantorowicz *et al.* 1987; Bryant *et al.* 1988), although most primary sedimentary structures have been obscured by the intense bioturbation. Sedimentary structures that have survived are mainly small-scale dish-shaped scours occurring sporadically in the lower half of the succession (Davies 1967, 1969; Hounslow 1987). In contrast to the underlying formations, the clay mineralogy of the uppermost Upper Lias is predominantly smectitic (Sellwood & Sladen 1981).

In detail, grain-size increases up through the Down Cliff Clay and reaches a maximum in the lower half of the Bridport Sands, coincident with the highest rate of sediment accumulation as indicated by the wide bed-spacing in the Moorei Subzone. The mean grain size of the Bridport Sands then decreases to a minimum in the upper part of the formation from which it progressively increases again up to the condensed top; changes in bed-spacing coincident with changes in grain size are not clearly demonstrable for the Aalensis Subzone (Fig. 15). A thin iron-stained clay seam overlies an irregular hardground at some localities near the cliff section (the lane section at Burton Bradstock [SY 487 892] and the road cutting at Vinney Cross [SY 509 928]) and forms the Rusty Bed which marks a subzonal boundary. The uppermost beds are packed with ammonites and other fossils indicating condensation.

A storm-wave-influenced, lower or middle shoreface depositional environment for the Bridport Sands in the south Dorset area has been inferred by previous authors (e.g. Davies 1969; Colter & Havard 1981; Hounslow 1987; Bryant *et al.* 1988) but precise interpretations of the regional three-dimensional geometries have not been published and whether deposition took place in a coastal or a shoal setting remains unproven. Although the Bridport Sands young to the south, coeval deposits to the north have a normal marine fauna and the depositional geometry of the sand may have been roughly in the form of lobes, with a source to the southwest (Boswell 1924; Davies 1969) or conceivably northeast (Knox *et al.* 1982) rather than in the form of a migrating bar, the model developed in detail by Davies (1969).

A local facies of cross-bedded bioclastic limestone, not seen on the coast, occurs as the Ham Hill Stone within the Yeovil Sands (Wilson *et al.* 1958; Cope *et al.* 1969; Davies 1969; Jenkyns & Senior 1991) and also, with berthierine ooids, in at least two levels within the Bridport Sands in the subsurface (Knox *et al.* 1982; Bryant *et al.* 1988). Where the vertical succession is clear, as in the nearby Winterborne Kingston Borehole [SY 847 979], the limestones, which may have been tidally influenced, are developed in conjunction with coarsening-upward cycles, as miniature versions of the Lias cycles seen on a stage-scale and alluded to in the introduction. In the borehole, the limestones are floored by erosion surfaces and are thought to represent an initial transgressive phase in each cycle (Knox *et al.* 1982). Also, in a manner very similar to that displayed in the Moorei Zone of the coastal exposures (Fig. 15), any one sedimentary cycle in the borehole has the widest bed-spacing coincident with the coarsest grain-size and is probably representative of a shallowing.

Near the base of the Bridport Sands of East Cliff, there is a unit, prominent in the cliff, comprising undulating cemented bands with a wavelength of about 20 m and an amplitude of about 3 m (Fig. 15). The same unit occurs on Thorncombe Beacon [SY 435 913] where it is somewhat expanded (Fig. 16). The broad undulations of cemented bands were interpreted by Davies (1967) as reflecting a level of deep scours, but the sinusoidal form and absence of unambiguous truncation surfaces and pebbly lags in the troughs argue against such an origin. Close inspection reveals an underlying pattern of multiple, burrowed surfaces, picked out by iron-staining, not all of which are preferentially calcite-cemented (drawn to our attention by Finn Surlyk in 1992). The regularity of the undulations strongly suggests a bottom topography of corrugations rather than domes, oriented approximately perpendicular to the present coastline. Their occurrence at the transitional boundary between predominantly argillaceous and predominantly arenaceous deposits suggests that the ridges formed, possibly as aggradational features, at the toe of a slope of

**Fig. 15.** Measured section through the Bridport Sands, West Bay to Burton Beach. Precise locations and lithostratigraphical and biostratigraphical sources are discussed in the text. See Fig. 7 for key. Grain sizes were determined from acid-treated samples using a laser granulometer.

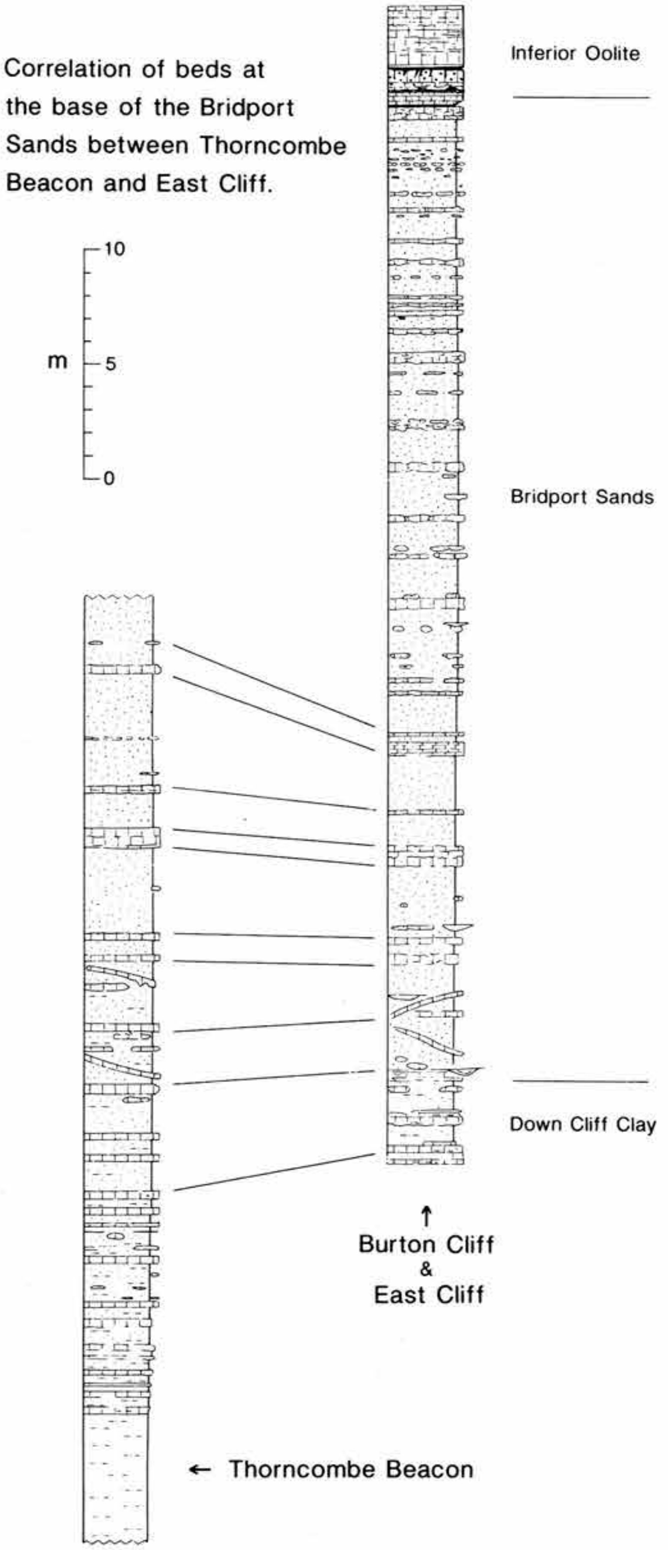



**Fig. 16.** Correlation of the Bridport Sands section of Fig. 15 (Burton Cliff and East Cliff) with a section measured on Thorncombe Beacon, west of West Bay. There is a clear, consistent expansion of the Thorncombe Beacon succession relative to that at West Bay.

advancing sand. These structures lack internal cross-bedded geometry, whereas cross-stratification is observed in smaller metre-scale scours near the base of the Bridport Sands.

In the 3 km long stretch of Burton Cliff and East Cliff, the accessible parts of the Bridport Sands maintain a remarkably constant thickness and vertical succession. The exposure on Thorncombe Beacon, a further 3 km west of East Cliff, shows the same succession but is expanded by about 140% with respect to the thicknesses at Burton Cliff and East Cliff (Fig. 16). In addition to the Eype's Mouth Fault, which had a downthrow in the wrong direction to account for the observed thickness changes (see below), two other faults have been crossed in this traverse: the NNE–SSW-trending Mangerton Fault and an east–west-trending fault which passes through West Bay. Both of these latter faults intersect the coast west of West Bay (in the vicinity of SY 455 905) although sadly there is now no significant exposure here due to modern coastal protection work. Loose boulder-bed facies, similar to that seen at 'Burton Villas' described below, do still occur on the foreshore at low tide and these and other synsedimentary fault-related features, seen also by previous workers, have been described by Wilson *et al.* (1958). The West Bay Fault currently has a downthrow to the north and apparently defines the southern edge of a narrow graben which is bounded on the northern side by the Eype's Mouth Fault; the whole graben may be offset laterally or possibly is terminated by the Mangerton Fault which may itself have had a modest downthrow to the west in the Middle Jurassic (since reversed) judging by the facies distribution in the Inferior Oolite (Jenkyns & Senior 1991).

### *Burton Cliff, Aalenian and Bajocian (Inferior Oolite)*

The Inferior Oolite section (Fig. 17) is based mainly on Richardson (1928–30) with the bed numbers of Torrens (*in* Cope *et al.* 1969) and the biostratigraphy mostly as revised by Callomon & Chandler (1990). Although the latter authors found no ammonites in Bed 8, the 'Snuff-Box Bed', it probably belongs to the Discites Zone, based on the ammonite evidence of Parsons (1973) from a nearby temporary exposure. The upper limit of the Bridport Sands is taken at the top of the bed 5, the Foxy Bed, following Arkell (1933). Several fallen blocks at the western end of Burton Cliff (around SY 481 893) allow detailed investigation of all the beds, which can also been seen, albeit less clearly, in the lane section mentioned in connection with the Bridport Sands [SY 487 892].

*Inferior Oolite*. The Inferior Oolite of the Wessex Basin is a lithologically varied limestone, locally highly condensed and of great stratigraphical complexity. The palaeogeographical setting is thought to have been an intrabasinal structural high (Sellwood & Jenkyns 1975) distal to carbonate ramp facies developed around the London–Brabant landmass and the Worcester Graben to the north (Jones & Sellwood 1989).

At Burton Cliff the unit can be conveniently divided into four unequal parts separated by significant stratigraphical breaks (Fig. 17) described in detail by Buckman (1910) and Richardson (1928–30). The lowest unit, the Scissum Bed, is a light brown, very fine-grained, highly calcareous sandstone, similar in aspect to the cemented bands in the Bridport Sands, but with much better sorting; it is assigned to the Scissum Subzone. Above a hiatus, equivalent to two ammonite zones, are the Yellow Conglomerate and the Snuff-Box

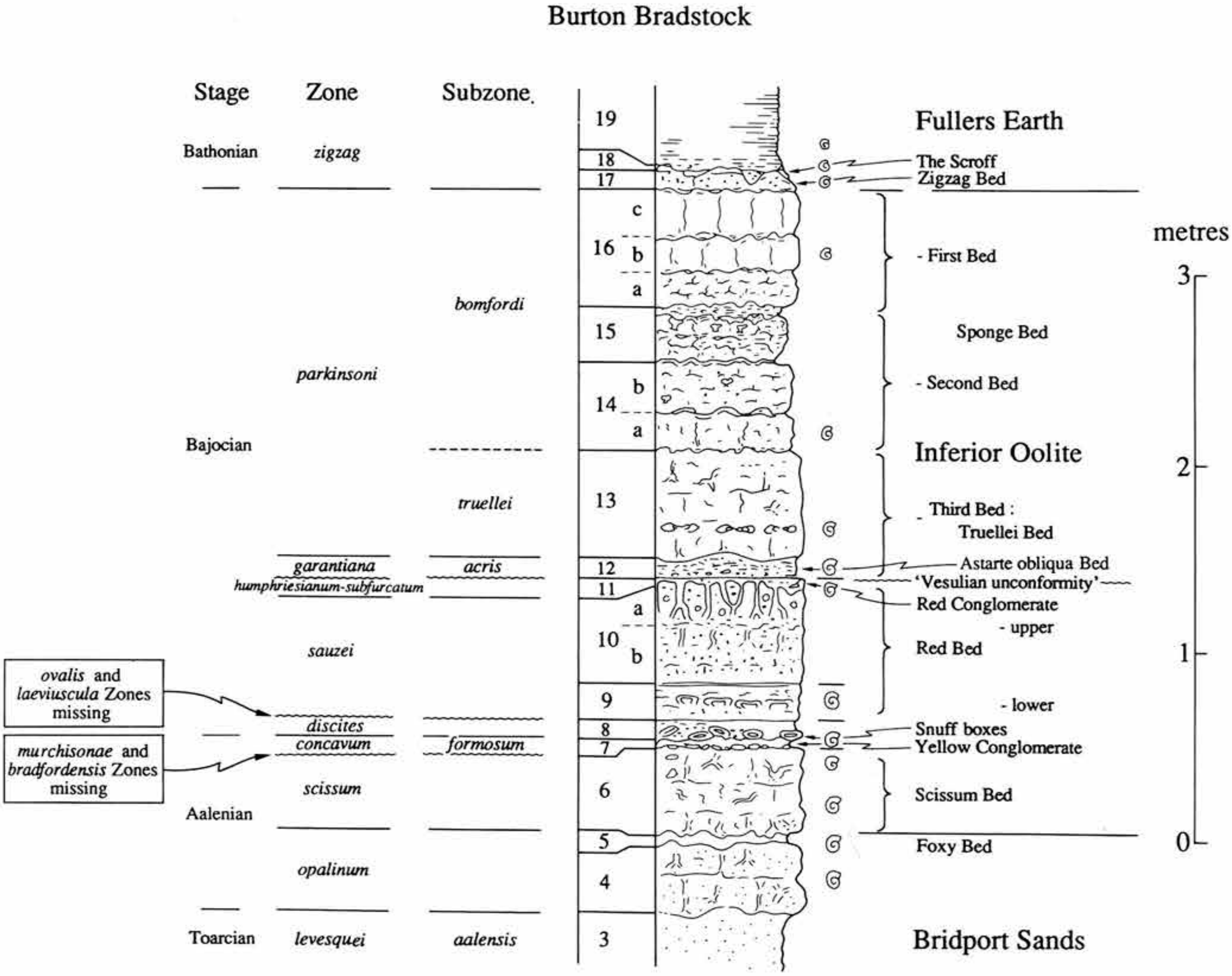



**Fig. 17.** The Inferior Oolite section of Burton Cliff. Precise location and lithostratigraphical and biostratigraphical sources are discussed in the text.

Bed; the former is a thin unit of Concavum Zone age containing the reworked remains of Murchisonae Zone and Bradfordensis Zone ammonites; the latter, the lowest unit of the Red Beds, is a layer of large limonitic oncoids. Above a second non-sequence, at which the Ovalis and Laeviuscula Zones are missing, are the upper parts of the Red Beds, limestones with few ammonites, containing scattered limonite ooids. The Red Beds are capped by an irregular hardground with a morphology strongly influenced by *Thalassinoides* as described by Sellwood *et al.* (1970). This third non-sequence in the Inferior Oolite is marked by a discontinuous Red Conglomerate, containing remanié ammonites, mostly of the Humphriesianum Zone, but also derived from the Sauzei Zone, and penetrated and cemented by white limestone containing Subfurcatum Zone ammonites (Gatrall *et al.* 1972). The whole Red Conglomerate complex is overlain by a rough laminated pavement of similar composition to the Snuff Boxes. The upper half of the Inferior Oolite at Burton comprises the Burton Limestone with, at its base, the Astarte Bed, a brown bioclastic limestone belonging to the uppermost Garantiana Zone capped by the Truellei Bed, a blue-grey bioclastic limestone, in turn overlain by light grey marly and rubbly limestones with abundant sponges and bryozoans belonging to the Parkinsoni Zone. The basal Bathonian is a highly condensed limestone unit of light grey nodular limestone and brown marl which gives way upwards to the expanded Fuller's Earth above. Clay minerals in the Inferior Oolite are strongly smectitic (Knox 1982; Jones & Sellwood 1989).

The Snuff Box Bed is typical of several horizons within the Aalenian–Bajocian of southern England and northern France and has been the focus of most sedimentological attention directed at the Inferior Oolite (Sellwood *et al.* 1970; Gatrall *et al.* 1972; Palmer & Wilson 1990). The Snuff Boxes are roughly discoidal, range from 3 to 30 cm in diameter and form an essentially 'grain-supported' fabric. The internal structure reveals discontinuous limonite lamellae with encrusting calcareous organisms and diagenetic fibrous calcite at interlamella boundaries: the encrusting fauna includes foraminifers, sponges, serpulids, bivalves, bryozoans and brachiopods (Palmer & Wilson 1990). Nucleation was on large fossil fragments or intraclasts, with accretion tending to occur as discrete bundles on either one side or the other, indicating that individual Snuff Boxes may have been overturned several times during growth which occurred only on one side. Palmer & Wilson (1990) suggested that the lamellae accreted, developing a convex-down form, on the undersides of each Snuff Box, for two main reasons: (a) the encrusting fauna consists of gloomy-cavity dwellers; and (b) the outermost lamella bundle is predominantly convex-down. They further indicated that if micro-organisms were involved in the genesis of Snuff Boxes, as suggested by Sellwood *et al.* (1970) and Gatrall *et al.* (1972), then they must have been non-photosynthetic. A number of questions remain to be further investigated. Do the gloomy encrusters reflect a lack of light which is related to water depth rather than shadow? Is the present orientation of the Snuff Boxes consequent upon ease of overturning by large scavengers or bottom-current activity rather than final *in situ* growth position?

At 'Burton Villas' (now the almost anagrammatical Barton Olivers) at the eastern end of Burton Cliff [SY 489 887] the Bride Fault cuts the coast and juxtaposes the Bridport Sands, of Toarcian and Aalenian age, against Fuller's Earth (Bathonian). The trace of a fault, identified as the Bride Fault by Jenkyns & Senior (1991), is at times visible on the upper beach where a sliver of Inferior Oolite is caught up in the fault zone; the Inferior Oolite here is anomalous in yielding (Jenkyns & Senior 1991) ammonites of the Subfurcatum Zone, Baculata Subzone, which is unknown from the normal Bajocian succession in this area. A second substantial fault, mapped offshore by Darton *et al.* (1981), may also intersect the coast at about this point (Fig. 4), and the fault seen on the beach is probably the onshore extension of this, rather than the Bride Fault, although the two undoubtedly join. Large blocks of Bridport Sands litter the foreshore to the west of the fault trace. These contain bedding-subparallel fissures full of laminated peloidal white calcilutites with variable quantities of angular quartz grains (Jenkyns & Senior 1991). The general aspect of the facies are similar to those seen at 'Fault Corner' but the ammonites in the fills are indicative of the Bajocian Garantiana Zone, probably Tetragona Subzone. As at 'Fault Corner', discussed above, the fissure-fills caused early workers considerable interpretative difficulties as is evident from the colourful discussions in Buckman (1910, 1922), Richardson & Butt (1912) and Richardson (1915, 1928–30). Subhorizontal fissures within the Bridport Sands were formerly well seen *in situ* in the cliff face adjacent to the exposed fault trace (Richardson & Butt 1912; Jenkyns & Senior 1991) but at the time of writing this guide, these had mostly been obscured or removed by erosion.

Occasionally, a boulder-bed limestone is exposed as loose, half-metre- to metre-scale blocks, a few tens of metres west and south of the fissured Bridport Sands. The age of this limestone is presently uncertain, although it most likely belongs to the Bajocian Inferior Oolite. These beds cannot have accumulated at the foot of a fault scarp if, as seems most likely, the faults responsible for the fissuring had a downthrow to the south in the Jurassic; instead the boulder-beds may be seen as formed by local shedding of rock-debris on the footwall side, due to deformation in a band parallel to the crest of the fault block which took place during fault activity. That such crest-parallel deformation of the footwall took place is also indicated by the thinning to nothing of the Junction Bed some 10–20 m north of the Eype's Mouth fault as described by Jenkyns & Senior (1991).

## Yorkshire

The coast of Yorkshire, like the coast of Dorset, cuts an oblique section across tectonic structures active during the Jurassic. Of particular relevance is the Peak Fault, which is a north–south-oriented fault, intersecting the cliffs just to the south of Robin Hood's Bay (Fig. 1a). On the western side of the fault, strata of late Toarcian age are missing and the Aalenian sits with marked unconformity on the Whitby Mudstone. The exact nature of Jurassic or post-Jurassic motion on this fault has been a matter for some debate (e.g. Hemingway 1974) but on the basis of offshore seismic reflection data it is now clear that the fault defines the western margin of a narrow graben, the Peak Trough (Milsom & Rawson 1989). However, apart from the enhanced Lower–Middle Jurassic unconformity, there is very little other evidence apparent in the field to suggest that the fault was continuously active over the Early Jurassic interval. Facies and thickness changes associated with the Peak Trough are much more apparent in the Middle Jurassic (Farrow 1966; Knox 1973; Hemingway & Riddler 1982; Holloway 1985; Alexander 1986; Milsom & Rawson 1989). Other north–south-oriented faults in the region probably had a similar synsedimentary history to that of the Peak Fault (Alexander 1986; Alexander & Gawthorpe 1993).

### *Robin Hood's Bay, Sinemurian to Pliensbachian (the Calcareous Shales, Siliceous Shales and Pyritous Shales of the Redcar Mudstone)*

The major exposures of the Yorkshire Lower Lias are at Redcar and Robin Hood's Bay (Fig. 18) with intermittent exposure of high parts of the sequence between. Successions in both these areas have been described by Tate & Blake (1876) and their work remains the most detailed published account of the lithostratigraphical sequence. The whole Lower Lias succession is exposed around Redcar, but generally poorly. In the Robin Hood's Bay area, the exposure is superior but the lowest strata seen are early Sinemurian in age.

The section in Fig. 19 was measured in the vicinity of the mouth of Stoupe Beck where it enters Robin Hood's Bay. Beds 1 to 27 were measured during low spring tides in the nearly flat-lying foreshore between NZ 965 034 and 961 032; although some uncertainty exists regarding the thicknesses of the units, particularly the thicker shales, the sequence can be traced with confidence. Beds 28–43 were measured in the low cliffs between NZ 961 032 and 955 041 (Boggle Hole).

Through the work of Tate & Blake (1876), Simpson (1884) and particularly Bairstow (1969), it is known that a good sequence of ammonite faunas exists through the Lower Lias of Robin Hood's Bay. Unfortunately, there is as yet no published documentation of the link between Bairstow's biostratigraphical and lithostratigraphical schemes, and the sections of Tate & Blake (1876), although correct in general, appear to be flawed in detail. The positions of the boundaries of the Semicostatum, Turneri and Obtusum Zones shown in Fig. 19 are based on collections of ammonites made by us (now held in the University Museum, Oxford) and kindly identified by Desmond Donovan; the location of the Denotatus Subzone is based on ammonites collected and identified by Kevin Page. The zonation shown should be regarded as preliminary, pending further collection or correlation with Bairstow's log. The boundaries of the Oxynotum Zone are taken from Getty (1972; *in* Cope *et al.* 1980*a*).

The lithostratigraphical names in Fig. 19 (and Figs 20–22) are taken from Buckman (1915) and have enjoyed a long period of usage, despite having never been clearly defined. Presently, they stand as informal members of the Redcar Mudstone Formation (Powell 1984). The Calcareous Shales to Siliceous Shales boundary has been taken to be at the base of Buckman's bed 8 according to Getty (*in* Cope *et al.*

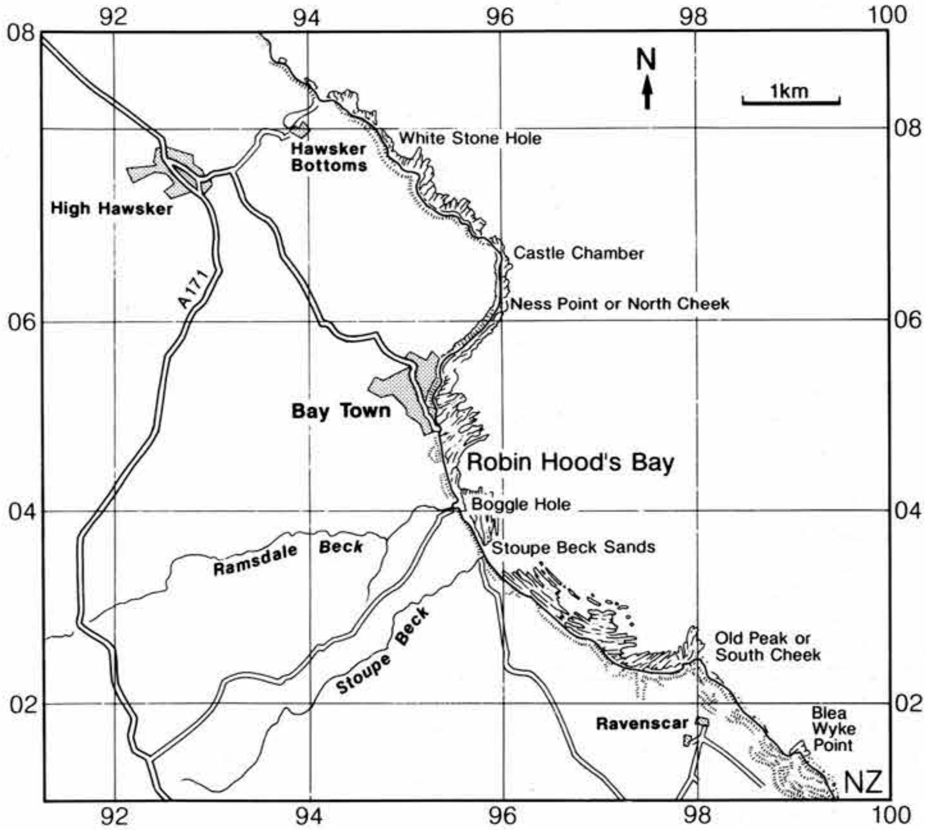



Fig. 18. Location map for the Robin Hood's Bay area, Yorkshire. © Crown Copyright.

1980*a*). Recognition of this level can be achieved with no great certainty and we identify it as the base of our bed 29 by equating Buckman's bed 7 with the base of our bed 32, the 'Lower Triplet', which comprises three light-coloured siltstone beds, easily identified in the low cliffs. Unfortunately this does not coincide with the base of the Denotatus Subzone as indicated by Getty (*in* Cope *et al.* 1980*a*, p. 44) and neither is it coincident with any marked lithological change. Buckman appears not to have carried out very extensive fieldwork on the Robin Hood's Bay section and hence his sequence is rather difficult to follow at the present day. Thus, we propose to fix the base of the Siliceous Shales at the base of bed 23, a resistant well-cemented sandstone forming a very prominent ledge on the foreshore opposite Stoupe Beck (Fig. 18) which marks the first significant sandstone bed in the succession. It is noteworthy that Ivimey-Cook & Powell (1991) placed the base of the Siliceous Shales at a very similar prominent sandstone in the Felixkirk borehole, on the eastern side of the Cleveland Basin [SE 483 858].

Other horizons which are easily identified are bed 13, a shelly pyritic limestone with red-weathering spots; bed 26, a moderately prominent ledge of sandstone with abundant *Gryphaea*; and bed 43, the so-called Double Band (Tate & Blake 1876; Simpson 1884; Buckman 1915), a bioturbated silty sandstone forming a well-marked ledge high on the foreshore near Boggle Hole [NZ 955 041].

The section in Fig. 20 was constructed from the cliff exposures between Stoupe Beck [NZ 961 032] and South Cheek [NZ 978 024]. The sequence is also exposed on the foreshore in the vicinity of Bay Town [NZ 953 051] and these exposures facilitate the observation of palaeontological and sedimentological features, although accurate thicknesses are difficult to obtain. The character of the section is constant across the whole Robin Hood's Bay area.

Biostratigraphical data come from Getty (1972; *in* Cope *et al.* 1980*a*). The base of the Pyritous Shales follows Getty (*in* Cope *et al.* 1980*a*) and is fixed at the top of the uppermost ledge in the sequence, 'Landing Scar', below Bay Town. The position of the Sinemurian–Pliensbachian boundary follows Getty (1972) and Dommergues & Meister (1992). The latter authors detail the ammonite occurrences across the Sinemurian–Pliensbachian boundary in Robin Hood's Bay: their bed 503a is equivalent to our bed 63; their bed 1000 is equivalent to our bed 68; their bed 1005 is equivalent to our bed 70; their bed 1012 is equivalent to our bed 72.

The well-cemented sandy levels in the Siliceous Shales form ledges on the foreshore: bed 53 contains abundant small echioceratid ammonites and has distinctive red-purple-weathering nodules, *c.* 5 cm thick, on the top surface. Beds 70 and 72 form an easily recognizable pair of sideritic septarian nodule beds, seen in the cliffs at South Cheek and on the foreshore below Bay Town (these correspond to Buckman's beds 19 and 16 respectively).

*Calcareous Shales and Siliceous Shales.* The Calcareous Shales are predominantly mudstones, of fully marine aspect, with occasional laterally extensive shell beds, commonly but not exclusively composed of *Gryphaea*, and interpreted by van Buchem & McCave (1989) as the products of storm deposition or winnowing. Ammonites are common and indicate that the Calcareous Shales belong mostly to the Turneri Zone and certainly extend down into the Semicostatum Zone (Bairstow

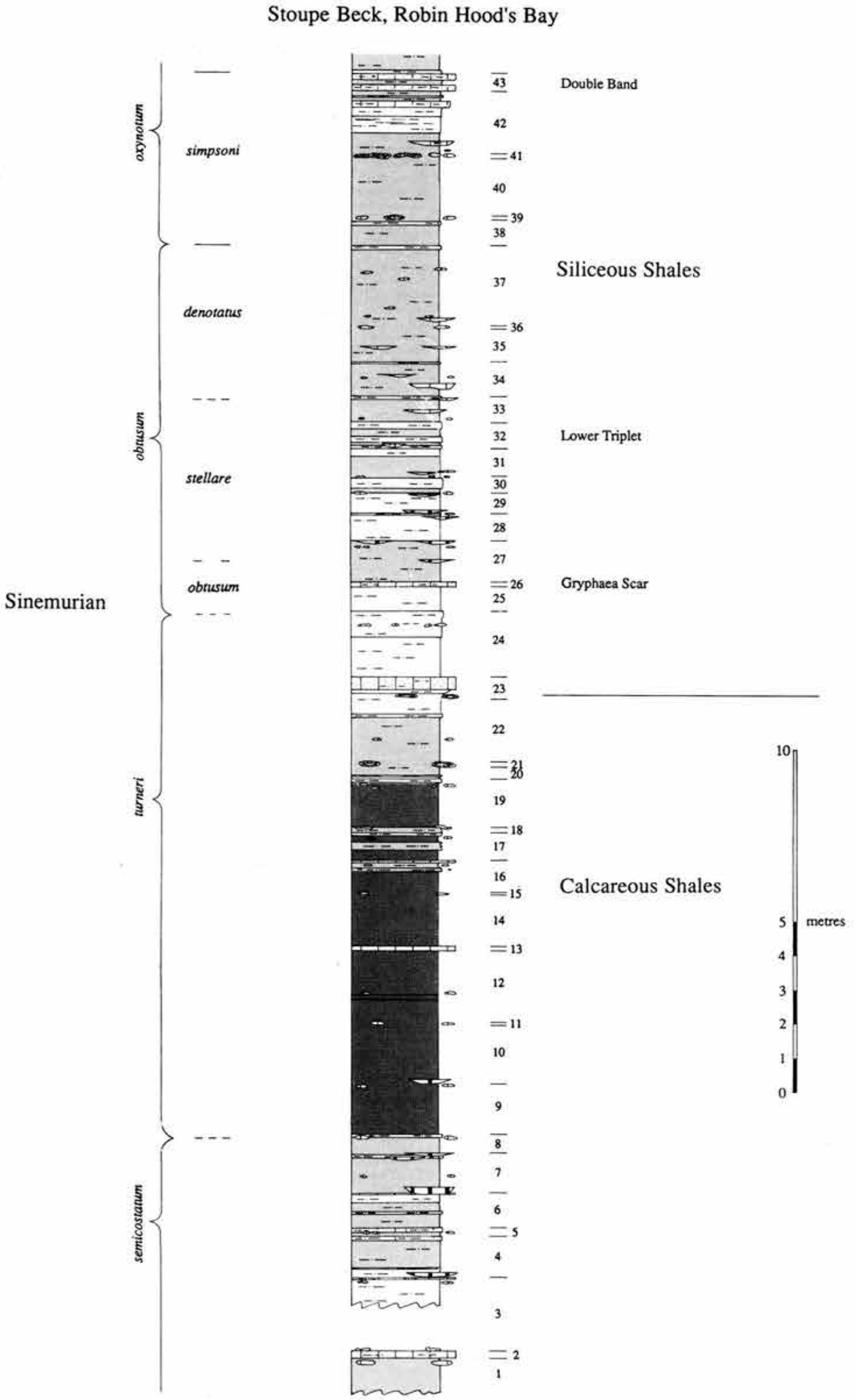



**Fig. 19.** Measured section of the upper Calcareous Shales and lower Siliceous Shales, Robin Hood's Bay. Precise locations and lithostratigraphical and biostratigraphical sources are discussed in the text. See Fig. 7 for key.

1969; this study; *contra* van Buchem & McCave 1989 and van Buchem *et al.* 1992). Most of the Calcareous Shales of Robin Hood's Bay are relatively featureless medium grey claystones, but the lower portions are somewhat more silty and have more abundant scours, now siderite cemented. These lowermost silty beds probably represent an environment that was less distal or more stormy than the bulk of the Calcareous Shales and they are similar to the Siliceous Shales.

The Siliceous Shales are fully marine mudstones containing abundant very fine quartz sand which occurs as discrete,

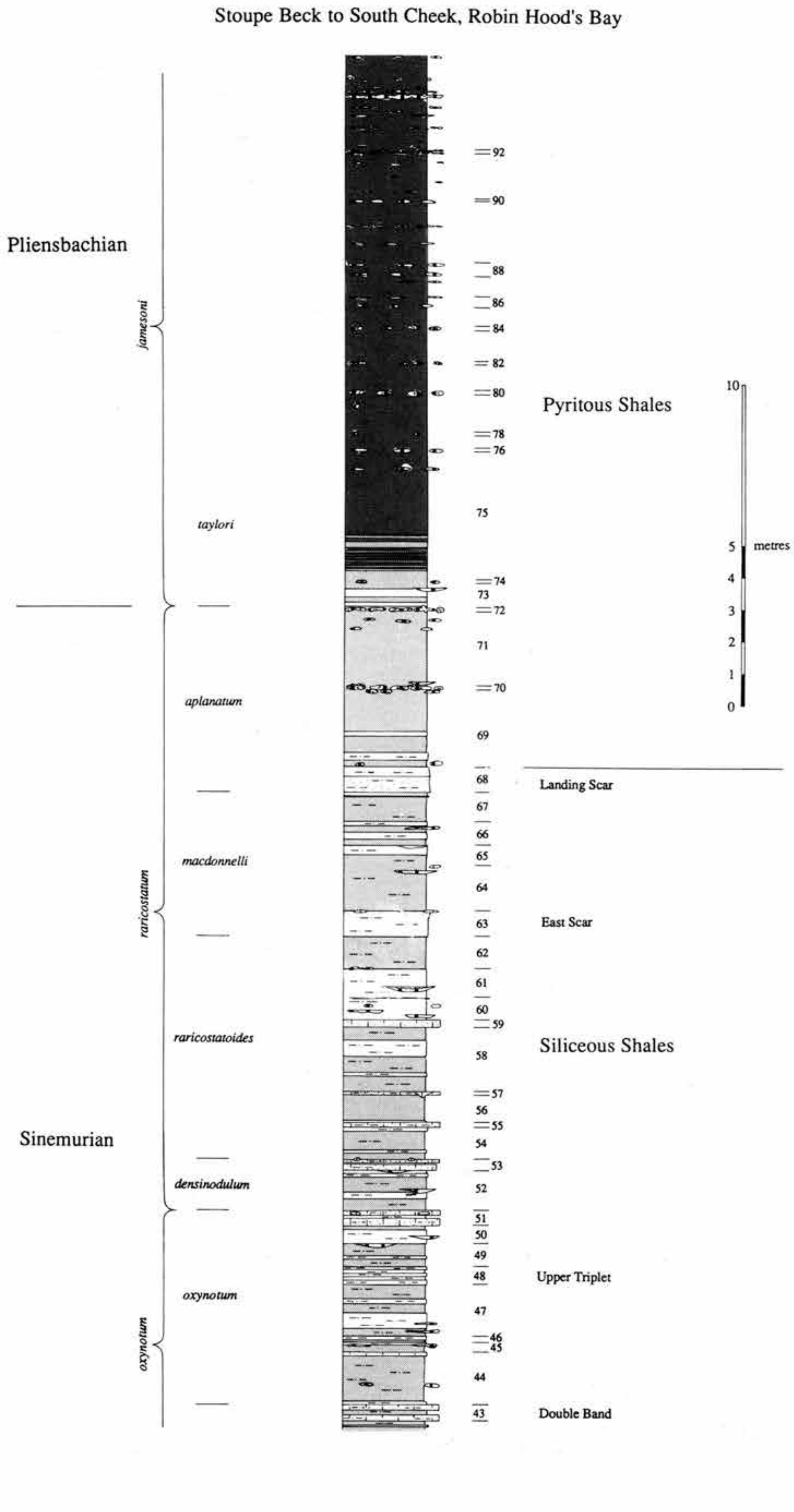



**Fig. 20.** Measured section of the upper Siliceous Shales and lower Pyritous Shales, Robin Hood's Bay. Precise locations and lithostratigraphical and biostratigraphical sources are discussed in the text. See Fig. 7 for key.

continuous decimetre-thick layers, as a fill to scours and as laminae of variable continuity (Sellwood 1970; van Buchem & McCave 1989; van Buchem *et al.* 1992). These features were interpreted by van Buchem & McCave (1989) as a continuum from proximal to distal storm beds, and the Siliceous Shales were inferred to have been deposited in a storm-dominated shallow-marine setting. The abundant marine trace and body fossils, and their relationships to the sedimentary structures, are described comprehensively by Sellwood (1970, 1972), who first recognized the fluctuating influence of wave activity on sedimentation and ecology. However, as pointed out by other authors (e.g. Knox *et al.* 1990), the more shaly and less shaly intervals are not as clearly arranged into coarsening-up cycles in the Raricostatum Zone as Sellwood suggested.

The detailed log of the Robin Hood's Bay section (Fig. 19) shows that there are discrete sandy intervals in the high Turneri, low Obtusum Zones and the high Oxynotum Zone to Raricostatum Zone, separated by a high Obtusum Zone and low Oxynotum Zone interval that is relatively shaley. It is notable that scours still occur over this interval and the environment was probably more proximal than the shaley interval in the low Turneri Zone (Calcareous Shales) mentioned above.

In comparison with Dorset, the stratigraphical packaging in Yorkshire is broadly similar in the Semicostatum and Turneri Zones (Figs 9, 10 & 19). The shaley interval in the upper Calcareous Shales is equivalent to the laminated organic-rich shale of the upper Shales-with-'Beef'; the sandy and silty portions of the lower Calcareous Shales and the lower Siliceous Shales are equivalent to the calcareous mudstones of the lower Shales-with-'Beef'and the lower Black Ven Marls, respectively. This pairing of facies of the same age between Yorkshire and Dorset (finer grained with organic-rich and coarser grained with calcareous) appears also to apply to the Pliensbachian, as described below. However, by way of contrast, there is no prominent shaley interval in Yorkshire equivalent in age to the laminated, organic-rich Obtusum Shale in Dorset; bed 27 in Yorkshire is the only, rather unconvincing, candidate for this event. One possible reason for its lack of expression in Yorkshire is that the mid-Sinemurian environment there was too proximal to register strongly any short-term, medium-scale regional transgression. It is relevant in this context that, on the basis of fossil insect occurrences in the Shales-with-'Beef' and Black Ven Marls, Whalley (1985) suggested the close proximity of land to the Dorset area in the mid-Sinemurian, reflecting similarly a long-term, mid-Sinemurian regression, albeit in deeper-water facies than those seen in Yorkshire.

Both the shaley interval in the middle of the Siliceous Shales in Yorkshire, and the more sandy interval overlying it, are the time equivalents of a stratigraphical break in the Black Ven Marls represented by the Coinstone in Dorset. If the origin of the Coinstone break is interpreted in terms of the shallowing or deepening as read from the Yorkshire succession, then both relative sea-level rise and fall are viable mechanisms; i.e. sediment starvation related to relative sea-level rise in the late Obtusum–early Oxynotum Zones, or winnowing due to relative sea-level fall in the late Oxynotum Zone.

*Pyritous Shales.* The Pyritous Shales are dark grey and black pyritic claystones, but do not show fine lamination. This unit belongs almost entirely to the Taylori Subzone at the base of the Pliensbachian and, given the thickness of the shales, relatively rapid accumulation can be inferred. Except in the lowermost and the uppermost few metres, scour structures do not occur (Figs 20 & 21). The fauna includes thin-shelled bivalves, ammonites and belemnites, but is sparse and relatively poor in species (Sellwood 1972). Dysaerobic, deep-water conditions are implied (Sellwood 1972; van Buchem & McCave 1989). The large ammonite *Apoderoceras* occurs at the base of the unit, defining the base of the Pliensbachian, and again within the Ironstone Shales, but appears to have been excluded from the environment represented by the bulk of the Pyritous Shales, possibly because it had a semi-benthic scavenging habit (Sellwood 1972).

The transition from the Siliceous Shales to the Pyritous Shales is clearly representative of deepening. This interval correlates with a non-sequence in the Dorset section, at the level of the Hummocky, where the upper two subzones of the Raricostatum Zone are missing. If the Hummocky is interpreted in terms of the same relative sea-level change inferred from the Yorkshire section, then its origin would be due to transgression-related starvation.

## *Robin Hood's Bay, Pliensbachian (the Pyritous Shales and Ironstone Shales of the Redcar Mudstone)*

Exposures of the upper part of the Pyritous Shales are poor and inaccessible in the South Cheek area; hence, the section in Fig. 21 is based on the cliffs around North Cheek and includes a stratigraphical overlap with section 20, from beds 76 to 92. The section begins at a minor promontory [NZ 953 051] and ends at the base of the cliff some 500–600 m to the north [NZ 954 056]. A small fault cuts the cliff at about NZ 954 055 and throws a few metres down to the north; a correlation across the fault is made by tracing the nodular siderite at the base of bed 114.

The subzonal distribution within the Pyritous Shales and lower part of the Ironstone Shales is not known in detail; all subzones appear to be present, but their relative thicknesses remain undetermined. The location of the Ibex Zone and its constituent subzones is based on the very careful work of Phelps (1985).

As with the other members named by Buckman (1915) it is unclear where exactly in the section the base of the Ironstone Shales is to be placed. We have chosen to put the boundary at the first continuous siderite bed occurring above the Pyritous Shales. The very apposite name 'Banded Shales' was proposed by van Buchem & McCave (1989) for the lower part of the Ironstone Shales. However, we have not used the name in this work because it contravenes generally accepted practice on the introduction of new names (e.g. Whittaker *et al.* 1991) and significantly alters the meaning of Ironstone Shales as previously employed by many workers. Bed numbers are our own except at the top where we have adopted the scheme of Phelps (1985). A striking concentration of belemnites occurs in bed 2 which we have labelled the Belemnite Bed. Good marker horizons are provided by this bed and bed 92 (associated with a well-defined bedding plane and forming a re-entrant in the cliff face). Although less distinctive, the continuous siderite beds (102, 104, 112, and 114) also provide reasonably good keys.

The section in Fig. 22 is based on the continuous exposure of the Ironstone Shales at the base of the cliff around the North Cheek to Castle Chamber [NZ 960 067]. The section is straightforward to follow with no complications in the form of faults or significant non-exposure. Biostratigraphy and bed numbers are from Phelps (1985). The base of the Staithes Sandstone is well defined (Howard 1985) at the base of bed 41 (Oyster Bed).

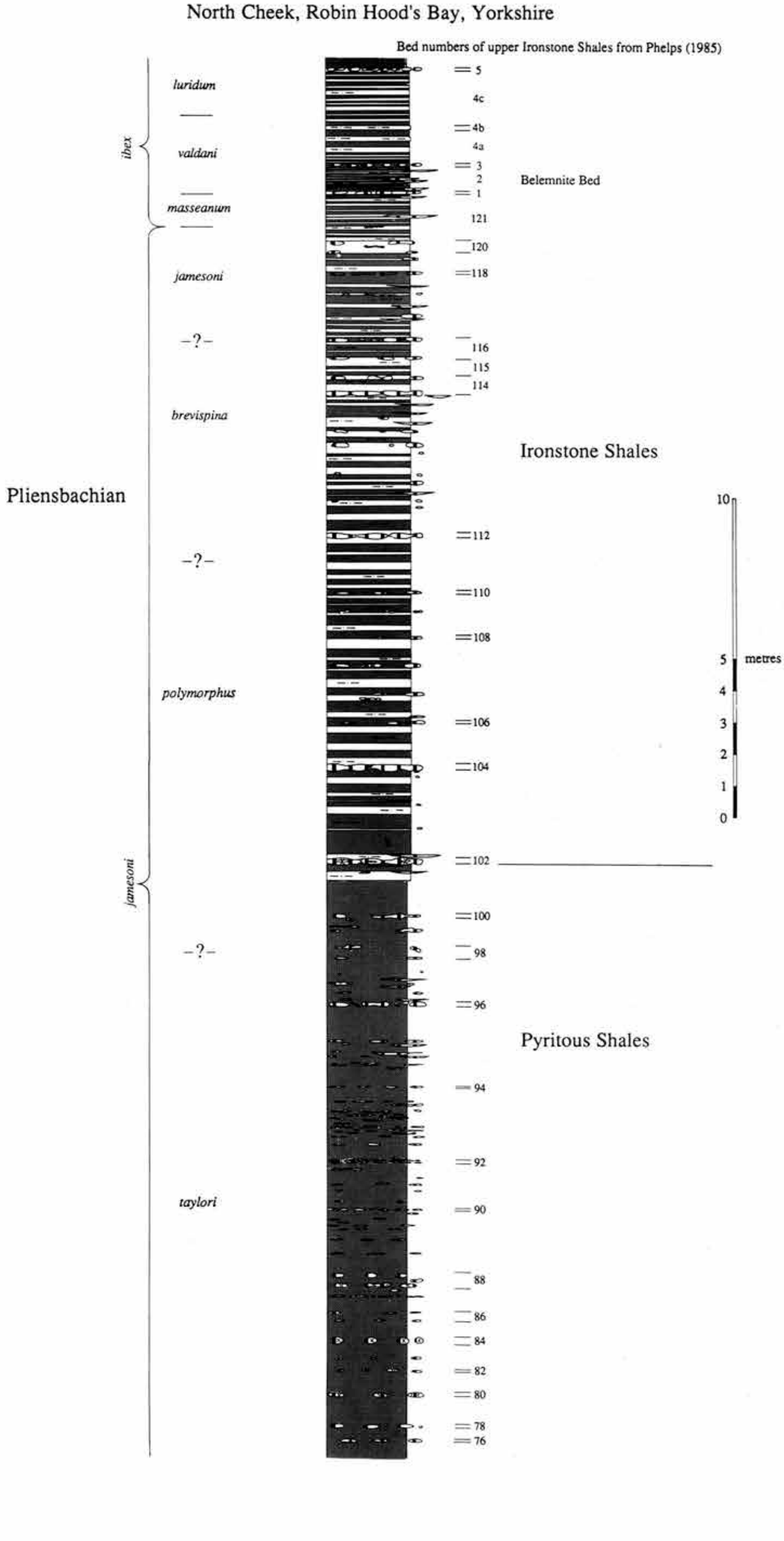



**Fig. 21.** Measured section of the upper Pyritous Shales and lower Ironstone Shales, Robin Hood's Bay. Precise locations and lithostratigraphical and biostratigraphical sources are discussed in the text. See Fig. 7 for key.

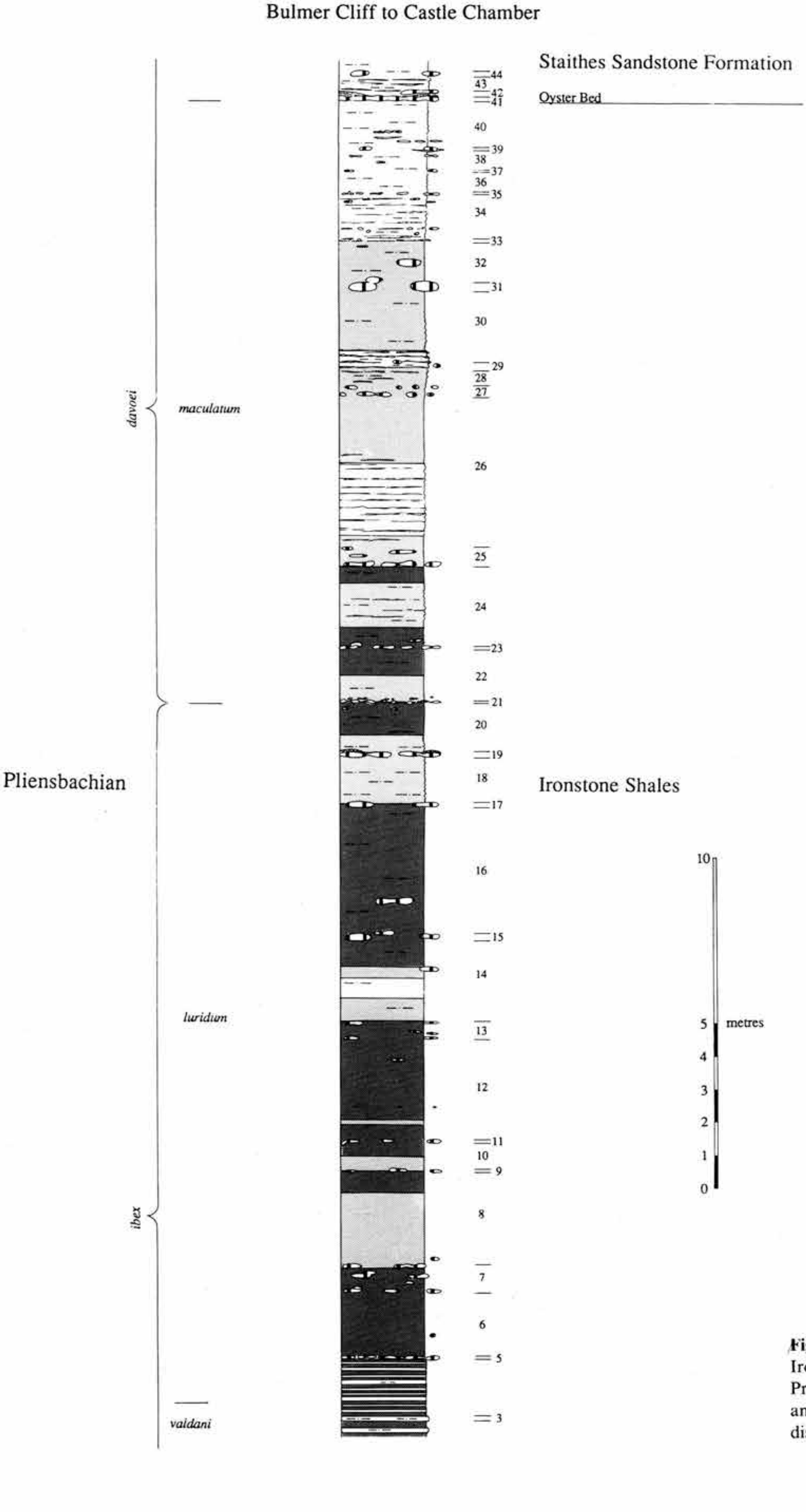



**Fig. 22.** Measured section of the upper Ironstone Shales, Robin Hood's Bay. Precise locations and lithostratigraphical and biostratigraphical sources are discussed in the text. See Fig. 7 for key.

Bed 21 is a distinctive oolitic ironstone brought to our attention by John Senior (University of Durham) and bed 5 is a well-marked level of discontinuous siderite nodules that caps the 'banded' part of the Ironstone Shales.

*Ironstone Shales*. The lower part of the Ironstone Shales, which ranges from the high Jamesoni Zone to the low Ibex Zone, is variously silty and locally sandy with the lithologies arranged in distinctive light and dark horizons much reminiscent of the coeval Belemnite Marls in Dorset (compare Figs 11 & 21). Light horizons are more carbonate-rich, coarser-grained, contain less organic matter and have more abundant and diverse fossil assemblages than the dark bands (Sellwood 1972; van Buchem & McCave 1989; van Buchem *et al.* 1992). Obvious body fossils in the light layers include *Pinna*, *Gryphaea* and belemnites and contrast with the sparse thin-shelled bivalves in the dark layers (Tate & Blake 1876; Sellwood 1972). Climatically driven variations in storm frequency, and possibly also storm magnitude, have been proposed as the generative mechanism, with orbital forcing as the ultimate control (van Buchem *et al.* 1994) just as in the case of the Belemnite Marls (Weedon & Jenkyns 1990).

Through the Jamesoni Zone and into the mid-Ibex Zone, the Ironstone Shales become progressively more silty and scours are more common; this trend reaches an acme in the Valdani Subzone and is accompanied by a general progressive upward decrease in the bed thicknesses (Fig. 21), in precisely the same manner as observed in the Belemnite Marls of Dorset. Close scrutiny shows some even more impressive parallels (Figs 11 & 21): ignoring those strata belonging to the Taylori Subzone, which do not comprise light and dark couplets in Yorkshire, we can correlate the light beds forming the top of bed 101 and 102 in Yorkshire with the light marl of bed 109 in Dorset; a group of light beds within bed 113 in Yorkshire with a similar group, bed 111, in Dorset; another group of light beds in Yorkshire (114 and 115) with 113 in Dorset; a prominent light bed (bed 120) in Yorkshire with the same (bed 117) in Dorset; and, perhaps most spectacularly, the Belemnite Bed in Yorkshire with the Belemnite Bed in Dorset. The strength of these correlations is demonstrated by the fact that they are quite compatible with the biostratigraphy and that very closely similar numbers of couplets occur between these ties in both sections (e.g. 29 light beds counted in Yorkshire and 30 light beds in Dorset between tie points in the Polymorphus Subzone). The upwards increase in grain size and concomitant upward predominance of scours strongly suggest shallowing into the mid-Ibex Zone in Yorkshire, and the identical upward condensation seen in Dorset indicates that that section too, is probably shallowing up.

The upper portion of the Ironstone Shales marks a return to fine-grained deposition, although the facies do coarsen up cyclically, each cycle with more common and thicker silty streaks, passing up into the Staithes Sandstone of the Middle Lias. The Ironstone Shales were interpreted by van Buchem & McCave (1989) as the shallowest facies in the Lower Lias of Yorkshire. The fine-grained, Luridum Subzone part of the Ironstone Shales is equivalent to condensed mudstones and a concretionary limestone in Dorset; the latter is not, however, the same as the condensed Valdani Subzone deposits, in that it does not contain a superabundance of belemnites. An association of belemnites and condensation by winnowing is suggested by these observations. Subsequent coarsening (and shallowing) upwards is exhibited by both successions.

### *North Cheek of Robin Hood's Bay to Hawsker Bottoms and the Staithes area, Pliensbachian to Toarcian (Staithes Sandstone and Cleveland Ironstone and the lower Whitby Mudstone)*

The cliff exposures used to construct the section in Fig. 22 continue to the north, around and beyond Castle Chamber [NZ 960 067] to NZ 952 073: these have been used as the basis for the section in Fig. 23. The biostratigraphy follows Phelps (1985) for the Lower Pliensbachian and is as summarized by Howarth (in Cope *et al.* 1980*a*) for the Upper Pliensbachian. Bed numbers are taken from these two authors, and the boundaries of the Staithes Sandstone Formation and Cleveland Ironstone Formation are after Howard (1985). Good markers are provided by the Oyster Bed (bed 41), a very shelly ferruginous cemented bed (?ankeritic: cf. Hallam 1967*a*), locally overlain by fine sandstone hummocks; beds 59–61, a unit of shelly, very fine sandstones; bed 6, similar to 59–61 but more indurated; and the oolitic ironstone seams (beds 18, 20, 23, and 25–27).

Exposures used to construct the section in Fig. 24 are present at the foot of the cliffs from NZ 952 073 to 948 078, beyond which point the Lower Jurassic is covered with scree. The lithostratigraphical and biostratigraphical scheme of Howarth has been used (summarized in Howarth in Cope *et al.* 1980*a*). It should be noted that very good exposures of the lower Toarcian mudrocks occur further to the north, in the vicinity of Saltwick Bay, Whitby, Runswick Bay and Port Mulgrave, and the interested reader should refer to Howarth (1962, 1973) for details. The Grey Shales has been defined as a member of this Whitby Mudstone Formation (Powell 1984). The Jet Rock, the Bituminous Shales and Ovatum Band are informal subdivisions of the Mulgrave Shale Member, also of the Whitby Mudstone Formation. 'Mulgrave Shale Member' is a new name suggested by Rawson & Wright (1992; see also Rawson & Wright this volume) as a replacement for the rather confusing 'Jet Rock Member', or 'Jet Rock *sensu lato*', as it has been commonly referred to by previous workers. Location in the section is facilitated by recognizing the siltstones and sandstones of the Hawskerense Subzone which form Hawsker High Scar [NZ 951 075], and by recognizing the unmistakable named nodule beds within the Jet Rock.

Staithes Sandstone and Cleveland Ironstone in more proximal facies than in the Castle Chamber–Hawsker Bottoms area can be examined on the coast around Staithes (Figs 25 & 26). The section up to bed 10 in Fig. 25 was measured in the cliffs west of the harbour from NZ 777 190 to 783 190, and that above bed 10 from east of the harbour; accurate maps of the foreshore exposures of the Staithes Sandstone are provided by Howarth (1955). Beds within the Ironstone Shales and Staithes Sandstone can be correlated easily on lithological grounds from Staithes to Castle Chamber. We have used the same bed numbers for the Ironstone Shales in both localities to place emphasis on this correlation. Bed numbers for the Staithes Sandstone are taken from Howarth (1955); apart from the obvious correlation of the Oyster Bed, we also correlate beds 4 & 5 at Staithes with bed 53 at Castle Chamber, beds 8 & 9 at Staithes with beds 58–61 at Castle Chamber and bed 15 at Staithes with bed 6 at Castle Chamber. An easily recognized bed in the Ironstone Shales is the oolitic ironstone of bed 21.

The section in Fig. 26 was measured from east of staithes Harbour to the middle of Brakenberry Wyke [NZ 794 183]. Biostratigraphy, lithostratigraphy and informal bed names

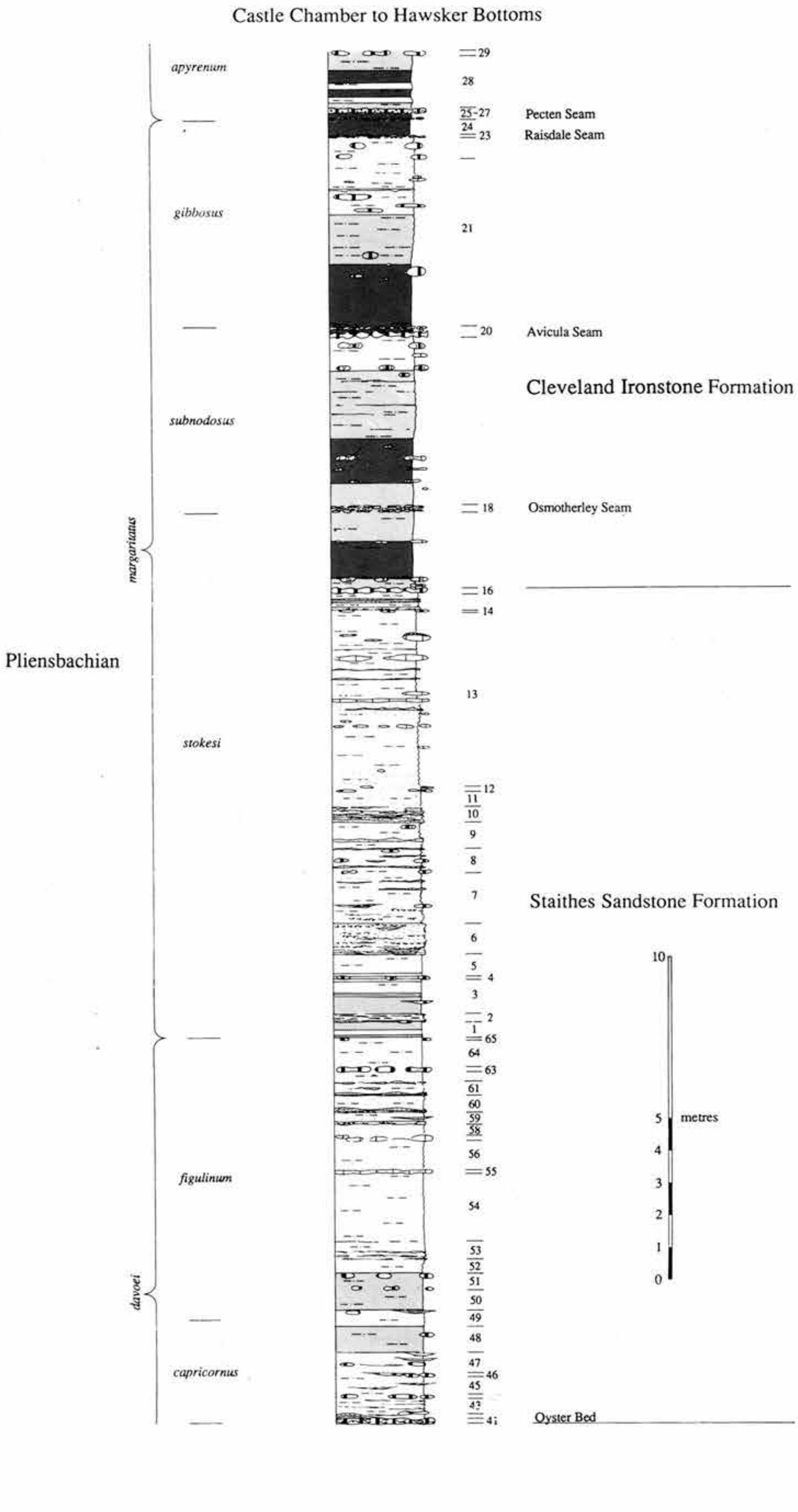



**Fig. 23.** Measured section of the Staithes Sandstone and lower Cleveland Ironstone, north of Robin Hood's Bay. Precise locations and lithostratigraphical and biostratigraphical sources are discussed in the text. See Fig. 7 for key.

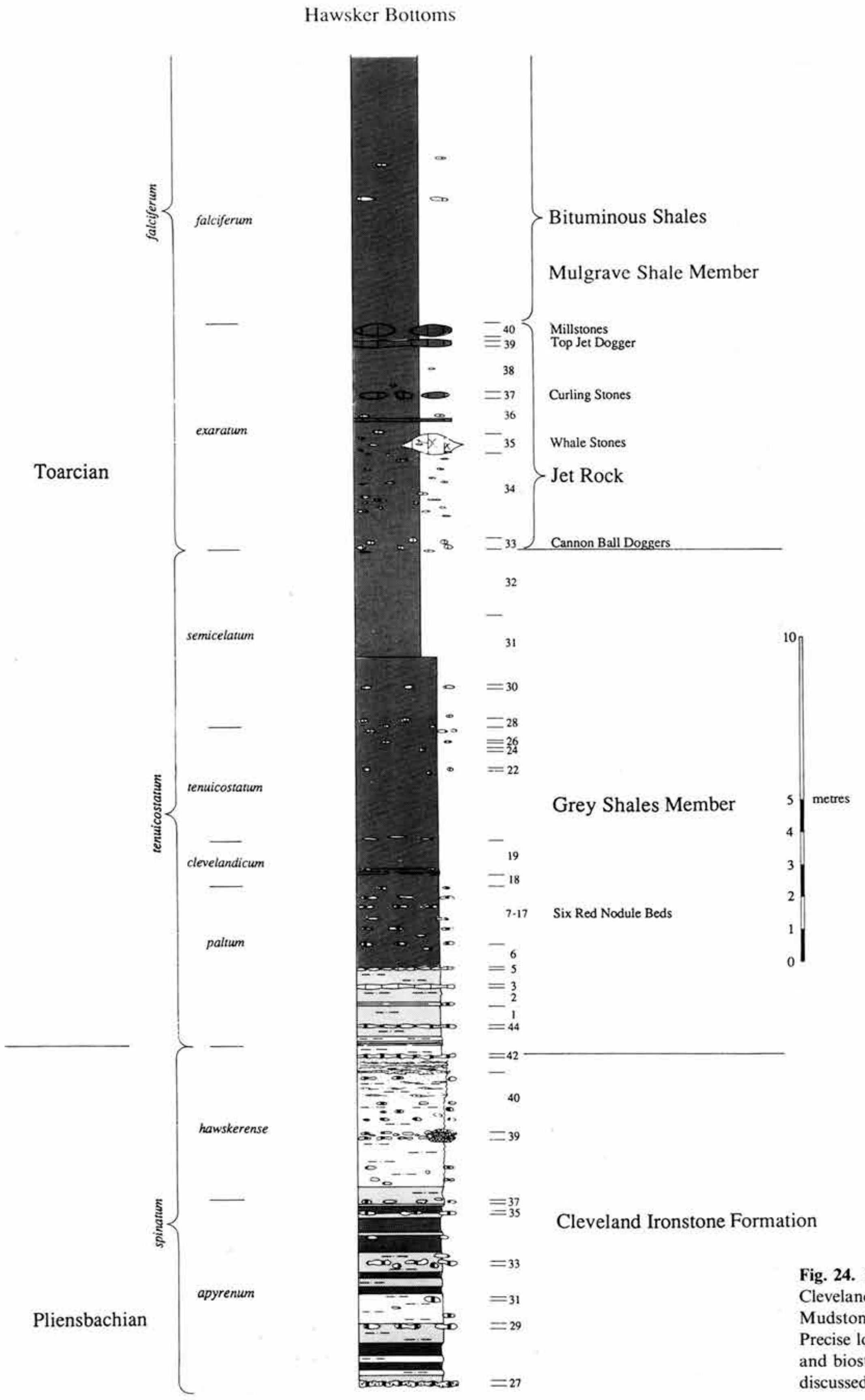



**Fig. 24.** Measured section of the upper Cleveland Ironstone and lower Whitby Mudstone, north of Robin Hood's Bay. Precise locations and lithostratigraphical and biostratigraphical sources are discussed in the text. See Fig. 7 for key.

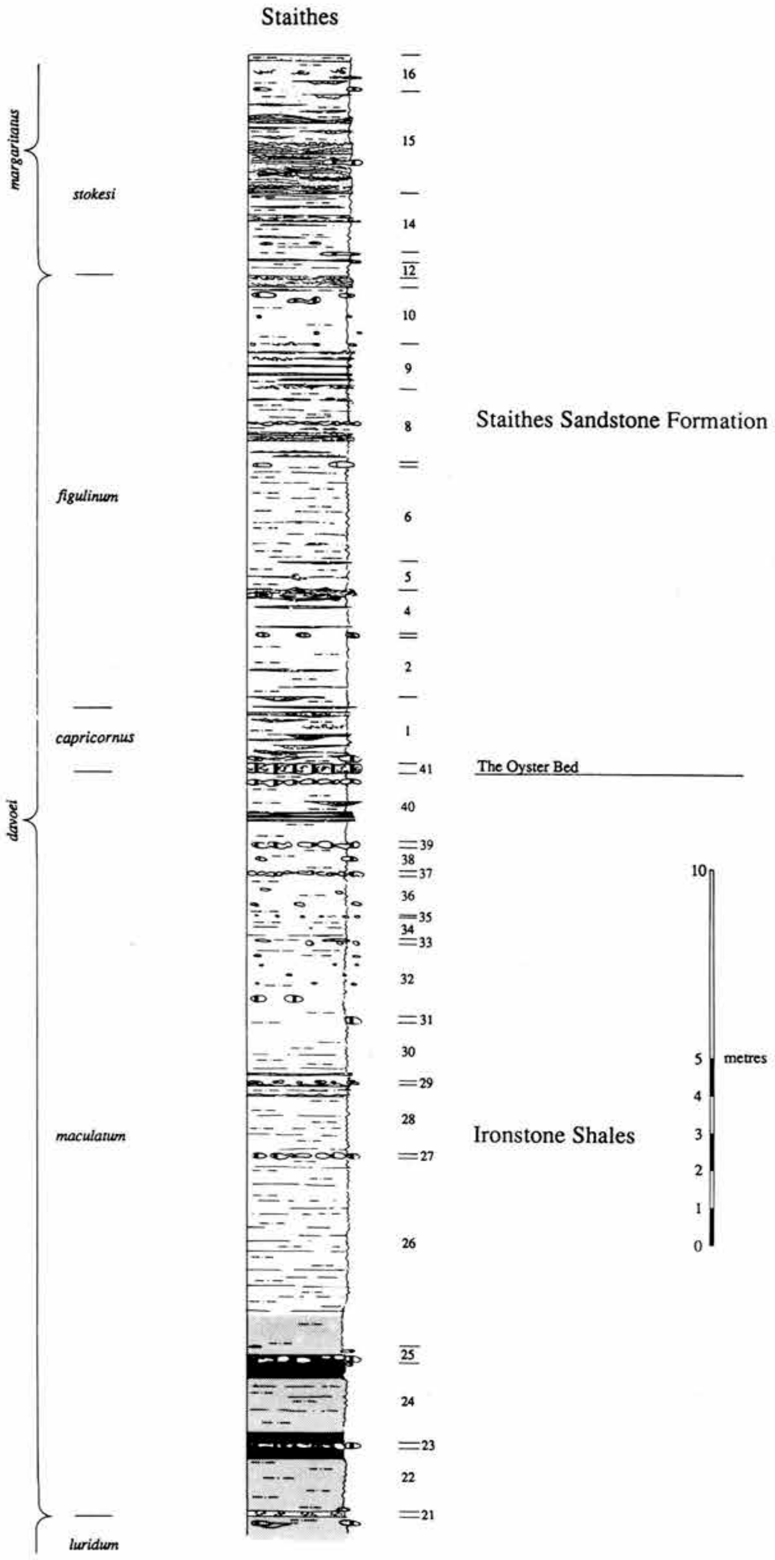



**Fig. 25.** Measured section of the upper Ironstone Shales and lower Staithes Sandstone, north of Staithes. Precise locations and lithostratigraphical and biostratigraphical sources are discussed in the text. See Fig. 7 for key.

are based on Howarth (1955), Greensmith *et al.* (1980) and Howard (1985). Correlation with the same interval at Castle Chamber and Hawsker Bottoms is straightforward for the Cleveland Ironstone on both lithological and faunal grounds (Howard 1985), and the following suggestions are made for correlation of levels in the Staithes Sandstone on lithological grounds: the base of bed 17 at Staithes correlates with beds 10 & 11 at Castle Chamber; the top of bed 17 at Staithes with the middle of bed 13 at Castle Chamber and 22–24 at Staithes with beds 16–18 at Castle Chamber.

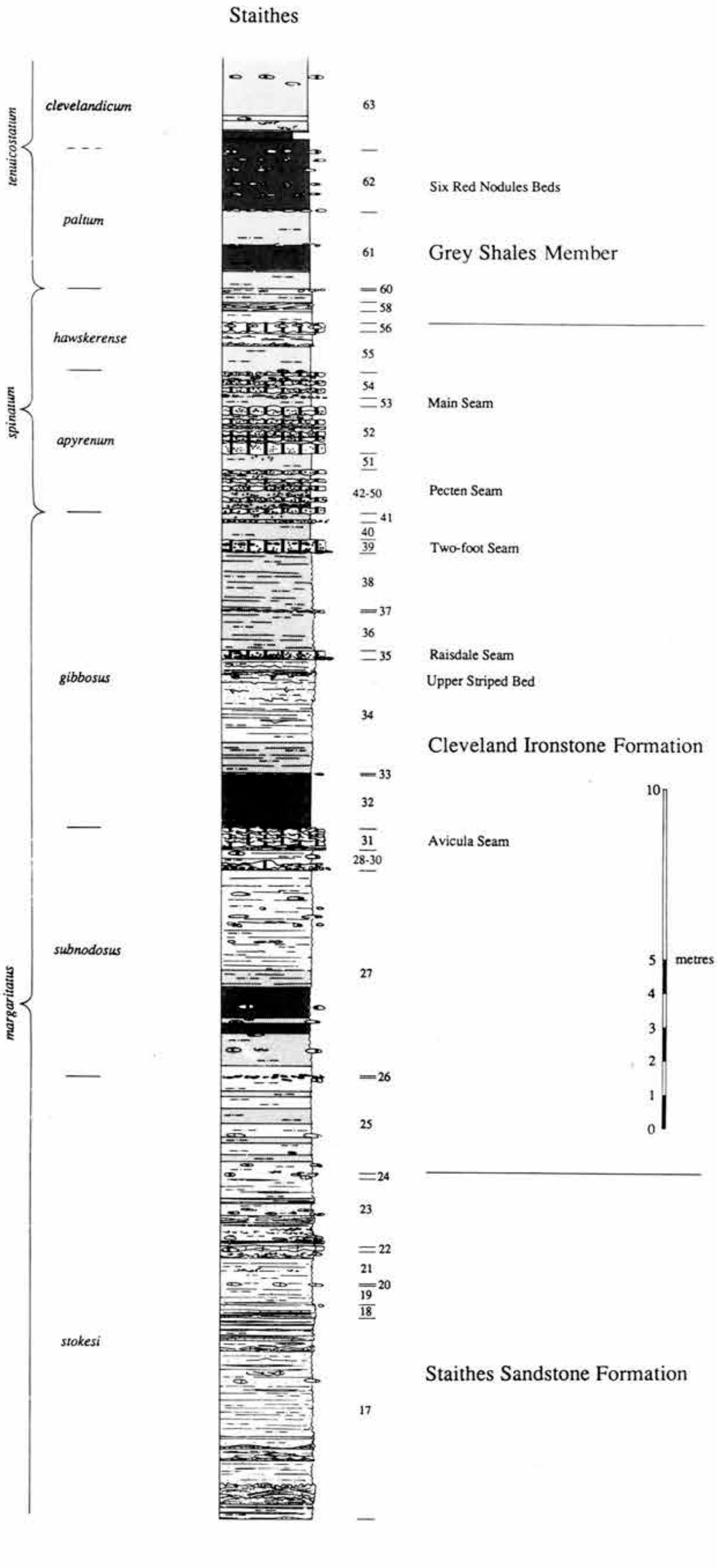



**Fig. 26.** Measured section of the upper Staithes Sandstone and the Cleveland Ironstone, south of Staithes. Precise locations and lithostratigraphical and biostratigraphical sources are discussed in the text. See Fig. 7 for key.

*Staithes Sandstone*. The Staithes Sandstone becomes progressively coarser through the Davoei Zone, and is maximally sandy in the lowest Margaritatus Zone (Stokesi Subzone), above which it gradually decreases in grain-size through to the Cleveland Ironstone. Smaller-scale coarsening and fining cycles are also apparent, particularly in the more distal setting at Hawsker Bottoms, each cycle approximately coincident with an ammonite subzone (Figs 25 & 26). A distinctive horizon which occurs at the base of the Capricornus Subzone in all localities, and which defines the base of the formation, is the Oyster Bed, a calcareous and ferruginous sandstone containing *Gryphaea*, *Oxytoma* and *Pseudopecten*. The lithologies in the Staithes Sandstone are silty sandstones, more or less bioturbated but also showing hummocky cross-stratification, wave-ripple lamination and gutter casts (Rawson *et al.* 1983; Howard 1985): storm-influenced lower-shoreface deposition has been inferred (Brenchley & Gowland 1985) and this formation is the best example of such an environment in the exposed British Jurassic.

There are clear parallels between the Dorset and Yorkshire successions in the development of sandstones around the mid-Pliensbachian. Coarsening is observed in Yorkshire one ammonite zone earlier than it is in Dorset, as would be expected given the more proximal setting of the former. It is notable also that the maximum thicknesses of sandstone in both cases occur in the Stokesi Subzone (Figs 13, 23 & 25). Howarth (1957) has pointed out that the Stokesi Subzone of Dorset is particularly thick; clearly, there was sufficient water depth in the Dorset area for substantial accumulation of relatively coarse sediment when it became available.

*Cleveland Ironstone Formation*. Modern studies of the Cleveland Ironstone are those of Chowns (1968), Catt *et al.* (1971), Greensmith *et al.* (1980), Howard (1985) and Young *et al.* (1990); these works, along with Rawson & Wright (this volume), should be consulted for reference to the significant early studies. The formation is predominantly a silty mudstone, but berthierine-rich oolitic ironstones occur in discrete horizons, mainly at the tops of metre-scale coarsening-upwards cycles.

The formation is complete to the level of biostratigraphical resolution in the coastal exposures, but non-sequences have been determined by documenting the geographical distribution of the ironstone seams (Chowns 1968) through correlation of metre-scale cycles (Howard 1985; Young *et al.* 1990). These latter authors also split the formation into two members, one corresponding to the upper part of the Margaritatus Zone and the other to most of the Spinatum Zone (Fig. 2). The two members are characterized by different styles of internal sedimentary cyclicity (Howard 1985). The lower (Penny Nab) member is built up from five small-scale sedimentary cycles, the lowest three of which are clearly coarsening-up and capped by oolitic ironstones whereas the upper two are interpreted as erosionally truncated below oolitic ironstone seams (Young *et al.* 1990). The Penny Nab Member is thinner, apparently most complete, and finer grained in the southeast. The upper (Kettleness) member is less obviously cyclic in nature and varies from a well-developed oolitic ironstone in the northwest to interbedded mudstones and sandstones in the southeast. An important erosion surface has been inferred at the base of the Kettleness Member which, perhaps surprisingly, is most marked in the otherwise most distal setting, i.e. at Hawsker Bottom in the southeast. The stratigraphical geometries and facies relationships have been explained in terms of progradation of the sediments forming the Penny Nab Member from the northwest, followed by progradation of those forming the Kettleness Member from the southeast (Young *et al.* 1990).

The ironstones are mostly oolitic wacke-ironstones, a texture that probably resulted from burrow-mixing of ooids with mud interbeds (Young *et al.* 1990). Berthierine ooids may be replaced with phosphate, siderite, calcite or, most commonly, kaolinite. The high Th/K ratios in the ironstones, strikingly evident through gamma-ray spectrometry (Myers 1989), is thought to have originated through the formation of thorium-bearing kaolinite in tropically weathered source lands (Catt *et al.* 1971; Howard 1985; Myers 1989). Body fossils are predominantly bivalves which are diverse and abundant in most of the ironstones (Howard 1985; Young *et al.* 1990).

Parallels between the Yorkshire and Dorset successions are again apparent for the time interval represented by the Cleveland Ironstone; apart from the generally shallow-water nature of the sedimentary deposits, there is an asymmetrical cyclicity of shale-sandstone in the Subnodosus Subzone common to both basins. In contrast, whereas the uppermost Pliensbachian of Yorkshire remains relatively sandy, the equivalent Dorset succession is represented only by a condensed limestone, the Marlstone (Figs 13, 23, 24 & 26). Although this difference may be interpreted as due to more local control on the sedimentary successions, the pattern is also compatible with the general tendency of the Dorset succession to evince sediment starvation during relative sea-level rise, as clearly occurred across the Pliensbachian–Toarcian boundary.

*Grey Shales Member*. These are pyritic silty micaceous mudstones, rich in quartz, micas, chlorite and kaolinite (Pye & Krinsley 1986). The environment of deposition was relatively well oxygenated, showing evidence of current activity in the lower part in the form of ripple-laminated siltstones, but the succession passes upwards into laminated shales deposited under less well-oxygenated conditions that were particularly prevalent during deposition of the overlying Mulgrave Shale Member (Hallam 1967*b*; Morris 1979; Myers & Wignall 1987). These mudstones, of Tenuicostatum Zone age (Howarth 1973), are equivalent to the upper part of the Marlstone in Dorset (Fig. 14).

*Mulgrave Shale Member*. In the lower part of the Mulgrave Shale Member (the Jet Rock *sensu stricto* belonging to the Exaratum Subzone) the shales are highly organic-rich and laminated on a millimetre-scale. Microbial mats have been suggested as the origin for wavy lamination observed at some horizons (O'Brien 1990). Organic carbon values typically range between 5% and 15% (Küspert 1982; Raiswell & Berner 1985); the fine fraction is dominated by quartz, kaolinite, illite, illite-smectite, chlorite, pyrite and calcite with lesser dolomite, feldspar and carbonate fluorapatite (Pye & Krinsley 1986). A characteristic feature of the Jet Rock is the presence of calcareous concretions, of centimetre to metre scale, some of which carry a pyritic skin (Hallam 1962; Coleman & Raiswell 1981). The fauna of the Jet Rock includes abundant ammonites, rare belemnites and the thin-shelled bivalve *Bositra buchi* (=*Posidonia alpina*) considered by some to be nektonic or pseudoplanktonic (Jefferies & Minton 1965; Sturani 1971; Oschmann 1993). Bottom-water conditions were severely oxygen depleted, possibly anoxic or euxinic (Raiswell & Berner 1985). The Jet Rock is the British facies equivalent of the German Posidonienschiefer and the French Schists Cartons and reflects regional or even global conditions peculiarly favourable to the deposition of carbon-rich facies (Jenkyns 1988). Such intervals of geological time, typically lasting less than a million years, have been termed Oceanic Anoxic Events. In the upper part of the Mulgrave Shale Member (Bituminous Shales of the Falciferum Subzone) the lamination is less pronounced and the content of organic matter is lower. This change in lamination style has been interpreted as compatible with the hypothesis of deepening water (O'Brien 1990), but it may equally reflect declining fertility in near-surface waters and reduced supply of organic matter to the sediment.

The Mulgrave Shale Member is equivalent to the base of the Junction Bed *sensu stricto* of Dorset and both units may be interpreted as deposited in deeper water than immediately underlying facies. The level of dissolved oxygen in the two environments was, however, very different as the Junction Bed, with its prevailing pink colour, was deposited in fully oxygenated conditions not conducive to the burial of organic matter.

### *Ravenscar, Toarcian (the Whitby Mudstone and Blea Wyke Sandstone)*

The section in Fig. 27 was measured in the base of the cliffs a few hundred metres south east of Old Peak [NZ 981 023], near Ravenscar at the south end of Robin Hood's Bay, and south also of the Peak Fault. A concretionary horizon, the Peak Stones, occurs some 9.6 m above the Millstones, the highest horizon correlatable from Hawsker Bottoms (Fig. 24) to Old Peak (Howarth 1962). In the section, the detailed biostratigraphy, lithostratigraphy and bed numbers are derived from Howarth (1962) without modification. The Hard Shales, Main Alum Shales and Cement Shales are informal units within the Alum Shale Member (Powell 1984).

Measured below Fox Cliff from NZ 985 019 to 987 016, the section in Fig. 28 uses the biostratigraphy, lithostratigraphy and bed numbers of Howarth (1962) for the Main Alum Shales and the lower part of the Cement Shales. For the upper Cement Shales and the Peak Mudstone Member, the bed numbers of Dean (1954) have been used with the modifications of Knox (1984). This part of the Toarcian section is particularly difficult to follow due to a general lack of unusual and continuous beds. The best markers are bed xxxvii (bed 21 of Dean 1954) and Dean's bed 57. The upper Cement Shales, in the sense modified by the changes of Knox (1984), are characterized by light and dark interbeds, the Peak Mudstone beginning about a metre above the highest light-coloured bed.

The uppermost Lower Jurassic section (Fig. 29) was measured between NZ 987 016 and 991 015 (Blea Wyke Point). Beds up to 63 were measured in the NE-facing cliff whereas beds 64 upwards were measured on the NW-facing side of the promontory. Bed numbers and biostratigraphy are those of Dean (1954) and the lithostratigraphy is that of Knox (1984).

The Alum Shale to Yellow Sandstone succession between Old Peak and Blea Wyke Point represents a gradual shallowing-up from poorly oxygenated mudstones with a restricted bottom fauna to well-bioturbated, very fine sandstones, the latter truncated by a minor unconformity below the Middle Jurassic Dogger sandstone. The succession here is unusual in that over most of the Yorkshire area the Dogger rests directly on Alum Shale and the coarsening-up part of the succession is truncated.

*Alum Shale Member.* The Alum Shale is a dark grey mudstone containing an abundant ammonite and bivalve fauna. It was formerly worked extensively for the production of potash alum. Apparently, only those strata containing the bivalve *Nuculana ovum*, essentially the Main Alum Shales, were suitable for making alum (Hunton 1836) and these are rocks particularly low in calcium carbonate. Particle-size data, although few in number, suggest that the Main Alum Shales is the least silty part of the Whitby Mudstone succession (Gad *et al.* 1969). The Hard Shales and the Cement Shales have higher carbonate contents and calcitic concretionary horizons in the latter have been worked for lime in the past. Close observation in the field shows that the uppermost part of the Cement Shales (Fig. 28) is characterized by decimetre-scale alternating light and dark mudstone horizons, possibly more and less silty, duplicating the facies of the lower Ironstone Shales of the Pliensbachian. Small phosphate nodules first occur within the cement Shales and continue to be present in the remainder of the Upper Lias (Knox 1984). The overall facies change through the Alum Shale Member is indicative of increasing bottom-water oxygenation (Pye & Krinsley 1986)

It would be unwise to suggest that the shallowing trend seen in Yorkshire is also visible in the Junction Bed on the Dorset coast; however, the basal Toarcian sandstones marginal to the Wessex Basin belong to the upper Bifrons Zone of the Cotswolds (Buckman 1889; Torrens in Cope *et al.* 1969), and the condensed subzones at the top of the Junction Bed on the coast are clearly more expanded in the Winterborne Kingston Trough (Ivimey-Cook 1982).

*Peak Mudstone and Fox Cliff Siltstone Members.* The Peak Mudstone comprises highly micaceous silty mudstones whose base is marked by a distinct coarser layer, above which there is a hardly perceptible decrease in grain size (Knox 1984). Kaolinite is the dominant clay mineral. Horizons of nodular siderite, mixed siderite/calcite and phosphate are common. Many of the nodule bands contain the bivalve *Meleagrinella substriata*. The Fox Cliff Siltstone comprises muddy siltstone and silty mudstone with nodular bands similar to those in the Peak Mudstone and upwards chlorite becomes dominant over kaolinite (Knox 1984). Pockets of weathered oolitic ironstone are prominent within the siderite-cemented band in the middle of the unit (bed 61) but berthierine ooids also occur scattered throughout the Fox Cliff Siltstone. Fossils are uncommon except locally within bed 57 which contains many bivalves (Dean 1954). The lithofacies and faunas of these two members are indicative of a distinct shallowing of the sedimentary environment. The Fox Cliff Siltstone can be subdivided into a fining-up lower half and a coarsening-up upper half (Knox 1984).

*Blea Wyke Sandstone Formation.* These are muddy siltstones and silty very fine sandstones with a generally coarsening-up profile. The formation is divisible into two smaller coarsening-up cycles (Knox 1984), separated by thin highly fossiliferous strata. The lower, grey-weathering cycle forms the Grey Sandstone Mbr and the upper, yellow-weathering cycle forms the Yellow Sandstone Mbr. All the sandstones are thoroughly bioturbated. Fossils present within the Grey Sandstone include belemnites, which are common throughout, *Lingula* in the lower half (the 'Lingula Beds'), ammonites in beds 71 and 80 and serpulids in beds 79 to 81 (the 'Serpula Beds'); the Yellow Sandstone has produced a fauna of bivalves and brachiopods, similar to that in the overlying Dogger sandstone, and ammonites (Rastall & Hemingway 1940; Dean 1954). The unconformity with the Middle Jurassic is marked by a concentration of brachiopods, the Terebratula Bed, and the underlying topmost portion of the Yellow Sandstone has abundant

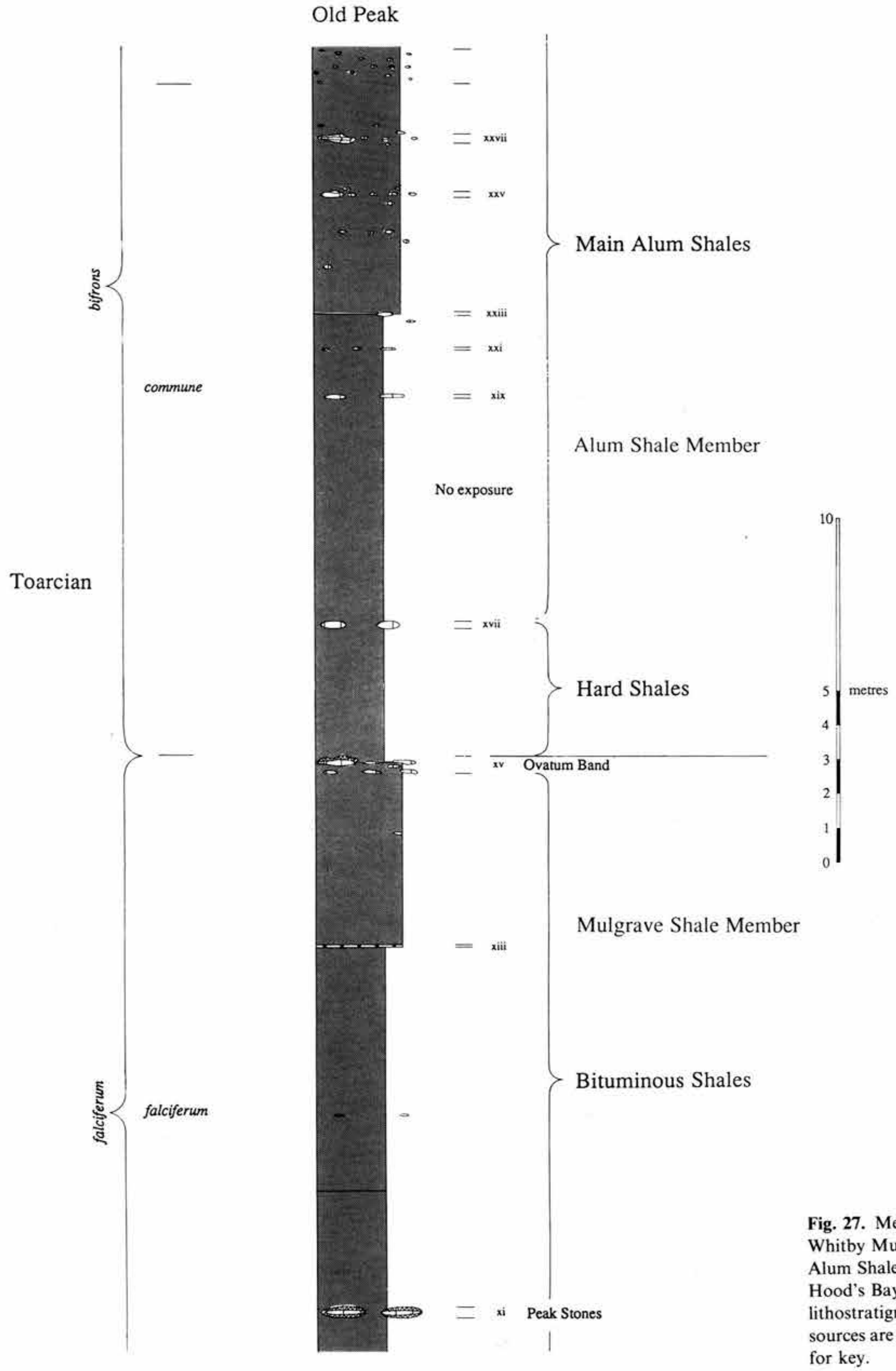



**Fig. 27.** Measured section of part of the Whitby Mudstone (Mulgrave Shale to Alum Shale Members), south of Robin Hood's Bay. Precise locations and lithostratigraphical and biostratigraphical sources are discussed in the text. See Fig. 7 for key.

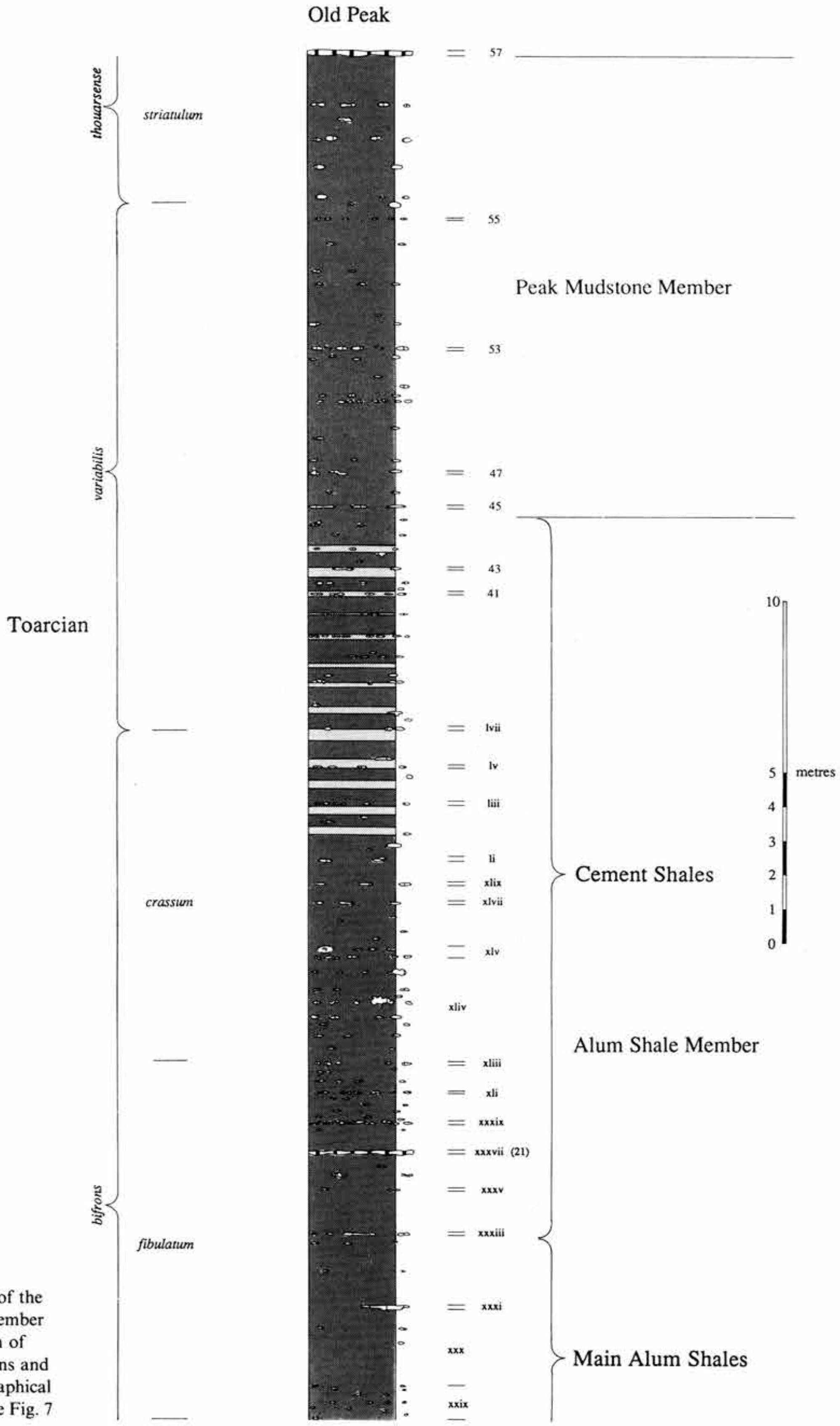



**Fig. 28.** Measured section of part of the Whitby Mudstone (Alum Shale Member to Peak Mudstone Member), south of Robin Hood's Bay. Precise locations and lithostratigraphical and biostratigraphical sources are discussed in the text. See Fig. 7 for key.

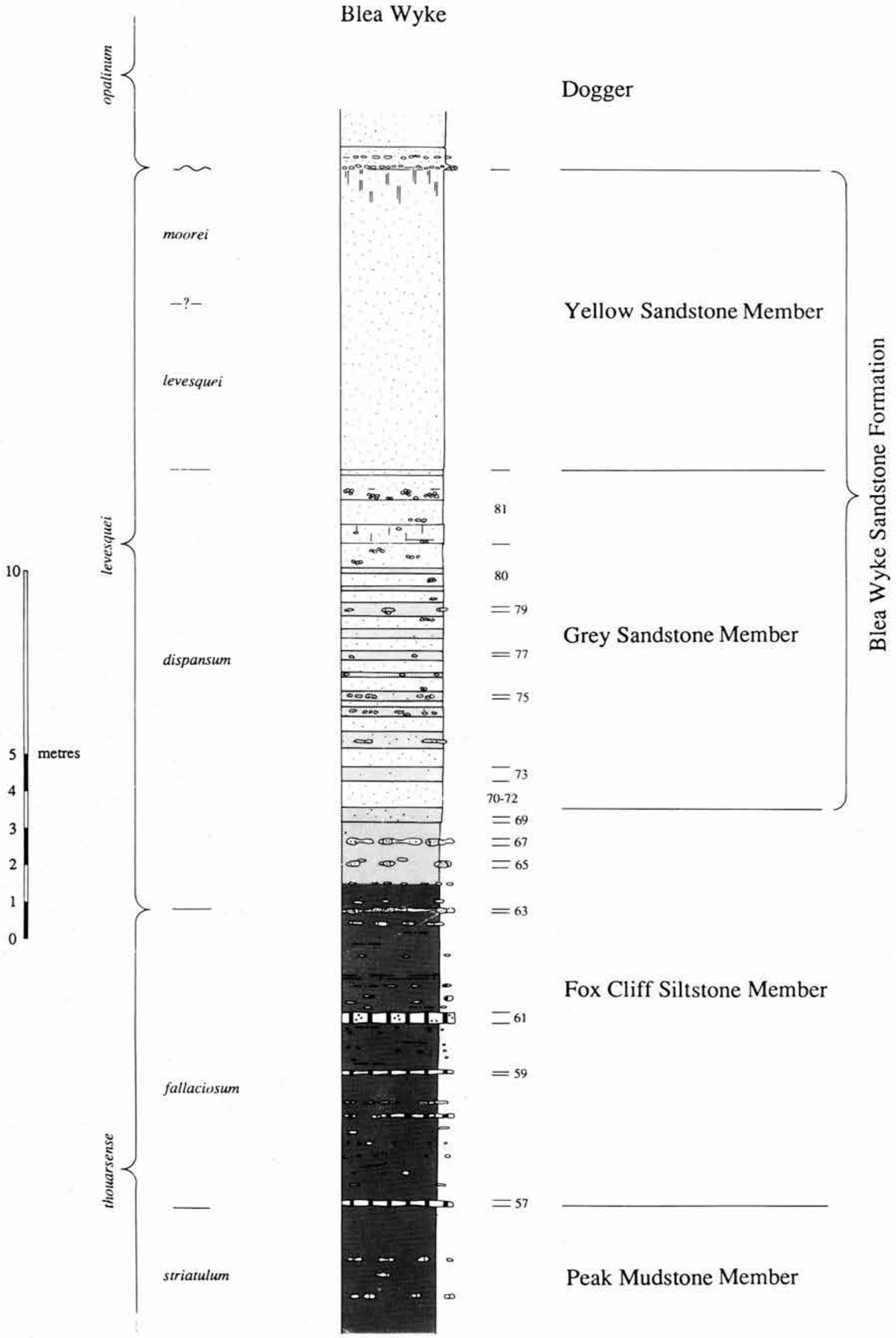



**Fig. 29.** Measured section of the upper part of the Whitby Mudstone and the Blea Wyke Sandstone, south of Robin Hood's Bay. Precise locations and lithostratigraphical and biostratigraphical sources are discussed in the text. See Fig. 7 for key.

*Skolithos*. In the Ravenscar area, a significant thinning of the Toarcian strata into the Peak Fault has been demonstrated and this is most marked for the coarser, uppermost units (Fox-Strangways & Barrow 1915; Hemingway 1974; Knox 1984).

The late Toarcian to early Aalenian overall shallowing, which is unarguably indicated by the Yorkshire succession, is also apparent in Dorset and, as in the upper Pliensbachian, the coarsening succession is evident about one ammonite zone earlier in Yorkshire than it is in Dorset as a result of the more proximal setting of the former.

### *Aalenian to Bathonian (the Dogger Formation and Ravenscar Group)*

Middle Jurassic sedimentation in the Cleveland Basin took place predominantly in non-marine environments. However, there are also four major marine units: the Dogger Formation, the Eller Beck Formation, the Lebberston Member of the Cloughton Formation and the Scarborough Formation; the last four being units within the Ravenscar Group (Hemingway & Knox 1973; Hemingway 1974). Comprehensive description of this thick and well-exposed succession is beyond the scope of this paper (see Black 1929; Hemingway 1974; Hancock & Fisher 1981; Alexander 1989, 1992*a*, *b*; Kantorowicz 1990; Alexander & Gawthorpe 1993; and references therein). Nonetheless, it is pertinent here to compare and contrast the main features of the Yorkshire section with those seen in Dorset, focusing particularly on the marine intervals (Fig. 3).

A late Toarcian–early Aalenian erosion surface cuts into folded Toarcian strata over most of the Yorkshire area: the surface is planar in the east and attributed to marine erosion (Hemingway 1974), but has a strong relief in the west which is attributed to the incision of river valleys (Black 1934). The erosion surface is overlain by the Dogger Formation (Hemingway 1974). Beds of this unit which are proven to be the oldest (Opalinum Zone) are situated in the east and the youngest (Murchisonae Zone) are in the west (Black 1934), but ammonites are rare (Parsons *in* Cope *et al.* 1980*b*) and this pattern may not hold up in the light of future discoveries. The western Dogger comprises conglomerates, limestones and ironstones, especially well developed in the deepest parts of the palaeovalleys, overlain by shales which spread widely and yield Murchisonae Zone ammonites. In a southeasterly direction the Dogger becomes more ferruginous and further south east still, as seen for example on the coast around Robin Hood's Bay, it is largely sandstone (Hemingway 1974). The Dogger passes, gradationally or abruptly, into plant-bearing shales or fluvial channel sandstones above. This non-marine unit, with some evidence for tidal influence, is the Saltwick Formation and contains large composite channel-sandstone bodies at the base; higher levels are mostly overbank mudstones with smaller, less common sand bodies and fewer rooted horizons, less evidence for desiccation and a greater abundance of plant material upwards, a pattern consistent with gradual abandonment of a delta lobe (Livera & Leeder 1980) or relative sea-level rise (Mjøs & Prestholm 1993).

The Eller Beck Formation is a thin marine interval with an ironstone and siltstone unit at the base, overlain by a thicker unit of shale or limestone passing upwards into sandstone (Knox 1973; Hemingway 1974; Powell & Rathbone 1983). The transgression is thought to have come from a southerly direction (Bate 1965). The age of the Eller Beck Formation is uncertain but it probably correlates with the Lower Lincolnshire Limestone (Bate 1965; Powell & Rathbone 1983) which would place it in the Discites Zone (Ashton 1980; Parsons *in* Cope *et al.* 1980*b*). The Eller Beck Formation passes up into the lower unit of the Cloughton Formation which is the Sycarham Member; this is a dominantly freshwater fluvio-deltaic deposit (Livera & Leeder 1981).

The Lebberston Member in the middle of the Cloughton Formation thins markedly from south to north and, on the coast, is divisible into a lower, calcareous part, the Millepore Bed, and an upper siliciclastic unit, the Yons Nab Beds (Bate 1959; Hemingway 1974; Livera & Leeder 1981). The Millepore Bed is a strongly cross-bedded, subarkosic sandstone and oolite, and the Yons Nab Beds are cross-bedded sandstones and shales. The Lebberston Member is thought to have been deposited in shallow marine to coastal settings, with environments such as beaches and lagoons being represented in the northern portion of the outcrop (e.g. Livera & Leeder 1981). The transgression is thought to have come from the south and the Lebberston Member has long been correlated with the Cave Oolite which occurs south of the Market Weighton structure, but the age of the Lebberston Member is less well constrained than for the other marine units of Yorkshire (Bate 1964, 1967; Parsons in Cope *et al.* 1980*b*). Upwards, the sequence continues conformably with the Gristhorpe Member which shows sedimentary features and a vertical succession similar to those of the Saltwick Formation.

The Scarborough Formation is the thickest of the marine units and is also the only one in the Ravenscar Group to yield an abundant ammonite fauna (Parsons 1977). The lithofacies include sandstones, siltstones and lime mudstones, fining up in the lower part and coarsening up towards the top, at which level there is truncation beneath the Moor Grit fluvial sandstone at the base of the Scalby Formation. Environments represented range from brackish, sandy embayments, to wave-dominated, sandy and muddy shoreface and muddy, offshore shelf (Gowland & Riding 1991). The ammonites are found in the more argillaceous beds and all three subzones of the Bajocian Humphriesianum Zone are present; maximum transgression probably occurred in the Humphriesianum Subzone, based on overall trends in grain size. Marine incursion was from an easterly direction (Bate 1965; Hancock & Fisher 1981).

The Scalby Formation is predominantly non-marine (Leeder & Nami 1979), but with marine influence on trace fossils and sedimentary structures (Livera & Leeder 1981). Marine palynomorphs also occur in lower part of the formation (Hancock & Fisher 1981). The possible unconformable nature of the bottom and top surfaces of the formation is a matter that has been debated: substantial downcutting certainly occurs at the base (e.g. Gowland & Riding 1991); the top was consolidated and eroded before deposition of Callovian Cornbrash (Riding & Wright 1989). Sandstones at the base (Black 1928, 1929) represent both low-sinuosity channels, and high-sinuosity channels which give way upwards to mudstones of alluvial marshes and floodbasins (Nami 1976; Nami & Leeder 1978; Livera & Leeder 1981; Alexander 1992*a*, *b*). Uppermost strata yield palynomorphs indicative of the Bathonian and re-analysis of palynomorph assemblages from lower beds in the Scalby Formation, reported on initially by Fisher & Hancock (1985), was thought to indicate a late Bajocian–early Bathonian age (Riding & Wright 1989). More recently (Hogg 1993) it has been suggested that the whole formation is late Bathonian in age, implying that a major stratigraphical break occurs at its base.

In the cases of the marine units that have sufficient age and facies control, it is apparent that those strata representing maximum transgression in Yorkshire correlate with horizons of erosional debris in Dorset. These are the Murchisonae Zone shales of the Dogger in Yorkshire which correspond to the Yellow Conglomerate in Dorset (*contra* Underhill & Partington 1993), and the Humphriesianum Zone Scarborough Formation in Yorkshire which corresponds to the Red Conglomerate in Dorset. This correlation suggests that at times of peak transgression, sediments temporarily accumulated in the Dorset area and that these had a poor preservation potential. The other marine levels in Yorkshire, the poorly dated Eller Beck Formation and the Lebberston Member (Discites, Ovalis and Laeviuscula Zones) also correspond to levels of extreme condensation or non-sequence in Dorset.

## Summary and conclusions

As a result of the long history of lithostratigraphical and biostratigraphical investigation, the Lower and Middle Jurassic successions of both Dorset and Yorkshire are known in almost unrivalled detail. Consequently, is possible to compare closely their parallel environmental evolution, allowing constraints to be placed on interpretation of the more ambiguous Dorset succession. Additionally, by applying an hypothesis of similar relative sea-level change, further elucidation of the stratigraphical history of the Dorset area is possible.

On a large scale, there is a roughly reciprocal relationship between Lower Jurassic stratal thicknesses when basins are compared: ammonite zones of the mid-Sinemurian, mid-Pliensbachian and late Toarcian are more expanded in Dorset than they are in Yorkshire. The condensed intervals in Yorkshire are relatively coarse-grained and represent deposition in shallower-marine environments. By inference, the concurrent expansion in the Dorset succession probably reflects increased sediment supply due to lack of accommodation space in adjacent more proximal settings. Similarly, the expanded successions in Yorkshire, of early Pliensbachian and early Toarcian age, are interpreted as deep-water facies and these relatively thick intervals are thought to reflect rising relative sea level in a proximal setting, with the increased accommodation space allowing deepening and sedimentary thickening. Again, by inference based mainly on comparison, the equivalent condensed sections in Dorset probably resulted from sediment starvation as sediment accumulation took place preferentially in more proximal settings. Synchronous long-term (*c.* 10 Ma) relative sea-level cycles appear to have dominated stratigraphies in both basins during the Early Jurassic. The Mid-Jurassic saw a high degree of differentiation of facies between Dorset and Yorkshire but, nonetheless, the same kind of large-scale reciprocal relationships described for the Early Jurassic appear also to be applicable. The expanded, mostly fluvial, succession of the Bajocian of Yorkshire correlates with condensed, offshore marine strata in Dorset, whereas the erosional unconformity equivalent to the most of the Bathonian in Yorkshire correlates with an expanded marine section in Dorset.

On a smaller scale, concerning sedimentary cycles with a duration of about 1 Ma or less, the relationships between stratal thickness, facies and relative sea-level change are more complex. However, analysis of the Yorkshire succession does help greatly with detailed interpretation of the Dorset succession. This is most clearly demonstrable in the uncommon cases where the stratigraphical patterns are identical in both basins. For example, consider the Jamesoni and Ibex Zones of the early Pliensbachian: through these zones in the Yorkshire succession, stratigraphical condensation is followed upwards by expansion, almost undoubtedly reflecting shallowing followed by deepening as determined from the facies. The precisely coeval condensation in Dorset is interpreted as reflecting the same shallowing trend. In contrast, the Dorset succession remains condensed at the same time as the depth clearly increased in Yorkshire. Thus, using an hypothesis of similar relative sea-level change in both basins, condensation in the relatively distal setting of Dorset appears to have occurred both as a result of winnowing (in shallow water) and as a result of starvation (in deep water).

Despite difficulties of interpretation, there is no evidence that disproves the case for synchronous, high-frequency relative sea-level changes generating both stratigraphies, and good evidence to support the case for some, albeit limited time intervals.

At all scales, it is apparent that the more distal setting of Dorset was more prone to the generation of stratigraphical breaks, whether related to relative sea-level rise or fall. The more proximal setting of Yorkshire maintained a balance of relative sea-level change and sediment supply, such that the succession is remarkably complete. No doubt, a more proximal succession still would contain as many gaps as Dorset, but their ages would be different, even if generated by synchronous cycles of relative sea-level change.

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## References

ALEXANDER, J. 1986. Idealized flow models to predict alluvial sandstone body distribution in the Middle Jurassic Yorkshire Basin. *Marine and Petroleum Geology*, **3**, 298–305.

——1989. Delta or coastal plain? With an example of the controversy from the Middle Jurassic of Yorkshire. *In*: WHATELEY, M. K. G. & PICKERING, K. T. (eds) *Deltas: Sites and Traps for Fossil Fuels*. Geological Society, London, Special Publications, **41**, 11–19.

——1992*a*. A discussion of alluvial sandstone body characteristics related to variations in marine influence, Middle Jurassic of the Cleveland Basin, UK, and the implications for analogous Brent Group strata in the North Sea Basin. *In*: MORTON, A. C., HASZELDINE, R. S., GILES, M. R. & BROWN, S. (eds) *Geology of the Brent Group*. Geological Society, London, Special Publications, **61**, 149–167.

——1992*b*. Nature and origin of a laterally extensive alluvial sandstone body in the Middle Jurassic Scalby Formation. *Journal of the Geological Society, London*, **149**, 431–441.

——& GAWTHORPE, R. L. 1993. The complex nature of a Jurassic multistorey, alluvial sandstone body, Whitby, North Yorkshire. *In*: NORTH, C. P. & PROSSER, D. J. (eds) *Characterization of Fluvial and Aeolian Reservoirs*. Geological Society, London, Special Publications, **73**, 123–142.

ANDERSON, F. W. 1964. Rhaetic Ostracoda. *Bulletin of the Geological Survey of Great Britain*, **21**, 133–174.

ARKELL, W. J. 1933. *The Jurassic System in Great Britain*. Oxford University Press.

ASHTON, M. 1980. The stratigraphy of the Lincolnshire Limestone Formation (Bajocian) in Lincolnshire and Rutland (Leicestershire). *Proceedings of the Geologists' Association*, **91**, 203–223.

BAIRD, G. C. 1978. Pebbly phosphorites in shale: a key to recognition of a widespread submarine discontinuity in the Middle Devonian of New York. *Journal of Sedimentary Petrology*, **48**, 545–555.

BAIRSTOW, L. 1969. Lower Lias. *In*: HEMINGWAY, J. E., WRIGHT, J. K. & TORRENS, H. S. (eds) *International Field Symposium on the British Jurassic, Excursion No. 3, Guide for North East Yorkshire*. Keele University Geology Department, C24–C37.

BARNARD, T. 1950. Foraminifera from the Lower Lias of the Dorset Coast. *Quarterly Journal of the Geological Society of London*, **105**, 347–391.

BATE, R. H. 1959. The Yons Nab Beds of the Middle Jurassic of the Yorkshire Coast. *Proceedings of the Yorkshire Geological Society*, **32**, 153–164.

——1964. Middle Jurassic Ostracoda from the Millepore Series, Yorkshire. *Bulletin of the British Museum (Natural History), (Geology)*, **10**, 1–34.

——1965. Middle Jurassic Ostracoda from the Grey Limestone Series, Yorkshire. *Bulletin of the British Museum (Natural History), (Geology)*, **11**, 73–134.

——1967. Stratigraphy and palaeogeography of the Yorkshire Oolites and their relationships with the Lincolnshire Limestone. *Bulletin of the British Museum (Natural History), (Geology)*, **14**, 111–141.

BLACK, M. 1928. 'Washouts' in the Estuarine Series of Yorkshire. *Geological Magazine*, **65**, 301–307.

——1929. Drifted plant-beds of the Upper Estuarine Series of Yorkshire. *Quarterly Journal of the Geological Society of London*, **85**, 389–439.

——1934. Sedimentation of the Aalenian rocks of Yorkshire. *Proceedings of the Yorkshire Geological Society*, **22**, 265–279.

BOSWELL, P. G. H. 1924. The petrography of the sands of the Lias–Inferior Oolite of the west of England. *Geological Magazine*, **61**, 246–264.

BOTT, M. H. P. 1988. The Market Weighton gravity anomaly – granite or graben? *Proceedings of the Yorkshire Geological Society*, **47**, 47–53.

——, ROBINSON, J. & KOHNSTAMM, M. A. 1978. Granite beneath Market Weighton, East Yorkshire. *Journal of the Geological Society, London*, **135**, 535–543.

BOTTRELL, S. & RAISWELL, R. 1989. Primary versus diagenetic origin of the Blue Lias rhythms (Dorset, UK): evidence from sulphur geochemistry. *Terra Nova*, **1**, 451–456.

BOWN, P. R. 1987. *Taxonomy, evolution and biostratigraphy of late Triassic–early Jurassic calcareous nannofossils*. Special Papers in Palaeontology, **38**.

BRADSHAW, M. J., COPE, J. C. W., CRIPPS, D. W., DONOVAN, D. T., HOWARTH, M. K., RAWSON, P. F., WEST, I. M. & WIMBLEDON, W. A. 1992. Jurassic. *In*: COPE, J. C. W., INGRAM, J. K. & RAWSON, P. F. (eds) *Atlas of Palaeogeography and Lithofacies*. Geological Society, London, Memoirs, **13**, 107–129.

BRENCHLEY, P. J. & GOWLAND, S. 1985. *The Sedimentology of Wave and Storm Influenced Shelf Facies: Carboniferous of Northumberland and Jurassic of Yorkshire*. Poroperm Excursion Guide No. 8. Poroperm, Chester.

BRYANT, I. D., KANTOROWICZ, J. D. & LOVE, C. F. 1988. The origin and recognition of laterally continuous carbonate-cemented horizons in the Upper Lias Sands of southern England. *Marine and Petroleum Geology*, **5**, 108–133.

BUCKMAN, S. S. 1889. On the Cotteswold, Midford and Yeovil Sands, and the division between the Lias and the Oolite. *Quarterly Journal of the Geological Society of London*, **59**, 445–58.

——1910. Certain Jurassic (Lias-Oolite) strata of south Dorset; and their correlation. *Quarterly Journal of the Geological Society of London*, **66**, 52–89.

——1915. A palaeontological classification of the Jurassic rocks of the Whitby district, with a zonal table of Liassic ammonites. *In*: FOX-STRANGWAYS, C. & BARROW, G. *The Geology of the Country Between Whitby and Scarborough*. Memoirs of the Geological Survey of Great Britain, 59–102.

——1922. Jurassic chronology II: Certain Jurassic strata near Eypesmouth (Dorset); the Junction Bed of Watton Cliff and associated rocks. *Quarterly Journal of the Geological Society of London*, **78**, 378–430.

CALLOMON, J. H. & CHANDLER, R. B. 1990. A review of the ammonite horizons of the Aalenian-Lower Bajocian stages in the Middle Jurassic of Southern England. *Memorie descrittive della Carta geologica d'Italia*, **40**, 85–112.

——& OATES, M. J. 1993. *Jurassic of Oxfordshire and Cotswolds*. Excursion Guide for the Arkell International Symposium on Jurassic Geology.

CATT, J. A., GAD, M. A. LE RICHE, H. H. & LORD, A. R. 1971. Geochemistry, micropalaeontology and origin of the Middle Lias ironstones in Northeast Yorkshire (Great Britain). *Chemical Geology*, **8**, 61–76.

CHADWICK, R. A. 1986. Extension tectonics in the Wessex Basin, southern England. *Journal of the Geological Society, London*, **143**, 465–488.

——1993. Aspects of basin inversion in southern Britain. *Journal of the Geological Society, London*, **150**, 311–322.

——, KENOLTY, N. & WHITTAKER, A. 1983. Crustal structure beneath southern England from deep seismic reflection profiles. *Journal of the Geological Society, London*, **140**, 893–911.

CHEN, Y. Y. & WRIGHT, R. C. 1987. Palynofacies analysis of the Blue Lias (Lower Jurassic) Dorset, southern England. *In*: *Innovative Biostratigraphic Approaches to Sequence Analysis: New Exploration Opportunities*. Selected Papers and Illustrated Abstracts of the Society of Economic Paleontologists and Mineralogists, Gulf Coast Section, eighth Annual Research Conference, Houston, Texas, 41–42.

CHOWNS, T. M. 1968. Depositional environment of the Cleveland Ironstone Series. *Nature*, **211**, 1286–1287.

COLEMAN, M. L. & RAISWELL, R. 1981. Carbon, oxygen and sulphur isotope variations in concretions from the Upper Lias of NE England. *Geochimica et Cosmochimica Acta*, **45**, 329–340.

COLTER, L. V. & HAVARD, D. I. 1981. The Wytch Farm oilfield Dorset. *In*: ILLING, V. C. & HOBSON, G. D. (eds) *Petroleum Geology of North-West Europe*. Applied Science, London, 494–503.

COPE, J. C. W. 1991. Discussion on correlation of the Triassic–Jurassic boundary in England and Austria. *Journal of the Geological Society, London*, **148**, 421–422.

——, DUFF, K. L., PARSONS, C. F., TORRENS, H. S., WIMBLEDON, W. A. & WRIGHT, J. K. 1980*b*. *A Correlation of Jurassic Rocks in the British Isles. Part Two: Middle and Upper Jurassic*. Special Reports of the Geological Society, London, **15**.

——, GETTY, T. A., HOWARTH, M. K., MORTON, N. & TORRENS, H. S. 1980*a*. *A Correlation of Jurassic Rocks in the British Isles. Part One: Introduction and Lower Jurassic*. Special Reports of the Geological Society, London, **14**.

——, HALLAM, A. & TORRENS, H. S. 1969. *Guide for Dorset and South Somerset: International Field Symposium on the British Jurassic, Excursion No. 1*. Geology Department, Keele University.

COPESTAKE, P. 1989. Triassic. *In*: JENKINS, D. G. & MURRAY, J. W. (eds) *Stratigraphical Atlas of Fossil Foraminifera*. Ellis Horwood, Chichester, 97–124.

——& JOHNSON, B. 1989. The Hettangian to Toarcian (Lower Jurassic). *In*: JENKINS, D. G. & MURRAY, J. W. (eds) *Stratigraphical Atlas of Fossil Foraminifera*. Ellis Horwood, Chichester, 129–188.

COX, B. M. 1990. A review of Jurassic chronostratigraphy and age indicators for the UK. *In*: HARDMAN, R. F. P. & BROOKS, J. (eds) *Tectonic Events Responsible for Britain's Oil and Gas Reserves*. Geological Society, London, Special Publications, **55**, 169–190.

DARTON, D. M., DINGWALL, R. G. & MCCANN, D. M. 1981. *Geological and geophysical investigations in Lyme Bay*. Report of the Institute of Geological Sciences, **79/10**.

DAVIES, D. K. 1967. Origin of friable sandstone–calcareous sandstone rhythms in the Upper Lias of England. *Journal of Sedimentary Petrology*, **39**, 1179–1188.

——1969. Shelf sedimentation: an example from the Jurassic of Britain. *Journal of Sedimentary Petrology*, **39**, 1344–1370.

DAY, E. C. H. 1863. On the Middle and Upper Lias of the Dorsetshire Coast. *Quarterly Journal of the Geological Society of London*, **19**, 278–297.

DEAN, W. T. 1954. Notes on part of the Upper Lias succession of Blea Wyke, Yorkshire. *Proceedings of the Yorkshire Geological Society*, **29**, 169–179.

——, DONOVAN, D. T. & HOWARTH, M. K. 1961. The Liassic ammonite zones and subzones of the North-West European Province. *Bulletin of the British Museum (Natural History), (Geology)*, **4**, 435–505.

DEWEY, J. F. 1982. Plate tectonics and evolution of the British Isles. *Journal of the Geological Society, London*, **139**, 371–412.

DOMMERGUES, J-L. & MEISTER, C. 1992. Late Sinemurian and Early Carixian ammonites in Europe with cladistic analysis of sutural characters. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **185**, 211–237.

DONATO, J. A. 1993. A buried granite batholith and the origin of the Sole Pit Basin, UK Southern North Sea. *Journal of the Geological Society, London*, **143**, 255–258.

DONOVAN, D. T., HORTON, A. & IVIMEY-COOK, H. C. 1979. The transgression of the Lower Lias over the northern flank of the London Platform. *Journal of the Geological Society, London*, **136**, 165–173.

——, CURTIS, M. T. & CURTIS, A. A. 1989. A psiloceratid ammonite from the supposed Triassic Penarth Group of Avon, England. *Palaeontology*, **32**, 231–235.

ENSOM, P. C. 1983. Examples of the trace fossil *Asteriacites* sp and tool marks from the Starfish Bed (Middle Lias) near Thorncombe Beacon. *Proceedings of the Dorset Natural History and Archaeological Society*, **105**, 165–166.

——1984*a*. Evidence of predation on, and post-mortem damage to, ammonites from the Eype Nodule Bed, Middle Lias, Dorset. *Proceedings of the Dorset Natural History and Archaeological Society*, **106**, 161–164.

——1984*b*. Hiatus concretions with a cemented, pedically and bysally attached fauna from the Eype Nodule Bed, Middle Lias, Dorset. *Proceedings of the Dorset Natural History and Archaeological Society*, **106**, 164.

——1987. Siltstone dykes in the Middle Lias of Dorset. *Proceedings of the Dorset Natural History and Archaeological Society*, **109**, 146.

FARROW, G. E. 1966. Bathymetric zonation of Jurassic trace fossils from the coast of Yorkshire, England. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **2**, 103–151.

FISHER, M. J. & HANCOCK, N. J. 1985. The Scalby Formation (Middle Jurassic, Ravenscar Group) of Yorkshire: reassessment of age and depositional environment. *Proceedings of the Yorkshire Geological Society*, **45**, 293–298.

FOX-STRANGWAYS, C. & BARROW, G. 1915. *The Geology of the Country Between Whitby and Scarborough*. Memoirs of the Geological Survey of Great Britain.

GAD, M. A., CATT, J. A. & LE RICHE, H. H. 1969. Geochemistry of the Whitbian (Upper Lias) sediments of the Yorkshire coast. *Proceedings of the Yorkshire Geological Society*, **37**, 105–139.

GATRALL, M., JENKYNS, H. C. & PARSONS, C. F. 1972. Limonitic concretions from the European Jurassic, with particular reference to the 'snuff-boxes' of southern England. *Sedimentology*, **18**, 79–103.

GAUNT, G. D., IVIMEY-COOK, H. C., PENN, I. E. & COX, B. M. 1980. *Mesozoic rocks proved in the IGS boreholes in the Humber and Acklam areas*. Institute of Geological Sciences Report, **79/13**.

GETTY, T. A. 1972. *Revision of the Jurassic ammonite family Echioceratidae*. PhD thesis (University of London).

GOLDRING, R. & STEPHENSON, D. G. 1972. The depositional environment of three Starfish Beds. *Neues Jahrbuch für Geologie und Paläontologie, Monatshefte*, 611–624.

GOWLAND, S. & RIDING, J. B. 1991. Stratigraphy, sedimentology and palaeontology of the Scarborough Formation (Middle Jurassic) at Hundale Point, North Yorkshire. *Proceedings of the Yorkshire Geological Society*, **48**, 375–392.

GREENSMITH, J. T., RAWSON, P. F. & SHALABY, S. E. 1980. An association of minor fining-upward cycles and aligned gutter marks in the Middle Lias (Lower Jurassic) of Yorkshire. *Proceedings of the Yorkshire Geological Society*, **42**, 525–538.

HALLAM, A. 1960*a*. The White Lias of the Devon Coast. *Proceedings of the Geologists' Association*, **71**, 47–60.

——1960*b*. A sedimentary and faunal study of the Blue Lias of Dorset and Glamorgan. *Philosophical Transactions of the Royal Society, London*, **B243**, 1–44.

——1962. A band of extraordinary calcareous concretions in the Upper Lias of Yorkshire, England. *Journal of Sedimentary Petrology*, **32**, 840–847.

——1964. Origin of the limestone-shale rhythm in the Blue Lias of England: a composite theory. *Journal of Geology*, **72**, 157–169.

——1967*a*. Siderite and calcite-bearing concretionary nodules in the Lias of Yorkshire. *Geological Magazine*, **104**, 222–227.

——1967*b*. An environmental study of the Upper Domerian and Lower Toarcian in Great Britain. *Philosophical Transactions of the Royal Society*, **B252**, 393–445.

——1969. A pyritized limestone hardground in the Lower Jurassic of Dorset (England). *Sedimentology*, **12**, 231–240.

——1975. *Jurassic Environments*. Cambridge University Press.

——1981. A revised sea-level curve for the early Jurassic. *Journal of the Geological Society, London*, **138**, 735–743.

——1986. Origin of minor limestone-shale cycles: climatically induced or diagenetic? *Geology*, **14**, 609–612.

——1987. Reply to comment on 'Origin of minor limestone-shale cycles: climatically induced or diagenetic?'. *Geology*, **15**, 92–93.

——1988. A re-evaluation of the Jurassic eustasy in the light of new data and the revised Exxon curve. *In*: WILGUS, C. K., HASTINGS, B. S., KENDALL, G. St. C., POSAMENTIER, H. W., ROSS, C. A. & VAN WAGONER, J. C. (eds) *Sea-Level Changes: an Integrated Approach*. Special Publications of the Society of Economic Paleontologists and Mineralogists, **42**, 261–275.

——1990. Correlation of the Triassic–Jurassic boundary in England and Austria. *Journal of the Geological Society, London*, **147**, 421–424.

——1991. Discussion on correlation of the Triassic–Jurassic boundary in England and Austria [reply]. *Journal of the Geological Society, London*, **148**, 420–422.

——1992. Jurassic. *In*: DUFF, P. MCL. D. & SMITH, A. J. (eds) *Geology of England and Wales*. The Geological Society, London, 325–354.

——& EL SHAARAWY, Z. 1982. Salinity reduction of the end-Triassic sea from the Alpine region into northwestern Europe. *Lethaia*, **15**, 169–178.

——& SELLWOOD, B. W. 1976. Middle Mesozoic sedimentation in relation to tectonics in the British area. *Journal of Geology*, **84**, 301–332.

HANCOCK, N. J. & FISHER, M. J. 1981. Middle Jurassic North Sea deltas with particular reference to Yorkshire. *In*: ILLING, L. V. & HOBSON, G. D. (eds) *Petroleum Geology of the Continental Shelf of North-West Europe*. Institute of Petroleum, London, 186–195.

HAQ, B. U., HARDENBOL, J. & VAIL, P. R. 1988. Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. *In*: WILGUS, C. K., HASTINGS, B. S., KENDALL, G. St. C., POSAMENTIER, H. W., ROSS, C. A. & VAN WAGONER, J. C. (eds) *Sea-Level Changes: an Integrated Approach*. Special Publications of the Society of Economic Paleontologists and Mineralogists, **42**, 71–108.

HEMINGWAY, J. E. 1951. Cyclic sedimentation and the deposition of Ironstone in the Yorkshire Lias. *Proceedings of the Yorkshire Geological Society*, **28**, 67–74.

——1974. Jurassic. *In*: RAYNER, D. H. & HEMINGWAY, J. E. (eds) *The Geology and Mineral Resources of Yorkshire*. Yorkshire Geological Society, Leeds, 161–223.

——& KNOX, R. W. O'B. 1973. Lithostratigraphical nomenclature of the Middle Jurassic of the Yorkshire Basin of north-east England. *Proceedings of the Yorkshire Geological Society*, **39**, 527–535.

——& RIDDLER, G. P. 1982. Basin Inversion in North Yorkshire. *Transactions of the Institute of Mining and Metallurgy*, **B91**, B175–B186.

HESSELBO, S. P. & PALMER, T. J. 1992. Reworked early diagenetic concretions and the bioerosional origin of a regional discontinuity within British Jurassic marine mudrocks. *Sedimentology*, **39**, 145–165.

HOGG, N. M. 1993. *A palynological investigation of the Scalby Formation and adjacent strata (Ravenscar Group, Middle Jurassic) from the Cleveland Basin, North Yorkshire*. PhD thesis, University of Sheffield.

HOLLOWAY, S. 1985. Middle Jurassic: the Inferior Oolite and Ravenscar Groups. *In*: WHITTAKER, A. (ed.) *Atlas of Onshore Sedimentary Basins in England and Wales: Post-Carboniferous Tectonics and Stratigraphy*. Blackie, Glasgow, 41–43.

HOUSE, M. 1985. A new approach to an absolute timescale from measurements of orbital cycles and sedimentary microrhythms. *Nature*, **315**, 712–725.

——1986. Are Jurassic sedimentary microrhythms due to orbital forcing? *Proceedings of the Ussher Society*, **6**, 299–311.

——1989. *Geology of the Dorset Coast*. Geologists' Association, London, Field Guide.

HOUNSLOW, M. H. 1987. Magnetic fabric characteristics of bioturbated wave-produced grain orientation in the Bridport–Yeovil Sands (Lower Jurassic) of Southern England. *Sedimentology*, **34**, 117–128.

HOWARD, A. S. 1985. Lithostratigraphy of the Staithes Sandstone and Cleveland Ironstone formations (Lower Jurassic) of north-east Yorkshire. *Proceedings of the Yorkshire Geological Society*, **45**, 261–275.

HOWARTH, M. K. 1955. Domerian of the Yorkshire coast. *Proceedings of the Yorkshire Geological Society*, **30**, 147–175.

——1957. The Middle Lias of the Dorset Coast. *Quarterly Journal of the Geological Society of London*, **113**, 185–204.

——1962. The Jet Rock Series and the Alum Shale Series of the Yorkshire coast. *Proceedings of the Yorkshire Geological Society*, **33**, 381–422.

——1973. The stratigraphy and ammonite fauna of the Upper Liassic Grey Shales of the Yorkshire coast. *Bulletin of the British Museum (Natural History), (Geology)*, **24**, 235–277.

——1980. The Toarcian age of the upper part of the Marlstone Rock Bed of England. *Palaeontology*, **23**, 637–656.

HUNTON, L. 1836. Remarks on a section of the Upper Lias and Marlstone of Yorkshire, showing the limited vertical range of the species of ammonites, and other testacea, with their value as geological tests. *Transactions of the Geological Society, London*, **5**, 215–220.

IVIMEY-COOK, H. C. 1982. Biostratigraphy of the Lower Jurassic and Upper Triassic (Rhaetian) rocks of the Winterborne Kingston borehole, Dorset. *In*: RHYS, G. H., LOTT, G. K. & CALVER, M. A. (eds) *The Winterborne Kingston Borehole, Dorset, England*. Report of the Institute of Geological Sciences, **81/3**, 97–106.

——& DONOVAN, D. T. 1983. Appendix 3: the fauna of the Lower Jurassic. In: WHITTAKER, A. & GREEN, G. W. *Geology of the Country around Weston-Super-Mare*. Memoirs of the Geological Survey of Great Britain, 126–130.

——& POWELL, J. H. 1991. Late Triassic and early Jurassic biostratigraphy of the Felixkirk Borehole, North Yorkshire. *Proceedings of the Yorkshire Geological Society*, **48**, 367–374.

JACKSON, J. F. 1922. Sections of the Junction Bed and contiguous deposits. *Quarterly Journal of the Geological Society of London*, **78**, 436–448.

——1926. The Junction Bed of the Middle and Upper Lias of the Dorset coast. *Quarterly Journal of the Geological Society of London*, **82**, 490–525.

JEFFERIES, R. P. S. & MINTON, P. 1965. The mode of life of two Jurassic species of '*Posidonia*' (Bivalvia). *Palaeontology*, **8**, 156–185.

JENKYNS, H. C. 1988. The early Toarcian (Jurassic) anoxic event: stratigraphic, sedimentary and geochemical evidence. *American Journal of Science*, **288**, 101–151.

——& SENIOR, J. R. 1977. A Liassic palaeofault from Dorset. *Geological Magazine*, **114**, 47–52.

——&——1991. Geological evidence for intra-Jurassic faulting in the Wessex Basin and its margins. *Journal of the Geological Society, London*, **148**, 245–260.

JONES, C. E., JENKYNS, H. C. & HESSELBO, S. P. 1994. Strontium isotopes in Early Jurassic seawater. *Geochimica et Cosmochimica Acta*, **58**, 1285–1301.

JONES, L. E. & SELLWOOD, B. W. 1989. Palaeogeographic significance of clay mineral distributions in the Inferior Oolite Group (mid Jurassic) of southern England. *Clay Minerals*, **24**, 93–105.

KANTOROWICZ, J. D. 1990. Lateral and vertical variation in pedogenesis and other early diagenetic phenomena, Middle Jurassic Ravenscar Group, Yorkshire. *Proceedings of the Yorkshire Geological Society*, **48**, 61–74.

——, BRYANT, I. D. & DAWANS, J. M. 1987. Controls on the geometry and distribution of carbonate cements: Bridport Sands, southern England and Viking Group, Troll Field, Norway. *In*: MARSHALL, J. D. (ed.) *Diagenesis of Sedimentary Sequences*. Geological Society, London, Special Publications, **36**, 103–118.

KARNER, G. D., LAKE, S. D. & DEWEY, J. F. 1987. The thermo-mechanical development of the Wessex Basin, southern England. *In*: HANCOCK, P. L., DEWEY, J. F. & COWARD, M. P. (eds) *Continental* Extensional Tectonics. Geological Society, London, Special Publications, **28**, 517–536.

KENT, P. E. 1949. A structure-contour map of the surface of the buried pre-Permian rocks in England and Wales. *Proceedings of the Geologists' Association*, **60**, 87–104.

——1980. Subsidence and uplift in east Yorkshire and Lincolnshire: a double inversion. *Proceedings of the Yorkshire Geological Society*, **42**, 505–524.

KIRBY, G. A. & SWALLOW, P. W. 1987. Tectonism and sedimentation in the Flamborough Head region of north-east England. *Proceedings of the Yorkshire Geological Society*, **46**, 301–309.

KNOX, R. W. O'B. 1973. The Eller Beck Formation (Bajocian) of the Ravenscar Group of NE Yorkshire. *Geological Magazine*, **110**, 511–534.

——1982. Clay mineral trends in cored Lower and Middle Jurassic sediments of the Winterborne Kingston borehole, Dorset. *In*: RHYS, G. H., LOTT, G. K. & CALVER, M. A. (eds) *The Winterborne Kingston Borehole, Dorset, England*. Report of the Institute of Geological Sciences, **81/3**, 91–96.

——1984. Lithostratigraphy and depositional history of the late Toarcian sequence at Ravenscar, Yorkshire. *Proceedings of the Yorkshire Geological Society*, **45**, 99–108.

——, MORTON, A. C. & LOTT, G. K. 1982. Petrology of the Bridport Sands in the Winterborne Kingston borehole, Dorset. *In*: RHYS, G. H., LOTT, G. K. & CALVER, M. A. (eds) *The Winterborne Kingston Borehole, Dorset, England*. Report of the Institute of Geological Sciences, **81/3**, 107–121.

——, HOWARD, A. S., POWELL, J. H. & VAN BUCHEM, S. P. 1990. *Lower and Middle Jurassic Sediments of the Cleveland Basin, NE England: Shallow Marine and Paralic Facies seen in the Sequence Stratigraphic Context*. Excursion Guide No. 5, 13th International Sedimentological Congress, Nottingham.

KÜSPERT, W. 1982. Environmental changes during oil-shale deposition as deduced from stable isotope ratios. *In*: EINSELE, G. & SEILACHER, A. (eds) *Cyclic and Event Stratification*. Springer-Verlag, Berlin, 482–501.

LAKE, S. D. & KARNER, G. D. 1987. The structure and evolution of the Wessex Basin, southern England: an example of inversion tectonics. *Tectonophysics*, **137**, 347–378.

LANG, W. D. 1924. The Blue Lias of the Devon and Dorset coasts. *Proceedings of the Geologists' Association*, **35**, 169–185.

——1936. The Green Ammonite Beds of the Dorset Lias. *Quarterly Journal of the Geological Society, London*, **92**, 423–455.

——1945. The Coinstone of the Charmouth Lias. *Proceedings of the Dorset Natural History and Archaeological Society*, **67**, 145–149.

——& SPATH, L. F. 1926. The Black Marl of Black Ven and Stonebarrow, in the Lias of the Dorset coast. With notes on the Lamellibranchia by L. R. Cox; on the Brachiopoda by H. M. Muir Wood; on certain Echioceratidae by A. E. Trueman and D. M. Williams. *Quarterly Journal of the Geological Society of London*, **82**, 144–187.

——, ——& RICHARDSON, W. A. 1923. Shales-with-'Beef', a sequence in the Lower Lias of the Dorset Coast. *Quarterly Journal of the Geological Society of London*, **79**, 47–99.

——, ——, COX, L. R. & MUIR WOOD, H. M. 1928. The Belemnite Marls of Charmouth, a series in the Lias of the Dorset coast. *Quarterly Journal of the Geological Society of London*, **84**, 179–257.

LEEDER, M. R. & NAMI, M. 1979. Sedimentary models for the non-marine Scalby Formation (Middle Jurassic) and evidence for late Bajocian/Bathonian uplift of the Yorkshire Basin. *Proceedings of the Yorkshire Geological Society*, **42**, 461–482.

LIVERA, S. E. & LEEDER, M. R. 1981. The Middle Jurassic Ravenscar Group ('Deltaic Series') of Yorkshire: recent sedimentological studies as demonstrated during a Field Meeting, 2–3 May 1980. *Proceedings of the Geologists' Association*, **92**, 241–250.

LORD, A. R., COPESTAKE, P., BOOMER, I. D., SHEPPARD, L. M., FULLER, N. G., CLEENTS, R. G., BOWN, P. R., RIDING, J. B., BATTERN, D. J. LISTER, J. K., & MACLENNAN, A. M. 1987. Jurassic. *In*: LORD, A. R. & BOWN, P. R. (eds) *Mesozoic and Cenozoic Stratigraphical Micropalaeontology of the Dorset Coast and Isle of Wight, Southern England*. British Micropalaeontological Society, Guide Books, **1**, 3–78.

MILSOM, J. & RAWSON, P. F. 1989. The Peak Trough – a major control on the geology of the North Yorkshire coast. *Geological Magazine*, **126**, 699–705.

MJØS, R. & PRESTHOLM, E. 1993. The geometry and organization of fluviodeltaic channel sandstones in the Jurassic Saltwick Formation, Yorkshire, England. *Sedimentology*, **40**, 919–935.

MELDAHL, K. H. 1987. Sedimentologic and taphonomic implications of biogenic stratification. *Palaios*, **2**, 350–358.

MORRIS, K. A. 1979. A classification of Jurassic marine shale sequences: an example from the Toarcian (Lower Jurassic) of Great Britain. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **26**, 117–126.

MYERS, K. J. 1989. The origin of the Lower Jurassic Cleveland Ironstone Formation of North-East England: evidence from portable gamma ray spectrometry. *In*: YOUNG, T. P. & TAYLOR, W. E. G. (eds) *Phanerozoic Ironstones*. Geological Society, London, Special Publications, **46**, 221–228.

——& WIGNALL, P. B. 1987. Understanding Jurassic organic-rich mudrocks—new concepts using gamma-ray spectrometry and palaeoecology: examples from the Kimmeridge Clay of Dorset and the Jet Rock of Yorkshire. *In*: LEGGETT, J. K. & ZUFFA, G. G. (eds) *Marine Clastic Sedimentology—Concepts and Case Studies*. Graham & Trotman, London, 172–189.

NAMI, M. 1976. An exhumed Jurassic meander belt from Yorkshire, England. *Geological Magazine*. **113**, 47–52.

——& LEEDER, M. R. 1978. Changing channel morphology and magnitude in the Scalby Formation (M. Jurassic) of Yorkshire, England. *In*: MIALL, A. D. (ed.) *Fluvial Sedimentology*. Memoirs of the Canadian Society of Petroleum Geologists, **5**, 431–440.

NICKLESS, E. F. P., BOOTH, S. J. & MOSLEY, P. N. 1976. *The celestite resources of the area north-east of Bristol. With notes on occurrences north and south of the Mendip Hills and in the Vale of Glamorgan. Description of 1 : 25000 resource sheet ST 68 and parts of ST 59, 69, 79, 58, 78, 67, and 77*. Institute of Geological Sciences Mineral Assessment Report, **25**, 1–83.

O'BRIEN, N. R. 1990. Significance of lamination in Toarcian (Lower Jurassic) shales from Yorkshire, Great Britain. *Sedimentary Geology*, **67**, 25–34.

OSCHMANN, W. 1993. Environmental oxygen fluctuations and the adaptive response of marine benthic organisms. *Journal of the Geological Society, London*, **150**, 187–191.

PAGE, K. N. 1989. A stratigraphic revision of the English Lower Callovian. *Proceedings of the Geologists' Association*, **100**, 363–389.

——1992. The sequence of ammonite correlated horizons in the British Sinemurian (Lower Jurassic). *Newsletters on Stratigraphy*, **27**, 129–156.

PALMER, C. P. 1965. The fauna of Day's Shell Bed in the Middle Lias of the Dorset Coast. *Proceedings of the Dorset Natural History and Archaeological Society*, **87**, 690–80.

——1972*a*. Revision of the zonal classification of the Lower Lias of the Dorset coast. *Proceedings of the Dorset Natural History and Archaeological Society*, **93**, 102–116.

——1972*b*. A revision of the zonal classification of the Lower Lias of the Dorset coast in SW England. *Newsletters on Stratigraphy*, **2**, 45–54.

PALMER, T. J. & WILSON, M. A. 1990. Growth of ferruginous oncoliths in the Bajocian (Middle Jurassic) of Europe. *Terra Nova*, **2**, 142–147.

PARSONS, C. F. 1973. A new temporary exposure in the Inferior Oolite of south Dorset. *Proceedings of the Dorset Natural History and Archaeological Society*, **93**, 117–118.

——1975. The stratigraphy of the Stony Head Cutting, Bridport. *Proceedings of the Dorset Natural History and Archaeological Society*, **96**, 8–13.

——1977. A stratigraphic revision of the Scarborough Formation (Middle Jurassic) of north-east Yorkshire. *Proceedings of the Yorkshire Geological Society*, **41**, 203–222.

PENN, I. E., CHADWICK, R. A., HOLLOWAY, S., ROBERTS, G., PHARAOH, T. C., ALLSOP, J. M., HULBERT, A. G. & BURNS, I. M. 1987. Principal features of the hydrocarbon prospectivity of the Wessex-Channel Basin, U.K. *In*: BROOKS, J. & GLENNIE, K. (eds) *Petroleum Geology of North West Europe*. Graham & Trotman, 109–118.

PHELPS, M. C. 1985. A refined ammonite biostratigraphy for the middle and upper Carixian (*ibex* and *davoei* Zones, Lower Jurassic) in North-West Europe and stratigraphical details of the Carixian–Domerian boundary. *Geobios*, **18**, 321–361.

POWELL, J. H. 1984. Lithostratigraphic nomenclature for the Lias Group in the Yorkshire Basin. *Proceedings of the Yorkshire Geological Society*, **45**, 51–58

——& RATHBONE, P. A. 1983. The relationship of the Eller Beck Formation and the supposed Blowgill Member (Middle Jurassic) of the Yorkshire Basin. *Proceedings of the Yorkshire Geological Society*, **44**, 365–373.

PYE, K. & KRINSLEY, D. 1986. Microfabric, mineralogy and early diagenetic history of the Whitby Mudstone Formation (Toarcian), Cleveland Basin, U.K. *Geological Magazine*, **12**, 191–203.

RAISWELL, R. & BERNER, R. A. 1985. Pyrite formation in euxinic and semi-euxinic sediments. *American Journal of Science*, **285**, 710–724.

RASTALL, R. H. & HEMINGWAY, J. E. 1940. The Yorkshire Dogger I. The coastal region. *Geological Magazine*, **77**, 177–179.

RAWSON, P. F. & WRIGHT, J. K. 1992. *The Yorkshire Coast*. Geologists' Association, London, Field Guide.

——, GREENSMITH, J. T. & SHALABY, S. E. 1983. Coarsening upward cycles in the uppermost Staithes and Cleveland Ironstone Formations (Lower Jurassic) of the Yorkshire coast, England. *Proceedings of the Geologists' Association*, **94**, 91–93.

RHYS, G. H., LOTT, G. K. & CALVER, M. A. (eds) 1982. *The Winterborne Kingston Borehole, Dorset, England*. Report of the Institute of Geological Sciences, **81/3**, 1–196.

RICHARDSON, L. 1906. On the Rhaetic and contiguous deposits of Devon and Dorset. *Proceedings of the Geologists' Association*, **19**, 401–409.
——1915. Report of an excursion to Bridport, Beaminster and Crewkerne. *Proceedings of the Geologists' Association*, **26**, 47–78.
——1928–30. The Inferior Oolite and contiguous deposits of the Burton Bradstock–Broadwindsor district (Dorset). *Proceedings of the Cotteswold Naturalists' Field Club*, **23**, 35–68; 149–85; 253–264.
——& BUTT, W. 1912. Excursion to Bridport, Dorset. *Proceedings of the* Cotteswold Naturalists' Field Club, **18**, 31–38.
RIDING, J. B. & WRIGHT, J. K. 1989. Palynostratigraphy of the Scalby Formation (Middle Jurassic) of the Cleveland Basin, north-east Yorkshire. *Proceedings of the Yorkshire Geological Society*, **47**, 349–354.
SELLEY, R. C. & STONELEY, R. 1987. Petroleum habitat in south Dorset. *In*: BROOKS, J. & GLENNIE, K. (eds) *Petroleum Geology of North West Europe*. Graham & Trotman Ltd, London, 139–148.
SELLWOOD, B. W. 1970. The relation of trace fossils to small-scale sedimentary cycles in the British Lias. *In*: CRIMES, T. P. & HARPER, J. C. (eds) *Trace Fossils*. Special Issue of the Geological Journal **3**, 489–504.
——1972. Regional environmental change across a Lower Jurassic stage-boundary in Britain. *Palaeontology*, **15**, 125–157.
——& JENKYNS, H. C. 1975. Basins and swells and the evolution of an epeiric sea (Pliensbachian-Bajocian of Great Britain). *Journal of the Geological Society, London*, **131**, 373–388.
——& SLADEN, C. P. 1981. Mesozoic and Tertiary argillaceous units: distribution and composition. *Quarterly Journal of Engineering Geology*, **14**, 263–275.
——, DURKIN, M. K. & KENNEDY, W. J. 1970. Field meeting on the Jurassic and Cretaceous Rocks of Wessex. *Proceedings of the Geologists' Association*, **81**, 715–732.
——, SCOTT, J. & LUNN, G. 1986. Mesozoic basin evolution in Southern England. *Proceedings of the Geologists' Association*, **97**, 259–289.
SENIOR, J. R., PARSONS, C. F. & TORRENS, H. C. 1970. New sections in the Inferior Oolite of South Dorset. *Proceedings of the Dorset Natural History and Archaeological Society*, **91**, 114–119.
SIMPSON, M. 1884. *The fossils of the Yorkshire Lias, described from nature, with a carefully measured section of the strata and the fossils peculiar to each*. Whitby.
SIMPSON, S. 1957. On the Trace Fossil *Chondrites*. *Quarterly Journal of the Geological Society of London*, **112**, 475–499.
SMITH, D. G. 1989. Stratigraphic correlation of presumed Milankovitch cycles in the Blue Lias (Hettangian to earliest Sinemurian), England. *Terra Nova*, **1**, 457–460.
SPATH, L. F. 1956. The Liassic ammonite faunas of the Stowell Park Borehole. *Bulletin of the Geological Survey of Great Britain*, **11**, 140-164.
STONELEY, R. 1982. The structural development of the Wessex Basin. *Journal of the Geological Society, London*, **139**, 545–552.
STURANI, C. 1971. Ammonites and stratigraphy of the "Posidonia alpina" beds of the Venetian Alps (Middle Jurassic, mainly Bajocian). *Memoria dell'Istituto di Geologia e Mineralogia dell'Università di Padova*, **28**, 1–190.
TATE, R. & BLAKE, J. F. 1876. *The Yorkshire Lias*. J. van Voorst, London.
UNDERHILL, J. R. & PARTINGTON, M. A. 1993. Jurassic thermal doming and deflation in the North Sea: implications of the sequence stratigraphic evidence. *In*: PARKER, J. R. (ed.) *Petroleum Geology of Northwest Europe: Proceedings of the 4th Conference*. Geological Society, London, pp. 337–345.
VAN BUCHEM, F. S. P. & MCCAVE, I. N. 1989. Cyclic sedimentation patterns in Lower Lias mudstones of Yorkshire (GB). *Terra Nova*, **1**, 461–467.
——, MELNYK, D. H. & MCCAVE, I. N. 1992. Chemical cyclicity and correlation of Lower Lias mudstones using gamma ray logs, Yorkshire, UK. *Journal of the Geological Society, London*, **149**, 991–1002.
——, MCCAVE, I. N. & WEEDON, G. P. 1994. Orbitally induced small scale cyclicity in a siliciclastic epicontinental setting (Cleveland Basin, Lower Lias, Yorkshire, UK) *In*: DE BOER, P. L. & SMITH, D. G. (eds) *Orbital forcing and cyclic sedimentary sequences*. Special Publications of the International Association of Sedimentologists, **19**, 345–366.
WARRINGTON, G. & IVIMEY-COOK, H. C. 1990. Biostratigraphy of the late Triassic and early Jurassic: a review of type sections in southern Britain. *In*: RUGET, C. & GUEX, J. (eds) *Rapport du Working-Group "Limite Trias/Jurassique", Lyon 28–29 Novembre 1988*. Les Cahiers de l'Université Catholique de Lyon, Série Sciences, **3**, 207–213.
——, AUDLEY-CHARLES, R. E., ELLIOTT, W. B. IVIMEY-COOK, H. C. KENT, P. E., ROBINSON, P. L., SHOTTON, F. W. & TAYLOR, F. M. 1980. *A correlation of Triassic rocks in the British Isles*. Geological Society, London, Special Reports, **13**.
WEEDON, G. P. 1986. Hemipelagic shelf sedimentation and climatic cycles: the basal Jurassic (Blue Lias) of S. Britain. *Earth and Planetary Science Letters*, **76**, 321–335.
——1987*a*. *Paleoclimatic significance of open marine cyclic sequences*. DPhil thesis, University of Oxford.
——1987*b*. Comment on: "Origin of minor limestone-shale cycles: Climatically induced or diagenetic?". *Geology*, **15**, 92–93.
——& JENKYNS, H. C. 1990. Regular and irregular climatic cycles and the Belemnite Marls (Pliensbachian, Wessex Basin, UK). *Journal of the Geological Society, London*, **147**, 915–918.
WEST, I. M. 1964. Evaporite diagenesis in the Lower Purbeck Beds of Dorset. *Proceedings of the Yorkshire Geological Society*, **34**, 315–330.
——1973. Vanished evaporites—significance of strontium minerals. *Journal of Sedimentary Petrology*, **43**, 278–279.
——1979. Review of evaporite diagenesis in the Purbeck Formation of southern England. *In*: *Symposium de sédimentation jurassique W. européen*. Publications Spéciale de l'Association des sedimentologistes français, **1**, 407–416.
WHALLEY, P. E. S. 1985. The systematics and palaeogeography of the Lower Jurassic insects of Dorset, England. *Bulletin of the British Museum (Natural History), (Geology)*, **39**, 107–189.
WHITTAKER, A. (ed.) 1985. *Atlas of Onshore Sedimentary Basins in England and Wales: Post Carboniferous Tectonics and Stratigraphy*. Blackie, Glasgow.
——& GREEN, G. W. 1983. *Geology of the Country around Weston-Super-Mare*. Memoirs of the Geological Survey of Great Britain, 126–130.
——, COPE, J. C. W., COWIE, J. W., GIBBONS, W., HAILWOOD, E. A., HOUSE, M. R., JENKINS, D. G., RAWSON, P. F., RUSHTON, A. W. A., SMITH, D. G., THOMAS, A. T., & WIMBLEDON, W. A. 1991. A guide to stratigraphical procedure. *Journal of the Geological Society, London*, **148**, 813–824.
WIGNALL, P. B. & HALLAM, A. 1991. Biofacies, stratigraphic distribution and depositional models of British onshore Jurassic black shales. *In*: TYSON, R. V. & PEARSON, T. H. (eds) *Modern and Ancient Continental Shelf Anoxia*. Geological Society, London, Special Publications, **58**, 291–309.
WILSON, V., WELCH, F. B. A., ROBBIE, J. A. & GREEN, G. W. 1958. *Geology of the Country around Bridport and Yeovil*. Memoirs of the Geological Survey of Great Britain.
WOOD, M. W. & SHAW, H. F. 1976. The geochemistry of celestites from the Yate area near Bristol (UK). *Chemical Geology*, **17**, 179–193.
YOUNG, T. P., AGGETT, J. R., HOWARD, A. S. & PARSONS, D. 1990. *Jurassic and Ordovician Ooidal Ironstones*. Excursion Guide No. 9, 13th International Sedimentological Congress, Nottingham. British Sedimentological Research Group.
ZEUNER, F. E. 1962. Fossil insects from the Lower Lias of Charmouth, Dorset. *Bulletin of the British Museum (Natural History), (Geology)*, **7**, 155–171.
ZIEGLER, P. A. 1981. Evolution of sedimentary basins in north-west Europe. *In*: ILLING, L. V. & HOBSON, G. D. (eds) *Petroleum Geology of the Continental Shelf of North-West Europe*. Heyden, London, 3–39.
——1990*a*. *Geological Atlas of western and central Europe*. Shell International Petroleum Maatschappij BV.
——1990*b* Tectonic and palaeogeographic development of the North Sea rift system. *In*: BLUNDELL, D. J. & GIBBS, A. D. (eds) *Tectonic Evolution of the North Sea Rifts*. Oxford Science Publications, Oxford, 1–36.