Black Country Geological Society Field Excursion Dorset

Friday 13th to Monday 16th September 2019

(Led by the Dorset Geologists' Association Group)

Organised by: Allan Holiday (DGAG) & Andrew Harrison (BCGS)

Leader Saturday: Richard Edmonds

Leader Sunday: John Scott

Monday: Steve Etches

Field notes by : Ray Pratt

Sunday: Lulworth Cove & Durdle Door

First stop: Meet at 9.30 at Lulworth Cove car park (nearest post code: BH20 5RQ or GR: SY 82100 80100).

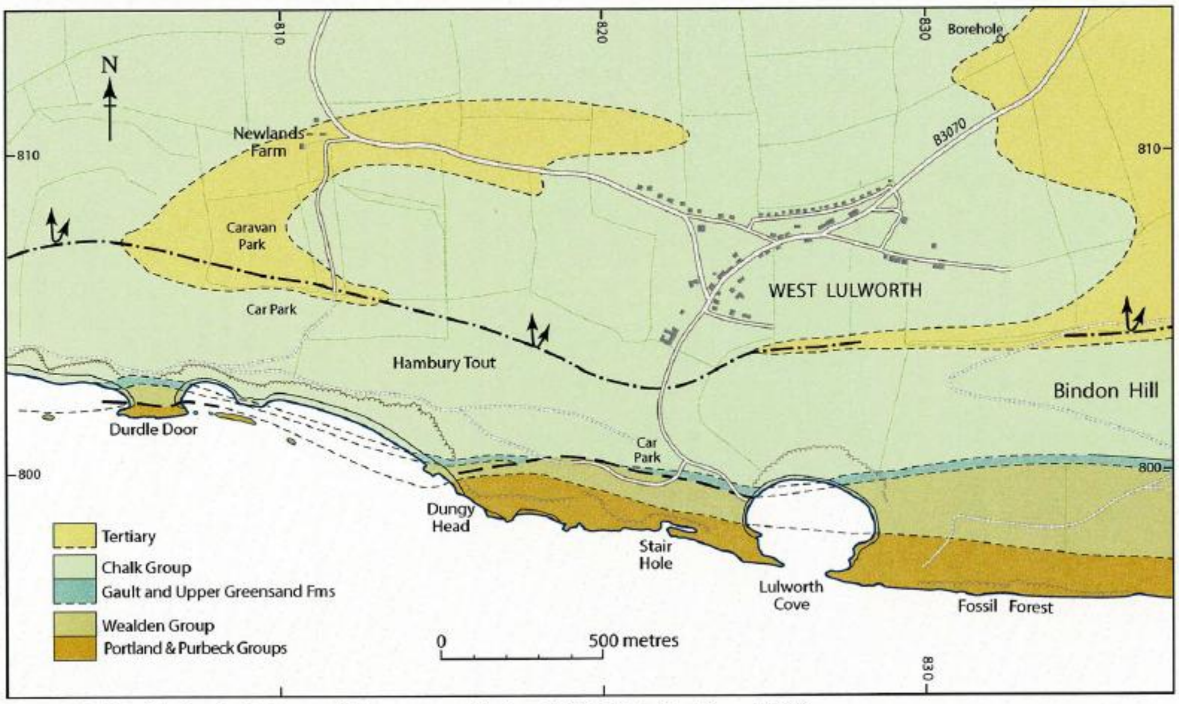
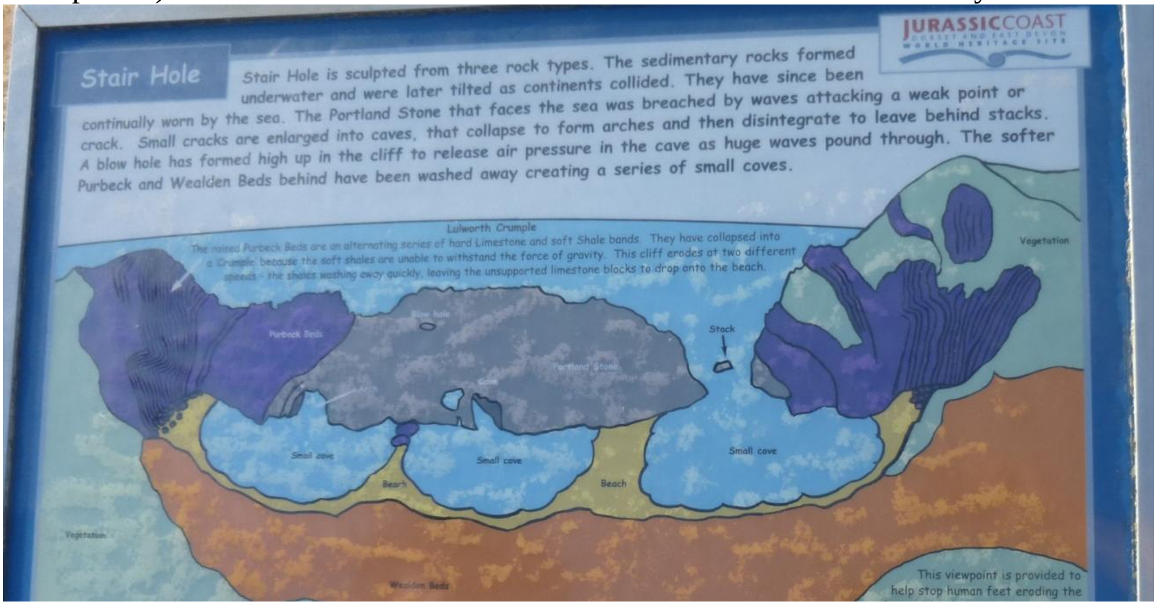


Figure 57. Simplified geological map of the area around Lulworth. Modified after House (1989).

- Chalk. Pure, soft limestone. Dorset chalk highly impacted by tectonic movements and is quite hard. Not a good building stone.
- Greensand: can be a reasonably good building stone, cemented by calcite, weathers well
- Wealden beds soft sands with ironstones

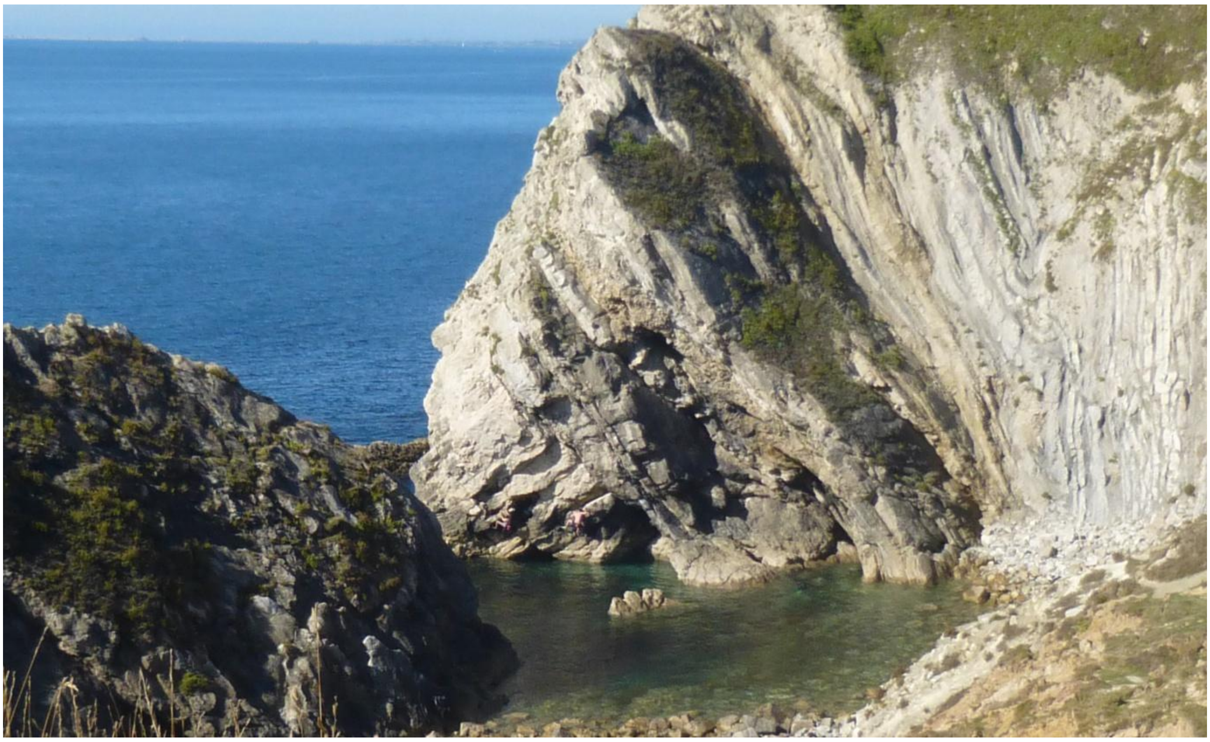
Stair Hole

Beds facing the sea are Portland beds (massive, sallow marine, oolitic in parts of Portland but here is just bioclastic), then towards land are the Purbeck beds of shales, marls, evaporites (now replaced). Where we stand is the Wealden - unconsolidated sand and clays.




Stair Hole (viewed from west side)

The traditional mechanism for the formation of these holes and bays , as outlined on the visitor panel, doesn't really take into account the resistance of the Purbeck beds. It has been suggested that this was once a quarry of the Purbeck Limestone (not shown in any textbooks). Stone could be easily moved out by boat. The village of Lulworth made from Purbeck limestone.


Stair Hole formations (viewed from east side)

Folding done during the Alpine orogeny, Pyrenean circa 44mmya (north south compression).

As rocks starting to fold the rocks may not have been fully cemented so there was the possibility that we could also be seeing sliding events. However, the folds require some form of plasticity which indicates deformation at depth where sliding would not occur. There could be some accommodation movement along shale bands. John suggests only buried 500m. (I think he could be wrong on this).

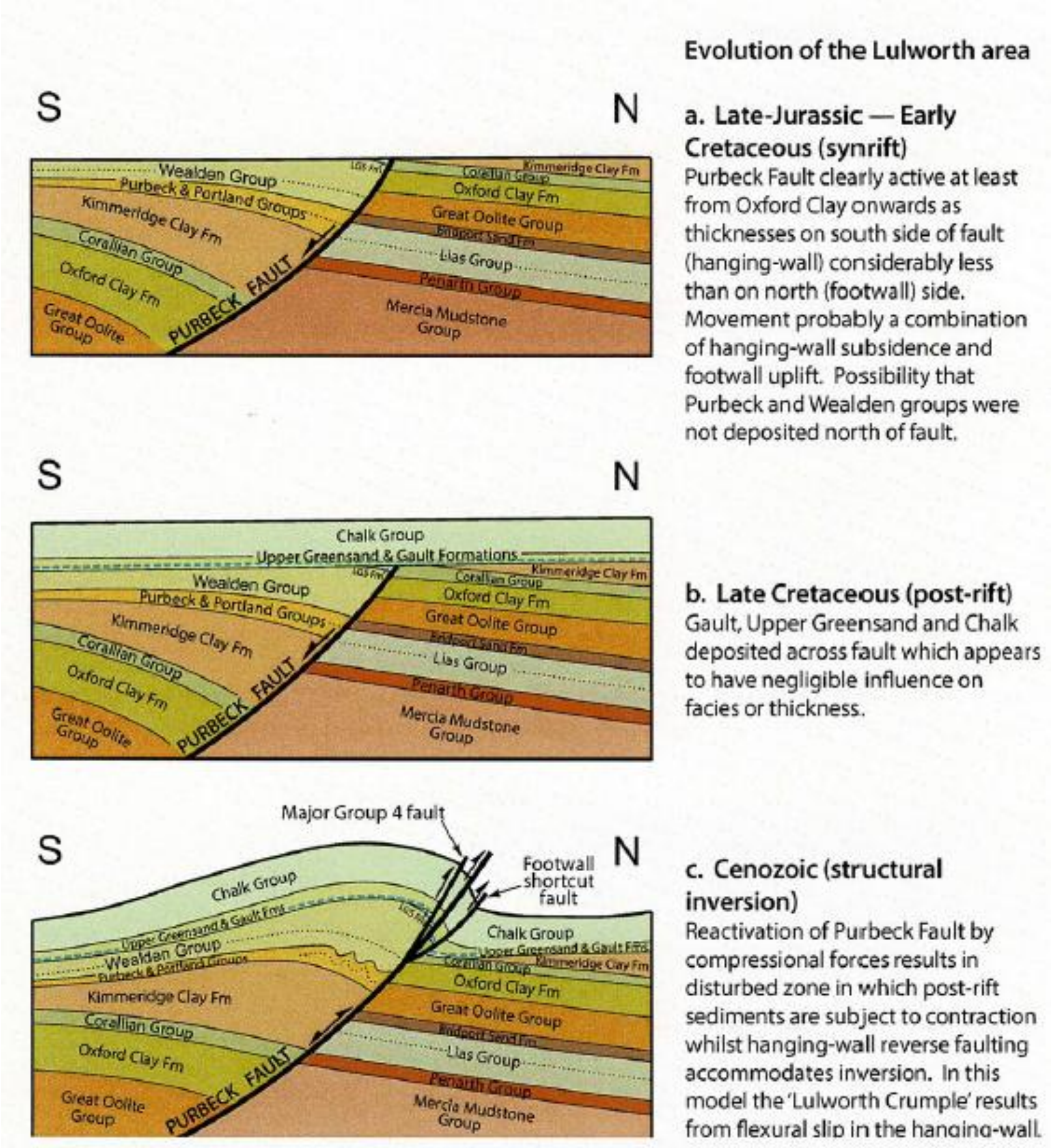


Figure 65. Diagrams to illustrate the possible evolution of the structures in the Lulworth area. Modified after Underhill and Paterson (1998).

The Purbeck environment was lagoonal, restricted circulation with the western side just the other side of Weymouth and the eastern edge in Germany (some lagoon). Initially was a closed lagoon without marine incursions. Basal beds contained evaporites (today find pseudomorph's). A bit higher we have a grey bed called the cinder bed which is full of oysters, which represents the first marine incursion into the lagoon. Following this we see cyclic marine incursions reverting back to a freshwater environment before another incursion.

The top bed is a limestone with (vivi paris ?) a freshwater gastropod. Then get the fluviatile Wealden strata. Folding commenced during the late Cimmerian period (200-150mmya) and Alpine phases creating the 3 major anticlines (Marshwood, Weymouth and Purbeck). Movement was still ongoing during the Wealden before deposition of the Gault Clay. There was lots of erosion going on with Jurassic fossils being redeposited in the Purbeck beds (Worbarrow Tout).

Variscan orogeny gave underlying EW structures with deep seated faults. Lots or erosion during the Permian and Triassic. Breaking up of Pangea caused space for further deposition in basins in the area. Cimmerian movement during early Cretaceous. More directed structures coming up . During Alpine orogeny existing normal faults became reverse faults. The Purbeck fault, was originally a normal fault and is now a reverse fault. Explains variability in thickness across the fault of the Wealden

Major work on faults in the area undertaken by Arkell in 1947, which is still used to this day

Lulworth Cove.

Formed at the mouth of a river valley. Also follow the line of a possible fault

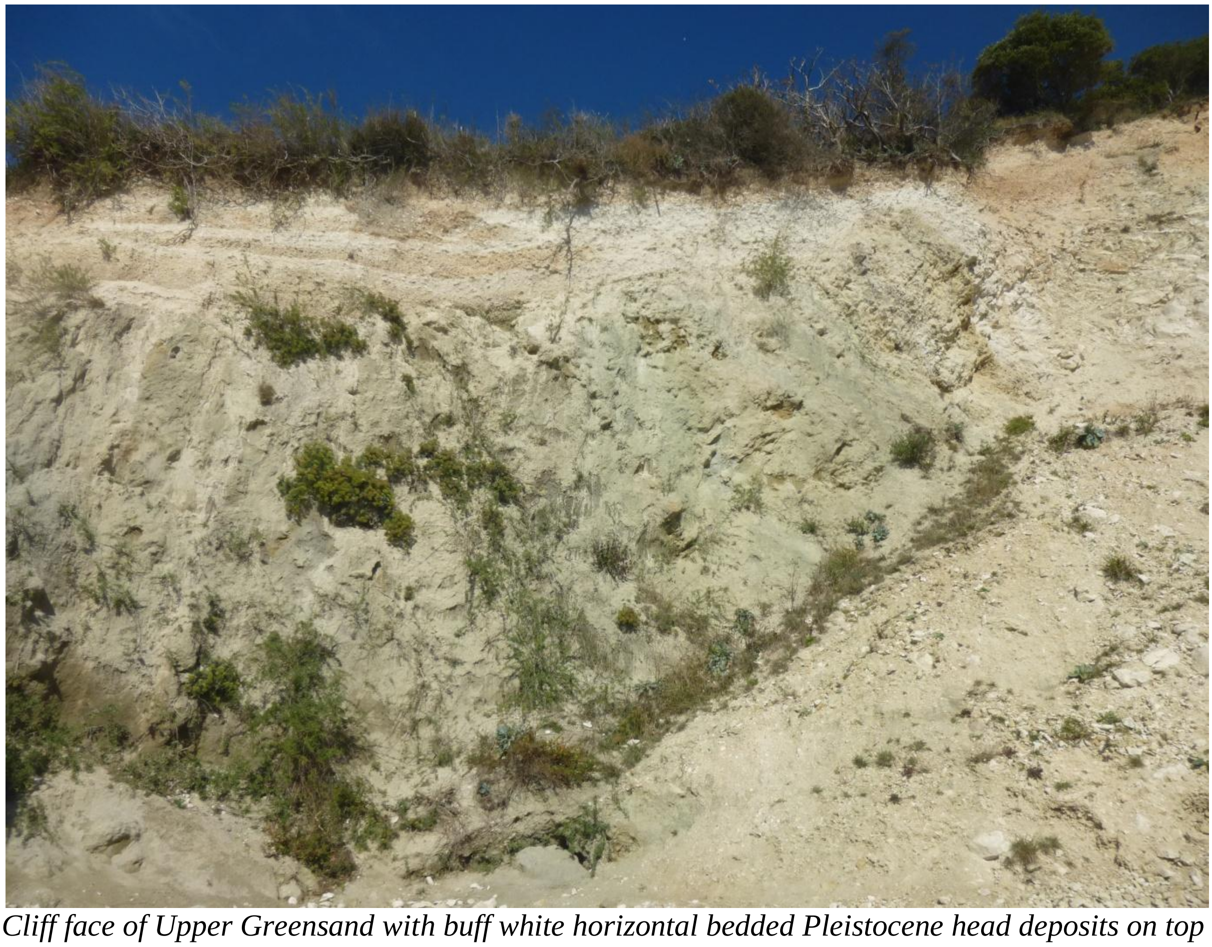
Lulworth cove looking east from the west side

Walk down into Lulworth cove and walk to the western point of the bay, Look at the UNIL beds named after the bivalve contained within. Purbeck marble (with the Vivi Paris Gastropod) lies above it..

	The UNIL beds is more of an algal limestone. Structures within are "higgledy piggledy" as a result of seismic movement whilst still unconsolidated.. Known as a seismite

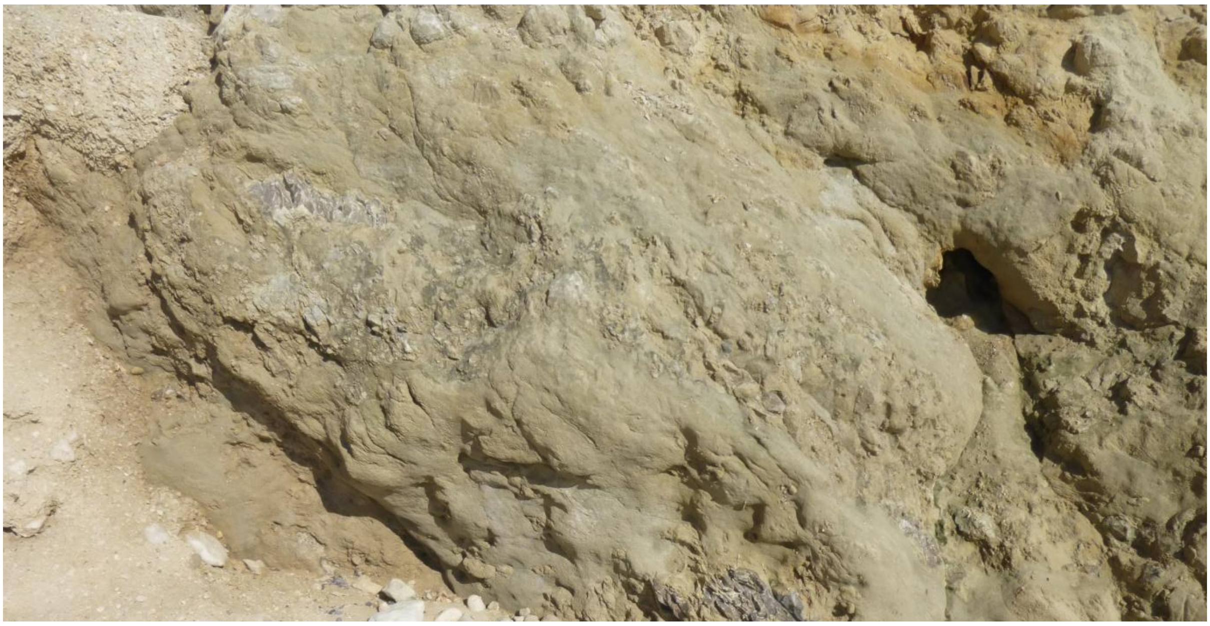
	Unil bed bivalves

Upper Greensand Lulworth Cove



Cliff face of Upper Greensand with buff white horizontal bedded Pleistocene head deposits on top

The Purbeck fault is seen in this face. The top of the Upper Greensand merges into the chalk,. The boundary is an unconformity with a basal conglomerate however the greensand conditions were still prevalent during early chalk deposition resulting in chlorite being deposited within the chalk.



Basal Beds - Conglomeratic chloritic chalk. It is highly burrowed giving it a nodular appearance. This chalk contains chert.

Above the chloritic chalk is the West Melbury chalk and zig zag chalk, not present in Lulorth. The diachronous equivalent is the phosphatic conglomerate, the chalk basement bed. and above this is

The Dorset swell occurred during the time of chalk deposition resulting in condensed deposits here, with some missing time (disconformities).

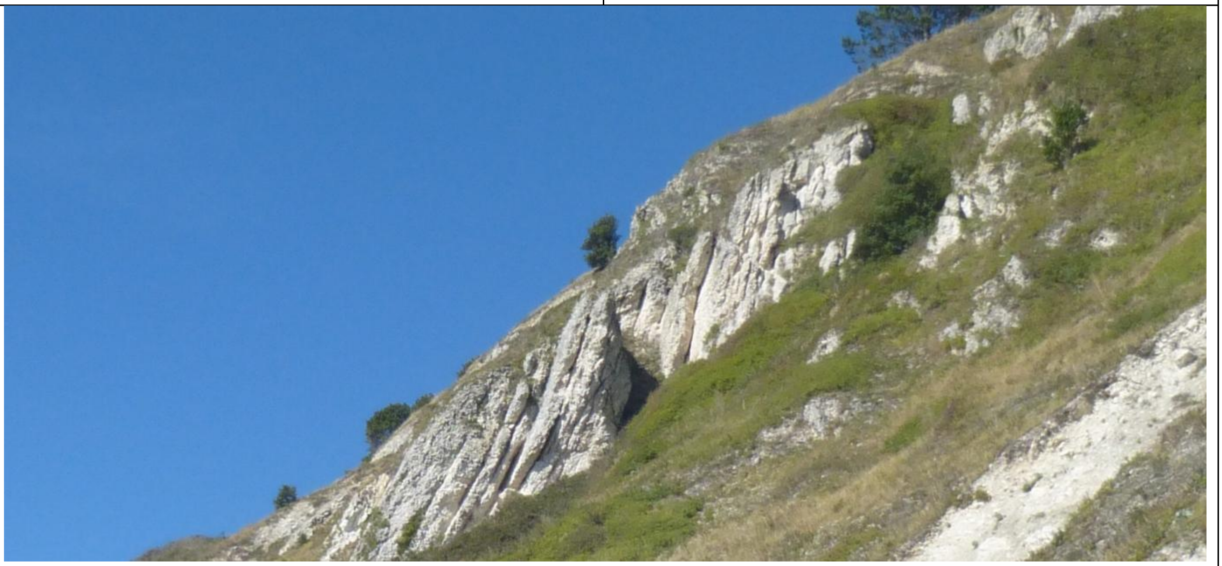
Disconformity between Chalk and greensand

	*The white rock is chalk proper and the grey coloured material are burrows*

This cliff face is a major fault. Slickensides are very visible

	*Low angle thrust fault in chalk cliff face*



The chalk is faulted in many directions. The cliff face above showing vertical bedding is actually showing overturned beds

Arkell 1947 identified 12 sets of faults.. Phillips, 1968, found another set. Bevan 1985 reduced it to 3 conjugate sets. One of the sets of faults belong to the Purbeck faulting period, but the thrusts are probably Alpine. Some faults have been reactivated from normal to reverse. The chalks have been tectonically hardened with a porosity of just 9%.

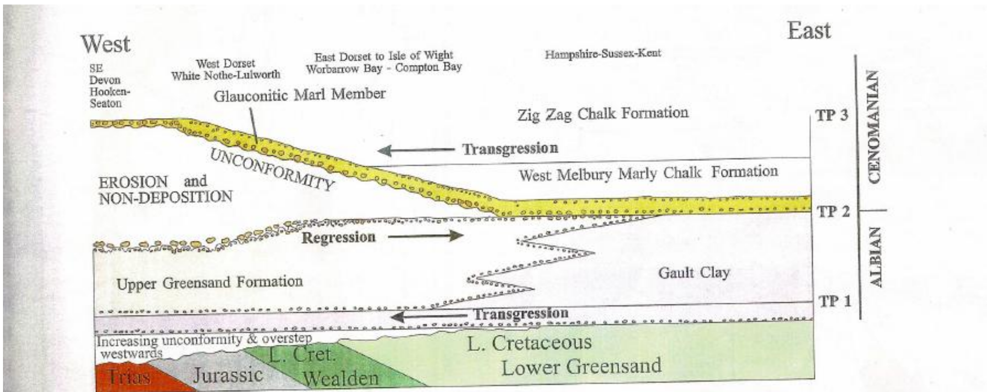


Fig. 7. Schematic illustration of the unconformities and disconformities at the base of the Gault and the base of the Chalk traced westwards into Dorset and southeast Devon. Upper Greensand replaces most of the Gault Clay on the Wessex Shelf. The Glauconitic Marl at the base of the Chalk is diachronous. TP1, 2 3 are conceptual Time Planes. Modified from Mortimore, 2014.

Upper Greensand (These beds crop out on the east side of the cove)

Upper Greensand. Deposited following the Gault clay which marks a major marine transgression

Junction between the Greensand and the Chalk with a large landslide sliding on the Gault clay and covers the lower greensand

Wealden beds with landslip caused by overlying Gault lubricity

Wealden beds. Liesegang rings can be seen in some parts of this deposit.


Iron rich waters permeating through the Wealden rocks precipitate out to form this conglomerate (recent). It captures pebbles laid down when the beach was higher.


Coarse sand with a liesegang ring

Moving around to the eastern cliffs of the cove we see an extensive vein of Beef Calcite

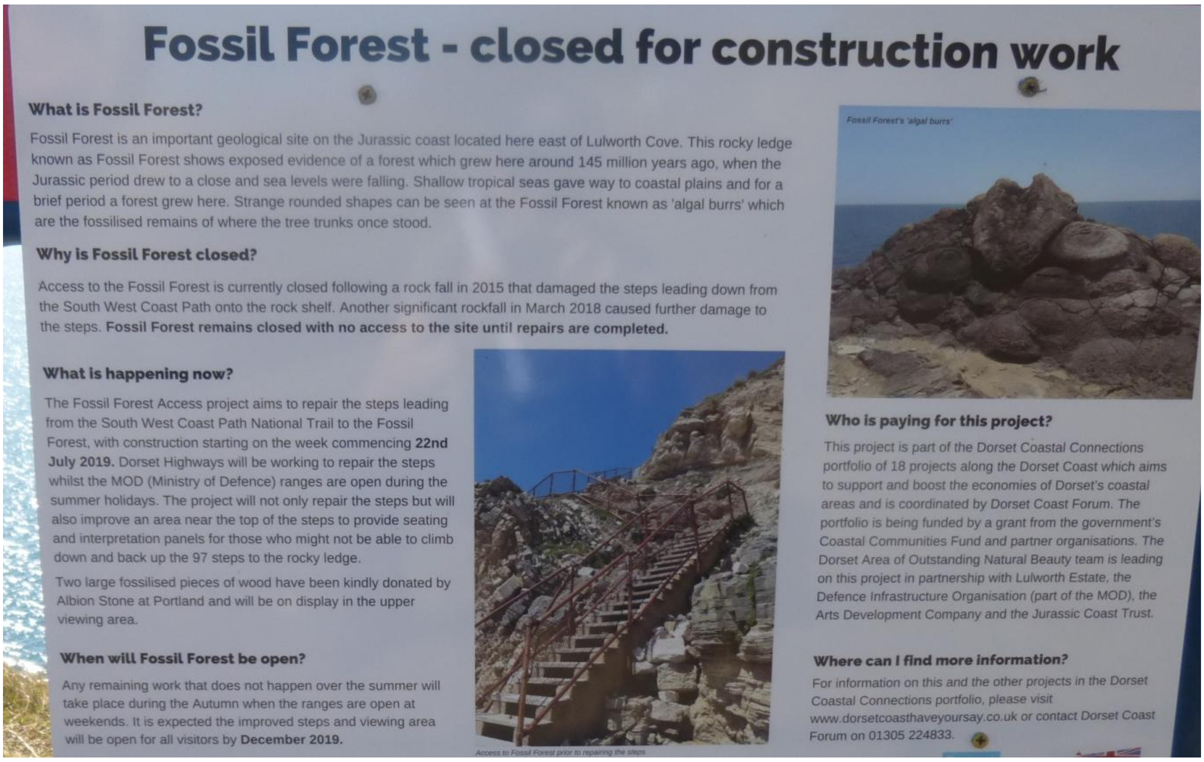
	*Blocks of cliff on foreshore: Microbial limestone (grey) and interbedded marl?*
	*Blocks on foreshore:* *Seismite beds ?*

Eastern cliffs East Point of Lulworth cove. Lower section contains rare examples of extensive bedding plane exposures providing valuable evidence for plan-view shapes of mounds; their sizes and spacing.

Here, the upper surface of the Hard Cap microbial mounds are partially exhumed on the bedding surface dipping to the foreground. The upper cliff comprises the Broken Beds, currently widely regarded as an evaporite collapse breccia.

Purbeck Pellitoidal or Unil beds ? on a faintly rippled bedding plane. Seen close to the top of the eastern side of Lulworth Cove

Fossil Forest



Stomatolites

During growth of trees the area was actively faulting. Relay ramps were in existence leading to variable thickness of accumulations. The faulting led to a drop in the land surface allowing lagoonal water to drown the trees. Algal growth around the base of the trees. Oval shaped rings are where trees had fallen and effected the growth of the algal mats. All material replaced by silica.

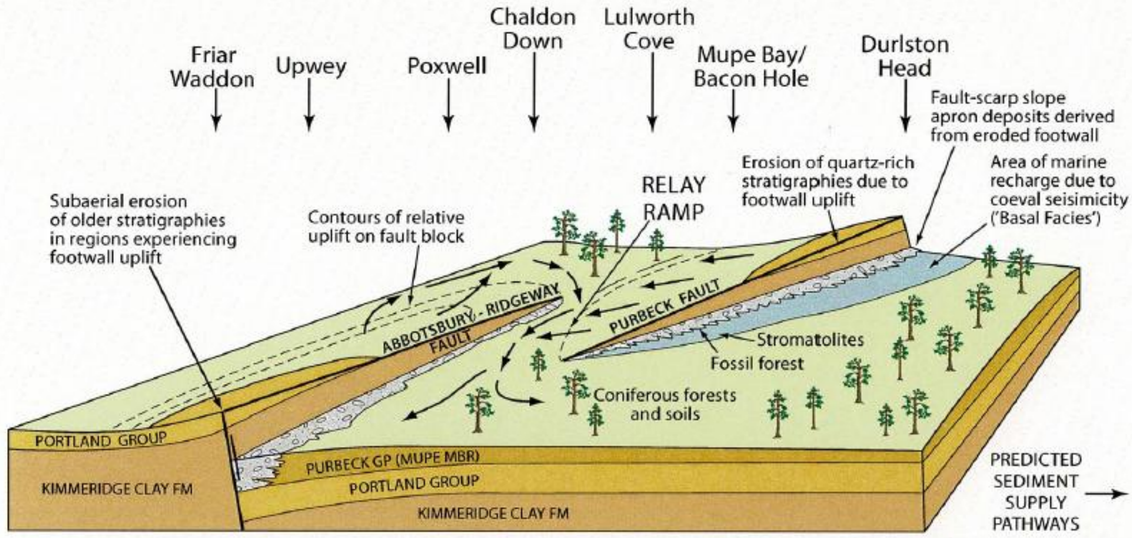
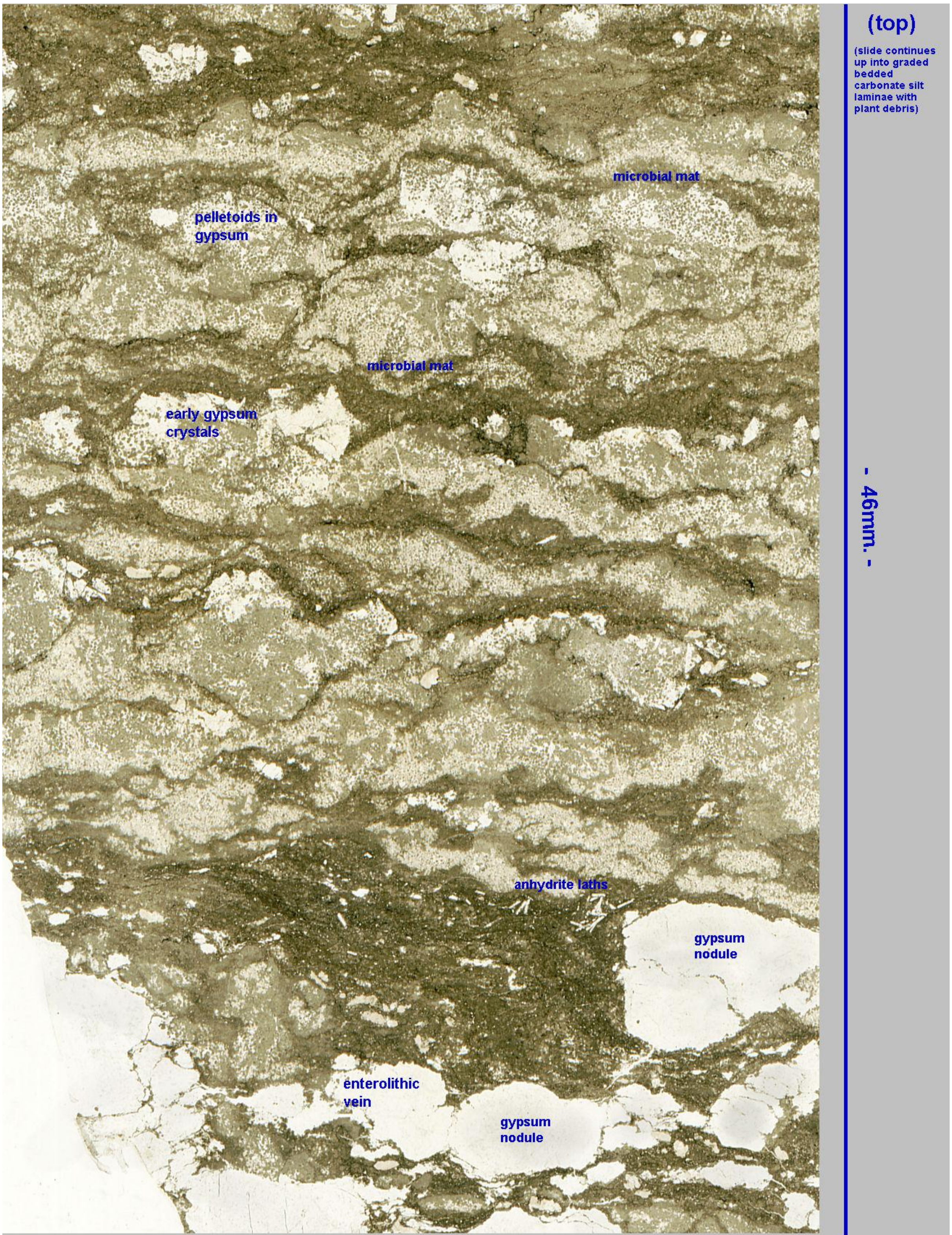


Figure 6. Diagrammatic representation of basal Purbeck Group (Mupe Member) deposition across eastern Dorset, showing relay ramp between Abbotsbury-Ridgeway and Purbeck faults. Modified after Underhill (2002).

This cliff below is made of the broken beds through salt dissolution leaving salt pseudomorph's and collapsed beds. (Collapse breccia). Unable to view due to path closure. Some beds made up of pellets



THIN-SECTION, PURBECK EVAPORITES, ABOVE No. 1 SEAM, MOUNTFIELD MINE, SUSSEX.
Light-coloured material is gypsum and celestite (with lutecite). Sabkha nodules and incipient enterolithic veins are present in the lower part. Above that is microbial mat, irregular, with numerous small pelletoids of carbonate in the intervening sulphate layers (originally gypsum). A few secondary anhydrite laths are visible. This rock is now late diagenetic and the gypsum present now is secondary (post anhydrite, post primary gypsum). Ian West (c) 2011.

(Notice the early upward disruption of some of the mats by poikilotopic, sublenticular gypsum crystals. In the lower part of the slide there has been quite major disruption by early growth of gypsum nodules and small, incipient enterolithic veins. It has common features of carbonate pelletoid sabkhas.)

(Thin-section no. LP 371, part only shown)

Durdle Door car park (nearest post code: BH20 5PU or GR: SY 81130, 80550).

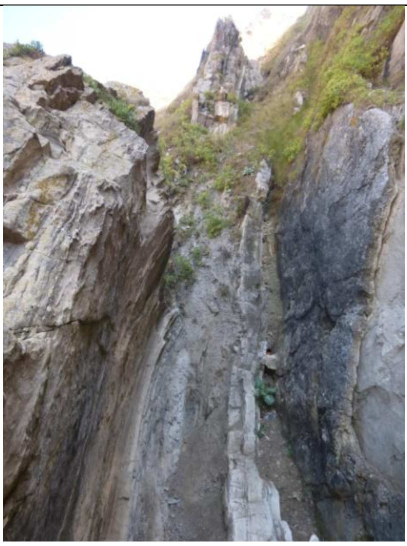
Man o War cove on left and Durdle Door on right. Wealden here, (beds we are stood on), are much thinner than at Lulworth Cove

Man O War cove. Reefs are Portland limestone. Standing on the chalk. This is the closest the Portland and chalk come together along the entire coast (only a few metres). In front of us is the Purbeck bed, similar but thinner than at Lulworth Cove, Wealden, Greensand, Chalk.

Tectonics has squeezed the Wealden beds out as it was not consolidated. The chalk is almost vertical

View westwards from Durdle Door

Durdle Door. Same structure as Stair Hole in Lulworth Cove

	*Photos of the broken beds of the Purbeck (Lulworth Formation). The Purbeck is split into two formations, the Lulworth and the Durleston Formations. Unable to find the Cinder beds which include oysters and represent the first incursion of marine water into the lagoon. Lower Greensand not present.* *Beds can be seen with ripple marks, but still lagoonal. Ripple marks with current flowing both ways are symmetrical e.g. tidal. Asymmetrical indicate a unidirectional flow e.g. a river.*

Nodularity a function of burrowing. Lot of chert from sponges

	
Plenus marl. Top of Plenus Marl is the base of the White Chalk Group	*Bedding is vertical (and overturned). The Plenus Marl, to the left of the prominent whit chalk, is sheared out at the top*

Row of caves line the thrust plane

Two thrust planes join. Everything here is totally crushed to clay grade particles

Fault face

Flints highlight vertical beds. Flints become crushed in fault zones.

Vertical beds & flint bands cut by a thrust fault. Head deposit in the upper 2 m

Spectacular folding highlighted by the cherts

Large accumulation of Pleistocene head on top of the chalk. Valleys would have been created with the permafrost sealing the chalk then the summer melt washes the sediment into the valleys below, enlarging them with the abrasive sediment load.

Spectacular fault face (conjugate faults as there are several)

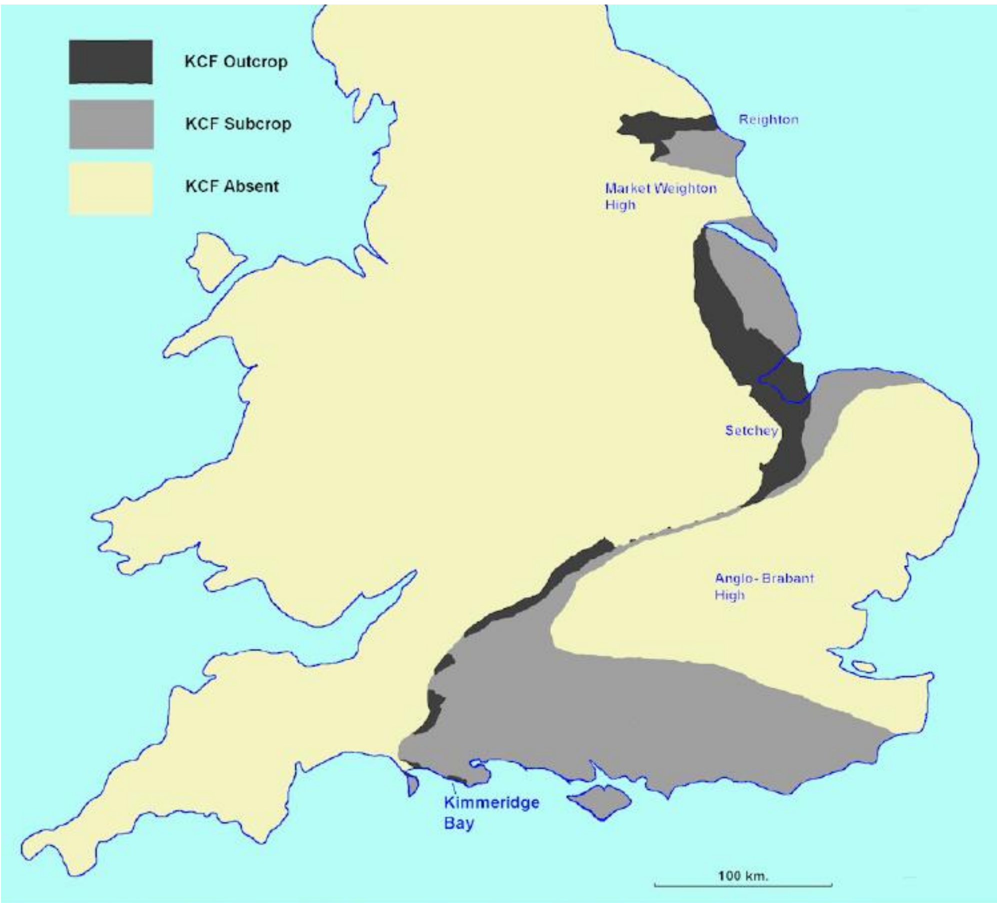
Sunday PM Remainder of the Group - Durdle Door in background

Monday AM: The Etches Collection Museum - Kimmeridge

(see book)

Monday PM: Kimmeridge Bay

View of Kimmeridge Bay looking west (from the oil facility).



DISTRIBUTION OF THE OUTCROP AND SUBCROP OF THE KIMMERIDGE CLAY IN ENGLAND, REDRAWN AFTER GALLOIS, 2012.
This is a simplified map and the British Geological Survey, Bedrock Geology, UK South, 1:625,000 should be consulted for outcrop details.
See particularly: Gallois, R. 2012. The Norfolk oil shale, 1916-1921. Proceedings of the Geologists' Association, vol. 123, pp. 64-73.
Ian West 2013.

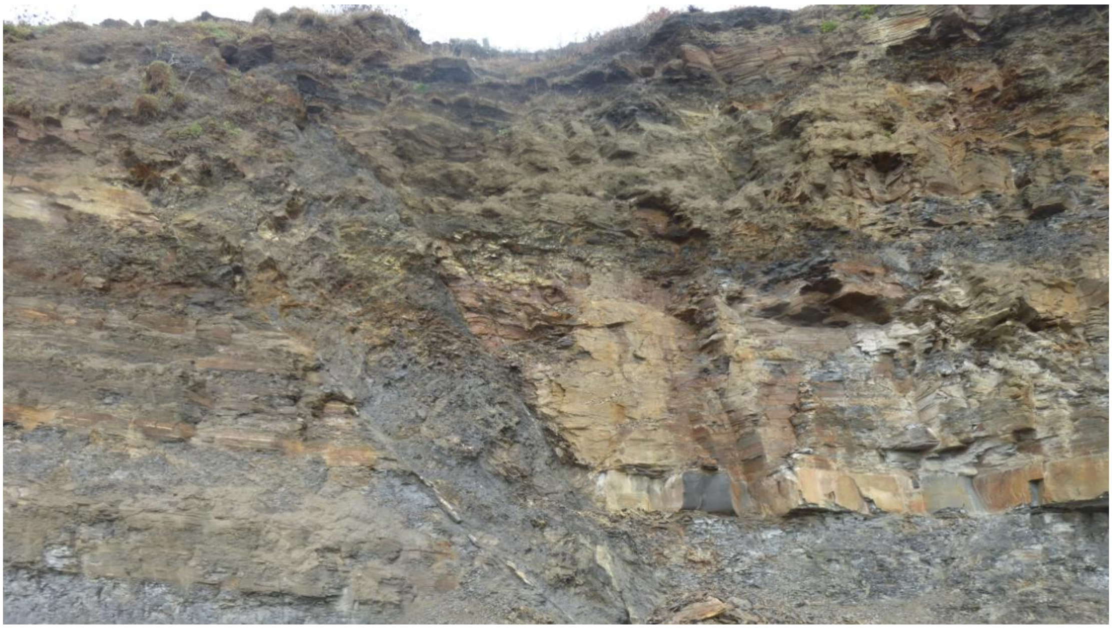
The part of the Kimmeridge Clay exposed in the bay shows cyclic sedimentation, first described by Downie (1955). The idealized cycle is:

D. coccolith limestone
   this may be laminated with alternating dark sapropelic and pale coccolith laminae or homogenised by bioturbation
C. oil shale
   up to 70% organic matter; the thickest is the Blackstone
B. bituminous clay
   clays with 10–30% organic matter
A. clay
   clays with up to 10% organic matter. Frequently shelly with abundant benthos

The cycles are often incomplete in this part of the succession and belong to the Autissiodorensis Zone and the top of the underlying Eudoxus Zone. Most frequently around Kimmeridge Bay the repetition is ABAB, with member C of the cycle appearing less frequently (Fig. 73). The stone bands around Kimmeridge Bay are not coccolith limestones, but were secondarily formed while buried in the methanogenic zone and are dolomitic (Irwin, 1979; Scotchman, 1989); they are thus laterally impersistent, whereas the coccolith limestones are remarkably persistent laterally.

The origin of the cycles has been explained by Milankovitch cyclicity. This was first suggested by Dunn (1974). The most recent analysis by Weedon *et al.* (2004) ascribed the larger cycles, of the range 1·87–4·05 m wavelengths, to orbital obliquity (*c.* 40,000-year cycle) and the smaller cycles, of about half this wavelength, to precession (21,000-year cycle). They recognised 95 longer wavelength cycles for the Kimmeridgian Stage (Lower Kimmeridge Clay) and 103 for the Bolonian Stage (Upper Kimmeridge Clay), from this they calculated that the Kimmeridgian lasted 3·6 Ma and the Bolonian 3·9 Ma.

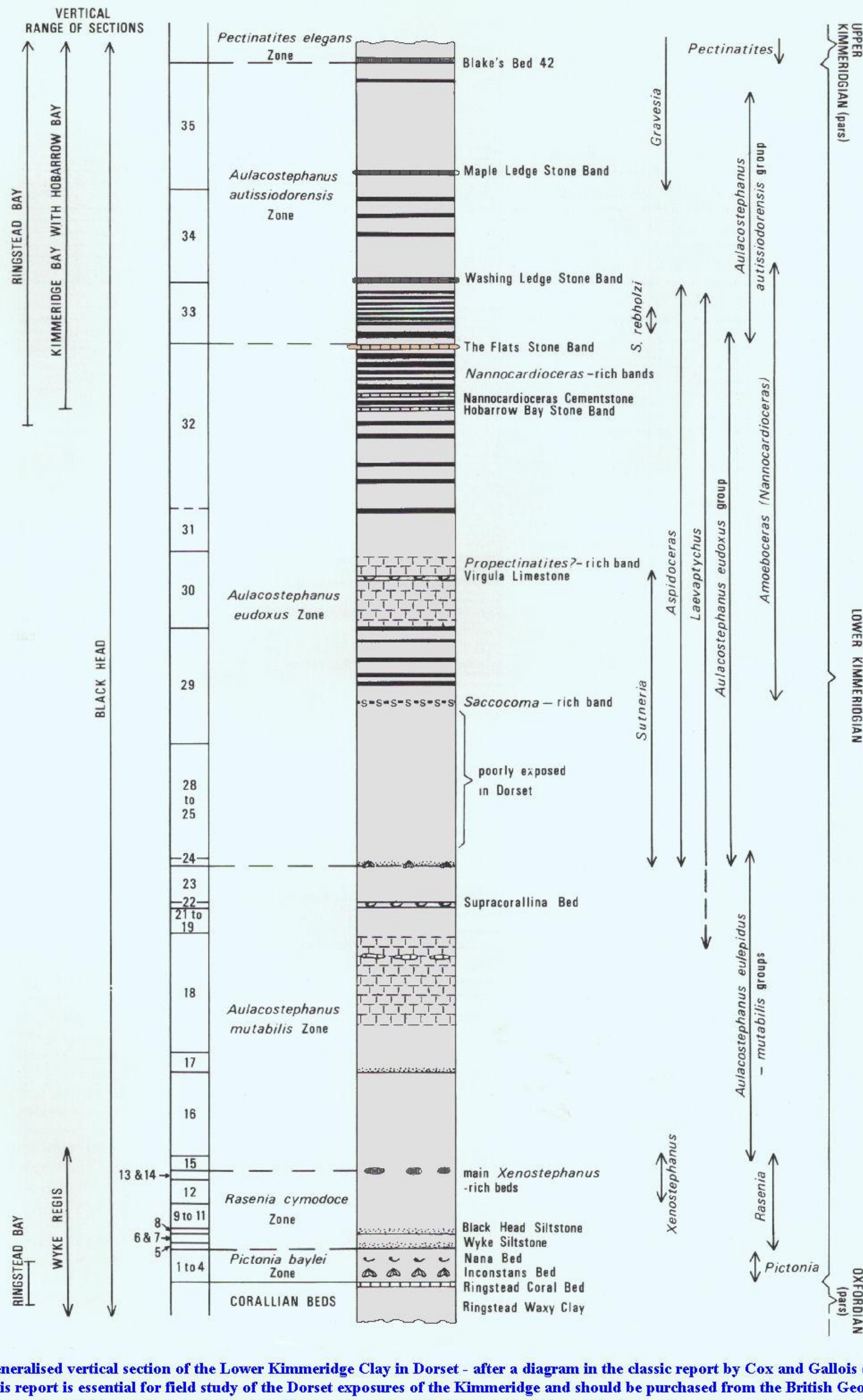
Cliffs on east side of Kimmeridge Bay



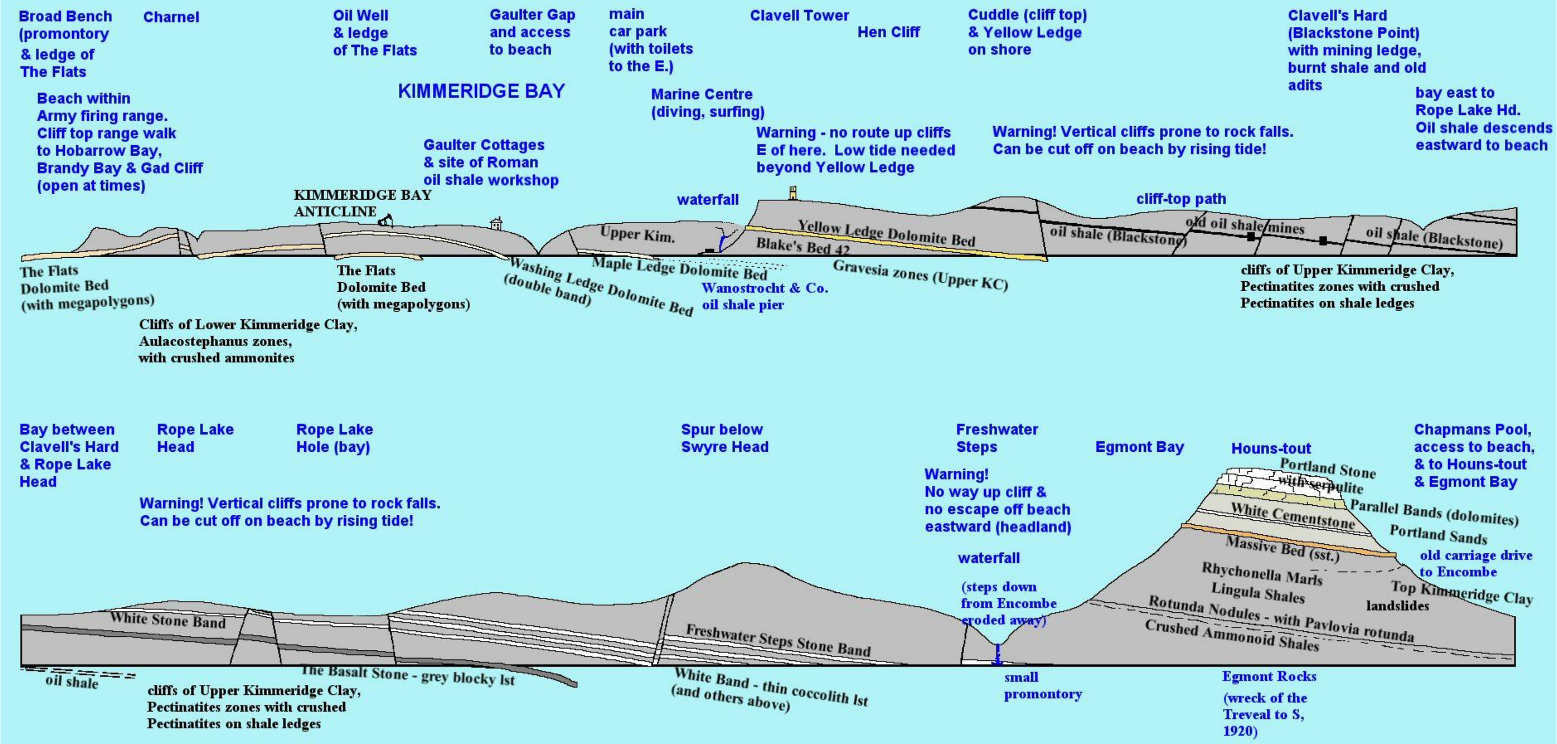
A fault zone is clearly visible in this cliff face

There has also been considerable debate about the depositional conditions of the Kimmeridge Clay. Most models, following Tyson *et al*. (1979), require a stratified water column, and these authors suggested considerable deepening of the sea. However, the water cannot have been much deeper than during the preceding Oxfordian Stage as palaeogeographical reconstructions show only minor trangression onto the surrounding land (Cope *et al*., 1992, maps J8 and J9), negating the deepening envisaged by Tyson *et al*. (1979). Sælen *et al*. (2000) suggested that in a stratified water column, the bottom waters became nutrient rich relative to the upper waters, a condition favourable for the planktonic microflora of dinoflagellates, cyanobacteria and bacterioplankton. Strong winds mixed the waters allowing nutrients to escape upwards, producing surface dinoflagellate blooms and, if the conditions persisted, coccolith blooms. Such blooms caused oxygen depletion through decay and instead of being restricted to deeper waters, anoxia rose through the water column to depths perhaps as shallow as 10 m. These changes allowed the phytoplankton group Chlorobiaceae to bloom; this is particularly significant because this group comprises phototrophic oxidising bacteria that develop during photic zone anoxia. In such blooms their biomass can dominate the phytoplankton and they appear to be closely associated with the genesis of oil shales as their typical biochemical markers occur in the Kimmeridge oil shales. Further wind-induced mixing of the water column eliminated the Chlorobiaceaea and the abundance of nutrients produced a normal food chain, followed by algal blooms and then back to conditions favouring the Chlorobiaceae. Wignall (1989) suggested that periodic storms introduced oxygen to the lower parts of the water column.

The fauna is crushed to varying degrees. Bivalves are common in the clay (A. of the sedimentary cycle); their palaeoecology was studied by Wignall (1990). The most frequent ammonites belong to the genus *Aulacostephanus*, which has a ventral smooth band. The microconchs have a pair of lateral lappets, while the macroconchs have plain peristomes. Other ammonites include the spiny *Aspidoceras* and its microconch *Sutneria*; both have calcitic aptychi (probably paired lower jaws) and these also occur. At certain horizons perisphinctid ammonites that are ancestral to the Bolonian genus *Pectinatites* occur. Other ammonites include *Nannocardioceras* (the last of the cardioceratids) that abounds at certain levels, whilst rarer forms include *Pseudogravesia* (Enay *et al*., 2014).

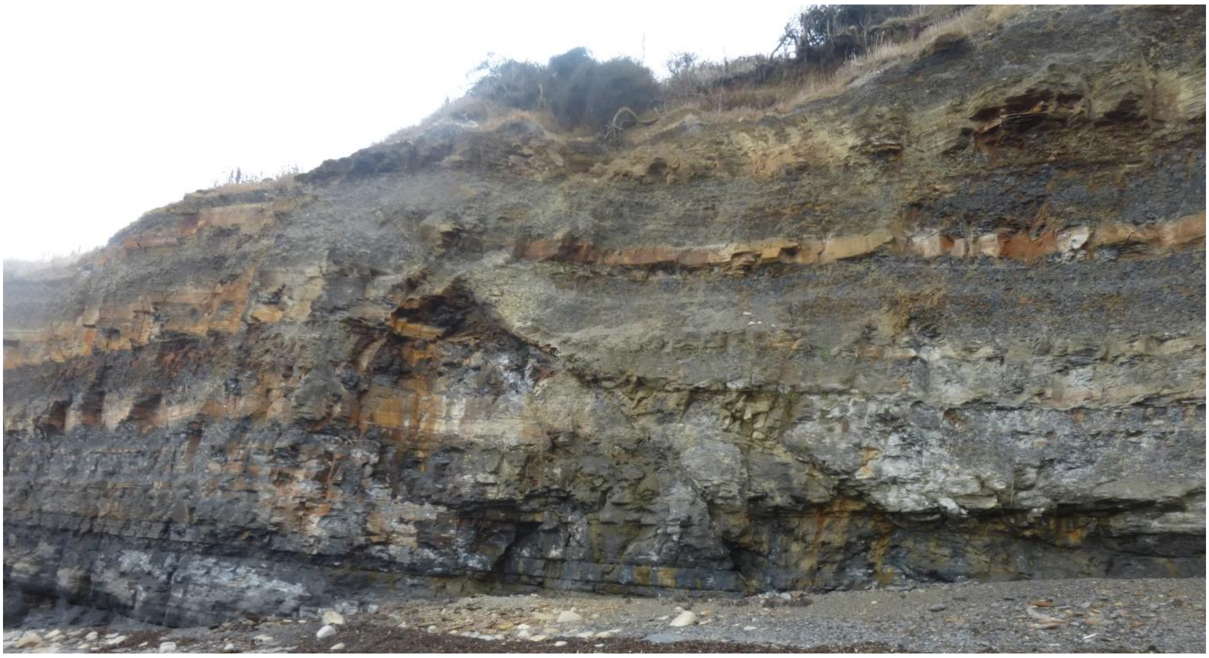


Generalised vertical section of the Lower Kimmeridge Clay in Dorset - after a diagram in the classic report by Cox and Gallois (1981). This report is essential for field study of the Dorset exposures of the Kimmeridge and should be purchased from the British Geological Survey. Cox, B.M. and Gallois, R.W. 1981. The Stratigraphy of the Kimmeridge Clay of the Dorset Type Area and its Correlation with some other Kimmeridgian sequences. Institute of Geological Sciences, Report 80/4. 44pp. (Ian West, 2009).



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

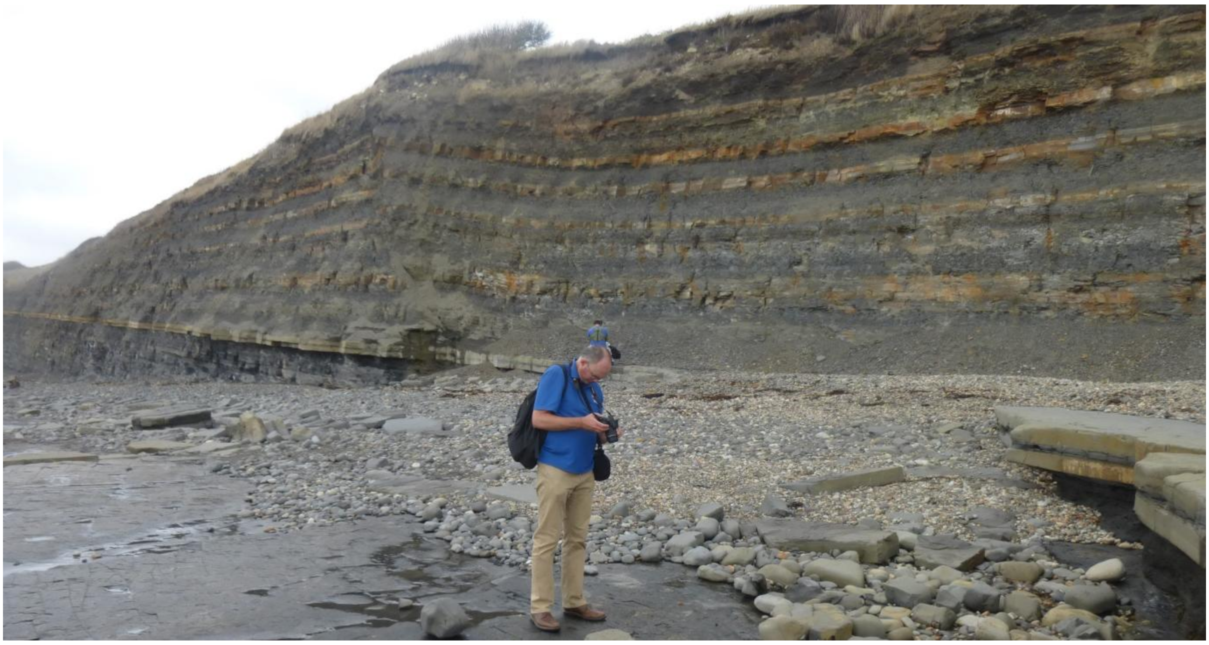
East side of the bay. The black shale overlying Maple Ledge stone band is the Kimmeridge oil shale (cycle C).



Stink Corner Fault, a normal fault in cliffs of the east side of Kimmeridge bay

STINK CORNER FAULT, THE EASTERMOST FAULT IN THE CLIFFS WITHIN KIMMERIDGE BAY, DORSET, - WITH A DAMAGE ZONE.
This occurs in the Mapple Ledge Mudstone (see Gallois, 2012) of the Aulacostephanus autissiodorensis Zone, near the top of the Lower Kimmeridge Clay. The position of the fault in the cliff is about 100m northwest of Stink Corner (rotting seaweed), the easternmost corner of Kimmeridge Bay. The downthrow is to the east (right) and is small but varies along the outcrop of the fault. Notice particularly the development of a damage zone in the bituminous beds (lower) but not in the calcareous mudstone (above). (Relevant to fracking). Ian West © 2014.


On the west side of the bay by Washing Ledge with its oil shale patrting, lies below the Autissiodorensis Zone, showing the ABAB type cyclicity developed there. Light brown Head deposit at top.


Brown bands of the hard, finely laminated bituminous shale and the grey material is blocky mudstones with less organic matter but with some carbonate content

Flats Stone Band. Conjugate fracture patterns are seen in these dolomitic stone bands.

The stone bands that break up the Lower Kimmeridge Clay succession ,(in descending order, The Maple Ledge, The Washing Ledge and The Flats Stone Band), are all secondary dolomitic stone bands. Some show interesting compressional structures. Above photo showing the slickensided surface of a thrust plane

Flats Stone Band showing compressional features. This small thrust is part of a megapolygon. The "breaking wave" type front of the thrust is heavily jointed.

Students from Southampton University make detailed maps of the megapolygons at Kimmeridge Bay and undertake structural geology studies both on these and on the joint systems. *Photograph courtesy of Dr. Jim Andrews (c) 2006.*

Aerial view of Flats Stone Band showing thrusts and joint patterns

The cliff-top nodding donkey marks the site of the oil well that produces oil from a Cornbrash reservoir that has a Lias Group source (Fig. 7). The Cornbrash was encountered at a depth of 550 m on the summit of the Broad Bench anticline. The drill hole went lower, but the drill string was lost in the upper part of the Bridport Sand at 670 m. Initially the oil was sufficiently pressurized to flow to the surface, but for some decades now has required pumping; the present yield is about 65 barrels per day. There is a simplified geological section displayed on the perimeter fencing.

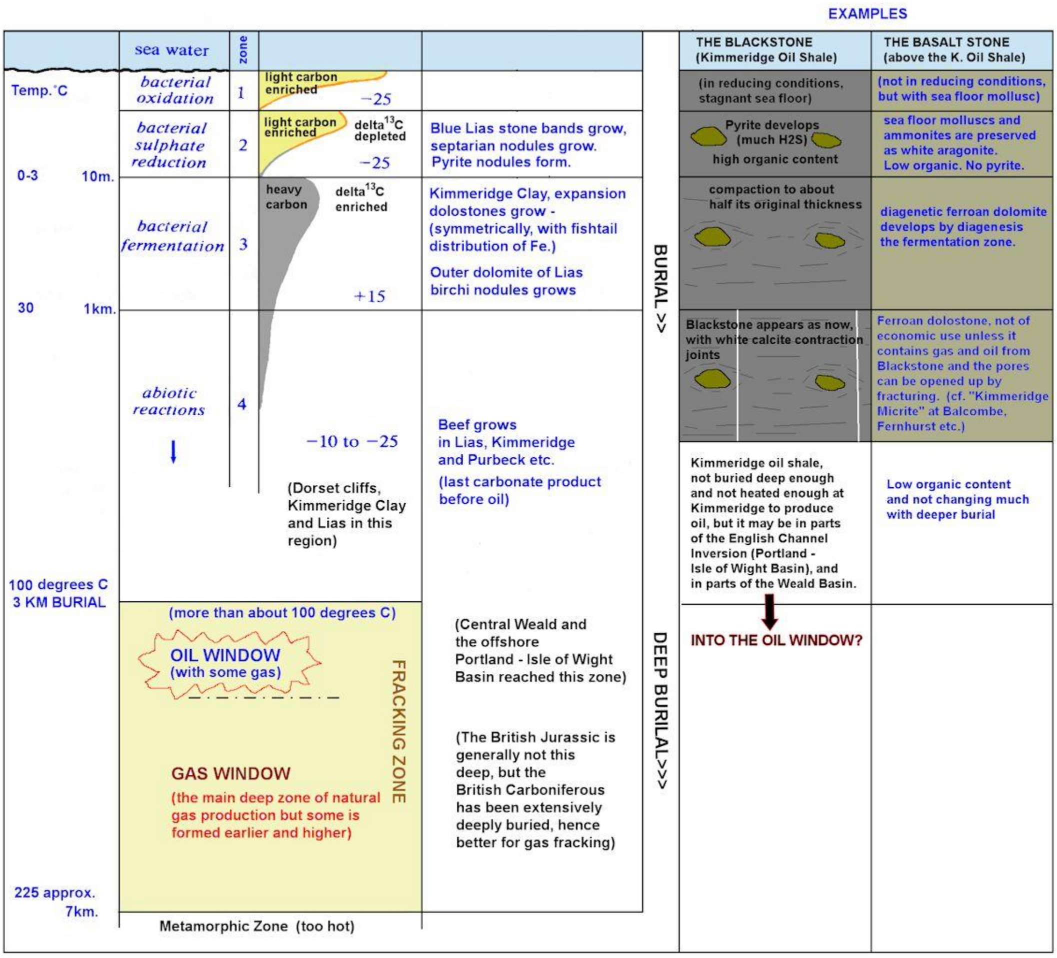
The oil is not coming from the Kimmeridge Clay which is at surface in the cliffs at Kimmeridge. However, such an origin is sometimes a misconception amongst the non-geological public, probably because the Kimmeridge Clay is the major source rock for the oil in the North Sea. There is no liquid oil in the exposed Kimmeridge cliffs, only oil-shale and bituminous shale containing kerogen, a brown waxy substance. The Kimmeridge Clay at Kimmeridge is not thermally mature (it has not been sufficiently heated by sufficiently deep burial at this particular locality). The real source of this oil is probably the deeper-buried, Lower Jurassic (Lias) bituminous shales in the offshore English Channel Basin

The Kimmeridge field was discovered in 1959, long after the initial search for oil in Dorset. It began producing in 1961 ((Gluyas et al. 2003). For a short time the production was up to 350 barrels a day, but later declined to about 100 BOPD and is now about 60 BOPD.

The porosity of the Cornbrash limestone here is very low (around 1 percent) and permeability is negligible. However fracture porosity is present, and this not well understood. Different estimates were made for the average porosity including that provided by the fractures. It is very difficult to average out the variable volumes of fracture porosity in relation to the volume of almost non-porous limestone. The details of the fractures are not known, and the extent of fracture porosity is one of the uncertain variables.

Geological intervals in the borehole

Lower Kimmeridge Clay	0-243m
Corallian	243-340
Oxford Clay	340-519
Kellaways Beds	519-537
Cornbrash	537-564
Forest Marble and Fuller's Earth	564-889
Inferior Oolite	889-909
Bridport Sands	909-1042



SIMPLIFIED DIAGRAM OF BURIAL DIAGENESIS & FRACKING POTENTIAL FOR JURASSIC SHALES, UK. The shallow diagenetic scheme is based on Irwin, Bellamy etc, with generalisations for deeper fracking from BGS (DECC) 2013 and others. The scheme relates to the burial history, not the present depths of the strata. The British onshore Jurassic was only just deep enough in the central Weald Basin, but there was also fairly deep burial offshore, south of Poole and Christchurch Bays (Portland - Isle of Wight Basin). The diagram is not to a consistent vertical scale. Ian West © 2013.

WITH THE ABOVE ADDED SECTION TO EXPLAIN kIMM. OIL SHALE AND HIGHER CARBONATE RELATIONSHIPS. (Simplified and schematic)