A Carbonate Cornucopia on the Jurassic Coast: Field Excursion, 14th Bathurst Meeting of Carbonate Sedimentology

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14th Bathurst Meeting of Carbonate Sedimentology, Bristol University

Field excursion, Saturday 9th – Monday 11th July 2011

A Carbonate Cornucopia on the Jurassic Coast

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with contributions from
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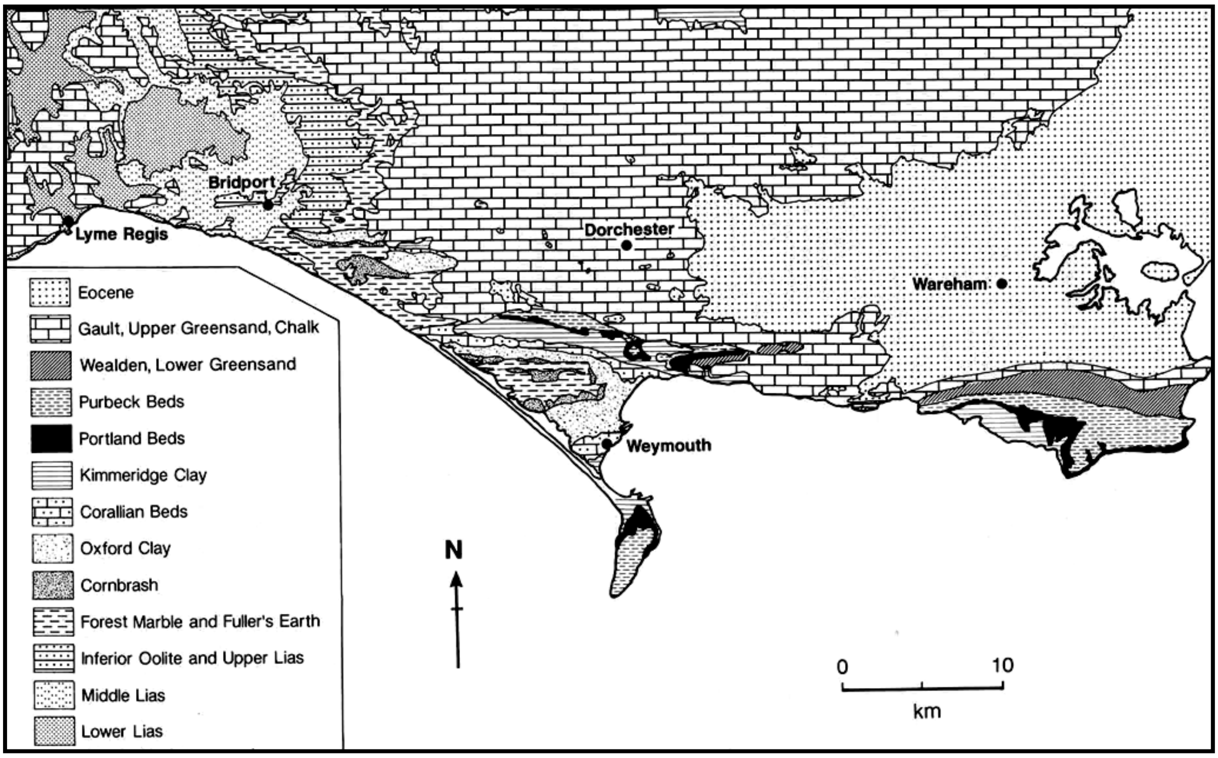

Geological Map of Dorset, from Callomon and Cope (1995)

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PLANNED ITINERARY

	Morning	Afternoon
Saturday 9th July ***Low tide 18.15***	*Arrival in Weymouth*	Freshwater Bay, Isle of Portland
Sunday 10th July ***High tide 14.45***	Osmington Mills	Lulworth Cove and Stair Hole Kimmeridge Bay
Monday 11th July ***High tide 15.20***	Chippel Bay, Lyme Regis Watton Cliff, Eype Mouth	Burton Cliff, near Bridport *Onward to Bristol*

HAZARD ASSESSMENT

All of the key localities to be visited are coastal; most are on the beach but some are on cliff tops accessed by footpaths. In several cases there are unprotected drops that may be uncomfortable for vertigo sufferers, but there is no requirement to go close to the edges! Accessing some of the beaches involves clambering over uneven, sometimes slippery boulders. Please wear walking boots with good ankle protection, go as slowly as you need, and take care. Tides are far from ideal, but there is no danger of being cut off. The most significant hazard is from cliff fall. You are therefore advised to avoid lingering near sites of recent cliff fall or beneath overhangs with open fissures, and to wear a hard hat whenever close to the cliffs.

Please be equipped for a range of temperatures (e.g. 12 - 25°C) and sunny or wet weather – July in the UK is unpredictable. You are recommended to bring sun cream and a hat, as well as a rain jacket.

If you wish to collect samples please do so from fallen blocks rather than pristine exposure. The coast is a World Heritage site and unnecessary hammering is to be avoided. We should seek to comply with the Jurassic coast code of practice for fossil collecting http://www.charmouth.org/chcc/downloads/WestDorsetFossilCode.PDF

ACCOMMODATION

The Portland Heights Hotel, Yeates Road, Isle of Portland, Dorset DT5 2EN.

Telephone +44 (0) 1305 821361

The Heights hotel is situated on the cliff tops at the south end of the Isle of Portland, directly on top of a succession that extends from the upper Kimmeridge Clay at sea level to the top of the Portland Limestone Formation. From the terrace there are views to the east across Portland Harbour to cliffs of Callovian - Oxfordian mudrocks, limestones and sandstones uplifted in the Weymouth anticline. To the north is Weymouth with the Chalk scarp in the distance marking the monoclinal flexure above the Abbotsbury – Ridgeway fault zone (see Geological Context below). To the west the cliffs in the distance are of Middle and Lower Jurassic strata, but in between them is Chesil Beach separating the open sea from the brackish tidal Fleet lagoon. This world-famous coastal land form is 29km long, up to 14.7m high and up to 200m wide, and is a storm-dominated barrier beach (or tombolo, as it links the Isle of Portland to the mainland). It overwhelmingly consists of flint pebbles sourced from Pleistocene raised beaches and river gravels (now largely eroded away) which fined westwards owing to longshore drift. Underlying peats date the formation of the barrier to a maximum of 6.1 Ka and it was therefore established during the Flandrian transgression. Ravines on the landward side of the barrier developed owing to water seepage and destabilisation of the shingle during major storms. For more detailed information see Ian West's web site "Geology of the Wessex Coast": http://www.soton.ac.uk/~imw/chesil.htm

Chesil beach, viewed from close to the Portland Heights Hotel. Photograph by Alan Holiday on Ian West's web site (http://www.soton.ac.uk/~imw/jpg-Chesil/10CHB-Alan-Holiday-21Nov2010.jpg).

A LITTLE LOCAL HISTORY

Portland is not really an island but is reached over a narrow causeway from Chesil Beach. Portland is, in effect, a huge block of limestone, measuring 4.5 miles by 1.75 miles and rising to a height of 400 feet above sea level in the north. The famous Portland Stone quarried here has been used for many well-known buildings including the United Nations Building in New York and London's St Paul's Cathedral. In the second half of the 17th century, Sir Christopher Wren used Portland Stone to rebuild London after the Great Fire. Over six million tonnes of stone, taken by barges along the coast to the River Thames, was used to rebuild around fifty churches and other buildings.

There is evidence that the occupation of Portland dates back thousands of years. It was called Vindilis by the Romans and there is evidence of successive settlements of the island. Much later, the author Thomas Hardy described it as 'The Isle of Slingers'. This was because some Portlanders would throw stones to keep strangers away. Portland Castle was built at Castledown in 1539 following attacks by the French. This fortress, overlooking Portland Harbour, was built by Henry VIII to defend nearby Weymouth from further attempts of invasion from France and Spain. During the Civil War in the mid 17th century, it was seized by both Parliament and Royalist forces.

The Verne was originally constructed as a citadel and could accommodate as many as two thousand troops in war time. Today it is a prison. In the mid 1800s, prisoners from the original Portland prison constructed the breakwaters in Portland Harbour, to form one of the largest harbours in the world. Work was started in 1849, when Queen Victoria's husband, Prince Albert, laid the foundation stone, and was completed in 1872. Before the Verne was completed, twenty two men lost their lives in its construction.

The cruel conditions in the original Portland prison and its quarries during the latter half of the 19th century were a major catalyst for penal reform in this country. Many prisoners died while working to quarry the blocks of stone necessary to build Portland's naval breakwater. During the 1870s, deaths within the prison ran at nearly one per week. Local entrepreneurs living adjacent to the prison quarries would charge eagerly awaiting visitors, who came to the Island on the newly constructed railway, to view the prisoners at work from the upper windows of their houses.

INTRODUCTION AND AIMS OF THE EXCURSION

The Jurassic of the Dorset Coast forms the main part of a UNESCO World Heritage Site (http://www.jurassiccoast.com/), recognised for the superb well exposed variety of richly fossiliferous marine to marginal marine strata, their importance in Jurassic palaeontology and stratigraphy, and their wealth of sedimentological and palaeonevironmental information. The successions and their fossils were studied and described by some of the leading exponents of British Mesozoic geology and palaeontology such as William Arkell, Sydney Buckman, William Lang and even Adam Sedgwick and William Smith. Despite their fame of these successions (or maybe because of it?) their sedimentology has received relatively little detailed study in recent decades. Much more work has been done on the palaeontology and biostratigraphy. The post-depositional modification of the sediments, and the complex interplay of biological, geochemical and physical processes that they record, merit a fresh look from a "21st-century" perspective.

This excursion has arisen from taking student groups to these "classic" locations and appreciating that their story may not be as simple as it first seems. Additionally, a wealth of new and historical field information has been compiled and presented on Ian West's "Geology of the Wessex Coast" web site (http://www.soton.ac.uk/~imw/) over the past 15 years. It therefore seems timely to revisit some key carbonate and mixed carbonate-siliciclastic successions. It is also a chance to see some of the spectacular coastal scenery that made the Dorset Coast famous long before its geological significance was fully appreciated. We might even have a look at some tectonics.

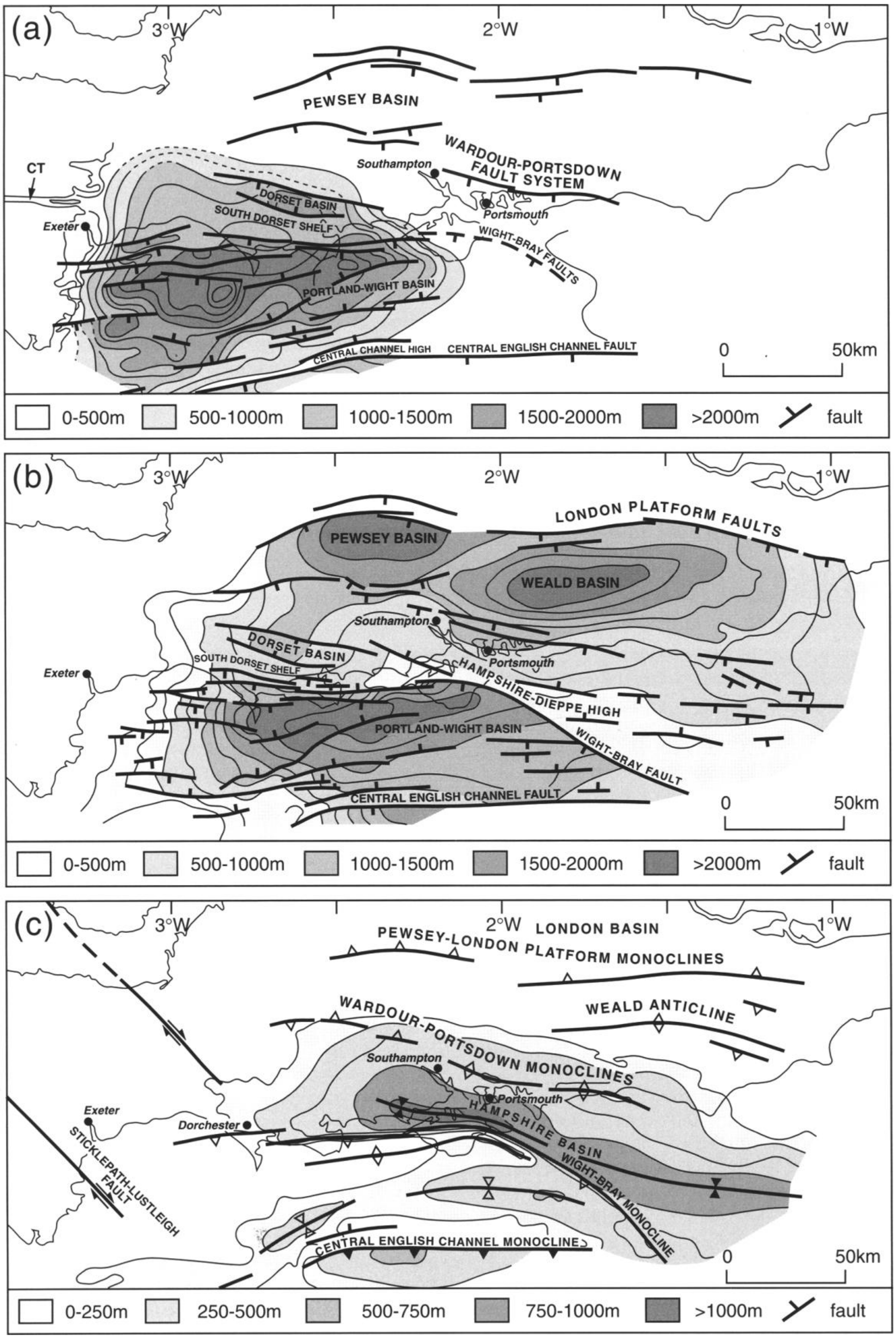
The principal aim of the excursion is to show you some of the most interesting carbonate-rich facies of the Dorset coast Jurassic successions. Because of the leaders' interests there will be a mild bias towards exploring the inter-relationship of biological, geochemical and physical sedimentary processes, rather than gross stratigraphic architectures. You will **not** be offered a set of definitive new models, but a wonderful chance to observe, debate and discuss aspects of these world-renowned yet still enigmatic deposits.

This field guide provides the background information and references, introduces key highlights of localities that we will visit, and includes links to specific pages on Ian's web site where many more details can be browsed at your leisure. Hopefully we will encourage you to come back and visit more of the Jurassic coast in the future – there is much more to see than we can cram into 2 days. It is a very well established natural teaching laboratory for the geosciences, but there is much intriguing research still to be done especially of an inter-disciplinary nature.

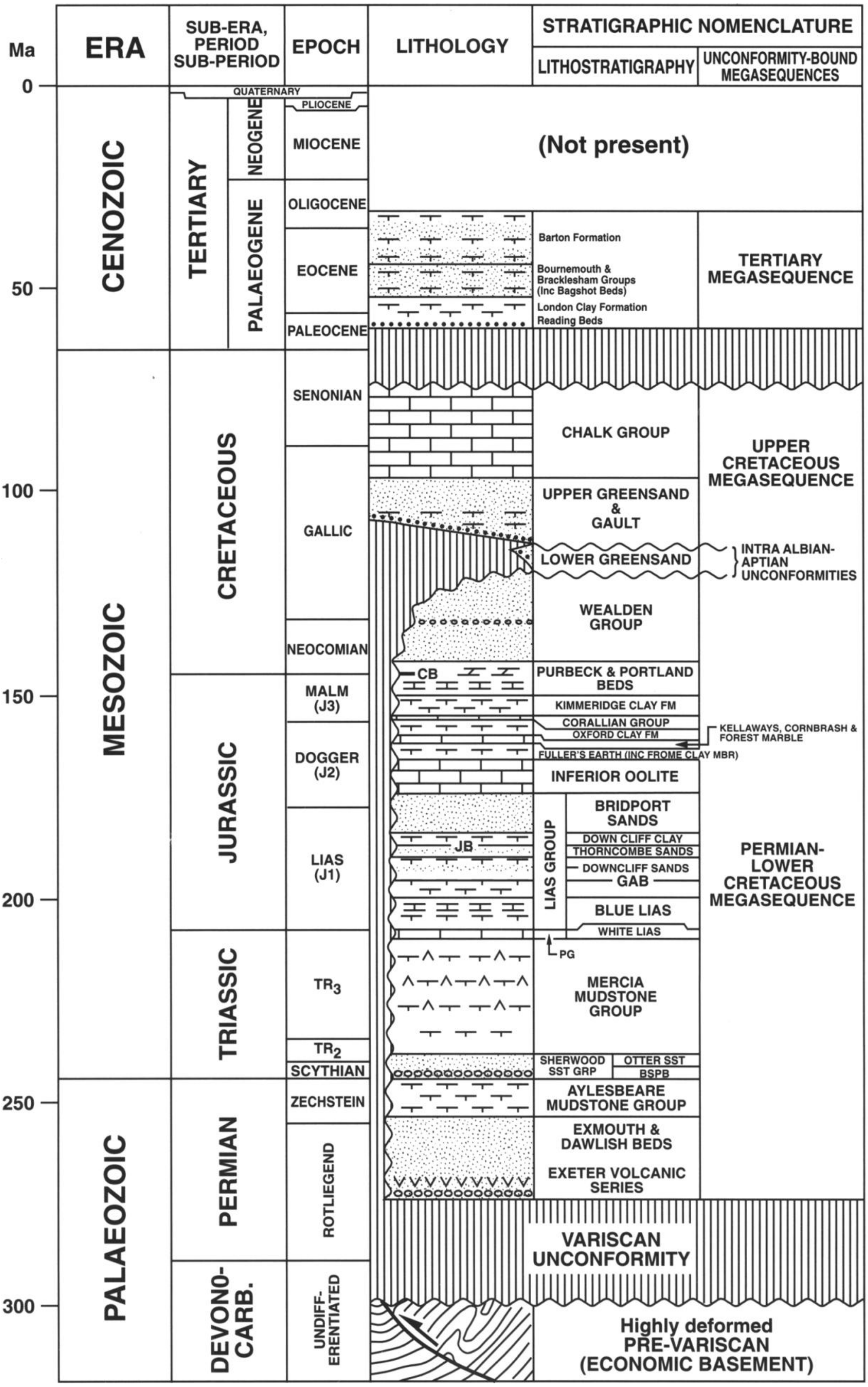
GEOLOGICAL CONTEXT

The Wessex Basin

The Wessex Basin represents a series of Mesozoic extensional grabens and northerly-dipping half-grabens in southern and south-eastern England. It developed as part of a wider series of early Mesozoic intracratonic rift basins throughout NW Europe that were associated with the break-up of Pangaea and the opening of the central Atlantic and Tethyan oceans (Underhill and Stoneley, 1998, Stoneley, 1982). Its pre-Permian basement is believed to consist of imbricated thrust sheets of deformed but only mildly metamorphosed Carboniferous to Devonian sedimentary rocks; presumably bearing some similarity to those exposed in the external Variscides of Devon and Cornwall (Sellwood and Scott, 1986). In common with many of these early Mesozoic basins, the Wessex Basin experienced alternate episodes of rapid subsidence through rifting and gentler subsidence due to thermal relaxation (Karner et al., 1987; Chadwick, 1986). It was also subjected to structural inversion during the Cenozoic (Blundell, 2002; Chadwick, 1993; Simpson et al., 1989; Lake and Karner, 1987), which featured substantial reversal on major basin margin and intrabasinal faults coupled with more widely distributed regional uplift between these structures. The Wessex Basin *sensu lato* is bounded to the southwest, west and north by Palaeozoic basement massifs, and to the south the Central Channel high separates it from the Channel Basin and the Paris Basin system. Its northeast and northwest boundaries are less clearly defined; in the former case it passes onto the Midland Platform (Hendry, 2002) and in the latter case it is obscured by the erosional limit of the Mesozoic strata.



Sedimentary depocentres and key structural elements of the Wessex Basin. From Underhill and Stoneley (1998)



A generalised stratigraphic column for the fill of the Wessex Basin. Note the Tertiary sediments are geographically limited to the inverted Hampshire Basin (former Hampshire-Dieppe arch). From Underhill and Stoneley (1998).

An overview of the pertinent literature quickly reveals that the geographical definition of “Wessex Basin” is contentious. Certain authors limit it to the areas of thick Triassic – Lower Jurassic rocks in Dorset, and define the Weald Basin of Hampshire – Sussex as a separate entity characterised by its thick Lower Cretaceous succession and more severe tectonic inversion. Others view the two as contiguous tectonic structures that share a common geodynamic origin. The broader view is adopted here, and four main depocentres are identified, as shown in the figure above. These are the Vale of Pewsey, Portland - Wight, South Dorset and Weald sub-basins. All are half grabens, with the exception of the narrow South Dorset graben (which is also known as the Winterborne Kingston trough). This field excursion will examine localities within and on the margin of the Portland-Wight sub-basin.

The component depocentres of the Wessex Basin are delimited by Mesozoic structural highs. The Portland – Wight and South Dorset sub-basins are separated by the South Dorset shelf, a narrow zone of relatively lower subsidence. The Portland-Wight and Weald sub-basins are separated by the important Hampshire-Dieppe high. The northern edge of this high is the Portsdown – Wardour fault zone. Its southern edge is defined by the Purbeck – Isle of Wight disturbance. This major tectonic lineament was particularly important as a control on intrabasinal stratigraphic development and displays varying structural styles along its length. These partly reflect a direct linkage to basement structures (more prevalent in the east) versus soling out within the Mesozoic succession (common in the west). The Hampshire – Dieppe high was inverted to a gentle down-warp at the end of the Cretaceous to become the focus of Tertiary sedimentation in southern England, bounded by monoclinal axes developed above the two peripheral fault zones.

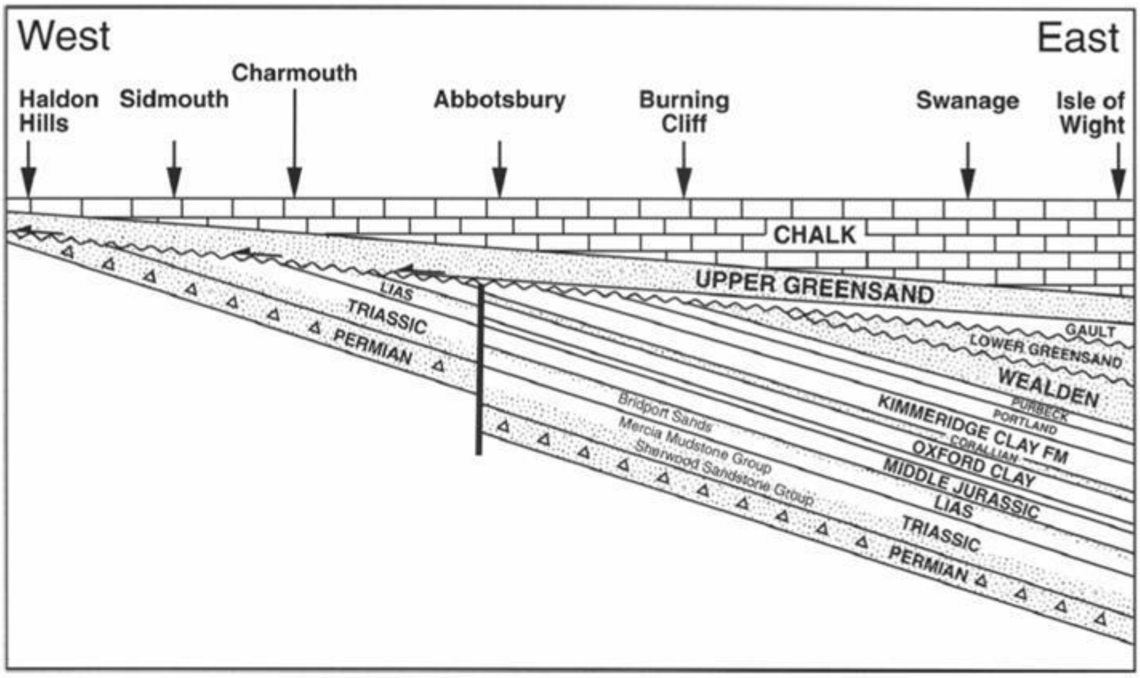
Tectonics and basin development

Devonian-Carboniferous rifting in southern England resulted in a passive margin on the southern edge of Laurentia with predominantly E-W oriented, southward-dipping normal faults. In the late Carboniferous the incipient collision of Armorica with Laurentia compressed this passive margin to form an orogenic belt and a foreland basin that extended from southwest Ireland through south Wales, southern England and into the Ardennes. Although the subsequent Variscan orogeny was accompanied by large scale NE-SW oriented strike slip tectonics, in southern England northward-directed thrust faulting was accompanied by NW-SE oriented strike-slip faulting with kilometre-scale sinistral offsets (Lake and Karner, 1987). These Variscan mid-crustal thrust and sinistral wrench faults were reactivated in an extensional NW-SE oriented regional stress field during the Permo – Triassic and became the major structures delimiting the Wessex Basin (Chadwick, 1986). Synchronous activity on the two fault systems compartmentalised the basin, hanging wall collapse on the former thrusts producing the discrete depocentres of quasi-rhomboidal shape typical of transtensional tectonic regimes. Broadly speaking, rifting and subsidence migrated eastwards in importance through time, from the west of the Vale of Pewsey and South Dorset sub-basins in the Permian to the Weald sub-basin by the early Jurassic (Lake and Karner, 1987).

Stratigraphic back-stripping analyses applied to boreholes in the Wessex Basin have revealed a gentle exponential subsidence typical of thermal relaxation, punctuated by rapid rift-related events that can be correlated within and between the sub-basins. The most important of these were in the late Triassic, early and late Jurassic, and early Cretaceous (Karner et al., 1987; Chadwick, 1986). Extension was largely taken up by reactivation of the Variscan E-W basement thrusts and their upward propagation through the accumulating sedimentary cover as growth faults. Syn-depositional movement on these significantly influenced north-south depositional thickness trends both regionally and locally (Underhill and Stoneley, 1998). Moreover, it led to some erosion of tilted footwall crests producing localised stratigraphic breaks, and the development of gentle rollover anticlines in hanging walls. These features were best developed where faults developed listric geometries owing to a Triassic salt décollement at depth (Butler, 1998; Chadwick, 1993, 1986). Episodes of overpressuring and fluid flow associated with the faulting are recorded in horizontal “beef” (fibrous calcite) veins in Liassic mudrocks (Stoneley, 1983;, Marshall, 1982) and from liquefaction structures in Toarcian carbonates adjacent to the Eypemouth Fault (Jenkyns and Senior, 1991).

Aggregated crustal extension during the Mesozoic was probably in the range 13 – 17% (Karner et al., 1987), but in the Aptian NW-SE extension is thought by some authors to have become subordinate to east-west oriented strike-slip (Lake and Karner, 1987). Subsequently through the middle - late Cretaceous the basin was tectonically quiescent with thermal relaxation dominating subsidence.

Unrelated to faulting within the Wessex Basin, regional uplift of southern England took place in the late Jurassic to early Cretaceous (McMahon and Turner, 1998; Underhill and Stoneley, 1998; Ruffell, 1992). A major Aptian unconformity was related to thermal doming associated with onset of sea floor spreading of the Bay of Biscay and northern central Atlantic. Associated easterly tilting led to progressive truncation of the preceding Mesozoic succession towards the west (Chadwick, 1985). The transgressive Albian Upper Greensand Formation directly overlies Upper Triassic strata in westernmost Dorset but in easternmost Dorset Valanginian to Aptian strata are preserved beneath it. Marginal immaturity of Lower Lias mudrocks at Charmouth suggests that 1200 – 1500m of overburden was removed.

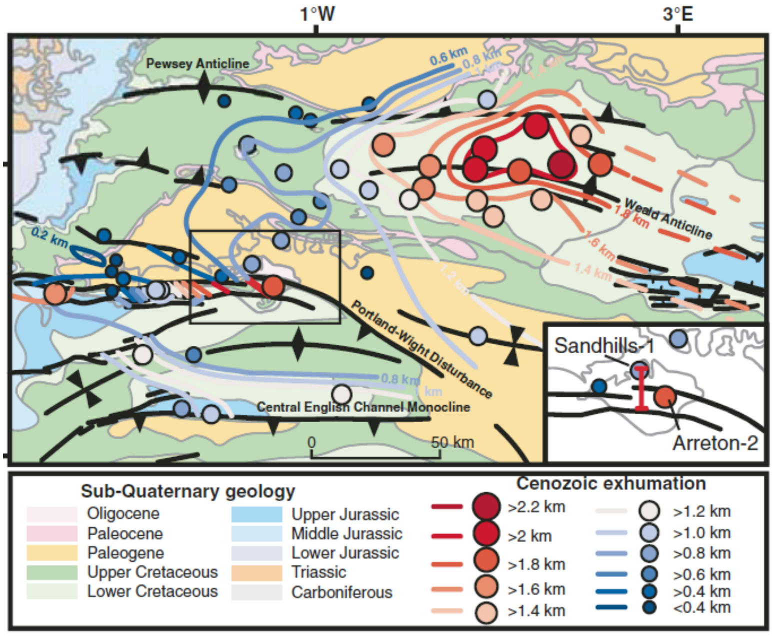


Schematic representation of the progressive westerly truncation of the tilted Permian – Jurassic succession beneath the Aptian unconformity. From Underhill and Stoneley (1998).

The preserved early Cretaceous strata in east Dorset contain evidence for a second unconformity of Berriasian age that dies out eastwards into the Weald Basin. Subsidence data from offshore boreholes in the Channel, Western Approaches and Celtic Sea basins also revealed substantial erosion, or at least reduced subsidence rates, at this level. It has been linked to an end-Jurassic uplift event centred on the Cornubian massif, pre-dating rifting in the Bay of Biscay and of uncertain (albeit probably thermal) origin (McMahon and Turner, 1998). Jurassic sediment eroded at these early Cretaceous unconformities was transported eastwards into the Weald Basin. Renewed subsidence coupled with eustatic rise permitted marine sedimentation to extend across the Wessex Basin in the Albian and the region remained submerged thereafter.

A major change in regional tectonics occurred towards the end of the Cretaceous. The extensional stress regime of the preceding Mesozoic was replaced by north-south to northwest-southeast oriented compression arising from intra-plate stresses associated with Alpine convergence and North Atlantic opening (Chadwick, 1993; Stoneley, 1982). The consequence was to structurally invert many of the Wessex Basin's extensional sub-basins. Inversion was not regionally synchronous but began in the Maastrichtian – Palaeocene and culminated in the Oligocene – Miocene. Gentle regional uplift due to bulk shortening of the poorly lithified basin fill was both preceded and followed by intense local uplift along reactivated normal fault segments, in particular those of Variscan parentage bounding the Central Channel high and constituting the Purbeck – Isle of Wight disturbance (Butler and Pullan, 1990). This change from tectonic shortening to widespread uplift has been attributed to a lull in convergence between Africa and Eurasia causing relaxation of the intra-plate stress field (Nielsen et al., 2007). Most of southern England was emergent at the end of the Cretaceous, with a major unconformity between marine Chalk Group and non-marine early Palaeogene strata. Karstic fissures developed in the Upper Cretaceous Chalk along the Purbeck – Isle of Wight disturbance are commonly filled by orange-brown Palaeocene terrigenous sediments.

The greatest amount of inversion took place in basins that accumulated the thickest late Jurassic and early Cretaceous successions, particularly the Weald sub-basin and the northern part of the Portland – Wight sub-basin, with about 2000m of strata removed as compared to about 500m elsewhere in the other sub-basins (Hillis et al., 2008; Bray et al., 1998; Simpson et al., 1989). The Weald sub-basin was transformed into a gentle regional westerly-plunging anticline. Many of the principal basin-bounding and intrabasinal faults underwent oblique reverse motion. Former rollovers in extensional faults were tightened into hanging wall anticlines and additional low angle reverse faulting resulted from the shortening discrepancy on reactivated major listric geometries (Chadwick, 1993).



Sub-Quaternary geological map of the Wessex Basin with estimates of Tertiary uplift from fission track, vitrinite reflectance and stratigraphic back stripping with decompaction. From Hillis et al. (2008).

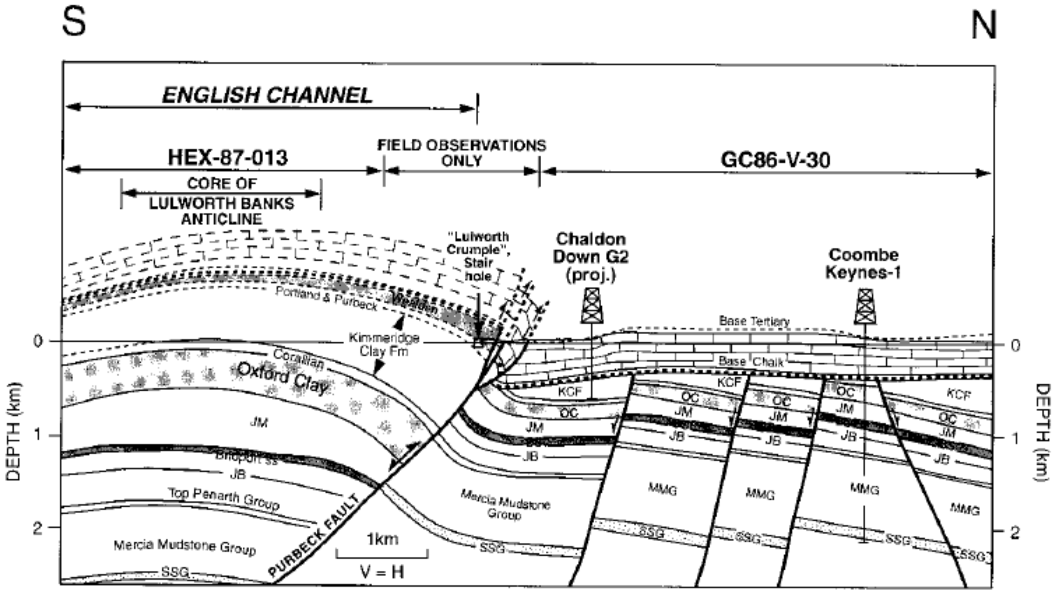
The inversion of former structural highs such as the Hampshire-Dieppe shelf into depocentres may have been caused by loading and down-warping of the footwall of major Mesozoic extensional faults associated with the change to regional transpression in the late Cretaceous (Lake and Karner, 1987). Alternatively, it may be related to the Palaeocene relaxation of intra-plate stress field as discussed by Nielsen et al., (2007).

The Purbeck – Isle of Wight disturbance

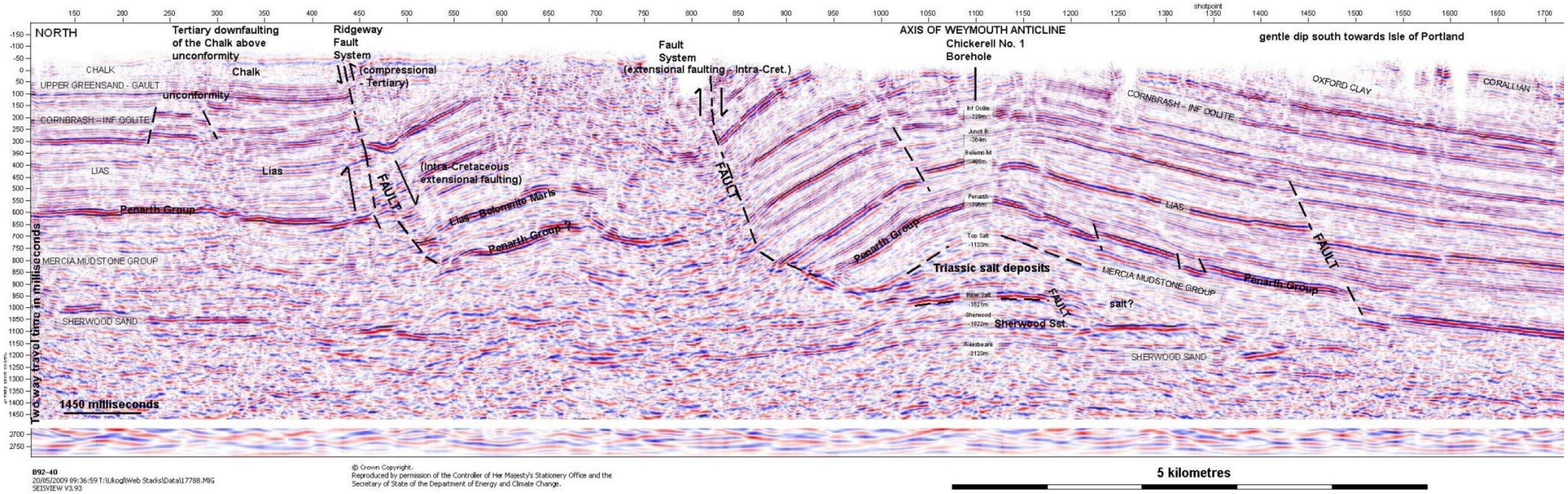
This tectonic lineament defines the northern and north-eastern margin of the Portland – Wight sub-basin and was a key influence on the geology now exposed along the Dorset coast. Together with its westerly extension (the Abbotsbury – Ridgeway fault zone) and its easterly continuation (the Wight – Bray fault zone) it consists of a series of gently scalloped, en-echelon fault segments. These are convex to the north and were downthrown to the south, with frequent uplift of footwall block crests, and northward-dipping strata in hanging walls where the faults had a strongly listric profile. Varying geometries of syn-depositional displacement across the faults are recognisable in facies and thickness variations of Jurassic strata, local footwall unconformities, and development of hanging-wall rollovers that were later steepened into anticlines during Tertiary inversion (e.g. Underhill, 2002; Selley and Stoneley, 1987).

Extensional faulting was still active in the early Cretaceous. Barremian alluvial sediments are confined to the hanging wall of the Purbeck – Isle of Wight faults, with easterly directed drainage suggesting confinement between the fault scarp and the rollover axes to the south. Intraformational conglomerates and abundant soft-sediment deformation (particularly well displayed on the Isle of Wight) attest to syn-depositional tectonism (Hendry et al., 2011). Meanwhile, Portlandian to Aptian strata are absent on the north side of the fault, where Albian deposits directly overlie Kimmeridgian or older strata. In the vicinity of Wytch Farm more than 1000m of Upper Jurassic and Lower Cretaceous strata are absent, compared to the succession preserved in the hanging wall of the fault zone, and north of the Abbotsbury – Ridgeway fault segment pre-Albian erosion extends down into the Oxfordian. Although thickness variations in early Cretaceous strata hamper precise determination of the net throw of these faults it is estimated as 2000m or more at Triassic level in east Dorset.

Following the rift-drift transition Cretaceous and Neogene strata were deposited horizontally across the fault zone, and these strata were buckled into northerly-verging tight monoclinal folds as the underlying faults were reversed. In the vicinity of Swanage the amplitude on the monocline is in excess of 1200m. Renewed normal faulting (intraformational flexural slip) and parasitic folding took place in the steep limb of these monoclines, depending upon the mechanical competence of the upturned strata under tectonic and gravitational compression (Underhill and Paterson, 1998). The classic example of this is displayed at Lulworth Cove.



North - south cross section based on seismic and field data across the Purbeck – Isle of Wight fault at Lulworth Cove. From Underhill and Paterson (1998).



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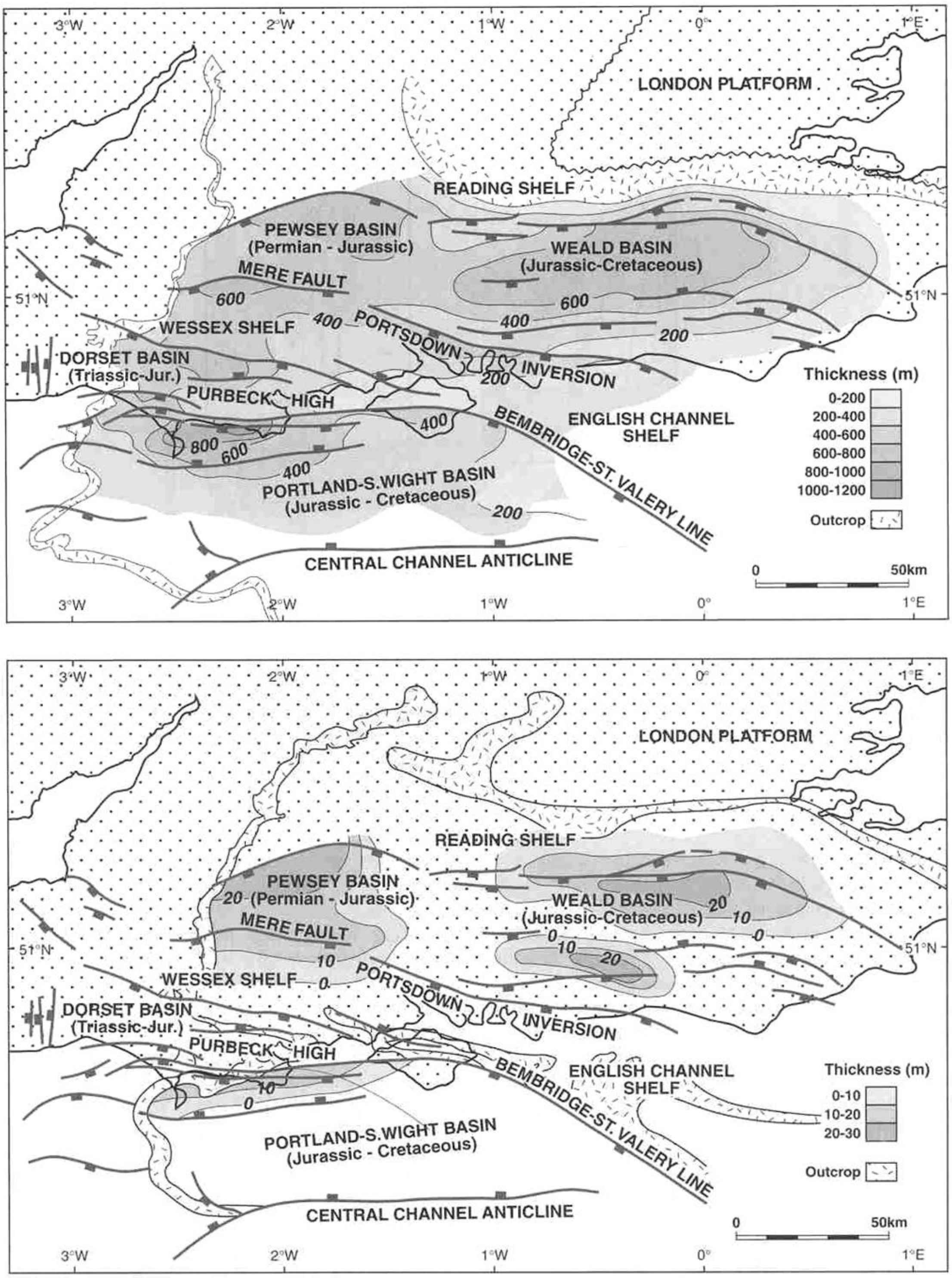
JPEG image generated directly from digital source data as supplied to UKOGL.
Designed to be viewed at horizontal scale of 1:25,000 and vertical scale of 10cm per second.
For futher details please visit the UKOGL website at www.ukogl.org.uk

An example seismic image on a section north-south across the Weymouth Anticline, courtesy of the UK Onshore Geophysical Library. Part of the original images has been cut away to reduce the size and some labelling has been added. Go to the website of UK Onshore Geological Library - Google "ukogl", or type in - "www.ukogl.org.uk" for full version and more information. See original for serious work.
(this version has been modified by Ian West, 2010 - interpretation of faults etc. shown here is provisional and not accurate)

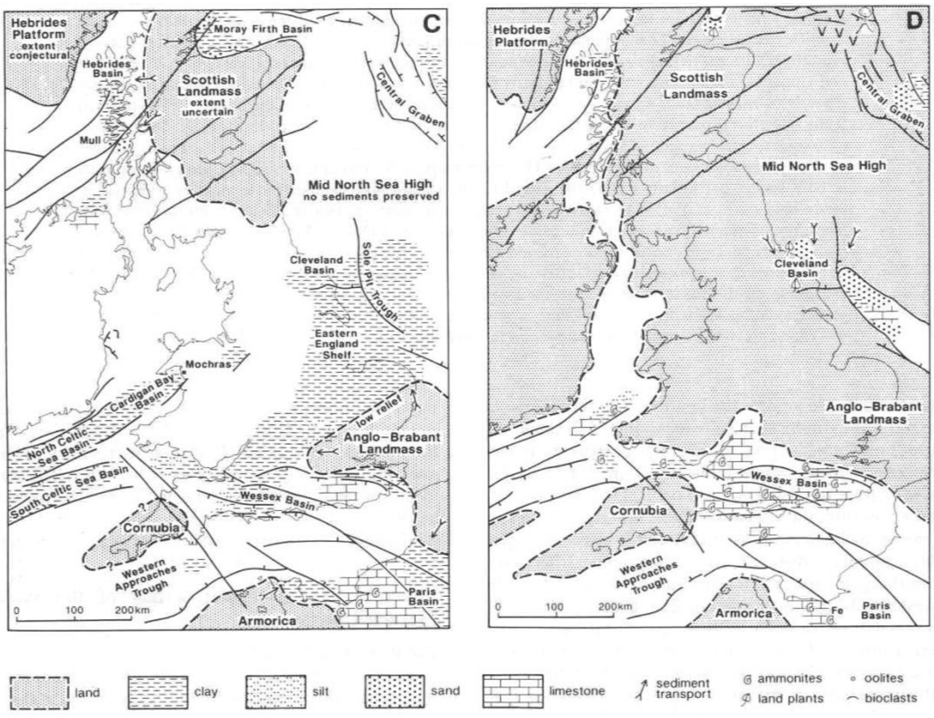


Isopach maps for the Lias Group (top) and Corallian Group (bottom) showing the basin-wide influence of extensional faulting on sediment accumulation. From Hawkes et al. (1998).

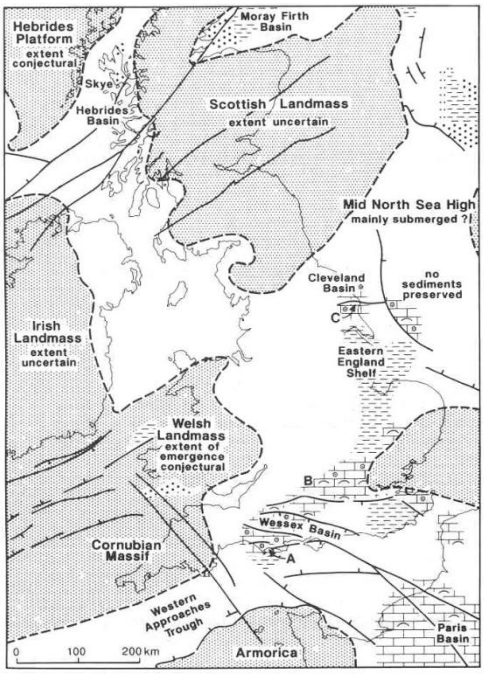
Jurassic palaeogeography and sedimentation

Sedimentation in the Wessex Basin was limited to the western sub-basins in the Permo-Triassic where intra-montane environments accumulated terrestrial dryland fluvial and subordinate aeolian deposits. Rhaetian (late Triassic) marine transgression from the south-west initiated paralic and then fully marine conditions eastwards across the basin. Latest Triassic deposits of the Penarth Group in west Dorset and Somerset are bivalve-rich black shales overlain by paler shales and thin microbialite-bearing and faunally-impoverished micritic limestones, and point to deposition in a series of very shallow and variably restricted brackish-marine lagoons. In contrast, by the middle part of the Early Jurassic fully marine conditions were established across much or all of the Wessex Basin. Offshore mudrocks and limestones hosted rich ammonite and bivalve faunas.

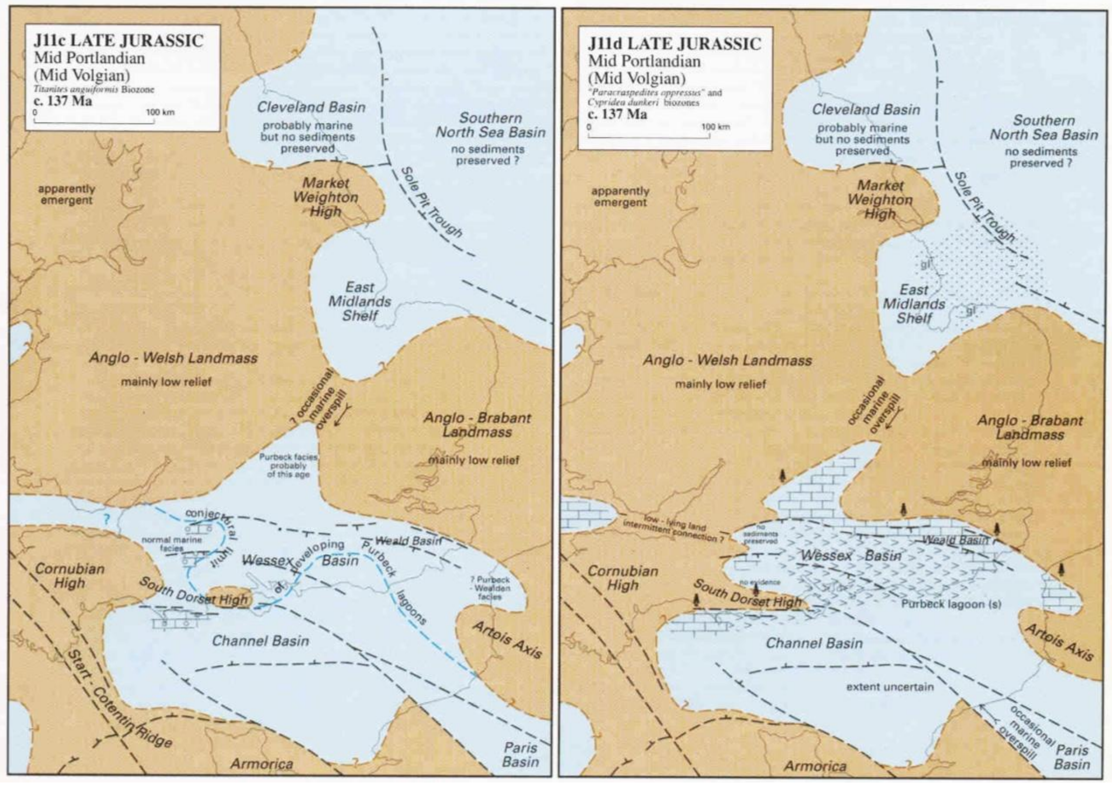
Although marine inundation of the Wessex Basin was initially from the southwest, by the Hettangian a marine connection was established to the Tethys Ocean via the Paris Basin to the east. Eustatic sea level rise and basin subsidence continued through the Jurassic, although Palaeozoic basement highs such at the London – Brabant and Cornubian massifs were never inundated. For much of the Jurassic Dorset therefore lay at the western end of a sub-tropical epeiric seaway connecting the opening Tethyan and Atlantic oceans (Callomon and Cope, 1995; Bradshaw et al., 1992). At a palaeolatitude of about 35°N, it occupied an area north of the main belt of Tethyan carbonate deposition but south of the siliciclastic-dominated Boreal environments. Faunal characteristics fluctuated between Tethyan and Boreal dominance in response to climate and sea level change, and sedimentation was of mixed carbonate – siliciclastic character. However, the adjacent basement massifs appear to have supplied little sand-grade sediment into the Wessex Basin. In the Portland – Wight sub-basin fine grained sandstones are present in the Pliensbachian - Toarcian and in the Oxfordian, but otherwise were apparently limited to the fringes of the Palaeozoic land masses. It follows that these were probably low-lying and well vegetated. For most of the Jurassic deposition in Dorset as elsewhere in the Wessex Basin was dominated by offshore clayey to silty muds with abundant calcareous fauna and early diagenetic carbonate cements. Proximity to land is suggested by the frequent presence of fossil wood, even in the offshore mudrock facies.



Jurassic palaeogeography in the early Pliensbachian (left) and late Bajocian (right). From Hesselbo and Jenkyns (2005).



Jurassic palaeogeography in the Mid Oxfordian. From Coe (1995)

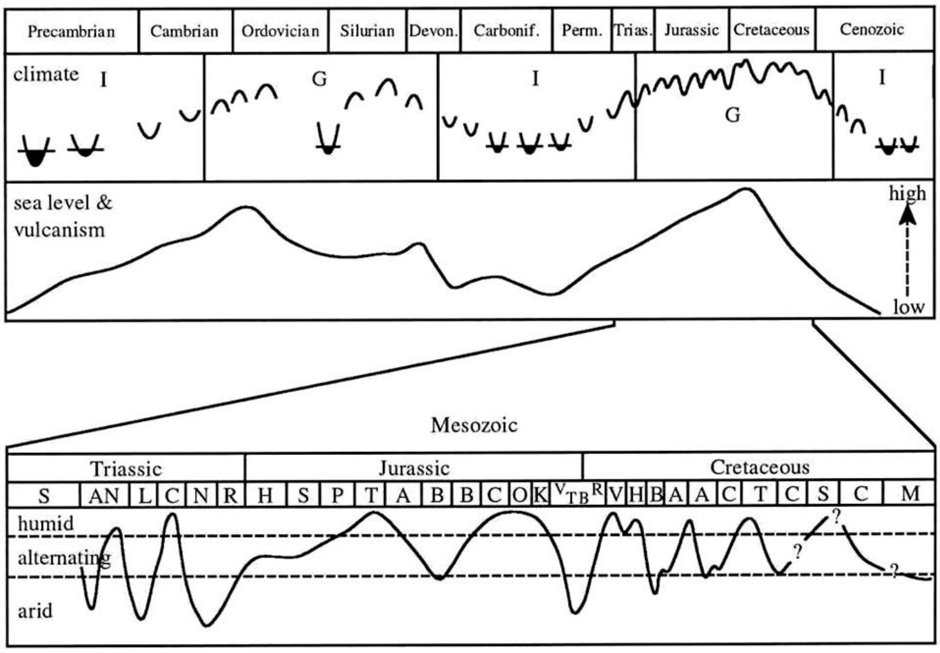


Jurassic palaeogeography in the Mid Tithonian. From Bradshaw et al. (1992)

Although some localised effects of faulting can be seen in the sedimentary record, there is a broad similarity of the preserved Jurassic depositional record throughout the Wessex Basin. The same is true of the Weald Basin to the east, although being closer to the London – Brabant Massif it tended to develop more extensive shallow marine carbonates and sandstones during the regressive episodes. However, these are now obscured beneath the thick Cretaceous cover and are known mostly from petroleum industry boreholes and seismic sections.

Three regressions punctuated the progressive Jurassic marine transgression and were highly significant for carbonate deposition. Regional up-warping caused by thermal doming in the “triple junction” area of the Central North Sea had a mild influence in the Wessex Basin. It is reflected locally in the deposition of calcareous shallow marine sandstones (Toarcian) and of highly condensed shallow marine limestones (Aalenian – Bajocian) on the South Dorset shelf. Of more significance was an episode of eustatic sea level fall coincident with renewed rifting and block faulting in the latest Jurassic. This is exemplified in a shallowing-upward carbonate ramp succession culminating in coastal lagoons, sabkhas and palaeosols (Tithonian - Berriasian). A third development of shallow marine carbonates and calcareous sandstones in the Oxfordian is tentatively ascribed to a minor episode of uplift on the London-Brabant massif.

Jurassic climate is inferred to have been predominantly warm and either humid or seasonally arid (Mediterranean-style) (Frakes et al., 1993). There are few published isotopic palaeotemperature analyses from the Dorset coast, although much data probably resides in PhD theses. Price and Page (2008) obtained temperatures of 9-14°C for Oxfordian benthic bivalves, 11-16°C for belemnites and 13-20°C for ammonites. Price and Teece (2010) calculated values of more than 25°C from Bathonian brachiopods. Similarly warm temperatures have been obtained from well preserved Jurassic marine fossils elsewhere in the UK. Global climate perturbations have been suggested for the Toarcian and Callovian, but there is no evidence that they had a significant temperature influence at the low latitude that Dorset occupied in the Jurassic. Spectral gamma-ray and X-ray diffraction data from Jurassic mudrocks confirms increasing aridity in the latest Jurassic Ruffell et al. (2002), which is also supported by lagoonal evaporites developed in the lowest part of the Late Tithonian Lulworth Formation (West, 1975). These were either thinly developed or have been diagenetically removed in Dorset, but thick gypsum / anhydrite deposits of occur in the subsurface Weald Basin. It is unlikely that the climate became permanently arid, because the coniferous trees that are known to have colonised low-lying areas between the lagoons would not have been tolerant of such conditions (Francis, 1984).



Humid and arid phases of Mesozoic climate based on clay-mineral data in conjunction with other geochemical and sedimentary proxies. From Ruffell et al. (2002).

Lithostratigraphy, biostratigraphy and sequence stratigraphy

The stratigraphic and sedimentological record of the Wessex Basin represents the convolution of its polyphase subsidence history with the changes in global sea level. Since Arkell's observations in 1947 the succession has been recognised as cyclical in nature, with shallowing-upward sequences of offshore mudrock – inshore silt/sandstone – near shore carbonates arising from the balance of tectonic and eustatic influences. In simplistic terms rifting events tend to correspond to clay-dominated transgressive facies, whereas sandstone and limestone were produced during regressions accompanying the return to gradual thermal subsidence and the uplift events described above (Karner et al., 1987). Thickness variations in the non-marine Lower Cretaceous were controlled much more directly by syn-sedimentary faulting and siliciclastic sediment supply from uplifted basement massifs to the north and west. Various attempts have been made to establish a framework of regionally-correlatable sea level changes for the British Jurassic, of which the most recent is Hesselbo (2008), who also reviews and assesses previous work.

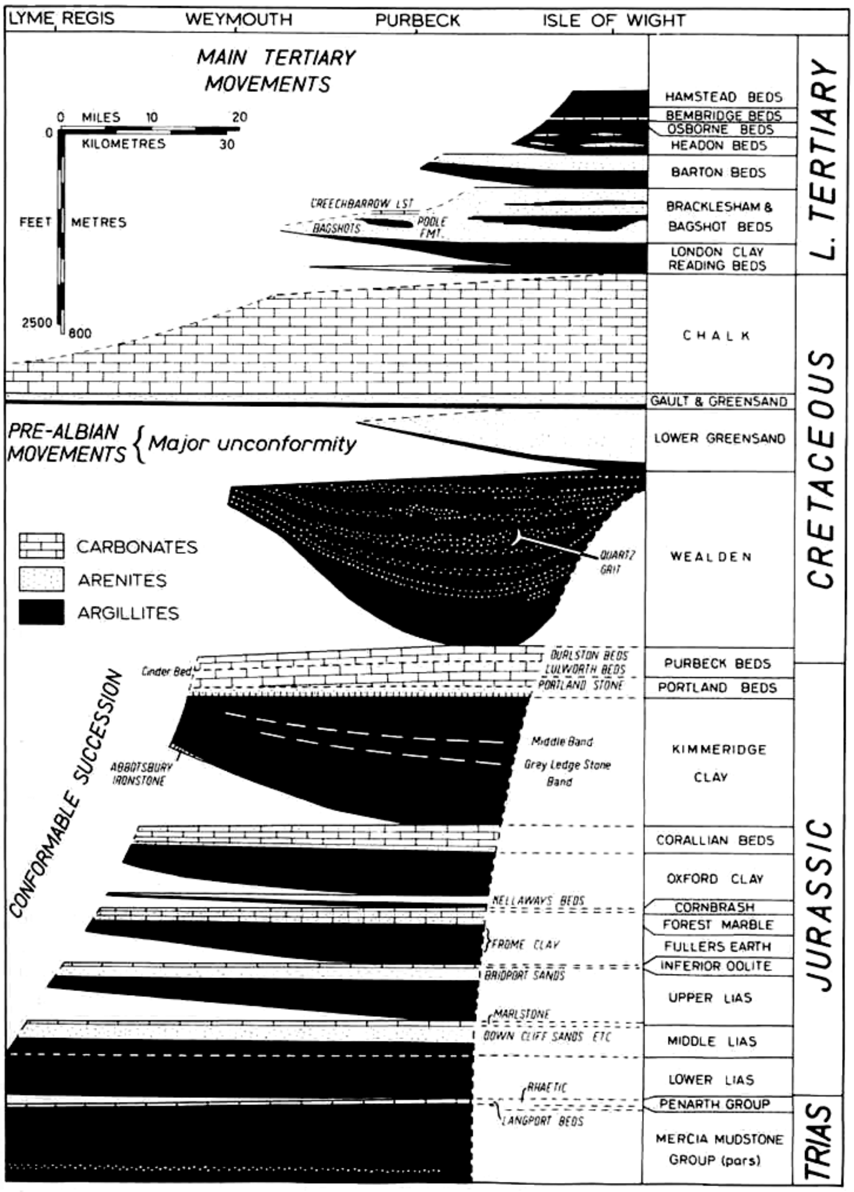
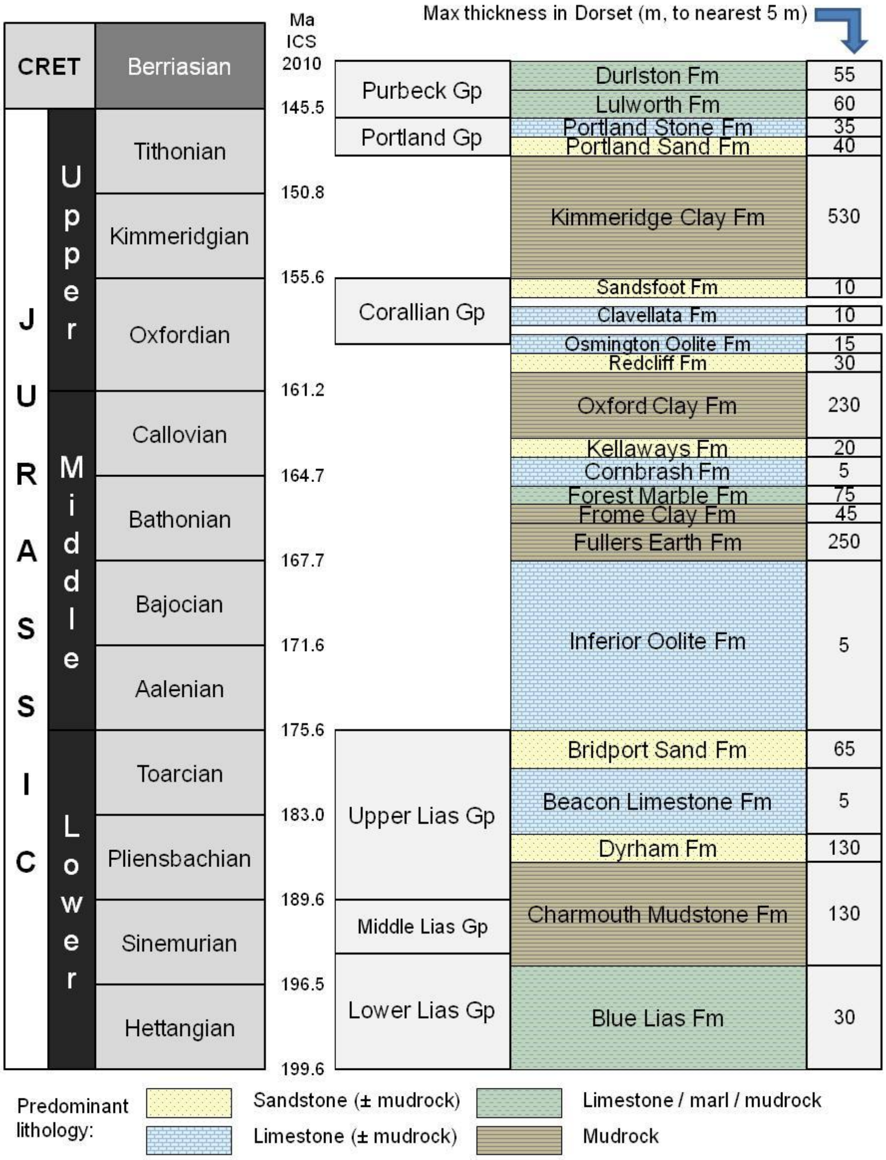


Diagram emphasizing regional thickness changes and broad cyclicity in Jurassic lithologies within the coastal exposures of the Wessex Basin. From House (1993).

Dating of the Jurassic marine strata was originally based on ammonite zonation and has been frequently updated to account for a growing appreciation of ammonite provincialism that impacts the location of Dorset in between the Boreal and Tethyan realms (see references in Callomon and Cope, 1995). The biostratigraphy has subsequently been refined micropalaeontologically using ostracods, foraminifers and dinocysts (Ainsworth et al., 1998a). In contrast, lithostratigraphic nomenclature of the British Jurassic remains peppered with colloquial, historical and local variations, many dating back as far as William Smith (1769-1839). Formal revisions have been proposed from time to time (e.g. Cope et al., 1980a, b), and the most currently accepted version is presented in the Geological Conservation Review (GCR) Series publications of the Joint Nature Conservancy Council; Simms et al. (2004) for the Lower Jurassic, Cox and Sumbler (2002) for the Middle Jurassic, and Wright and Cox (2001) for the Oxfordian - Kimmeridgian. A fourth volume will cover the Portlandian and lowermost Cretaceous (Allen et al., in prep).

The detailed lithostratigraphy and biostratigraphy of the Dorset Jurassic is presented in Callomon and Cope (1995), Hesselbo and Jenkyns (1995) and Coe (1995) for exposed onshore sections and is extended by Ainsworth et al. (1998b) for the subsurface both onshore and offshore. The latter includes wireline log characteristics and regional thickness variations. Updated biostratigraphies (to ammonite sub-zonal level) are available in the GCR volumes cited above. The Figure and Table below give an overview of the lithological and stratigraphic succession.



Formation (Member)	Age	Sedimentology
Durlston	Berriasian	**Peveril Point Mb**: The base of this member is a massive, pinkish-brown bivalve-fragment biosparite. Overlying it are brownish grey shales (sometimes gypsiferous) with interbedded biomicritic limestones. Many of these are rich in low diversity faunas of freshwater bivalves and/or gastropods and ostracods. However, some of these also contain abundant diagenetic green clay (glauconite?) and pyrite. **Stair Hole Mb**: A prominent oyster-rich pale grey biomicrite near the base ("Cinder Bed") is succeeded by interbedded barren to shelly micritic limestones and variably calcareous mudrocks. The limestones tend to display low diversity mollusc and/or ostracod faunas characteristic of brackish environments. Charophytes are locally present and vertebrate remains have been recovered. The top of the member is dominated by gypsiferous clays. Fibrous calcite veins are locally present (possibly replacing gypsum).
Lulworth	Upper Tithonian to Lower Berriasian	**Worbarrow Tout Mb**: Pale brown cross laminated sandy limestones passing up into white micrites interbedded with grey-brown mudrocks. Nodular gypsum (or secondary celestite) are locally present, as is stromatolitic lamination. The fauna is sporadically developed and mostly limited to low diversity bivalve and ostracod assemblages. However towards the top of the member cherty biomicrites contain freshwater bivalves and gastropods. **Ridgeway Mb**: Calcareous mudrocks and micritic limestones, locally with ostracods and sporadically rich in insect remains **Mupe Mb**: Laterally variable mixtures of white to beige marly and micritic limestones, brown argillaceous and pebbly palaeosols ("dirt beds"), gypsiferous clays, stromatolites, thrombolites ("caps"), and brecciated laminated pelmicrites and pelsparites ("broken beds") sometimes with halite pseudomorphs. Skeletal fauna is rare and mostly represented by ostracod-rich packstones. Fossil tree trunks and branches, frequently silicified, have been found in this member. They are intimately associated with microbialite encrustations.
Portland Stone	Upper Tithonian	**Portland Freestone Mb**: Cross bedded to bioturbated white oolitic grainstones. Very limited macrofauna apart from rare bivalve-encrusted hardgrounds, poorly preserved ammonites, and a laterally impersistent bivalve-gastropod rich shell bed at the top of the formation. Sporadic oyster – algal (*Solenopora*) bioherms also occur at this level. A notable feature of the formation is its abnormally high porosity, reflecting pervasive aragonite dissolution but relatively minor calcite cementation. A shelly micrite is locally present in the middle of the member. **Cherty Beds Mb**: Pale grey micritic, spiclular and peloidal limestones with extensive burrowing and prominent stratabound cherts. Size and shape of the chert nodules varies bed to bed, most are nodular but some have a more tabular habit. Ammonites and bivalves are present throughout, the latter frequently concentrated into shell beds. **Basal Shell Bed Mb**: Pale grey shelly micritic limestone with a diverse fauna of bivalves, gastropods, serpulids, echinoids and bryozoans **Portland Clay Mb**: Bioturbated fine grained dolomites similar to those below.
Portland Sand	Upper Tithonian	**West Weare Sandstone Mb**: Highly bioturbated, silty, finely crystalline grey dolomites and nodular black dedolomites. Rare ammonites and bivalves. ***Exogyra* bed Mb:** Argillaceous, silty limestone very rich in bivalves, serpulids and sponge spicules. Cementation sometimes defines concretions. **Upper Black Nore Beds Mb**: Variably calcareous and dolomitic, bioturbated argillaceous sandstones and siltstones.

Kimmeridge	Kimmeridgian to Lower Tithonian	Upper Kimmeridge Clay: Dark grey pyritic shales, frequent oil shales and subordinate ferroan dolomite-cemented beds. Common cyclical succession of brownish grey oil shale – dark grey mudrock – pale grey calcareous mudrock. Towards the top of the unit the bituminous shales become less frequent and the clays become siltier and more calcareous overall. Ammonites, bivalves and forams are common throughout and abundant in certain beds. Lower Kimmeridge Clay: Bioturbated shelly clays with calcareous concretions and thin siltstones, passing up into dark grey pyritic mudrocks with subordinate paler grey calcareous mudrocks, coccolith limestones and laminated bituminous shales. Ammonites are abundant (mostly flattened), and oysters or brachiopods are concentrated in sporadic shell beds. At the base there is common cyclicity of siltstone – dark grey mudrock – pale grey calcareous mudrock, capped by an erosion surface.
Sandsfoot	Upper Oxfordian	**Osmington Mills Ironstone**: Condensed brownish-grey argillaceous limestones with ferruginous ooids, phosphate nodules, bored and encrusted surfaces. Contains abundant well preserved bivalves, gastropods and serpulids as well as cm-sized, bored fragments of coral. **Ringstead Clay Mb**: Pale grey to reddish bioturbated calcareous clay with impoverished bivalve fauna but some ammonites and abundant forams and ostracods. **Sandsfoot Grit Mb**: Ferruginous reddish-brown sandstones, variably argillaceous or calcite cemented, locally oolitic and commonly bioturbated. Several lags of phosphatic nodules or bivalve shells are present suggesting condensed deposition. The member generally coarsens up from fine to medium grained.
Clavellata	Upper Oxfordian	**Sandsfoot Clay Mb**: Calcareous silty clays with thin lenses of sandstone and a sparse, low diversity bivalve fauna. **Clavellata Mb**: Consists of 4 sub-members. From base: (i) Sandy Block: Sandy, sparsely oolitic, bioturbated, micritic limestone with clay partings and frequent intact and fragmented bivalves. (ii) Chief Shell Beds: Argillaceous oolitic limestone crowded with intact *Myophorella clavellata* bivalves. Sideritic towards top. (iii) Clay Band: Dark grey-brown mudrock with sparse ooids. (iv) Red Beds: Alternations of argillaceous shelly oolite and micritic, sideritic limestones with disseminated shell fragments and some ooids.
Osmington Oolite	Middle Oxfordian	**Nodular Rubble Mb**: Nodular (oo)biomicrites with sponge spicules. Marly seams separate the nodules, suggesting some diagenetic enhancement of an originally burrowed fabric. Ammonites and bivalves are present. **Shortlake Mb**: Cross bedded beige to pale grey oosparites, passing upwards into bioturbated oobiomicrites and marls with sporadic ammonites that are interbedded with ooid-bearing dark brown clays. One bed near the transition is marked by unusual concretions with dilatational fractures inside burrows. **Upton Mb**: Thin, bioturbated, oolitic, bioclastic and argillaceous grey limestones separated by mudrocks. One bed is a microbial oncolite. The limestones are highly bioturbated with a diverse ichnofabric.
Redcliff	Lower to Middle Oxfordian	**Bencliff Grit Mb**: Fine grained sandstone with spectacular swaley cross stratification and limited bioturbation other than in sporadic heterolithic beds which also contain mud-draped wave ripples. Frequent m-scale ellipsoidal calcite concretions with poikilotopic cement. **Nothe Clay Mb**: Grey calcareous mudstone with interbedded ferruginous (sideritic or berthierine-bearing), oolitic or bivalve-bearing micritic limestones. **Preston Grit Mb**: Pale grey sandy limestone passing up into bioturbated argillaceous sandstone with relic cross lamination, minor ooids and pebbles. Contains ammonites, oysters and serpulids in upper part. **Nothe Grit Mb**: Bioturbated fine sandstone with local carbonate

		cementation. Contains infrequent ammonites, oysters and serpulids.
Oxford Clay	Upper Callovian to Lower Oxfordian	**Weymouth Mb**: Bioturbated marly dark grey clays with sparse ammonites but a rich molluscan benthos and minor siderite nodules. **Stewartby Mb**: Calcareous bioturbated clays with sparse ammonites and bivalves, local beds of large calcareous concretions. Poorly exposed in Dorset. **Peterborough Mb**: Dark grey, pyritic, organic-rich laminated mudrocks with abundant flattened aragonitic ammonites and nuculacean bivalves.
Kellaways	Lower Callovian	**Kellaways Clay Mb**: Poorly exposed grey-brown mudrocks with calcareous concretions. **Kellaways Sand Mb**: Poorly exposed calcareous sandstones with abundant ammonites.
Cornbrash	Upper Bathonian to Lower Callovian	Bioturbated, rubbly to nodular, greyish-brown biomicrites and intervening marls. Rich benthic mollusc and echinoid fauna, plus common ammonites. Becomes more sandy and ferruginous upwards.
Forest Marble	Upper Bathonian	Intercalated pale brown shell-fragment limestones, marls and darker brown bivalve-rich clays. Limestones display local cross bedding and scour surfaces, and may be oolitic.
Frome Clay	Upper Bathonian	Blue-grey marls and grey clays with sporadic oyster, bivalve and brachiopod-rich beds. Ammonites are rare other than in the basal shell bed.
Fullers Earth	Lower – Middle Bathonian	Blue-grey marly clays with minor oyster-rich beds. This Formation is largely cut out by faulting on the Dorset coast.
Inferior Oolite	Lower Aalenian to Lower Bathonian	Highly condensed succession of pale grey to reddish brown biomicrites and oobiosparites. Each bed is distinctive in terms of its fabric, benthic fauna (ammonites and belemnites are common throughout) and bioturbation. Stromatolitic crusts, borings and erosion surfaces occur on the tops of some beds, and some burrow fill lithologies are not represented in the overlying strata. Each bed has its own ammonite assemblage and is separated by a substantial hiatus. The formation spans 14 ammonite zones in about 5.5 m but thickens considerably to the north and northwest.
Bridport Sand	Upper Toarcian to Lower Aalenian	Yellow-orange, highly bioturbated fine sandstones with regularly spaced calcite-cemented beds and stratabound nodules. These become closer together towards the top of the Formation where grain size also fines to silt. Poorly fossiliferous at outcrop although belemnites and poorly preserved ammonites are locally present and shell fragments are abundant in thin sections of the calcareous beds. hummocky cross stratification is locally visible and dune- scale bed forms (up to 3m amplitude by up to 20m wavelength) are preserved near the base of the sandstone. The unit is regionally diachronous (becoming older to the NW) and thickens to the west albeit increasingly truncated by the Aptian unconformity. **Down Cliff Clay Mb**: Brown silty clays coarsening up into silty sandstones.
Beacon Limestone	Upper Pliensbachian to Lower Toarcian	The Beacon Limestone formation is highly condensed overall (≈ 7 ammonite zones) but thickens from about 4m to < 1m over 50m from west to east as it approaches the Eypemouth fault, suggesting that this structure was active during deposition. **Eype Mouth Limestone Mb**: Pink to beige biomicrites with stromatolitic crusts, planar erosion surfaces, intraclast pebbles and horizontal sediment ± spar-filled cavity systems. Ammonites in the cavities are younger than those in the host rock. **Marlstone Rock Mb**: Pinkish brown ferruginous conglomeratic, oolitic (berthierine, goethite ooids) and bioclastic limestone with abundant ammonites, bivalves, brachiopods, gastropods. Planar erosion surface at top.
Dyrham	Upper Pliensbachian	**Thorncombe Sands Mb**: Bioturbated yellowish sandstones, locally preserved hummocky cross stratification intercalated with burrowed intervals, stratabound calcareous concretions. Rich ammonite and bivalve

		fauna. Erosion surface at top. **Down Cliff Sands Mb**: Siltstones and fine sandstones with lenticular zones of calcite cementation. Sand content increases upwards. The fauna is dominated by bivalves and ophiuroids. Overlain by ammonite-bearing sandy limestone with some evidence for syn-depositional reworking (“Margaritatus stone”). **Eype Clay Mb**: Base consists of three ammonite-bearing fine sandstone beds with planar and ripple lamination, separated by mudrocks (“Three Tiers”). This is succeeded by pale blue-grey micaceous silty mudrocks and shales which are poorly fossiliferous other than in localised bands of ammonite-bearing calcareous nodules. Overlain by calcareous sandstones with planar, ripple or hummocky cross lamination. Certain beds within these have abundant bivalves, brachiopods, gastropods (“Eype nodule bed”, “Day’s Shell Bed”) and ophiuroids (“Starfish Bed”). Preservation of the latter may reflect rapid sedimentation reducing the impact of bioturbation.
Charmouth Mudstone	Lower Sinemurian to Lower Pliensbachian	**Green Ammonite Mudstone Mb**: Dark blue-grey mudrocks with scattered calcareous nodules and more persistent ferruginous limestone beds. Rich ammonite fauna, especially in nodules, plus belemnites, crinoids, bivalves and gastropods. Dark green pyritic mudrock at top of member. **Belemnite Marls Mb**: Alternating blue-grey mudrocks and pale grey marls with prominently bioturbated contacts. Possible Milankovitch cycles; mudrocks are relatively enriched in organic carbon and marls contain more finely comminuted bioclastic debris. Rich belemnite fauna throughout, with subordinate echinoderm and epifaunal bivalve content concentrated in the lowermost (“Hummocky”) and uppermost (“Belemnite Stone”) beds. Ammonites are present throughout but very poorly preserved. **Stonebarrow Pyritic Mb**: Dark grey pyritic mudstones. Rich ammonite fauna, but low diversity byssate and free-swimming bivalve fauna. Pyritised internal molds of ammonites but only one calcareous cemented bed (“Watch ammonite stone”), which also has higher benthic diversity. **Black Ven Marls Mb**: Blue-black mudrocks and shales with local calcareous and pyritic nodules. Locally bioturbated, but organic-rich and laminated in the middle part of the member. Rich ammonite fauna, especially in nodules. Bivalves and brachiopods are present in the bioturbated facies only. Insect fossils, pseudopelagic crinoids, exquisitely-preserved ammonites, and vertebrates with some soft tissue preservation are preserved in certain nodule bands (“Flatstones”, “*Pentacrinite* beds”, “*Stellare* nodules”, “Topstones”). A hiatus with some erosion (≈ 3 ammonite zones missing) is present near the top of the member, locally marked by bored and encrusted concretions (“Coinstones”). **Shales With Beef Mb**: Blue-grey bioturbated marls overlain by brown organic-rich paper shales. Contains bedding-parallel fibrous calcite veins and stratabound calcareous nodules. Rich ammonite fauna in nodules (e.g. “*Birchi* nodules”), otherwise poorly preserved. Diverse bivalve and brachiopod fauna at the base of the member but diminishes upwards and no benthos in the laminated facies.
Blue Lias	Hettangian to Lower Sinemurian	Repetitive dm-thick limestone – marls – bituminous shale cycles. Diagenetic enhancement of a primary (climatic) cyclicity of possible Milankovitch periodicity. Rich ammonite, bivalve and crinoids fauna, rare reptile remains. Frequent bioturbation between limestone and marl beds. Many of the thicker limestone beds have colloquial (quarrymen’s) names.

Lithological summary of the Jurassic succession exposed on the Dorset Coast

The combination of multiple controlling factors and a paucity of palaeo-coastal deposits hinder the application of a detailed sequence stratigraphic framework to the Jurassic strata on the Dorset coast, despite good biostratigraphical resolution and a nearly-complete record (only the Middle Bathonian is completely unexposed, owing to faulting). In practice, a relative sea level history has been proposed for the Hettangian – Bajocian by correlation to the relatively more proximal facies in the Cleveland Basin of NE England (Hesselbo and Jenkyns, 1995), and candidate sequence boundaries have been proposed for the Toarcian (Morris et al., 2006), Aalenian – Bajocian (Rioult et al., 1991), Oxfordian (Coe, 1995, again in comparison with the Cleveland Basin) and for the Portlandian (Coe, 1996). In addition, Cole and Harding (1998) adopted a genetic stratigraphic sequence approach for the Sinemurian - Pliensbachian, using candidate maximum flooding surfaces to package the sediments. However, this has not been applied to other parts of the succession. More details are provided in the context of the field localities (see below).

Petroleum geology

Source rocks

The Wessex Basin is the UK's largest onshore petroliferous basin, and although reserves in the Portland – Wight sub-basin are heavily concentrated in one field (Wytch Farm, the largest onshore field in Europe) they are more widely dispersed between several fields in the Weald sub-basin. In all cases the source rocks are laminated organic-rich intervals in lower Liassic mudrocks, which contain oil-prone type II kerogen. Up to 7.5% TOC has been measured from these at outcrop although values in the subsurface are more typically 1 or 2%, and they probably reach ≥ 100 m thickness in the subsurface. As well as being typically dark, laminated, pyritic and impoverished in benthic fauna, these source intervals are detectable by elevated U contents on spectral gamma ray logs (Bessa and Hesselbo, 1997, Parkinson, 1996). These source rocks were buried into the oil window in deeply-subsiding parts of the basin, such as south of the Purbeck – Isle of Wight disturbance, in the South Dorset sub-basin and in the centre of the Weald sub-basin. Burial history modelling suggests that the Liassic source rocks entered the oil window in the early Cretaceous with peak generation in the middle to late Cretaceous (Underhill and Stoneley, 1998; Butler and Pullan, 1990). Stoneley (1982) also reported a surface gas seep from Portlandian limestones exposed on the sea floor south of Swanage, suggesting that burial was sufficient in this area for the Liassic mudrocks to enter the gas window. The same was probably true in the deepest part of the Weald sub-basin (Butler and Pullan, 1990). Early Cretaceous uplift may have terminated maturation in west Dorset, but it probably continued in deeply buried parts of the Portland – Wight sub-basin and the Weald sub-basin until early Tertiary inversion lifted the source rocks back out of the oil window.

The Kimmeridge Clay Formation is the principal source rock for the North Sea oil and gas fields, and its type section is a Kimmeridge Bay on the Dorset coast where some laminated m-thick bituminous shales reach a TOC of 70%. These readily produce oil when heated in a test tube and have historically been known to spontaneously combust (e.g. at “Burning Cliff” near Kimmeridge Bay). The TOC values more typically range up to 20.5% in the laminated non-bituminous mudrocks. However, the Kimmeridge Clay remained immature to marginally immature for oil generation throughout the Wessex Basin, except possibly in the deepest part of the Weald sub-basin (Scotchman, 1991). There is also modest source potential in some Lower Oxford Clay mudrocks (TOC of up to 12.4%), although these were only locally buried enough for oil generation and appear to contribute little to the known accumulations. Other Jurassic mudrocks in the Dorset region were deposited in oxygenated conditions, contained a rich benthic fauna and infauna, and preserve low contents of mostly derived type III kerogen.

Reservoirs

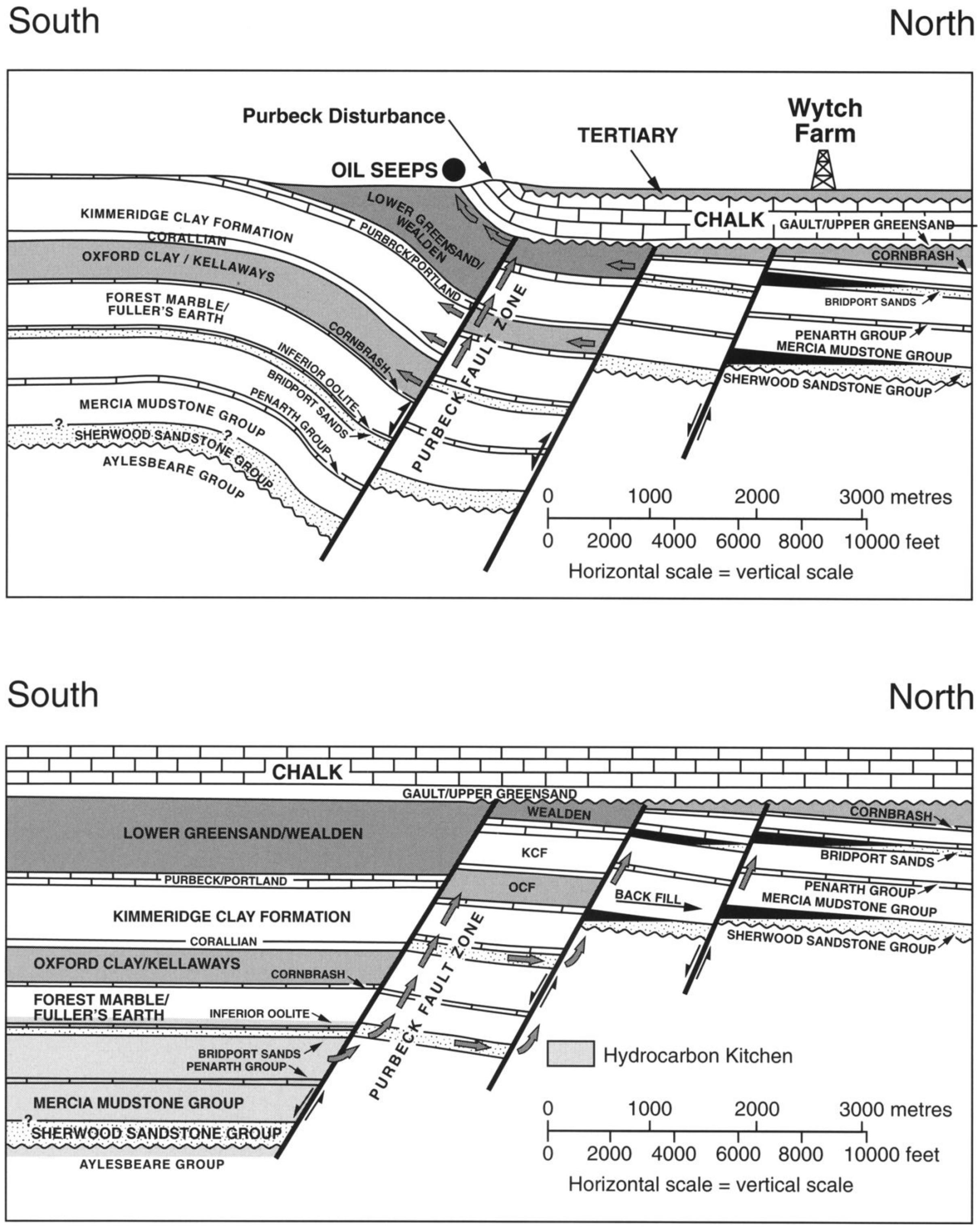
Various sandstone and grainy limestone units within the Triassic - Cretaceous of the Wessex Basin are potential reservoirs. Most are covered by mudrocks that would form a good seal, but in practice few of these candidate reservoirs are thick enough or porous enough to be significant. In the Portland – Wight sub-basin 95% of recoverable reserves are hosted in the Wytch Farm oil field, which is situated below Poole Harbour. The dominant reservoir consists of high net:gross braided fluvial sandstones and subordinate aeolian sandstones of the Lower Triassic Sherwood Sandstone Formation (Mc Kie et al, 1998; Bowman et al., 1993). These have porosities up to 29% and permeabilities up to 7D, and exhibit some fault-related compartmentalisation. They are effectively sealed by thick mudrocks and salts of the Upper Triassic Mercia Mudstone Group. There are subordinate reservoirs in the Toarcian shallow marine Bridport Sandstone Formation, which is overlain by > 200m of bentonitic mudrocks of the Bathonian Fullers Earth Formation. These sandstones have porosities of up to 32% and permeabilities of up to 800 mD, but are vertically compartmentalised by closely spaced and laterally extensive calcite-cemented beds. A third minor reservoir at Wytch Farm is located in a fractured oyster-reef in the lower part of the Bathonian Frome Clay Formation. The main reservoir extends eastwards beneath Poole Harbour and is exploited using extended reach horizontal drilling.

Oxfordian sandstones of the Bencliff Grit Formation are oil-impregnated at outcrop at Osmington Mills but are not known as a reservoir in the subsurface. Likewise, the Portland Limestone Formation exhibits good primary and secondary porosity at outcrop on the Isle of Portland but is not known to be a reservoir. The reservoir for the Kimmeridge oil field (which cheekily sits on top of cliffs of *immature* Kimmeridge Clay source rock facies) is heavily fractured shallow marine Cornbrash Formation limestones. The limestones are about 20m thick and tightly cemented other than in the fractures (Evans et al., 1998). The fracture system was probably generated during inversion in the Miocene and may extend into the adjacent Kellaways Sandstone, Oxford Clay and Forest Marble Formations. Despite its small size the reservoir has continued in production since 1961 and it is likely that the reservoir extends offshore. The field is abnormally under-pressured, probably owing to rapid uplift and enlargement of the fracture system during Miocene folding.

Petroleum habitat within the Weald sub-basin is significantly different from the Portland-Wight sub-basin, with a majority of productive reservoirs within thick Bathonian oolitic limestones that have good intergranular porosity and permeability (Trueman, 2003; Sellwood et al., 1989, 1985; Penn et al., 1987). These were deposited on a SW-dipping shallow ramp, and their time-equivalent facies in Dorset are offshore mudrocks of the Frome Clay and Fullers Earth Formations. Subordinate reservoirs are locally developed in Oxfordian sandstones and reefal limestones (Sun et al., 1992; Sun and Wright, 1998), and in Portlandian sandstones (Butler and Pullan, 1990; Penn et al., 1987). Diagenesis was important in controlling reservoir quality, and in the carbonate reservoirs early oil emplacement has helped to reduce burial cementation by ferroan calcite.

Traps and migration

Traps in the Portland-Wight sub-basin are exclusively structural. The Wytch Farm and small Wareham fields consist of tilted fault blocks in the footwall of the Purbeck – Isle of Wight disturbance that have maintained their integrity and net extensional displacement despite inversion (Underhill and Stoneley, 1998). Because they are north of the major fault zone, the oil charge must have relied upon migration up and across these faults. At the time of maximum migration they would have been sealed off by overlying Chalk, but the presence of a syn-depositional oil seep in Barremian fluvial conglomerates at Mupe Bay suggests that migration up the faults had already begun in the early Cretaceous. These intraformational conglomerates contain dark oil-impregnated clasts and paler oil in their sandstone matrix. The paler oil has been interpreted as of relatively higher maturity and evidence for a “live” seep and therefore two episodes of migration (Selley, 1992; Cornford et al., 1988). However, detailed biomarker analysis suggests that the two oils are of similar maturity albeit with variably severe biodegradation (Parfitt and Farrimond, 1998, and references therein). The relative ages of the oils therefore remain equivocal.



Present-day and restored Late Cretaceous north - south cross sections across SE Dorset showing the evolution of the petroleum system and likely origin of surface oil seeps. From Underhill and Stoneley (1998)

To preserve the footwall accumulations during and after Tertiary inversion the faults of the Purbeck – Isle of Wight disturbance must have become sealing under compression. However, the presence of modern surface oil seeps along the line of the disturbance suggests that the faults regained some permeability. These seeps include examples in Oxfordian sandstones at Osmington Mills, and in Lower Cretaceous (Wealden) sandstones and upper Purbeck limestones at Lulworth Cove, St Oswald's Bay and Worbarrow Bay. Geochemical biomarker analysis has revealed significant variation in the source rock facies, maturity and degree of biodegradation for these examples, although all can be fingerprinted to the Liassic source (Bigge and Farrimond, 1998). The fault blocks between Wytch Farm and the disturbance contain no residual oil and it was probably lost to these surface seeps. The Chalk is intensely fractured along the fault zone, but this deformation does not extend more than a few hundred metres north and hence does not constitute a seal risk for the Wytch Farm and Wareham fields.

The Kimmeridge field is the only successful prospect in the hanging wall of the Purbeck – Isle of Wight disturbance. It is a periclinal trap that probably originated as a rollover anticline and was steepened in its northern limb during inversion. The closure was already in place for peak migration to fill the structure in the Late Cretaceous, and the oil was probably sealed in by the Early Tertiary to account for the subsequent under-pressuring. Oxfordian mudrocks (Oxford Clay Formation) provides the seal. It is intriguing that no other hanging wall prospects have been successful; they have either been breached or were never charged (Bigge and Farrimond, 1998). The Kimmeridge, Wytch Farm and Wareham oil fields may therefore be remnants of a much larger play that was substantially destroyed during inversion.

In the Weald sub-basin Bathonian and Oxfordian carbonate reservoirs were sealed by Oxfordian mudrocks (Oxford Clay Formation), whilst Berriasian evaporites sealed the Portlandian sandstone fields. The traps are mostly associated with Jurassic-Cretaceous tilted fault blocks around the periphery of the sub-basin, which were modified (tilted) during Tertiary inversion. As well as migration up fault zones, lateral up-dip migration of 10s km took place within the Bathonian oolites from the deeply buried Liassic source kitchen (Sellwood et al., 1989). Some of the productive Bathonian reservoirs preserve evidence of two filling episodes whereby a diagenetic interface independent of sedimentary facies records a fossil oil-water contact (Heasley et al., 2000). Two stages of hydrocarbon migration were also suggested by Sellwood et al. (1993) from fluid inclusion analysis of burial cements. Although the episodes are difficult to time, they suggest that remigration on the flanks of the Weald sub-basin was more important and widespread than in the Portland – Wight sub-basin. It is likely that some deeper traps were breached during Tertiary inversion, allowing the oil to migrate upwards into shallower closures.

In contrast to the peripheral areas, the central inverted arch of the Weald sub-basin is devoid of significant oil fields. It only contains sub-economic gas fields with thin oil rims. The lack of prospectivity in this central region is likely due to a combination of poor reservoir facies development, breaching of pre-Tertiary traps, and extensive cementation (Hawkes et al., 1998; Butler and Pullan, 1990). Effective traps are limited to Tertiary structures which presumably accumulated gas that was able to re-migrate over longer distances than oil.

Play risk

The play risk in the Portland – Wight sub basin is defined by:

- The eastward pinch-out of the Early Triassic Sherwood Sandstone Formation and increasing clay and limestone content of the Toarcian Bridport Sandstone Formation
- The westward limit of the source kitchen due to insufficient burial or excessive early Cretaceous uplift

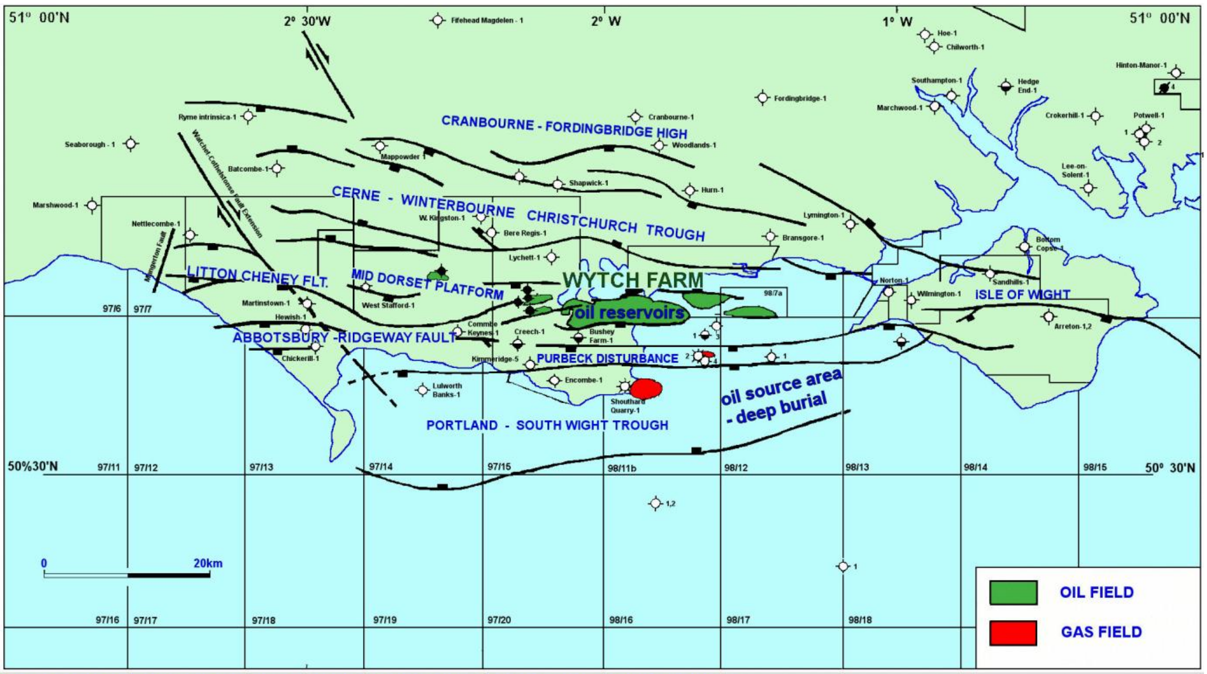
- The northward extent of oil migration along suitable fairways
- The southward extent of faults with suitable geometries (preserved pre-inversion or inversion-related) and/or sealing properties for trapping
- Difficulty of resolving structures on available seismic data

The play risk in the Weald sub-basin is defined by:

- The distribution of porous and permeable Jurassic reservoir units, particularly the westward transition of the Bathonian Great Oolite Group limestones into Fuller's Earth Formation mudrock facies
- Early emplacement of oil in carbonate reservoirs such that burial cementation was impaired
- The presence of tilted fault block traps which retained their seal integrity during Tertiary inversion
- The distribution of permeable strata hosting migration pathways that linked the traps to the source kitchen in the basin centre

For more information on the petroleum geology of the Wessex Basin see Ian West's web pages:

http://www.soton.ac.uk/~imw/Oil-South-of-England.htm



OIL AND GAS FIELDS, BOREHOLES AND MAJOR STRUCTURAL ELEMENTS OF THE WESSEX BASIN.
Redrawn and simplified after a map of Butler (1998), p. 68. See the original map and read the paper for a good overview of the petroleum geology of the Wessex Basin.
Note that fault positions are mapped at base Jurassic level and thus are not necessarily at the surface position (often further N.).
The strike-slip faults are showing Variscan sense of movement. Ian West (c) 2011.

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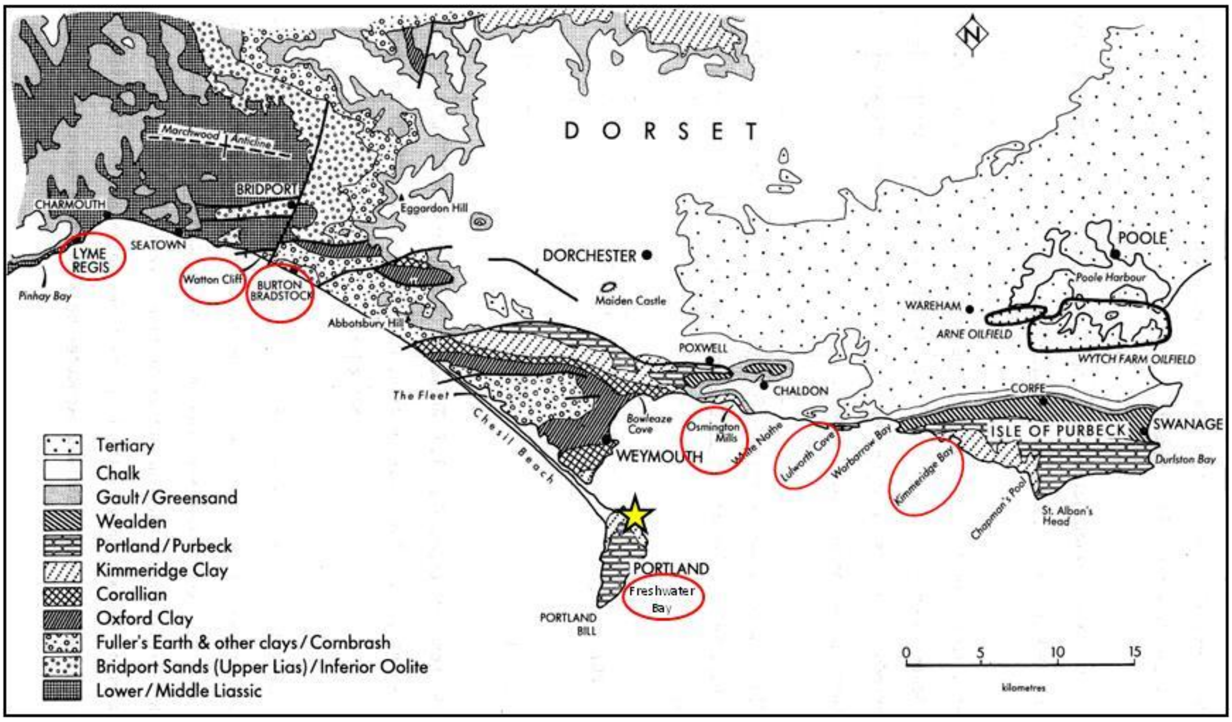
FIELD LOCALITIES

Grid references refer to the UK Ordnance Survey national grid.
The corresponding map sheets are as follows:

- **Topographic: 1:50,000 Landranger series 193, 194, 195**
- **Topographic: 1:25,000 Explorer series OL15**
- **Geological: British Geological Survey 1:50,000 sheets E327, E341/2, E343**



Field localities to be visited. The star marks the location of the hotel

1. THE PORTLAND LIMESTONE FORMATION AND THE LOWER PURBECK FORMATION ON THE ISLE OF PORTLAND

Introduction

These strata will be examined in cliffs and abandoned quarries on the western side of the Isle of Portland (Freshwater Bay south towards Portland Bill). There are many inland quarry exposures but access is not permitted at weekends and without prior arrangement. Access is from a small car park adjacent to a quarry entrance at 690704, via a footpath on the other side of the main Easton – Southwell road and descends southwards to the cliff top quarries (SY691702-688695). Hazards to be aware of are loose / unstable cliff and quarry faces, cracks and holes in the quarry floors, and steep unprotected cliff edges. Please tread carefully and wear a hard hat when close to vertical faces; avoid standing beneath areas of overhang and open vertical fissures.

Overview

The Portland Limestone Formation is a spectacularly exposed example of a carbonate ramp, which has been surprisingly under-studied in recent years. The basic sedimentological model was proposed by Townson (1975), and has been little modified. The succession coarsens up from offshore mudrocks, siltstones and fine grained dolomites to spiculitic wackestones and shelly packstones with large epifaunal bivalves and sponges. The spiculitic limestones developed regularly spaced horizons of chert nodules. The cherts are typically irregular and appear to follow *Thalassinoides* burrows, but more complicated habits are also present suggesting possibly more than one episode of precipitation. Some of the cherts have concentric dark and pale banding on a mm-scale (Gorman et al., 1993), and isotopic studies suggest formation under the influence of meteoric waters at mildly elevated temperatures (Maliva et al., 1999). Continued shallowing brought in ooid grainstones that formed extensive low-angle dunes or sand waves that prograded southwards. Most of the movement took place during storms, with quieter episodes resulting in colonisation of the shoals by a varied benthic fauna of bivalves, algae and crustaceans. Ammonites are present throughout, but corals are rare. In detail there are several breaks in the succession, as well as shell beds indicating a slowing or temporary break in sedimentation. Coe (1996) has recognised three cycles within the overall regression, each marked at its base by an erosional surface. On the Isle of Portland the lower two of these represent biostratigraphic gaps, compared to the more complete succession on the south-east Dorset coast (Isle of Purbeck). Coe's paper contains highly detailed and beautifully drafted logs that are indispensible in the field, but she did not extend her study into the many quarries inland on the Isle of Portland. The succession in these has been studied by Howard Falcon-Lang in an unpublished report for Dorset County Council.

The upper oolitic part of the Portland Stone Formation is a famous and historically highly exploited building stone, resulting from its textural homogeneity (Falcon-Lang, 2011). In detail it consists of four subdivisions: the Basebed (about 2.5 m thick), the Curf (about 1 m), the Whit bed (up to 3 m) and the Roach (1 m). The Basebed and Whit bed are pure oolites, with minor quartz silt forming some ooid nuclei. They have very few fossils, reflecting the inhospitable environment of mobile shoals for infaunal or epifaunal colonisation. However, they do contain sporadic metre-scale bioherms constructed by oysters, bryozoans and calcareous algae and stabilised by peloidal marine cements (Fürsich and Palmer, 1994). The reefs are heavily bored, and support a diverse secondary encrusting and nestling fauna. The Curf contains abundant chert nodules and is finer grained than the surrounding oolites. The Roach bed, where present, is rich in molds of the high spired gastropod *Aptyxiella portlandica* ("the Portland screw") as well as trigoniid bivalves. It probably represents a back-barrier lagoonal setting.

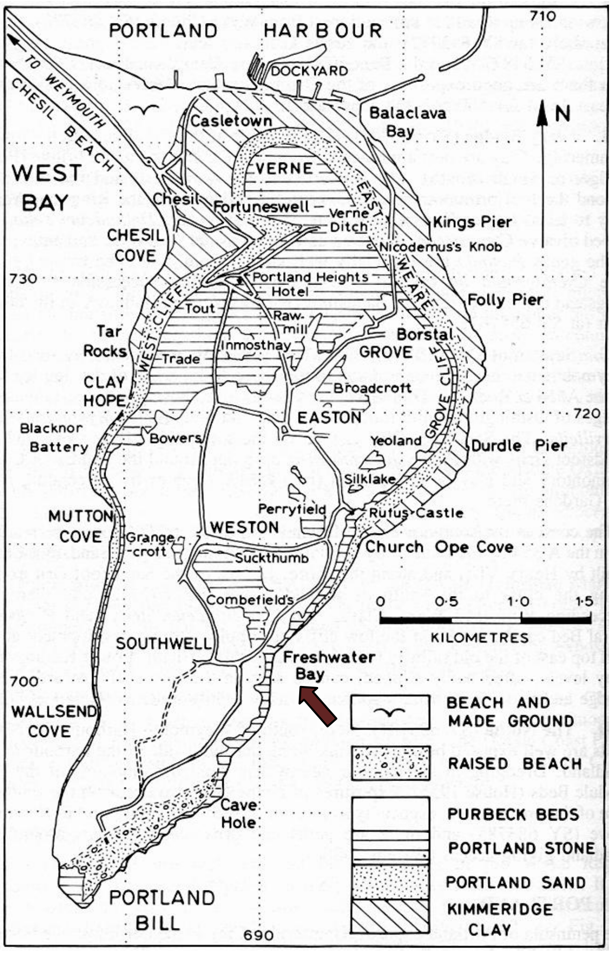
A striking and poorly studied feature of the Portland Stone Formation is its high porosity. This is due to incomplete calcite cementation of the intergranular pore space coupled with dissolution of aragonite bioclasts without subsequent filling of the moldic voids. This is highly unusual in the Dorset Jurassic, and its cause is uncertain. Fresh water could have flushed into the unit after deposition, as the overlying Lulworth Formation contains several palaeosols. However, there is no evidence of karstification at the top of the Portland Stone, and the basal Lulworth Formation elsewhere contains evaporites suggesting that the climate was more arid than humid. The Roach bed does contain a small proportion of sparry calcite crystals that might represent vadose zone cementation, but no detailed petrographic and geochemical study has been published on them. More strikingly, the moldic pores in the Roach commonly contain preserved endolithic microborings, showing that these were filled by calcite whilst the surrounding shells were still aragonite (Fürsich and Palmer, 1994).

The basal part of the non-marine Lulworth Formation is notable on the Isle of Portland for the development of stromatolitic and thrombolitic build ups. The succession has a tripartite division colloquially called the Skull Cap, Hard Cap and Soft Cap, each separated by carbonaceous clay palaeosols with limestone pebbles (Falcon-Lang, 2011; Andrews et al., 1988). The limestones of the "caps" are fine grained wackestones and packstones with ostracods and diminutive gastropods, and were deposited in lagoons that probably (taking into account the slightly different successions further east) varied between fresh and hypersaline. The microbial build ups are present in all of the three limestones, but their morphology differs. In the lower and upper unit they tend to show cm-m sized domes and laminar crusts, but in the hard cap the thrombolites have a spectacular concentric arrangement around the (now decayed) braches or roots of trees. At Lulworth Cove similar facies are developed around the former base of coniferous tree trunks. Perry (1994) has studied the examples on the Isle of Portland in detail, and considers them to be freshwater tufa deposits that initiated as biofilms on the soil substrate and enveloped the trees as the lagoon level rose. The thrombolites have a complex, micro- and macro-porous internal fabric, and both isopachous and peloidal calcite cements.

Objectives

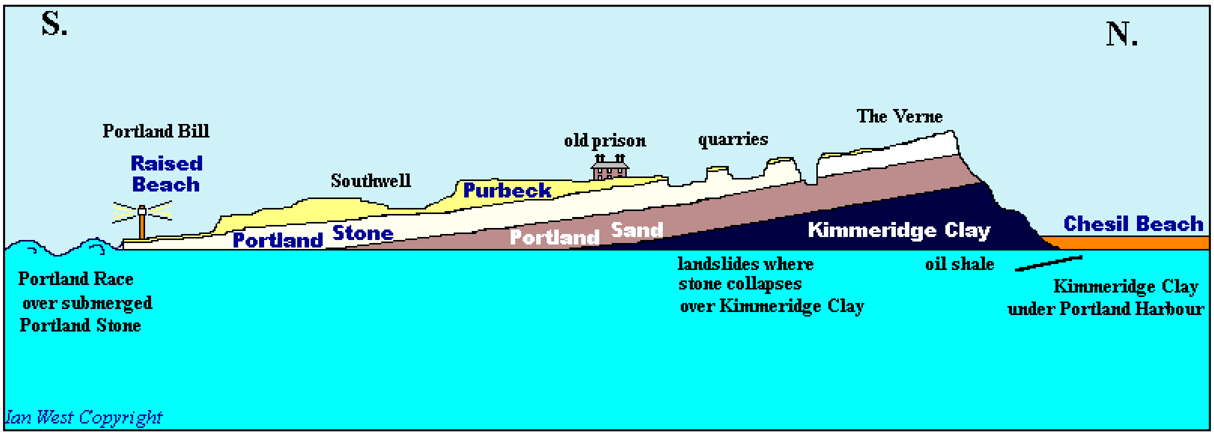
1. To examine the upper part of the Portlandian ramp succession (Cherty Beds member to Portland Freestone); to consider possible causes of porosity preservation and value as a potential reservoir analogue.
2. To examine unusual thrombolitic and stromatolitic bioherms in Lower Purbeck lagoonal limestones, their size, shape, internal structure, and relationship to contemporaneous vegetation; to consider possible modern analogues and value for research on microbial processes.

Figures

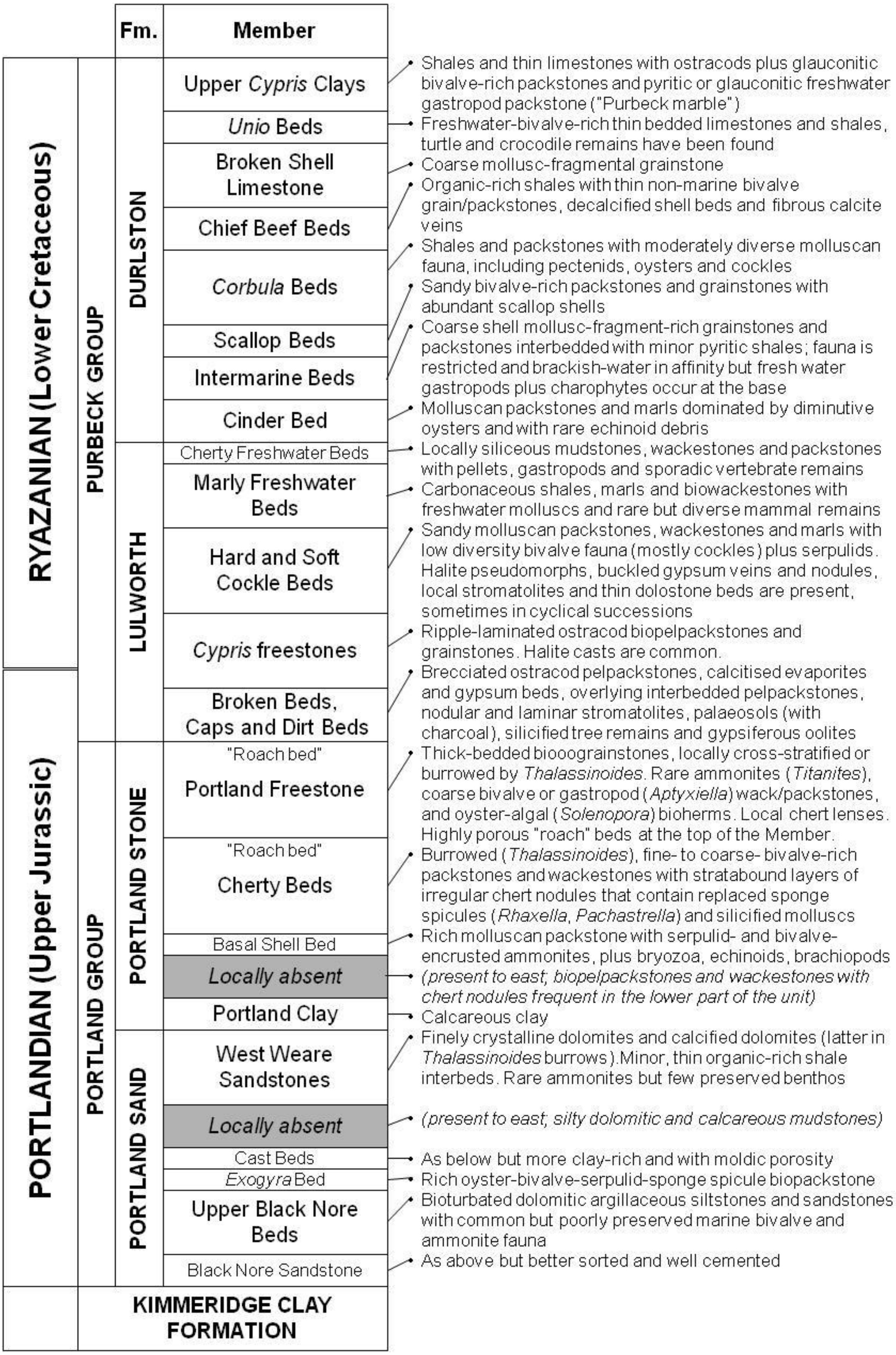


Geological map of the Isle of Portland, showing quarries and coastal exposures. From House (1993).

An aerial photograph of the Isle of Portland looking southward. Photograph taken by Ken Van Dellen, Grosse Pointe Park, Michigan, at 9.45am on 24th June, 2006. The surface of Portland slopes southward with the southward dip of the Portland Stone. The southern part is fairly natural, but the northern part has urban development , large quarries and two prisons. The Chesil Beach abuts against the high West Weare cliffs. *Photograph courtesy of and copyright of Kenneth J. Van Dellen, 2007.*

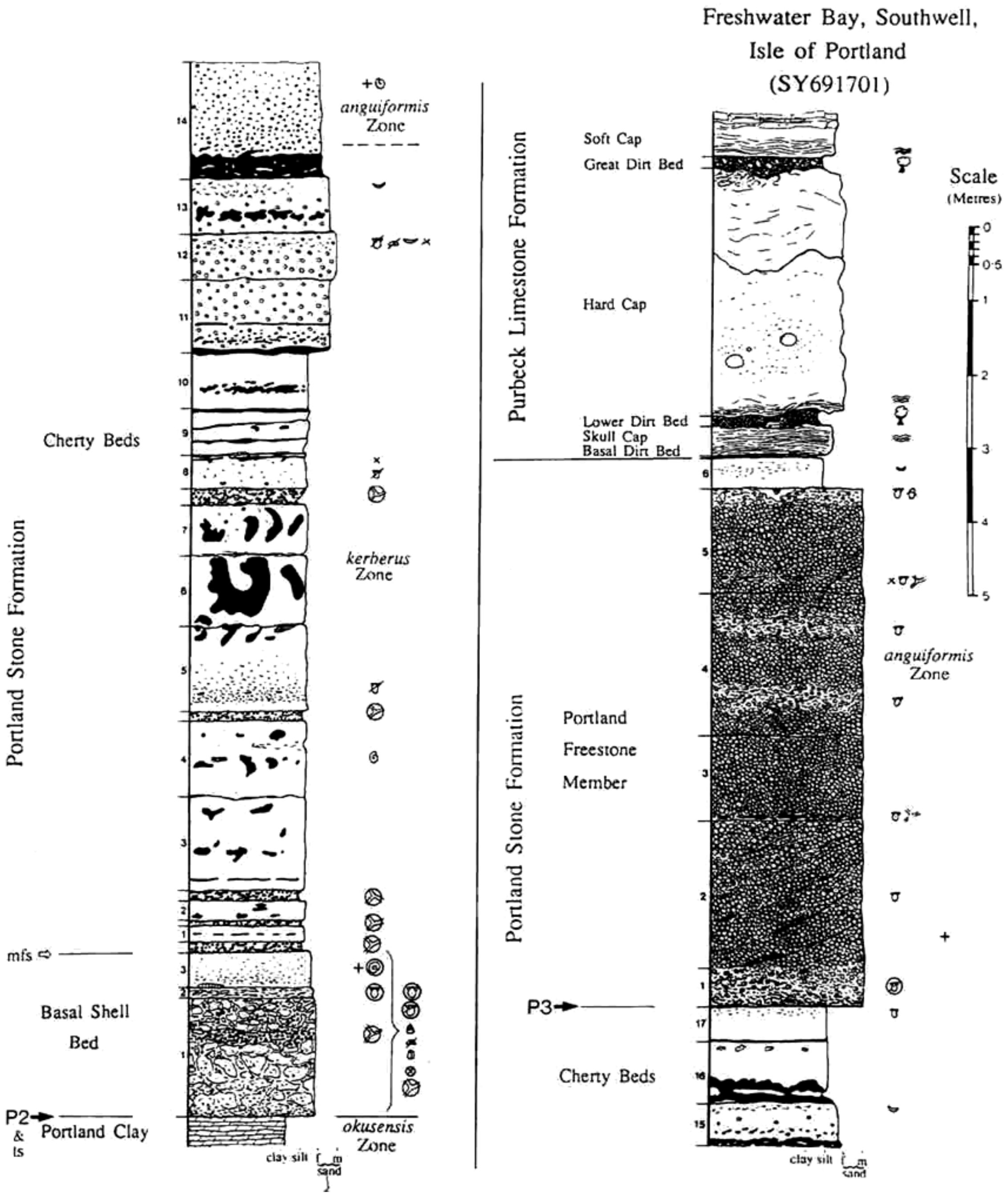


Geological cross section of the Isle of Portland. From "Geology of the Wessex Coast" web site.

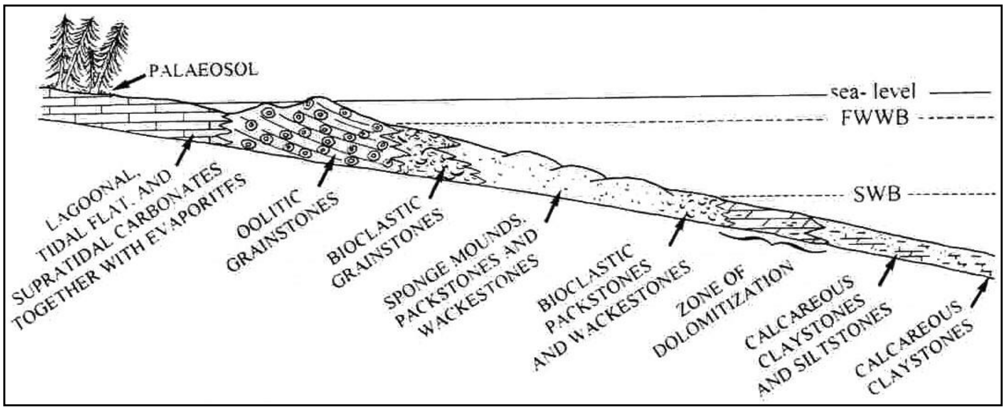


		Fm.	Member	
RYAZANIAN (Lower Cretaceous)	PURBECK GROUP	DURLSTON	Upper *Cypris* Clays	Shales and thin limestones with ostracods plus glauconitic bivalve-rich packstones and pyritic or glauconitic freshwater gastropod packstone ("Purbeck marble")
			Unio Beds	Freshwater-bivalve-rich thin bedded limestones and shales, turtle and crocodile remains have been found
			Broken Shell Limestone	Coarse mollusc-fragmental grainstone
			Chief Beef Beds	Organic-rich shales with thin non-marine bivalve grain/packstones, decalcified shell beds and fibrous calcite veins
			Corbula Beds	Shales and packstones with moderately diverse molluscan fauna, including pectenids, oysters and cockles
			Scallop Beds	Sandy bivalve-rich packstones and grainstones with abundant scallop shells
			Intermarine Beds	Coarse shell mollusc-fragment-rich grainstones and packstones interbedded with minor pyritic shales; fauna is restricted and brackish-water in affinity but fresh water gastropods plus charophytes occur at the base
			Cinder Bed	Molluscan packstones and marls dominated by diminutive oysters and with rare echinoid debris
		LULWORTH	Cherty Freshwater Beds	Locally siliceous mudstones, wackestones and packstones with pellets, gastropods and sporadic vertebrate remains
			Marly Freshwater Beds	Carbonaceous shales, marls and biowackestones with freshwater molluscs and rare but diverse mammal remains
			Hard and Soft Cockle Beds	Sandy molluscan packstones, wackestones and marls with low diversity bivalve fauna (mostly cockles) plus serpulids. Halite pseudomorphs, buckled gypsum veins and nodules, local stromatolites and thin dolostone beds are present, sometimes in cyclical successions
			Cypris freestones	Ripple-laminated ostracod biopelpackstones and grainstones. Halite casts are common.
PORTLANDIAN (Upper Jurassic)			Broken Beds, Caps and Dirt Beds	Brecciated ostracod pelpackstones, calcitised evaporites and gypsum beds, overlying interbedded pelpackstones, nodular and laminar stromatolites, palaeosols (with charcoal), silicified tree remains and gypsiferous oolites
	PORTLAND GROUP	PORTLAND STONE	"Roach bed" Portland Freestone	Thick-bedded biooograinstones, locally cross-stratified or burrowed by *Thalassinoides*. Rare ammonites (*Titanites*), coarse bivalve or gastropod (*Aptyxiella*) wack/packstones, and oyster-algal (*Solenopora*) bioherms. Local chert lenses. Highly porous "roach" beds at the top of the Member.
			"Roach bed" Cherty Beds	Burrowed (*Thalassinoides*), fine- to coarse- bivalve-rich packstones and wackestones with stratabound layers of irregular chert nodules that contain replaced sponge spicules (*Rhaxella*, *Pachastrella*) and silicified molluscs
			Basal Shell Bed	Rich molluscan packstone with serpulid- and bivalve-encrusted ammonites, plus bryozoa, echinoids, brachiopods
			Locally absent	*(present to east; biopelpackstones and wackestones with chert nodules frequent in the lower part of the unit)*
			Portland Clay	Calcareous clay
		PORTLAND SAND	West Weare Sandstones	Finely crystalline dolomites and calcified dolomites (latter in *Thalassinoides* burrows).Minor, thin organic-rich shale interbeds. Rare ammonites but few preserved benthos
			Locally absent	*(present to east; silty dolomitic and calcareous mudstones)*
			Cast Beds	As below but more clay-rich and with moldic porosity
			Exogyra Bed	Rich oyster-bivalve-serpulid-sponge spicule biopackstone
			Upper Black Nore Beds	Bioturbated dolomitic argillaceous siltstones and sandstones with common but poorly preserved marine bivalve and ammonite fauna
			Black Nore Sandstone	As above but better sorted and well cemented
	KIMMERIDGE CLAY FORMATION			

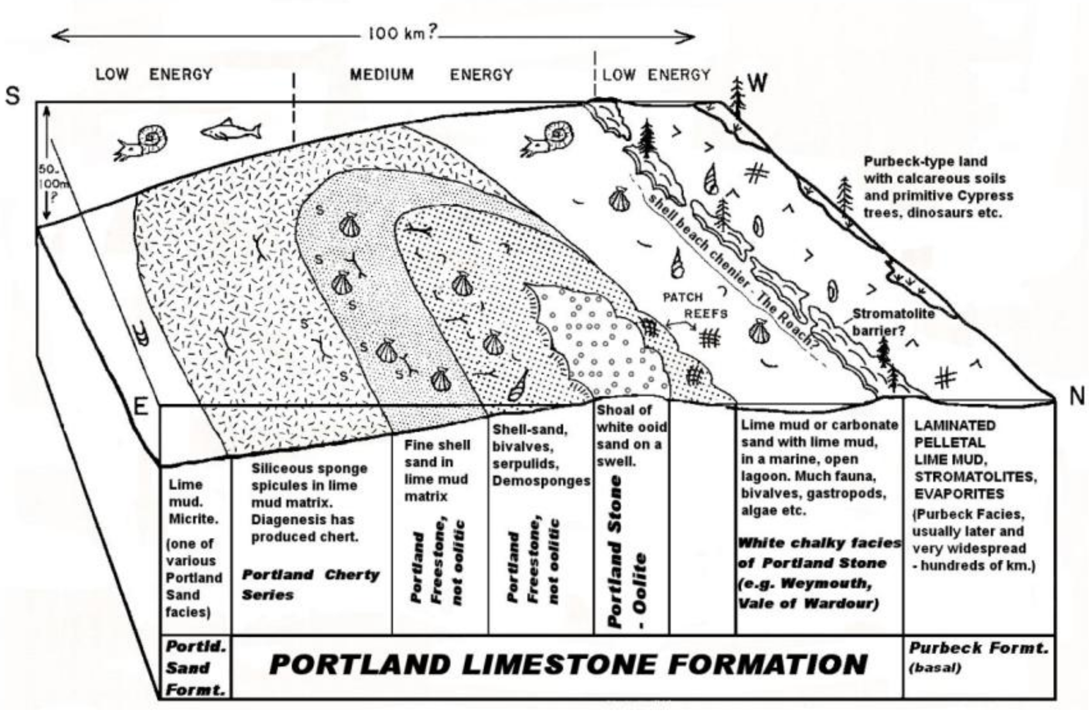
Lithostratigraphy of the Portland and Purbeck Groups. Note the broken beds are not present on the Isle of Portland, but appear towards the Purbeck – Isle of Wight disturbance (e.g. Lulworth Cove).



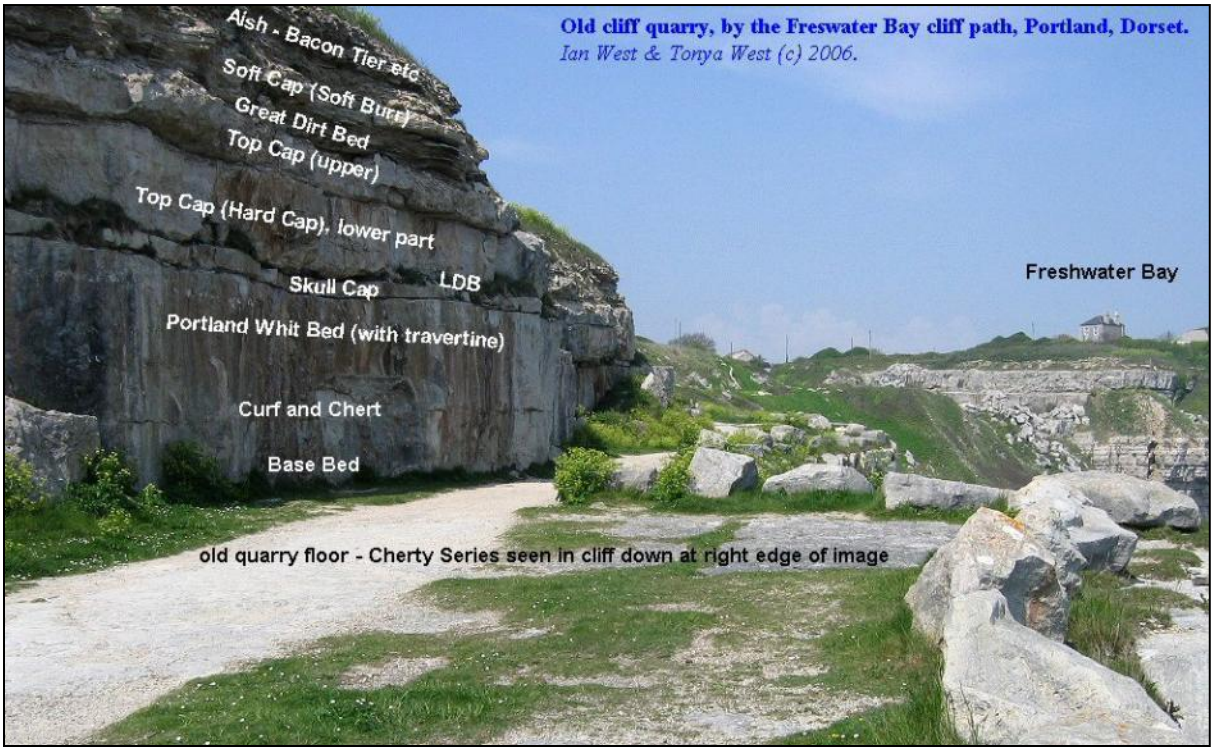
Graphic log of the succession at Freshwater Bay. From Coe (1996). P2 and P3 are regionally correlatable unconformities, but only P2 represents a biostratigraphic break.

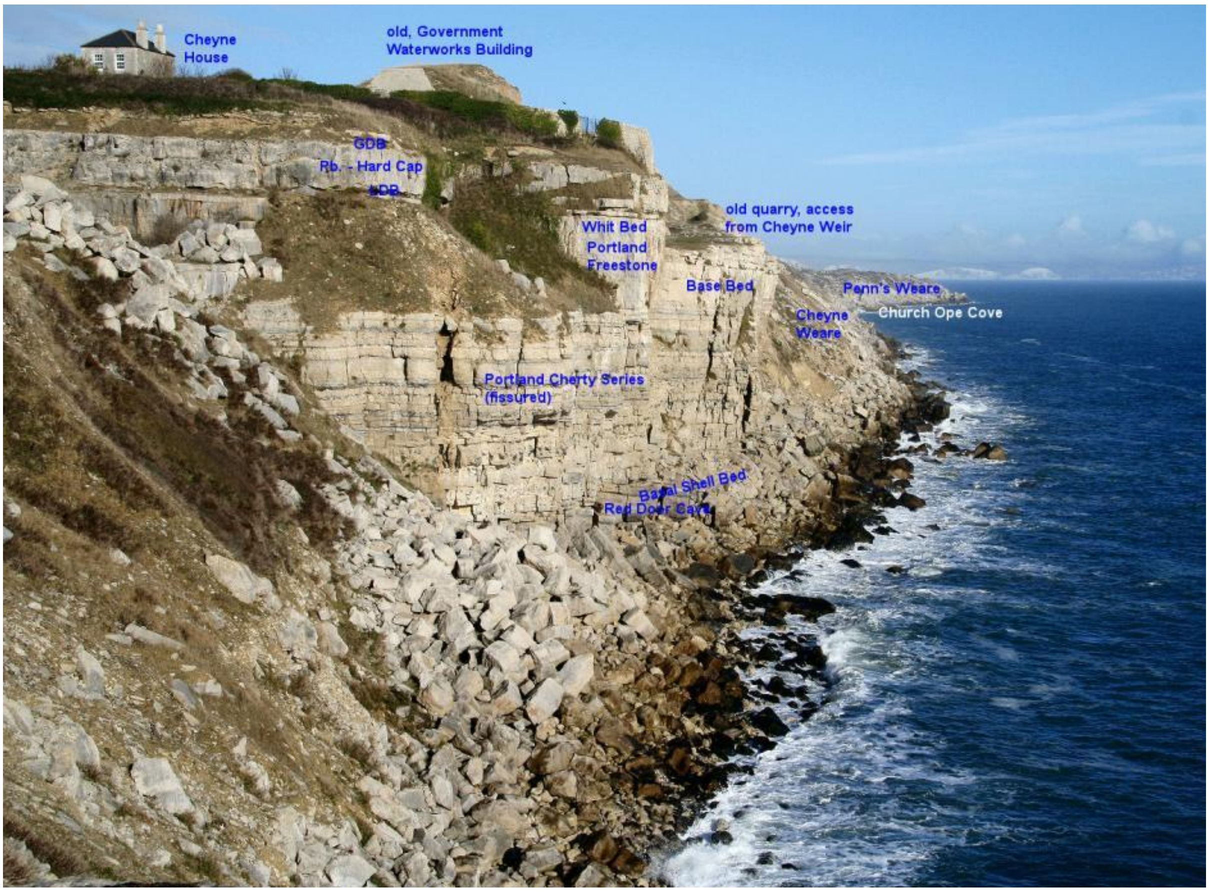


Simplified model for the Portland Group carbonate ramp. From Coe (1996). The origin of the dolomites is uncertain. They have only slightly negative δ^{13}C values (about -3‰ V-PDB) and near normal marine δ^{18}O values (about +2‰ V-PDB). They also have higher than normal organic carbon contents (0.4 – 1.4%). Coe proposes that hypersaline brines sank down through the overlying limestones when evaporites were being deposited in the lower Lulworth Formation. However, it is difficult to envisage why the limestones were unaffected, and there is no evidence for significant evaporite deposition on the Isle of Portland. A bacteriogenic origin seems more likely, aided by bioturbation and dissolution of aragonite in marine pore fluids.

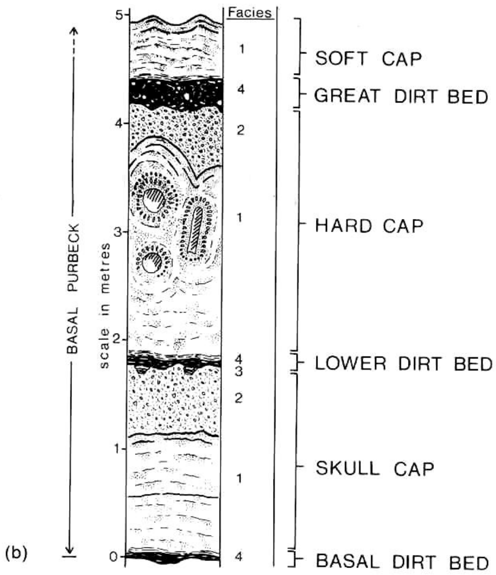


Facies model for deposition of the Portland Group and lower part of the Lulworth Formation, modified from Townson (1975) by Ian West.





Photographs of the exposures at Freshwater Bay, from "Geology of the Wessex Coast" web site.



Stratigraphy of the lowermost Purbeck Formation on the Isle of Portland. From Perry (1994).

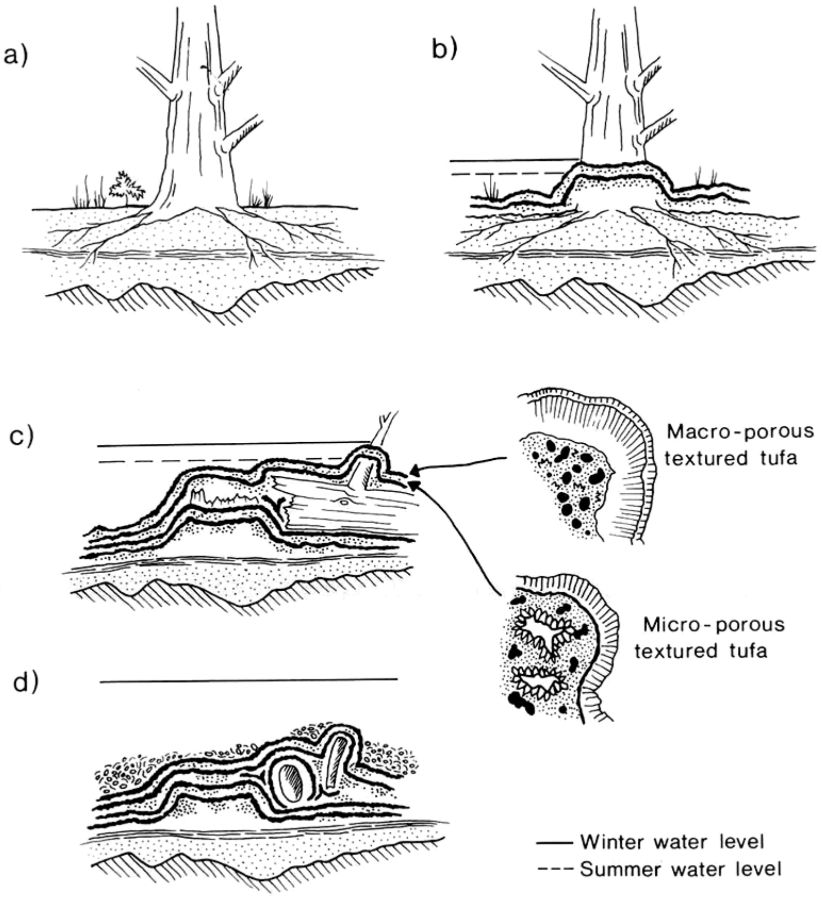
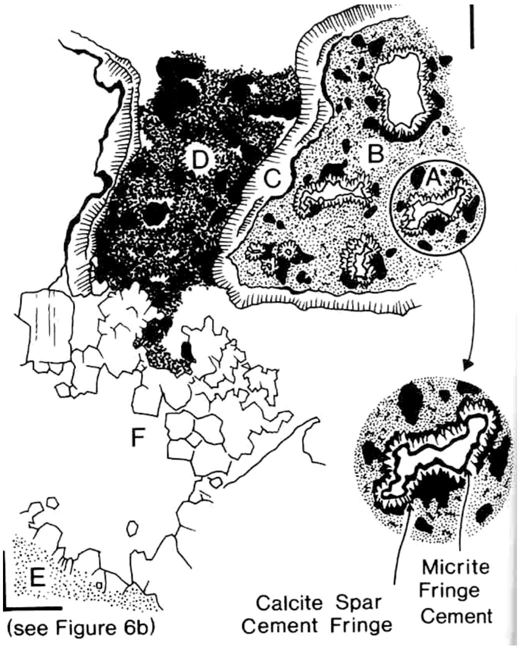


Figure 8. Model of tufa stromatolite development in the Portland area of southern Dorset. (a) Conifers grow in the calcareous soil around the Portland area. A laminated calcrete horizon develops within the soil. (b) Rising water level brings about the formation of extensive, shallow freshwater lake or lagoonal conditions. An active biofilm develops above the soil and around trees and associated vegetation. The soil provides nutrients for microbial activity and tufa starts to develop seasonally, especially around the tree bases. (c) As water levels continue to rise, the trees start to die and collapse, falling into the shallow waters. There is extensive tufa development, 'draping' all previously formed deposits. The soil is gradually broken down and washed out about the calcrete. (d) With continued transgression marine or saline waters flood the area. Tufa development stops and skeletal debris, mostly ostracodes, starts to accumulate above the submerged tufa deposits.

Model for microbialite development in the Lulworth Formation "caps". From Perry (1994).



Internal sediments, fringing cements and peloidal matrix within micro-porous thrombolite. From Perry (1994)

Web link to "Geology of the Wessex Coast"

- **http://www.soton.ac.uk/~imw/Portland-Isle-Geological-Introduction.htm**

  Also

- http://www.soton.ac.uk/~imw/Portland-Bill.htm
- http://www.soton.ac.uk/~imw/Portland-Quarries.htm

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2. THE CORALLIAN GROUP BETWEEN OSMINGTON MILLS AND BRAN POINT

Introduction

We will examine aspects of this succession in cliff and foreshore exposures east and west of Osmington Mills. Parking is possible on the road side just before (but not in) the turning space at the end of the road at Osmington Mills, or by permission within the adjacent cliff-top car park of the Smuggler's Inn (SY735817). Access to the exposures is via a footpath that starts at the pub entrance, passes behind some houses and then across a field to meet the coast at a small headland. From there it is necessary to carefully walk over boulders and seaweed eastwards until the cliff exposure of the lower and middle parts of the Corallian Group begins. These cliffs are notoriously unstable, and caution must be exercised in avoiding areas with obvious dilatational fractures or recent evidence of collapse. The exposure continues along the rocky and boulder-strewn foreshore around Bran Point (SY743814) until the western end of Ringstead Bay is reached. On a rising tide it is advisable to work back westwards along the section; there is little risk of being cut off but the best foreshore exposures are close to Bran Point. Heading west from the access footpath upper parts of the Corallian Group are exposed in the foreshore close to Black Head (SY727819), about 500 m walk west from the access path along the boulder and shingle beach. A steep land slipped slope directly back to the car park can be followed in dry weather, rather than back-tracking to the access path.

Overview

The Corallian Group consists of a cyclical alternation of fully marine sandstones, mudrocks and limestones. They contain a rich and diverse assemblage of invertebrate fossils as well as exquisite trace fossils. The succession is unusual for its intimate association of oolitic limestones with terrigenous mudrocks, and there have been many conflicting attempts to interpret its palaeoenvironment and sequence stratigraphy. Lithologies of the constituent members are summarised in the introductory section of this field guide, and detailed accounts can be found in Coe (1995), Wright (1986), and Wright and Cox (2001). The trace fossils within the Corallian Group at Osmington have been described and interpreted by Fürsich (1975, 1977), and Goldring et al. (1998).

The Redcliff Formation is the lowest division of the Corallian Group and rests on an erosional surface cut into the indurated top of the Oxford Clay Formation, and the formation coarsens upwards. Argillaceous sandstones of the Nothe Grit Member are eroded into by coarser shelly, bioturbated calcareous sandstones of the Preston Grit Member. The conformably overlying Nothe Clay consists of mudrock interbedded with thin bivalve-rich limestones near its base, and becoming siltier upwards. The overlying Bencliff Grit Member represents a sharp increase in grain size, although there is no evidence of an erosional contact. The fine grained sandstones of the Bencliff Grit display a variety of gently undulating, swaley-style (predominantly concave-up) cross stratification (Allen and Underhill, 1989). The foresets are picked out by oil staining and also in spectacular m-sized calcite concretions that are eroded out onto the beach. The oil staining suggests that the member may have been a reservoir prior to Tertiary inversion and unroofing. In detail the patterns of stratification within the Bencliff Grit are complex, with erosion surfaces separating units that include cross bedded sands, silty mudrocks, flaser-bedded heterolithics and ripple cross laminated sandstones (Goldring et al., 1998). The depositional setting is variously interpreted as lagoonal to upper shoreface. As with much of the Dorset coastal successions, inland data from boreholes and temporary exposures is needed to constrain possible interpretations.

The Osmington Oolite Formation marks a return to carbonate-dominated deposition, although it is a complex and laterally variable unit. The Upton Member begins with sandy oolitic limestones that sharply overlie the Bencliff Grit and locally fill burrows extending down into the sandstones. The limestone are overlain by a calcareous mudrock and an oncolitic limestone. The oncoids are described as algal but consist of dense micrite coatings suggestive of microbialite and merit further study. The oncolite is succeeded by ammonite bearing nodular calcareous mudrocks, and sandy bioturbated marls. Overall the member displays a deepening then shallowing trend. West of Osmington Mills, towards Black Head, the basal part of the overlying Shortlake Member consists of 2-3 m of clean, cross bedded oolite that sharply overlies the marls of the Upton Member. This prominent erosional surface cuts down into the underlying strata to the west. Foresets in the oolite dip to the west However, at Bran Point the equivalent limestones are thinner, more micritic and bioturbated. The depositional environment was probably a lagoon with tidal channels in which the oolites accumulated. The oolites pass upward into bioturbated oolitic calcareous clays. These contain some unusual concretions with calcite spar-filled shrinkage cracks. These are difficult to access *in situ* but are frequently washed out onto the boulder beach. The Nodular Rubble Member was deposited after a break in deposition, and is dominated by irregularly bedded nodular limestone and intervening marl. As with the nodular mudrocks in the Upton Member it is likely that the fabric represents preferential cementation within *Thalassinoides* burrows, and it is likely that a complex early diagenetic interplay of burrowing and cementation took place.

A bored erosional surface at the top of the Nodular Rubble Member marks the transition to the Clavellata Formation. This is best exposed near Black Head, but parts of it can be seen at Bran Point. It begins with shelly and oolitic argillaceous limestones (Sandy Block Member), overlain by an oobiomicrite crowded with thick shelled, strongly ribbed *Myophorella clavellata* bivalves (plus other bivalve species) (Chief Shell Beds Member). The unit contains disseminated siderite, giving it a reddish hue. The origin of the siderite presumably relates to bacterial iron reduction in sub-oxic conditions during shallow burial. A bioclastic ferruginous clay (Clay Band Member) overlies these beds, and is followed by complex, reddish-grey, bioturbated, sideritic and oolitic limestones of the Red Beds Member. The ferruginous nature of this unit suggests condensation, and this is emphasized by the fact that some burrow fills preserve facies that are absent in the immediately overlying succession. Phosphatised internal molds of gastropods can also be found in the limestones.

The uppermost formation of the Corallian Group is the Sandsfoot Formation, and it is only exposed at Black Head and westwards towards Weymouth. It largely consists of sandy and silty mudstones and bioturbated sandy clays overlain by ferruginous bioclastic and oolitic sandstones, calcareous mudstones with sideritic concretions and serpulid-encrusted oyster shells. It is capped by a condensed ferruginous calcareous mudstone, the Osmington Mills Ironstone Member. This is laterally variable in facies and thickness, and has been described in detail by Williams (2003). Parts of the unit are a richly fossiliferous argillaceous or silty limestone with small to large (cm-sized) bioclasts including molluscs, echinoids, ammonites, serpulids and corals. The corals are dominated by discoidal colonies of *Thamnasteria* sp. and more upright colonies of *Thecosmilia* sp. Many are reworked, and bored by bivalves. Elsewhere the unit consists of calcitised or limonitic ooids in a shell hash with a siderite matrix. Despite being 12 – 25 cm thick at Osmington, the unit spans an entire ammonite zone and contains several hiatal surfaces. It was deposited in an offshore environment during a transgressive event.

Cyclicity within Corallian Group was initially recognised by William Arkell and subsequently elaborated by Talbot (1973). He regarded the cycles to be initiated by offshore limestones and to shallow up into outer shelf mudrocks and shoreface sandstones. Sun (1989) re-interpreted the succession as four regressive-transgressive cycles. Coe (1995) proposed four unconformity surfaces within the Corallian Group, based on correlation to Oxfordshire and thicker successions in Yorkshire. These are at the top of the Bencliff Grit, top of the Upton Member, top of the Nodular Rubble Member, and top of the Sandsfoot Clay Member. She suggests that the Upton Member unconformity actually cuts down from within the Shortlake Member at Bran Point into the top of the Upton Member at Black Head, and is marked by the base of a clean oolitic grainstone. More recently, Newell (2000) has proposed a sequence stratigraphic scheme based upon the erosion surfaces that bound the four constituent formations of the Group. His interpretation is summarised in the Table below, but the cause of relative sea level change remains equivocal, with both eustatic and intrabasinal tectonic influences likely to be important (e.g. De Wet, 1998). Hesselbo (2008) has recently reviewed and rationalised the various sequence stratigraphic schemes, although favouring Coe's (1995) sequence boundary interpretation.

Sequence 1 **(Redcliff Formation)**	The Nothe Grit, a distal shelf clastic deposit, overlain by a transgressive systems tract comprising the Preston Grit and limestones of the Nothe Clay. The Preston Grit is interpreted as part of a transgressive sheet forming in a mid-ramp setting. This system was drowned around maximum flooding, and covered by mudstone containing bored micrites and bioclastic and sideritic limestones typical of the condensed zone formed under very low sedimentation rates. The highstand systems tract is represented by the fine mudstones of the upper part of the Nothe Clay. The falling stage systems tract is represented by the Bencliff Grit. The sharp-based sandstone bodies of this member are typical of those formed under the control of relative sea-level falls. Here, the shoreface zone of wave scour moved basinwards, producing a regressive surface of erosion. This erosion surface is overlain by thin sand bodies that are smeared across the shoreface in response to falling sea level. Wave scour reworked and concentrated sufficient sand in an onshore direction to develop a prograding sand body.
Sequence 2 **(Osmington Oolite Formation)**	The Upton Member represents the transgressive systems tract, with sandy, bioclastic limestone overlain by deeper-water nodular clay. The highstand systems tract is dominated by oolitic limestone of the Shortlake Member. The occurrence of trough and planar cross-bedding, mud drapes and tidal scours indicates the importance of tidal processes in ooid formation. The Nodular Rubble Member formed at a highstand, but also appears to be part of the succeeding transgressive event.
Sequence 3 **(Clavellata Formation)**	The transgressive systems tract follows the same pattern as in the underlying sequences, with sandy, bioclastic wackestone (Sandy Block) overlain by high-energy, skeletal-ooidal intraclast grainstone (Chief Shell Beds). The finer-grained Red Beds Member mark a maximum flooding condensed interval. The highstand systems tract comprises calcareous, intensely bioturbated, sandy mudstone (Sandsfoot Clay Member), passing up, into fine clays with well-preserved, siderite-infilled bivalves and ammonites, a facies reminiscent of the Weymouth Member.
Sequence 4 **(Sandsfoot Formation)**	This sequence begins with the medium-grained, bioturbated sands of the lower Sandsfoot Grit (transgressive systems tract), followed by the phosphatic chamosite oolite sands of the upper Sandsfoot Grit (condensed stage), the Ringstead Clay (highstand systems tract) and Osmington Mills Ironstone (condensed interval or falling stage systems tract). This is erosively overlain by Early Kimmeridgian strata.

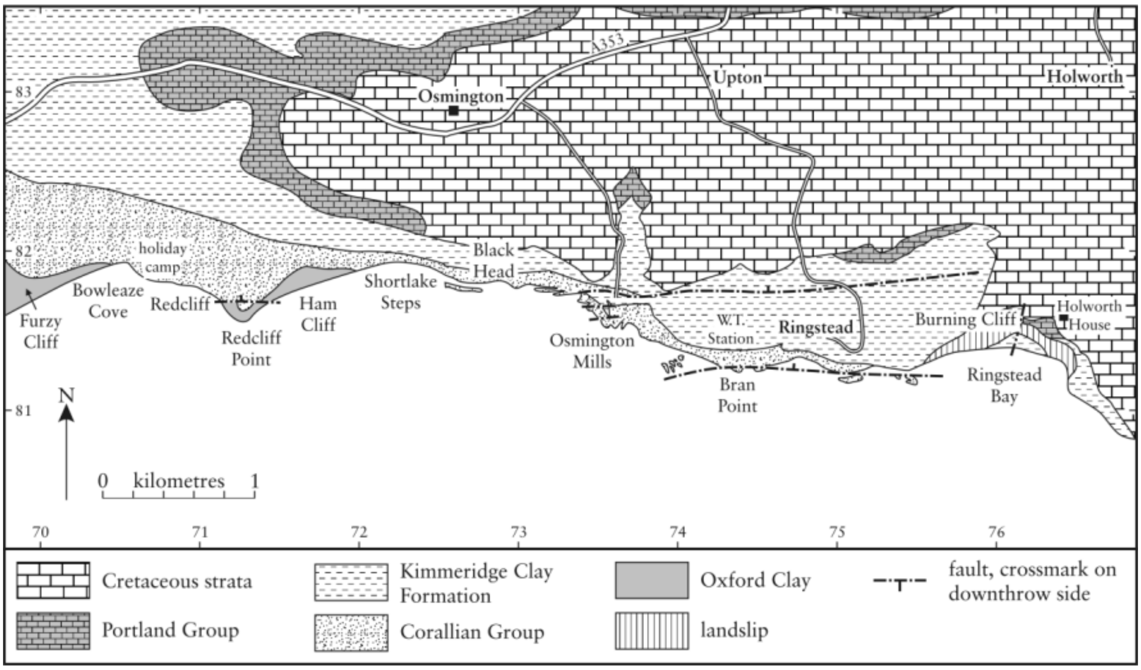
Summarised sequence stratigraphic interpretation of the Corallian Group based on Newell (2000), abridged and reproduced from Wright and Cox (2001).

The first diagenetic study of the Corallian Group in Dorset was published by Talbot (1971), who identified three main cement stages; a localised non-ferroan calcite assumed to be of meteoric origin, a more widespread fibrous ferroan calcite, and a pervasive blocky ferroan calcite spar. Subsequently, Sun (1990) described the diagenesis in parts of the Corallian succession in the context of his proposed regressive and transgressive cycles. He suggested that transgressive units featured aragonite neomorphism, isopachous cement fringes and ferroan sparry calcites. Non- to dull-cathodoluminescent zoning suggested transition from oxygenated marine phreatic to anoxic burial conditions. In the regressive units Sun suggested that aragonite grains were mostly dissolved and cementation was dominated by mildly ferroan calcite spars with bright-dull luminescent subzones, which he linked to invasion of meteoric water. However, more detailed work on the diagenesis including stable isotope analyses has been lacking other than in unpublished PhD theses. The most recent of these is by Samuel Bishop (2002, Cambridge University). He considered that most of the diagenesis took place during shallow burial and mediated by bacterial activity. Much of the early calcite cementation took place during sulphate reduction, but with bicarbonate supplied from seawater and dissolution of metastable biogenic aragonite. Siderite formed during methanogenesis and bacterial iron reduction. Late ferroan calcite and dolomite cements in the limestones were sourced from continuing aragonite dissolution, augmented by chemical compaction. The concretions of the Bencliff Grit were also cemented during burial in modified marine pore fluids, with bicarbonate derived from shell dissolution. Bishop noted that there is no evidence for meteoric diagenesis below the sequence boundaries proposed by Coe (1995) and within regressive parts of cycles by Sun (1990).

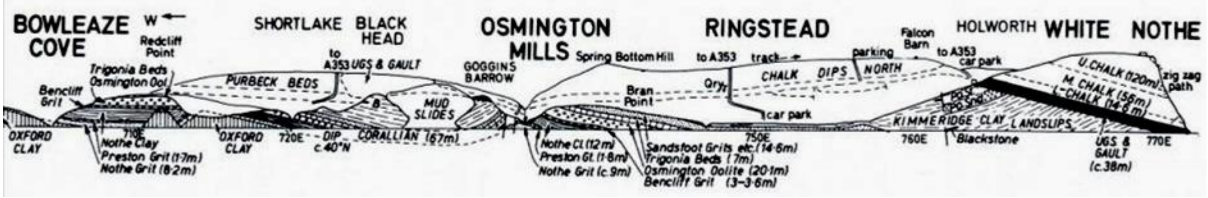
Objectives

- To examine evidence for early diagenesis and its relationship to bioturbation in the Osmington Oolite Formation
- To consider the origin of the lithological (mudrock – sandstone – limestone cyclicity in the Corallian Group as a whole
- To see the oil seep and spectacular carbonate cementation in the Bencliff Grit Formation
- To examine condensed ferruginous limestones of the Clavellata Beds Formation

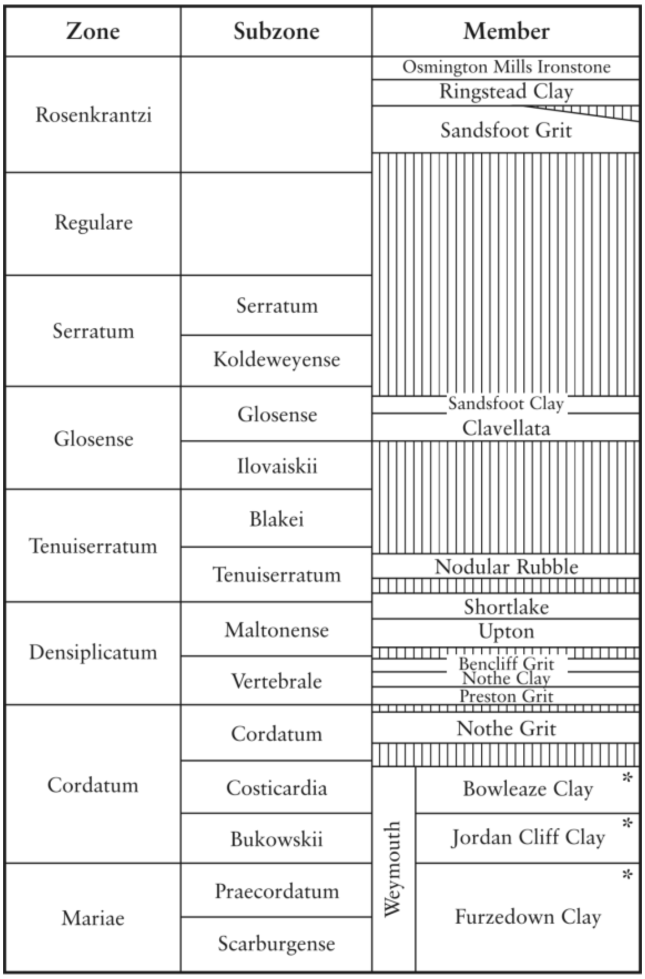
Figures



Geological map of the Osmington Mills area. From Wright and Cox (2001).

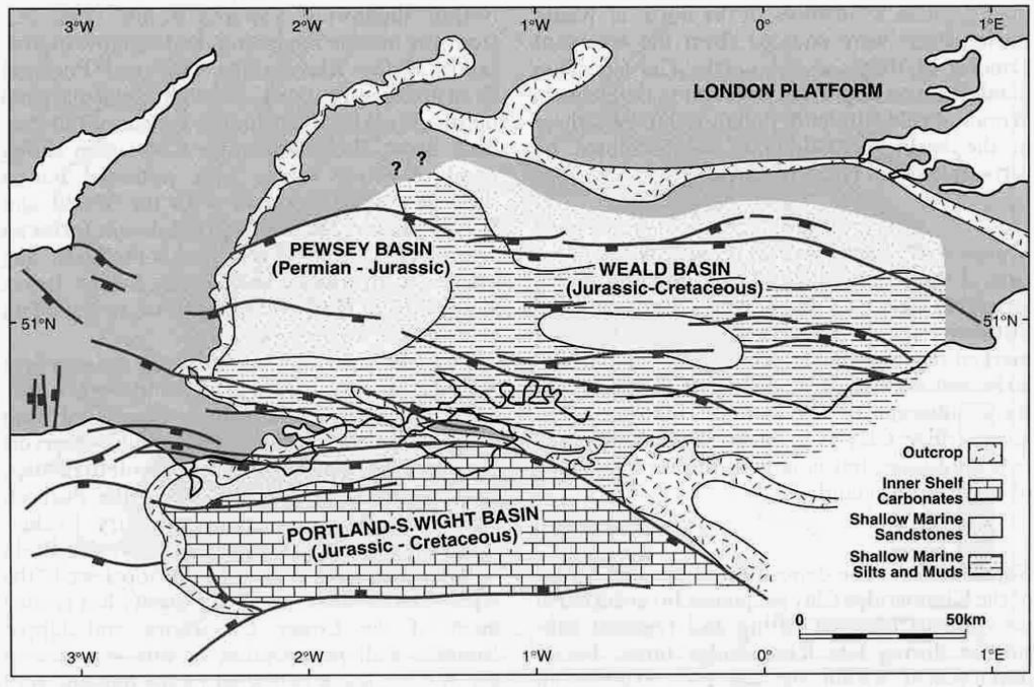


Cliff profile at Osmington Mills. From House (1993).

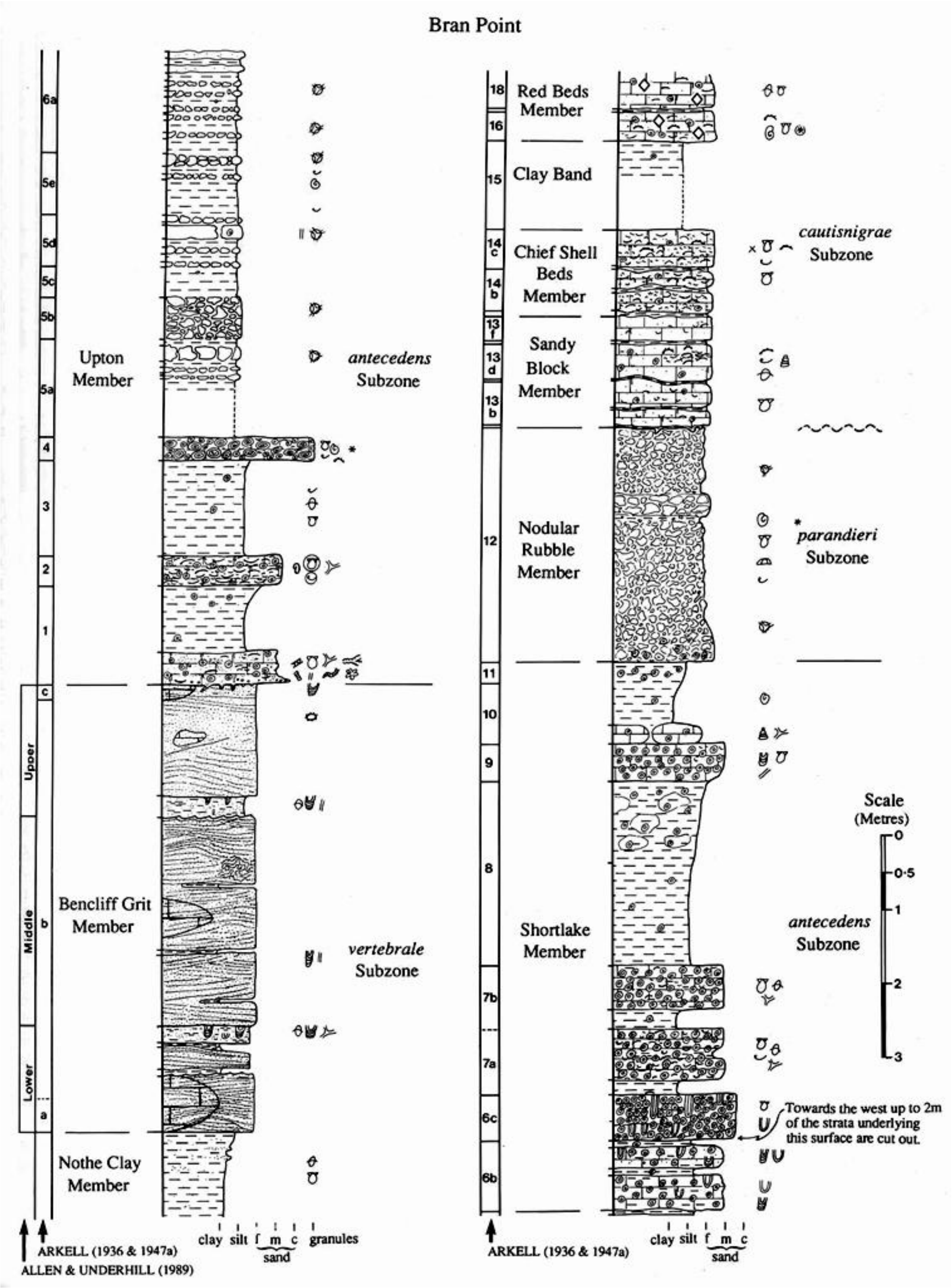


Zone	Subzone	Member	
Rosenkrantzi		Osmington Mills Ironstone Ringstead Clay Sandsfoot Grit	
Regulare			
Serratum	Serratum		
	Koldeweyense		
Glosense	Glosense	Sandsfoot Clay Clavellata	
	Ilovaiskii		
Tenuiserratum	Blakei		
	Tenuiserratum	Nodular Rubble	
Densiplicatum	Maltonense	Shortlake Upton	
	Vertebrale	Bencliff Grit Nothe Clay Preston Grit	
Cordatum	Cordatum	Nothe Grit	
	Costicardia	Weymouth	Bowleaze Clay *
	Bukowskii		Jordan Cliff Clay *
Mariae	Praecordatum		Furzedown Clay *
	Scarburgense		

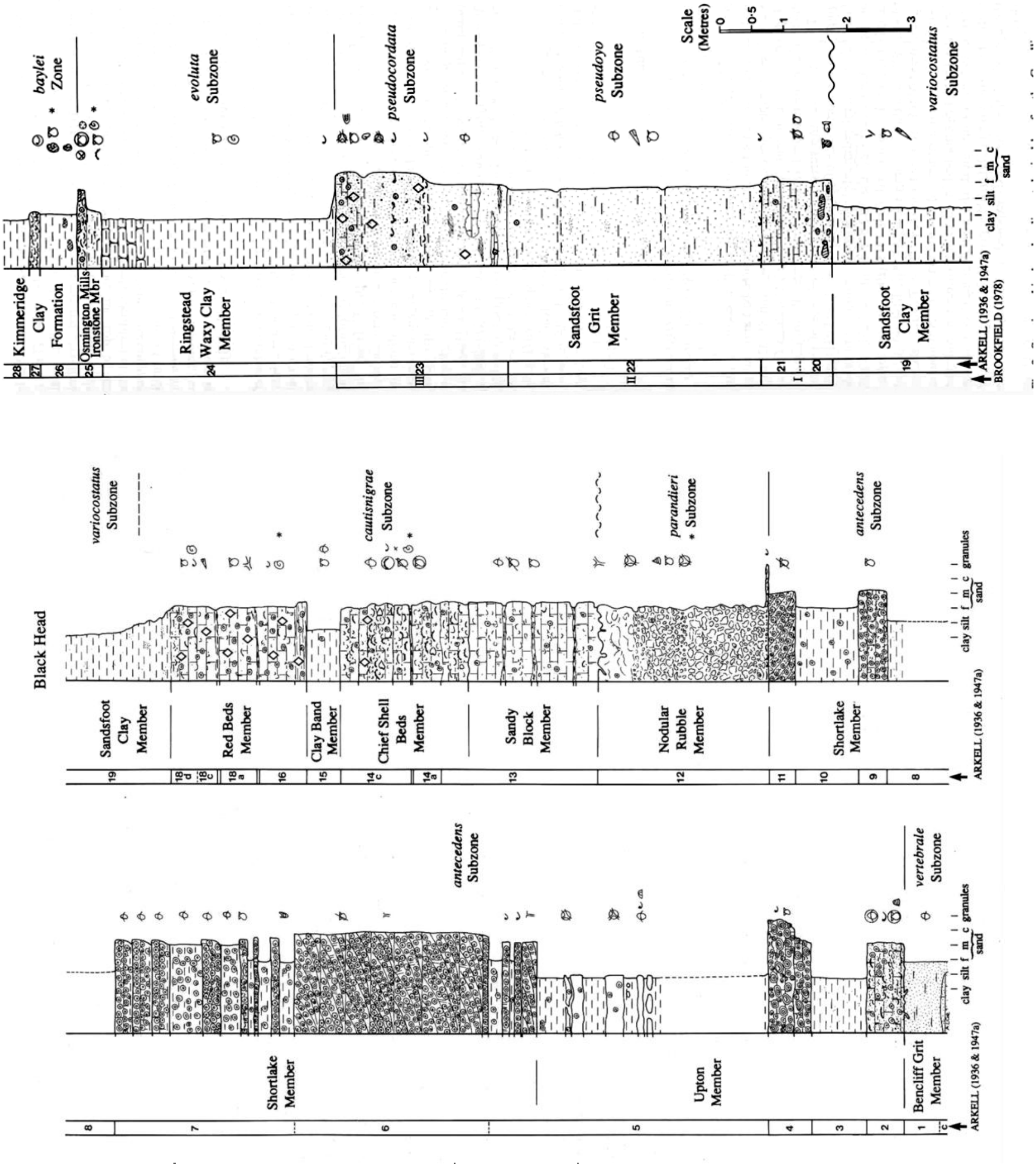
Biostratigraphy of the Corallian Group at Osmington Mills. From Wright and Cox (2001)



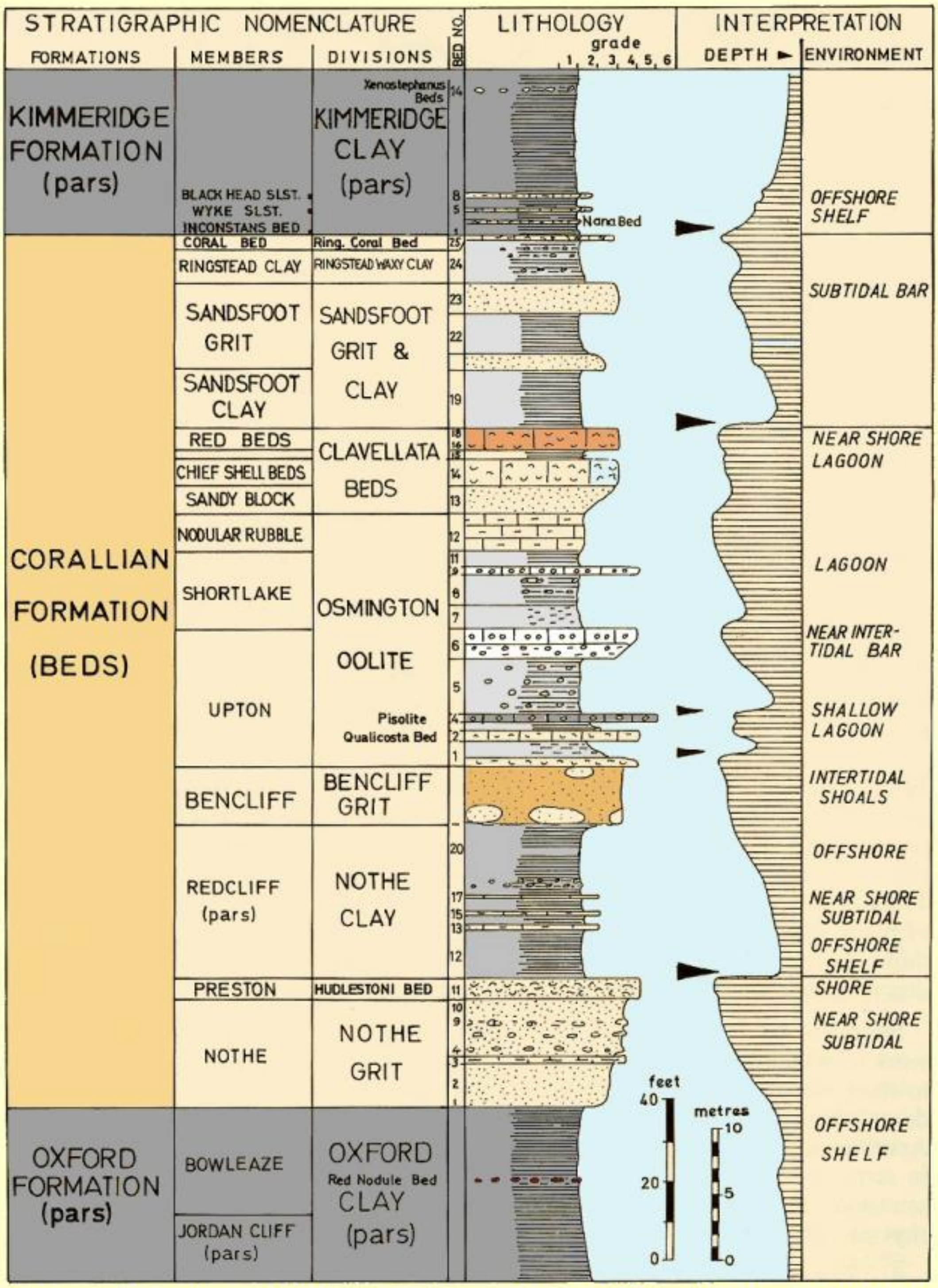
Regional gross lithological map for the subsurface Corallian Group, showing development of more siliciclastic facies close to basin margins and intra-basinal highs. From Hawkes et al. (1998)



Graphic sedimentary log of the Corallian Group exposed at Osmington Mills to Bran Point. From Coe (1995)

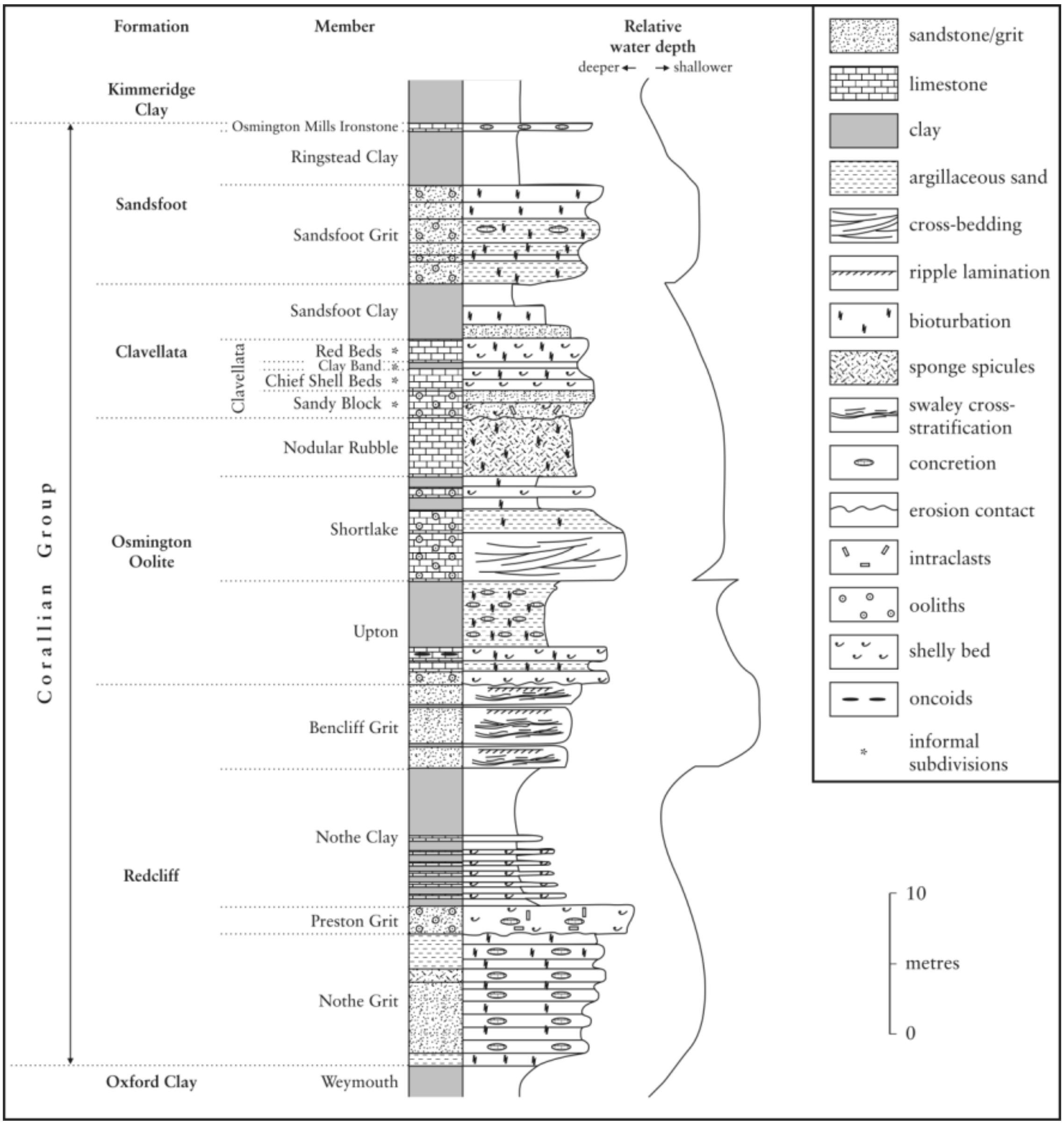


Graphic sedimentary logs of the Corallian Group exposed at Black Head. From Coe (1995)

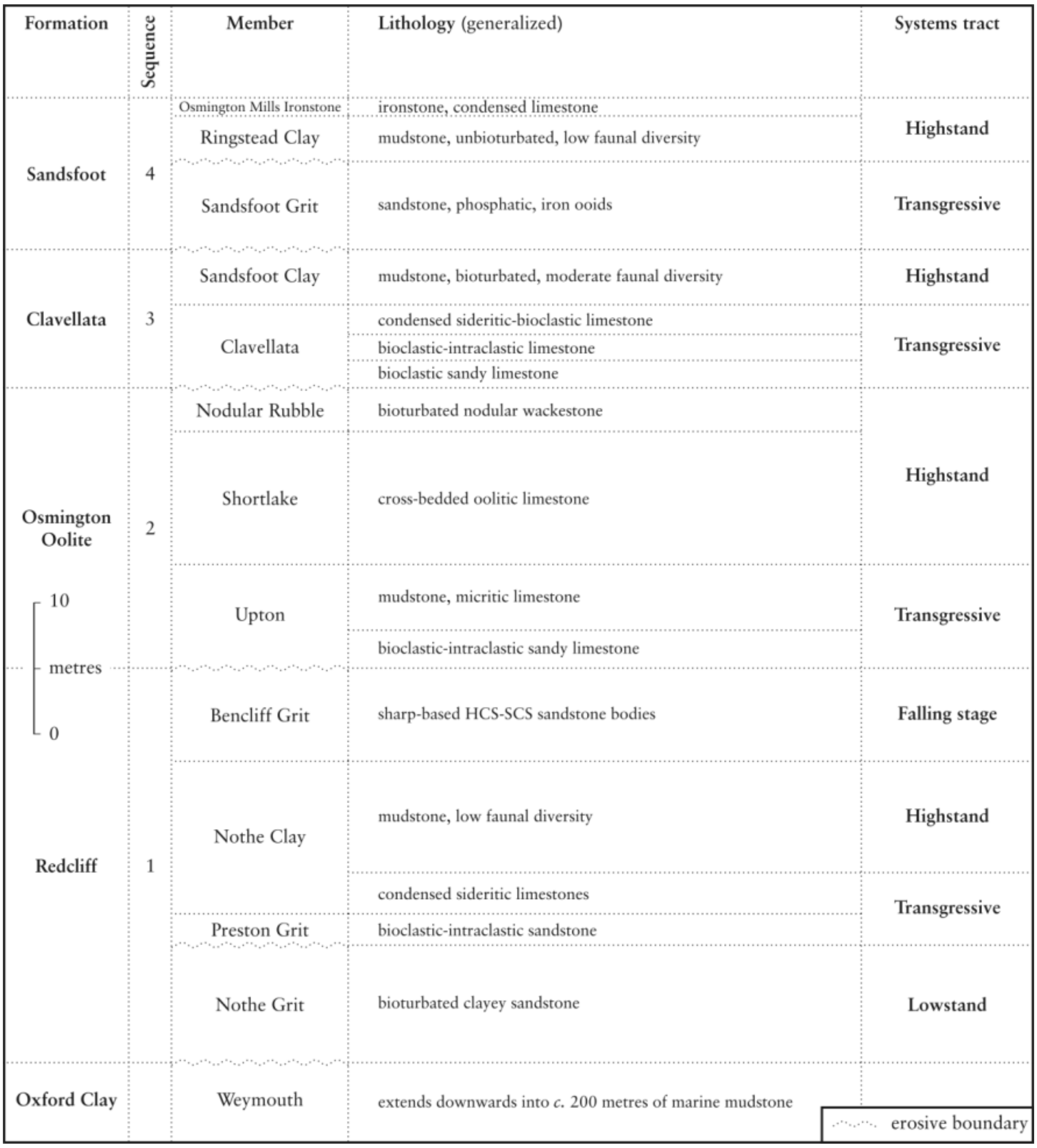


The sequence of Corallian strata in the Osmington Mills area. Modified after House (1993), based on Arkell (1947) and Talbot (1973). *Ian West & Tonya West (c) 2006.*

From "geology of the Wessex Coast" web site.

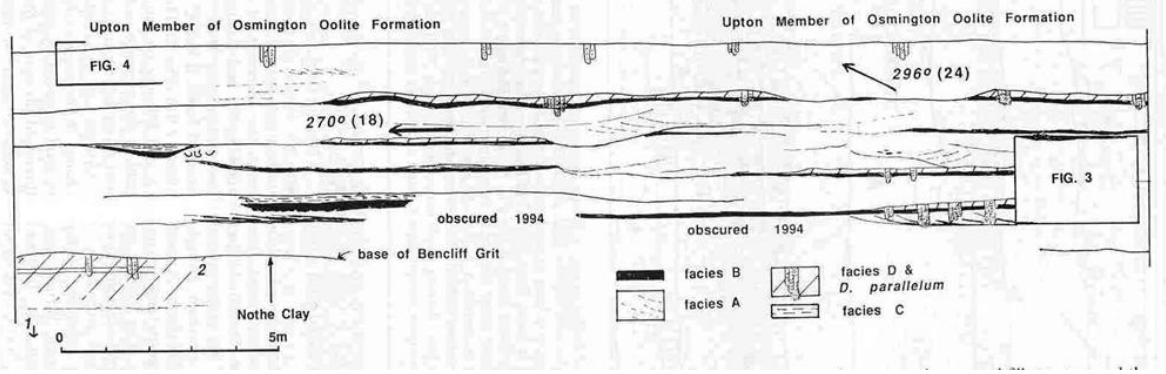


Sequence stratigraphic interpretation of the Corallian group, based on Newell (2000), in Cox and Wright (2001)

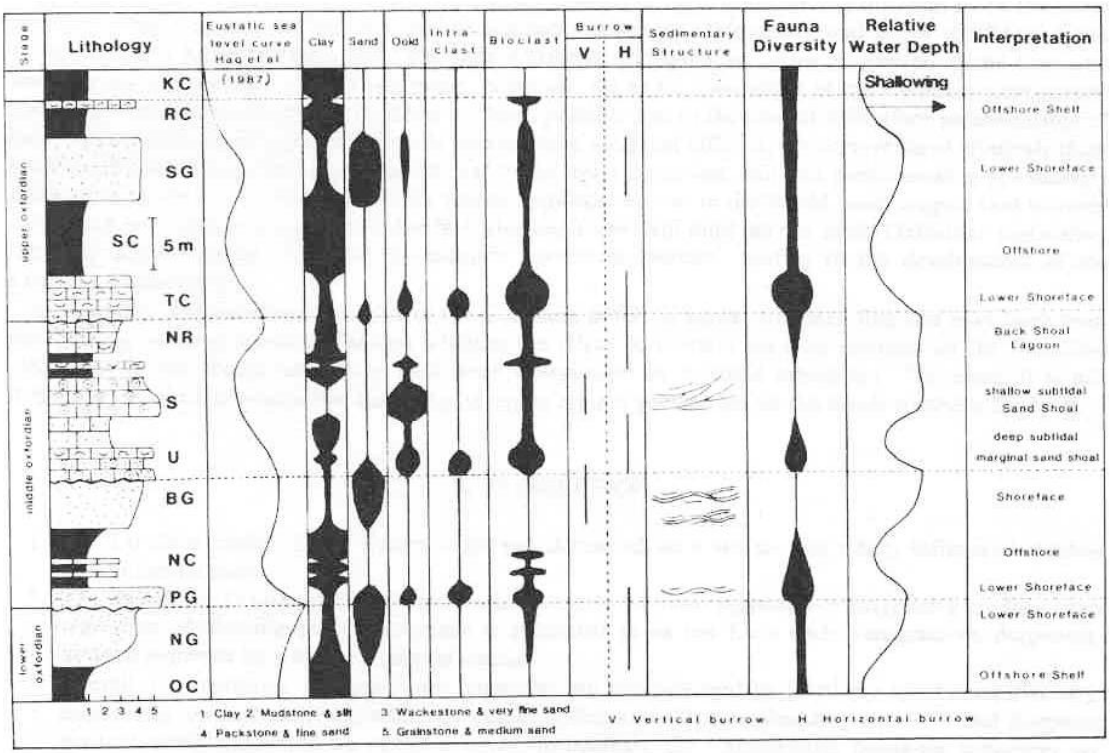


Formation	Sequence	Member	Lithology (generalized)	Systems tract
Sandsfoot	4	Osmington Mills Ironstone	ironstone, condensed limestone	Highstand
		Ringstead Clay	mudstone, unbioturbated, low faunal diversity	
		Sandsfoot Grit	sandstone, phosphatic, iron ooids	Transgressive
Clavellata	3	Sandsfoot Clay	mudstone, bioturbated, moderate faunal diversity	Highstand
		Clavellata	condensed sideritic-bioclastic limestone bioclastic-intraclastic limestone bioclastic sandy limestone	Transgressive
Osmington Oolite	2	Nodular Rubble	bioturbated nodular wackestone	Highstand
		Shortlake	cross-bedded oolitic limestone	
		Upton	mudstone, micritic limestone bioclastic-intraclastic sandy limestone	Transgressive
Redcliff	1	Bencliff Grit	sharp-based HCS-SCS sandstone bodies	Falling stage
		Nothe Clay	mudstone, low faunal diversity	Highstand
			condensed sideritic limestones	Transgressive
		Preston Grit	bioclastic-intraclastic sandstone	
		Nothe Grit	bioturbated clayey sandstone	Lowstand
Oxford Clay		Weymouth	extends downwards into *c.* 200 metres of marine mudstone	

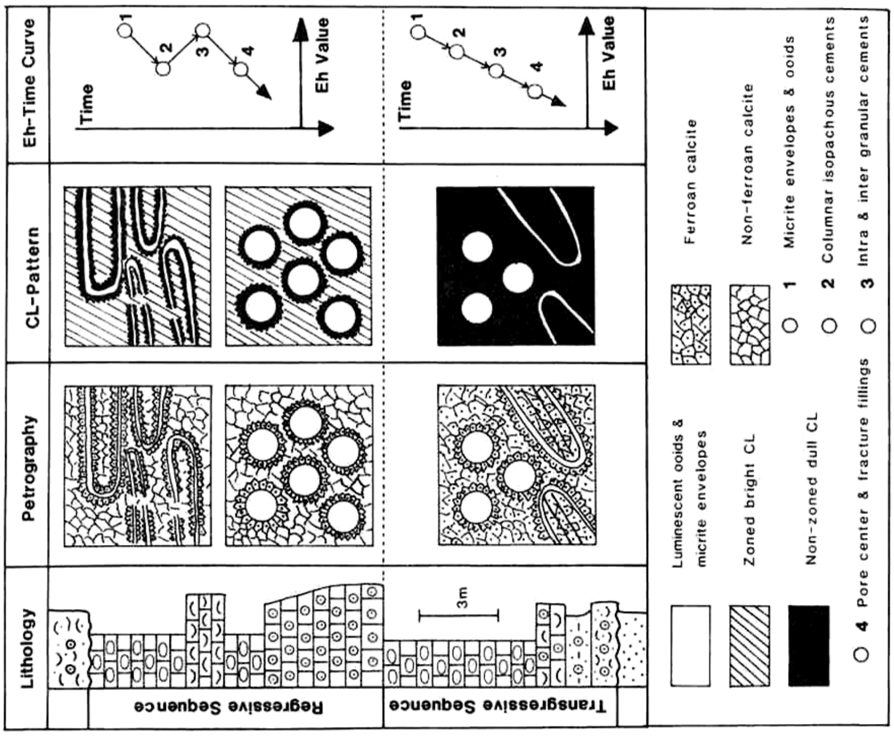
Sequence stratigraphic interpretation of the Corallian group, based on Newell (2000), in Cox and Wright (2001)



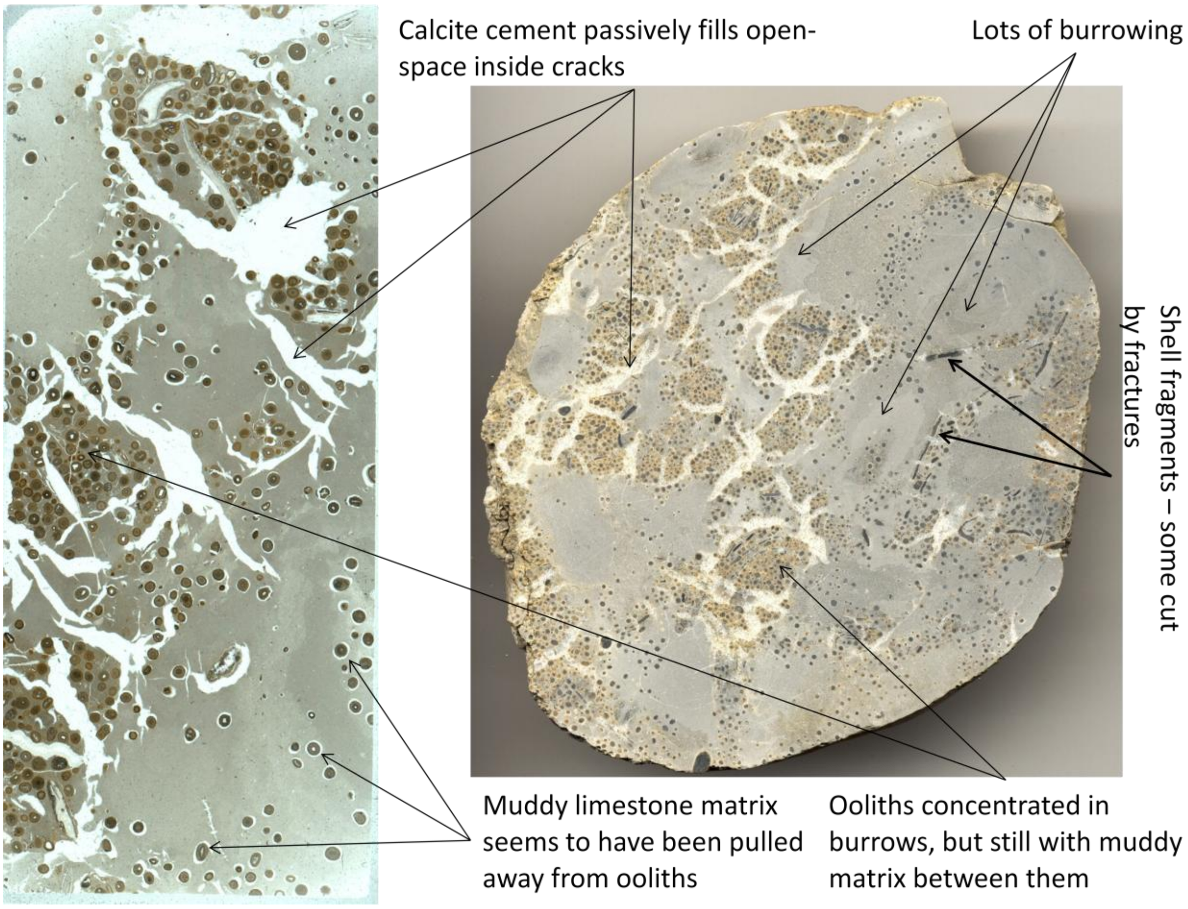
Facies profile of the Bencliff Grit at Osmington Mills. A = Swaley cross bedded sandstones. B = mudstone / siltstone. C = flaser bedded heterolithics. D = bioturbated heterolithics. From Goldring et al. (1998)



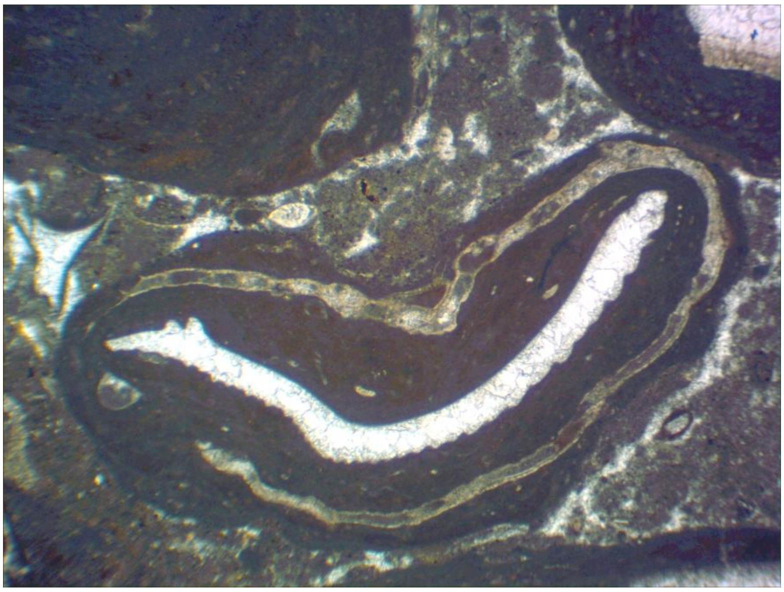
Facies and sea-level interpretation of the Corallian Group in Dorset by Sun (1989)



Contrasting calcite cement petrography in regressive and transgressive units of the Corallian Group. From Sun (1990)



Example of unusual concretionary limestone from the Shortlake Member at Osmington Mills



Oncoid with bivalve nucleus, Upton Member, Osmington Mills. Field of view 4 mm.

Web link to "Geology of the Wessex Coast"

- **http://www.soton.ac.uk/~imw/osmill.htm**

  Also

- http://www.soton.ac.uk/~imw/osring.htm
- http://www.soton.ac.uk/~imw/osben.htm
- http://www.soton.ac.uk/~imw/Osmington-Oolite.htm

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3. THE PURBECK FORMATION AT LULWORTH COVE AND STAIR HOLE

Introduction

Lulworth Cove and Stair Hole are world famous for their coastal geomorphology, as well as their Upper Jurassic – Middle Cretaceous sedimentary succession and their spectacular tectonic deformation. We will park in the visitor centre car park at Lulworth Cove (SY822800) and walk up to a view point on the western side of Stair Hole from where it is possible to examine the deformation in the Lulworth Formation owing to Alpine inversion on the underlying segment of the Purbeck – Isle of Wight Fault zone. Of particular note is the small scale folding and faulting ("The Lulworth Crumple") and its geodynamic significance. Tide permitting, the Lulworth Formation strata can be examined more closely in Stair Hole and also at the Fossil Forest site above the eastern side of Lulworth Cove. The latter is accessed by footpath to the cliff top from the eastern side of the cove (SY827797), and access is only possible when the adjacent firing range is not being used by the Ministry of Defence (red flags indicate that access is prohibited). Additional features of interest will be pointed out as we walk around the cove. The only significant hazards that may be encountered are some steep drops, and a risk of cliff fall in Stair Hole and at the eastern side of Lulworth Cove. Please avoid standing beneath overhangs, close to sheer cliff faces or on unprotected cliff edges.

Please note that hammering is not allowed at Lulworth Cove.

Overview

Much has been written about the Purbeck Group, and it is one of the most intriguing units in the Jurassic of the Dorset coast. It consists of a thinly bedded, heterolithic succession of limestones, marls and shales, many of which have high-abundance low-diversity mollusc and ostracod faunas indicative of environmental stress. Detailed lithostratigraphic descriptions are available for its type section in eastern Dorset (Clements, 1993) and for an important section in Worbarrow Bay (Ensom, 1985), and the overall lithostratigraphy was revised by Westhead and Mather (1996). Diagenesis of the Purbeck Group limestones has been addressed by El Shahat and West (1983).

The Purbeck Group was deposited during a regressive episode at the end of the Jurassic and beginning of the Cretaceous, and the depositional environments were coastal lagoons and lakes of varying salinity and shorelines that probably changed substantially through time. The overall palaeoenvironment is summarised in Batten (2002). Climate was semi-arid during deposition of the Lulworth Formation, as evidenced by the presence of evaporites in some units (West, 1975), illite and smectite-rich clay mineralogies, palaeosol characteristics (Andrews, 1988; Francis, 1986), and palynological data. It became more humid during deposition of the Durlston Formation in the Berriasian. In general depositional palaeoenvironments were brackish and occasionally marine for the Lulworth Formation, and marginally brackish to fresh for the Durlston Formation. Underhill (2002) interpreted regional variability in Purbeck Group facies and thicknesses in terms of syn-depositional faulting on the segmented Purbeck – Isle of Wight fault system. Underhill (2002) postulated that preservation of coniferous tree trunks associated with palaeosols in the lowermost part of the Lulworth Formation may have been due to rapid submergence following movement on adjacent normal faults. Most of these tree trunks have been removed, but silicified examples are still uncovered during quarrying operations on the Isle of Portland. They have been described by Francis (1983, 1984).

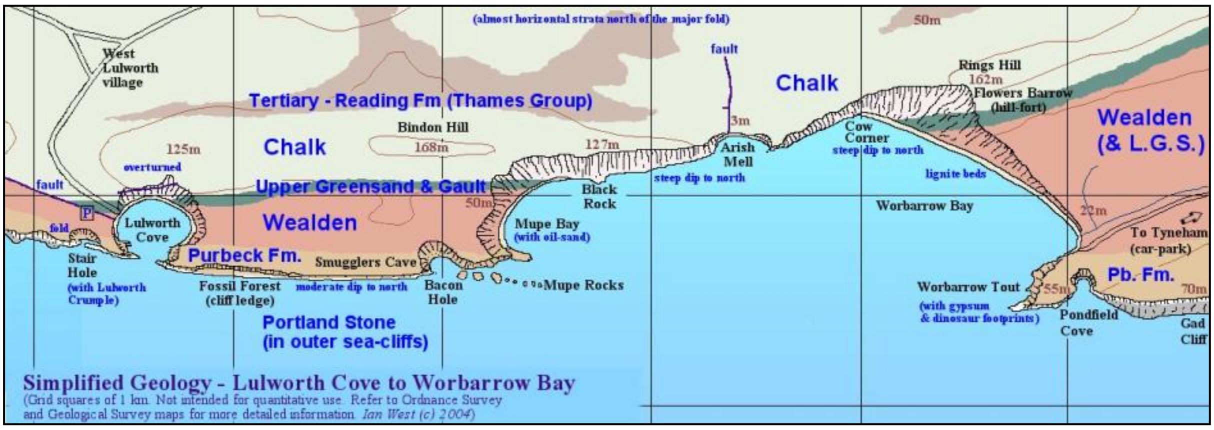
The lower part of the Lulworth Formation (Stair Hole Member) is laterally variable. On the Isle of Portland it consists of pebbly carbonaceous marl palaeosols, microbial bioherms, pelletal wackestones with foraminifera, and ostracod packstones. At Lulworth Cove this part of the succession is thicker and additionally contains an important development of the "broken beds". These are intraformational breccias, most of which consist of clasts of finely crystalline, laminated limestones that West (1975) interpreted as calcitised evaporites. However, in the upper part of the unit at Lulworth Cove the clasts consist of pelletal and ostracod-rich limestones similar to those of the overlying un-brecciated strata. the brecciation thereby transgresses facies boundaries. The cause of brecciation is contentious, with theories including collapse into voids left by rotting vegetation rooted in the underlying palaeosols, collapse into voids created by evaporite dissolution, and gravity sliding down the northern flank of the hanging wall anticline of the Purbeck – Isle of Wight fault (House, 1993). The broken beds thicken northwards towards the fault and thin dramatically across it, and folds in the broken beds visible at the Fossil Forest locality east of Lulworth Cove show a northerly vergence.

In addition to providing excellent exposure of the Lulworth Formation, Lulworth Cove is usefully situated on the steeply dipping northern limb of a monoclinal flexure developed above the inverted Purbeck – Isle of Wight fault system. Hence the exposed strata (from the Portland Stone Formation to the Lower Chalk) are steeply dipping or vertical, and smaller scale folding and faulting can also be seen. The Chalk overlies a pre-Middle Cretaceous fault that was downthrown to the south, such that on the footwall the Chalk unconformably overlies the Kimmeridge Clay. This fault was reactivated in reverse sense during the Tertiary. In Stair Hole the Lulworth Formation (and part of the Durlston Formation) is contorted into several small scale folds with associated faults, called the “Lulworth Crumple”. There have been a variety of tectonic interpretations for this structure, including upward squeezing of strata from the region of the tight monoclinal fold hinge, gravity collapse on the steep fold limb, and a compressional drag fold formed during relative movement of the Portland Limestone Formation and the Berriasian Wealden Group. Underhill and Paterson (1998) use seismic data as well as field observations to show that the structure most likely represents folding produced by intraformational (flexural) slip during buckling of the strata against the footwall of the Purbeck-Isle of Wight fault as it was compressed and reactivated.

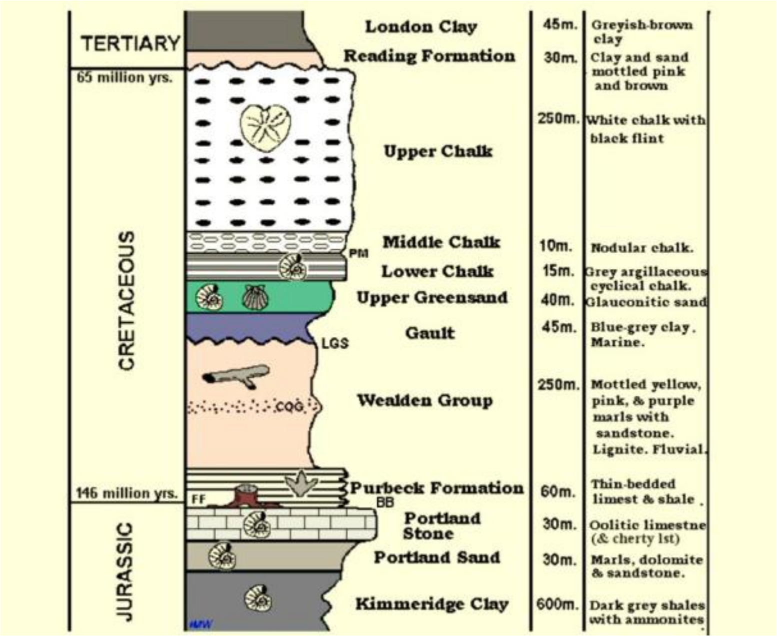
Objectives

- To examine the sedimentology of the Lulworth Formation, especially its lower part in comparison with the exposures on the Isle of Portland
- To consider the tectono-diagenetic origin of the basal Lulworth Formation “broken beds”
- To examine the tectonic deformation in the “Lulworth Crumple”

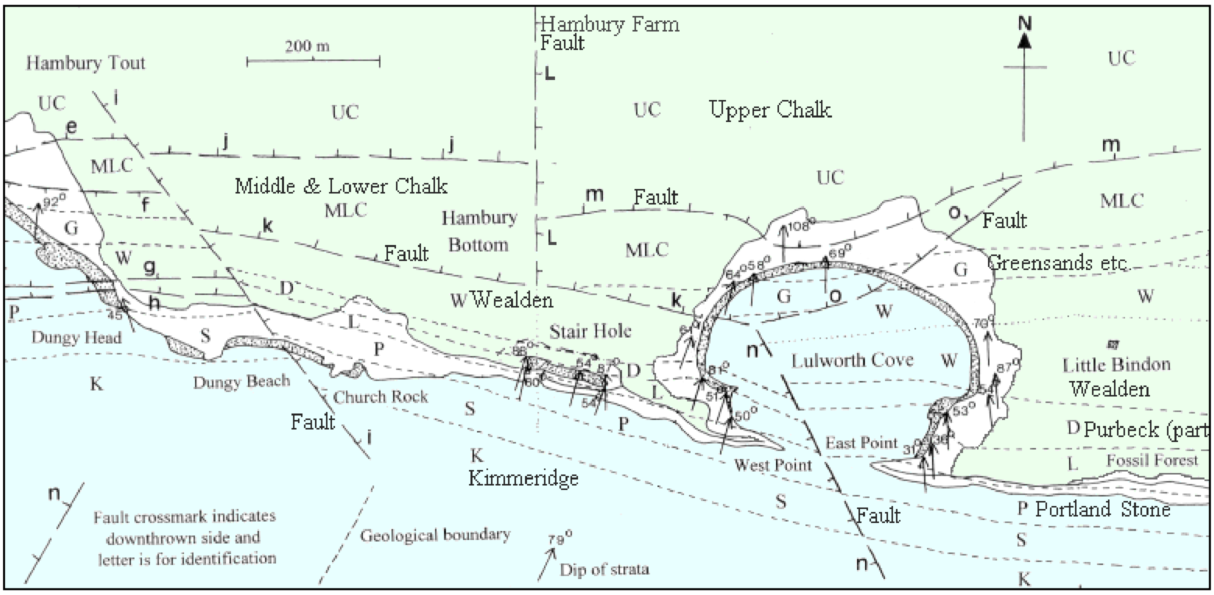
Figures



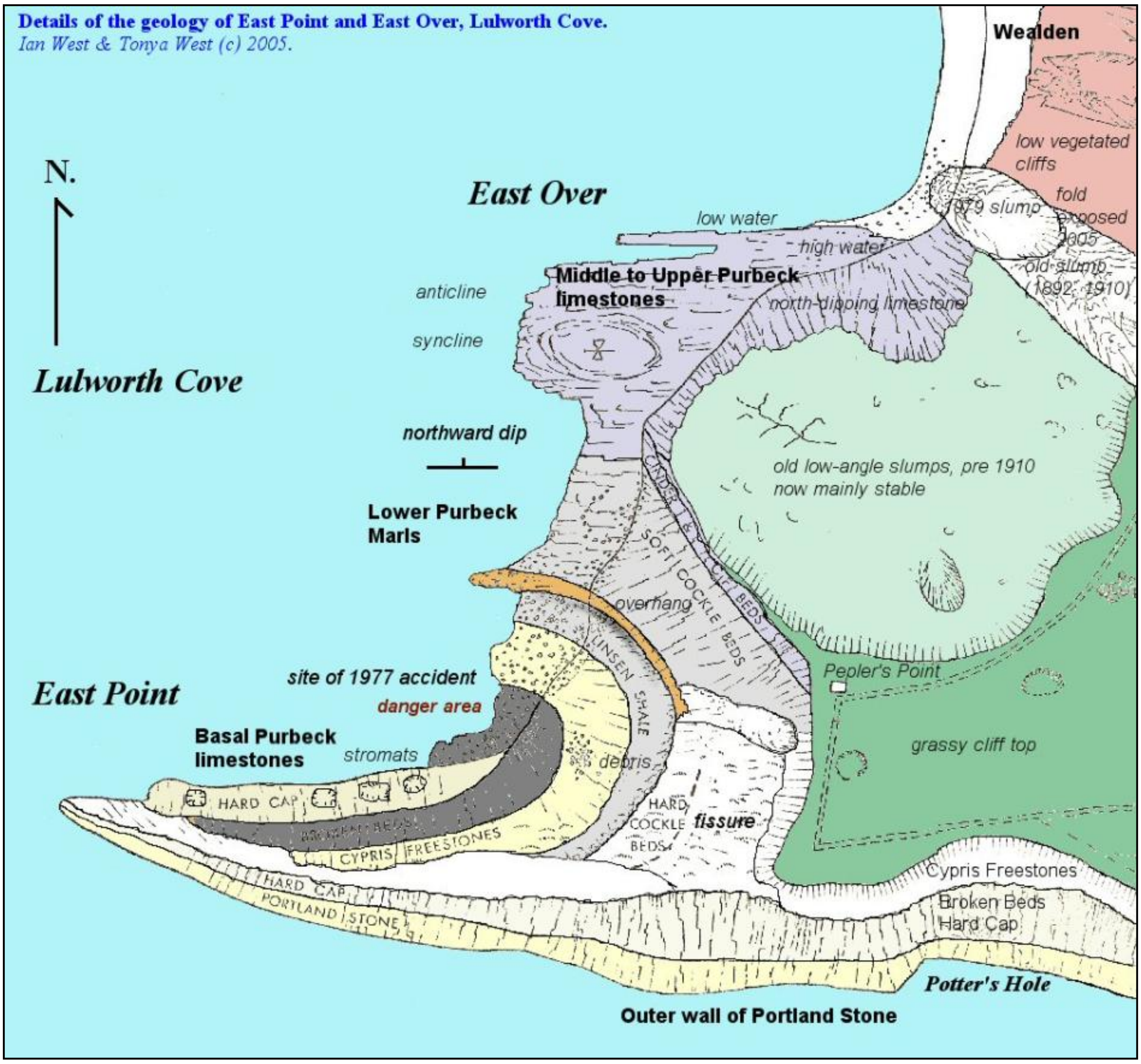
From “Geology of the Wessex coast” web site

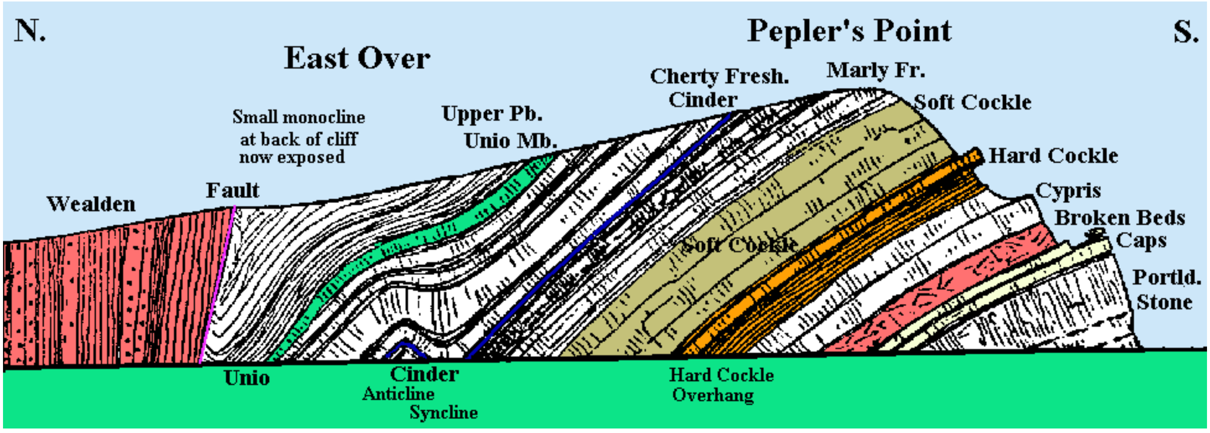


Summary of the succession at Lulworth Cove. From "Geology of the Wessex Coast" web site

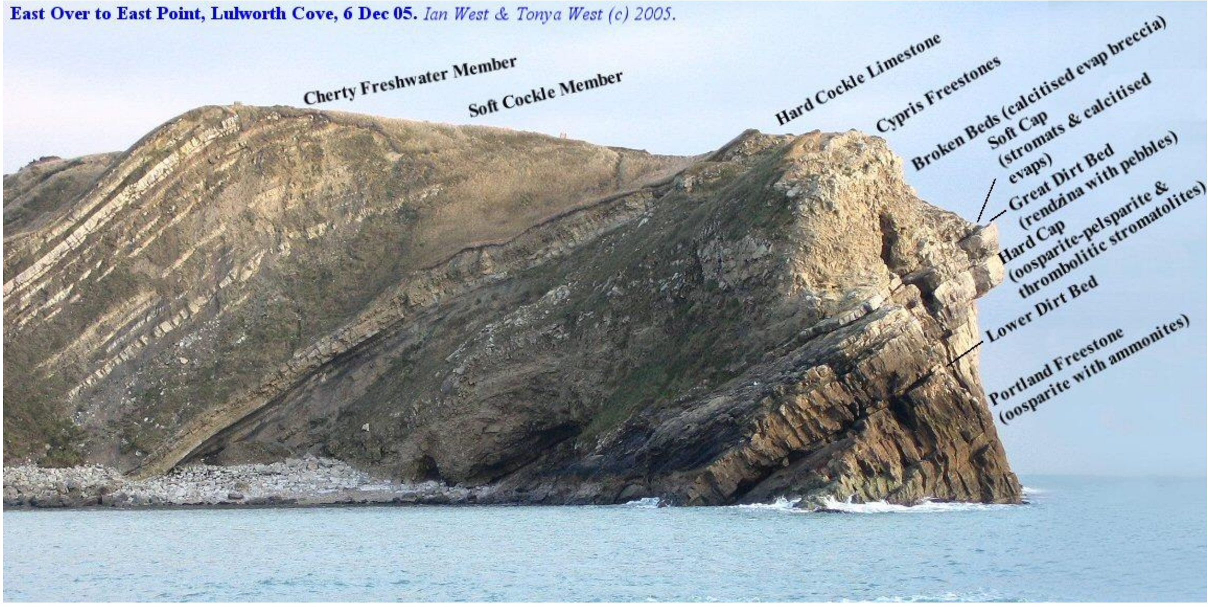


Geological map of Lulworth Cove. From "Geology of the Wessex Coast" web site.



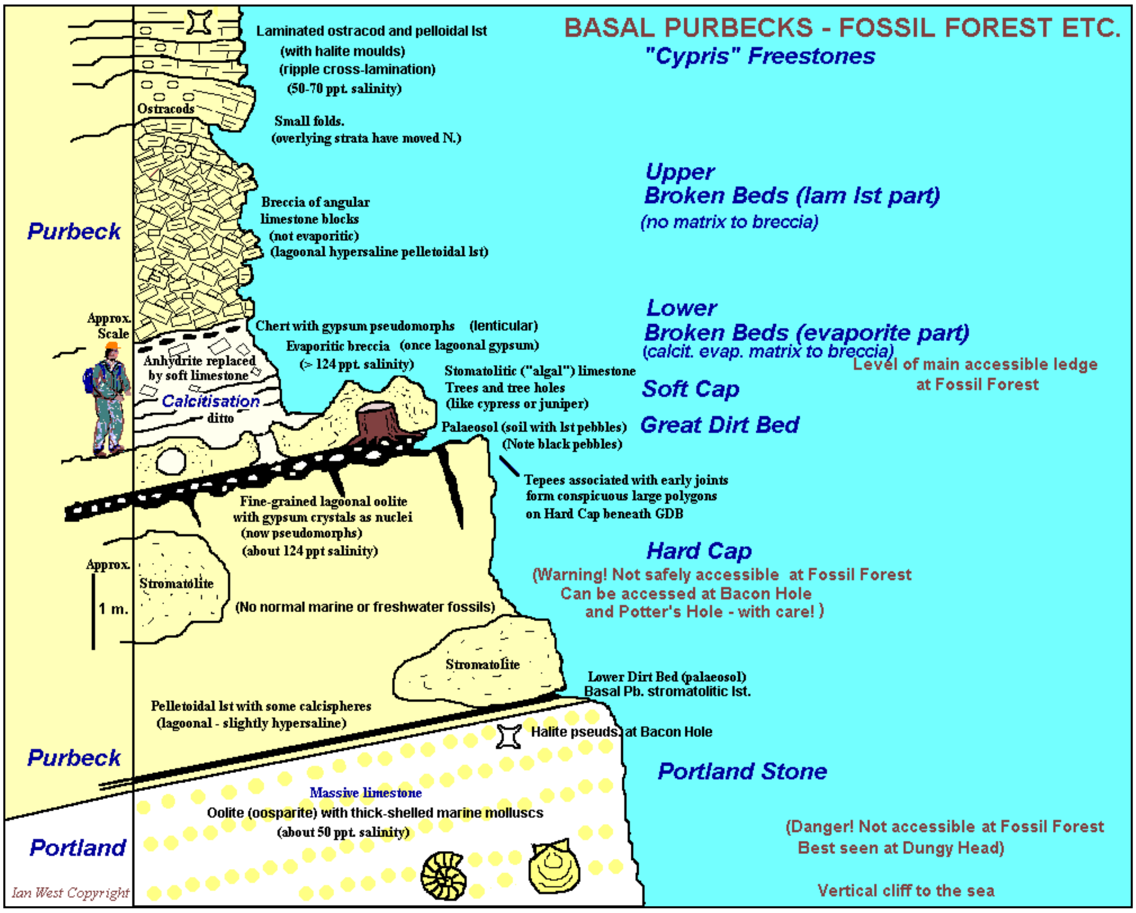


Detailed geological map and cliff profile from the eastern side of Lulworth Cove. From *"Geology of the Wessex Coast" web site.*



Annotated photo of the eastern side of Lulworth Cove. From "Geology of the Wessex Coast" web site.

Annotated photo of the western side of the Fossil Forest cliff-top exposure. From "Geology of the Wessex Coast" web site.



Geological interpretation of the succession visible at the Fossil Forest exposure. From "Geology of the Wessex Coast" web site.

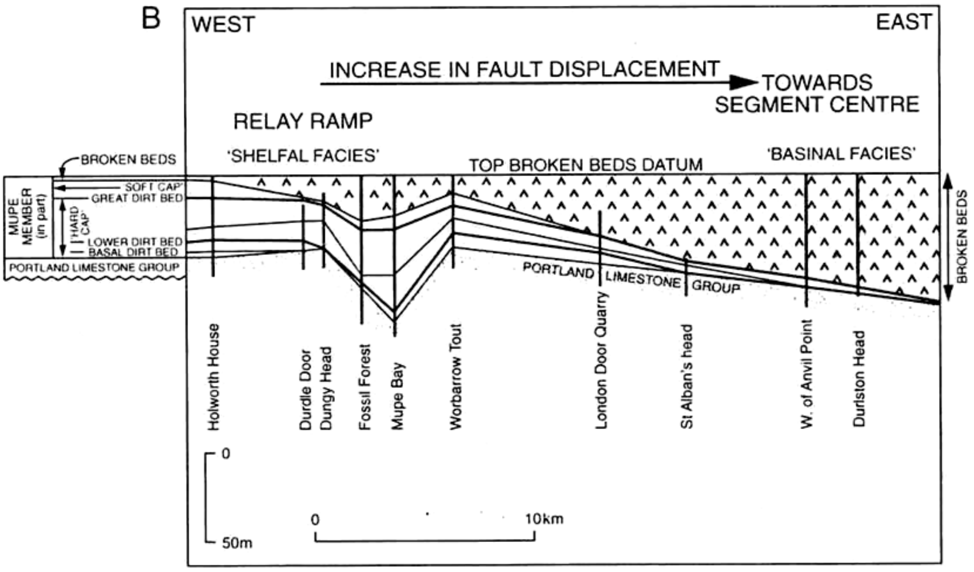
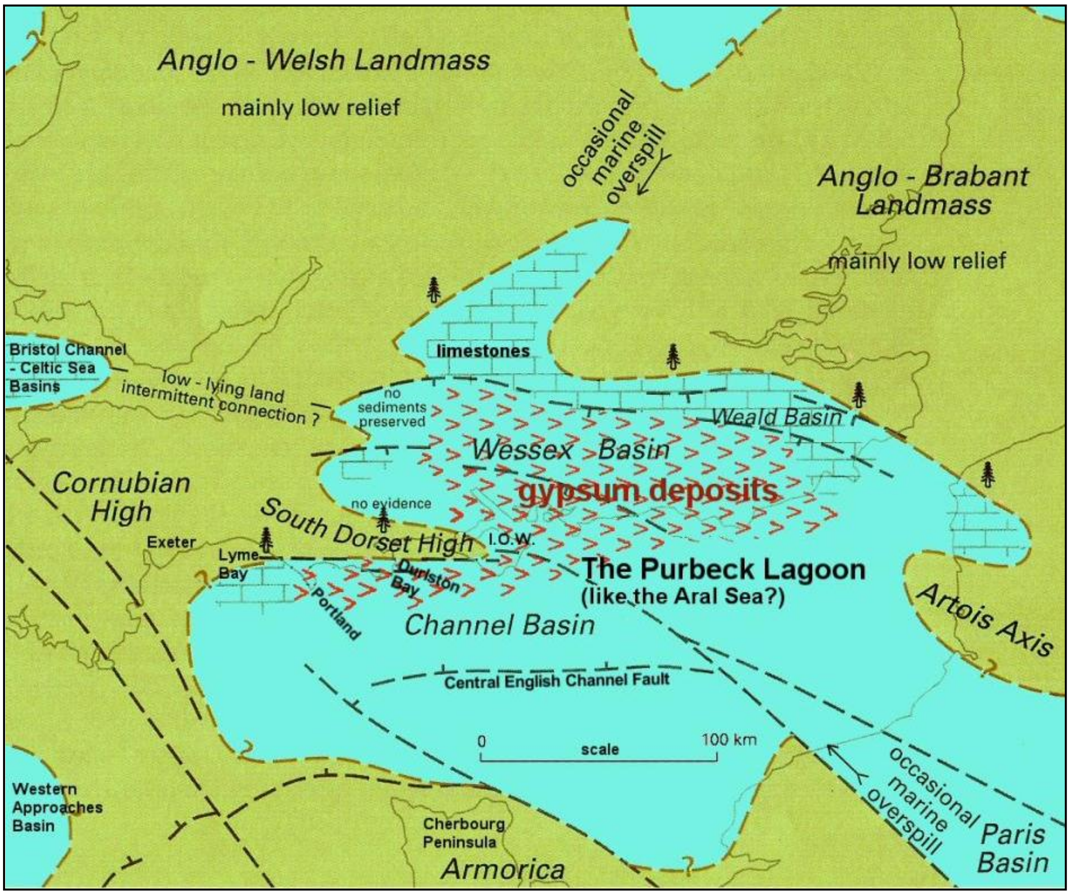
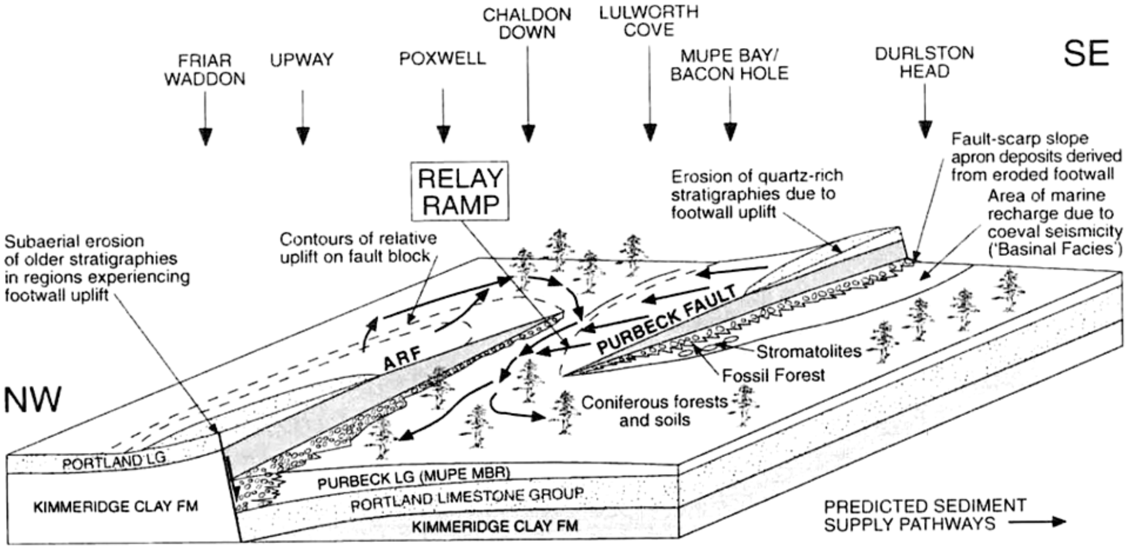


Diagram showing west to east increase in thickness of the Broken Beds, interpreted as reflecting greater thickness of evaporites deposited where syn-depositional throw on the segment of the Purbeck – Isle of Wight fault was greatest. From Underhill (2002). Away from the fault, on Portland, there was minimal development of the hypersaline lagoon.



Palaeogeography of the Lulworth Formation showing that Dorset was on the margin of the evaporite depocentre. From "Geology of the Wessex Coast" web site.



Depositional model for the lower part of the Lulworth Formation showing how syn-sedimentary faulting influenced facies changes and thicknesses. Ephemeral hypersaline lagoons were established where hanging wall subsidence and rollover created accommodation space. From Underhill (2002).

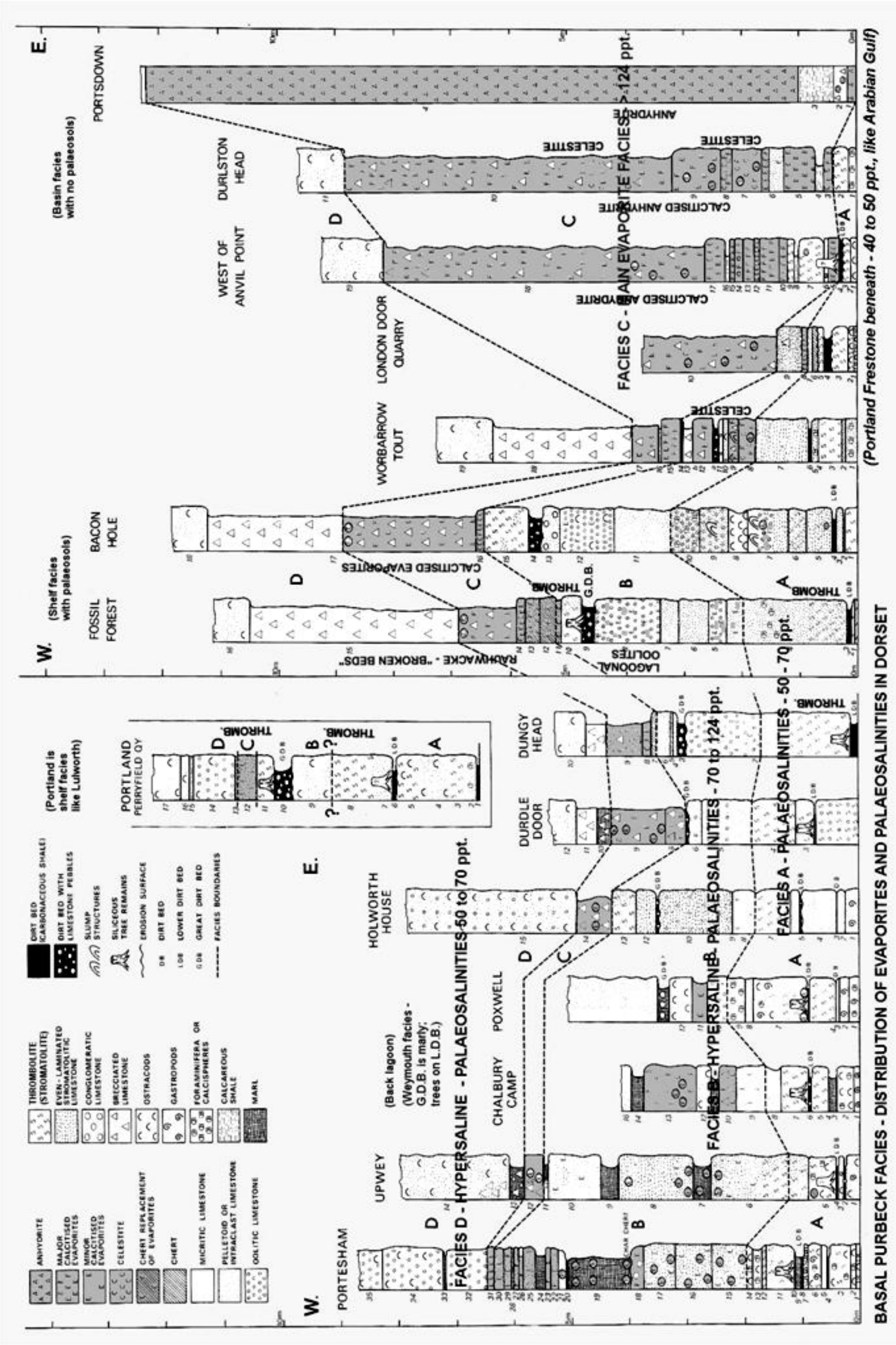
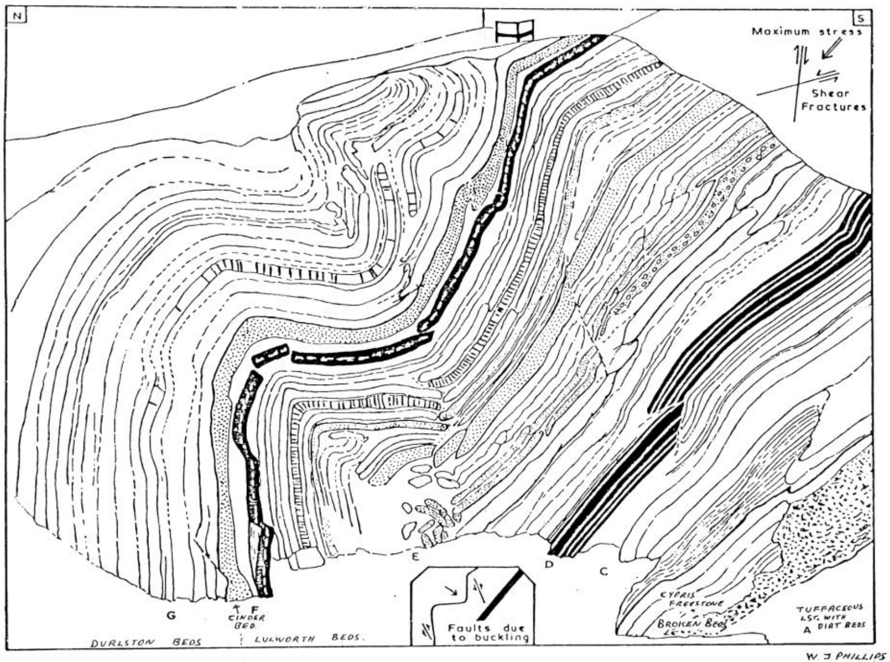
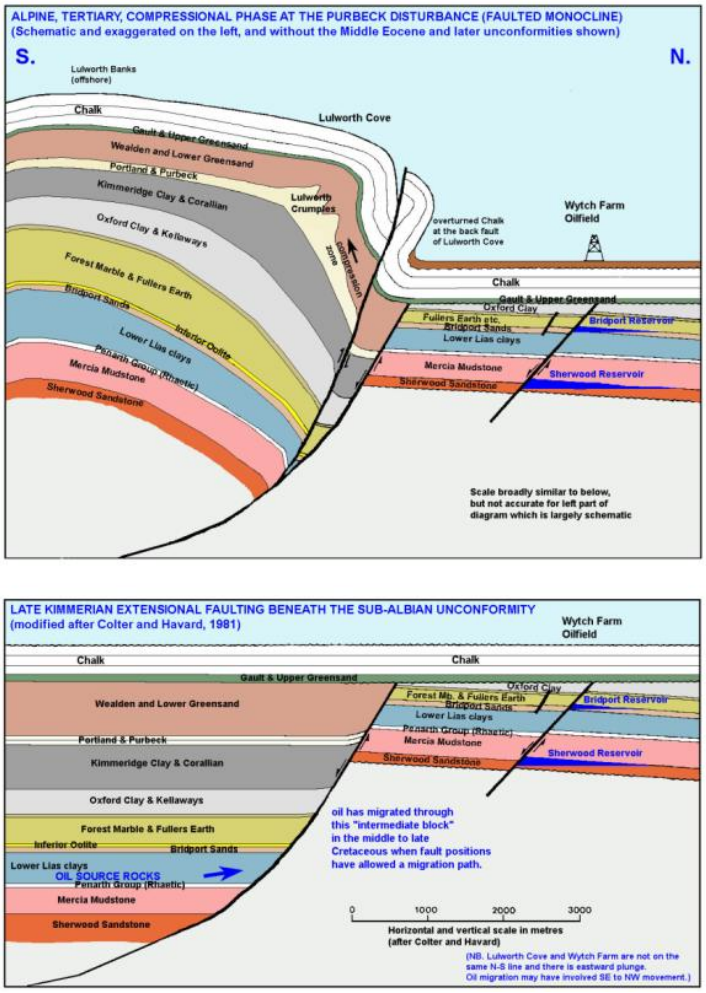


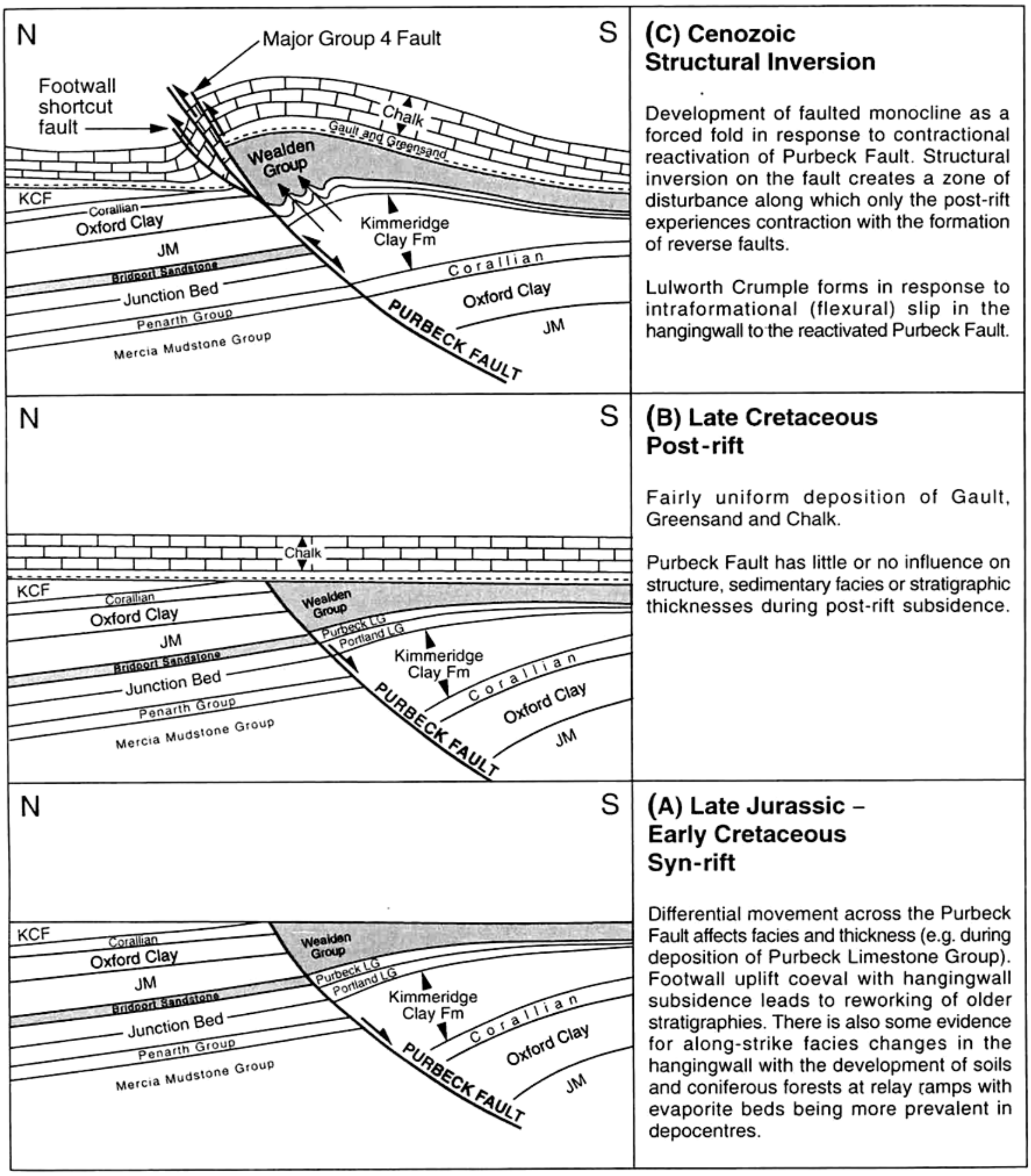
Diagram showing lateral variability in lower Lulworth Formation facies. From "Geology of the Wessex Coast" website, modified after West (1975).



The east side of Stair Hole (from a photograph taken from the opposite cliff)



Interpretation of the "Lulworth Crumple" modified from House (1993) by Ian West. In this version the folding is the result of compression forcing the strata upwards



(C) Cenozoic Structural Inversion

Development of faulted monocline as a forced fold in response to contractional reactivation of Purbeck Fault. Structural inversion on the fault creates a zone of disturbance along which only the post-rift experiences contraction with the formation of reverse faults.

Lulworth Crumple forms in response to intraformational (flexural) slip in the hangingwall to the reactivated Purbeck Fault.

(B) Late Cretaceous Post-rift

Fairly uniform deposition of Gault, Greensand and Chalk.

Purbeck Fault has little or no influence on structure, sedimentary facies or stratigraphic thicknesses during post-rift subsidence.

(A) Late Jurassic – Early Cretaceous Syn-rift

Differential movement across the Purbeck Fault affects facies and thickness (e.g. during deposition of Purbeck Limestone Group). Footwall uplift coeval with hangingwall subsidence leads to reworking of older stratigraphies. There is also some evidence for along-strike facies changes in the hangingwall with the development of soils and coniferous forests at relay ramps with evaporite beds being more prevalent in depocentres.

Interpretation of the "Lulworth Crumple" as the result of lateral compression of the strata against the footwall of the fault. From Underhill and Paterson (1998).

Web link to "Geology of the Wessex Coast"

- **http://www.soton.ac.uk/~imw/Lulworth.htm**

  Also

- http://www.soton.ac.uk/~imw/Stair-Hole-Lulworth.htm
- http://www.soton.ac.uk/~imw/Fossil-Forest.htm

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4. DOLOMITE BEDS WITH EXPANSION STRUCTURES IN THE UPPER KIMMERIDGE CLAY FORMATION AT KIMMERIDGE BAY

Introduction

The Kimmeridge Clay Formation is a series of mudrocks, bituminous shales and thin carbonates that are well exposed at several places on the Dorset coast. Overall the formation exhibits a trend of upward decreasing and then increasing silt and carbonate content, with the middle part dominated by organic-rich mudrocks and diagenetic carbonate beds (Cox and Gallois, 1981). Within the formation there is cyclicity at several scales, some possibly related to orbitally-forced climate changes. There has been intense study of the formation in Dorset because, although immature for oil generation, it is the best exposure of what is the principal source rock for North Sea oil. Much recent research has focussed on high-resolution stratigraphy (e.g. Cope, 2009; Hesselbo et al., 2009; Gallois, 2002; Morgans-Bell et al., 2001). The diagenetic carbonates are best exposed on the western side of Kimmeridge Bay. Access is via a toll road, through Kimmeridge village, to a private car park (SY907793). From there a path descends to the foreshore, which can be followed westwards parallel to the foot of the cliffs for about 250m. Owing to the gentle regional dip, cemented beds form prominent relatively more resistant “ribs” that stand proud of the beach level below high tide mark. Hazard-wise, the two things to be aware of are the slippery seaweed- and algae-covered foreshore, and the frequent cliff fall even in good weather. Hard hats should be worn when close to the cliff, but any vertical or overhanging sections are best avoided.

Overview

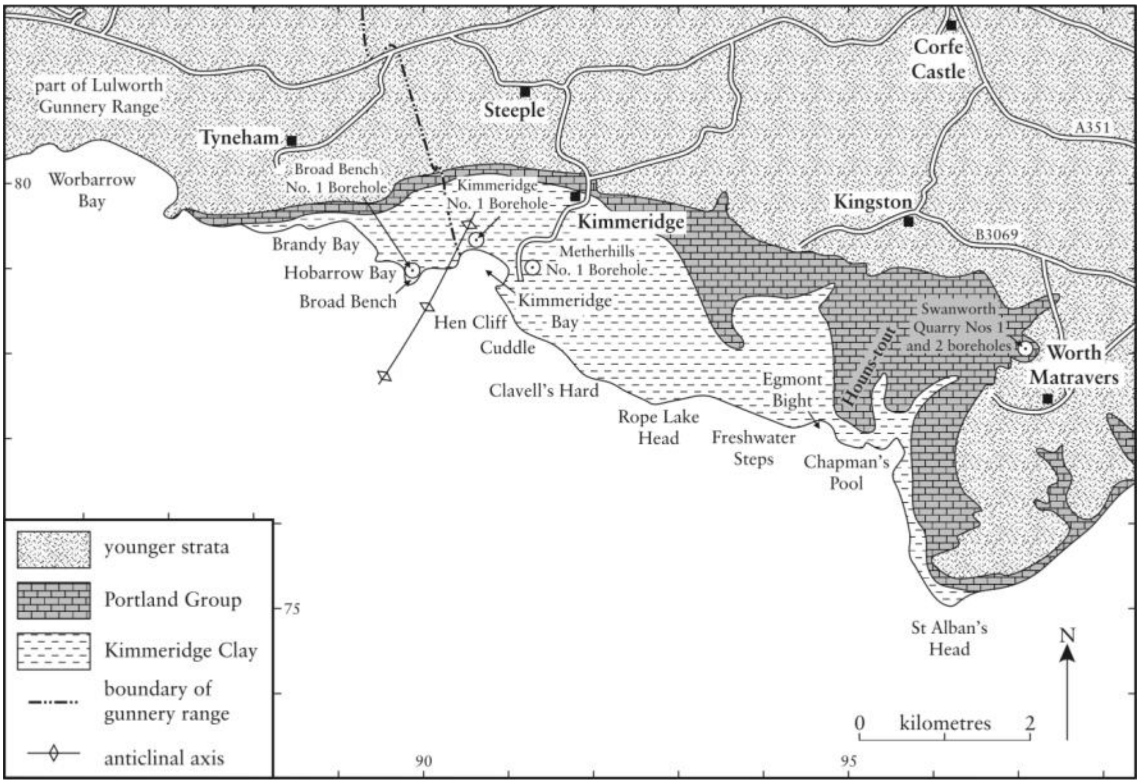
The cemented beds in the middle part of the Kimmeridge Clay have been studied isotopically by Irwin (1980, 1981) and petrographically by Feistner (1989). Their origin is established as being due to the bacterial and thermal breakdown of organic carbon. Unlike early diagenetic calcite concretions in the lower part of the Kimmeridge Clay (Scotchman, 1991, 1989) these continuous cemented beds are formed of ferroan dolomite. They nucleated during moderately deep burial in beds containing detrital carbonate (probably coccoliths) and show outward trends of depletion in ^{18}O (increased burial) and ^{13}C (change from methanogenesis to thermal decarboxylation as a bicarbonate source). Irwin ascribed these to concentric growth of the concretionary bed, but Feistner demonstrated zonation of the component dolomite crystals that supports a pervasive growth model whereby paragenetically later cements fill porosity remaining between earlier nucleated precipitates. Concentration of the diagenetic carbonate in specific beds suggests that changes in sedimentation rate may have been important for maximising the exposure of organic matter to bacterial methanogenesis. However, sedimentation must have been sufficient to transport labile organic matter beyond the sulphate reduction zone, as authigenic pyrite and calcite are rare. Matthews et al. (2004) reported an iron-isotope study of the dolomites that summarises previous research on their formation as well as presenting new data on Fe isotope fractionation between the dolomite and pore fluids.

One of the dolomite beds, the Flats Stone Band, is very distinctive. It contains a polygonal set of small-scale thrust faults that have been interpreted as either diagenetic or tectonic in origin. Bellamy (1977) proposed that they record expansion of the bed during dolomitisation, noting the relatively clay-poor composition of the bed (up to 95% dolomite) and the elongation of dolomite crystals perpendicular to bedding. However comparable features are not present in other cemented beds within the formation. Leddra et al. (1987) also considered the thrusts to be burial diagenetic in origin, but many structural geologists disagree.

Objective

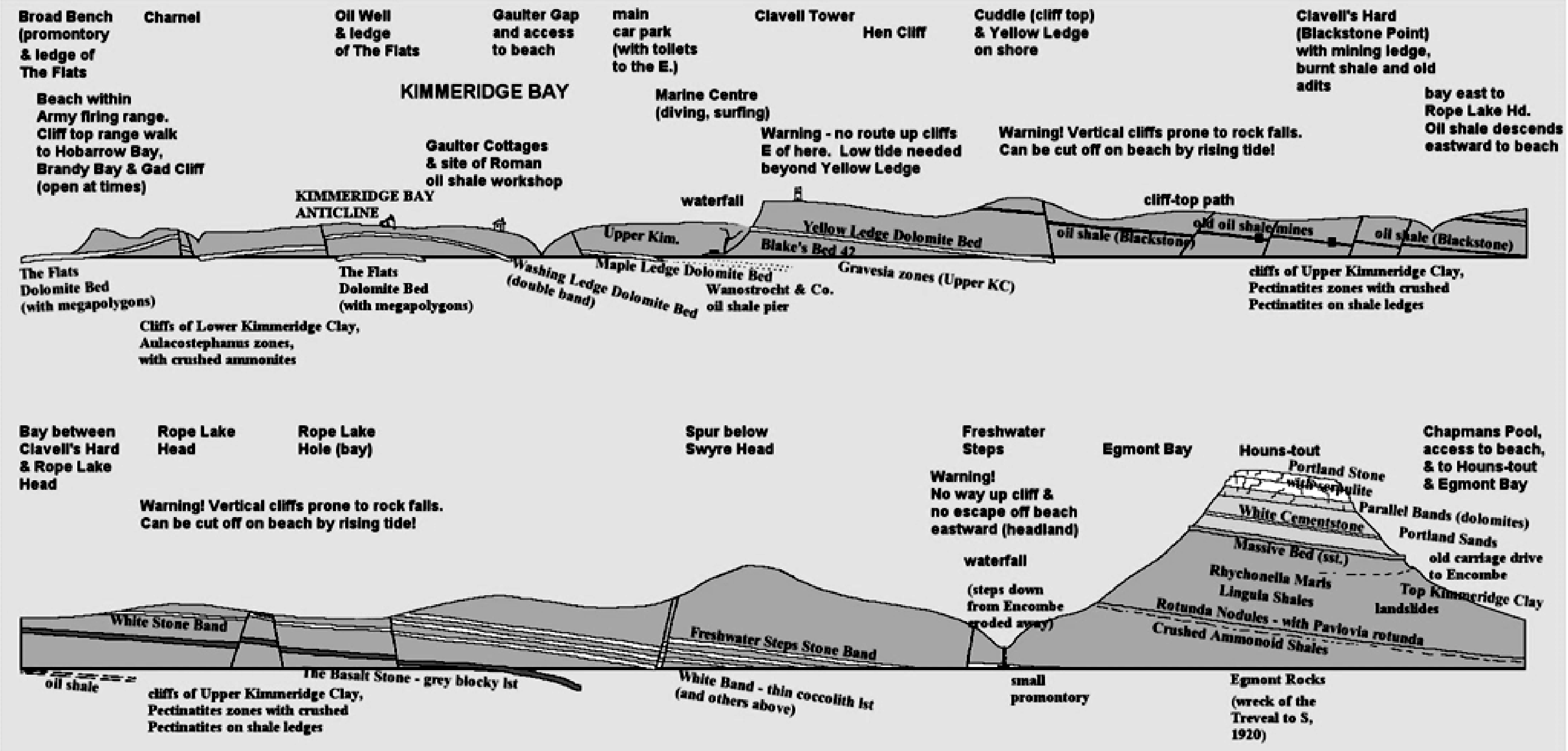
- To examine the Flats Stone band and its polygonal thrust faults, and to discuss possible interpretations for its characteristics.

Figures



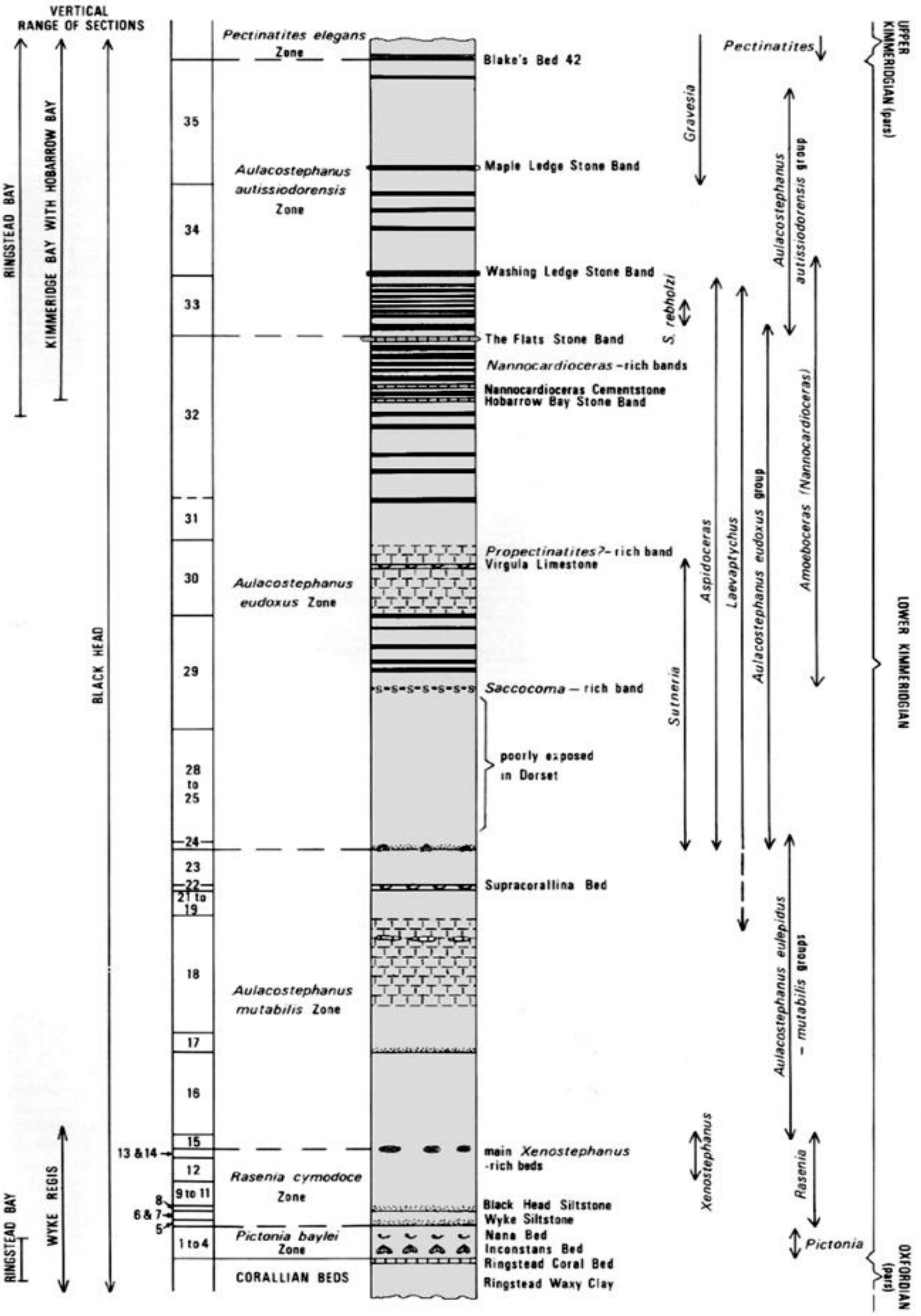
Geological map of Kimmeridge Bay. From Cox and Wright (2001).

Photograph of the west side of Kimmeridge Bay showing the Flat Stones bed with its polygonal thrust pattern on the top left of the image. Another dolomitic bed is visible in the bottom right. From "Geology of the Wessex Coast" website.

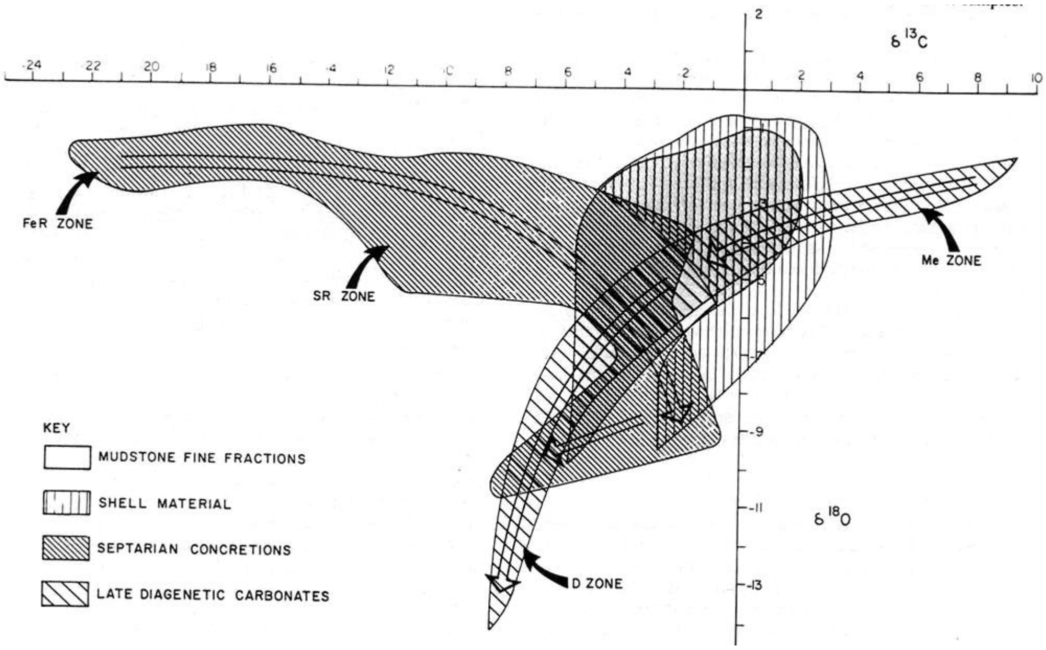


Section of the Kimmeridge cliffs from Broad Bench, Kimmeridge in the west eastward to Houns-tout, at Chapman's Pool.
Based, with modifications and additions on Arkell (1933) and Cox and Gallois (1981). Ian West & Tonya West (c) 2006.

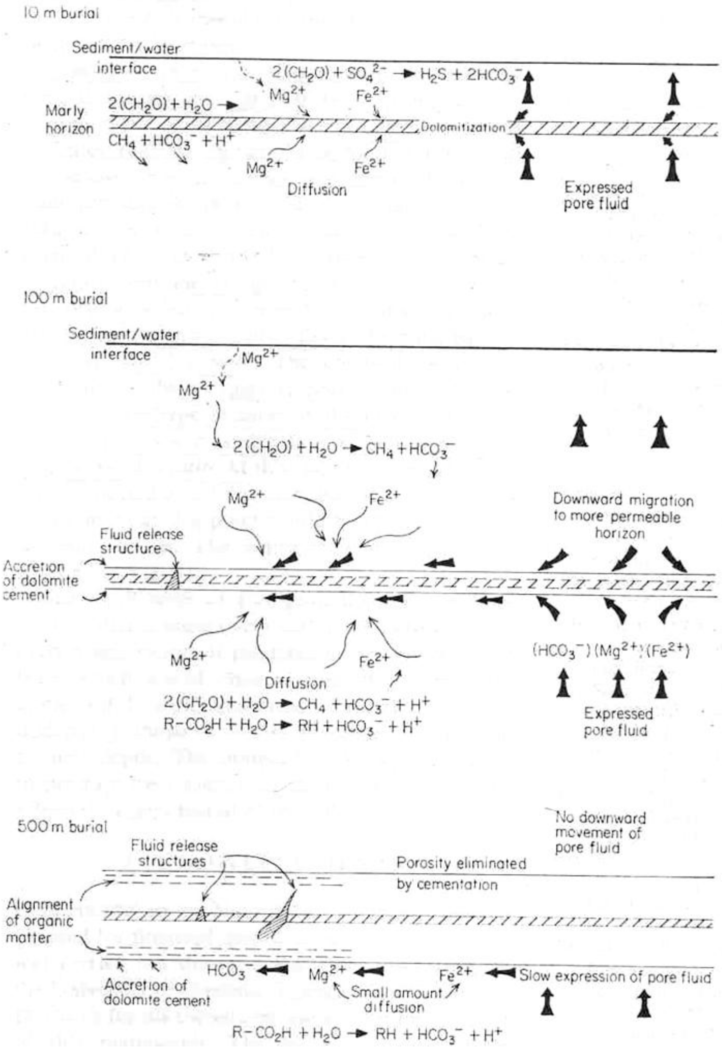
Cliff profiles of the Kimmeridge Clay at its type locality. From "Geology of the Wessex Coast" website.



Generalised vertical section of the lower to middle Kimmeridge Clay based on Cox and Gallois (1981). From "Geology of the Wessex Coast" website. Black bands are bituminous shales.



Stable isotope data from Kimmeridge Clay diagenetic carbonates. From Scotchman (1989)



Model for the formation of dolomitic beds in the Kimmeridge Clay. From Irwin (1980).

Web link to "Geology of the Wessex Coast"

- http://www.soton.ac.uk/~imw/Kimmeridge-Bay.htm

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5. AMMONITE PRESERVATION AND THE PRIMARY VERSUS DIAGENETIC ORIGIN OF LIMESTONE-SHALE CYCLES, BLUE LIAS FORMATION AT CHIPPEL BAY

Introduction

We aim to examine a small part of the famous cyclical limestone – mudrock succession of the Blue Lias, in Chippel Bay about 750m west of the Cobb at Lyme Regis. This cliff and foreshore section beautifully displays the principal lithologies and their relationships, and is richly fossiliferous both in terms of ammonites (although belemnites are almost absent) and a benthos dominated by bivalves and crinoid debris. If there is space, it is possible to park at the public car park at Monmouth Beach, close to the Cobb (SY337915). Otherwise, the best place to park is the car park on the west side of the town (on Pound Street at the junction of Cobb Road; SY337920) and then to walk down Cobb Road to the beach. Walking west along the cobble beach the Blue Lias Formation is continuously exposed in cliffs, but these are subject to episodic cliff-fall. It is best to proceed until the foreshore exposure begins (SY325908), and to combine that with parts of the cliff that are stepped or sloping rather than vertical. Even so, hard hats should be worn close to the cliff and areas of obvious recent collapse should be avoided. A good marker bed is bed 29 in W.D. Lang's numerical sequence, colloquially called the "Top Tape" and crowded with *Metophioceras conybeari* ammonites. Shortly before reaching this, bed 23 called "Mongrel" has a distinctive highly irregular upper surface. Ammonites are difficult to sample from the Blue Lias, and hammering is discouraged other than from loose or fallen material.

Overview

The Blue Lias is famous for its rich ammonite fauna and as a historical source of well preserved marine reptilian fossils such as the ichthyosaurs collected by Mary Anning. Sedimentologically, it is also well known for its strongly cyclical character. Symmetrical cycles of limestone – marl – bituminous shale – marl – limestone are frequently well developed and there has been much historical debate over the primary versus diagenetic origin of the cycles. On the assumption of at least a primary climate-driven "signal" (later enhanced by diagenesis) there has also been interest in attempting to recognise Milankovitch periodicities in the succession. In detail the cycles vary as to their completeness, although most are laterally correlatable (Gallois and Paul, 2009), and two distinct limestone types are seen. The first and most frequent are tabular to nodular, richly fossiliferous and bioturbated. The second are tabular with planar surfaces, are internally laminated, and are devoid of benthos. They are limited to two intervals within the middle part of the exposed succession (between beds 30-36 and 46-52).

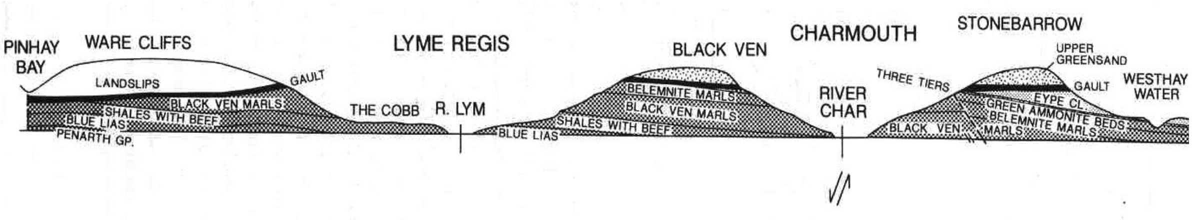
Hallam (1986) proposed that many of the cycles in the Blue Lias originated from diagenetic "unmixing" (preferential carbonate dissolution and re-precipitation), but this was challenged by Weedon (1987). Based on pyrite abundance and composition Bottrell and Raiswell (1991) concluded that they were diagenetic enhancements of an original cyclicity in detrital carbonate content. The cementation, they postulated, would have been promoted by breaks in sedimentation. Paul et al. (1998) used the taphonomy of ammonites in the different lithologies and trace fossil infills to suggest that the limestones were event beds, rapidly deposited and possibly under the influence of current activity. Based on stable isotopic evidence they suggested that calcite cementation to form the limestones took place from contemporaneous marine pore fluids. Pursuing this argument and using trace fossil evidence, Moghadam and Paul (2000) proposed the limestones to be fully authigenic, with cyclicity caused by differences in the primary sedimentary composition rather than self-organisation favoured by Hallam.

Attempts to match the Blue Lias cycles to Milankovitch periodicities have been made by Weedon (1986) and Weedon et al. (1999). The approach has been more successful in the younger Belemnite Marls Member of the Charmouth Mudstone Formation where the striking cyclicity is less influenced by diagenesis (Weedon and Jenkyns, 1999). Relative proportions of kaolinite and illite in the contrasting lithologies suggest a climatic control to sedimentation, although dilution by diagenetic carbonate masks the signal in Dorset compared to coeval Blue Lias outcrop in Somerset where this is less intense (Deconinck et al., 2003).

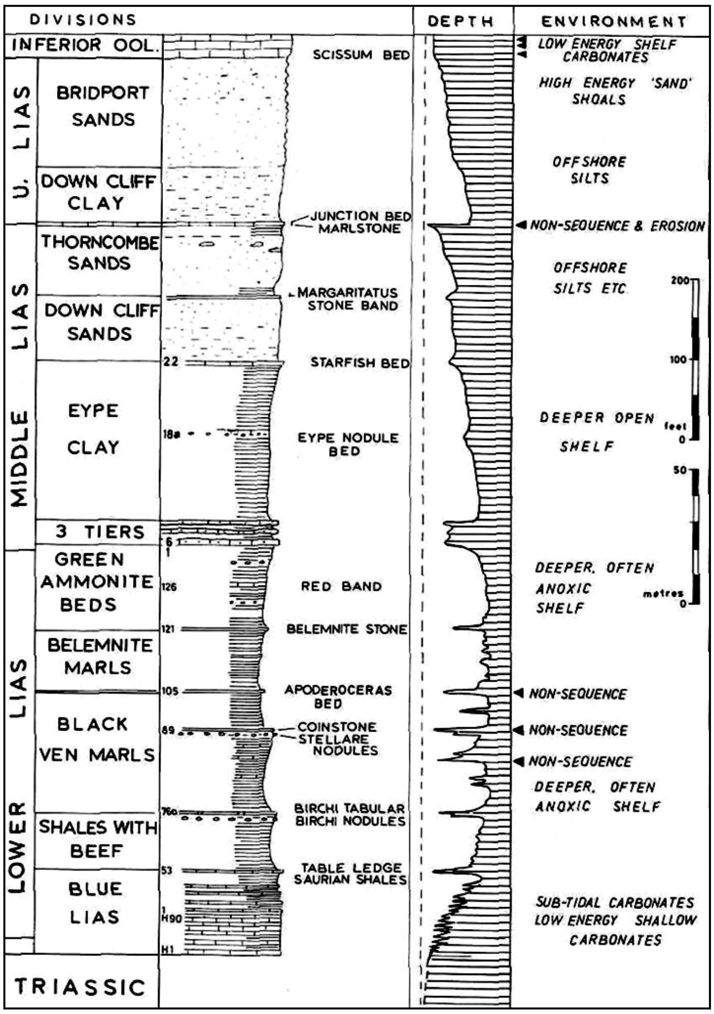
Objectives

- To consider the extent to which the limestones are primary as opposed to diagenetic in origin, based on sedimentological, ichnological and geochemical evidence.
- To discuss the preservation and cementation of ammonites in the limestones.

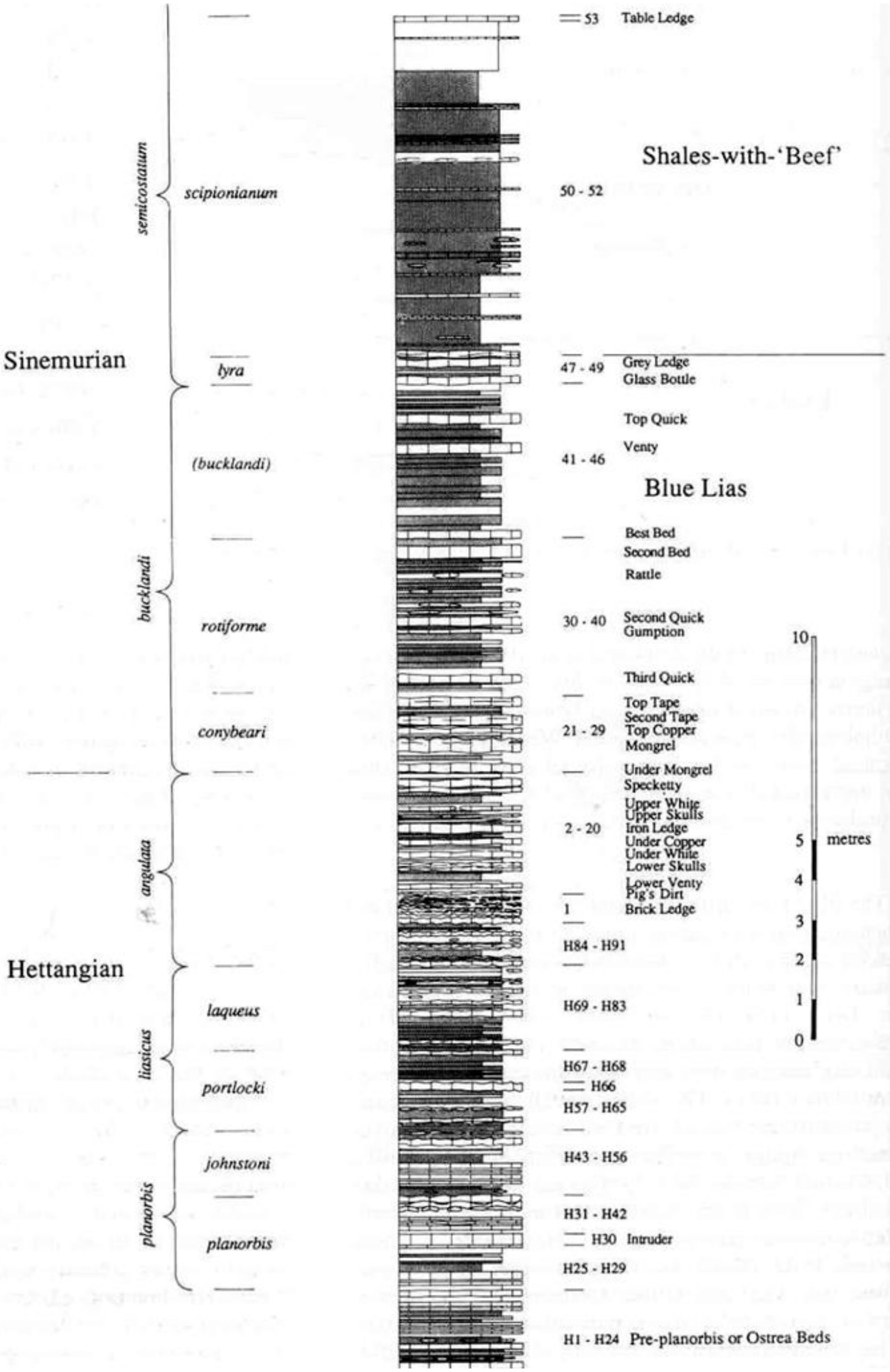
Figures



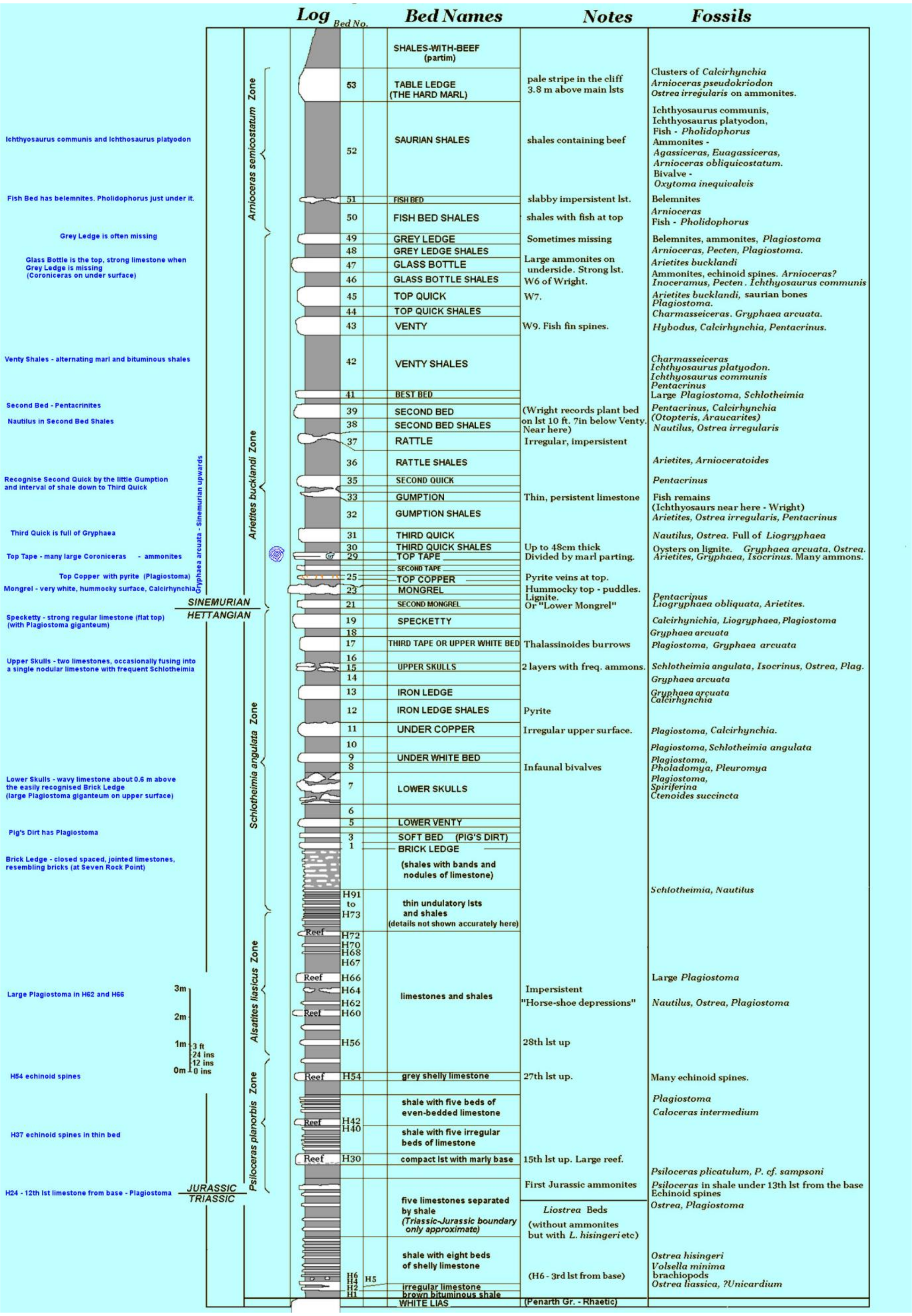
Cliff Profile at Lyme Regis. From House (1983)



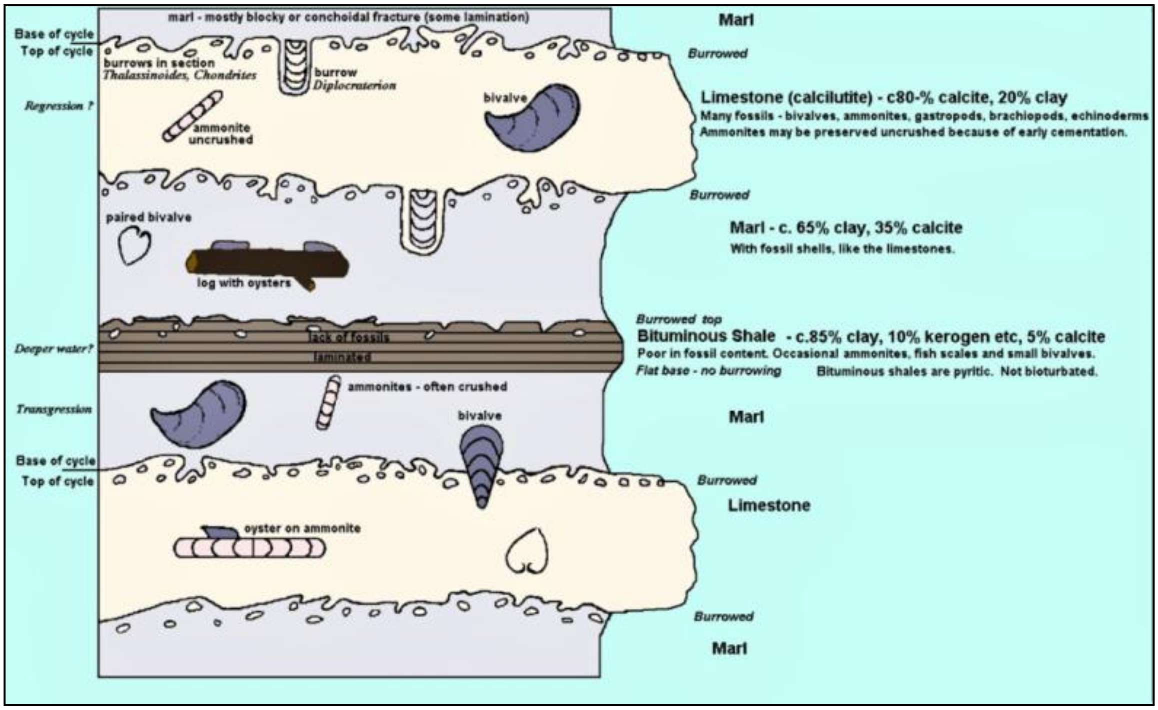
Lithological and depositional summary of the Lias Group succession in southwest Dorset. From House (1993).



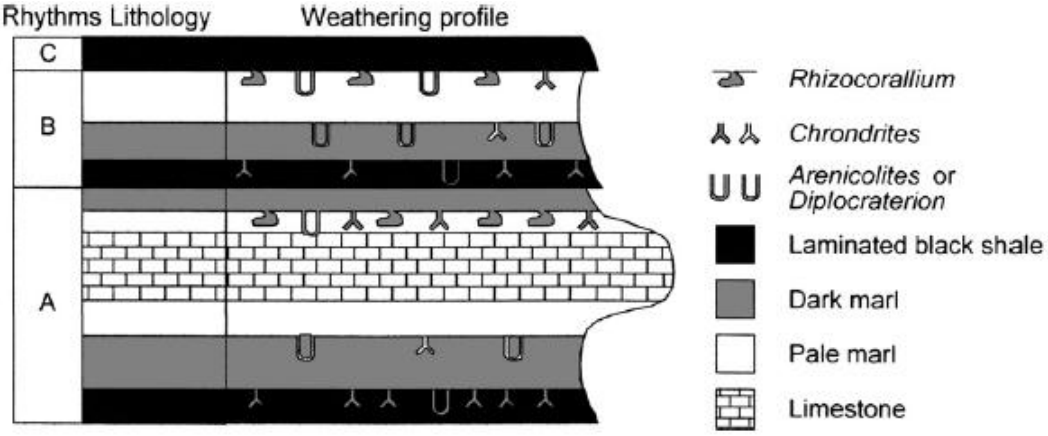
Graphic sedimentary log of the Blue Lias Formation at Lyme Regis. From Hesselbo and Jenkyns (1995)



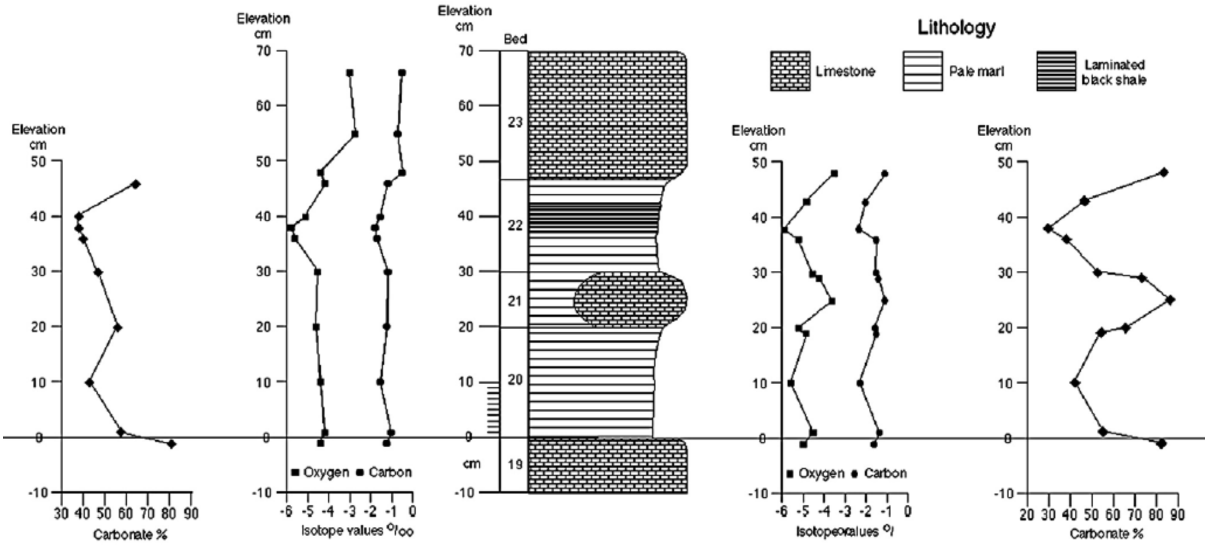
The Blue Lias sequence at Lyme Regis, modified from House (1993). From "Geology of the Wessex Coast" website



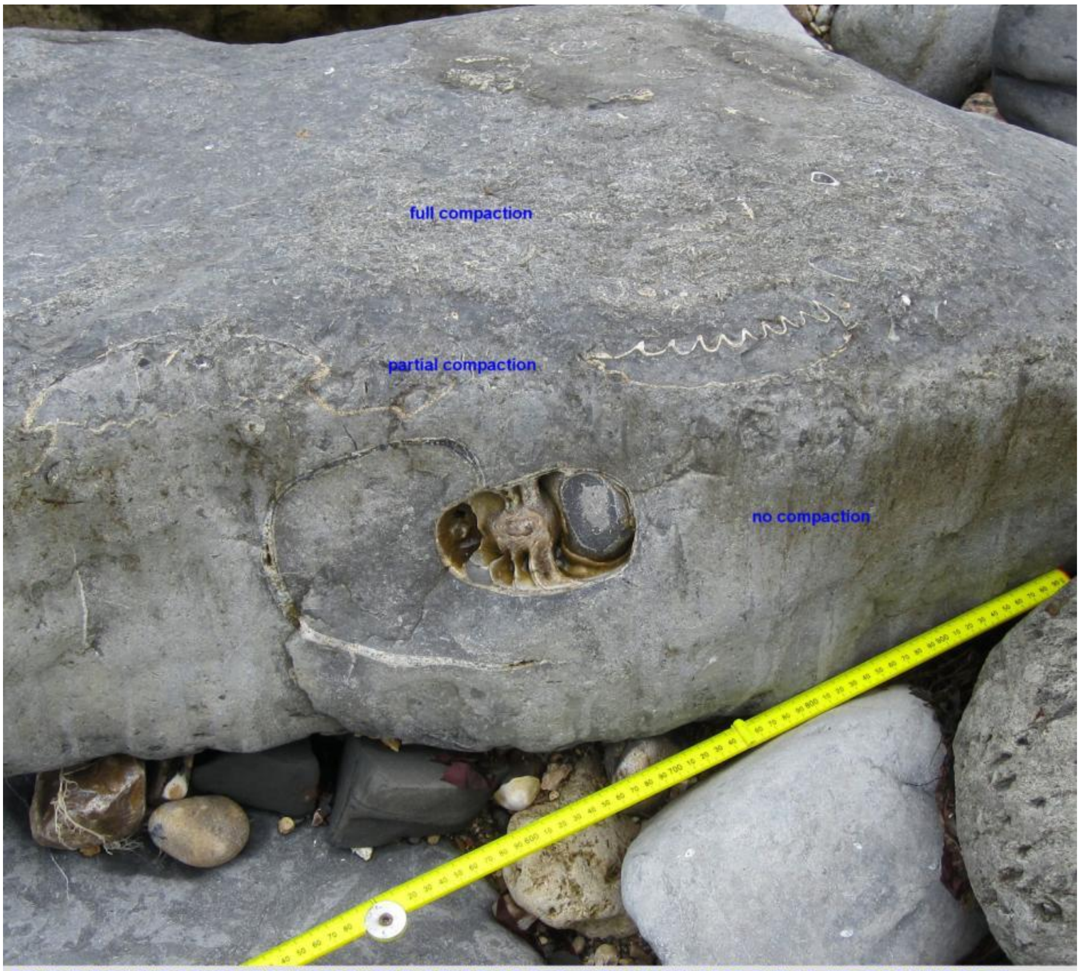
Idealised depiction of complete (symmetrical) cycle in the Blue Lias Formation. From "Geology of the Wessex Coast" website.



Idealised Blue Lias cycles. In A. the pale marl has been diagenetically cemented into a limestone bed. In B. the pale marl remains uncemented and the overlying dark marl has been eroded away, although it is retained within burrows penetrating the top of the pale marl. From Paul et al. (2008).



Profiles of stable isotopes and acid-insoluble residue taken over beds 19-23 in Chippel Bay. Those on the left exclude the nodule of bed 21. Lowest values are in the black shales. From Paul et al. (2008)



CEMENTATION AND COMPACTION HISTORY OF THE TOP TAPE, SHOWN BY CEPHALOPOD SHELLS, WEST OF LYME REGIS.
The nautiloid has no significant compaction. Prior to cementation there was sediment infill of the body chamber but the nucleus was mostly unfilled. The inner end of the fill can be seen on the right, and there has been some partial geopetal fill of a chamber on the left. (Incidently, notice the retrochoanitic septal neck of the siphuncle). Ammonites above have been partially compacted before cementation. The top shows full compaction. Photo: 10th June 2011. Ian West (c) 2011.

Web link to "Geology of the Wessex Coast"

- http://www.soton.ac.uk/~imw/Lyme-Regis-Westward.htm

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6. CONDENSED LIMESTONES WITH UNUSUAL CAVITIES ASSOCIATED WITH SYN-SEDIMENTARY FAULTING, EYPEMOUTH LIMESTONE AT WATTON CLIFF (“FAULT CORNER”)

Introduction

Eype Mouth is reached by a narrow road through Eype village with limited parking at its end (SY447912). The succession exposed in the cliffs to the west of the access point (SY451908) comprise the Dyrham Formation, but in the cliffs to the east the Eype Mouth fault cuts down at a low angle and brings the Dyrham Formation into juxtaposition with downthrown Bathonian mudrocks of the Frome Clay Formation (with Forest Marble Formation visible in the top of the cliff). The fault has a throw of about 200m. Roughly where the fault plane reaches the beach are several fallen blocks of the Beacon Limestone Formation, which are the focus of this locality. They are usually accessible except at high tide, but may be partly covered by beach shingle. Other blocks can be found by following a steep grassy slope (land slip) towards the upper part of the cliff, but this is very uneven underfoot and muddy after wet weather.

Overview

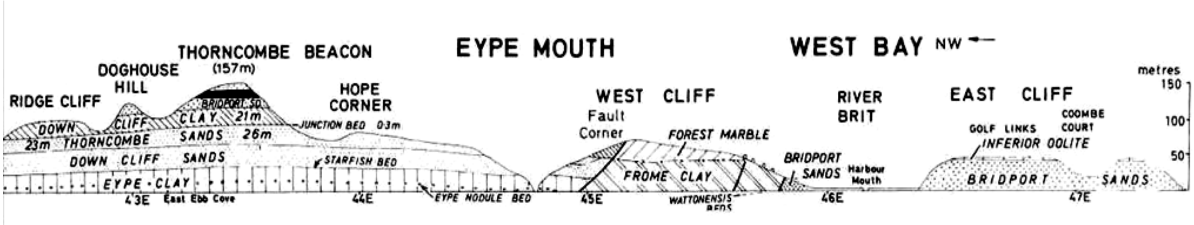
The Eype Mouth fault is believed to have been active during deposition of the Dyrham and Beacon Limestone Formations, owing to their marked thickness change across it. In particular, the condensed Beacon Limestone Formation thickens considerably eastwards towards the fault plane from about 0.5m to > 3.5m over about 50m laterally (Jenkyns and Senior, 1977). Close to the fault the Eypemouth Limestone member contains a complex diagenetic fabric of neptunian dykes and horizontal cavities with irregular roofs (similar to *stromatactis* cavities), sediment infills and included fossils that are younger than those in the surrounding rock.

The Eypemouth Limestone varies laterally in facies, and adjacent to the fault it is a grey to reddish brown calcareous shelly sandstone to intraformational conglomerate. The cavities or fissures are both vertical and horizontal, and exhibit cross cutting relationships. The horizontal ones are typically several cm – 10s cm thick and are filled geopetally with laminated finely peloidal calcite, sometimes in multiple events. Fibrous or sparry calcite occupies the upper part of incompletely filled cavities. The internal sediments contain bioclasts, and some are subtly graded. Limited stable isotope data for the peloidal sediment gives typical marine values, but some of the cements have several ‰ depletion in ^{13}C and ^{18}O (Jenkyns and Senior, 1991). These cavities are only seen adjacent to the fault, and have been interpreted as being related to tensile failure in partially lithified sea floor and intrusion of overlying soft sediment and bioclasts under vacuum suction. The presence of ammonites in cavities is good evidence that they were open at the sea floor; indeed close to the fault ammonites have been found in cavities 3m below their in situ stratigraphic level. A later set of vertical neptunian dykes cross cut the sediment-filled cavities but do not contain bioclasts. Jenkyns and Senior (1977) ascribed the abrupt lateral thickness change in the Beacon Limestone Formation to syn-sedimentary movement on the fault creating increased accommodation space. However, the authors modified this interpretation in 1991 to suggest that opening and filling of the horizontal cavities was a dominant factor. Laminated fissure facies are also known several other Jurassic units adjacent to extensional faults that are believed to have been active at the time of deposition, but these are poorly exposed and difficult to study.

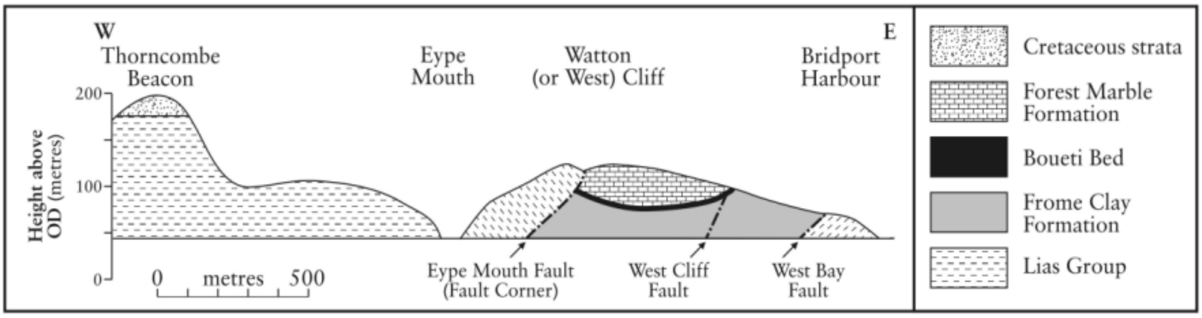
Objectives

- To examine and discuss the origin of sediment-infilled cavities in fallen blocks of the Beacon Limestone in terms of diagenetic and tectonic processes

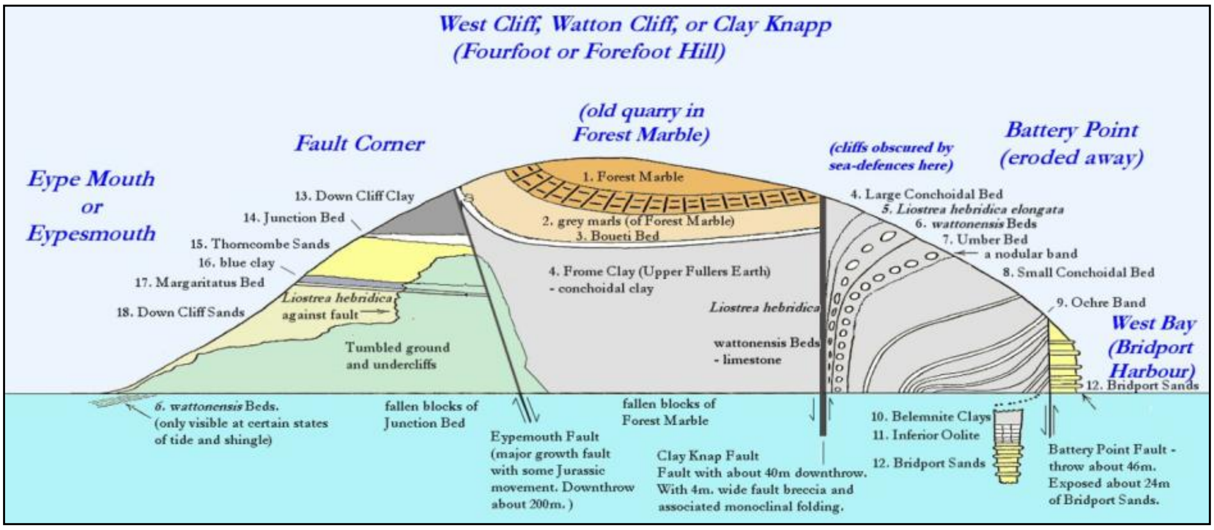
Figures



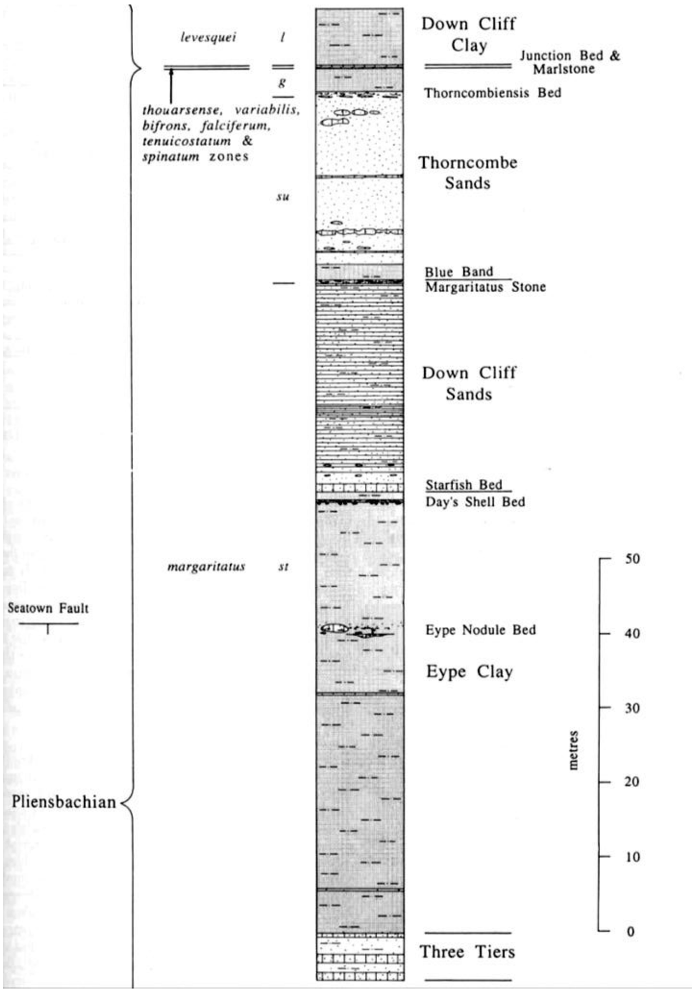
Cliff profile between Thorncombe Beacon and Bridport (West Bay), from House (1993).



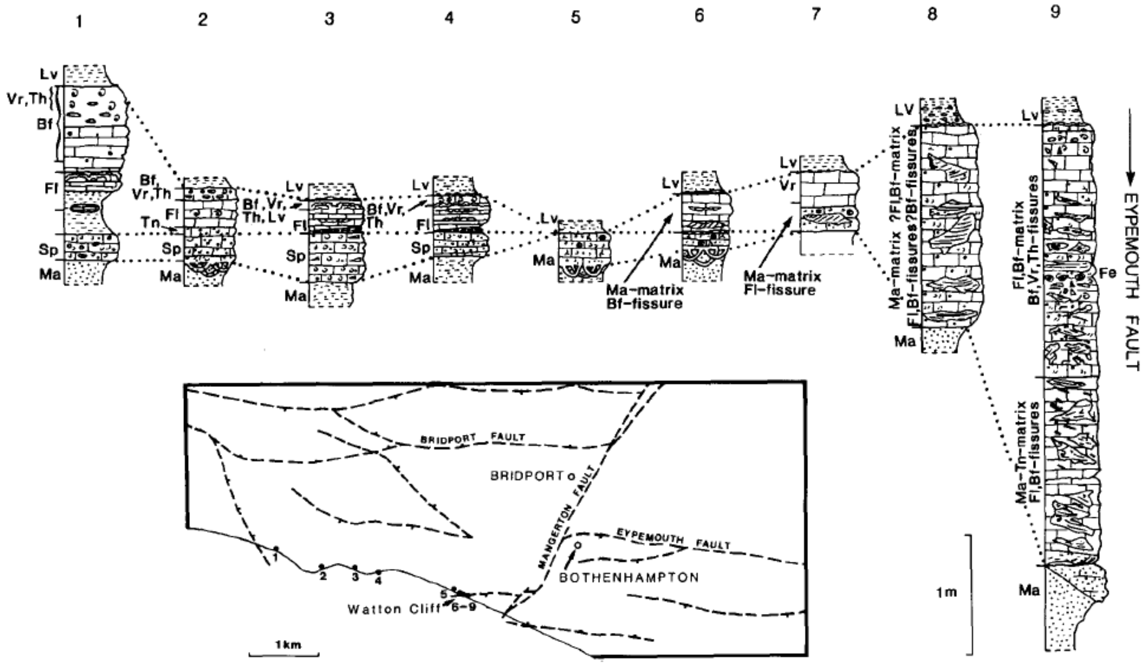
Simplified cliff profile at Eype Mouth. From Simms et al. (2004)



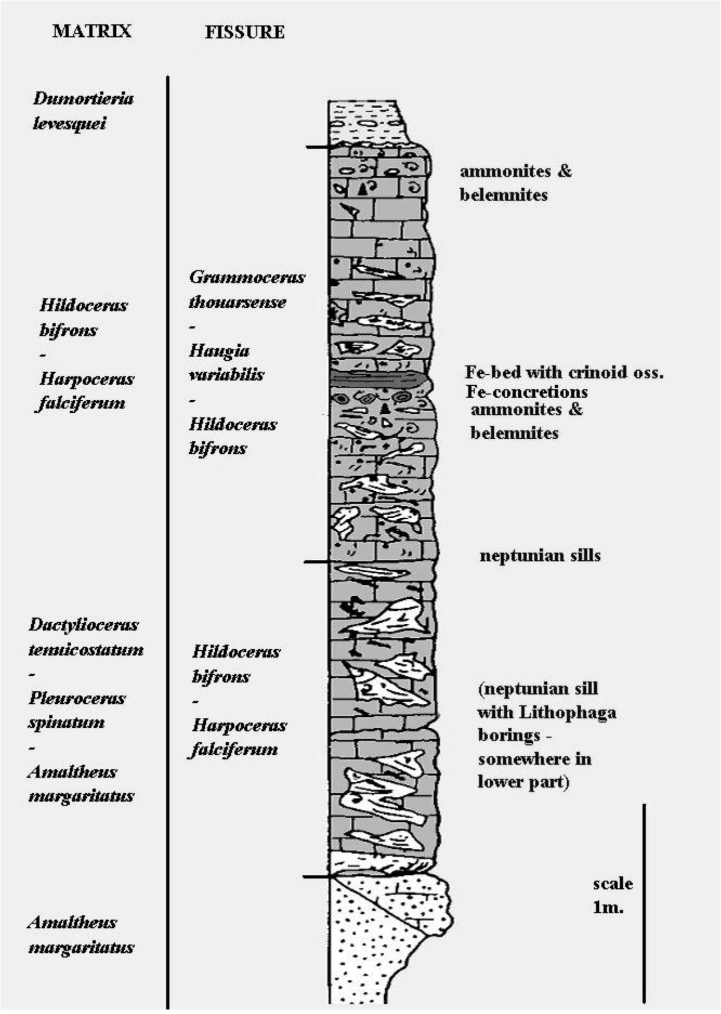
Interpreted diagram of the geology on Watton Cliff, taking into account some past exposures that are no longer visible. Vertically exaggerated for clarity. From "Geology of the Wessex Coast" website.



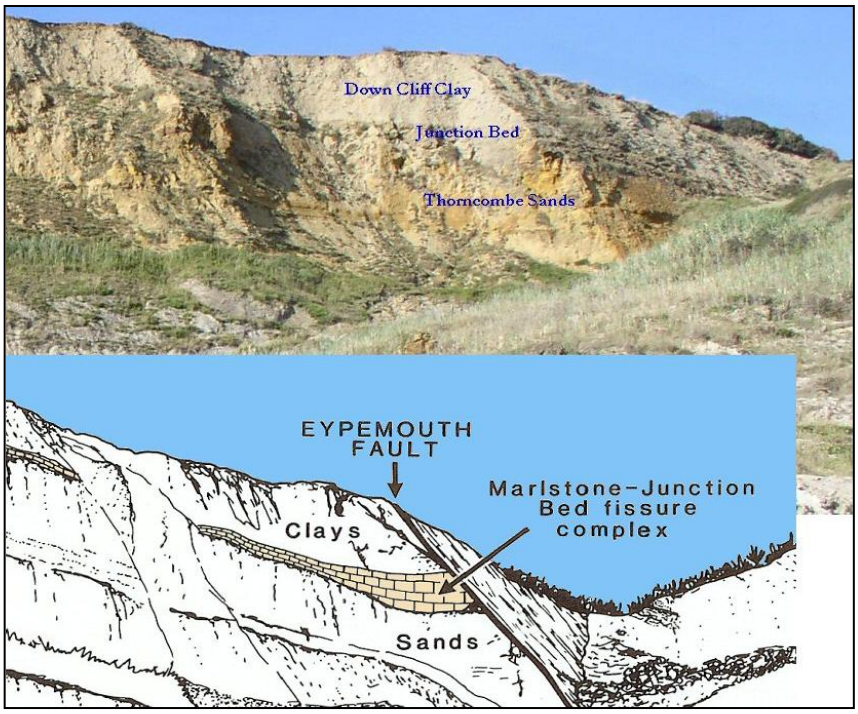
Graphic sedimentary log of the succession at Eype Mouth. From Hesselbo and Jenkyns (1995).

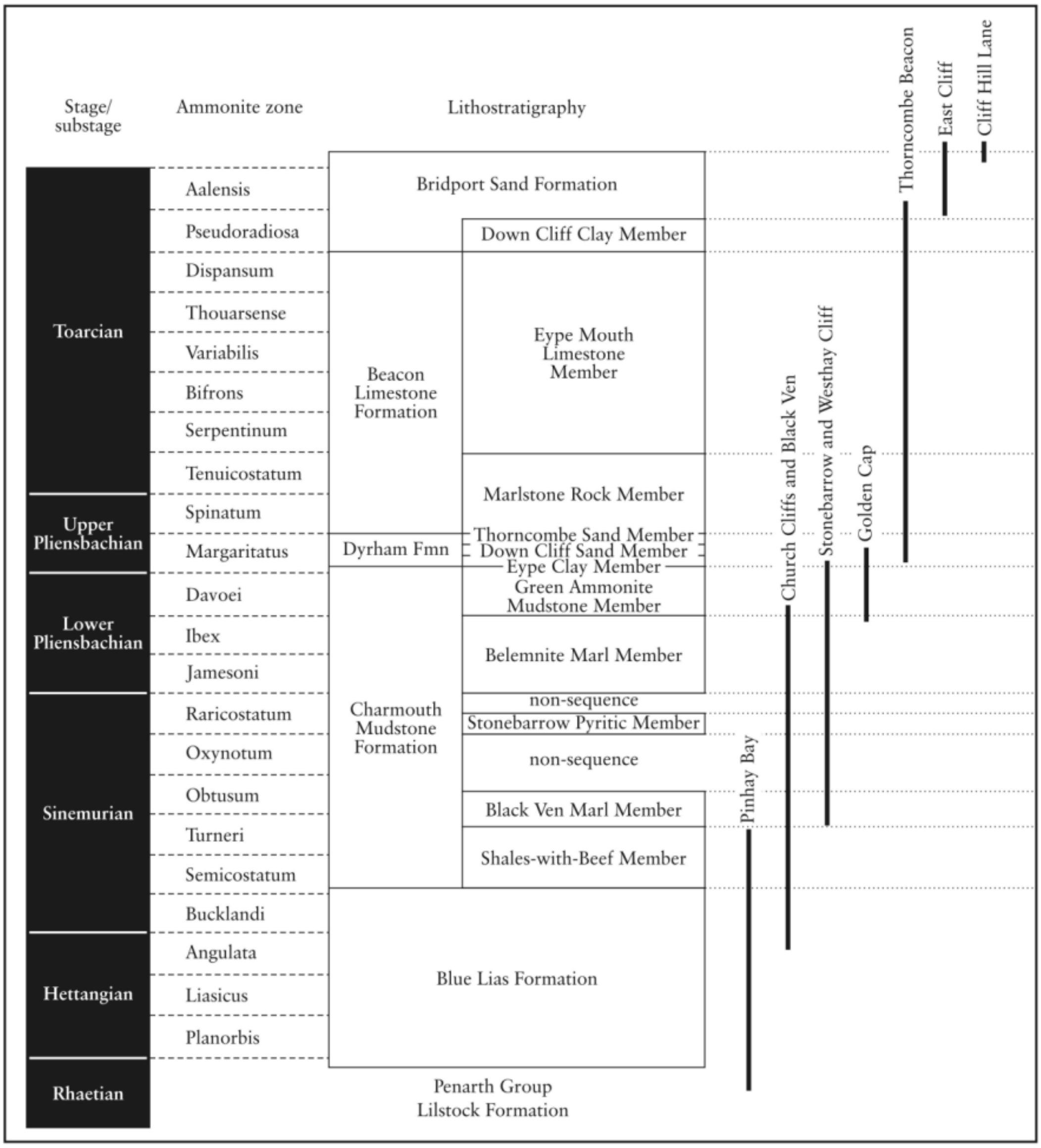


Correlation panel showing thickening of the Beacon Limestone Formation into the Eypemouth fault. Ma, Sp, Tn, Fl,Bf, Vr, Th, Lv refer to successive ammonite zones. From Jenkyns and Senior (1991)



Schematic log of the Eypemouth Limestone Member in fallen blocks adjacent to the Eypemouth fault. From "Geology of the Wessex Coast" web site.





Biostratigraphic column for the Lias Group in Dorset, emphasizing the condensation in the beacon Limestone Formation (and especially the Eypemouth Limestone Member). From Simms et al. (2004).

Web link to "Geology of the Wessex Coast"

- http://www.soton.ac.uk/~imw/Bridport-West.htm

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7a. CONDENSED FOSSILIFEROUS AND OOLITIC LIMESTONES OF THE INFERIOR OOLITE FORMATION BETWEEN WEST BAY AND BURTON BRADSTOCK

7b. STRATABOUND CALCITE CONCRETIONS AND CEMENTED BEDS IN THE BRIDPORT SANDSTONE FORMATION BETWEEN WEST BAY AND BURTON BRADSTOCK

Introduction

The cliffs of the Bridport Sand Formation east of Bridport and west of Burton Bradstock are visually striking owing to their warm golden colour, together with their strongly layered character and jagged weathering profile that result from carbonate cementation at remarkably consistent stratigraphic intervals (albeit more frequent towards the top of the cliff). The uppermost part of the cliff is highly fossiliferous Inferior Oolite Formation limestone, which is inaccessible in situ but present at shore level owing to episodic cliff fall. Access to the beach section is possible from the Freshwater Beach caravan park (with permission) (SY479897) or from the National Trust car park at Burton Bradstock (SY491887), although the fallen blocks of Inferior Oolite are concentrated close about 250 m east of Freshwater Beach and require a long walk from Burton Bradstock. The cliff exposure and fallen blocks are all above high tide, and the main hazard is as ever from cliff fall. Overhands and obviously unstable parts of the cliff should be avoided and hard hats should be worn close to the cliffs.

Bridport Sand Overview

The Bridport Sand Formation has been interpreted as lower to middle shoreface shoal deposit (Hounslow, 1987; Bryant et al., 1988). Petrographic studies of the calcite cemented intervals revealed them to be of similar grain size to the softer intervening beds, but lower in clay content and richer in benthic bioclastic (molluscan, brachiopod, echinoderm and bryozoan) detritus. The cemented beds were also noted to have mostly vertical burrows, whereas the softer beds had mixed vertical and horizontal burrow systems. The alternation could then be explained as reflecting fair weather (soft) versus storm (cemented) conditions, provided that the sand was already well sorted prior to deposition. As such, the cemented beds could be regarded as tempestites. If so, it is surprising that they are so regularly spaced.

From regional data, Morris et al. (2006) have proposed a detailed sequence stratigraphic model for the formation using ichnofabrics to help define facies and identify stratal surfaces. Using 3D seismic data, borehole core and well logs they recognised progradational sets of clinoform-bounded sedimentary packages (forced regressions) punctuated by transgressive flooding surfaces that are amalgamated with sequence boundaries. The strongly progradational architecture is interpreted as resulting from high sediment input into a setting of low net accommodation, although areas of greater subsidence such as the Portland – Wight sub-basin developed a more aggradational stacking pattern. The surface weathering at outcrop partly obscures trace fossil fabrics and makes this sequence stratigraphic scheme difficult to apply to the coastal exposures. Moreover, the Bridport – Burton Bradstock cliff section is interpreted to be aligned along the depositional strike.

Several studies have addressed the stratabound carbonate cementation. It is dominated by blocky to poikilotopic ferroan calcite spar, but Kantorowicz et al. (1987) documented earlier bioclast-fringing non-ferroan calcite cements that were sometimes replaced by ferroan calcite. In contrast, the soft sandstone beds that were not rich in detrital clay contained only minor and patchy ferroan calcite, minor quartz overgrowths, and common grain-coating berthierine. In general aragonitic grains have been dissolved and replaced by cement, Mg-calcite grains have been replaced by Fe-calcite, and calcite grains are well preserved. Calcite cementation is supposed to have been early, because burrows are well preserved in 3D on the base of cemented beds, and internally they contain un-deformed shell fragments and mica flakes whereas in the softer beds these have undergone some mechanical compaction. Bjørkum and Walderhaug (1993) used a gridded sampling pattern for stable isotopes to show that cementation took place in a radial manner from merging of originally discrete concretionary nuclei. This is compatible with the observation that some of the cemented beds are nodular and discontinuous in character.

It is tempting to ascribe the origin of the cement to diagenetic reworking of labile bioclastic carbonate, and published carbon isotope data generally support this ($\delta^{13}C \approx 0$ to -2‰ V-PDB). Oxygen isotope data are more difficult to interpret ($\delta^{18}O \approx -4.5$ to -9‰ V-PDB). If precipitation took place from marine pore fluids these require an elevated temperature during burial (up to 60°C), which is at odds with the textural evidence for shallow burial cementation. Alternatively, the pore fluid may have had a groundwater contribution as part of a larger scale "plumbing system" possibly associated with exposure at the Aptian unconformity (cf. Hendry, 1993). An unpublished PhD thesis by Jeremy Storey (Reading University, 1990) contained a more detailed and very thorough diagenetic study of the Bridport Sands Formation but reached a similar conclusion with regard to the Fe-calcite cementation.

A final enigma pertaining to the Bridport Sands Formation at this locality is the presence (best shown towards the foot of the cliffs west of Freshwater Beach) of large scale undulating bed forms picked out by nodular cemented beds. These are roughly symmetrical in profile and up to 2m high by 29 - 42m wavelength. They lack any conspicuous internal stratification other than bioturbated soft sandstone, diffuse relic horizontal lamination, and discontinuous sub-horizontal cemented layers that are truncated against the troughs of the bed forms. The bed forms are draped by the alternating hard and soft sandstones so as to smooth out the topography. These features have been used to suggest their origin as erosional bed forms produced beneath long period standing waves (edgewaves) during a major storm (Pickering, 1995). Interaction of such waves with incoming swell on modern beaches helps to create regularly spaced offshore rip currents that help to erode the foreshore and upper shoreface into alternate cusps and troughs.

Inferior Oolite Overview

Despite being one of the most spectacularly fossiliferous units in the British Jurassic, the Inferior Oolite has received astonishingly little sedimentological attention. This highly condensed succession of bioclastic and oolitic limestone beds encompasses 14 ammonite zones in under 5m. However, the component beds typically have their own distinctive ammonite assemblages, and are severely bioturbated with some large burrows still recognisable. The bed surfaces are sometimes erosively scoured and sometimes mineralised or coated by subtidal stromatolitic crusts. It consequently represents a series of time-snapshots of relatively slow deposition separated by frequent hiatuses. Rioult et al. (1991) published a detailed sequence stratigraphic analysis of the succession, linked to its correlative in northern France.

There are many prominent beds within this short succession, which can be reconstructed from the fallen blocks on the beach using published logs. One of the most intriguing of these is the Snuff Box bed, which contains saucer-sized limonitic oncoids (Palmer and Wilson, 1990). The non-concentric ferruginous laminae have been ascribed to the action of non-photosynthesising iron-oxidising bacteria, and the intergrown encrusting fauna of serpulids, bryozoa, forams, sponges and bivalves are all heterotrophs. This raises a possibility that the oncoids accreted either in deep, dark water or preferentially on their shaded undersides between episodes of storm reworking or scavenging that flipped them over. A varied orientation of the oncoids within the bed, and local imbrication, suggests that the water was not particularly deep.

A detailed account of the Inferior Oolite succession is given below, abridged from the Burton Cliff GCR site report in Cox and Sumbler (2002) and also at http://www.thegcr.org.uk/SiteReports.cfm.

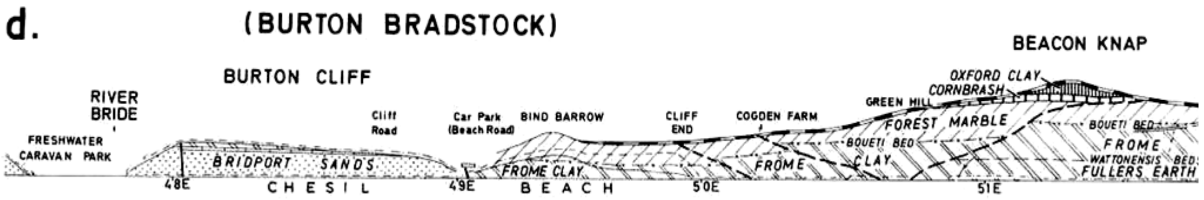
		Thickness (m)
FULLERS EARTH FORMATION		
19	Clay, grey, somewhat calcareous and silty; poorly fossiliferous; bivalves	seen to 5.0
INFERIOR OOLITE FORMATION		
18	**The Scroff**: Marl, rusty, iron-stained, impersistent; belemnites; brachiopods; poorly preserved ammonites, often encrusted with serpulids	0.05–0.15
17	**Zigzag Bed**: Limestone, nodular, hard, blue-hearted, locally limonitic or pyritic; diverse ammonites, including *Zigzagiceras* welded to underlying bed	c. 0.15
Burton Limestone		
16	Limestone, pale, more-or-less hard and massive, bioclastic, bioturbated, poorly fossiliferous; parting into three courses	0.65
15	**Sponge Bed**: Limestone, marly, variable; well bedded in several courses, separated by thin, marly partings; thicker limonitic marl at top; coarsely bioclastic with clasts largely of sponge fragments; occasional poorly preserved ammonites; profuse calcareous sponges; bivalves; brachiopods; bryozoans; crinoids; echinoids; marl parting at base	0.35
14	Limestone, harder than above, coarsely biodetrital and somewhat rubbly packstone; clasts largely of echinoids; divided into two courses (a,b) by undulating parting; sparsely fossiliferous with fauna as above but better preserved; ammonites; large nautiloids; bivalves; brachiopods; echinoids; sponges; undulating parting at base	0.40
13	Limestone, in three main courses (a–c), variably hard; brachiopods abundant throughout	
13c	Packstone, fine grained, biomicritic, marly, somewhat ferruginous with weathered pockets of limonite; macroconch and microconch ammonites, as wholly decalcified internal casts; nautiloids	0.30
13b	**Truellei Bed**: Biosparite, hard, somewhat peloidal with scattered large, cream-coloured ooids and characteristic small black grains or specks; many well-preserved but difficult to extract fossils including macroconch and microconch ammonites; large thick-shelled bivalves; echinoids; gastropods; nautiloids; parting at base	0.15–0.20
13a	Limestone, marly, biomicritic packstone or wackestone; sparsely (upper part) to fairly densely (lower part) ooidal with large, weathering cream-coloured, ooids; less fossiliferous than 13b with ammonites; belemnites	0.10
12	**Astarte Bed**: Limestone, softer than bed above, marly, densely ‘iron-shot’ ooidal, variable; richly fossiliferous with diverse fauna ranging from bored, thick-shelled bivalves encrusted with epifauna and limonite to diverse ‘fresh’ ammonites with lappets preserved; bivalves; gastropods; small, solitary corals; spectacular limonitic, algal crust at base	0.10
11	**Red Conglomerate**: Oolite, ‘iron-shot’ with berthierine, highly variable, preserved in patches and pockets let down into karstic undulating surface of bed below; often conglomeratic with limonite-encrusted worn pebbles including belemnites and ammonite nuclei; locally re-cemented in crimson limonite, sometimes with stromatolitic lamination; in places, thickening into	0–0.15

	lenticular ‘iron-shot’ oolite with ‘fresh’ fossils, particularly ammonites; undulating, sharp base	
Divisible into		
11c	Limestone, white, preserved in blocks as fissure-infills; ammonites; large nautiloids; brachiopods; echinoids	
11b	Limestone, white, soft, in small pockets; ammonites	
11a	Oolite, ‘iron-shot’, bioturbated but well bedded; well-preserved ammonites	
Red Bed		
10	Limestone, massive, hard, in two courses; somewhat ooidal, coarse bioclastic packstone rich in crinoid and echinoid plates; weathering white or pale-pink; totally bioturbated with overprint of large, irregular, vertical burrows often marked by red limonite; sparsely fossiliferous; belemnites; undulating surface largely covered in stromatolitic crusts up to 0.05 m thick at base	0.30–0.50
9	Limestone, biodetrital packstone as bed above but somewhat finer; moderately to densely ooidal; weathering olive-grey; ammonites; large bivalves; gastropods; sharp base	0.20–0.25
8	**Snuff-box Bed**: Limestone, marly, blue-grey; sparsely to densely ooidal; ooids large and limonitic, concentrated in pockets; scattered large echinoid spines and plates; numerous ellipsoidal, limonitic, strongly laminated oncoids (‘snuff-boxes’) concentrated locally and embedded at all angles; sharp base	0–0.10
7	**Yellow Conglomerate**: Limestone, marly, weathering yellow with masses of pebbles including rolled, worn ammonites and many belemnites; ‘fresh’ ammonites; sharp but undulating erosive base	0.05
6	**Scissum Bed**: Limestone, sandy, hard, massive when unweathered; diverse ammonites; large bivalves; fossil wood	
BRIDPORT SAND FORMATION		
5	Rusty or Foxy Bed: Marl, sandy, brown, somewhat laminated, moderately fossiliferous with ammonites; brachiopods	c. 0.05

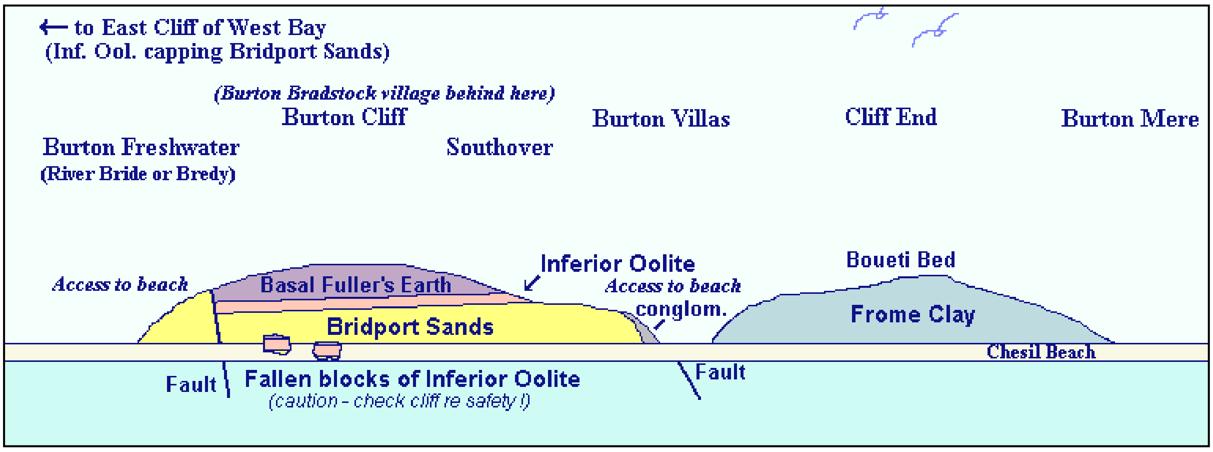
Objectives

- To consider the origin, facies relationship and economic significance of stratabound cementation in the Bridport Sandstone Formation
- To examine the litho-, bio- and ichno-facies and early diagenesis in fallen blocks of the Inferior Oolite Formation

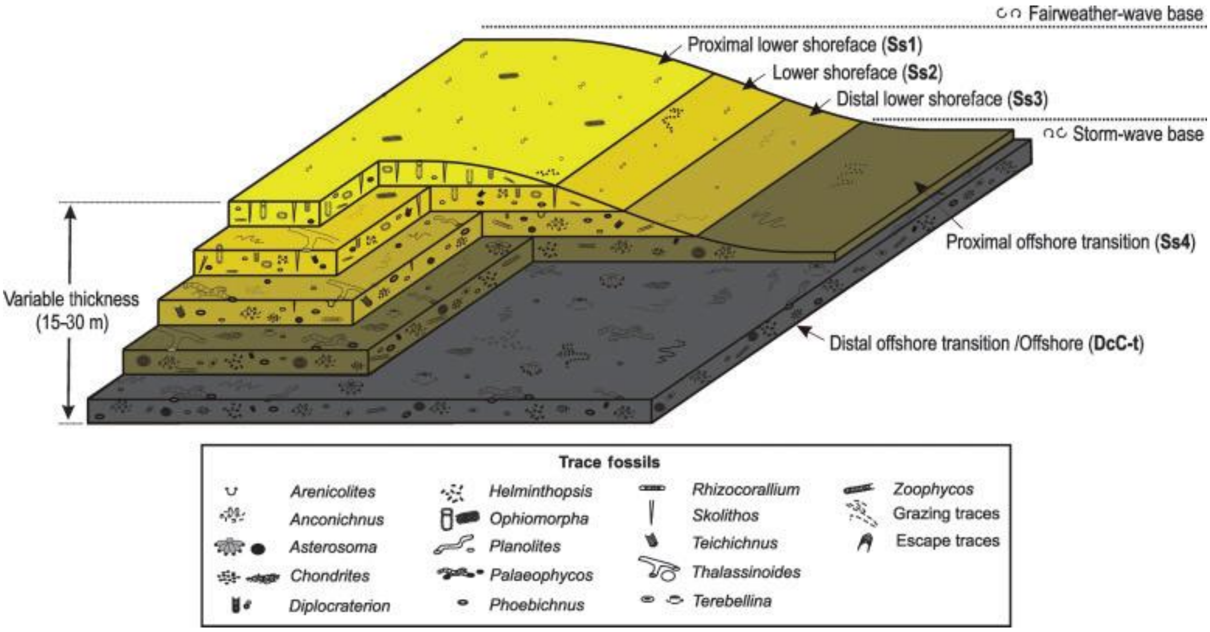
Figures



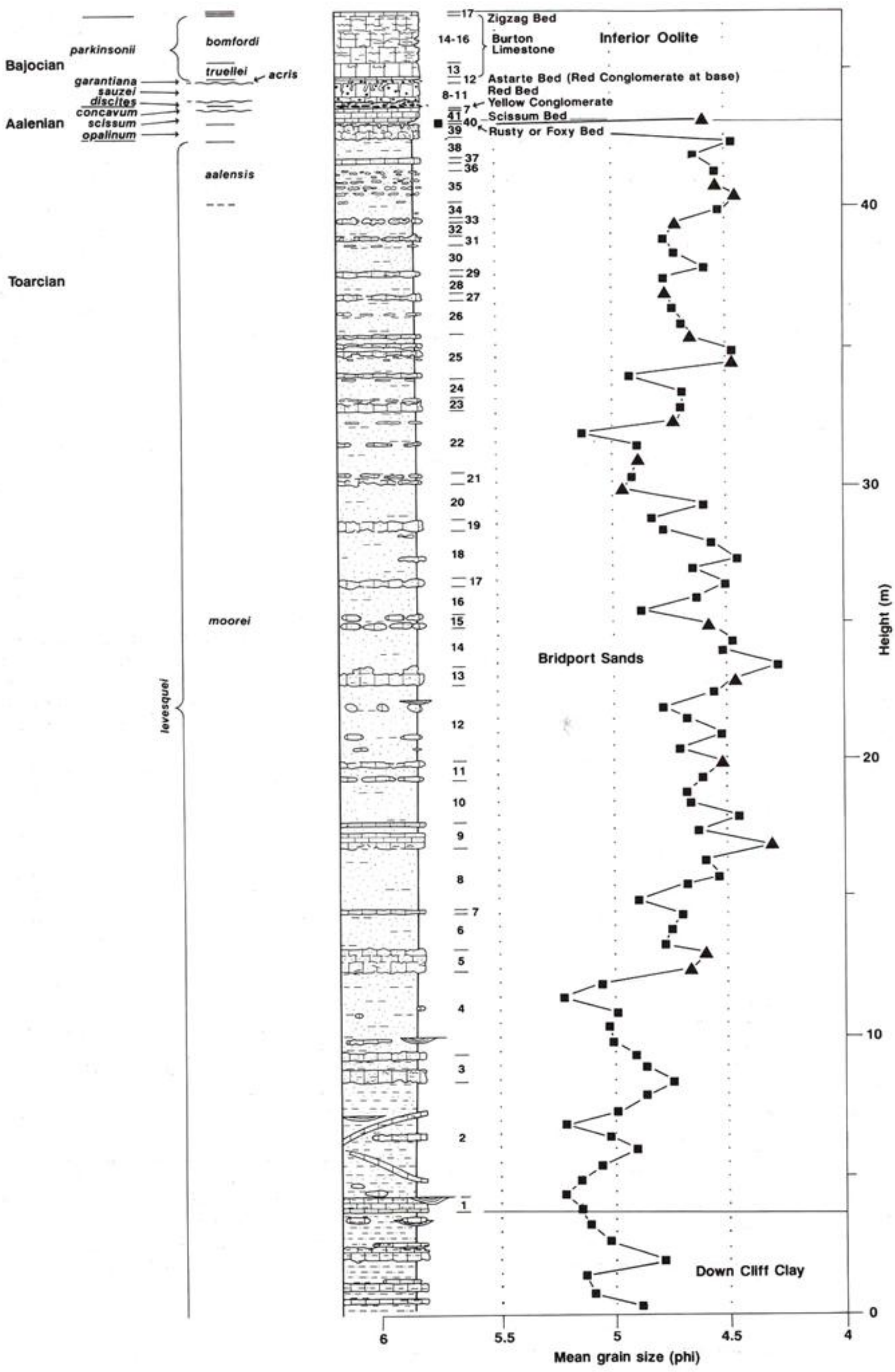
Cliff profile at Burton Bradstock. From House (1993)



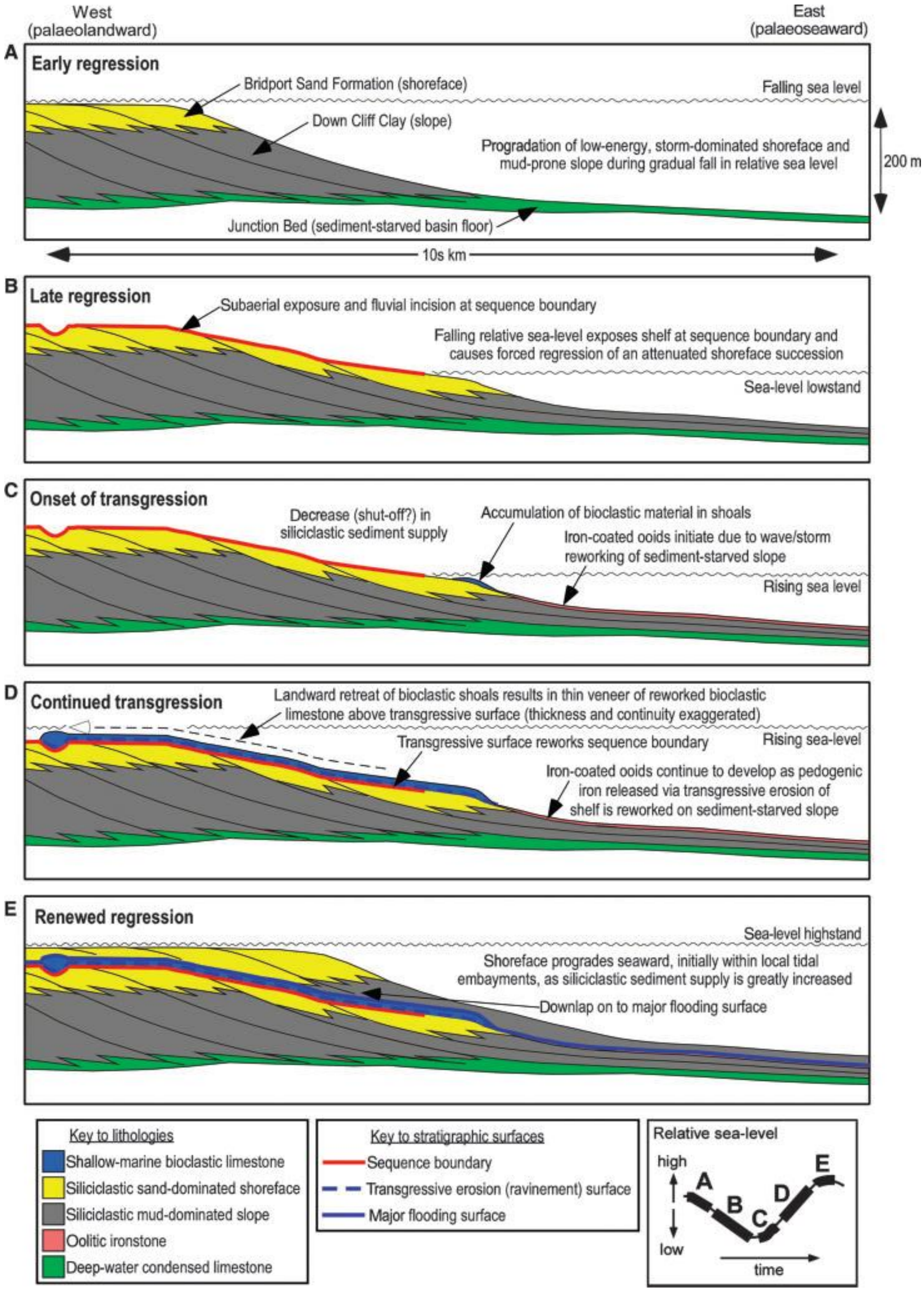
Simplified diagram of the cliffs at Burton Bradstock, vertically exaggerated for clarity. From "Geology of the Wessex Coast" website.



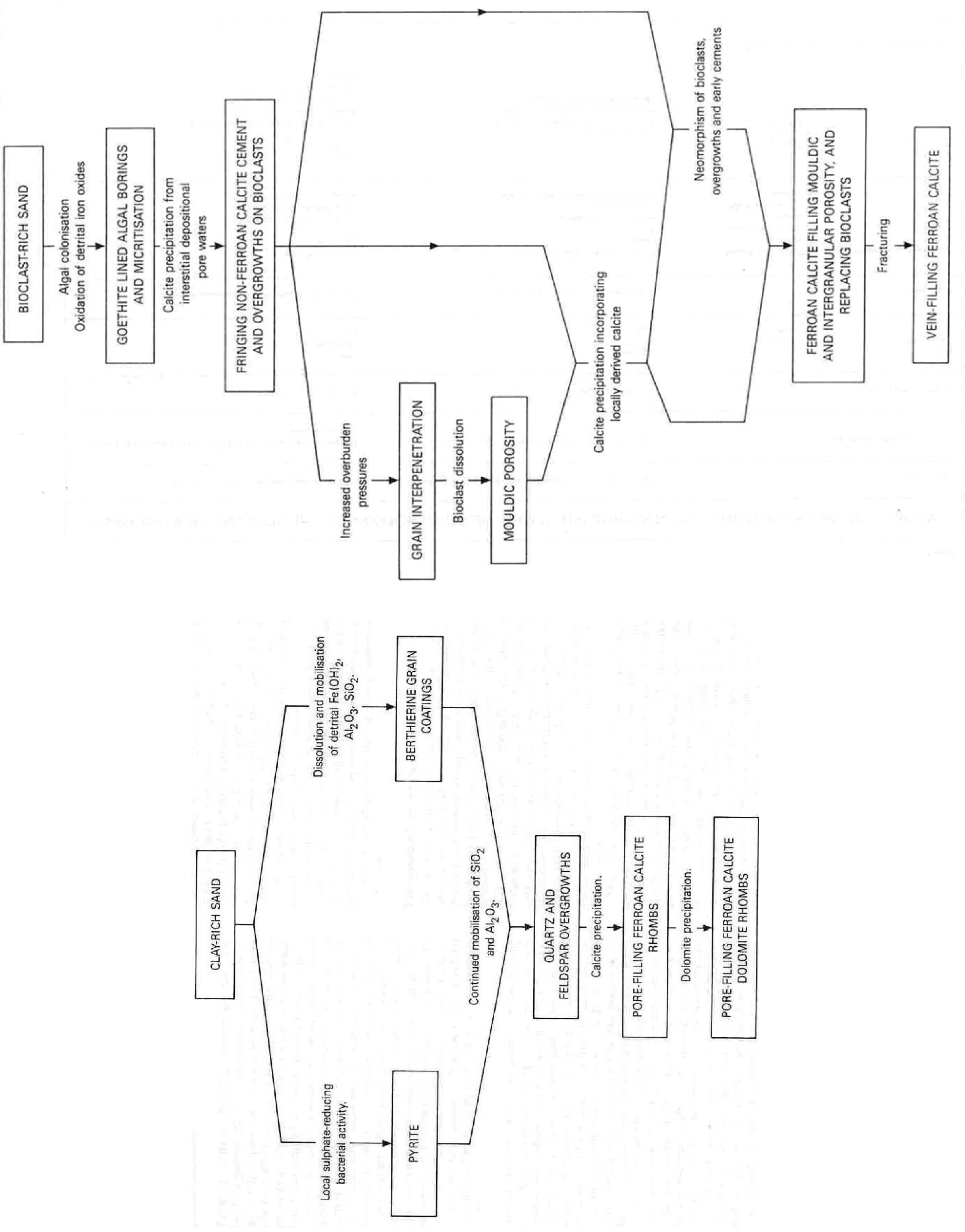
Facies model for the bioturbated sandstones that dominate the Bridport Sands Formation. From Morris et al. (2006).



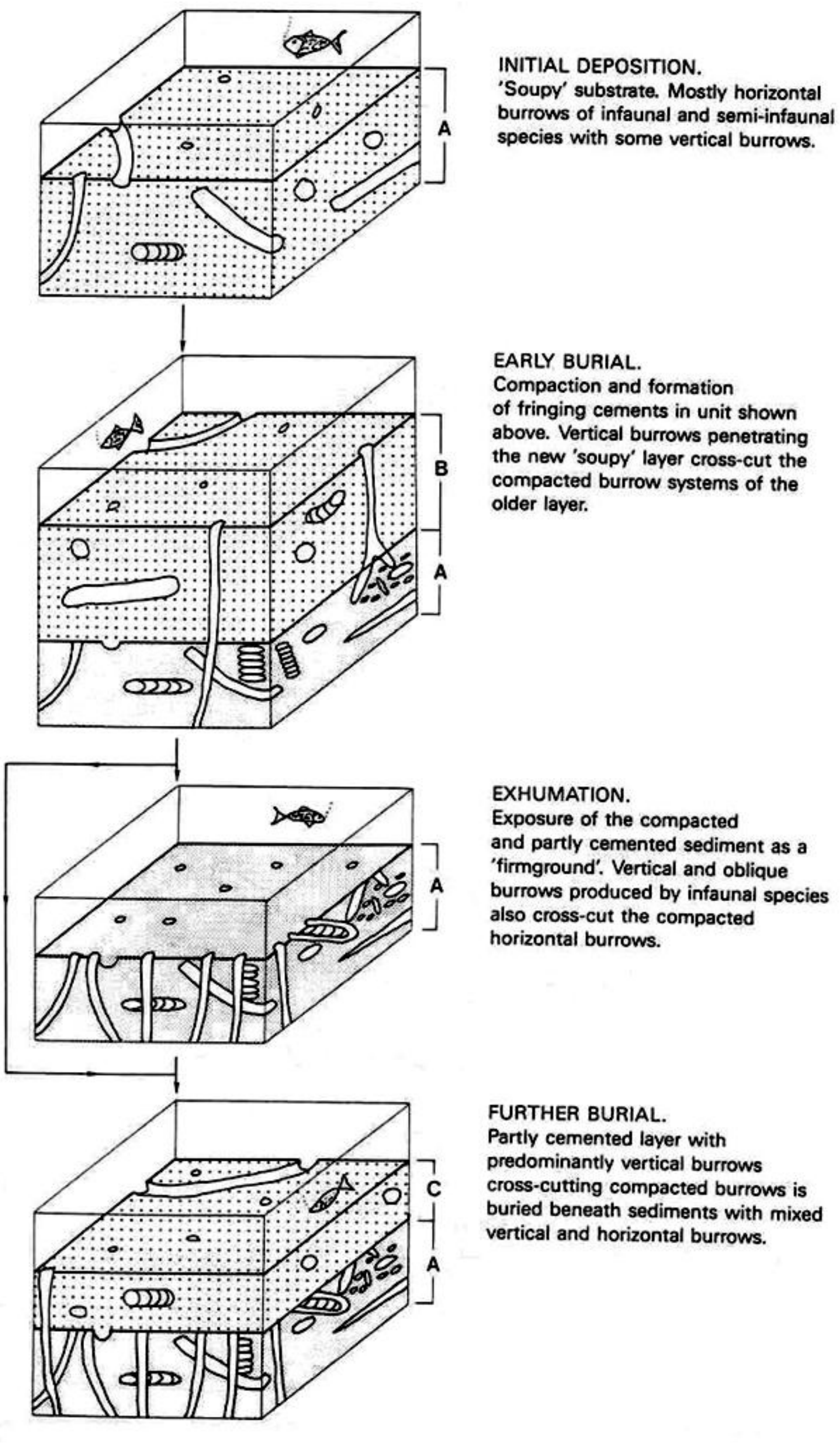
Graphic log through the Bridport Sands Formation. From Hesselbo and Jenkyns (1995).



Model for high-frequency sequence development in the Bridport Sands Formation based on regional data. The coastal exposure is effectively a strike section so clinoform geometries are not seen. From Morris et al. (2006).



Diagenetic pathways in soft argillaceous and hard shelly sandstones of the Bridport Sands Formation. From Bryant et al. (1988). Kantorowicz et al. (1987) measured δ^{13}C and δ^{18}O values for the ferroan calcite cement as 0.0 to -1.5‰ V-PDB and -4.5 to -6.5‰ V-PDB respectively. Their δ^{13}C and δ^{18}O values for the ferroan dolomite were +0.5 to -1.5‰ V-PDB and -4.0 to -6.0‰ V-PDB respectively.



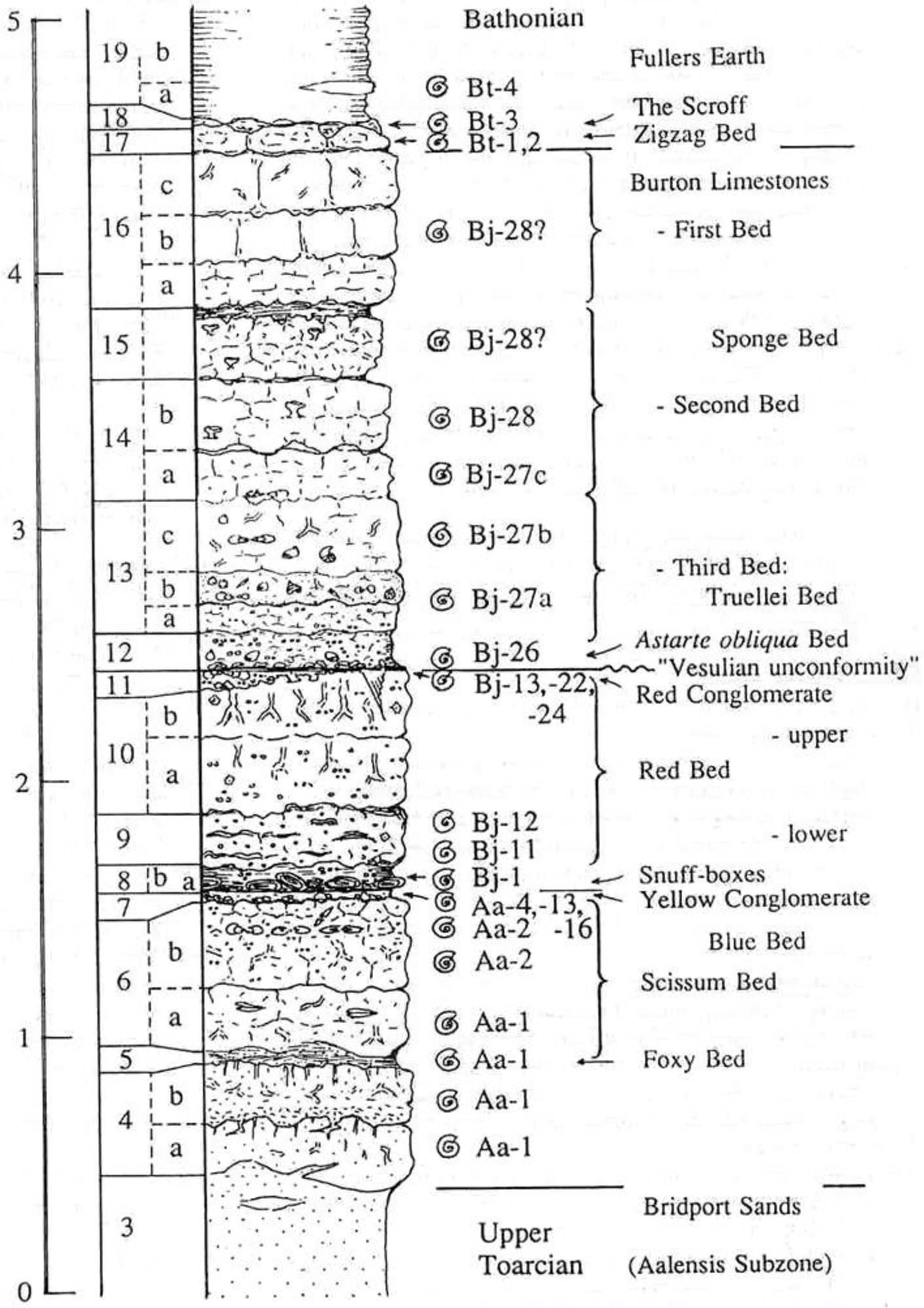
INITIAL DEPOSITION.
'Soupy' substrate. Mostly horizontal burrows of infaunal and semi-infaunal species with some vertical burrows.

EARLY BURIAL.
Compaction and formation of fringing cements in unit shown above. Vertical burrows penetrating the new 'soupy' layer cross-cut the compacted burrow systems of the older layer.

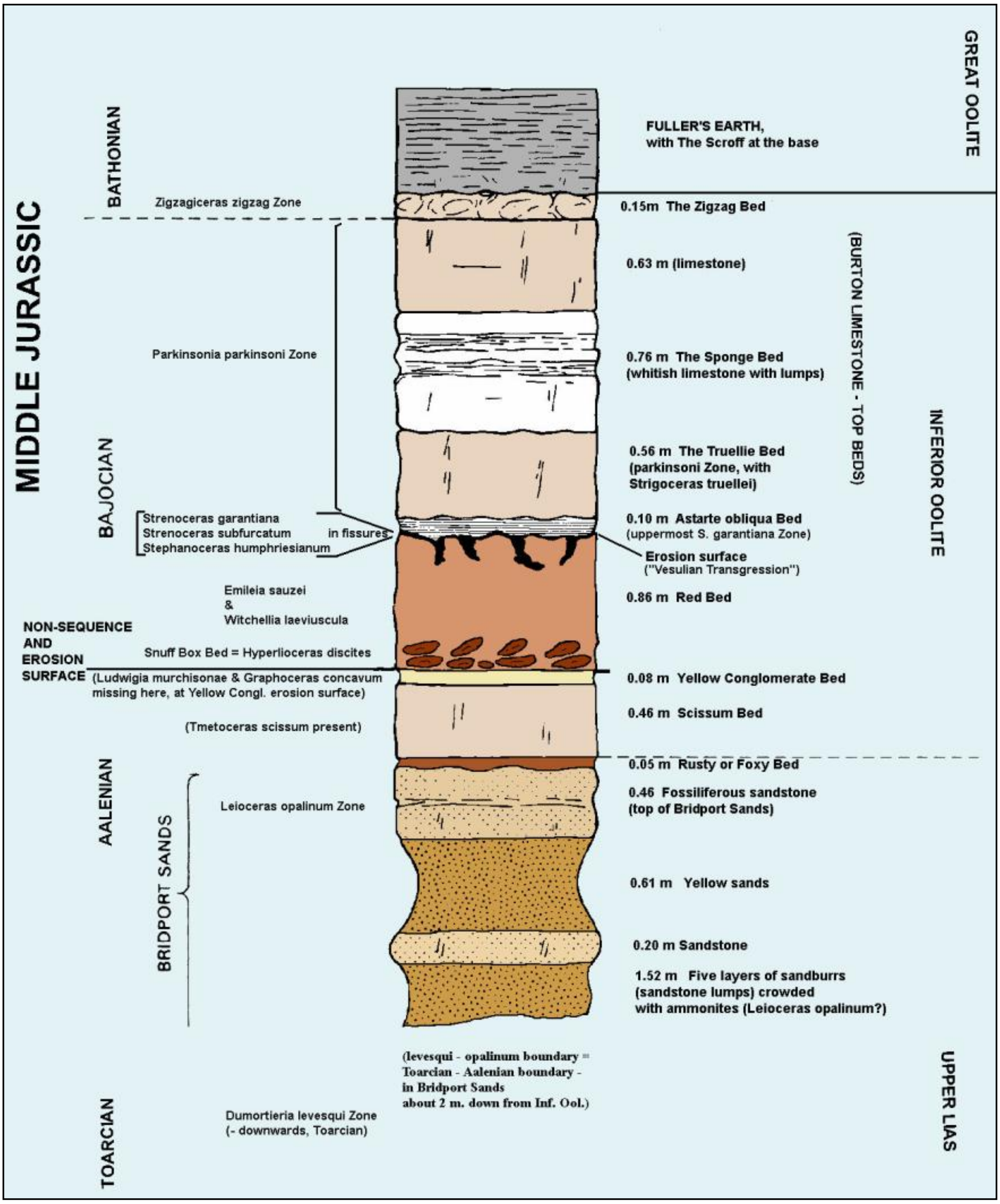
EXHUMATION.
Exposure of the compacted and partly cemented sediment as a 'firmground'. Vertical and oblique burrows produced by infaunal species also cross-cut the compacted horizontal burrows.

FURTHER BURIAL.
Partly cemented layer with predominantly vertical burrows cross-cutting compacted burrows is buried beneath sediments with mixed vertical and horizontal burrows.

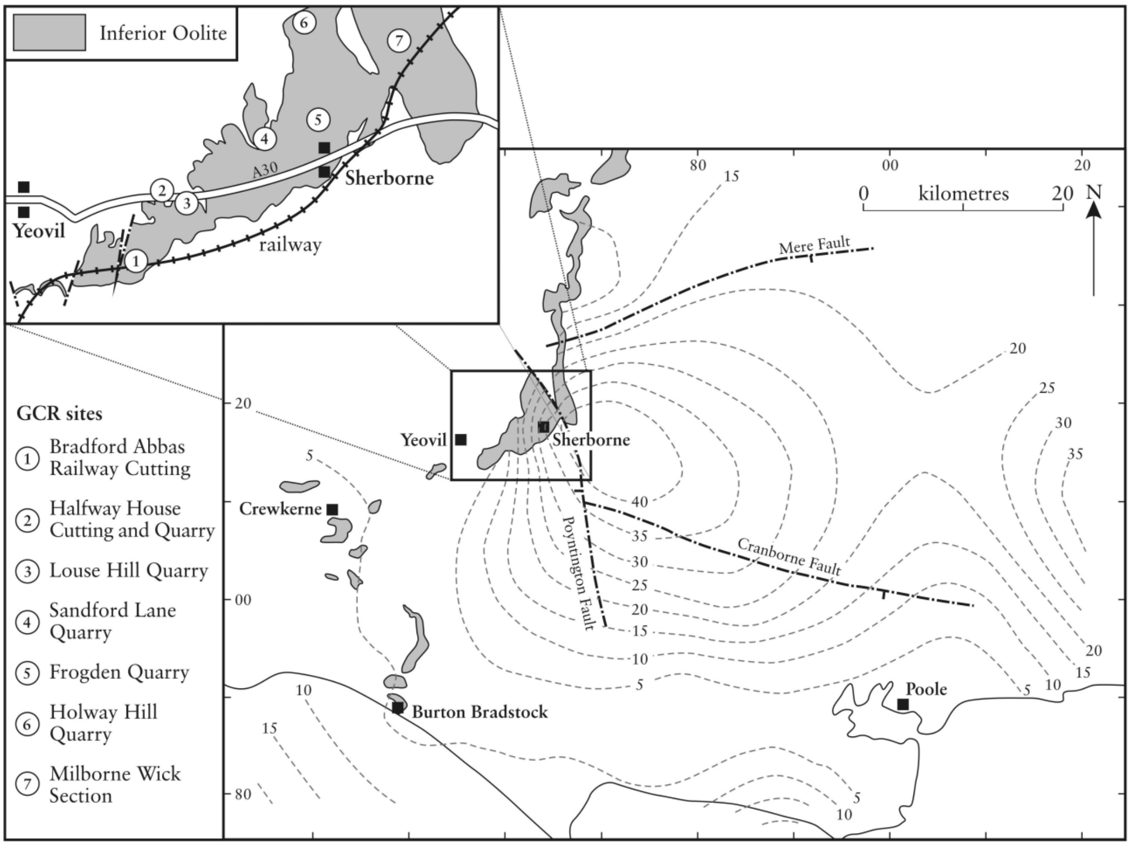
Ichnofabric relationships interpreted for the Bridport Sands Formation, showing the development of mixed vertical and horizontal burrows in some beds, and predominantly vertical burrows in others. From Bryant et al. (1988).



Detailed sedimentary and biostratigraphic log of the Inferior Oolite Formation at Burton Cliff, based on inland sections and fallen blocks near Freshwater Beach. From Callomon and Cope (1995). Aa, Bj and Bt are Aalenian, Bajocian and Bathonian ammonite subzones respectively. The 5m section encompasses 14 ammonite zones in total. There are major non-sequences between the Scissum and Snuff Box beds (at least 3 zones), between the Snuff Box and Red Beds (> 1 zone) and between the Red Conglomerate and the Astarte Bed (≥ 1 zone).



Simplified log of the Inferior Oolite Formation at Burton Cliff. From "Geology of the Wessex Coast" web site.



Isopachs for the Inferior Oolite in Dorset showing thickening away from the south Dorset shelf. From Cox and Sumbler (2001).

Web link to "Geology of the Wessex Coast"

- http://www.soton.ac.uk/~imw/burton.htm

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