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THIRD CONJUGATE MARGINS CONFERENCE 2012

Basin development and hydrocarbon systems of the Mesozoic and Cenozoic

THE WESSEX BASIN OF SOUTHERN ENGLAND - FIELD TRIP GUIDE

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Third Conjugate Margins Conference- DUBLIN 2012

The Wessex Basin of Southern England- Field Trip guide Basin Development & Hydrocarbon systems of the Mesozoic and Cenozoic

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Grant Wach was appointed Professor of Petroleum Geoscience at Dalhousie University in 2002. A specialist in Reservoir Characterization and Stratigraphy, his interest in complex oil reservoirs began at Syncrude, in the oil sands of Alberta. Prior to Dalhousie he was with Exxon (now ExxonMobil) and was Geoscience Research Associate at Texaco (now Chevron) involved with exploration and commercialization with business units around the globe. He has conducted research on, and led field schools and courses in exploration, development and reservoir characterization in several countries. In 2012 he was the first recipient of "Professor of the Year" award from the AAPG Foundation. Professor Wach has an Honours B.A.(Geography/Geology) from the University of Western Ontario, a M.Sc. (Geology) from South Carolina, and a D.Phil. (Geology) from the University of Oxford.
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Stephen Hesselbo is the Sackler Clarendon Professor of Stratigraphy at the University of Oxford and Sackler Fellow at St Peter's College, Oxford. His recent research has focussed on the mid-Mesozoic time interval but he is interested in the record of past events through the whole of Earth history in the area of geological history aimed at understanding the dynamics of major past perturbations in the Earth's physical and biological systems, employing a range of laboratory and field techniques at the interface of stratigraphy, sedimentology, isotope geochemistry, and palaeobotany. He is Secretary for the International Subcommission on Jurassic Stratigraphy and member of editorial boards for Geology, Palaeogeography, Palaeoclimatology, Palaeoecology, and Newsletters on Stratigraphy. He can be contacted at +44 1865 272029; stephen.hesselbo@earth.ox.ac.uk

Front Cover- East cliff at West Bay, Dorset. View of the Bridport Sandstone in the near cliff, and in the Bridport Sandstone capped by the Inferior Oolite and Frome Clay in the far cliff. The Bridport sandstone is a progradational shoreface sandstone of latest Toarcian and early Aalenian age (i.e. early and Middle Jurassic), whilst the overlying distal ramp limestone of the Inferior Oolite is Aalenaian, Bajocian and early Bathonian age (Middle Jurassic) and is highly condensed. The overlying Bathonian Frome Clay is a basinal deposit that grades up into a carbonate ramp. The Bridport Sandstone is a (rather poor) reservoir level within the Wytch Farm Oil Field. Unusual metre-scale accretional mounds are visible running along the foot of the cliff and these are delineated by surfaces picked out by *Ophiomorpha* trace fossils (Photo: Grant Wach).

Published by PIPCo RSG Ltd
ISBN: 978-0-9572517-1-4-4

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Introduction

Welcome-
The Wessex Basin of Southern England field trip will traverse a classic section of Mesozoic and Cenozoic strata and examine the petroleum systems of the strata. The transect will examine outcrops of Triassic, Jurassic, Cretaceous and Tertiary rocks along the South Coast of England and look at the elements of source, reservoir and seal. Migration pathways, timing and trapping mechanisms will be discussed and illustrated in the field.

The Dorset and East Devon coasts, and Isle of Wight have an outstanding combination of globally significant geological and World Heritage sites along nearly 200 km of largely undeveloped coast. The geology displays approximately 185 million years of the Earth's history, including a number of internationally important fossil localities. These sections have been a pleasure for us to study over the years and we are sure you will share our enthusiasm for the south coast throughout this trip.

Grant Wach and Stephen Hesselbo

Trip Itinerary

4 NIGHTS, 16-20 AUGUST 2012

STARTING AT LONDON HEATHROW AIRPORT (THURSDAY AFTERNOON) AND ENDING AT LONDON HEATRHROW AIRPORT (MONDAY EVENING).

Tide times will control trip locations

DAY 1: Thursday August 16th

Pick up at Heathrow airport. Leave ~14.00.
Travel time ~3 hours to hotel in Sidmouth, Dorset.

DAY 2: Friday August 17th Low Tide: 12:00

- Sidmouth- Triassic fluvial and lacustrine facies Sherwood Sandstone [reservoir] and Mercia Mudstone groups.

- Lyme Regis–Pinhay Bay. Examine the facies transition at the Triassic–Jurassic boundary. Early Jurassic transgression, deep marine sedimentation, Penarth Group, Lias Group (source rock).

DAY 3: Saturday August 18th Low Tide: 13:00

- West Bay to Burton Bradstock- Early and Middle Jurassic shallow marine deposition (Bridport Sandstone Formation [reservoir], Inferior Oolite Group [reservoir], Frome Clay [seal].

- Kimmeridge Bay- Late Jurassic basinal mudstone [source rock] and oil well producing from the Middle Jurassic Cornbrash limestone.

- Hengistbury Head – Paleo oil seep in Eocene marine and non-marine facies.

Travel to Isle of Wight (Lymington–Yarmouth ferry crossing).
Hotel in Shanklin, Isle of Wight.

DAY 4: Sunday August 19th Low Tide: 18:00

- Basin evolution and Cretaceous overview (National Trust Car park) near Gore Cliff- and Blackgang Chine. Basin evolution and Cretaceous overview from the Early Cretaceous non-marine and shallow marine siliciclastics (Wealden Group, Lower Greensand Group) through to the Gault, Upper Greensand Group and the Chalk Group
- Hanover Point and Compton Bay. Early Cretaceous non-marine and shallow marine siliciclastics (Wealden Group, Lower Greensand Group) through to the Gault and Upper Greensand Group at the base of the Lower Chalk.
- Shanklin and Horse Ledge (Optional)- Examination of baffles and barriers to flow produced by firmground and hardground development in Lower Cretaceous reservoirs

DAY 5: Monday August 20th Low Tide: 19:00

- Whitecliff Bay, Unconformity on Chalk, Eocene marine siliciclastics, inversion history.

Leave Isle of Wight (ferry from Ryde to Portsmouth) ~15.00

Return to Heathrow airport -arrive APPROXIMATELY 18.00, end of excursion- connect with flights to DUBLIN


Legend
Towns/cities
Geology stops
Heathrow airport
London
Heathrow Airport
Bristol
Southampton
Portsmouth
Hengistbury Head
West Bay
Lyme Regis
Sidmouth
Kimmeridge Bay
Compton Bay
Hanover Point
Ryde
Whitecliff Bay
Shanklin
Plymouth
Scale
0
Km
100
Day 1
A30
A35
A35
A3052
Lyme Regis
Sidmouth
Scale
Km
0
10
Day 2
Southampton
M27
A337
A35
A352
West Bay
Hengistbury Head
Kimmeridge Bay
A3054
A3020
A3055
Shanklin
Scale
Km
0
20
Day 3 & 4
Southampton
M27
To London
A3
Portsmouth
A337
Ryde
Whitecliff Bay
A3054
A3020
A3055
Compton Bay
Hanover Point
Gore Cliff
Shanklin
Scale
Km
0
20

Basin Structure and Petroleum Systems

Wessex-Channel Basin Structural Evolution- Summary

The following section includes a brief description of the mechanics of basin evolution as it applies to the Wessex Basin, with specific features applicable to the Channel Basin and the Isle of Wight. There are still problems in reconstructing the structural evolution of the basin, but it is now known to be more complicated than the previously proposed tensional-compressional tectonic model.

Devonian and Carboniferous:

The Palaeozoic basement was deformed during the Variscan Orogeny which culminated during the late Carboniferous. Permian, Mesozoic and Tertiary sediments were subsequently deposited.

Triassic:

North-south extension continued until the early Cretaceous. A series of east-west faults, associated with pre-existing structures in the Palaeozoic basement, comprise one of the three major zones of normal faults that trend east-west across the Wessex Basin. Subsidence continued with motion along the system of faults, possibly related to Variscan thrusts. Extensional activity lasted until the end of Barremian times and possibly well into the Aptian, while thermal relaxation continued until the end of the Cretaceous.

Early Cretaceous - beginning of Lower Greensand:

The late "Cimmerian" unconformity, a period of erosion throughout southern England, occurred during a continued period of crustal extension from the Late Jurassic to the Early Cretaceous. In the Channel Basin, the amount of erosion of the strata is not known. This was an area of rapid basin subsidence and the erosional effects of the unconformity may have been minimized. The fault zone remained active, with downthrow to the south. Syn-depositional basin infill resulted in a relatively thick Lower Cretaceous sediment infill of the basin south of the fault, while a thin veneer of Cretaceous sediment was deposited north of the disturbance.

Late Cretaceous:

Basin extension ceased during the beginning of the Chalk deposition. The Late Cretaceous was relatively stable until the latest Cretaceous. A thick layer of sediment was deposited throughout the Channel basin due to the combined effects of basin subsidence, caused by thermal relaxation and sediment compaction.

Early Tertiary:

From the end of the Late Cretaceous through the early Tertiary, tectonic inversion was caused by compression thought to be associated Pyrenean Orogeny. Lithospheric shortening produced crustal uplift and subsequent erosion. Reactivation and reversal of the fault systems folded the overlying strata. Maximum compression occurred during the Tertiary. In areas where the normal faults are offset by transfer zones, folds (or monoclinal flexures) are displaced.

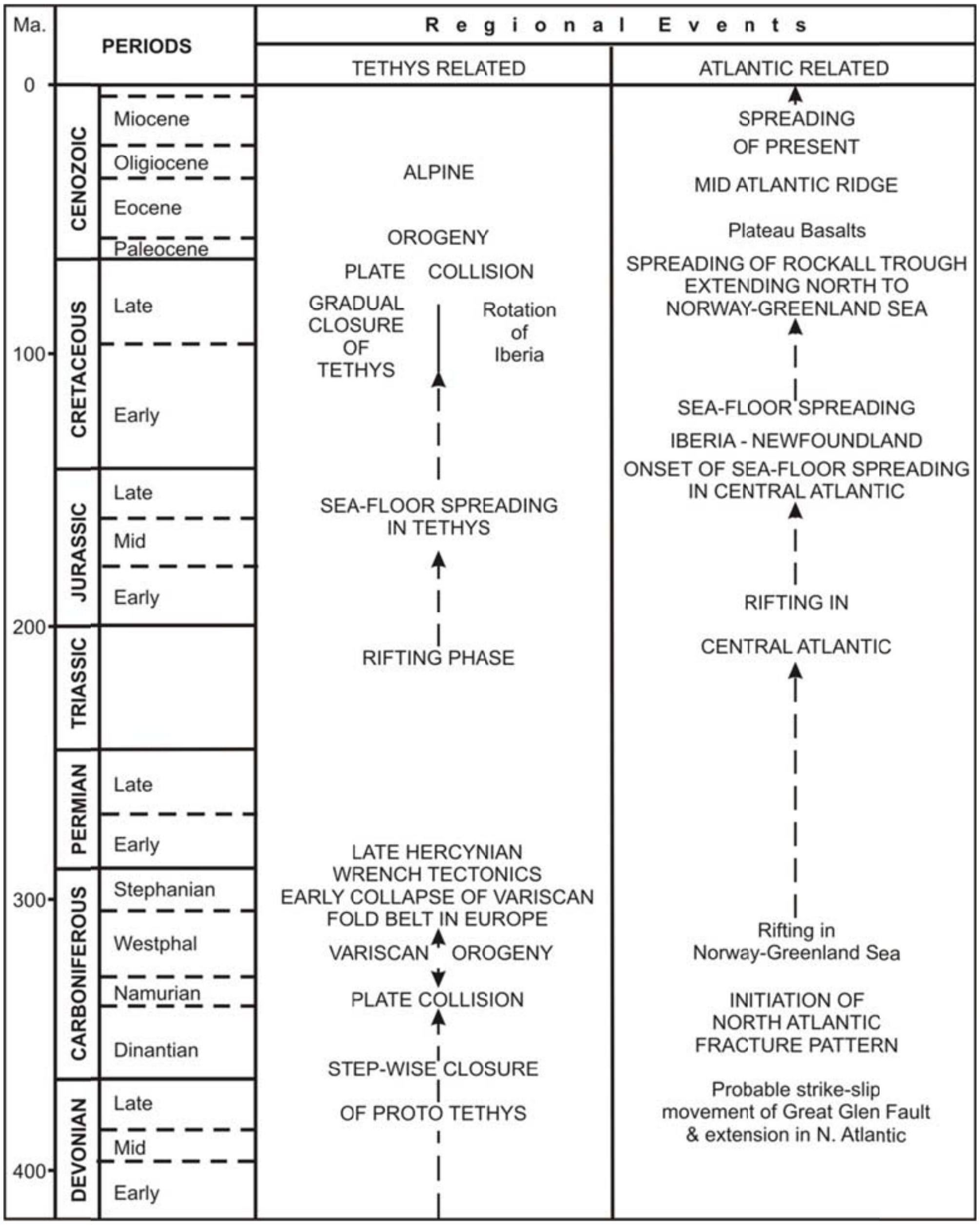


Figure 1: Regional tectonic events (adapted from Glennie, 1986).

Petroleum Systems of the Wessex Basin (Christians A., Simon S., Tobey D. & Wach G.)

An understanding of basin evolution is crucial to deciphering the petroleum systems and controls on sedimentation and the depositional history of the Wessex Basin and the Channel sub-Basin. These regional tectonic events coupled with eustatic variations had direct impact on the petroleum systems of the Wessex Basin (Fig. 2).

Source Rock and Maturity:

According to Bray et al. (1998), there were four major heating events in the Wessex Basin complex: mid-Triassic to early Jurassic, early Cretaceous, mid-Tertiary and late Tertiary. Due to basin tectonics (periods of uplift and burial), maturity levels vary within different sub-basins of the Wessex. There are two potential (depending upon maturity) Jurassic source rocks, the lower Oxfordian Clay/ Kimmeridge Clay, and a proven source rock in the Lias Group.

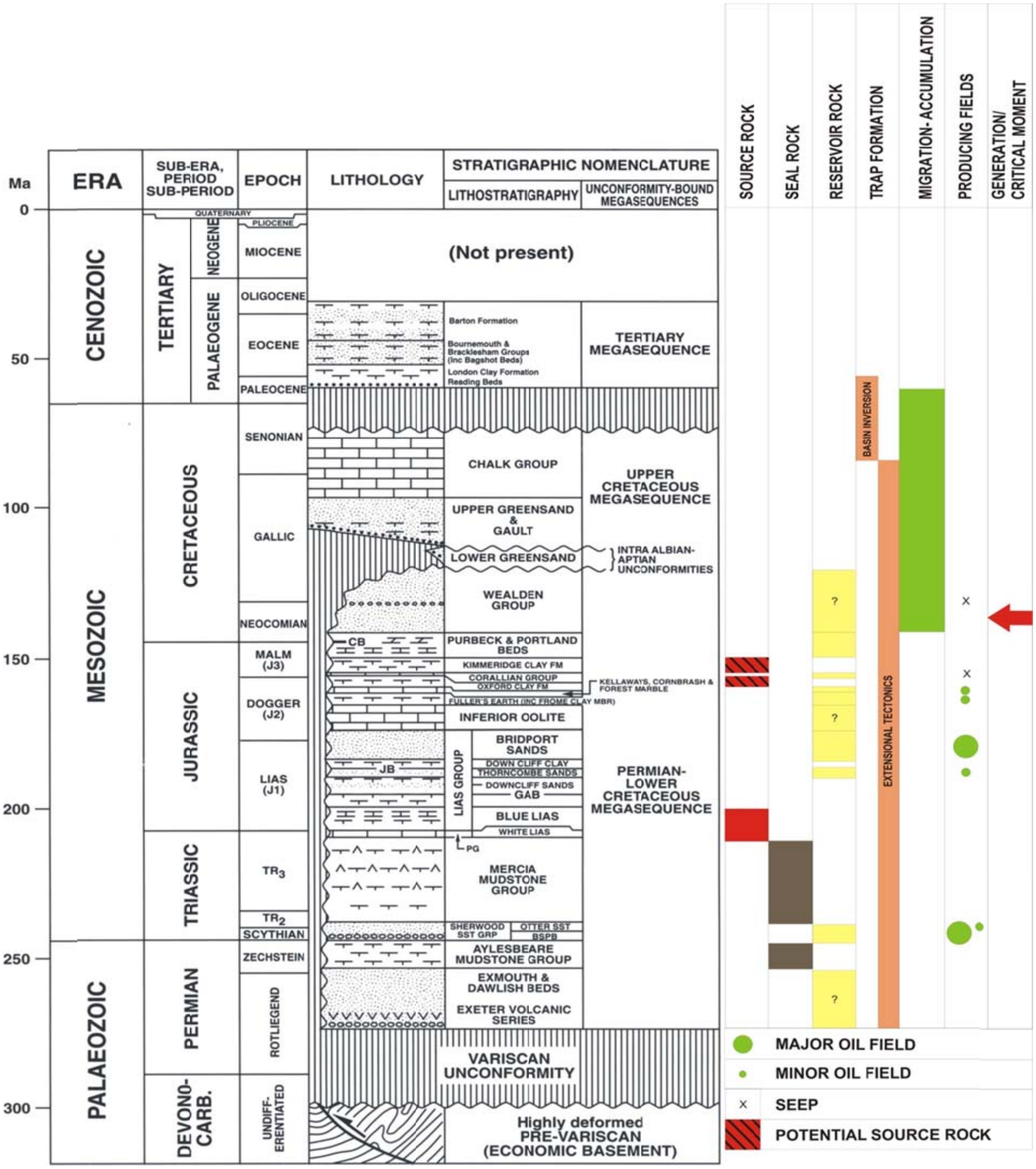


Figure 2: The petroleum systems of the Wessex Basin. The diagram is modified from Underhill & Stoneley (1998), with the addition of the petroleum system elements.

The Lias Group shows large variations in maturation along the basin due to regional tectonics and subsequent compartmentalization of the hydrocarbon systems. This compartmentalization is apparent in the Kimmeridge-5 well which experienced source rock generation in the early Cretaceous to mid-Tertiary (Bray et al., 1998). It is during this interval within the early Cretaceous that these hydrocarbons entered the oil window, i.e. the critical moment (Fig. 2). Underhill and Stoneley (1998) suggest that peak generation was around Middle to Late Cretaceous. Other areas of the basin, for example the Wytch Farm Block, did not reach maturity at any time during the Jurassic and early Cretaceous due to shallow burial (Fig. 3- from Bray et al., 1998).

Different kerogen types yield different results: Type I produces oil (algal), Type II kerogen produces a mix of oil and gas (planktonic), Type III produces gas (humic) and Type IV has no yield (oxidized residue). The Kimmeridge Clay consists of the Type II and III kerogen whereas the Oxfordian and Lower Lias consists of Type II, III and IV (Ebukanson and Kinghorn, 1985). The Kimmeridge and Oxford Clay have high total organic carbon (TOC) content (up to 20%) however; these rocks were not sufficiently buried to become mature (Farrimond et al. 1984 *cited in* Underhill & Stoneley 1998). TOC values in the black shales of the Lower Lias have values recorded up to 8% in a Type II kerogen (Ebukanson & Kinghorn, 1985).

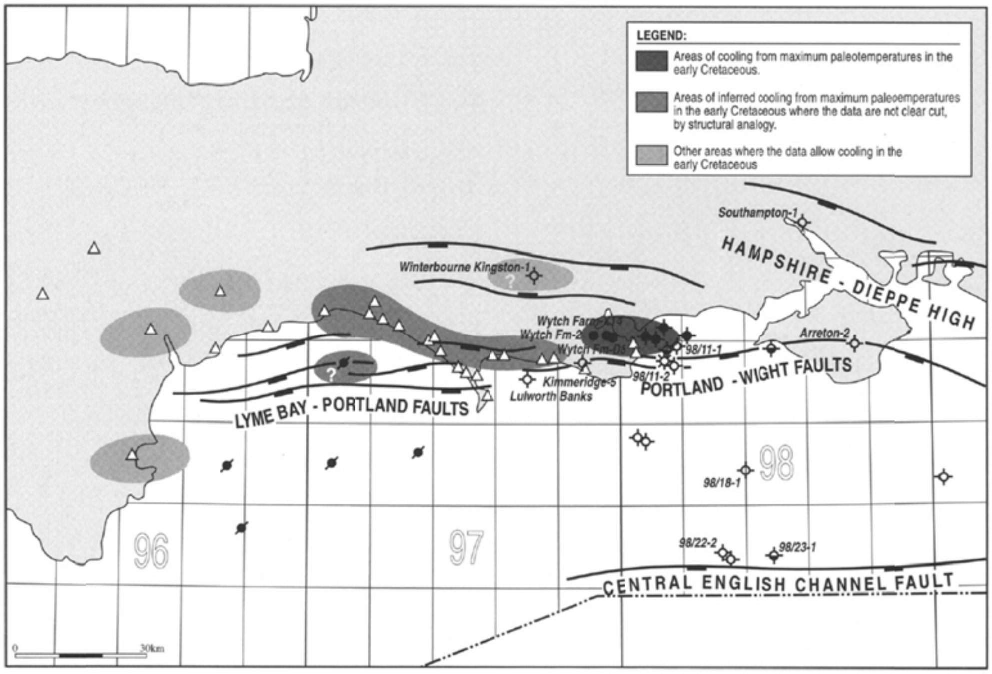


Figure 3: Areas showing cooling from maximum paleo-temperatures during the Early Cretaceous by Bray et al. (1998).

Reservoir Rock:

Within the Wessex basin, the siliciclastic units have the highest reservoir rock potential (Underhill, J. R. & Stoneley, R. 1998) with high primary porosities, high net: gross values and sufficient lateral extent to hold commercial oil accumulations. Some examples of potential and producing reservoirs are:

- The Lower Triassic Sherwood Sandstone which has porosities varying up to 30% depending on the type of facies: (fluvial channel sands, sheet flood deposits and aeolian sandstone) facies being analyzed.

Type of Facies	Range of Porosities %
Fluvial channel sands	6- 18
Sheet flood deposits	14- 22
Aeolian sandstones	14- 26

Table 1: Correlation between the facies type and reservoir quality (porosity). Data compiled from Meadows, N. S. & Beach, A. (1993).

- The thick, fine- grained Early Jurassic Bridport Sands which have porosities up to 15% based on outcrop exposure and up to 32% in the Wytch Farm field based on core data.
- The fractured Mid- Jurassic Frome Clay.

There are other units with higher reservoir risk due to the reduction in permeability, limited lateral extent (e.g. aeolian Permian sand), or a high content of fine grained material (e.g. Thorncombe Sandstone). Some carbonate units also act as good reservoirs when secondary porosities are created by fracturing or dissolution of cement. These include the Middle Jurassic Inferior Oolite and Portland Limestone.

Seal:

Most of the reservoir rocks are sealed by the presence of thick cap rock or perhaps by thin, impermeable layers. Some examples of these are the Aylesbeare Mudstone Group overlying the Permian aeolian sands, Mercia Mudstone overlying the Sherwood Sandstone and potentially the Kimmeridge Clay overlying the early Jurassic reservoirs.

Structural tilting of the blocks during extensional tectonics (Permian to Cretaceous) and later by structural inversion (Tertiary) may have contributed to the sealing of the reservoirs. In these cases, lateral traps are set up depending on the lithology, thickness (sand/ shale ratio) and the amount of throw on these faults. Inversion may initiate remigration of hydrocarbon into shallower reservoirs. However, based on the exploration drilling program which targeted these plays, it is quite evident that the faulting which acted previously as conduits for the migration of hydrocarbon became barriers or seals as a result of compressional forces (Selley & Stoneley 1987) and perhaps cementing of the fault trace through diagenesis.

Trap:

The traps in the Wessex Basin are primarily structural rather than stratigraphic and can be divided into two major tectonics events: extensional in the Mesozoic and basin inversion tectonics during the Cenozoic. Extensional faulting began during the Paleozoic Variscan fold and thrust belt progressing to the Late Cretaceous (Underhill and Stoneley, 1998). The extensional tectonics subdivided the basin into several fault blocks tilting the strata and thus creating potential traps. Hydrocarbon exploration shifted to these buried and tilted extensional blocks which are related to the structural plays in the Wytch Farm and Wareham oilfields (Underhill and Stoneley, 1998). Structures related to the Tertiary based inversion are periclinal traps developed from the Campanian to the Paleocene, late Cretaceous to early Tertiary (Underhill and Stoneley 1998).

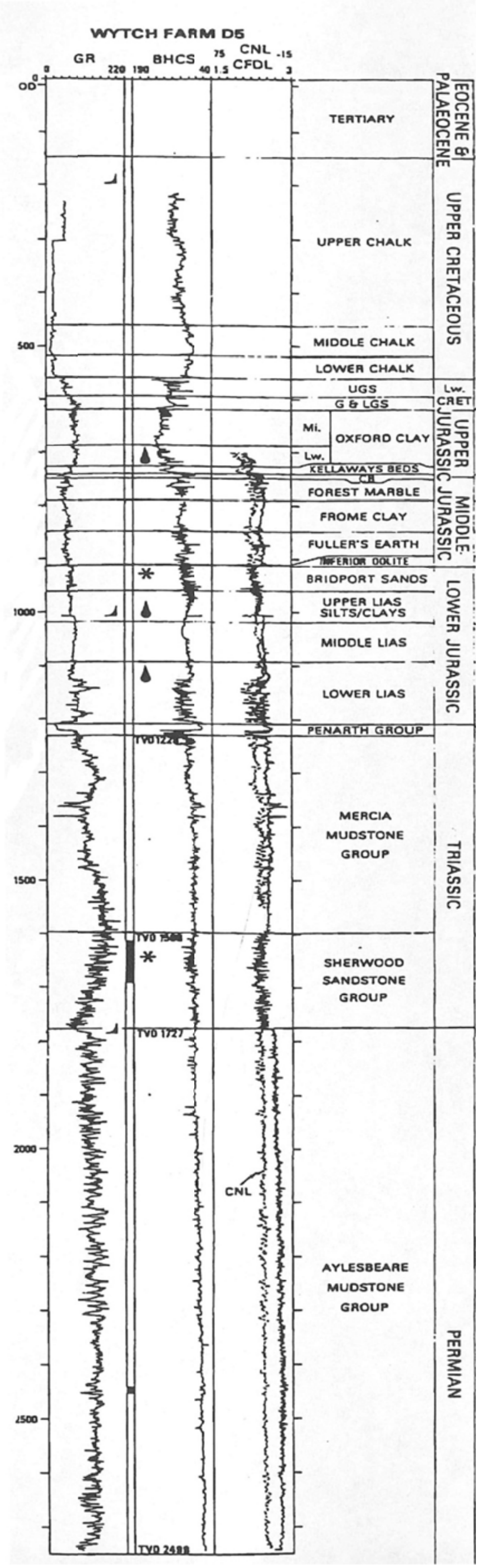


Figure 4: The Wytch Farm D5 well illustrating the reservoir and seal intervals of the petroleum systems of the Wessex Basin. The diagram is an excerpt from Penn, et al. Chapter 10, Principal features of hydrocarbon prospectivity of the Wessex- Channel Basin, UK, Volume 1 Petroleum Geology of Northwest Europe (J. Brooks and K.W. Glennie, eds.).

Wessex-Channel Basin Structure:
The Wessex Basin has three major east-west trending normal fault zones (Fig.5):

1) Pewsey-Hog's Back-London Platform zone
2) Mere-Portsdown zone
3) Purbeck-Isle of Wight zone

These subdivide the region into smaller sub-basins: the Vale of Pewsey and Wealden basins in the northern region: the Mere Basin in the centre: the Dorset Basin to the southwest: and the Channel Basin, the southernmost basin of the Wessex Basin complex.

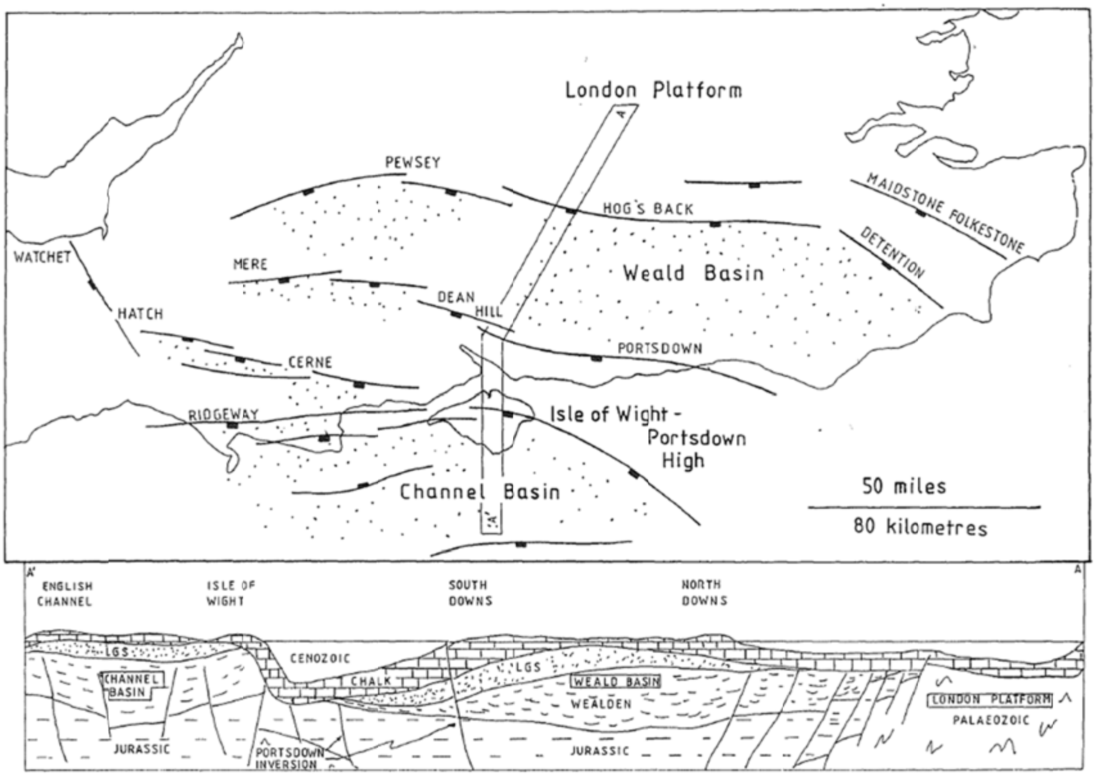


Figure 5: Wessex Basin structural controls and sub-basins (from Wach and Ruffel, 1991).

The Variscan fold belts across the Wessex Basin began as thrust or reverse faults (Whittaker, 1986). The depth to the top of the Variscan basement on the Isle of Wight ranges from 1400-1600m north of the monocline, to 2000m on the southwestern side, deepening to 2200 m on the central and southeastern area of the island. This deepening to the south central area of the island coincides with the thickest deposit of Lower Greensand sediment in this region.

Stoneley (1982) and Chadwick (1986b) describe the faulting during compression along the Purbeck-Wight zone (Dorset-Isle of Wight disturbance) as resulting in en echelon offsets of several kilometres, possibly related to strike-slip motion of considerable magnitude. Stoneley (1982) believes the *en echelon* offset is sinistral in the western half of the Isle of Wight, becoming dextral beneath the sea, south of Christchurch and dextral again in Dorset where the Purbeck monocline dies out. The offsets may be border faults (step faults) developed on prior Palaeozoic fault structures. Later reactivation and inversion developed the monoclinal flexure with interference folding and minor swells in the region adjacent to the Central Downs.

A half-graben may have formed at some point, perhaps during the Permian (Chadwick, 1986b) to late Cretaceous. If this has occurred facies changes during the deposition of the Gault, Upper

Greensand and Chalk should be evident. The Chalk facies in outcrop should show evidence of reworking on the margins of the Central Downs and possible hardgrounds near the top of the strata in the middle of the Central Downs, which would be evidence of syn-tectonic activity. Thinning of the Chalk Strata across the Central Downs may be further evidence of syntectonic faulting.

Movement was concentrated during the Mesozoic and Cenozoic with an interval of relative quiescence during the mid to late Cretaceous. This movement was followed by reversal at the end of the Cretaceous (Stoneley, 1982). This re-activation during the Tertiary was along pre-existing fold axes which resulted in further development of steeply folded strata, with movement along pre-existing structures in the Palaeozoic Basement.

Accommodation Space Compaction and Basin Infill:

During early basin development, the rate of Permo-Triassic sedimentation kept pace with basement subsidence (Chadwick, 1986b). Compaction became a factor later in the basin development with loading allowing sediment accommodation to exceed the rate of basin subsidence. Thus, fluvial conditions were maintained during the deposition of the Wealden Group in the beginning of the Lower Cretaceous, despite rapid basin subsidence, with abundant sediment supply from the erosion of the proximal massifs. Lowering of sea level towards in the latest Jurassic to Early Cretaceous created two distinct depocentres, separated by the London-Brabant Massif. The northern basin was characterised by relatively slow subsidence and correspondingly low rates of sediment infill. In southern England, ample sediment supply from the erosion of nearby massifs, coupled with rapid subsidence rates, "rapidly" filled the basins.

Late Cimmerian Unconformity:

There are minor ·unconformities and non-sequences which are due to eustatic changes and variable rates of local tectonic subsidence. These were subsequently superseded in the Late Jurassic and Early Cretaceous times by a major unconformity associated with late Cimmerian tectonism, cutting the entire Mesozoic sequence in southern England. This period extensive erosion is referred to as the late "Cimmerian" unconformity.

The late "Cimmerian" unconformity formed in an extensional setting, by the combined effects of isostatic footwall block uplift and a contemporaneous eustatic lowering. This produced a syn-extensional or early post-extensional isostatic disequilibrium which can be recognized throughout southern England. Only in small areas of rapid basin subsidence were the effects of the unconformity minimized and the extent of this is not clearly known.

The deposition of the Lower Greensand in southern England marked the end of the late "Cimmerian" event. Only in areas of rapid crustal subsidence were the erosional effects minimized. These areas were the central part of the Weald and Channel Basins (Chadwick. 1986c, 1986d). The Lower Greensand thins and pinches out to the north against the London Platform and along the western margins of the Wessex Basin (Fig. 5), overstepping progressively older sediments. In turn the Lower Greensand is succeeded by the Gault and Upper Greensand with the Gault marking the second mid-Cretaceous marine transgression. The dark grey mudstone of the Gault oversteps the Lower Greensand to lie unconformably on lower Palaeozoic strata of the London Platform.

Palaeogeography and Palaeoclimate- Mesozoic

Fig 1: The major **Mesozoic** depositional basins and massifs are bounded by the boreal ocean to the north and the Tethys to the south and east. Jeanne d'arc Basin may be further east then actual position. Longitude and latitude correspond to the present (from Wach & Ruffell, 1991).

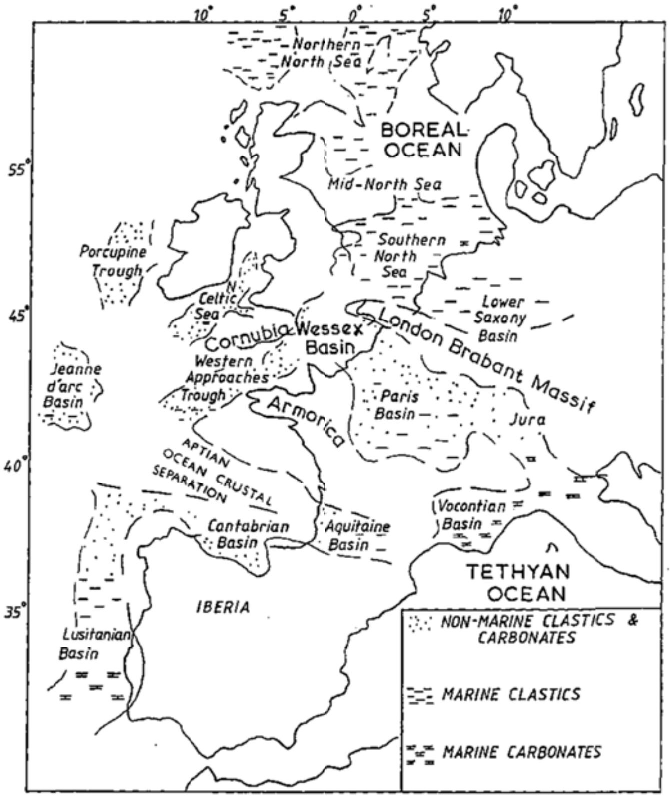
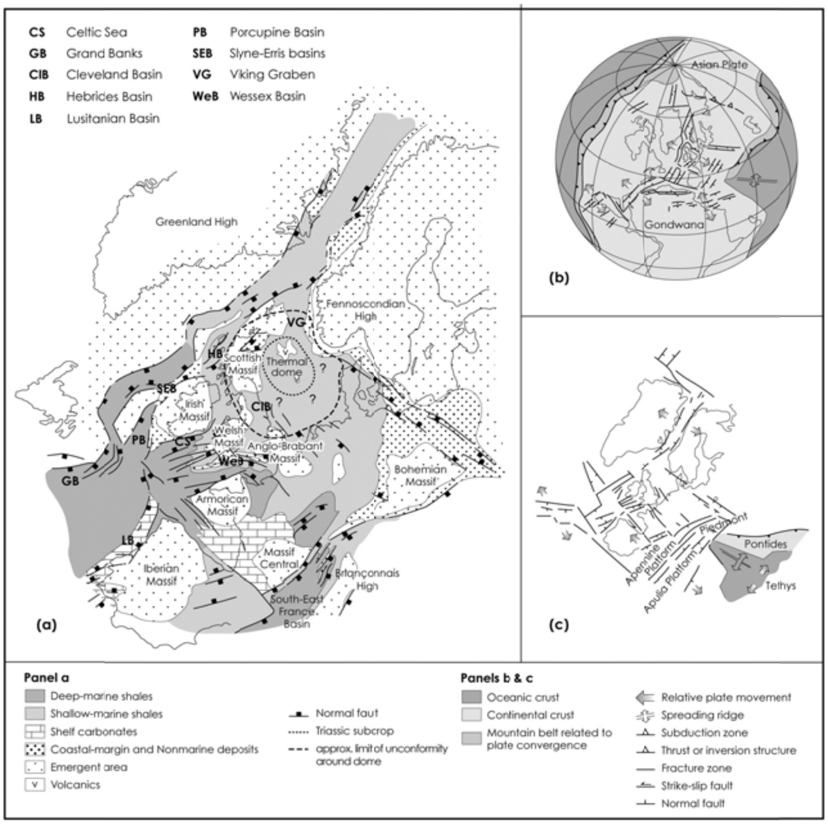


Fig 2: Palaeogeographic map for the **Early Jurassic** of the area of Britain and Ireland (redrawn from Coward et al. (2003)). Also shown is the region centred on the central North Sea that was uplifted during the Mid Jurassic. References: Coward M P, Dewey J F, Hempton M & Holroyd J (2003) Tectonic Evolution. In Evans D, Graham C, Armour A & Bathurst P (eds.) *The Millennium Atlas: Petroleum Geology of the Central and Northern North Sea*. London: The Geol. Soc. 17–33.



Cretaceous- Palaeogeographic reconstructions (e.g. Briden *et al.,* 1974) show the landmass of what is now Britain, c. 15° south of its present-day location (N 50°-55°, 0°). This would place southern Britain at Cretaceous latitude of N 35° to 40°, longitude E 20° to 30°, comparable to the present-day subtropical zone (S 30° to N 30°). Subtropical conditions persisted during much of the Lower Cretaceous (Allen, 1989), but were subject to variations in humidity and aridity. Evidence of such climatic changes can be found in the Barremian-Aptian sediments of southern England. Earlier Barremian and late Aptian-early Albian sediments were deposited under more humid weathering regimes compared with mid-Barremian Wealden and early Aptian Lower Greensand sediments that were deposited in an area of, or in close proximity to, a region of semi-arid to arid weathering. The palaeo-drainage patterns were from Cornubia to the west and from Armorica lying to the southwest (Allen, 1975; Stewart, 1981b) until the late Barremian to early Aptian. This means there must have been a landmass between the proto-Atlantic and the Channel Basin. Stewart (1981a) interpreted the fine grained fluvial system as meander belt in the Channel Basin suggesting the region had a low relief. Marine connection to the Tethyan Seaway may have occurred across the Paris Basin, or through the Western Approaches Trough and proto-N. Atlantic (Anderton et al. 1979); although Owen (1975) has the Cornubia-Armorican Massif remaining intact into the mid-Albian. The Boreal Sea periodically breached the London-Brabant Massif to flood the Wessex Basin, with a continuous connection established in the mid-Albian. Lower Cretaceous storm paths calculated by Parrish (1985) were from the southeast to the northwest. Conditions today are similar, with storms from the southwest, moving up through the Western Approaches (from Wach, 1991).

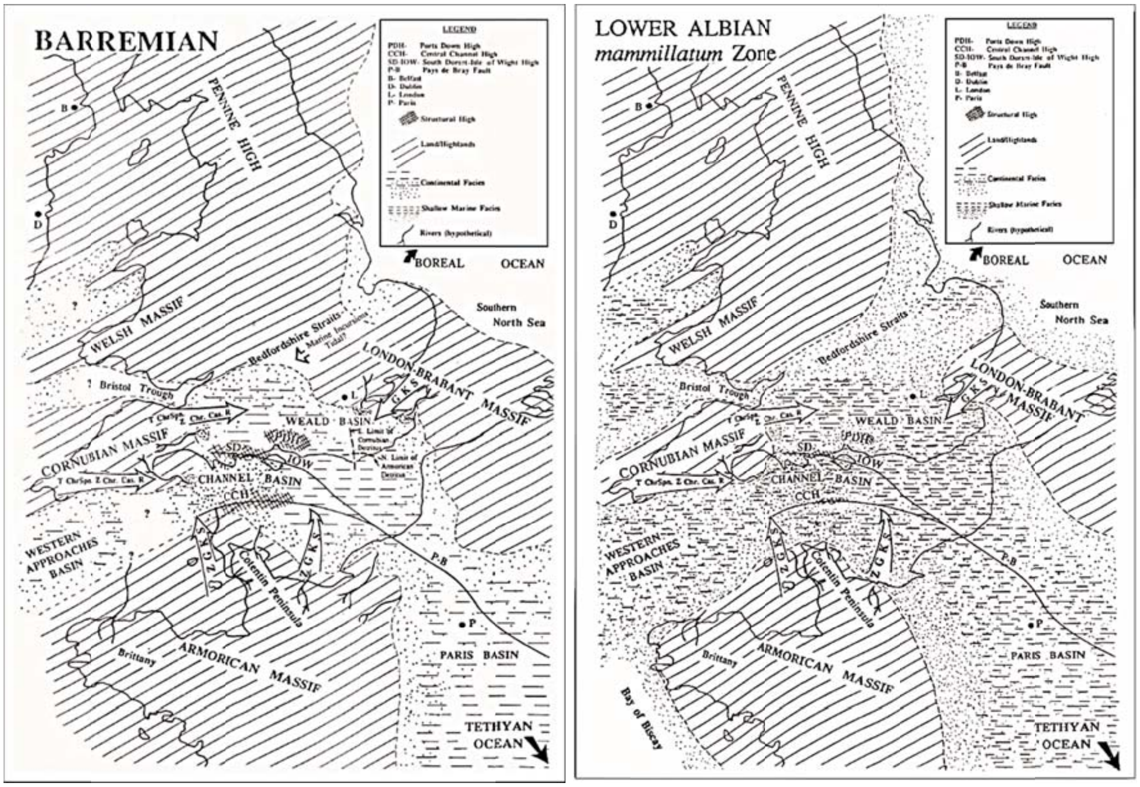


Fig 3 Palaeogeographic maps for the Lower Cretaceous area of Britain and northern France for the Barremian and Albian stages (from Wach, 1991).

WESSEX BASIN- DORSET FIELD STOPS

Sidmouth: Stephen Hesselbo

LOCATION: Sidmouth (Budleigh Salterton and Ladram Bay)

2012).

OBJECTIVES

- Triassic fluvial and lacustrine facies - Budleigh Salterton Pebble Beds, Sherwood Sandstone [reservoir], Mercia Mudstone Group
- To examine the various facies within the Triassic Sherwood Sandstone Group of Devon, reservoir facies of the Otter Sandstone Formation

BACKGROUND

The Sherwood Sandstone Group occurs across the Wessex Basin and is subdivided into two parts, a lower Budleigh Salterton Pebble Beds Formation and an upper Otter Sandstone Formation. Both formations are continental red beds and the ages are poorly known, but tetrapod fossils that are thought to be Anisian (Middle Triassic, ~145 Ma) provide the age for the Otter Sandstone (Hounslow and McIntosh, 2003 and references therein). The Budleigh Salterton Pebble Beds contain no age significant fossils but are thought by Hounslow and McIntosh (2003) to be Olenekian–Anisian age (i.e. Early–Middle Triassic) on the basis of magnetostratigraphy and regional geology. The cliff immediately west of Budleigh Salterton village provides a fine section through the Budleigh Salterton Pebble Beds and the base of the Otter sandstone, whilst Ladram Bay, some 4 km to the NE provides excellent 3D exposures within the Otter Sandstone.

Figure SM1 is a general overview of the cliff at Budleigh Salterton. The Budleigh Salterton Pebble Beds Formation is overwhelmingly conglomeratic here, comprising well-rounded pebbles, cobbles and boulders of quartzite, in a sandy matrix, with subordinate interbedded sandstone and occasional mudstone lenses (Holloway et al., 1989). Some pebbles have yielded Ordovician and Devonian fossils. The Budleigh Salterton Pebble Beds were laid down in a braided river system (Smith, 1990) and the clasts are derived from source terrains to the south and south-west, on the basis of palaeocurrent directions and specifically identified source materials (e.g. Selwood et al. 1984). The Budleigh Salterton Pebble Beds Formation has a somewhat localised distribution in the Wessex Basin, based on borehole records; eastwards in Dorset the unit is not developed in the Wytch Farm area, but traced further to the east the formation reappears at the base of the Mesozoic succession on the Isle of Wight (Holloway et al., 1989). Nevertheless this formation represents an unusually widespread example of this conglomeratic facies in NW Europe, and an Early–Middle Triassic palaeo-climatic control (monsoonal) on erosional denudation of Variscan mountains to the south has been suggested as an origin of the deposit (McKie and Williams, 2009; Tyrrell et al., 2012).

The lithostratigraphic boundary with the overlying Otter Sandstone Formation contains angular ventifacts and is interpreted as a desert-formed deflation surface. The ventifact pebbles are coated with a desert varnish (Henson, 1970; Laming, 1982; Leonard et al., 1982).

At Ladram Bay the Otter Sandstone is predominantly sandstone, comprising erosive, cross bedded and commonly weakly fining-upward sandstone beds, with somewhat limited lateral continuity. Some beds are well-cemented. Rhizocretions are common, and locally mud- and heterolith-filled channels occur. Also present are localised conglomerates containing mud-chips and reworked calcrete nodules. McKie and Williams (2009, p. 716) state with regard to the more sandy facies of the Sherwood Sandstone: "migration and avulsion of sandy fluvial systems of varying plan form geometry [took place] across these basins. [There is] typically no evidence of large-scale cross-stratification or substantial fining-upward cycles indicative of deep and large rivers, and the overall impression throughout the region is of relatively shallow streams with bank-full depths of a few metres and rarely up to 5m".

Not visible at the beach level, but seen in the high cliff to the east of Ladram Bay is the sharp transition into the Mercia Mudstone Group, which is the seal facies for the Sherwood sandstone reservoirs in the Wytch Farm area. The mud-dominated facies of the Mercia Mudstone Group is thought to have been deposited mostly in a playa lake environment (Talbot et al., 1994; Porter and Gallois, 2008).

Figure 2: Field appearance of the Sherwood Sandstone Group at Budleigh Salterton, near Sidmouth, Devon. The Budleigh Salterton Pebble Beds dominates this view of the cliff and is overlain abruptly (at a deflation surface) by the Otter Sandstone Formation.

Figure 3: Overview of the mainly sand-dominated fluvial facies of the Otter Sandstone at Ladram Bay, near Sidmouth, Devon. In the bottom right of the photograph is a heterolith-filled abandoned channel.

Lyme Regis: Stephen Hesselbo

LOCATION: Lyme Regis – Pinhay Bay

egis to
2012).

OBJECTIVES

- To examine one of the principal source rock facies of the Wessex Basin petroleum
- To examine the facies transition at the Triassic–Jurassic boundary

BACKGROUND

The succession exposed in the cliffs to the west of Lyme Regis shows the junction between the shallow-marine Penarth Group and deeper marine Lias Group. In detail Pinhay Bay shows the facies transition between the probable carbonate ramp represented by the Langport Member of the Lilstock Formation, and the mostly offshore, hemipelagic facies represented by the Blue Lias Formation. The age of the strata here span the Triassic–Jurassic boundary (i.e. Rhaetian–Hettangian stages) and thus this locality provides a record of the Triassic–Jurassic boundary mass extinction. In the context of development of the Wessex Basin, the base of the Blue Lias signifies a major marine transgression that took place close to the period boundary, and which initiated deposition of the major source rock interval within the Wessex Basin petroleum system, the organic-rich shale of the Lias.

A stratigraphic log through the Pinhay Bay succession is given in Figure PB1 and this includes bulk rock carbon-isotope analyses (Korte et al., 2009). The Langport Member is a largely micritic limestone showing abundant evidence of syn-sedimentary downslope mass transport in the form of slumps and debris flows (e.g. Hesselbo et al., 2004). Fossil content included taxa that are fully marine, such as some solitary corals. The intraclasts within some of the debris flow units are evidence of penecontemporaneous sea-floor cementation prior to downslope transport. There has been some discussion as to the sequence stratigraphic significance of the top Langport/basal Blue Lias surface. Earlier authors thought that this surface represents an episode of major global sea-level fall on the basis of erosion and shale intercalations which were taken as evidence of subaerial exposure of the sea-floor (Hallam, 1960, 1988; Wignall, 2001) whereas others have interpreted the same phenomena as indicative of transition into a progressively more distal and deeper water ramp setting, with some beds within the lower Blue Lias interpreted as distal dilute turbidites (Hesselbo & Jenkyns, 1995; Hesselbo et al., 2004).

The Blue Lias itself comprises decimetre-scale interbedded mudstone lithologies that range from micritic limestone, through calcareous and/or organic-rich mudstone, to laminated black shale. Total organic carbon contents are up to ~8% (Deconinck et al., 2003). A regular cyclic signal has been detected by spectral analysis of time series of various data from the Blue Lias and the interbedding is interpreted as a Milankovitch signal (Waterhouse 1999a, b; Weedon et al., 1999). However, as yet there is no agreement as to which periodicities are expressed.

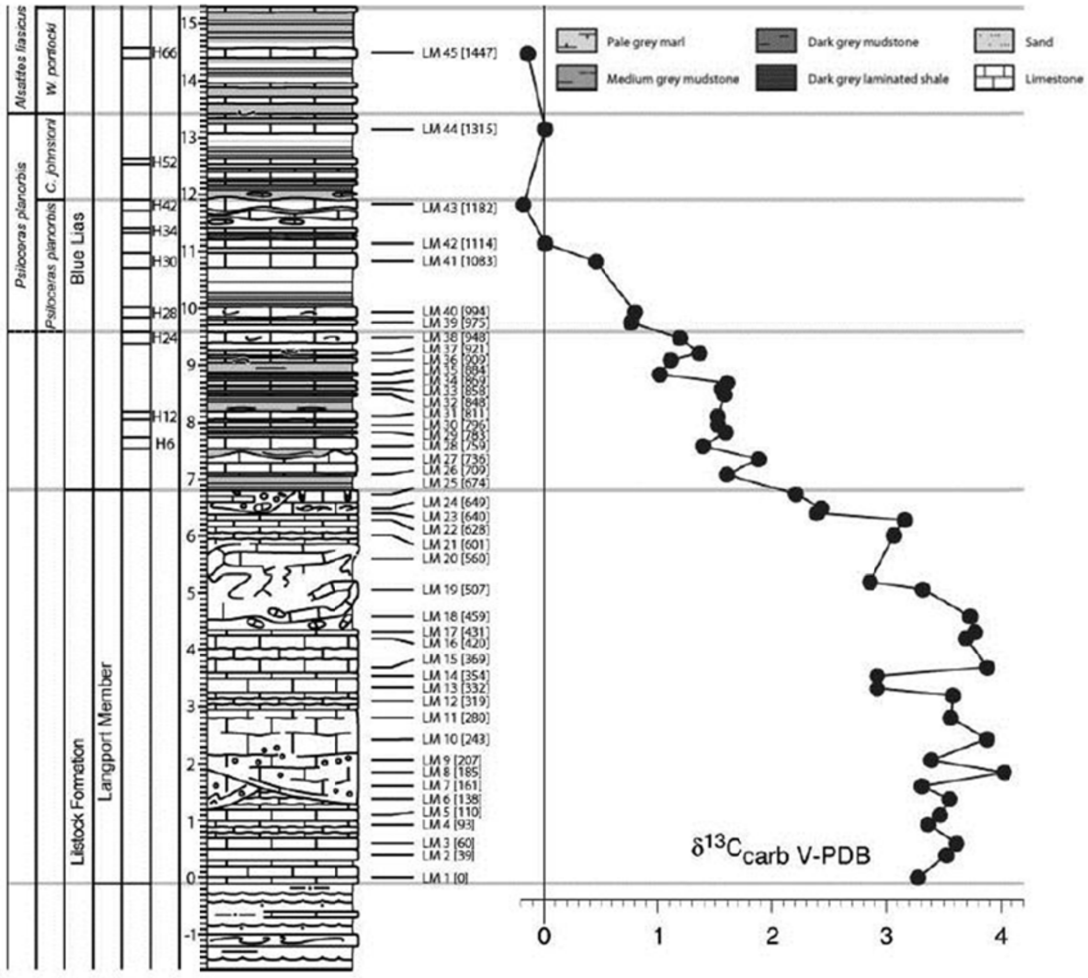


Figure 2: Lithology and bulk $\delta^{13}C_{carb}$ data for the section at Pinhay Bay, Lyme Regis, Devon (Korte et al., 2009).

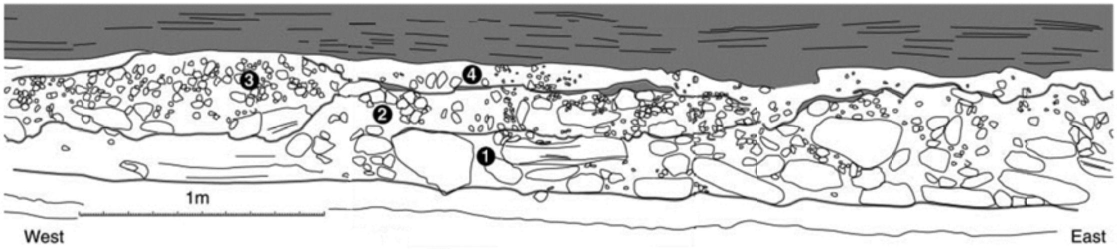


Figure 3: Line drawing based on photomontage (taken on 28 October 2003) of upper c. 1 m of Langport Member, Pinhay Bay, Devon (section 2 of Wignall, 2001). Bed 2 is separated from bed 4 by a thin discontinuous laminated shale that was deformed and partly eroded during deposition of bed 4 (from Hesselbo et al., 2004). Deposition is interpreted as occurring in the form of highly viscous debris flows.

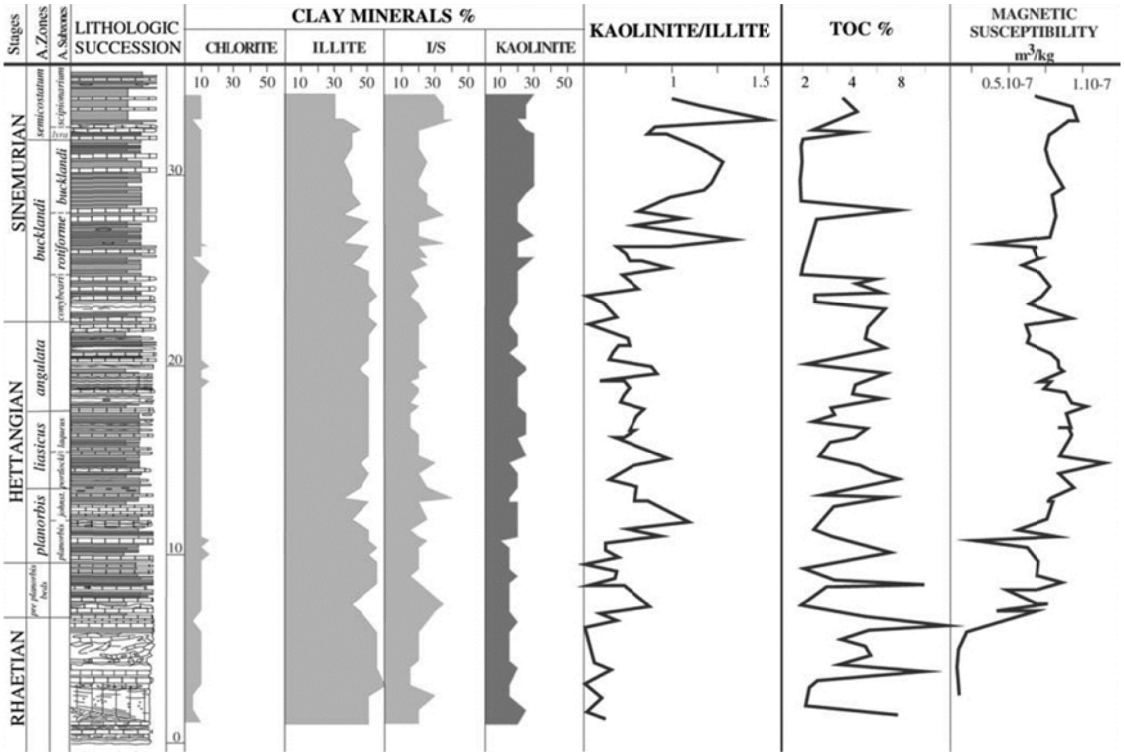


Figure 4: Total organic carbon, clay mineral and magnetic susceptibility data form the Blue Lias Formation, Pinhay Bay, Lyme Regis (from Deconinck et al., 2003).

Figure 5: Overview of whole thickness of Blue Lias Formation at Pinhay Bay, together with the top few metres of the underlying Lilstock Formation (pale grey limestone) and about 10 m of the overlying Shales-with-Beef Member which forms the lowest unit of the Charmouth Mudstone Formation.

West Bay to Burton Bradstock: Stephen Hesselbo

LOCATION: 5116083m E, 5617891m N

Figure 1: Aerial photo of West Bay to Burton Bradstock (from Google Maps, 2012

OBJECTIVES

- West Bay to Burton Beach. Early and Middle Jurassic shallow marine deposition (Bridpor Sandstone Formation [reservoir], Inferior Oolite Group [reservoir], Frome Clay [seal]
- To examine the reservoir facies within the Jurassic
- To examine evidence for synsedimentary faulting during the Early Jurassic

BACKGROUND

The Cliff section between West Bay and Burton Bradstock exposes a complete section through the Bridport Sand Formation and the Inferior Oolite. Overlying the Inferior Oolite is the Frome Clay (see cover photograph and Figure WB1). The Bridport Sand is latest Toarcian and early Aalenian age, whilst the Inferior Oolite spans most of the Aalenian and Bajocian stages. Thus these two facies have very different depositional rates – the Bridport Sandstone probably accumulated here in under half a million years whereas the Inferior Oolite was deposited discontinuously over a period of some 5 million years. The Fuller's Earth Formation is a medium to pale grey offshore marine mudstone of Bathonian age that is generally poorly exposed on the Dorset coast.

Detailed study of the Bridport Sand Formation in the Wessex Basin concluded that it was laid down as a series of progradational clinoform packages, best explained by pulsed forced regression (Morris et al., 2006). The depositional environment is thought to be shoreface, and progradational siliciclastic shoreface environments were developed in several UK basins at this time (Hesselbo & Jenkyns, 1995; Hesselbo, 2008), an observation related by Underhill and Partington (1993) to uplift of the North Sea dome. The sediment is thoroughly bioturbated with rare preservation of cross-bedded storm scours. The base of the formation comprises long wavelength (several metres) undulations about two metres in height, which are in some case picked out by preferential cementation and in other cases by subtle burrow-mottled (*Ophiomorpha*) surfaces. These appear to represent a series of large scale bedforms, possibly produced by contour parallel currents at the foot of the shoreface (Hesselbo & Jenkyns, 1995) or, alternatively, produced in much shallower shoreface setting by 'edgewaves' (Pickering, 1995).

The Inferior Oolite shows considerable lithological diversity. Below Burton Cliff the lithology is mostly bioclastic, comprising concentrations of marine molluscs and calcareous sponges. The palaeogeographical setting is thought to have been an intrabasinal structural high (Sellwood and Jenkyns, 1975) distal to a carbonate ramp developed around the London Brabant landmass to the north of the Wessex Basin (Jones and Sellwood, 1989). One notable horizon, the Snuff Box Bed, contains ferruginous oncolites associated with a significant hiatus (Gatrall et al., 1972). The hiatuses may be related to regional or even global sea-level changes and shifting facies belts but there is no evidence of subaerial exposure of the limestone.

In terms of petroleum geology, the Bridport Sand/Inferior Oolite, sealed by the Fuller's Earth mudstone, comprise a relatively minor and reservoir of indifferent quality in the Wytch Farm oil field (Underhill and Stonely, 1998).

At the eastern end of Burton Cliff the Bridport Sand is faulted out by the Bride Fault which cuts the coast obliquely (e.g. see Hesselbo and Jenkyns, 1995). In the superficial deposits at the back of the beach here there are many loose blocks of Inferior Oolite and Bridport Sand that have fissures and sharp-margined voids that are filled with a laminated very fine-grained creamy limestone. These limestones contain common ammonite and nautiloid fossils, some of which are of biostratigraphic value, indicating a history of fissure-filling along the line of the fault during the Aalenian and Bajocian. These observations are described and discussed in detail by Jenkyns and Senior (1991) who concluded that the fissuring resulted from synsedimentary fault movements. In the case of the

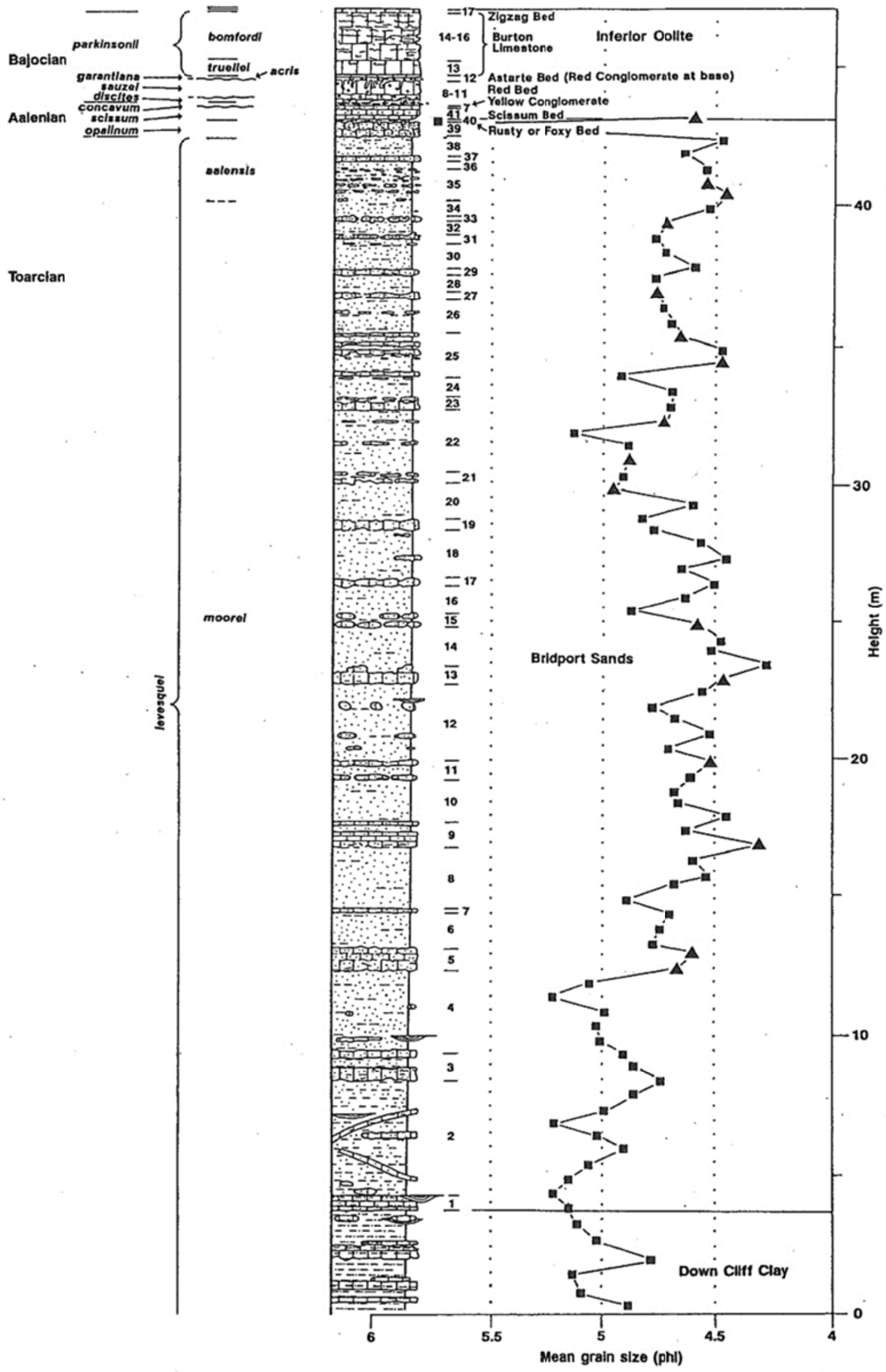


Figure 2: Stratigraphic log with grain size data for the Bridport Sand and Inferior Oolite, West Bay to Burton Bradstock cliff section (from Hesselbo & Jenkyns, 1995). Note that despite the name, the Bridport Sand is has an average grain size that is mostly coarse silt (between 4–5 phi). Squares = uncemented sand; triangles = cemented sand. All grain size measurements made by laser granulometer.

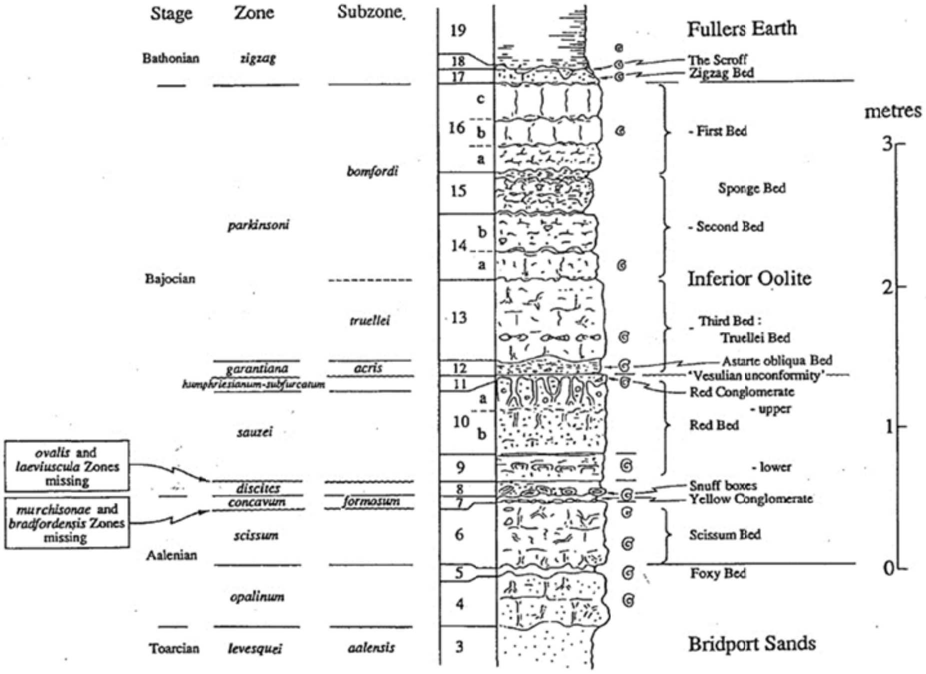


Figure 3: Detailed stratigraphy of the Inferior Oolite based work of numerous authors (summarised in Hesselbo & Jenkyns, 1995). The Inferior Oolite is best inspected from fallen blocks at the western end of Burton Cliff.

Figure 4: Detail of geopetal fill of a tubular void, formed in a large fallen block of Inferior Oolite Limestone in association with the Bride Fault, at Burton Bradstock. The lower part of the void is filled with a very fine grained creamy 'lithographic' limestone, typical of fissure fillings associated with several Wessex Basin faults, and interpreted by Jenkyns and Senior (1991) to be a manifestation of syndepositional faulting. The top part of the void is filled with drusy sparite cement. Pencil for scale.

Kimmeridge Bay: Stephen Hesselbo and Grant Wach

LOCATION 561350m E, 5607042m N

OBJECTIVES

- Kimmeridge Clay- Late Jurassic basinal mudstone [source rock]
- Oil well producing from the Middle Jurassic Cornbrash limestone.

BACKGROUND

At the type section along the Dorset coast, as well as in other parts of England, the formation essentially consists of mudrocks that can be simply categorized as medium-dark-grey, dark-grey-black laminated, and greyish-brownish-black. Intercalated are medium-grey to creamy-white coccolith limestones, and minor grey and pale-yellow limestones and dolostones. The Kimmeridge Clay Formation on the Dorset coast around Kimmeridge Bay (Cox and Gallois 1981) is about 500 m thick and comprises a variety of more or less organic-rich mudstones intercalated with limestone and dolostone beds. Both the top and bottom of the formation include beds of siltstone and silty mudstone and the succession is very well known on account particularly of cores obtained for research purposes through the Rapid Global Geological Events (RGGE) project (Gallois 2000; Morgans-Bell et al. 2001). Total organic carbon content rises locally to > 35% at the Blackstone Band (Morgans-Bell et al. 2001, and references therein.). The Kimmeridge Clay Formation is Kimmeridgian and Tithonian age (Late Jurassic, ~145–157 Ma) and contains an abundant and well-preserved marine molluscan fauna (Cope 1978; Wignall, 1990). The Kimmeridge Clay is the major oil source rock in the North Sea, but in the Wessex Basin it has not been buried to sufficient depth to generate significant quantities of hydrocarbon (Buchannan, 1998).

The component lithologies of the Kimmeridge Clay are rhythmically bedded (Figure KB1), and the formation has long been of interest to cyclostratigraphers (e.g. Dunn, 1974; Weedon et al. 2004, amongst others). The most recent cyclostratigraphic calibration is by Huang et al. (2010) who recognised all the major Milankovitch frequencies based on analyses of high-resolution resistivity image logs and TOC analyses from RGGE cores: this work allows precise estimation of sedimentation rates and contributes to calibration of the otherwise purely relative biostratigraphic scale. Other work on clay mineralogy and spectral gamma ray logs has demonstrated systematic changes in primary clay mineralogy through the formation, likely reflecting palaeoclimate-influenced weathering characteristics in the hinterland (Hesselbo et al., 2009).

The laterally persistent ‘stone bands’ are of primary origin (the coccolithic limestones) and diagenetic. The dolostones in particular are less laterally continuous due to their diagenetic origin (Irwin, Curtis & Coleman, 1977; Feistner, 1989; Scotchman, 1989). Prominent at Kimmeridge Bay is The Flats Stone Band, which has been deformed by expansion during diagenesis, forming an array of trust faulted polygons restricted to this single horizon (Bellamy, 1977; Figure KB2).

There have been several attempts to define a sequence stratigraphy for the Kimmeridge Clay Formation based on, for example, well-log characteristics and intrabasinal correlation (Taylor et al. 2001) or SEM-estimated quartz silt content and correlation to shallow-water facies on the basin margin in northern France (Williams et al. 2001; Figure KB3). At present differences in sequence stratigraphic interpretation remain unresolved.

Across the Weald Basin, wireline logs indicate that in this more northeasterly area the bands are relatively weakly developed (Taylor et al. 2001). The Hobarrow Bay Fluidized Bed is present in borehole and at the type section.

Oil Production

The oil well has been producing since 1959 from a surface anticline. The reservoir is fractured Cornbrash limestone (Bathonian–Aalenian; Middle Jurassic) and the well was drilled in an inversion-related anticline. Note the windsock at the well to indicate that this is a “sour gas” well with H2S. The Kimmeridge Oilfield was discovered in 1959 and is still producing today. This is the only producing field in the hanging wall of the Purbeck-Wight structure, and the only inversion structure in the Wessex Basin to contain a commercial quantity of oil (Gluyas et al., 2003).

Kimmeridge oil production is part of the former BP Wytch Farm production unit (now Perenco UK Ltd.). In December 2011, Perenco completed the acquisition of the Wytch Farm area from BP. Perenco now holds a 50.1% interest in the Wytch Farm and Wareham fields and 100 % in the Kimmeridge fields. Total production is around 15 000 bopd and is expected to increase following additional investment. The well in Kimmeridge Bay is a beam pump, or nodding donkey and produces 80 bbls/day (12,720litres/day). The oil is collected approximately twice a week and transported by road tanker to the terminal at Hamble near Southampton.

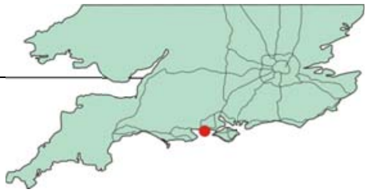
Oil shale production actually began in the Neolithic Period, Late Iron Age and during the Roman occupation, initially to produce ornaments and table tops. Later the oil shale was used for Alum works in the 117th C. In 1848 there was a Bituminous Shale Company in Weymouth and in 1854 there was fertilizer production in Wareham. In 1858 a contract was awarded to a company to light the streets of Paris and adits and shafts were made on the cliff and 50T of oil were exported each month.

Figure 2: The well in Kimmeridge Bay. This is a beam pump, also called a nodding donkey.

Figure 3: Cliff exposure of Kimmeridgian age (*autissiodorensis* Zone) Kimmeridge Clay Formation at Kimmeridge Bay showing regular rhythmic bedding and diagenetically well-cemented so-called 'stone bands'. The dominant rhythm in this image is likely orbital obliquity, or ~40 kyr (Weedon et al. 2004).

Figure 4: View down on to the Flats Stone Band in Kimmeridge Bay, whose surface is marked by mega-polygons, each some several metres across, which formed as a result of diagenetic expansion (Bellamy, 1977).

Hengistbury Head: Stephen Hesselbo Grant Wach



LOCATION 588843m E, 5619474m N

OBJECTIVES

- To examine a probable palaeo oil seep in the Late Eocene marine and non-marine facies.

BACKGROUND

The sand and glauconitic muddy silt succession at Hengistbury Head is Middle Eocene (late Lutetian, ~42 Ma) in age and was deposited in shallow marine and/or estuarine environments (Plint, 1983a; Pollard et al.1993) that can be interpreted within a cycle stratigraphic or sequence stratigraphic framework (Stamp, 1921; Plint, 1983b, 1988; King, 2007). The succession in the cliff comprises the Boscombe Sand Formation (top Bracklesham Group), overlain by members of the Barton Clay Formation including, at the top of the cliff, a shallow-marine deposit known as the Warren Hill Sand (Hooker, 1975; Bristow et al. 1991; King, 2007; Figure HH1). The Boscombe Sand has been interpreted most recently as a shoreface sand (Pollard et al., 1993). Overlying the Boscombe Sand the remainder of the succession at this locality comprises a transgressive-regressive succession with maximum flooding thought to be represented at bed rich in nummulitic foraminifers – the *Nummulites prestwichiensis* Bed (King, 2007).

Of particular interest for this field excursion is evidence for penecontemporaneous cementation of sand by bitumen, and reworking of boulders of the bitumen-cemented sand to form a conglomerate at the base of the Barton Clay Formation (Gardner, 1879; Plint, 1983a; Pollard et al. 1993; Figure HH2). The most detailed description and interpretation is by Plint (1983a), who originally suggested that the bitumen formed as a result of decomposition of Eocene terrestrial plant material. However, the similarity of the observed phenomena to the now well-documented palaeo oil seeps in the Mesozoic parts of the Wessex Basin succession (e.g. Hesselbo & Allen, 1991; Wimbledon et al. 1996) suggests the strong possibility that the Hengistbury example is also a palaeo oil seep (Plint pers comm., 2010), indicating active migration of probably Lias-sourced oils during the Middle Eocene. Plint (1983a) has also described fluid-escape structures in the underlying sand that are spatially associated with brecciation of the bitumen-cemented sand, and likely also penecontemporaneous with development of the conglomerate. Evidence for seeps reaching multiple levels – yet to be fully explored. An outline of the geometry of the probable seep horizon is given in Figure HH3 (from Plint, 1983a).

Figure 2: The Hengistbury Eocene Succession showing dark brown/black-stained Boscombe Sand Formation at the base, overlain by the Barton Clay Formation. The yellow sand at the top of the cliff is assigned to the Warren Hill Sand Member of the Barton Clay Formation (Photo: S. Hesselbo).

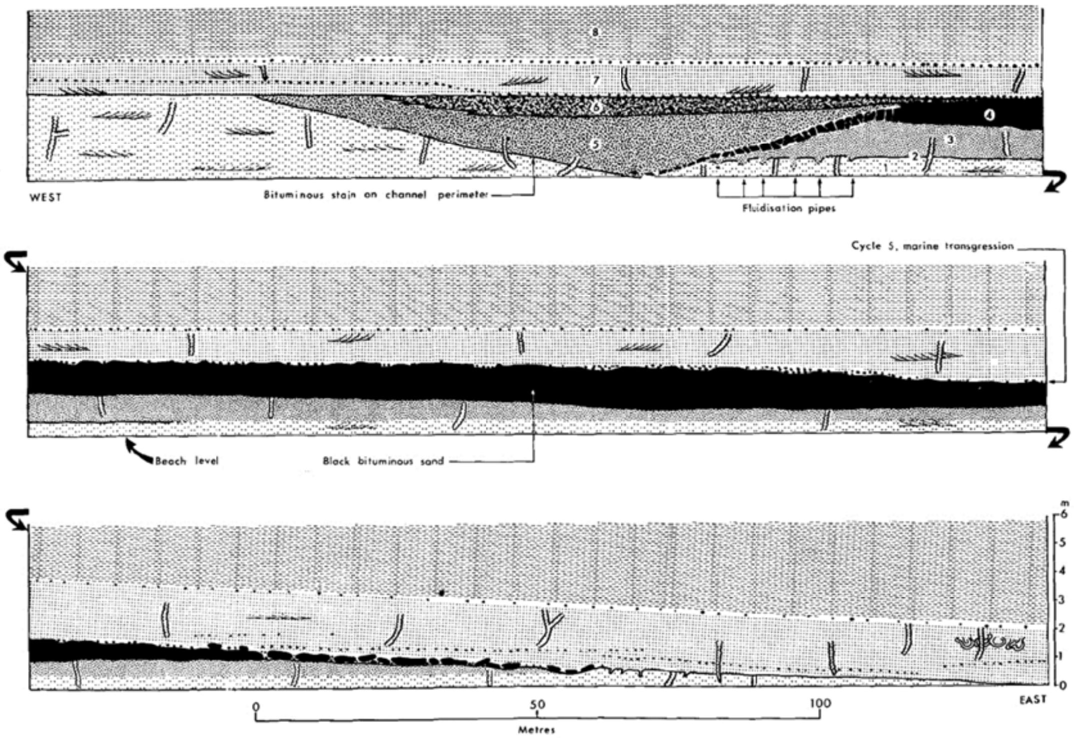


Figure 3: Sketch of the lower part of the cliff at Hengistbury Head (Plint 1983a), showing bitumen-cemented sand in black. At the western end of the outcrop brecciated bitumen-cemented sand

occurs fluid escape structures on the margins of a channel. At the eastern end of the outcrop burrowed bitumen-cemented boulders are interbedded with flint pebbles. There is more than one flint pebble bed in the transgressive facies sequence leading in to the Barton Clay.

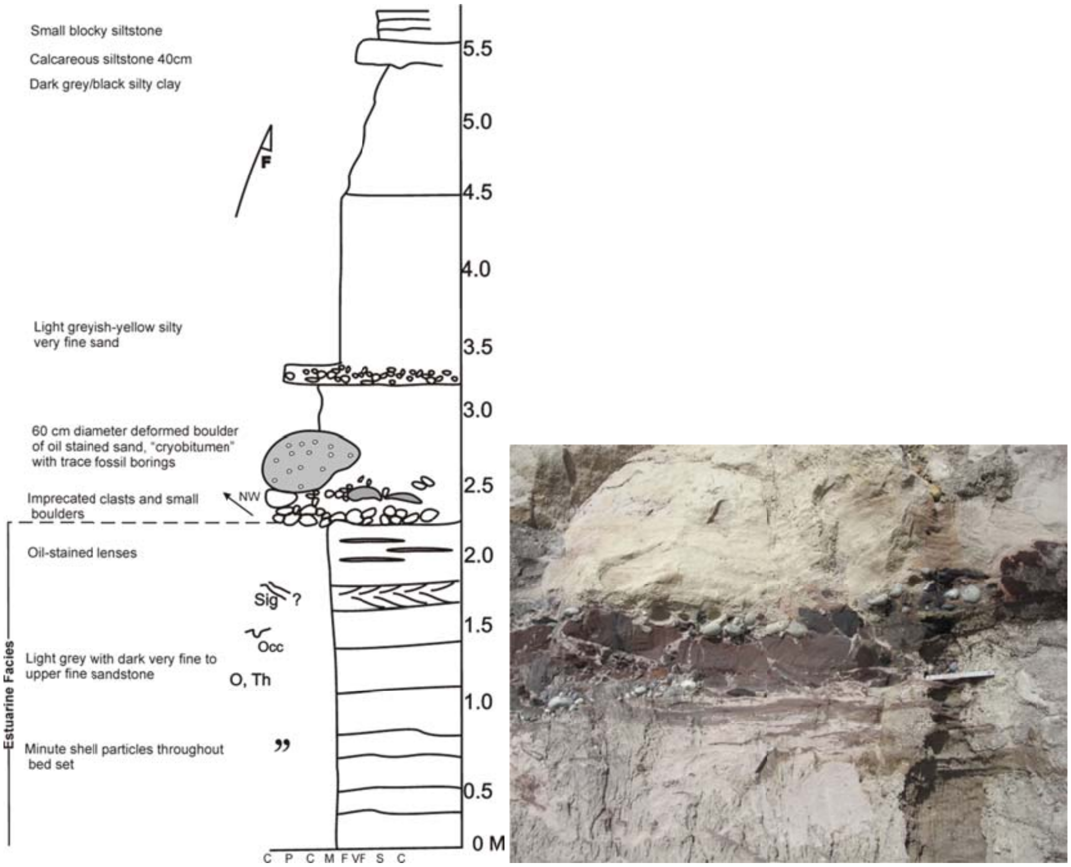
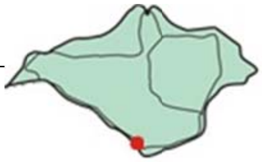


Figure 4: Measured section at Hengistbury Head (G. Wach, field notes, Aug. 2011) and detail photo of the palaeo oil seep horizon, showing bitumen-cemented boulders of sand penetrated by *Thalassinoides* and mixed with chert (flint) pebbles derived from Late Cretaceous Chalk. Localised oil-staining occurs in the less permeable portions of the underlying sand, including the clayey margins of *Ophiomorpha* burrows, suggesting the former presence of oil throughout the exposed basal sand (Photo: S. Hesselbo).

Channel Basin and Isle of Wight Field Stops

Gore Cliff Overview: Grant Wach and Stephen Hesselbo



LOCATION - National Trust Car park near Gore Cliff and Blackgang Chine

Fig 1: Blackgang & Gore Cliff (Google Earth, 2012).

OBJECTIVES

- Basin evolution and Cretaceous overview from the Early Cretaceous non-marine and shallow marine siliciclastics (Wealden Group, Lower Greensand Group) through to the Gault, Upper Greensand Group and the Chalk Group.
- Examination of Upper Greensand and Chalk sections

BACKGROUND

<u>Locality Details</u>

To the south the section at Gore Cliff demonstrates the stratigraphy of the succession with the “Passage Beds” making a transition into the Upper Greensand with glauconitic and calcareous dark gray marl and the beginning of the Chalk Group.

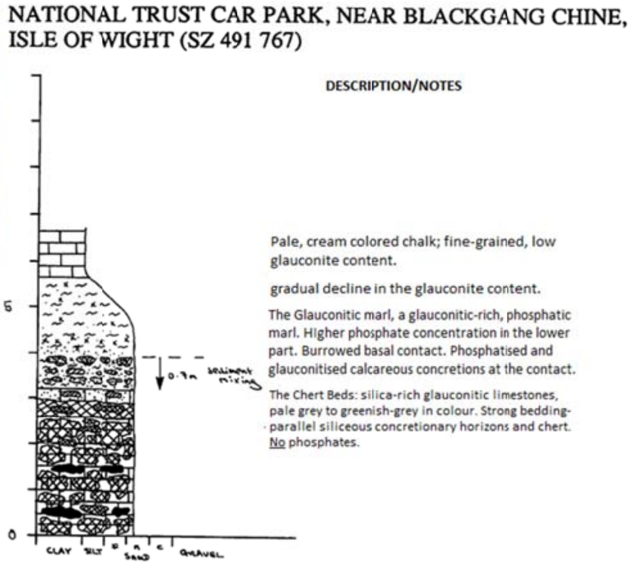


Figure 2: Upper Greensand section in Natiola Trust car park illustrating the Glauconitic Marl and Chert Beds (from Hart, 1991 unpublished).

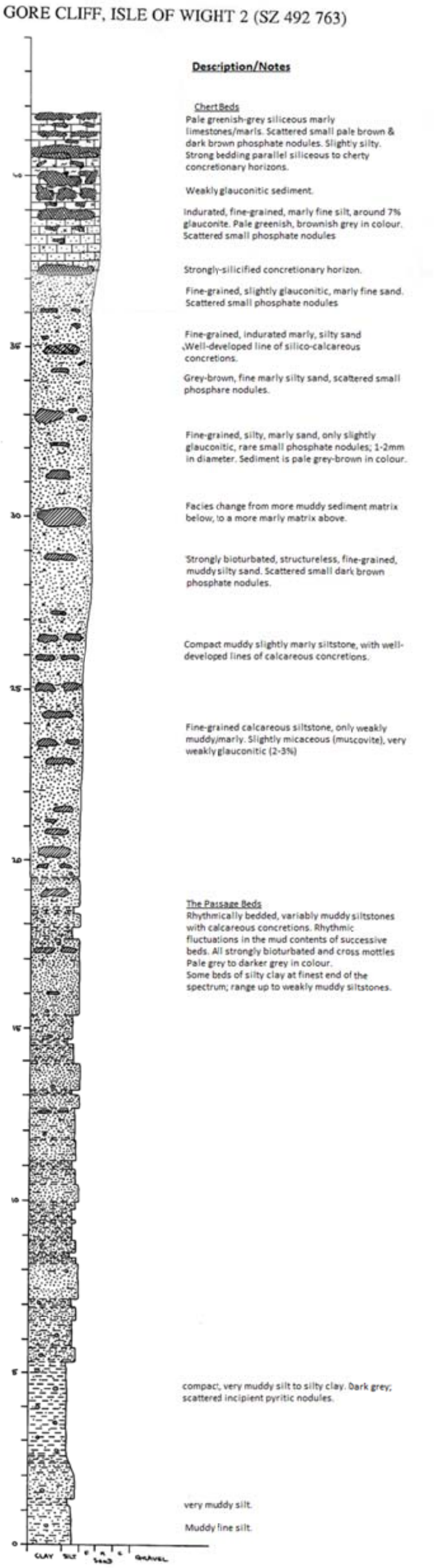


Fig 3: Gore Cliff section beginning with the "Passage Beds" , a transition into the Upper Greensand (UGS) with glauconitic and calcareous dark gray marl and the beginning of the Chalk Group (from Hart, 1991 unpublished). The UGS sediments on the IOW are repsentative of deeper water facies compared to areas of Wessex basin towards the west (Hart, pers. comm., 2012).

Channel Basin & Isle of Wight:
Introduction to the Stratigraphy and Structure

(with excerpts from Wach and Ruffell, 1991; 1998)

GEOLOGICAL SETTING

Location:

The Isle of Wight lies off the south coast of England and forms a continuation of the coastal topography of Dorset to the west and Sussex to the east. The Solent forms the narrow straits that separate the island from the mainland. The Isle of Wight is the smallest county in England with a population of 129,000. It is diamond-shaped, 21 km north to south and 37 km east to west. Although only a short journey across the Solent by ferry, the barrier of the sea has preserved much of the island's natural beauty. The geology, illustrated in Figure 1, controls the scenery; the unconsolidated Palaeogene sediments of the north of the island result in a subdued topography, rich farmland and sandy beaches. The Cretaceous rocks and sediments to the south form Chalk downs in an east-west swath across the middle of the island. The Greensands and Wealden to the south form heath and arable farmland with dramatic coastal cliffs along which this trip will concentrate.

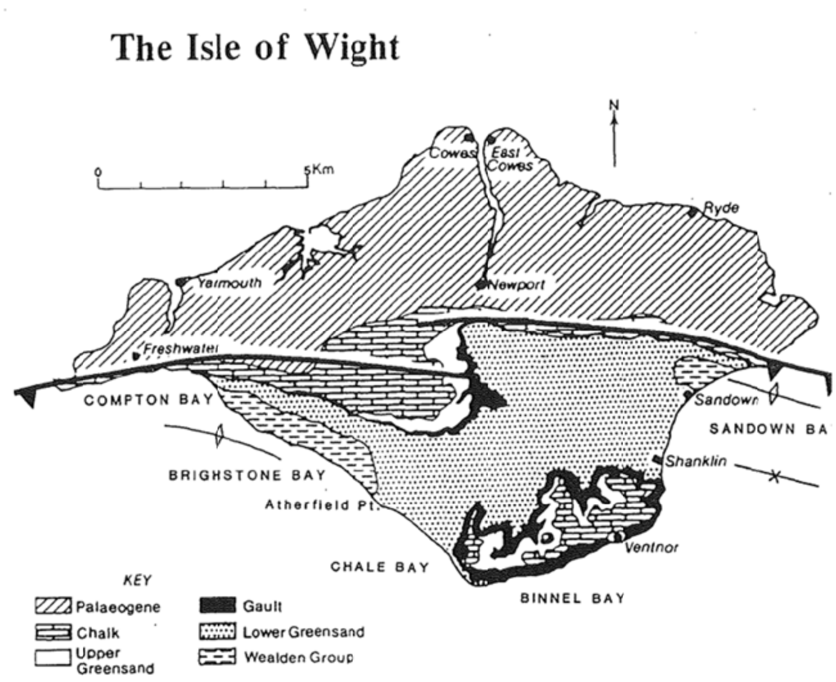


Fig 1: Geology of Isle of Wight (modified from Daley and Insole, 1984).

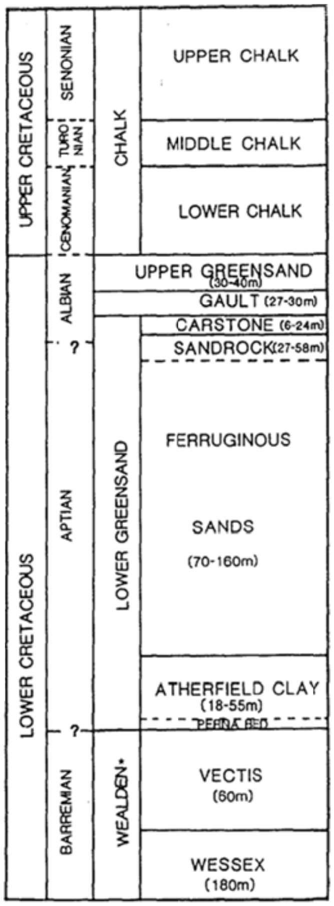


Fig 2: Exposed Cretaceous strata on the IOW.

Structural Controls and Tectonic Influences on Sedimentation: The Cretaceous succession belongs to the Channel sub-basin of the Wessex Basin and is separated from the Weald Basin by a structural high. The Channel Basin was extensional during most of Mesozoic time. At depth, underlying the steeply-dipping strata of the Isle of Wight monocline large-scale listric faults that were active throughout the Mesozoic occur and define the northern margin of the sub-basin. These faults are thought to be related to Hercynian thrusts in the underlying basement rocks. The Wessex Basin developed initially through mechanical subsidence in the Permian- Triassic, followed by Jurassic - Cretaceous thermal subsidence and Tertiary basin inversion (Whittaker, 1985). The Isle of Wight is an excellent locality to discern the variations in sea level brought on by both eustatic and tectonic events. The east-west trending monoclinal fold forms the backbone of the island with near vertical inclined bedding on the east and west of the island. The steeply dipping beds of Upper Cretaceous Chalk on the west coast give rise to the stacks called the "Needles". Bedding is near horizontal in the centre region of the island where the *en echelon* nature of the structure is apparent, possibly initiated by strike-slip motion during compression. The oldest Wealden Group strata are exposed on the Brighstone and Sandown anticlines. These structures are asymmetrical with gently dipping southern limbs and steeper northern flanks. The monoclinal flexures on the Isle of Wight are very evident where the Cretaceous strata form the Central Downs.

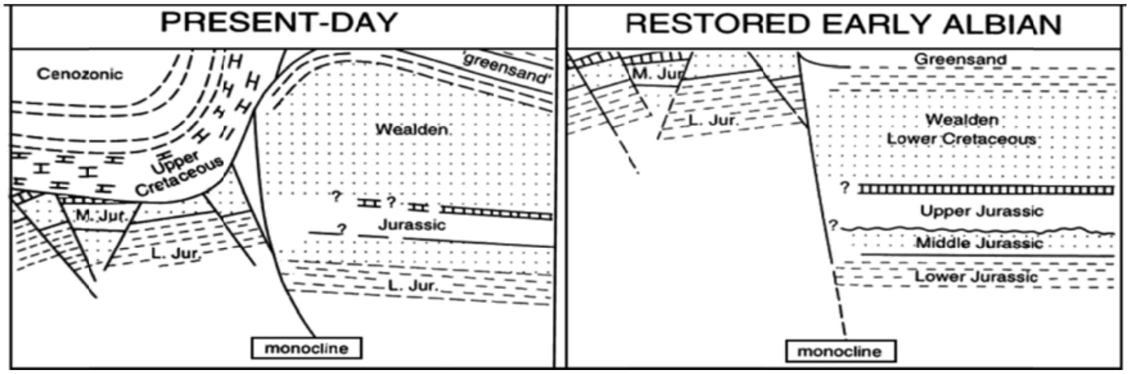


Figure 3: Mesozoic and Cenozoic sedimentation across the Isle of Wight- Purbeck structure. Note the late Cimmerian unconformity between the Upper Jurassic and Lower Creatceous (vertical dash bar) (from Wach and Ruffell, 1998, unpublished).

When the regional and local dips of the strata are plotted, breaks in the monoclinal flexural system become readily apparent. Broad areas of nearly flat lying strata quickly merge with steeply folded strata with dips reaching vertical. Phillips (1964) initially suggested the Isle of Wight/Purbeck Monocline (Dorset-Isle of Wight [IOW] disturbance) is the surface expression of a fault in the Palaeozoic Basement, but White (1921,p.135) first hinted at a structural link between the Mesozoic and Palaeozoic strata.

Mesozoic depocentres were concentrated to the south of the island, on the subsiding hanging-wall of the Isle of Wight disturbance. At no time was this more evident than in the early Cretaceous: no sediments of pre-Albian age are preserved to the north of the Isle of Wight disturbance, where Albian Carstone sediments, at the base of the Gault Clay, rest unconformably on Jurassic. Lack of Lower Cretaceous deposits north of the Isle of Wight monocline indicate that this structure must have had some effect on deposition to the south of the monocline. This structural interpretation is supported by the difference in facies and fauna between the Wealden and Lower Greensand Groups of the Channel and Weald Basins. Abundant Upper Jurassic clasts found in the various pebble beds of the Lower Greensand Group suggest contemporaneous erosion of the margins of the Cretaceous depositional basin. The Portsdown anticline, and to a lesser degree the Isle of Wight disturbance, acted as structural controls to sedimentation and must have restricted the influence of the Boreal Sea to the north and limited the marine transgression to the Tethys Sea to south and east.

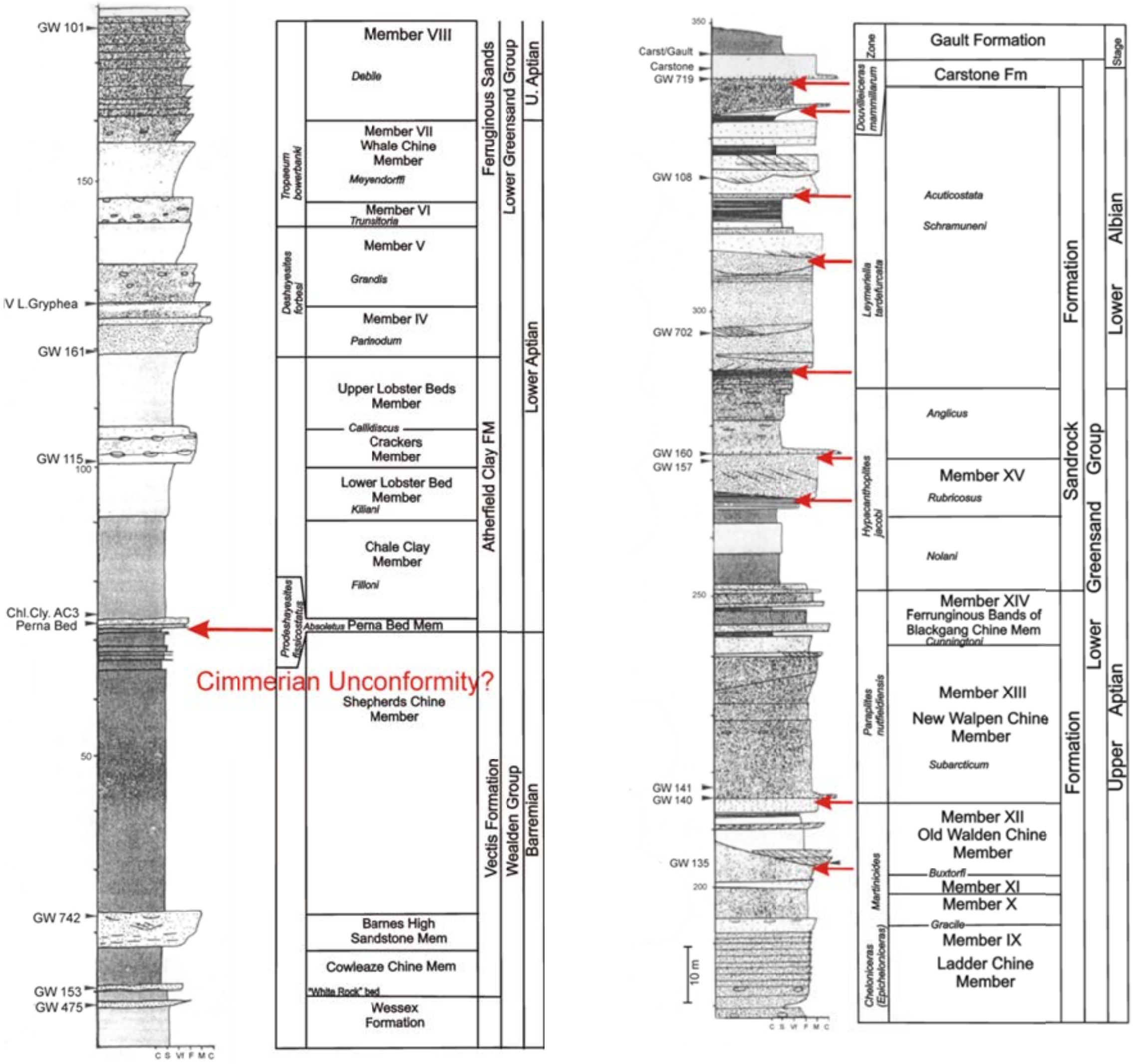
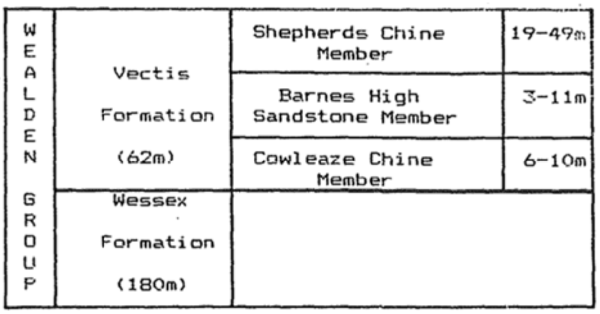


Figure 4: Unconformities (red arrows) within the Lower Cretaceous succession visible in outcrop on the Isle of Wight. Complex phases of thermal and mechanical subsidence are suggested by Karner et al. (1987) to explain unconformities in the Wessex-Channel basin; including their singular "Aptian unconformity", several of which will be examined on this trip. The roles of eustasy and tectonism can be readily examined and should lead to some excellent discussion.

THE CRETACEOUS SUCCESSION

Wealden Group:

The Wessex Formation and the Vectis Formation comprise the Wealden Group. The fluvial-floodplain sediments of the Wessex Formation are overlain by the Vectis Formation sediments which record progressively greater marine influence during the first of the Cretaceous transgressions. Stewart (l978a & b, 1981a & b) describes the Barremian-aged sediments of the Wealden Group, concentrating on the fluvial-dominated Wessex Formation sediments. Ruffell (1988) discusses the biofacies associated with the beginning of the transgression. Stewart et al. (1991) examine the lagoonal environments of the Vectis and the relationship of facies change to fluctuating salinities zonal fossils in the sediments of fresh and brackish water origin. Hughes (1958) used palynomorphs to date the Wessex Formation as Barremian. On the basis of ostracod evidence Anderson (1976) placed the sediments of the Vectis Formation within the *Cypridea valdensis* zone (upper Barremian age). Magnetostratigraphic evidence contradicts this earlier micropalaeontological data suggesting correlation of the upper two thirds of the Shepherd's Chine Member with Lower Aptian reverse polarity Chron CM-0 (Kerth & Hailwood, 1988). This interpretation effectively places the base of the Aptian well down into the Vectis Formation.



WEALDEN GROUP	Vectis Formation (62m)	Shepherds Chine Member	19-49m
		Barnes High Sandstone Member	3-11m
		Cowleaze Chine Member	6-10m
	Wessex Formation (180m)		

Fig 1: Wealden Group Stratigraphy (Reid & Strahan, 1889; White, 1921; Stewart, 1978).

Stewart (1978b) recognised three lithostratigraphic members in the type section of the Vectis Formation along Brighstone Bay; the Cowleaze Chine Member represents the lower mud facies, the Barnes High Sandstone Member, the intervening sand body while the Shepherd's Chine Member marks the return to the mud facies. These members are present across the island, but cannot be identified in the Vectis succession at Swanage Bay to the west. The succession consists of black mud, finely laminated with discontinuous silt laminae and occasional pyritic nodules which characterise sediments interpreted to be lagoonal or bay deposits. These sediments are common to the Cowleaze Chine and Shepherd's Chine Members. Limited bioturbation of the sediment and the paucity of fauna suggest dysaerobic conditions. Bioturbation is restricted to near vertical burrows, seldom deeper than 5 mm (approximately the depth to the zone of reduction) and some horizontal burrows less than 2 mm in diameter. The sandstone is a broad, extensive body essentially confined to the Barnes High Sandstone Member, which lies between the Cowleaze Chine and Shepherd's Chine Members. The sandstone generally coarsens upwards and contains evidence of erosional surfaces, flaser bedding, wavy lenticular bedding, uni- and bidirectional bedding, trough cross-bedding, large scale ripple forms, as well as intraformational clasts, shell debris and lag deposits. The sandstone is of variable thickness; from several thin 0.5-2 m coarsening upward beds, separated by laminated and blocky mud (Compton Bay); to single sand bodies over 9 m thick, formed of several coarsening up cycles (Foxes Bridge in Fig.6). The smaller sand bodies (e.g. Compton Bay) are interpreted as small, flood deposited deltas, with some control by channel avulsion. The stacked, coarsening up cycles are larger deltaic bodies, influenced by several flood impulses. Reworking of the tops of these deposits can occur in both a lagoonal and interdistributary bay setting, forming small delta mouth bars and inner shores of the lagoons. The sands are reworked by micro-tidal and wind-driven currents producing a bi-modal (but not necessarily bi-polar) directional component to the sediment. Thin deposits 5-50 cm thick, ranging from sandy silt to very coarse sand suggest rapid deposition of sediment during flood conditions.

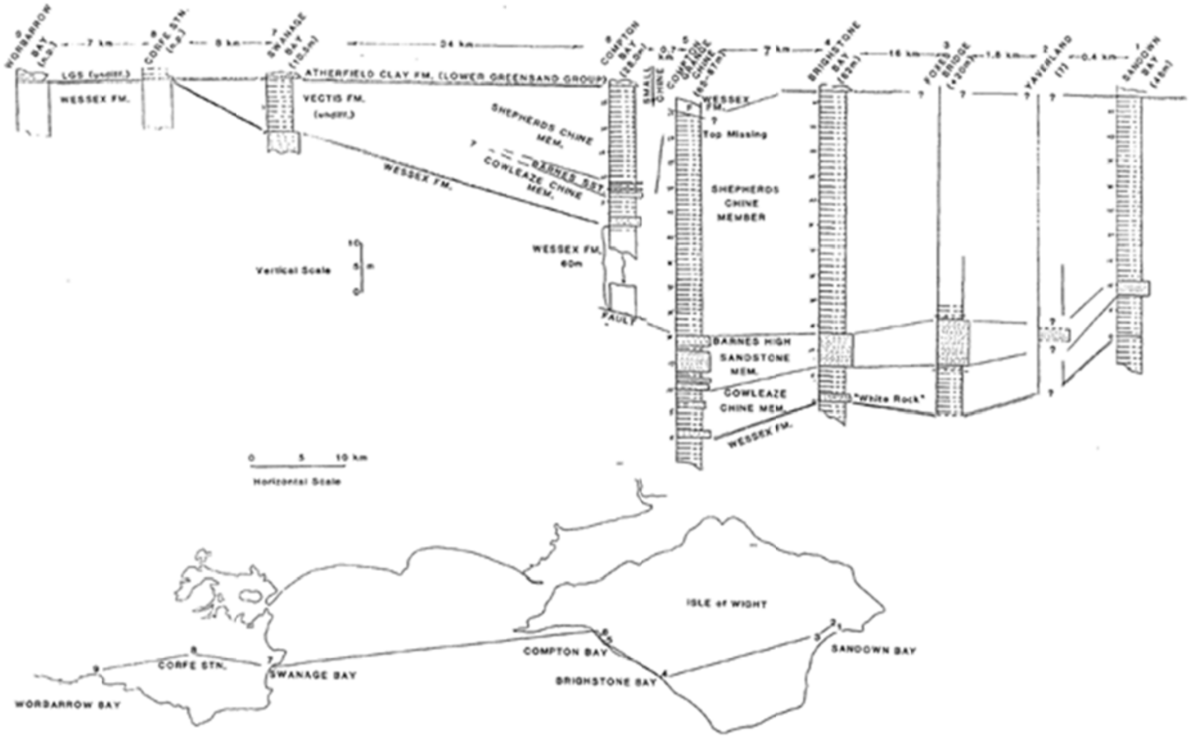


Fig 2: Wealden Group Vectis Formation stratigraphy across the Isle of White to the mainland across Bournemouth Bay to Swanage. This section demonstrates thinning of the succession on to the IOW-Portsdown high and the thicker depocentres to the southwest of the Isle of Wight at the Brighstone Bay section

Depositional Model- In all probability there is not a modern analogue to explain the extensive Wealden facies found throughout Europe. In the Channel Basin, the thick accumulation of Wealden sediment culminated with the muddy coastal environment of the Vectis Formation. Broad wind-tidal flats bordered bays and lagoons with freshwater input from a number of small delta complexes. The lagoon and tidal flats were covered at irregular intervals by water from wind-generated tides and storm surges. Periodic desiccation of the flats created mud cracks which were preserved by the shell debris, as the lagoon fauna was swept across the flats by storm-driven currents. The Vectis Formation, with its storm-swept coasts set the stage for subsequent patterns of sedimentation during the beginning of the Aptian, when the Lower Cretaceous transgression reached fully marine conditions with the deposition of the Atherfield Clay of the Lower Greensand.

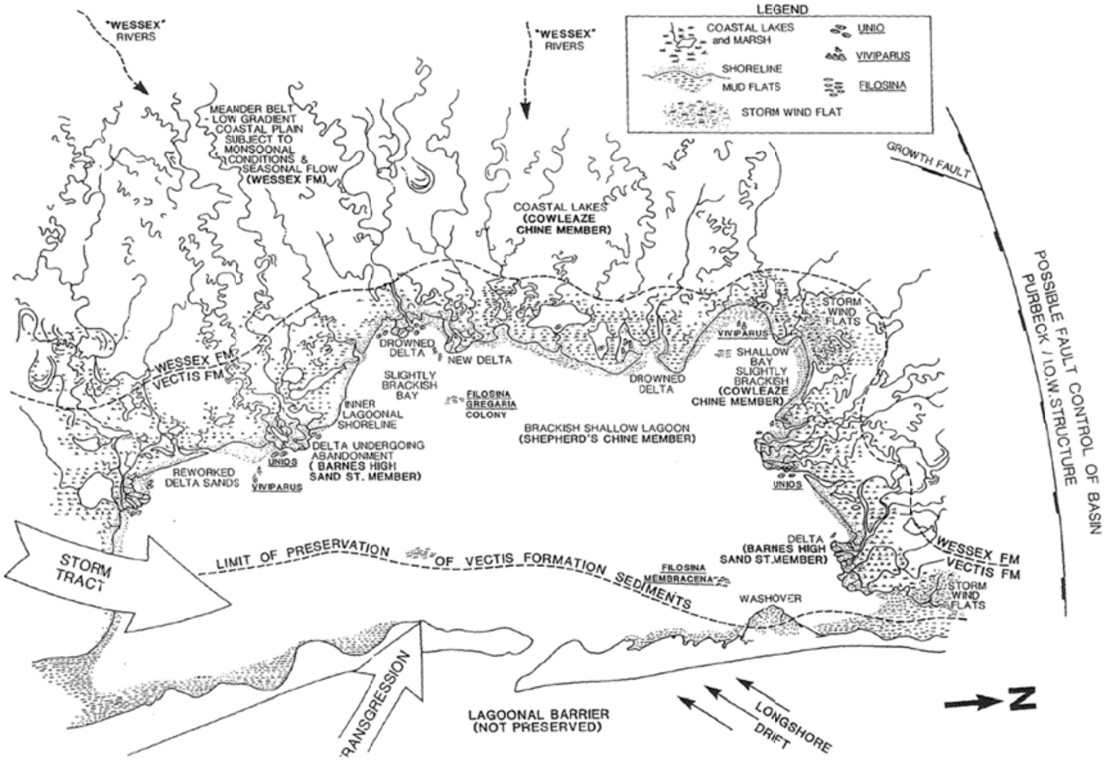


Fig 3: The diagram illustrates the depositional conditions during Wealden times. To orient the diagram use the Purbeck-I.O.W. structure as the northern margin of the basin. The growth fault to the north would be the area of the Compton Bay section. No attempt is made to try and determine palaeogeography across these structures, or their influence on sedimentation. The diagram is essentially a time slice of the Wealden and shows five sets of information:

1) Depositional conditions and the distribution of environmental facies.

2) Distribution of the formations and members with respect to these facies. The facies distributions do not overlap the formational boundaries. In the Wessex Formation this break is broadly interpreted as the change from the low gradient fluvial-floodplain environment, to the coastal plain facies of lakes and bays, bordering the lagoon. Within the Vectis Formation the distribution of the members and facies reflect the complexity of the depositional system which to some degree is controlled by progradation and abandonment of the small delta systems (Barnes High Sandstone Member).

3) A simplified illustration of the faunal component of the sediment based on the inferred salinity tolerance of the species or genus.

4) The interpreted direction of storm influence. Alongshore drift, fair-weather processes, secondary storm tracts and ultimately the direction of the transgression and the proportion of sediment eroded from the basin. The storm tract was calculated from the orientation of gutters and corresponds to the L. Cretaceous storm paths calculated by Parrish (1985) i.e. from the SW to NE.

5) The subtle influence of tectonics in controlling the development of the basin and to some extent the type and style of basin fill.

Lower Greensand Group:

Introduction- The Lower Greensand Group comprises sediments which record an overall marine transgression during the Aptian / Albian, interrupted by periods of static and falling sea levels. The shallow marine succession of Aptian to early Albian age sediments overlies the fluvial and brackish sediments of the Wealden Group (Allen, 1989). In the 120-245 m thick succession four broad facies associations have been interpreted, beginning with micro-tidal, low energy, shallow shelf deposits which were subjected to periodic intense storms (Atherfield Clay Formation). The succession then becomes cyclic, with the sediments representing environments ranging from tidal estuarine conditions to shelf/ offshore deposits, dependent upon the relative change in sea level. Firmgrounds developed during periods of static or slow sedimentation. The Lower Greensand thins along the northern margin of the Channel Basin, delineated by the monocline. This can be illustrated along a section drawn between the easternmost outcrop at Sandown Bay and Swanage Bay to the west. The Carstone, which is locally erosive onto the Sandrock Formation, is the only formation which thickens towards the east.

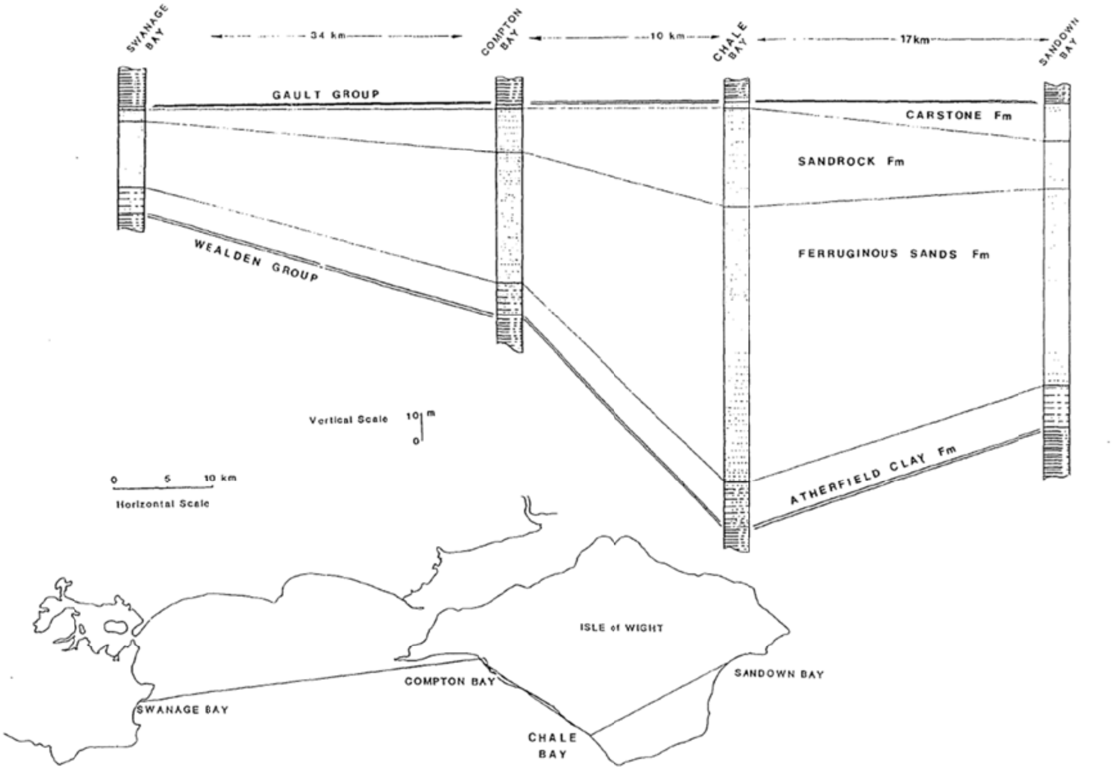


Fig 4: The Lower Greensand Group stratigraphy across the Isle of White to the mainland. This section demonstrates thinning of the succession on to the IOW-Portsdown high and the thicker depocentres to the southwest of the Isle of Wight at the Chale Bay section. Compare this section to the Wealden Group section in Figure 2 to see evidence of shifting depocentres within the basin.

Fitton (1847) deciphered the lithostratigraphy of the Lower Greensand on the Isle of Wight after examination of the strata exposed along the coast of Chale Bay which became to be the type section for southern England. He divided the section into 6 divisions, 16 "groups" and 55 beds. Fitton's "groups" are regarded as members (Wach, 1991; Wach and Ruffell, 1991; Ruffell and Wach, 1998; Insole et al. 1998), while the remainder of his stratigraphic nomenclature has fallen in to disuse. Reid and Strahan (1889) simplified Fitton's stratigraphy by dividing the Lower Greensand into the formation names used today. Casey (1961) defined the ammonite zonation from a study of the Chale Bay section, using Fitton's lithostratigraphic nomenclature.

Atherfield Clay Formation:

The Atherfield Clay Formation comprises 5 members beginning with the Perna Bed Member, followed by the Chale Clay, Lower Lobster Bed, Crackers and Upper Lobster Bed members (Simpson, 1985). The Atherfield Clay is interpreted as a mud-dominated shelf or broad, open estuary. The formation is characterised by blocky brown and blue-grey silty clays with some phosphatic and calcareous nodules. Clear sedimentary structures are not common but include starved wave ripples and thin lag deposits, and gutter casts infilled with cross-laminated silts and shell debris, perhaps representing relict storm features. The Crackers concretions, most evident in the Chale Bay section have formed in bioturbated silty sand, with evidence of scour and fill horizons and omission surfaces representing hiatuses in sedimentation. Fluid escapes structures and slumping are also evident, usually associated along the lithologic boundaries formed on the omission surfaces. Thus, the surfaces are significant not only as a record of contemporaneous depositional events such as bioturbation and sedimentation rates producing a detailed stratigraphic marker, but also through control of post-depositional events

Perna Bed Member- The member of early Aptian age, represents the basal member of the Lower Greensand Group and the lowermost member of the Atherfield Clay Formation. The Perna Bed Member are erosive, onto the dark grey, laminated muds of the Shepherds Chine Member of the Wealden Vectis Formation, interpreted as lagoonal in origin. The Perna Bed is a transgressive shoreface/shelf deposit with abundant derived Jurassic debris. This transgressive ravinement surface culminated in the development of a mature firmground with over fifty recorded epifaunal species, including the coral *Holocystis elgans.* The section illustrates the five beds of the Perna Bed Member. The Perna Bed is a significant surface and could correspond to either the latest Barremian, minor 113.5 ma *(bidentaum* zone), or the earliest Aptian, major 112rna *(fissicostatus* zone) sequence boundaries (Mesozoic-Cenozoic Cycle Chart, version 3.1 A, Haq, *et al.,* 1987). It is possible that the both sequence boundaries are amalgamated in the Perna Bed. The combination of an erosional contact and reworked sediments illustrates that erosional episodes that may be linked to the late "Cimmerian" event did effect the Channel Basin, but not to the extent as in most areas of southern England.

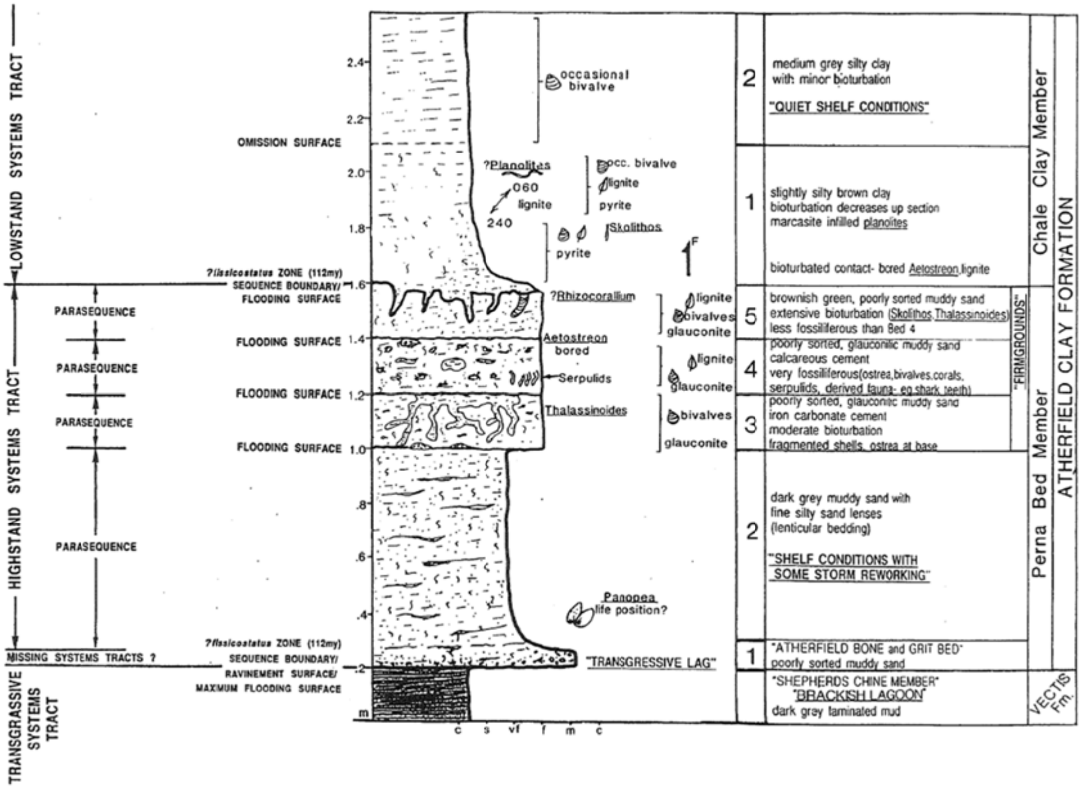


Fig 5: Measured section of the Perna Bed and sequence stratigraphic interpretation of the Barremian – Aptian boundary at Atherfield Point type section (Wach and Ruffell, 1991).

Ferruginous Sands Formation:

The contact between the Atherfield Clay Formation and the Ferruginous Sands Formation is gradational but with a "rapid" change in lithology. The sediments of the Ferruginous Sands Formation was deposited on a shelf setting with periods of relatively quiet deposition during which bioturbation and reworking by organisms destroyed most of the primary sedimentary fabric. Variations is in relative sea level produced corresponding higher energy conditions with coarser sediment deposition followed by abrupt flooding of the shelf deposited finer-grained mud representing a deeper shelf facies. Firmground horizons, often thoroughly bioturbated by Thalassinoides, cap these cycles. More marked drops in sea level produced a basinward shift in facies often marked by incision of the underlying strata. The unconsolidated glauconitic and white quartzose sands with clay drapes are interpreted to be estuarine in origin and are typical of the estuarine cycles found in the Aptian-Albian Sandrock Formation above.

The lowest bed of the Ferruginous Sands Formation and rests abruptly, but conformably on the Upper Lobster Beds of the Atherfield Clay Formation. The sediments range from clay-rich sand with large Thalassinoides burrows, glauconitic sand with wood fragments and brachiopods *(Sellithyris sella:* Terebratulida and to a lesser degree *Sulcirhynchia hythensis:* Rhynchonellida), glauconitic sand with limonite grit fragments. The beds are cyclic and can culminate the formation of firmgrounds that can form ledges on the beachface. These beds are cemented by a mixture of carbonate, phosphate and iron oxides. The scoured upper surface includes pockets of angular limonite and rounded quartz clasts. The limonite is probably reworked from proximal subaqueous firmgrounds, while the quartz may be derived from Jurassic shorelines to the northwest. The irregular surfaces can contain cemented hummocks of pebbles and typical firmground fauna dwellers, including numerous bored and encrusted large oysters, such as the large bivalve *Aetostreon;* brachiopods; and bryozoa.

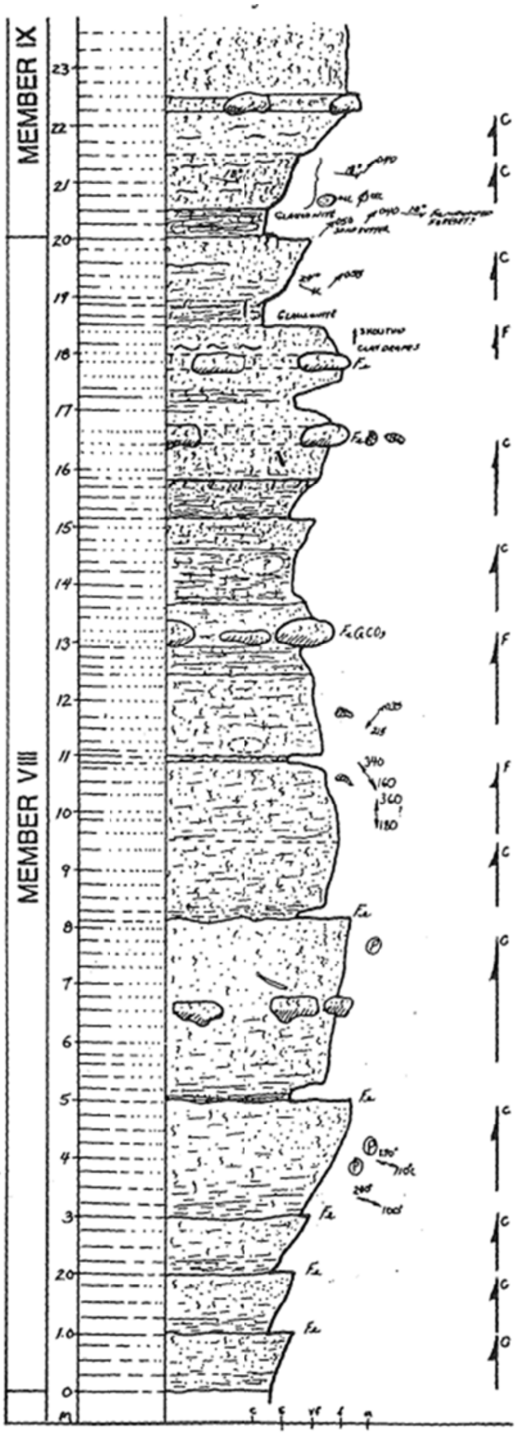


Fig 6: Firmground and hardground horizons in Members VIII and IX at the type section at Chale Bay. The coarsening and fining-up units represent progradational, aggradational and retrogradational parasequences.

The accumulation of fossils at the top (or base) of cycles is common throughout the Ferruginous Sands Formation. This represents the condensation of fauna and may be coupled to winnowing of sediment probably during a hiatus in sedimentation. Thus, one must be aware that the ammonite zonation of Casey (1961) is related to these horizons of condensed fauna and that there is actually a paucity of fauna preserved within the sediment of the intervening beds. This suggests strongly that you cannot apply the length of an ammonite zone or subzone to determine actual rate or accumulation of sediment and that there were important episodes of non-deposition that could be followed by relative rapid periods of sedimentation on the shelf that may represent a resumption of sedimentation which could be related to changes in sea level. For instance a lowering of sea level would result in the progradation of the shoreline, coupled with incision of the shelf thus transporting coarser sediment out on to the shelf. Climate may also be a factor; with humid phases resulting in the transport of finer grained sediment onto the shelf. Arid phases would limit sediment transport and may in fact invoke a period of mixed carbonate-siliciclastic deposition. This rhythmicity of climate could be seasonal or in more likely represents far longer periods of indeterminate length.

Phosphate and carbonate have cemented the concretions, typical of the slow deposition associated with firmground formation. Small coarse lag deposits and winnowed plant and fauna remains suggest that scouring of these surfaces occurred. Thus, there may have been periods of extensive erosion if these nodule horizons, which likely formed through shallow burial diagenesis, were exhumed and possibly "planed" down via erosion. The ichnofabric consists of clay-filled and clay-lined burrows which give way to sand-lined and sand-filled burrows, up each cycle of the section. Thus the change in ichnofabric reflects a general cleaning-up or coarsening of the overall fabric of the sediment. Throughout the section semi-continuous horizons of nodules are present.

These nodules are often fossiliferous with a central nucleus of fossils which precipitated the outward growth of the concretion. The development of the concretions and accumulations of fauna (the intervening sediment is remarkably devoid of fossils in most instances) points to a hiatus or slowing in the rate of sedimentation allowing early diagenetic cementation of the sediment and the development of a firmground surface.

Sandrock Formation:

The sediments of the Sandrock Formation form laterally extensive sand bodies separated by thick intervals of mud. The exposed sections of the sandstone and mud facies are variable in thickness. The sandstone generally coarsens upward and contains evidence of erosional surfaces, flaser bedding, wavy lenticular bedding, uni- and bi-directional bedding, trough cross-bedding, large scale ripple forms, as well as intra-formational clasts, and lag deposits. The structures preserved in these sediments could represent several depositional environments including barrier ridges, shallow shelf deposits, deltaic sediments, mouth bars, or tidal deposits of shoals and sand ridges. The mud facies are also an enigma. The dark grey to black, often glauconitic muds, have few sedimentary structures and are either finely laminated or extensively bioturbated. The presence of brackish microfauna suggests marginal marine conditions. Environments representative of muddy shelf deposits, estuary mud fill or intertidal flats could be interpreted from the available evidence. The section at Blackgang is the continuation of Fitton's type section along Chale Bay, from Atherfield to Rocken End.

Carstone Formation:

The Carstone Formation is the only formation of the Lower Greensand Group to thicken towards the east as noted earlier. It is Albiian in age. The dark red sediments of the formation comprise coarse grained consolidated sandstone with iron cements pehaps derived from glauconite rich sediments. Layers of rounded pebbles form beds and suggest winnowing and condensation of sediment.

Gault:

Dark, grey to black silt and clay characterise the Gault and represent a major transgression in the Albian with deposition of fully marine sediments.

Upper Greensands:

The Upper Greensands on the Isle of Wight comprise represent a major drop in sea level and resumption of ssedimentation on a shallow shelf. The sediments comprise light pale yellow rto greeensish sanstone with glauconite, pale brown sands, followed by dark grey cherty marls.

Chalk:

The contact of the Lower Chalk with the Upper Greensand appears over much of southern England as a hardground. On the Isle of Wight the contact is heavily bioturbated. With abundant *Thalassinonides* burrows piping-in the Glauconitic Marl sediments of the Lower Chalk around concretions, into the top of the Upper Greensand. Pelagic components dominate the sediments compared with the terrigenous clastics fraction, particularly coccolithophorid planktonic algae. Calcarous concretions and phosphaticnodules, often with pyrite are common. Throughout the Chalk Marl and Grey Chalk there are abundant signs of post-depositional solution of calcite in the form of marl flasers, modification of burrows, or more rarely, stylolites. The Plenus Marls represent the top of the Lower Chalk. The Middle Chalk is a cleaner with some minor marl seams. The Upper Chalk is typically a hard nodular limestone with bands of flints.

Shanklin– Horse Ledge (optional): Grant Wach

LOCATION 608504m E, 5612295m N

Fig 1: Shanklin Village to Horse Ledge along Sandown Bay (Google Earth, 2012).

OBJECTIVES

- Examination of baffles and barriers to flow produced by firmground and hardground development in Lower Cretaceous reservoirs.

BACKGROUND

A major firmground forms Horse Ledge, near Shanklin, called the "Urchin Bed". Throughout the Ferruginous Sands Formation cycles representing parasequences form firmgrounds, usually with some concentration of fauna. The firmgrounds have been enhanced by preferential cementation by iron oxides on the impermeable horizons that develop in response to the deposition of clay at the base of each horizon. The development of these grounds varies in response to condensation and winnowing of fauna, due to the length of time of the break in sedimentation (hiatus). These surfaces are often capped by horizons of epifaunal bivalves, including the large bivalve *Aetostreon.* At Horse Ledge the firmground tops a succession where hummocky or swaley cross-stratification is apparent but overall the cycles are usually devoid of any characteristic sedimentary structures. The sediments are typically thoroughly bioturbated with only a few identifiable trace fossils which include *Teichichnus* and *Ophiomorpha*. The bioturbational fabric reflects the coarsening-up of each section with a typical pattern of clay-lined and clay-filled horizontal and sub-horizontal burrows in the bottom one third to half of the section, becoming sand-lined to sand-filled sub-horizontal to vertical burrows in the upper portion of each cycle. This change in the fabric clearly corresponds to the change in relative sea level, linked to the sediment supply and energy conditions on the shelf.

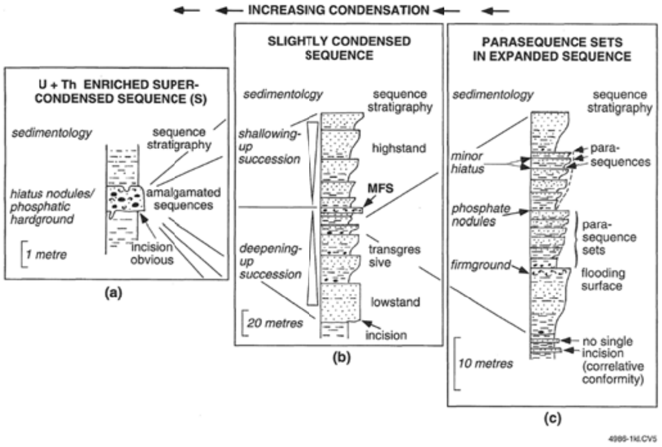


Fig 2: Relationship between parasequences, condensed sections and hardgrounds (from Ruffell & Wach 1998).

Hardgrounds, Firmgrounds & Softgrounds (Ruffell & Wach, 1998)

Fig 3: Types and distribution of hardground and firmground horizons in the Lower Greensand Group. Horse Ledge and Urchin Bed are c. 180m on the section (from Ruffell& Wach, 1998).

Firmground surfaces in the Lower Greensand 101

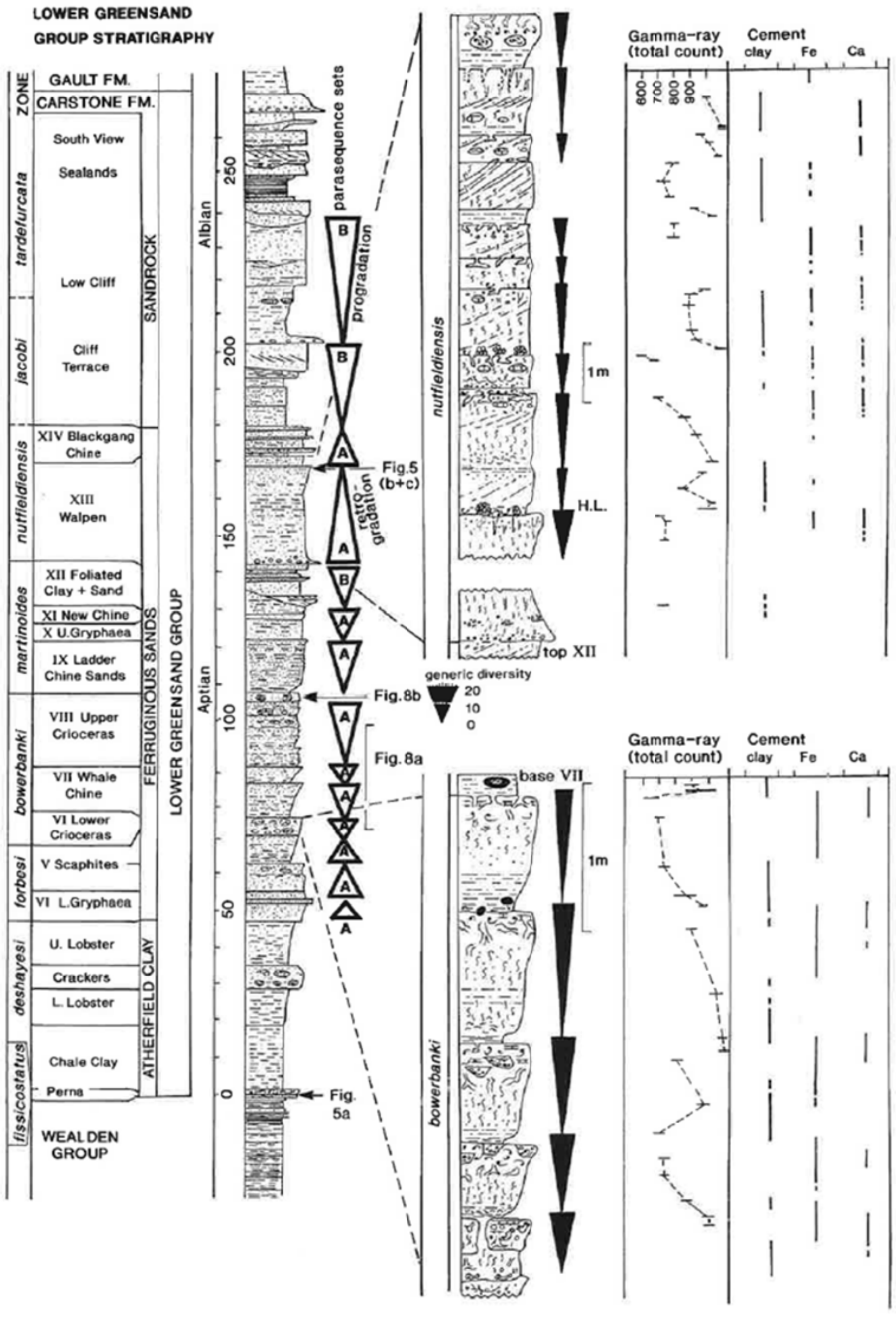
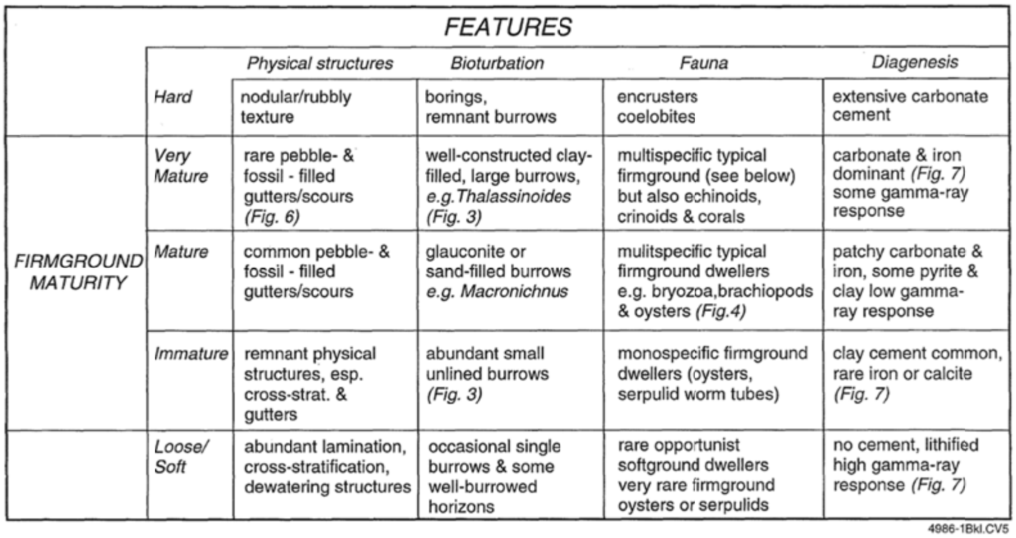


Fig 3: Diagnostic features, types and maturity of firmground horizons (from Ruffell & Wach, 1998).



		FEATURES			
		Physical structures	*Bioturbation*	*Fauna*	*Diagenesis*
	Hard	nodular/rubbly texture	borings, remnant burrows	encrusters coelobites	extensive carbonate cement
FIRMGROUND MATURITY	*Very Mature*	rare pebble- & fossil - filled gutters/scours *(Fig. 6)*	well-constructed clay-filled, large burrows, *e.g.Thalassinoides (Fig. 3)*	multispecific typical firmground (see below) but also echinoids, crinoids & corals	carbonate & iron dominant *(Fig. 7)* some gamma-ray response
	Mature	common pebble- & fossil - filled gutters/scours	glauconite or sand-filled burrows *e.g. Macronichnus*	mulitspecific typical firmground dwellers e.g. bryozoa,brachiopods & oysters *(Fig.4)*	patchy carbonate & iron, some pyrite & clay low gamma-ray response
	Immature	remnant physical structures, esp. cross-strat. & gutters	abundant small unlined burrows *(Fig. 3)*	monospecific firmground dwellers (oysters, serpulid worm tubes)	clay cement common, rare iron or calcite *(Fig. 7)*
	Loose/ Soft	abundant lamination, cross-stratification, dewatering structures	occasional single burrows & some well-burrowed horizons	rare opportunist softground dwellers very rare firmground oysters or serpulids	no cement, lithified high gamma-ray response *(Fig. 7)*

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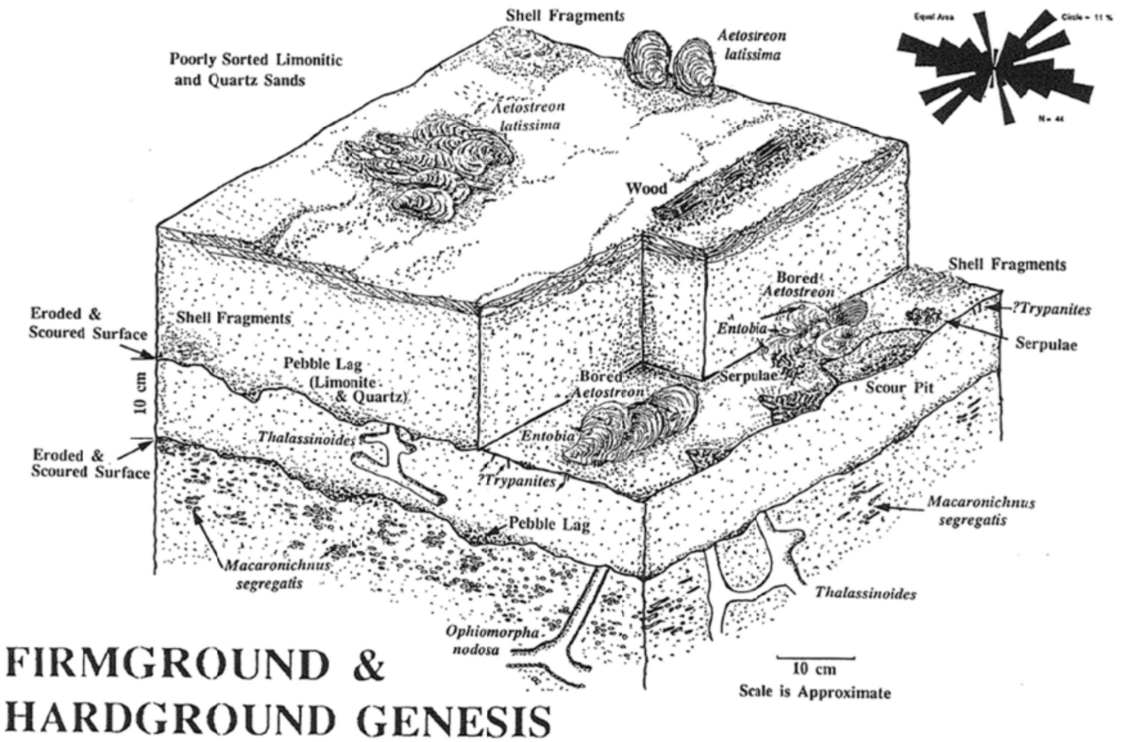


Fig 4: Development and gneiss of firmground horizons (from Wach, 1991).

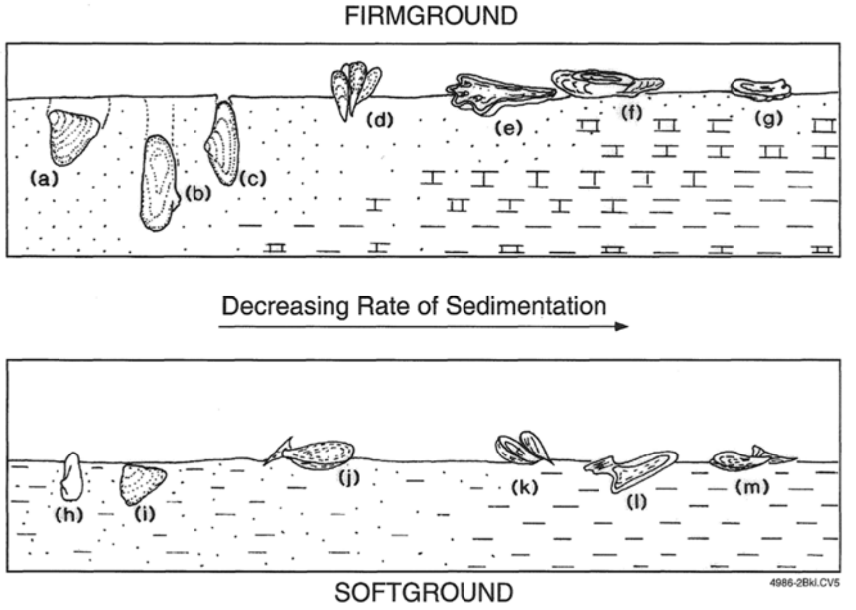


Fig 6: Firmground and softground development related to sedimentation rates and during a hiatus in each substrate (from Ruffell and Wach, 1998).

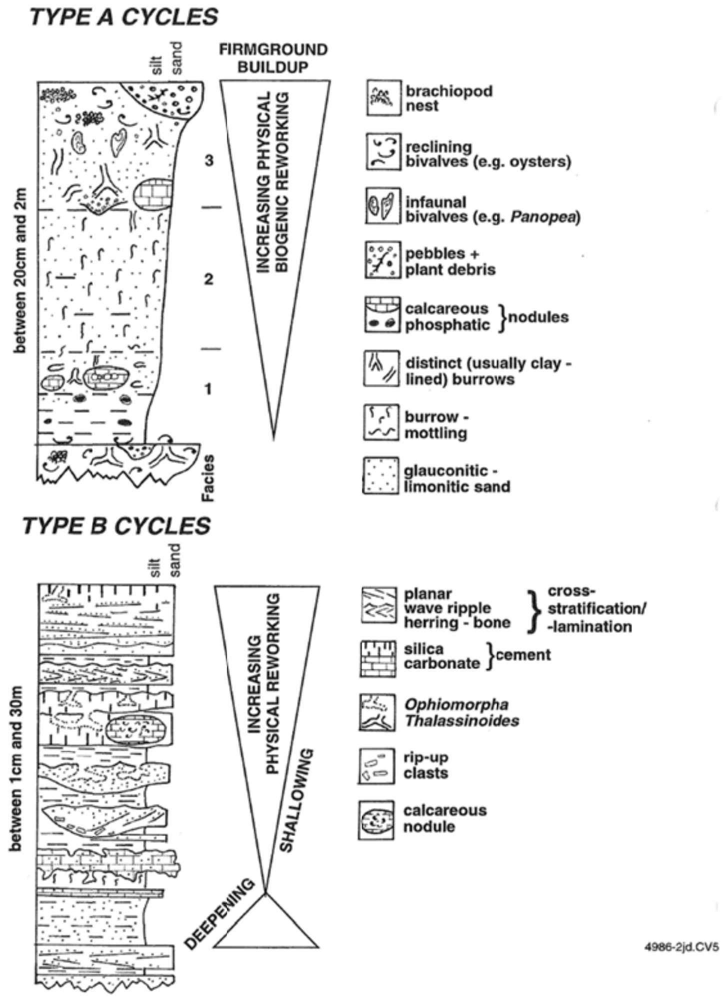
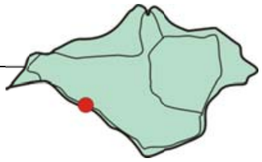


Fig 7: Cycle development in relation to physical and biogenic reworking of sediment and firmground development. Type A cycles generally form firmgrounds are more common in the Ferruginous Sands Formation. Type B cycles are more common in the Sandrock Formation and are marked by increasing energy (from Ruffell and Wach, 1998).

Hanover Point- Shippards Chine: Grant Wach



LOCATION 608504m E, 5612295m N

OBJECTIVES

- Hanover Pt to Shippards Chine- Early Cretaceous non-marine siliciclastics of the Wealden Group.

Fig 1: Hanover Point to Shippards Chine (from Google Earth, 2012).

BACKGROUND

The Cretaceous section begins at the famous Hanover Point Fossil Forests in the Barremian Wealden beds. We will walk NW up through the Wealden low gradient coastal floodplains with playa lakes, meander-belt rivers subject to flash floods, forest fires ending with a brackish lagoon/bay sediments with bayhead deltas. Within the Vectis Formation the facies distribution is controlled to some degree by progradation and abandonment of the small delta systems (Barnes

Fig. 2: A small growth fault demonstrates the active tectonism closer to the IOW-Purbeck structure and there is a repeat section of the Wessex Formation within the Vectis Formation sections.

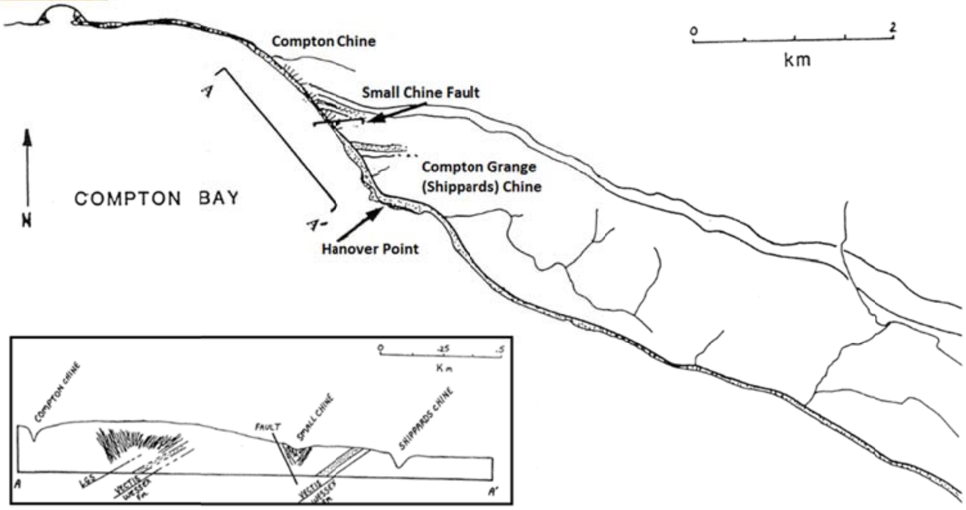


Fig 3: Fossil Forest at Hanover Point t in the foreground with the Chalk cliffs and Tennyson Down in the distance (photo- Aug 15 2011015).

The **Vectis and Wessex formations** outcrop along the shore of Compton Bay. The section begins approximately 250 m south east of Shippards Chine (also known as Compton Grange Chine) at Hanover Point location of the fossil forest and dinosaur footprints. Five channel sandstone beds are present within the section between Hanover Point and Shippards Chine. These units are (1-4m) and exhibit trough cross-stratification typical of the isolated channel sands of the Wessex Formation. There is a sharp contact above the mottled reddish grey sandy clayey silt marking the top of the Wessex Formation and the medium to dark grey mud of the basal portion of the **Cowleaze Chine Member**.

The sediments of the **Cowleaze Chine Member** consist of clay and silt, finely laminated on a millimetre to centimetre scale. Lignitic plant fragments and small fossils are found, including *Unio,* a freshwater bivalve and *Filosina*, a fresh to brackish water bivalve. The member represents the transgression of the lagoon-bay system which gradually inundated the Wessex Formation coastal plain sediments. To the northwest, the Cowleaze Chine Member grades rapidly into the 11 to 12 m thick **Barnes High Sandstone Member**, which consists of a series of coarsening upward, medium to coarse-grained sandstone units, with cross bedding visible near the top of the units. The sandstones are separated by medium to dark grey silty clay units. The echinoid *Micraster cortestudinarium* has sometimes found.

Stewart (1978b & 198lb) proposed three alternative interpretations for the **Barnes High Sandstone Member**; 1) tidal sand flats. 2) barrier bar and 3) a lagoonal delta. Based on the evidence at all the outcrops we favour a reworked deltaic model which explains the variability between each section and the range of sedimentary structures seen at each outcrop. The data indicates that there were a number of small prograding deltas flowing into the lagoon that became reworked by shoreline processes. The sands were transported along the shoreline of the lagoon probably may not have formed a continuous sand body across the area of the Isle of Wight. There was minor tidal influence in the lagoon in the micro-tidal range. Evidence of minor tidal activity is usually obscured by shoreline processes such as wave action, which dominate the system.

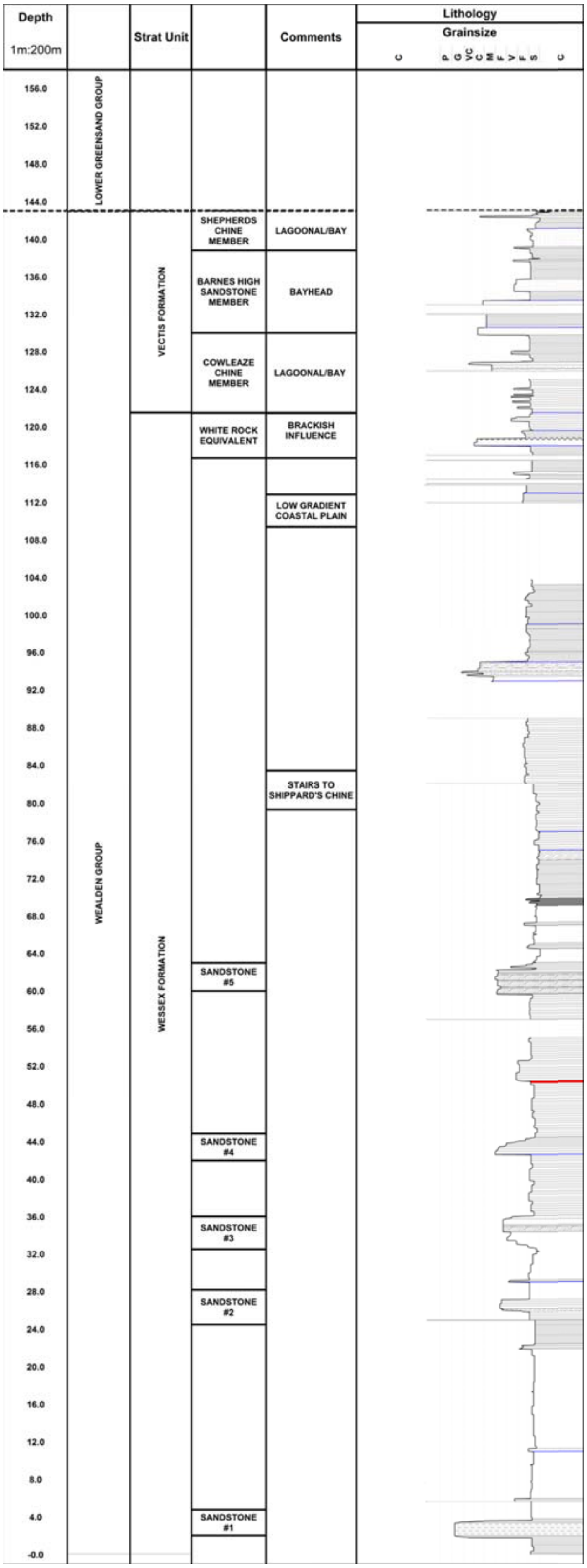


Fig 5: "Wealden" facies of grey and red mottled mudstone, with evidence of gleysols and paleosols, representative of sedimentation on low gradient coastal plains within the Wessex Formation, northwest of Shippards Chine stairs near Small Chine fault.

Fig 4: Meander belt channel sandstone body showing erosional scour beds and trough cross-stratification typical of the isolated channel sands of the Wessex Formation.

Fig 3: Measured section from Hanover Point to Small Chine Fault northwest of Shippards Chine.

Above the ledge forming the top of the Barnes High Sandstone lays the **Shepherd's Chine Member**. The abrupt contact is marked by interlaminated silty fine sand and mud, infilling the irregular rippled surface for a thickness of 10 to 20 cm. The medium to dark grey fissile muds appear identical in lithologic characteristics to earlier sediments of the Cowleaze Chine Member, indicating resumption of similar depositional conditions. Layers of the fern *Weichselia* may be found preserved as fusain (burnt plant matter). The section continues interrupted by landslips and the **Small Chine Fault.** A fault was long postulated for this area (Reid and Strahan, 1889), but was not observed until 1906 (Hooley, cited in White, 1921). The fault, perhaps a Lower Cretaceous growth fault, is often obscured by slumping. It was described by White (192l, p.10) as trending "east north-east and hades south-east". Northwest of the fault the Wessex Formation is repeated for 58 to 59 m, followed by the Vectis Formation for approximately 28 m. The exact thickness is difficult to define due to extensive landslips along the coast. The reduced thickness of all members of the Vectis Formation and the change in lithology and sedimentary structures may be the result of further faulting, or thinning of the sedimentary package towards the west and the monocline.

Interlaminated mud and very fine sand, wavy bedding and lenticular bedding, are common features of the sediments in the middle to upper beds of the **Shepherd's Chine Member**. The sediment may be cemented with pyrite and contain minor amounts of organic debris. Fining-up sequences on the scale of tens of centimetres are common in the succession. An ideal bed comprises; 1) a sharp contact, with gutters scoured into the black muds; 2) a graded layer of silt and fine sand; 3) small scale, cross stratification and discontinuous ripple laminations; and 4) resumption of argillaceous sedimentation.

Coquina beds (5-15 cm thick) can be traced laterally for tens of metres. The shells are the brackish bivalve *Filosina* and to a lesser extent the freshwater gastropod *Viviparus.* These multiple event beds illustrate a tripartite internal arrangement: I) shell-dominant, fragmented shells in a bioclast-supported framework; 2) shell-dominant, matrix-supported shell assemblages of articulated and dis-articulated valves; and 3) mud-dominant matrix-supported shells. The coquina beds represent either a single storm event, characterised by waxing/waning phases; or the beds may have been modified by further storm activity, fair-weather processes (including winnowing), or opportunist infaunal/epifaunal colonisation. Two coquina limestone beds are visible, one of which is underlain by a mudstone. The shells from the coquina bed are clearly visible infilling fissures interpreted to be mud cracks in the mudstone layer. The infill of the **gutters** in the Shepherd's Chine Member is near perpendicular to the gutter axis. The gutter infill is an indicator of waning storm conditions and fair-weather currents. The "coarser" silty fine sand infill is from suspended sediment, gradually settling out after the storm, which has produced a graded bed.

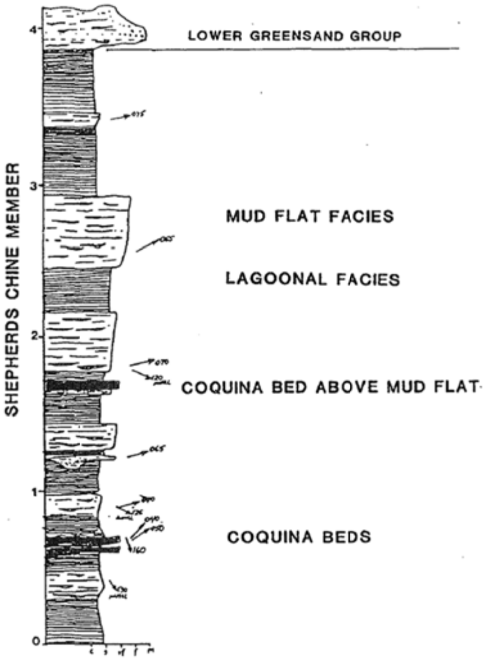
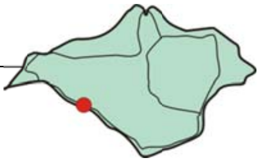
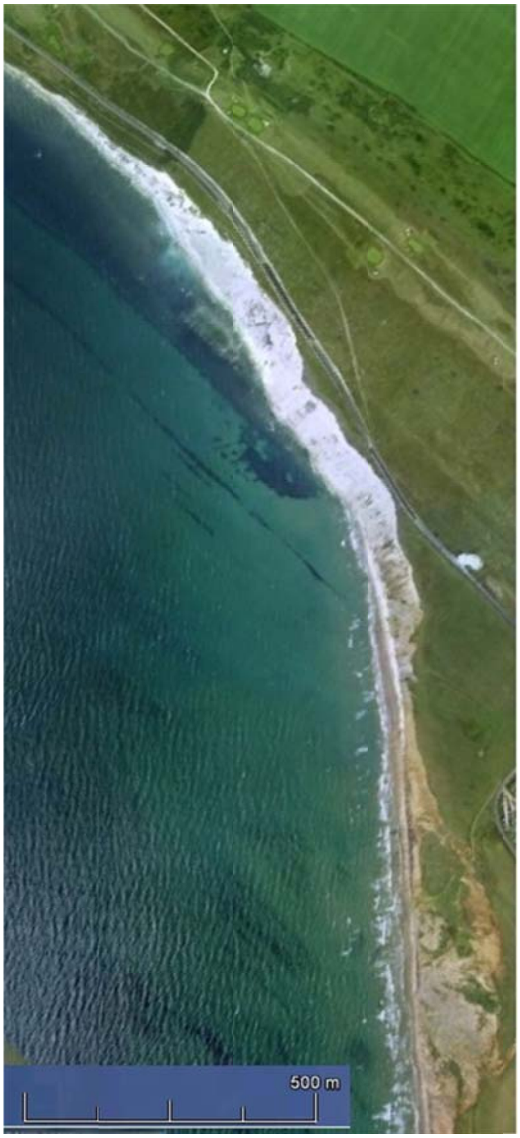


Fig 6: The top 4m of the Shepard's Chine Member at Compton Bay, northwest of Small Chine and Shippards Chine.

Compton Bay: Grant Wach



LOCATION 608504m E, 5612295m N



OBJECTIVES

- Examine the Lower Cretaceous succession from the Lower Greensands Group through to the Gault, Upper Greensands and Upper Cretaceous Chalk
- Examine reservoirs analogues of the Lower Greensands and potential baffles and barriers to reservoir fluid flow.

BACKGROUND

The Lower Cretaceous Lower Greensand Group section begins at the Perna Bed and continues through the shallow marine and estuarine reservoir and seal facies of the Ferruginous Sand and Sandrock. The Lower Greensand Group is capped by the condensed section of the Albian Carstone Formation. Above the Carstone are the dark grey deepwater mudstone shelf facies of the Gault, followed by shallower Upper Greensands glauconitic sands and Lower Chalk beds.

Fig 1: Compton Bay (from Google Earth, 2012).

Fig 2: Compton Bay- Aptian- Cenomanian section, Lower Greensand Group through to the Chalk.

Lower Greensand Group

The contact between the **Vectis Formation** of the Wealden Group and the **Atherfield Clay Formation** of the Lower Greensand Group lies in the vicinity of the beach access path but is often obscured by slumping. At low tide the contact can be found approximately 50 m to the northwest in the intertidal zone and is best viewed after storms when the shingle has been stripped from the beach. Two coquina limestone beds may be visible, one of which is underlain by a mudstone. The shells from the coquina bed are clearly visible infilling fissures interpreted to be mud cracks in the mudstone layer.

The **Ferruginous Sands Formation** section here is somewhat thinner than at Chale Bay, being 50 m thick as opposed to 100-110 m, and although also thinner again than Red Cliff (90 m), more of the members recognised at the Chale Bay type section can be seen at Compton. The composite log shows the distinctive lithological horizons of the Compton Bay section, which can easily be appreciated standing (at low water!) back from the cliff. East to west, beginning where the National Trust path reaches the beach, we see the landslip of Atherfield Clay Formation (22-25 m), with a resistant bed (possibly the Crackers Member equivalent) visible at the base of the cliff. Above we see 3 m of "Upper Lobster Beds", then 8 m of sand to the "Mottled Band" where two ammonites of the grandis subzone have been found. Three metres above is a resistant, weathering red iron pan, then 12 m of glauconitic sand to 18m of coarser red sands. On top of this is the "Black Band" which has yielded ammonites of the *meyendorfi* subzone, and forms an unmistakeable 3 m thick "stripe" across the cliff. Eight metres above is the grey band, with no ammonites but dated as lower martinioides zone from the microfauna and flora. From here there is 10m of sand to the basal pebble-bed of the correlative Member XII, the first of the estuarine phases. Above we see 11 m of Members XIII and XIV (nutfieldiensis) overlain (with a basal pebble bed) by the dark silts of Member XV (basal *jacobi* zone), with 22 - 30 m of **Sandrock Formation** (s.s.) above.

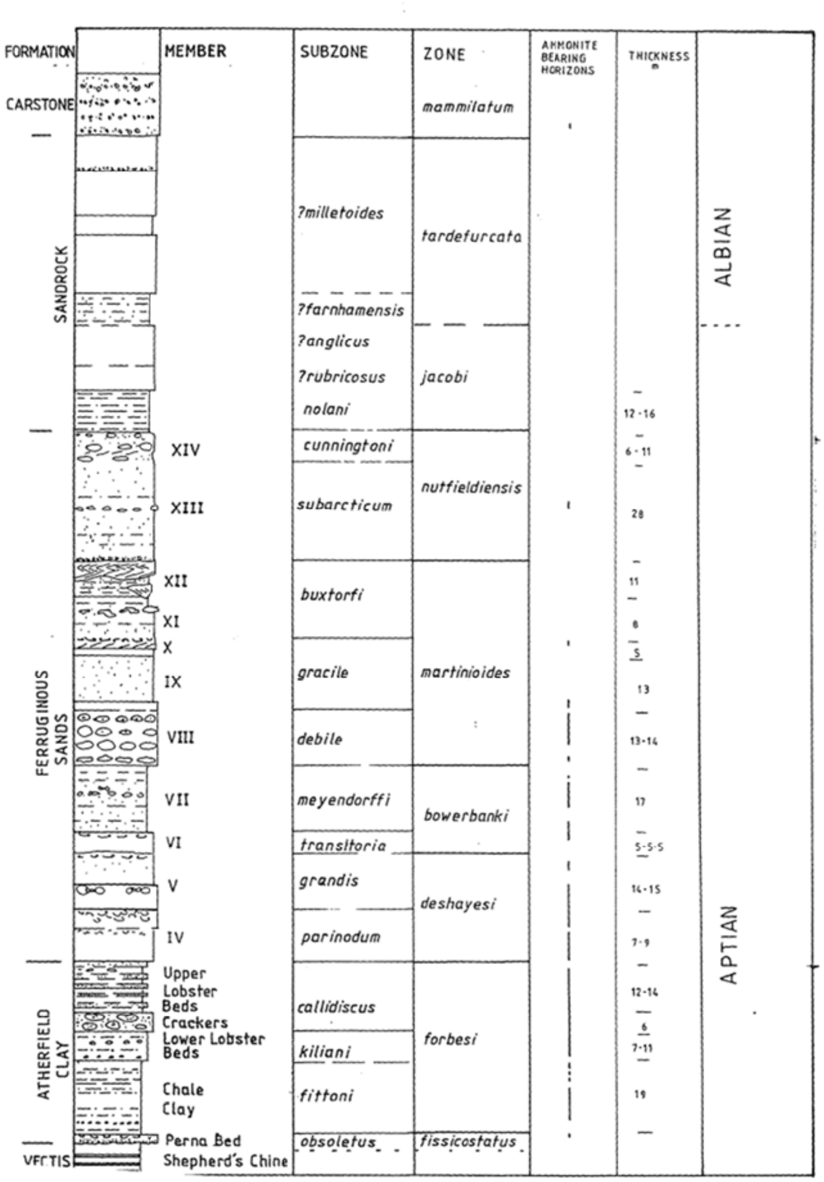


Fig 3: Compton Bay section of the Lower Greensand Group (LGS) beginning with the Atherfield Clay, Ferruginous Sands, Sandrock and capped by the Carstone formation. See text for discussion (from Wach and Ruffell, 1991).

The **Sandrock Formation** is mineralogically and texturally mature with quartz the primary component. The clean quartzose sands have been termed the "silver sands" in some regional locations given their brilliant white appearance and have excellent porosity. Permeability can be reduced by the heterolithic nature of the formation with black clay bands. Grain size ranges from fine to *very* coarse, with medium the median size. Grains are subangular to round with subround the mean. Glauconite is a common within some of the sand units. The sands have black mud drapes which X-ray diffraction analysis has shown to be dominated by the clay mineral kaolinite. The beds range in thickness from 0.1 m to 1.0 m and are characterized by small to large scale horizontal stratified, tabular, trough, or tangential foreset cross stratification. Set thickness generally increases up each sand interval with a corresponding slight increase in grain size due to the textural maturity of the sediment. Graded bedding is visible in the thicker sets, often in association with *very* coarse-grained sand and grit lag deposits. Individual set boundaries are delineated by black silty clay laminae ranging in thickness from 0.5 mm to 5 mm. The thicker sets are marked by discontinuous laminae of a similar texture and lithology. Foresets range from 0.1 m to 0.3 m and are commonly graded. Small to medium scale planar and tabular cross-stratification is common within the smaller sets, with occurrences of herringbone and trough cross-stratification. Toe sets form mud-draped ripples where they merge with the black muds of the set boundaries. Ripple forms are asymmetric with stoss slope angles of 12° to 18° and lee slope angles of 15° to 22°. In some examples reverse flow ripples are preserved and rip-ups of black mud laminae are common on the basal contacts.

Trace Fossils- Ichnofossils are difficult to see in the clean white quartzose sands (higher energy) and appear to be more common in the heterolithic deposits (lower energy) containing increased amounts of glauconite and clay. Ichnofossils identified include, *Ophiomorpha, Arenicolites,* bivalve escape traces, *Rosselia socialis* (Dahmer, 1937), *Conichnus* conicus (Myannil, 1966; Pemberton, *et al.,* 1988), *Macaronichnus segregatis* (Clifton and Thompson, 1978) *Skolithos, Asterosoma* and *Gyrophyllites. Skolithos* and *Ophiomorpha* are more common in the cleaner, white quartzose sands. *Asterosoma* and *Gyrophyllites* (a rare star-shaped trace) are Fodinichina (feeding traces), but are rarely found, except on the occasional fallen block beneath the cliff face at Rocken End. Feeding and grazing traces occur within the black mud of the set boundaries. These are difficult to discem in the vertical sections but can be clearly seen in fallen blocks which have split along the bedding planes. Species identified include *Scolicia, ?Helminthopsis* or *Planolites* and *Teichichnus.*

Trace Fossil Interpretation- The assemblage is characteristic of the *Skolithos* ichnofacies, indicative of high energy conditions that produce well-sorted, clean, sandy substrates (Seilacher, 1967). Physical reworking of the sediment produces rapid changes in the rates of deposition and erosion. The organisms that inhabit these conditions tend to be infaunal suspension feeders that construct vertical, often lined burrows (Frey and Mayou, 1971, cited in Ekdale, Bromley and Pemberton, 1984) which fit Seilacher' s (1953a, p.437; 1964a, p.254-255; 1964c, p.297) ethologic classification of dwelling (Domichnia) and feeding (Fodinichnia) structures. The *Skolithos* ichnofacies has been typically described in foreshore and shoreface zones with fewer examples identified in similar high-energy environments such as estuarine deposits (Frey and Howard, 1980 cited in Ekdale, Bromley and Pemberton, 1984). *Rosselia socialis* and *Conichnus conicus* are often found together in the smaller scale bedforms. The bedforms were probably formed rapidly, under flood tidal conditions likely within the intertidal zone. The traces exhibit evidence of adjustment to increased sediment supply. Box-like networks of *Ophiomorpha* can be found (not illustrated) that are characteristic of the transition zone between the high energy surf zone and below wave base. Within the surf zone burrows are near vertical while in quieter water conditions burrow systems are near-horizontal. Similar energy conditions can be expected within tidal environments, near the lower spectrum of the intertidal zone. The black mud forming the set boundaries are characterized by traces typical of the *Cruziana* ichnofacies. This is the most widespread of the ichnofacies, ranging from shallow epeiric seas to open continental shelves, but has also been identified in estuarine deposits (Ekdale, Bromley and Pemberton, 1984).

Sandstone Interpretation- The sandstone facies represents deposition in subtidal channels and adjacent shoals, within an estuarine environment. The clean submature to mature nature of the sediment resulted from reworking by a combination of tides and wave action. The occurrence of abraded, silt-sized grains of glauconite within some of the estuarine sand sequences can be attributed to the influx of glauconite from the shelf via storms, or perhaps strong flood tides, followed by extensive reworking by tidal processes. The large-scale cross-stratification was probably deposited within subtidal channels. Scouring and thin basal lag deposits support this view. Medium and small-scale bedforms represent migrating shoals formed in shallower water, which were subjected to greater variation of tidal conditions. Within the smaller bedforms reactivation surfaces, clay drapes, clay rip-ups, tidal bundles, herringbone cross stratification and counter-flow ripples are present. Tidal cyclicity is interpreted on the basis of tidal bundles found in the smaller heterolithic sets. The variation in the current flow within these shallow intertidal waters has resulted in several episodes of erosion and deposition.

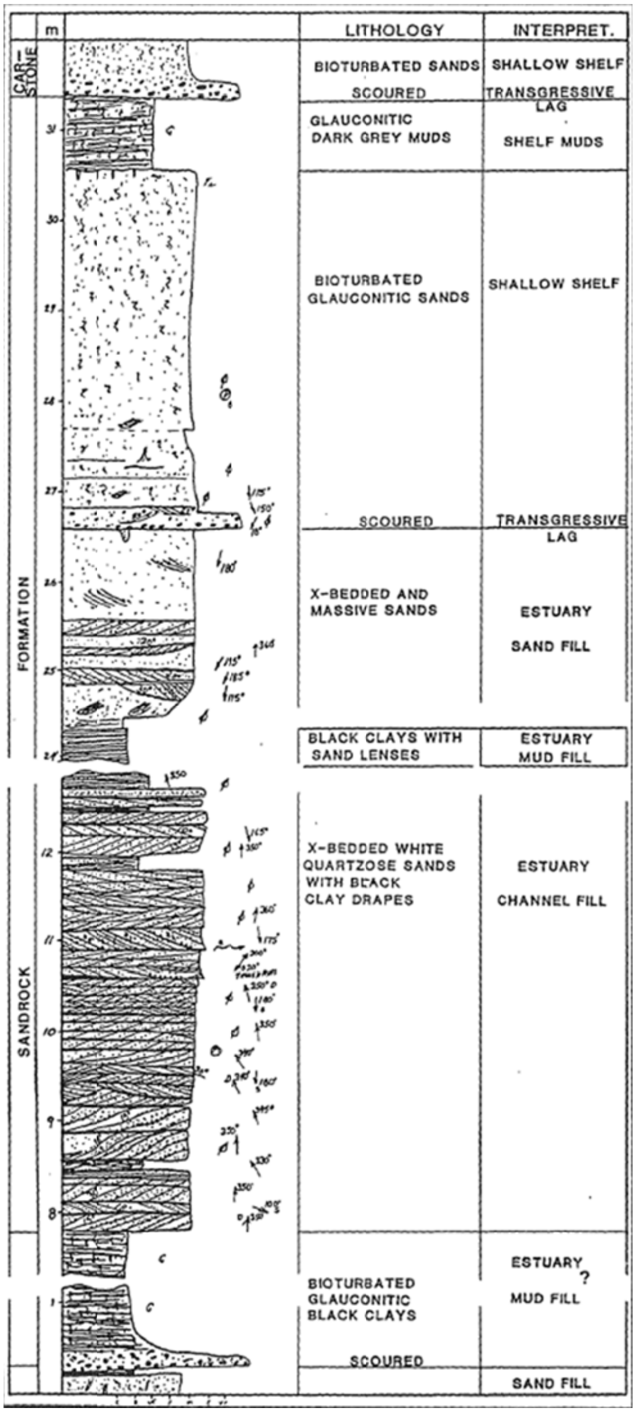


Fig 4: Compton Bay section of the Sandrock Fm truncated by the the Cartstone Fm. The two main sand units are separated by a thick 12m interval of dark greyis black clay with thin sand lenses. See text for discussion (from Wach and Ruffell, 1991).

Mudstone Facies- The mudstone is characterised by two lithofacies types; 1) black, laminated, clay dominant muds and; 2) greenish (glauconitic), dark grey massive, bioturbated, poorly sorted muds. 1) Laminated Muds- X-ray diffraction analysis indicates a mixture of kaolinite, illite, chlorite, mixed layer clays and varying quantities of glauconite. Kaolinite is the dominant clay mineral. The greenish, bioturbated muds have a similar assemblage of clay minerals, but with no clay mineral dominant. There is an increase in glauconite associated with a corresponding decrease in kaolinite. **Structure-** The black muds consist of laminae 0.5 mm - 2 mm thick with intermittent layers of fine-grained, white quartzose sand. These form discrete layers, but where sand supply was variable, or subsequent erosion has removed part of the layer, flasers are present. Asymmetric current ripples are preserved and in some cases, reverse-flow current ripples can be discerned.

Trace Fossils- Bioturbation is limited to grazing traces, which are infilled with fine-grained silty sand and 1.0 mm diameter clusters of small cylinder shaped traces *(?Helminthopsis* or *Planolites*) which

post-date the majority of the larger grazing traces. Interpretation- Laminated muds with flaser and linsen (lenticular) bedding depends on sediment supply and current flow. The style of bedding is typical of sediments deposited in subtidal and intertidal environments, especially within tidal flat conditions (Reineck and Singh, 1980, p.112-118). The combination of asymmetric current ripples and reverse-flow ripples is evidence of past tidal conditions. Wave modification of the ripples in the shallow would have occurred. The environmental interpretation from the microflora assemblage is of a palynofacies representative of a coastal swampy area under marine influence, through to nearshore marine conditions (D. Batten, 1988, pers. comm.).

Carstone Formation: The Carstone Formation is the only formation of the Lower Greensand Group to thicken towards the east as noted earlier. It is Albiian in age. The dark red sediments of the formation comprise coarse grained consolidated sandstone with iron cements pehaps derived from glauconite rich sediments. Layers of rounded pebbles form beds and suggest winnowing and condensation of sediment.

Gault: Dark, grey to black silt and clay characterise the Gault and represent a major transgression in the Albian with deposition of fully marine sediments.

Upper Greensands: The Upper Greensands on the Isle of Wight comprise represent a major drop in sea level and resumption of ssedimentation on a shallow shelf. The sediments comprise light pale yellow rto greeensish sanstone with glauconite, pale brown sands, followed by dark grey cherty marls.

Chalk: The contact of the Lower Chalk with the Upper Greensand is bioturbated with *Thalassinonides* burrows piping-in the Glauconitic Marl sediments of the Lower Chalk around concretions, into the top of the Upper Greensand. Calcareous concretions and phosphatic nodules are common. The Plenus Marls represent the top of the Lower Chalk.

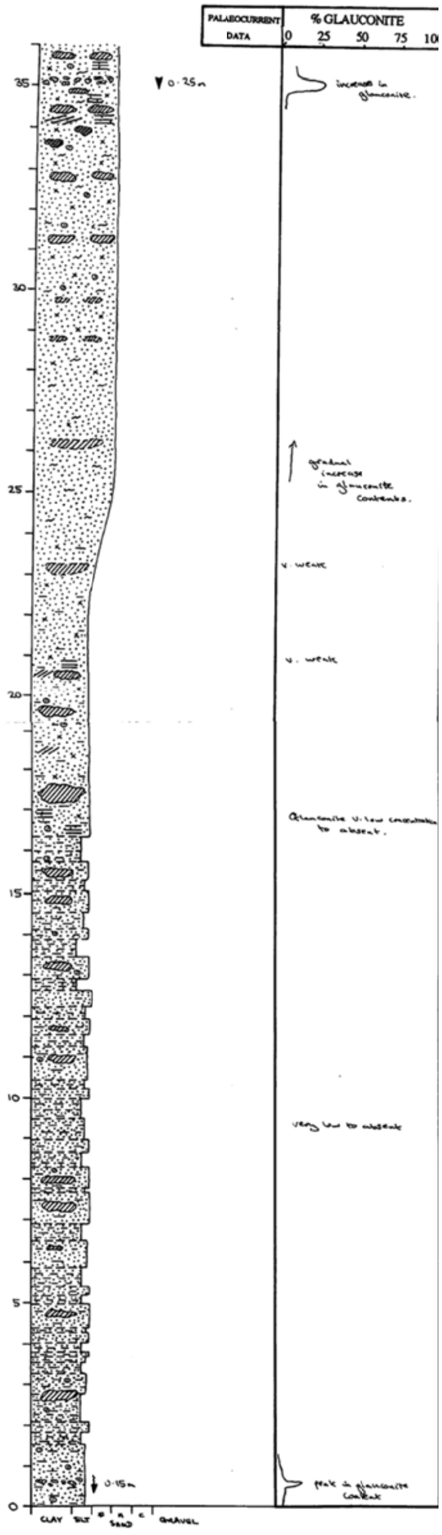
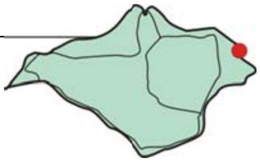


Fig 5: Compton Bay section of the Upper Greensand (UGS) with glauconitic and calcareous dark gray marl and the beginning of the Chalk Group (from Hart, 1991 unpublished).

Whitecliff Bay: Grant Wach and Stephen Hesselbo



LOCATION 634549m E, 5614508m N

Fig 1: Whitecliff Bay (from Google Earth, 2012).

OBJECTIVES

- Unconformity on Chalk, Lower Tertiary succession, inversion history.

Fig 2: Whitecliff Bay - Lower Tertiary section beginning with the Reading Beds on the left.

Fig 3: Overview of the succession at Whitecliff Bay with the karst surface of the Bembridge Limestone, though the Lower Tertiary succession to the Upper Cretaceous Chalk forming the cliffs of Culver Down towards the south.

BACKGROUND

Whitecliff Bay (With excerpts from Curry. et al.. 1972; Daley and Insole, 1984.)

The cliff section at Whitecliff Bay displays perhaps the most complete succession of Lower Tertiary beds in Europe demonstrating the relative positions of the London Clay, the various members of the Bracklesham Beds, and the Barton Beds. To the north beneath the Chalk cliffs of Culver Down are the near vertical beds of Eocene sands and clays; followed by Oligocene strata with the structural dip changing rapidly from vertical to horizontal. The Bembridge Limestone dips southwards, passing out to sea as a series of ledges surrounding the Bembridge Foreland.

Chalk: The south-western end of Whitecliff Bay comprises Chalk. The lower zones are accessible in calm weather at low tide at the foot of Culver Cliff beyond. The Middle Chalk is a cleaner with some minor marl seams. The Upper Chalk is typically a hard nodular limestone with bands of flints.

Reading Beds: This is a 46 m sequence of brick-red, purple and mottled pure clay, without recorded fossils, similar in appreance to the Lower Createceous terrestial “Wealden” beds of the Wessex Formation, seen at Compton Bay. The base of the formation is thought to unconformably lie on the possibly karst surface of the Chalk. A grey clay-rich fine sand, 1-2 m thick, contains flints derived from the Chalk.and a few flint-pebbles. It rests on a potholed surface of Chalk.

London Clay: This includes gray and brown clays and two thick beds of sands. Several horizons of marine fossils occur in the clays as well as indurated zones. The lowest unit (4.3 m) is muddy and glauconitic containing seams full of the worm *Ditrupa plana*, with molluscs, sharks' teeth and derived pellets of Reading Clay. There are several separian nodules throught the section. The London Clay is marked by a large landslip along the beach section.

Bagshot Sands: This is a 42 m yellow, grey and red sands, with pipeclays. It is probably continental and has no fossils recorded. The London Clay and Bagshot Sands together consists of four transgressiveregressive cycles separated by surfaces, often a thin pebble bed, representing major transgressive events. The cycles are essentially coarsening-upwards in nature. The sandstone beds are fractured with great de-watering structures.

Bracklesham Beds: A thick (177 m) series, consisting mainly of dark grey-green marine clays, with several important fossil horizons. This group comprises four transgressive cycles, somewhat different from the London Clay. At the base of each is a pebble bed or bioturbated junction overlain by glauconitic sandy clay or sands, usually containing an abundant marine fauna. These pass up into interbedded clays (often lignitic), silts and sands, which are unfossiliferous except for few poorly preserved leaves.

Barton Clay: This is poorly exposed with most of the 60m section being obscured by landslips and vegetation. It consists of blue-grey clay silts and sandy clays. Just north of the zig-zag path, the transition from the Barton Clay into the fine yellow clay of the Barton Sands can be seen.

Barton Sand: The lower part of the 55 m Barton Sand section is muddy and intensely bioturbated. In the upper part, the sand is cleaner with a few clay lenses and thin mud pellet conglomerates. *Ophiomorpha* burrows occur sporadically at this level.

Bembridge Limestone: This has been interpreted as a freshwater limestone. There is a very rugose top surface with irregular weathering to depths of 30-40cm that may represent surface exposure and karst weathering. The base of the Bembridge Limestone may represent the Eocene-Oligocene boundary.

Acknowledgements

We would like to thank Alastair Ruffell and Steve Hart for their contributions to this guide. We appreciate the technical assistance of Dawn Tobey, Andrea Christians, Sharane Simon and Kristie Mahoney all of Dalhousie University and David Sansom (Oxford) in the preparation of some of the text, figures and photographs used in this field guide.

References

Allen, P., 1975. Wealden of the Weald: a new model. Proc. Geol.Ass., 86, 63-76.

Allen, P., 1989. Wealden research- ways ahead. Proc. Geol. Ass. 100(4),529-65.

Anderton, R., Bridges, P.H., Leeder, M.R., and Sellwood, B.W., 1979. A dynamic stratigraphy of the British Isles. George Allen and Unwin, London, 301p.

Bellamy, J., 1977, Subsurface expansion megapolygons in Upper Jurassic dolostone (Kimmeridge, U.K.): Journal of Sedimentary Petrology, v. 47, p. 973–978.

Blanc, P., and Connan, J. (1994) Preservation, degradation , and destruction of trapped oil, in Magoon, L. B., and Dow, W. G., The petroleum system; from trap to source. AAPG Memoir 60, 237-247

Bray, R.J., Duddy I.R.& Green P.F. 1998. Multiple episodes in the Wessex Basin: Implications for geological evolution and hydrocarbon generation. In: Development, Evolution and Petroleum Geology of the Wessex Basin, Geology Society, London, by: J.R. Underhill. Special Publications **133**: 199-213.

Briden, J.C., Drewry, G.E. and Smith, AG.,1974. Phanerozoic equal-area world maps. Jour. Geol., 82, 555-574.

Brooks, M., Trayner, P.M., and Trimble T.J., 1988. Mesozoic reactivation of Variscan thrusting in the Bristol Channel area, UK. J. Geol. Soc. Lond., 145,439-444.

Casey, R, 1961. The stratigraphical palaeontology of the Lower Greensand. Palaeontology, 3(4), 487-621, pl. 77-84.

Chadwick, RA, 1986a. Extension tectonics in the Wessex Basin, southern England. J. Geol. Soc. Lond., 143,465-488.

Chadwick, RA, 1986b. Permian, Mesozoic and Cenozoic structural evolution of England and Wales in relation to the principles of extension and inversion tectonics. In: Whittaker, A (ed.), Atlas of onshore sedimentary basinsin England and Wales, B.G.S., Blackie, London, 9-25.

Chadwick, RA, 1986c. End Jurassic-early Cretaceous sedimentation and subsidence (late Portlandian to Barremian), and the late-Cimmerian unconformity. In: Whittaker, A. (ed.), Atlas of onshore sedimentary basins in England and Wales, B.G.S., Blackie, London, 52-56.

Chadwick, RA, 1986d. Cretaceous sedimentation and subsidence (Aptian to Albian). In: Whittaker, A (ed.), Atlas of onshore sedimentary basins in England and Wales, B.G.S., Blackie, London, 57-58.

Clifton, H.E. and Thompson, J.K., 1978. Macaronichnus segregatis:a feeding structure of shallow marine polychaetes. Journ. Sed. Petrol. 48, 1293-1301.

Cope, J.C.W., 1978, The ammonite faunas and stratigraphy of the upper part of the Upper Kimmeridge Clay of Dorset: Palaeontology, v. 21, p. 45-56.

Coward M P, Dewey J F, Hempton M & Holroyd J (2003) Tectonic Evolution. In Evans D, Graham C, Armour A & Bathurst P (eds & co-ords) The Millennium Atlas: Petroleum Geology of the Central and Northern North Sea. London: The Geological Society: 17–33

Cox, B.M., Gallois, R.W., 1981, The stratigraphy of the Kimmeridge Clay of the Dorset type area and its Correlation with some other Kimmeridge sequences. Report of the Institute of Geological Sciences. no. 80/4, 44 pp.

Curry D., and Smith A.J., 1975. New discoveries concerning the geology of the central and eastern parts of the English Channel. Philosophical Transactions of the Royal Society of London A279:155–167

Dahmer, G., 1937. Lebensspuren aus dem Taunusquartzit und den Siegener Schicten (Unterdevon). Preussische Geologische Landesanstalt, Jahrbuch, 1936, 57, 523-539, text-fig. 1,2, pl. 31-35.

Daley, B. and Insole, A, 1984. The Isle of Wight. Geologist's Association Guide No. 25, 36pp.

Deconninck, J-F., Hesselbo, S.P., Debuisser, N., Averbuch, O., Baudin, F., and Bessa, J., 2003, Environmental controls on clay mineralogy of an Early Jurassic mudrock (Blue Lias Formation, southern England): International Journal of Earth Sciences, v. 92, p.255-266.

Dike, E.F., 1972. Ophiomorpha nodosa Lundgren: environmental implications in the Lower Greensand of the Isle of Wight. Proc. Geol. Ass. 83(2), 165-177.

Dunn, C.E., 1974, Identification of sedimentary cycles through Fourier analysis of geochemical data: Chemical Geology, v. 13, p. 217–232.

Ebukanson, E. J. & Kinghorn, R. R. F. 1985. Kerogen Facies in the Major Mud-rock Formations of Southern England and the Implication on the Depositional Environments of their Precursors. Journal of Petroleum Geology, **8**, 435-462.

Ekdale,A.A., Bromley,R.G. and Pemberton, S.G., 1984. Ichnology: the use of trace fossils in sedimentology and stratigraphy. SEPM, Tulsa, Oklahoma, 317pp.

Farrimond P., Comet P., Englington G., Evershed R.P., Hall M., Park D.W. and Wardroper A.M.K. 1984. Organic Geochemical study of the Upper Kimmeridge Clay of the Dorset type Area. Marine and Petroluem Geology, **1**: 340- 354. *Cited in:* Underhill, J. R. & Stoneley, R. 1998. Introduction to the development, evolution and petroleum geology of the Wessex Basin. In: Underhill, J. R. (ed.) Development, Evolution and Petroleum Geology of the Wessex Basin,Geological Society, London, Special Publications, **133**, 1-18.

Feistner, K.W.A., 1989, Petrographic examination and reinterpretation of concretionary carbonate horizons from the Kimmeridge Clay, Dorset: Journal of the Geological Society, London, v. 146, 345–350.

Fitton, W. H., 1847. A stratigraphical account of the section from Atherfield to Rocken-end, on the southwest coast of the Isle of Wight. Quarterly Journal of the Geological Society of London, Vol. 3, 289-327.

Fitton, W.H. 1845. Comparative remarks on the Lower Greensand of Kent and the Isle of Wight. Proc. Geol. Soc., 4, 208-10.

Frey, R.W. and Howard, J.D .. 1980. Physical and biogenic processes in Georgia estuaries, II, Intertidal facies, in McCann, S.B.,ed .. Sedimentary processes and animal sediment relationships in tidalenvironments. Geol. Assoc. Canada, Short Course 1,183-200.

Frey. R. W. and Mayou, T.V., 1971. Decapod burrows in Holocene island beaches and washover fans. Senckenberg. Marit. 3, 53-77.

Gallois, R.W., 2000, The stratigraphy of the Kimmeridge Clay Formation (Upper Jurassic) in the RGGE Project boreholes at Swanworth Quarry and Metherhills, South Dorset: Proceedings of the Geologists' Association, v. 111, p. 265–280.

Gardner, J.S., 1879, Description and Correlation of the Bournemouth Beds.—Part I. Upper Marine Series: Quarterly Journal of the Geological Society, v. 35, p. 209–228.

Gatrall, M., Jenkyns, H.C., and Parsons, C.F., 1972, Limonitic concretions from the European Jurassic with particular reference to the "Snuff-Boxes" of Southern England: Sedimentology, v. 18, p. 79-103.

Glennie, K.W .. 1986. The structural framework and pre-Permian history of the North Sea area. In, Glennie, K.W. (ed.), Introduction to the Petroleum Geology of the North Sea, Blackwell Scientific Publications, London,25-62.

Gluyas, J.G., Evans, I.J., and Richards, D., 2003, The Kimmeridge Bay Oilfield, Dorset, UK Onshore, In: Gluyas, J.G. & Hichens, H.M. (eds) United Kingdom Oil and Gas Fields, Commemorative Millennium Volume: Geological Society, London, Memoir, v. 20, p. 943-948.

Hallam, A, 1960, The White Lias of the Devon coast: Proceedings of the Geologists' Association, v. 71, p. 47–60.

Hallam, A., 1988, A re-evaluation of the Jurassic eustasy in the light of new data and the revised Exxon curve. In: Wilgus, C.K., Hastings, B.S., Kendall, G.St.C., Posamentier, H.W., Ross, C.A. & van Wagoner, J.C. (eds.) Sea- Level Changes: an Integrated Approach. Society of Economic Paleontologists and Mineralogists, Special Publications, 42, p. 71–108.

Haq, B.U., Hardenbol, J. and Vail, P.R., 1988. Mesozoic and Cenozoic chronostratigraphy and eustatic cycles. In.: Wilgus, C.K. et aL (eds.), Sealevel Changes: an integrated approach, SEPM Spec. Pub. No. 42, 71-108.

Hart, S., 1991. Upper Greensands, Unpublished D.Phil dissertation. Dept. of Earth Sciences, University of Oxford.

Henson, M.R., 1970, The Triassic rocks of south Devon: Proceedings of the Ussher Society, v. 2, p. 172–177.

Hesselbo, S.P. & Allen, P.A., 1991, Major erosion surfaces in the basal Wealden Beds, Lower Cretaceous, south Dorset: Journal of the Geological Society, London, v. 148, p. 105-113.

Hesselbo, S.P., 2008, Sequence stratigraphy and inferred relative sea-level change from the onshore British Jurassic: Proceedings of the Geologists' Association, v. 119, p. 19–34.

Hesselbo, S.P., and Jenkyns, H.C., 1995, A comparison of the Hettangian to Bajocian successions of Dorset and Yorkshire. In: Taylor, P.D. (ed.) Field Geology of the British Jurassic: Geological Society of London, p. 105–150.

Hesselbo, S.P., Deconinck, J.-F., Huggett, J.M., and Morgans-Bell, H.S., 2009, Late Jurassic palaeoclimatic change from clay mineralogy and gamma-ray spectrometry of the Kimmeridge Clay, Dorset, UK: Journal of the Geological Society, London, v. 166, p. 1123–1134.

Hesselbo, S.P., Robinson, S.A., and Surlyk, F., 2004, Sea-level change and facies development across potential Triassic–Jurassic boundary horizons, south west Britain: Journal of the Geological Society, London, v. 161, p. 365-379.

Holloway, S., Milodowski, A.E., Strong, G.E., and Warrington, G., 1989, The Sherwood Sandstone Group of the Wessex Basin, southern England: Proceedings of the Geologists' Association, v. 100, p. 383–394.

Hooker, J.J., 1975, Reports of a field meeting to Hengistbury Head and adjacent areas, Dorset, with an account of published work and some new exposures: Tertiary Times, v. 2, p. 109–121.

Hounslow, M.W., and McIntosh, G., 2003, Magnetostratigraphy of the Sherwood Sandstone Group (Lower and Middle Triassic), south Devon, UK: detailed correlation of the marine and non-marine Anisian: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 193, p. 325–348.

Huang, C., Hesselbo, S.P., and Hinnov, L.A., 2010, Astrochronology of the Late Jurassic Kimmeridge Clay (Dorset, England) and implications for Earth system processes: Earth and Planetary Science Letters, v. 289, p. 242-255.

Hughes, N.F., 1958. Palaeontological evidence for the age of the English Wealden. Geol. Mag. 95, 41-49.

Insole, A., Daley, B. and Gale, A., 1998. 984. The Isle of Wight. Geologist's Association Guide No. 60, (Grensmit, J.T., ed.) 132pp

Irwin, H., Curtis, C., and Coleman, M., 1977, Isotopic evidence for source of diagenetic carbonates formed during burial of organic-rich sediments: Nature, v. 269, p. 209–213.

Jenkyns, H.C. and Senior, J.R., 1991, Geological evidence for intra-Jurassic faulting in the Wessex Basin and its margins: Journal of the Geological Society, London, v. 148, p. 245-260.

Jones, L.E., and Sellwood, B.W., 1989. Palaeogeographic significance of clay mineral distributions in the Inferior Oolite Group (Mid-Jurassic) of southern England: Clay Minerals, v. 24, p.93–105.

Kamer,G.D., Lake,S.D. and Dewey, J.F., 1987. The thermal and mechanical development of the Wessex Basin, southern England. In: Continental Extensional Tectonics, Coward, M.P., Dewey, J.F. and Hancock,P.L. (eds.).Geol.Soc.Spec.Pub. 28, 517-536.

Kerth, M. & Hailwood, E.A. 1988. Magnetostratigraphy of the Lower Cretaceous Vectis Formation (Wealden Group) on the Isle of Wight, southern England. Journal of the Geological Society, London, 145, 351-360.

King, C., 2007, Paleogene and Neogene: uplift and a cooling climate. In Brenchley, P.J and Rawson, P.F. (Eds). Geology of England and Wales (2nd Edition). Geological Society of London, p.395–428.

Korte, C., Hesselbo, S.P., Jenkyns, H.C., Rickaby, R.E.M., and Spötl, C., 2009, Palaeoenvironmental significance of carbon- and oxygen-isotope stratigraphy of marine Triassic–Jurassic boundary sections in SW Britain: Journal of the Geological Society, London, v. 166, p. 431–445.

Leonard, A.J., Moore, E.G., and Selwood, E.B., 1982, Ventifacts from a deflation surface marking the top of the Budleigh Salterton Pebble Beds, east Devon. Proceedings of the Ussher Society, v. 5, p. 333–339.

McKie, T. and Williams, B.J., 2009, Triassic palaeogeography and fluvial dispersal across the northwest European Basins: Geological Journal v. 44, p. 711–741.

Meadows, N. S. & Beach, A. 1993. Controls on reservoir quality in the Triassic Sherwood Sandstone of the Irish Sea. Petroleum Geology of Northwest Europe: Proceedings of the 4th Conference (edited by J. R. Parker)

Morgans-Bell, H.S., Coe, A.L., Hesselbo, S.P., Jenkyns, H.C., Weedon, G.P., Marshall, J.E.A., Tyson, R.V., and Williams, C.J., 2001, Integrated stratigraphy of the Kimmeridge Clay Formation (Upper Jurassic) based on exposures and boreholes in south Dorset, UK: Geological Magazine, v. 138, p. 511–539.

Morris, J.E., Hampson, G.J., and Johnson, H.D., 2006, A sequence stratigraphic model for an intensely bioturbated shallow-marine sandstone: the Bridport Sand Formation, Wessex Basin, UK: Sedimentology, v. 53, p. 1229–1263.

Myannil [Mannil]. RM., 1966. 0 vertikalnykh norkakh zaryvaniya v Ordovikskikh izvestiyakakh Pribaltiki (A small vertically excavated cavity in Baltic Ordovician limestone). In: Organizm i sreda v geologischeskom proshlom, Akademiya Nauk SSSR, Paleontologicheskiy Institute, 200-207, text fig. 1,2, pl. 1.2.

Nio, Swie-Djin, 1976. Marine transgressions as a factor in the formation of sandwave complexes. Geologie en Mijnbouw, 55, 18-40.

Owen, H.G., 1975. The stratigraphy of the Gault and Upper Greensand of the Weald. Proc. Geol. Ass. 86(4), 475-498, issue commemorating the centenary of publication of "The Geology of the Weald", by William Topley.

Parrish, J.T., 1985. Global paleogeography, atmospheric circulation, and rainfall in the Barremian Age (late Early Cretaceous). United States Geological Survey Open-File Report 85-728.

Pemberton, S.G., Frey, R.W. and Bromley, R.G., 1988. The ichnotaxonomy of Conostichus and other plug-shaped ichnofossils. Canadian Jour. Earth Sciences 25, 866-892.

Penn, et al. Chapter 10, Principal features of hydrocarbon prospectivity of the Wessex- Channel Basin, UK, Volume 1 Petroleum Geology of Northwest Europe (J. Brooks and K.W. Glennie, eds.)

Phillips, W.J .. 1964. The structures in the Jurassic and Cretaceous rocks on the Dorset coast between White Nothe and Mupe Bay. Proc. Geol. Ass., 75,373-403.

Pickering, K.T., 1995, Are enigmatic sandy wave-like bedforms in Jurassic Bridport Sands, Dorset, due to edgewaves?: Journal of the Geological Society, London, v. 152, p. 481–485.

Plint A.G., 1983b, Facies, environments and sedimentary cycles in the Middle Eocene, Bracklesham Formation of the Hampshire Basin: evidence for global sea-level change?: Sedimentology, v. 30, p. 625–653.

Plint A.G., 1988, Global eustasy and the Eocene sequence in the Hampshire Basin, England: Basin Research, v. 1, p. 11–22.

Plint, A.G., 1983a, Liquefaction, fluidization and erosional structures associated with bituminous sands of the Bracklesham Formation (Middle Eocene) of Dorset, England: Sedimentology, v. 30, p. 525–535.

Pollard, J.E., Goldring, R., and Buck, S.G., 1993, Ichnofabrics containing Ophiomorpha: significance in shallow-water facies interpretations: Journal of the Geological Society of London, v. 150, p. 149-164.

Porter R.J., and Gallois, R.W., 2008, Identifying fluvio–lacustrine intervals in thick playa-lake successions: an integrated sedimentology and ichnology of arenaceous members in the mid–late Triassic Mercia Mudstone Group of south-west England, UK: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 270, p. 381–398.

Reid and Strahan, 1889. The Geology of the Isle of Wight. Mem. Geol. Surv. Of England and Wales, 2nd edition, 349 pp, and plates.

Reineck, H.E. and Singh, I.B., 1980. Depositional sedimentary environments- with reference to terrigenous clastics. 2nd eidtion, Springer-Verlag, Berlin, 594pp.

Ruffell, A.H., 1988. Palaeoecology and event stratigraphy of the Wealden - Lower Greensand transition in the Isle of Wight. Proc. Geol. Ass., 99(2), 133-40.

Scotchman, I.C., 1989, Diagenesis of the Kimmeridge Clay Formation, onshore UK: Journal of the Geological Society, London, v. 146, p. 285–303.

Seilacher, A., 1953a. Studien zur palichnologie. 1. Uber die methoden der palichnologie. Neues Jahrb. Geologie, Palaontologie, Abhandl., 96, 421-452, text-fig. 1-10, pl. 14

Seilacher, A., 1964a. Sedimentological classification and nomenclature of trace fossils. Sedimentology, 3, 253-256.

Seilacher, A., 1964b. Biogenic sedimentary structures. In: Approaches to Paleoecology, J. Imbrie and N.D. Newell (eds.), John Wiley and Sons, Inc. (New York), 296-316

Seilacher, A., 1967. Bathymetry of trace fossils. Marine Geology, 5, 413-428.

Sellwood, B.W., and Jenkyns, H.C., 1975, Basins and swells and the evolution of an epeiric sea: Journal of the Geological Society of London, v. 131, p. 373-388.

Selley, R.C. & Stoneley, R. 1987. Petroleum Habitat in South Dorset. In: Brooks, J. & Glennie, K. W. (eds) Petroleum Geology of North West Europe.Graham & Trotman, London, 139-148.

Selley, R. C. 1992. Petroleum seepages and impregnations in Great Britain. Marine and Petroleum Geology, 9, 226-244

Selwood, E. B., Edwards, R.A., Simpson, S., Chesher, J.A., Hamblin, R.J.O., Henson, M.R., Riddolls B.W., and Waters, R.A, 1984. Geology of the country around Newton Abbot. Memoir of the British Geological Survey, Sheet 339 (England and Wales), 1–212.

Simpson, M.I., 1985. The stratigraphy of the Atherfield Clay Formation (Lower Aptian, Lower Cretaceous) at the type and other localities in southern England. Proc. Geol. Ass., 96 (1), 23-45

Smith S.A., 1990, The sedimentology and accretionary styles of an ancient gravel-bed stream: the Budleigh Salterton Pebble Beds (Lower Triassic), southwest England: Sedimentary Geology, v. 67, p. 199–219.

Stamp L.D., 1921, On Cycles of Sedimentation in the Eocene Strata of the Anglo-Franco-Belgian Basin: Geological Magazine, v. 58, p. 194-200.

Stewart, D.J., 1978a. Ophiomorpha; a marine indicator? Proc. Geol. Ass., 89, 33-41

Stewart, D.J., 1978b. The sedimentology and palaeoenvironment of the Wealden Group of the Isle of Wight, southern England. PhD. Thesis (Unpub) Portsmouth Polytechnic.

Stewart, D.J., 1981a. A meander belt sandstone from the Lower Cretaceous Wealdon Group of Southern England. Sedimentology, 28, 1-20.

Stewart, D.J., 1981b. A field giude to the Wealden Group of the Hastings area and Isle of Wight. Chapter 3, in: Field Guides to Modern and Ancient Fluvial Systems in Britian and Spain, T. Elliot (ed.), International Fluvial Conference, Keele University, 1981.

Stewart, D.J., Ruffell, A, Wach, G. and Goldring, R. 1991. Lagoonal sedimentation and fluctuating salinities in the Vectis Formation (Wealden Group, Lower Cretaceous) of the Isle of Wight, southern England. Sedimentary Geology.

Stoneley, R, 1982. The structural development of the Wessex Basin. J. Geol. Soc. London, 139, 543-554.

Talbot MR, Holm K, Williams MAJ. 1994. Sedimentation in low gradient desert margin systems- a comparison of the late Triassic of northwest Somerset (England) and the late Quaternary of east-central Australia. In Rosen MR (ed.) Paleoclimate and Basin Evolution of Playa Systems. Geological Society of America, Boulder, Colorado: Special Paper 289, p.97–117.

Taylor, S.P., Sellwood, B.W., Gallois, R.W., and Chambers, M.H., 2001, A sequence stratigraphy of the Kimmeridgian and Bolonian stages (late Jurassic): Wessex-Weald Basin, southern England: Journal of the Geological Society, London, v. 158, p. 179–192.

Tyrrell, S., Haughton, P.D.W., Souders, A.K., Daly, J.S., and Shannon, P.M., 2012, Large-scale, linked drainage systems in the NW European Triassic: Insights from the Pb isotopic composition of detrital K-feldspar: Journal of the Geological Society, London, v. 169, p. 279–295.

Underhill, J.R. and Stoneley, R., 1998, Introduction to the development, evolution and petroleum geology of the Wessex Basin: Geological Society, London, Special Publications, v. 133, p. 1–18.

Underhill, J.R., and Partington, M.A., 1993, Jurassic thermal doming and deflation in the North Sea: implications of the sequence stratigraphic evidence. In: Parker, J.R. (Ed.), Petroleum Geology of Northwest Europe: Proceedings of the 4th Conference. Geological Society, London, Petroleum Geology Conference series January 1, 1993, v. 4, p. 337–345.

Wach, G.D. and Ruffell, A.H., 1991. The sedimentology and sequence stratigraphy of a Lower Cretaceous tide and storm-dominated clastic succession, Isle of Wight and S.E. England. Field Trip B-16, 31 August - 4 September, 1990, XIIIth Congress, International Association of Sedimentologists, Nottingham, England, 100pp

Waterhouse, H.K., 1999a, Regular terrestrially derived palynofacies cycles in irregular marine sedimentary cycles, Lower Lias, UK: Journal of the Geological Society, London, v. 156, p. 1113–1124.

Waterhouse, H.K., 1999b, Orbital forcing of palynofacies in the Jurassic of France and the United Kingdom: Geology, v. 27, p. 511–514.

Weedon, G.P., Coe, A.L., and Gallois, R.W., 2004, Cyclostratigraphy, orbital tuning and inferred productivity for the type Kimmeridge Clay (Late Jurassic), Southern England: Journal of the Geological Society, London, v. 161, p. 655–666.

Weedon, G.P., Jenkyns, H.C., Coe, A.L., and Hesselbo, S.P., 1999, Astronomical calibration of the Jurassic time scale from cyclostratigraphy in British mudrock formations: Philosophical Transactions of the Royal Society, London A, v. 357, p.1787–1813.

Whitaker, J.H. McD., 1973."Gutter casts", a new name for scour-and-fill structures: with examples from the Llandoverian of Ringerike and Malmoya, southern Norway. Norsk Geologisk Tidsskrift, 53, 403-417.

White, H.J.O., 1921. Geology of the Isle of White. Mem. Geol. Surv. Gt. Brit.,201pp.

Whittaker, A. 1985. Atlas of Onshore Sedimentary Basins in England and Wales. Blackie, Glasgow.

Whittaker, A 1986. Atlas of onshore sedimentary basins in England and Wales: Post-carboniferous tectonics and stratigraphy. Blackie, Glasgow & London.

Wignall, P.B., 1990, Benthic palaeoecology of the Late Jurassic Kimmeridge Clay of England: Special Papers in Palaeontology, v. 43, 74pp

Wignall, P.B., 2001, Sedimentology of the Triassic–Jurassic boundary beds in Pinhay Bay (Devon, SW England): Proceedings of the Geologists' Association, v. 112, p. 349–360.

Williams, C.J., Hesselbo, S.P., Jenkyns, H.C., and Morgans-Bell, H.S., 2001, Quartz silt in mudrocks as a key to sequence stratigraphy (Kimmeridge Clay Formation, Late Jurassic, Wessex Basin, UK): Terra Nova, v. 13, p. 449–455.

Wimbledon W. A., Allen P., Fleet A. J., 1996, Penecontemporaneous oil-seep in the Wealden (early Cretaceous) at Mupe Bay, Dorset, U.K.: Sedimentary Geology, v. 102, p. 213–220.

Published by PIPCo RSG Ltd.

ISBN: 978-0-9573517-1-4

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