NATURAL ENVIRONMENT RESEARCH COUNCIL

INSTITUTE OF GEOLOGICAL SCIENCES

BULLETIN of the GEOLOGICAL SURVEY OF GREAT BRITAIN

No. 47

LONDON
HER MAJESTY'S STATIONERY OFFICE
1974

I. STRATIGRAPHY OF THE UPPER KIMMERIDGE CLAY OF THE WASH AREA

BY

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Text-figures 1–4

Summary. The stratigraphy of the Upper Kimmeridge Clay in six cored boreholes, drilled by the Institute of Geological Sciences during 1970 and 1971 in Norfolk and Lincolnshire, is described. Two of these boreholes were put down within The Wash by the drilling ship m.v. *Whitethorn* and, taken together, they provide a complete sequence through the Upper Kimmeridge Clay. This sequence has been correlated in detail, both lithologically and faunally, with the type section of the Upper Kimmeridge Clay in Dorset and with the sequence proved in the Institute's Warlingham Borehole, some 300 km and 180 km distant respectively. The Sandringham Sands (in Norfolk) and the Spilsby Sandstone (in Lincolnshire) rest unconformably on the Kimmeridge Clay in five of the boreholes; the youngest Kimmeridge strata preserved, assigned to the *Pectinatites (P.) pectinatus* Zone, lie in the middle of The Wash.

INTRODUCTION

WITH THE exception of the Dorset type section, the Upper Kimmeridge Clay is poorly exposed throughout England. In west Norfolk and south-east Lincolnshire where it underlies the great alluvial tract of the Fens, our knowledge of the Kimmeridge Clay is almost entirely derived from boreholes. The formation was extensively explored in this area during and shortly after the First World War, when an interest had been stimulated in possible British sources of oil shale. Pringle (1923) described the Kimmeridge Clay sequences in three of these oil exploration boreholes in the Southery area of south-west Norfolk referring to faunas obtained from other similar boreholes drilled between there and King's Lynn. Many of these boreholes were cored, or partially cored, although mostly at diameters (some as little as 25 mm) too small to be stratigraphically useful. In the best documented section, that at Severals House [TL 692 964][1] he recorded 125 ft (38·1 m) of Kimmeridge Clay, which he believed to include the full sequence of zones, overlain disconformably by the Sandringham Sands.

In Lincolnshire, Pringle (1919) described a partially cored borehole at Donington on Bain [TF 2428 8181], some 100 km NNW of Severals House and drilled for the same reason, which passed through 245 ft (74·7 m) of Kimmeridge Clay without reaching the base of the formation. The Kimmeridge Clay was disconformably overlain here by Spilsby Sandstone, which Pringle (1919, p. 51) thought rested on the upper part of the *Virgatites* Zone or on the lower part of the *pallasianus* Zone (*Pectinatites (P.) pectinatus* Zone and *Pavlovia* zones respectively of modern authors). Woodward (1904, p. 10) estimated the total Kimmeridge Clay thickness in this area to be about 300 to 320 ft (91·4–97·5 m) from water boreholes.

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[1] National Grid references are given in this form throughout the paper.

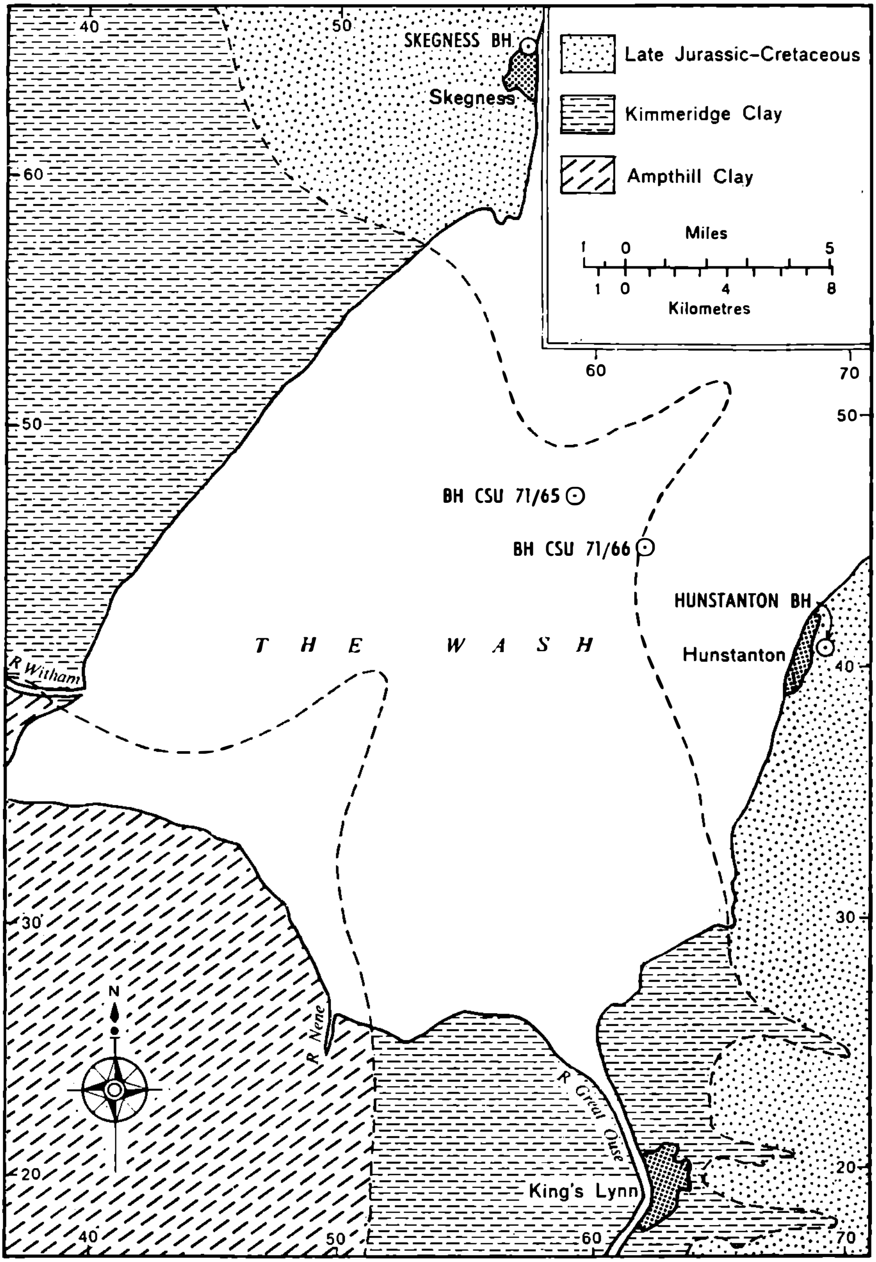

FIG. 1. *Sketch-map of the solid geology of the Wash area showing positions of boreholes referred to in the text*

It can be deduced from Pringle's descriptions that, of the total Kimmeridge Clay thicknesses at Severals House and Donington on Bain, about 12·2 and 15·2 m (40 and 50 ft) respectively, belong to the Upper Kimmeridge Clay as currently defined.

In 1970, the Institute drilled and cored four boreholes, at Marham [TF 7051 0803], Gayton [TF 7280 1974] and Hunstanton [TF 6857 4078] in Norfolk, and at Skegness [TF 5711 6398] in Lincolnshire, to examine the Upper Jurassic and Lower Cretaceous. These boreholes penetrated up to 20 m of Upper Kimmeridge Clay and it was found possible to make detailed correlations between these Kimmeridge Clay sequences using a combination of sedimentary rhythms and total gamma-ray logging (Gallois 1973).

In 1971, the Institute's Continental Shelf Unit 1 drilled and cored two boreholes, CSU 71/65 [TF 5850 4676] and CSU 71/66 [TF 6117 4475] within The Wash from the drilling ship m.v. *Whitethorn* as a preliminary to a more detailed study of the offshore geology of the area (Fig. 1). Taken together these two boreholes provide a complete section through the Upper Kimmeridge Clay. In the following account they are correlated with the four earlier Institute boreholes and the faunas and lithologies of all six boreholes are compared with those of the Upper Kimmeridge Clay of the Dorset type section (Blake 1875; Arkell 1933, 1947; Cope 1967) and of the Institute's Warlingham Borehole in Surrey (Worssam and Ivimey-Cook 1971; Callomon and Cope 1971). The names of the Dorset stone bands referred to in the text are those of Arkell (1933, 1947).

In making comparisons of faunal ranges and distributions the core sizes of the respective boreholes being compared can be important. The Upper Kimmeridge Clay cores at Warlingham were 152 mm (6 in) diameter, those of the CSU boreholes, 76 mm (3 in) diameter and those of the four land-area boreholes 91 mm (4 in) diameter.

The siting, on-ship supervision and provisional logging of the CSU boreholes was carried out by Mr. G. H. Rhys. Dr. A. Medd has quantitatively assessed the coccolith contents of selected samples from the Hunstanton, Skegness and CSU boreholes, and has commented on the nature of their coccolith floras. Mr. J. Dangerfield has determined the carbonate contents of a duplicate set of these samples, and his and Dr. Medd's combined work has been used as a basis for Table 1.

The ammonites referred to in the text and in the borehole logs have been determined by Dr. J. C. W. Cope; a more detailed account of these ammonite sequences together with a proposal for a new subzonal scheme for the Upper Kimmeridge Clay is given in Cope (1974).

STRATIGRAPHY

The Upper Kimmeridge Clay of Norfolk and Lincolnshire is made up of a complex sequence of small-scale rhythms, generally 0·3 to 2·5 m thick, consisting of soft mudstones, shelly mudstones, calcareous mudstones and, more rarely, thin beds of cementstone (argillaceous limestone). Many of the individual rhythms can be correlated within the Wash area. Superimposed on this rhythmic sequence are broader lithological changes, from more to less calcareous and from more to less bituminous, which can be regarded as larger scale rhythms and which can be correlated between the Wash area and Dorset, a distance of some 300 km.

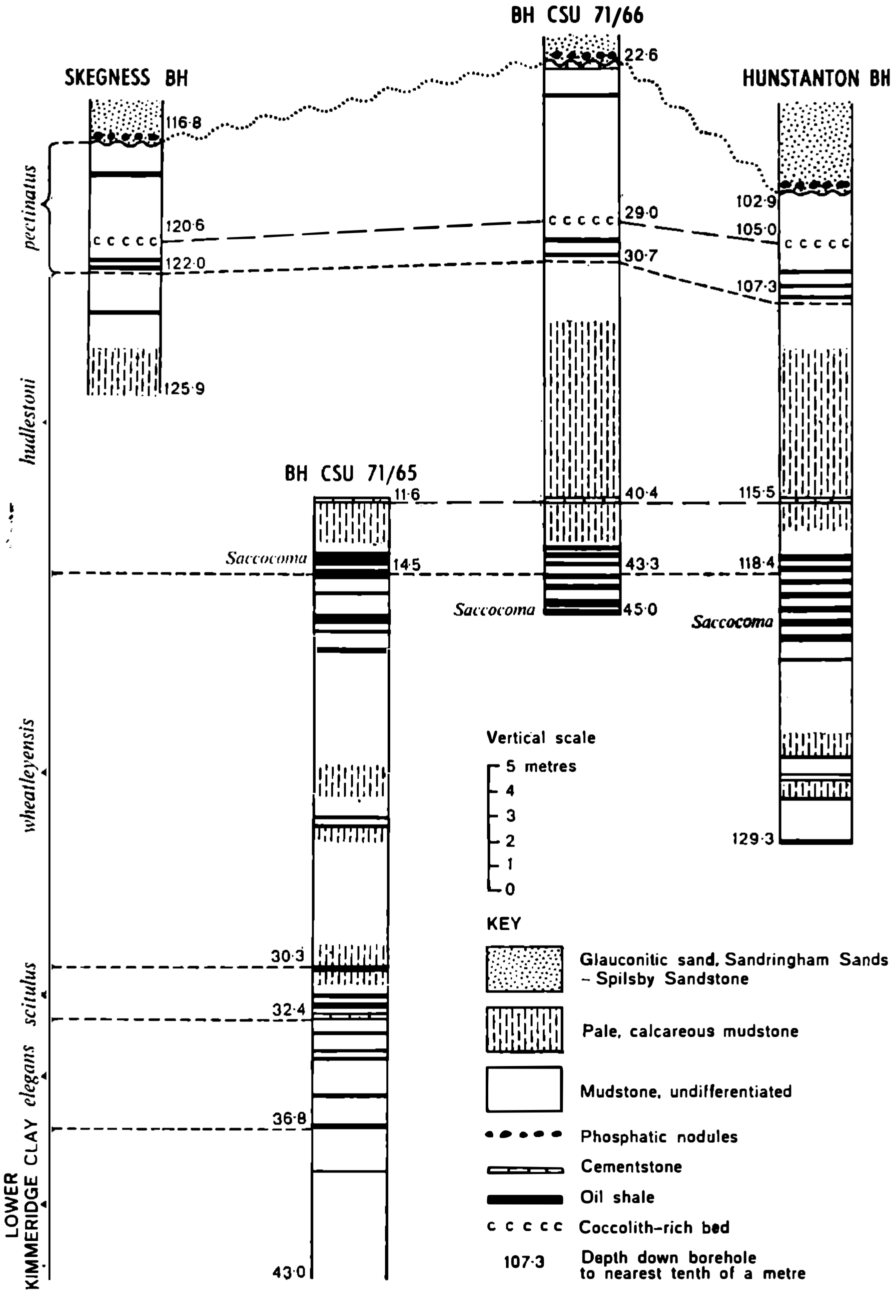

FIG. 2. *Correlations between the Upper Kimmeridge Clay sequences proved in and adjacent to The Wash*

The idealized small-scale rhythm is made up of brown or brownish grey, fissile, bituminous-smelling mudstone (referred to below as oil shale), usually shelly, and rich in both calcareous and chitinous microfossils, which passes upwards first into dark grey fissile shelly mudstones, characterized by plasters of small bivalves and small (finely-ribbed) ammonites, and then into dark grey blocky almost barren mudstones containing scattered oysters and larger (more coarsely-ribbed) ammonites. These last-named mudstones become paler upwards by increase in calcareous content, and culminate in pale grey mudstones having a sub-conchoidal fracture and locally containing a continuous tabular bed or line of doggers of muddy limestone that rings to the hammer. Within these rhythms the oil shales and the pale calcareous mudstones, including the cementstones, form the most easily identifiable lithologies. In Fig. 2, they are used to illustrate the correlations between the sequences in the Skegness, CSU 71/65, CSU 71/66 and Hunstanton boreholes. Similar correlations showing the relationship of the lithologies of the Hunstanton Borehole to those of the Gayton and Marham boreholes is given in Gallois (1973, fig. 4b).

In Dorset, the oil shales contain up to 40 per cent of brown organic matter which Forsman (1963, p. 158) has described as composed mostly of kerogen. Downie (1957, p. 416) had already shown this organic content to be largely derived from phytoplankton such as dinoflagellates and hystrichospheres. Cosgrove (1970) has drawn attention to the abnormally high iodine and bromine content present in some of the oil shales from the Kimmeridge Clay in Dorset, particularly from the Blackstone or Kimmeridge Coal, and has related this to the abundance of microplankton present.

The oil shales consistently give the highest total gamma-ray counts of all the Upper Kimmeridge Clay lithologies examined. Swanson (1960, p. 4), in a review of the uranium enrichment of sediments, has noted that some organic shales contain a hundred times as much uranium as other common sedimentary rocks, but that uranium enrichment tends to be associated with humic (i.e. decomposing land vegetation) rather than with sapropelic (marine) organic deposits. Cosgrove (1970, p. 831) found that uranium values in the Kimmeridge Clay oil shales were below the level of detectability in all the samples examined, so that although uranium enrichment has probably occurred to a sufficient extent in the oil shales to make them radiometrically distinguishable from the surrounding lithologies, such enrichment has been small. Hallam (1967) has described Liassic shales with bituminous laminae, lithologically very similar to the oil shales of the Kimmeridge Clay, and has suggested that these and similar sediments may have been deposited in a relatively shallow, open marine environment with the laminae representing seasonal or annual varves.

All the Upper Kimmeridge Clay lithologies of the Wash area are calcareous to some extent, due largely to their shelly microfaunal and macrofaunal contents, ranging from about 16 per cent carbonate content in the dark grey mudstones to over 50 per cent in the pale grey mudstones and locally to over 90 per cent in the cementstones (Table 1).

Three main types of cementstone can be recognized in the Wash boreholes and in the Dorset sections. In Dorset, the more persistent of these form unbroken tabular sheets which can be traced for several miles in the cliffs between Chapman's Pool and Kimmeridge Bay, and form the famous Kimmeridge Ledges.

The first type, as noted by Downie (1957, p. 416) is composed largely of coccoliths and consists of a very pale brown, earthy-textured limestone, typically light in weight and usually finely laminated, which generally occurs in association with beds of oil shale. In Dorset, the White Stone Band and the Rope Lake Head Stone Band are the most prominent examples of this type. The White Stone Band, both in Dorset and in the Warlingham Borehole, is made up of fine interlaminations of coccolith-rich and bituminous-rich material and its mode of

TABLE 1

Carbonate and coccolith contents of some typical Upper Kimmeridge Clay lithologies

Lithology	*Borehole*	*Depth down borehole* m	*Carbonate* %	*Approx. coccolith of carbonate fraction* %	*Approx. coccolith of total rock* %
Oil shale, shelly	Hunstanton	106·8	51·02	1	0·5
Oil shale, sparsely shelly	Hunstanton	106·4	18·06	2	0·4
Mudstone, dark grey, fissile, shelly	Hunstanton	105·4	26·30	10	2·6
Mudstone, dark grey, almost barren	Hunstanton	104·3	16·55	5	0·8
Mudstone, medium grey, almost barren	Hunstanton	105·2	26·67	25+ bits	6·8+
Mudstone, pale grey, almost barren	Hunstanton	105·1	50·63	25+ bits	12·5+
Cementstone	Hunstanton	115·4	93·45	nil	nil
'White Stone Band' lithology	Hunstanton	105·0	75·59	60+ bits	45·6+
	Skegness	120·6	57·86	90+	52·2+
	Skegness	121·9	34·21	90+	31·6+

deposition would seem to fit in well with the hypothesis of Hallam described above. Downie (*in* Worssam and Ivimey-Cook 1971, pp. 38–9) has drawn attention to the widespread persistence of the White Stone Band, or of a coccolith-rich bed at an equivalent horizon in the Upper Kimmeridge Clay, over a large part of south-east England. The present work has extended the recognition of this distinctive bed to the Wash area, although clearly the palaeontological control required to be sure that this bed is at precisely the same level and is in lateral continuity with the White Stone Band of Dorset is always likely to be wanting (see also p. 13).

Dr. Medd records that the coccolith contents of samples of the coccolith-rich bed from the Wash boreholes are composed almost wholly of one species, *Ellipsagelosphaera britannica* (Stradner). The same species occurs in similar abundance in the White Stone Band in Dorset. Seasonal blooms of coccoliths consisting largely of one species occur from time to time over large areas of the North Sea (Braarud and others 1953). Such blooms characteristically form in seas rich in land-derived nutrients and which are to some degree land-locked so that whilst they remain a fully marine environment their salinities are slightly lower than that of the open oceans.

The sudden appearance and disappearance of these blooms might explain some of the fine lamination seen in the White Stone Band as well as the persistence of this bed from The Wash to Dorset, over an area which must have embraced both the stable margins and the more rapidly subsiding parts of the Kimmeridge Clay basin of deposition. The White Stone Band probably does not represent a condensed deposit since in both the Warlingham and the Wash area boreholes it has a lower total gamma-ray count than the surrounding clays. Its high overall coccolith content seems to be due to a high rate of coccolith deposition probably at a time of low clastic influx.

The second type of cementstone is usually associated with pale calcareous ('dicey' weathering) clays and consists of a line of doggers, or a tabular bed, of dense microcrystalline limestone, probably of early diagenetic origin. In Dorset, the best examples are the Grey and the Cattle Ledge Stone Bands. Locally, this type of cementstone, particularly when in the form of doggers, contains septarian cracks infilled with coarsely crystalline calcite. The third type of cementstone, characterized in Dorset by the Yellow Ledge Stone Band and by the basal stone band of the Upper Kimmeridge Clay (Bed 42 of Blake 1875), is a brownish grey tabular bituminous limestone, commonly shelly or with shell ghosts, and is probably a shelly oil shale in which some re-solution, and precipitation of calcite has occurred.

In Dorset, the cementstones contrast prominently with the great thickness of surrounding mudstones and they have for a long time, for convenience, been used as datum planes against which to measure sections and collect faunas. Consequently, most zonal schemes (e.g. Arkell 1933; Cope 1967) have subdivided the Upper Kimmeridge Clay by placing the zonal boundaries at the cementstones, even though at the time, these had not been shown to be laterally persistent beyond the Dorset coast sections or to mark erosional breaks within the sequence. It has been demonstrated on geophysical evidence (Gallois 1973) that the cementstones of the Upper Kimmeridge Clay in the Wash area are the most laterally persistent horizons and are the most useful lithologies for long distance correlations. The present work has shown that some of the cementstones lie at persistently similar horizons in the Wash area, at Warlingham and in Dorset, and it seems likely that a few, e.g. the White and the Yellow Ledge Stone Bands, may even form laterally continuous beds from Dorset to The Wash.

The Dorset zonal succession of the Upper Kimmeridge Clay has been revised by Cope (1967) on the basis of the perisphinctid ammonite fauna, and this scheme has been successfully applied to the sequence in the Warlingham Borehole (Callomon and Cope 1971). Comparison of this zonal scheme with earlier schemes is given in Cope (1967, p. 67). More recent work on the Dorset sections and on the faunas of the present boreholes, has made it possible to position several of these zonal boundaries more precisely (Cope 1974).

All the zones of the Upper Kimmeridgian, up to and including the *pectinatus* Zone, have been recognized in the Wash boreholes although the thicknesses are considerably reduced in comparison to those of Warlingham and Dorset (Fig. 4). The gross lithologies and faunal sequences in all three areas are essentially similar despite these variations in thickness. There seems to be no evidence, such as faunal debris derived from fringing reefs, coarser clastic debris or non-sequences, to suggest that the Wash area was particularly close to a shoreline at this time. The differences in thicknesses between the three areas would therefore seem to be due largely to differences in rates of subsidence, the Dorset area being close to the axis of a Kimmeridgian subsiding trough, with The Wash and Warlingham on the stable flanks of the London Platform.

The maximum thickness of the Upper Kimmeridge Clay in Norfolk and Lincolnshire probably occurs in the middle of The Wash, where about 43 m of beds are preserved beneath the Sandringham Sands–Spilsby Sandstone unconformity. The highest zone proved in the Wash area is that of *P.* (*P.*) *pectinatus* (in the Hunstanton, CSU 71/66 and Skegness boreholes). Farther south in Norfolk, in the Marham and Gayton boreholes, the Sandringham Sands rest on the *Pectinatites* (*Arkellites*) *hudlestoni* Zone. Northwards from The Wash, the Spilsby Sandstone and Lower Cretaceous progressively overstep the Kimmeridge Clay until it is cut out completely at the Market Weighton axis.

The basal bed of the Sandringham Sands–Spilsby Sandstone has been shown by Casey (1971) to be Middle Volgian in age (and suggested to be equivalent to the Shrimp Bed of the Portland Stone). Derived fragments of pavlovid ammonites which occur in this basal bed throughout west Norfolk indicate that the *Pavlovia* zones were once at least partially represented in this area.

In Norfolk, the Upper Kimmeridge Clay thickens slightly between Marham and Hunstanton and from Hunstanton into The Wash to Borehole CSU 71/66 (in addition to the lessening of the overstep of the Sandringham Sands in the same direction) (Fig. 2).

The distribution of species of *Pectinatites*, together with a generalized lithological section, is shown in Fig. 3.

The non-ammonite macrofauna of the Upper Kimmeridge Clay consists mostly of long-ranging bivalves, brachiopods, gastropods and fish debris. None of these was found to be stratigraphically useful in the boreholes, although the detailed distribution of certain species can provide a broad stratigraphical guide in local areas.

Codakia (*Epilucina*) *miniscula* (Blake) forms plasters at levels throughout the Upper Kimmeridge Clay in the Wash area, although such plasters are more common in the *Pectinatites* (*Virgatosphinctoides*) *wheatleyensis* Zone and above. Scattered specimens occur at all levels. At Warlingham *miniscula* plasters are confined to the *wheatleyensis* Zone. *Protocardia morinica* (de Loriol) forms plasters both in the Wash boreholes and at Warlingham in the *wheatleyensis* Zone and below. Scattered specimens are common at higher levels in the Wash area but

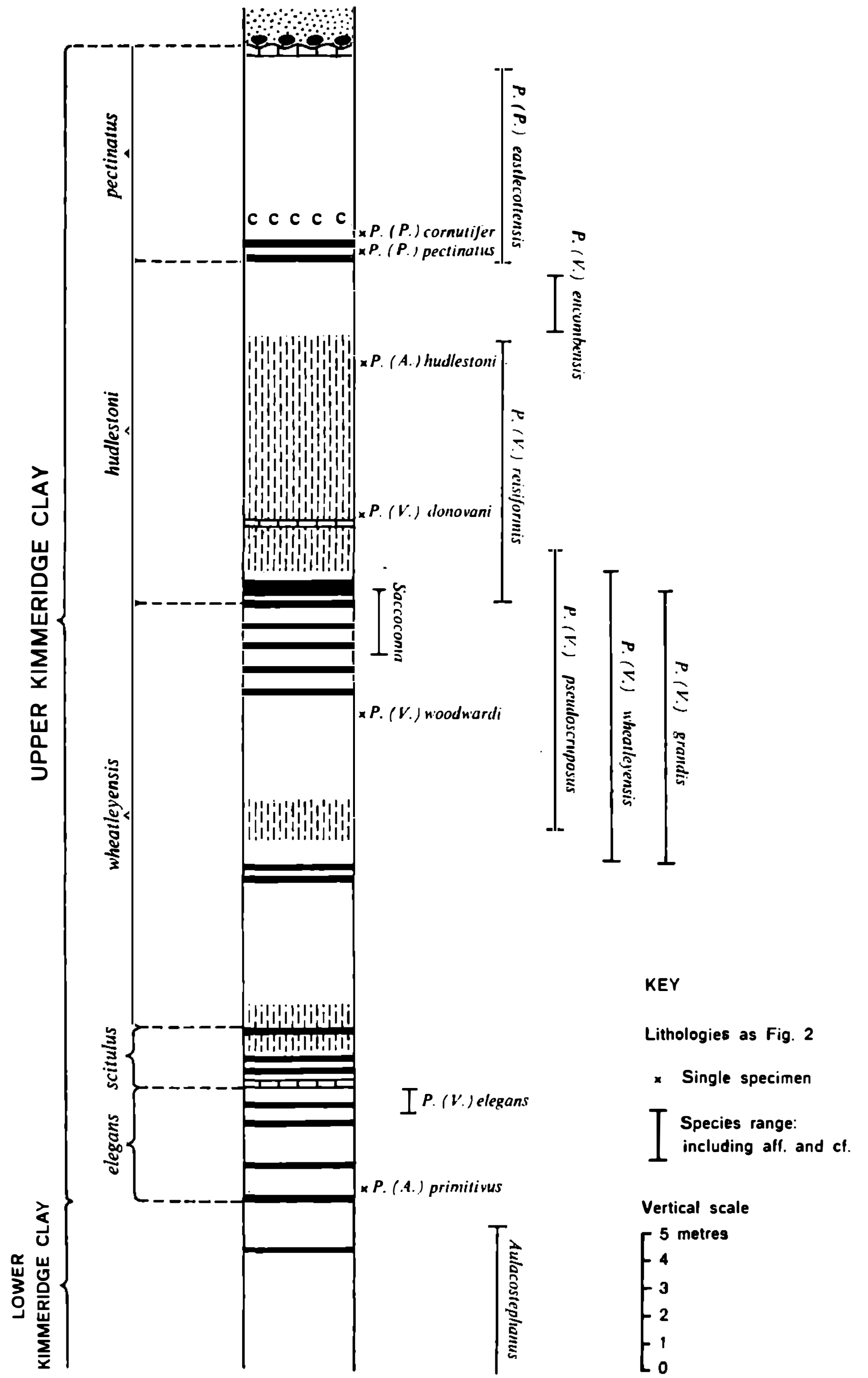

FIG. 3. *Generalized vertical section of the Upper Kimmeridge Clay of the Wash area*

these are almost always smaller forms and are possibly a distinct species. *Astarte mysis* d'Orbigny occurs only rarely above the *wheatleyensis* Zone in the Wash boreholes, becoming more common with depth and occasionally forming, or significantly contributing towards, plasters. At Warlingham, *Modiolus autissiodorensis* (Cotteau) is by far the most common bivalve in the upper part of the *hudlestoni* Zone and in the *pectinatus* Zone, where it locally forms plasters. In the Wash boreholes only a few scattered specimens were recorded and these at widely differing levels.

A single specimen of *Nanogyra virgula* (Defrance) was recorded 6·1 m above the base of the *wheatleyensis* Zone in Borehole CSU 71/65. Elsewhere, at Warlingham and in Dorset, *N. virgula* has been described in the Upper Kimmeridge Clay, only from the *Pectinatites* (*Virgatosphinctoides*) *scitulus* Zone and the *Pectinatites* (*Virgatosphinctoides*) *elegans* Zone. Other oysters, the brachiopods *Discinisca latissima* (J. Sowerby) and *Lingula ovalis* J. Sowerby, and the gastropod *Dicroloma* occur scattered throughout the sequence, are never abundant, and appear to have little stratigraphical value. Other brachiopods are rare within the Upper Kimmeridge Clay and any occurrence is noteworthy. A brachial valve of *Rhynchonella* aff. *subvariabilis* Davidson was recorded in the *wheatleyensis* Zone at 84·7 m in the Marham Borehole.

Pringle (*in* Strahan 1920, p. 37) recorded pyritized radial plates of the pelagic crinoid *Saccocoma* in several of the oil exploration boreholes in Norfolk, and he correlated these occurrences with those in the Blackstone of the Dorset sequence. He concluded (1923, p. 134) that in Norfolk *Saccocoma* had a vertical range of only about 1 ft (0·3 m) compared to a range of about 13 ft (4·0 m) in Dorset. Similar pyritized plates from the Kimmeridge Clay of the Penshurst Borehole in Kent had earlier been assigned by Bather (1911, p. 78) to the genus *Saccocoma*, by comparison with material from the Solenhofen Limestone. Although Bather recognized two forms, which he thought might prove to indicate two species, little further work has been done on the Kimmeridge Clay specimens and they continued to be assigned to a long-ranging genus known in Britain only from the Kimmeridgian and from the Campanian (Upper Chalk). Recently, Peck (1973, p. 94) has separated the Campanian forms under the genus *Applinocrinus*.

The usefulness of *Saccocoma* as a stratigraphical marker is dependent upon its occurrence in very large numbers over a narrow vertical range. Kitchin and Pringle (*in* Kitchin 1919, p. 43) were sufficiently impressed by its usefulness in Norfolk, and by their correlation with Dorset and with other boreholes in south-east England, to suggest that the beds with *Saccocoma* be designated a separate subzone. Their observations have been largely confirmed in the Wash boreholes, although the vertical range in Norfolk has been shown to be greater than they recorded. However, in the Warlingham Borehole, although *Saccocoma* was recorded at the same level in the Upper Kimmeridge Clay as elsewhere, it was also recorded from the *Aulacostephanus* (*A.*) *autissiodorensis* Zone of the Lower Kimmeridgian (Casey 1958). Even though it cannot be used as a subzonal index, *Saccocoma* is still known only from one thin band in the Upper Kimmeridge Clay and it continues to be useful as a stratigraphical marker at this level.

The *Saccocoma* Band was recorded in five of the six Wash area boreholes referred to here (the Skegness Borehole did not reach this level), but the modes of preservation and the vertical ranges recorded were varied. At Clavell's Hard,

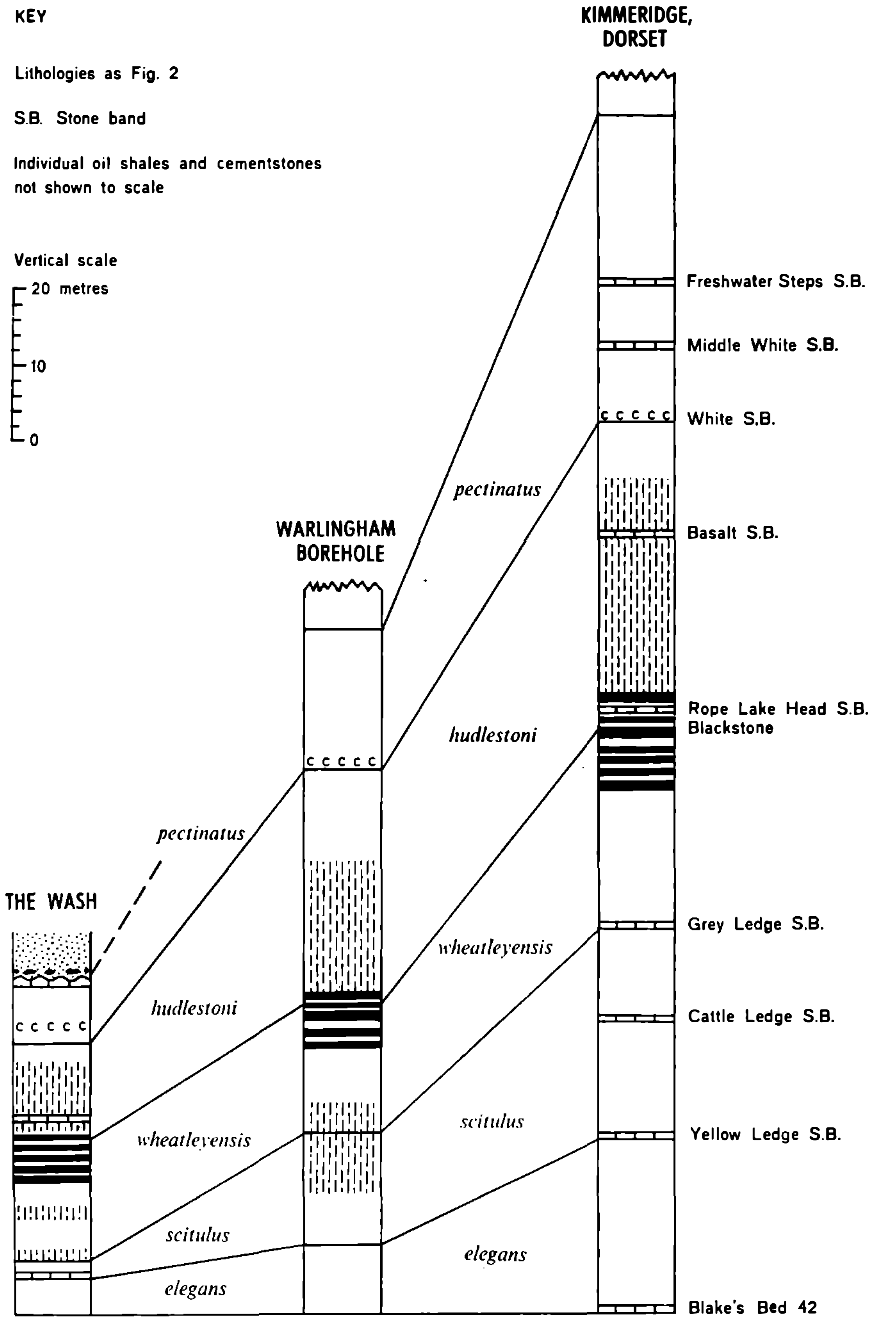

FIG. 4. *Comparison of the zonal thicknesses in the Upper Kimmeridge Clay sequences of the three areas referred to in the text*

near Kimmeridge Bay, *Saccocoma* occurs over a range of about 6·6 m, but is particularly common, preserved as pale shiny pyritized plates, in the lower part of the Blackstone and in a similar bituminous bed 4·8 m below the Blackstone. In the intervening beds it is only sporadically present, being common at some levels and apparently absent at others. At Warlingham, it shows a similar distribution and preservation, occurring abundantly at 2500 ft 8–9 in (762·20–762·23 m) in oil shale and again in the same lithology at 2513 ft 6 in to 2514 ft (766·12–766·27 m) but elsewhere within its overall range it is generally rare. In the Wash area, the recorded levels of *Saccocoma* occurrences suggest a similar distribution. In the CSU 71/65, CSU 71/66 and Hunstanton boreholes, *Saccocoma* was recorded over vertical ranges of only a few centimetres, usually being observed as abundant only on one bedding plane, and always in oil shale. However, the level at which it was recorded (as measured against the distances from an overlying cementstone which was taken as a stratigraphical datum) varied by up to 2 m in different boreholes. At Gayton and Marham, *Saccocoma* was recorded over much larger ranges (1·2 and 1·1 m respectively) and it is probably significant that in these last two boreholes the preservation was in pyrite and provided the most easily visible specimens. In the remaining Wash boreholes, the pyritized plates were almost wholly obscured by secondary overgrowths of gypsum, formed as the cores dried out. All the *Saccocoma* occurrences in the Wash area boreholes fall within the ranges observed in either the Gayton Borehole or in the Marham Borehole.

Description of Zones

Pectinatites (Pectinatites) pectinatus Zone

A maximum of 8·1 m of *pectinatus* Zone sediments was seen in the Wash area boreholes. They consist of dark grey mudstones with a number of pale calcareous bands in the upper part, and with a group of thin oil shale bands near the base, these latter including the coccolith-rich bed which is here correlated with the White Stone Band of Dorset. In the CSU 71/66 Borehole, which contains the stratigraphically highest Upper Kimmeridge Clay seen in the area, the Sandringham Sands rest on a 0·2-m thick tabular cementstone.

At Warlingham, the mudstones of the *pectinatus* Zone are strikingly different from those of the Wash area. In addition to their greater density and hardness, presumably caused by their greater depth of burial, they are much more uniform, consisting almost entirely of dark grey blocky mudstones with a few scattered bivalves and ammonites. This fauna is preserved as brown calcite films, in marked contrast to the white calcite preservation of the shelly faunas of the Wash area.

Pectinatites (*P.*) *eastlecottensis* (Salfeld) ranges throughout, with crushed but well-preserved specimens occurring in oil shales near the base of the zone. The marked lithological change where these oil shales rest on blocky mudstones has been taken as the junction with the underlying zone. This junction lies about 1·6 m below the coccolith-rich bed and immediately below the lowest recorded *P.* (*P.*) *eastlecottensis* in Borehole CSU 71/66. A similar lithological boundary has been taken in the Hunstanton and Skegness boreholes, and when the faunal ranges adjacent to these three boundaries are combined (Fig. 3), it can be seen that this lithological change corresponds closely with the upward replacement of *P.* (*Virgatosphinctoides*) *encombensis* Cope by *P.* (*P.*) *eastlecottensis*. In Dorset, the base of the zone has been taken at the base of the White Stone Band which marks the incoming of *P.* (*P.*) *eastlecottensis*. The presumed lithological equivalent of this stone band, seen in all the Wash boreholes which penetrated this stratigraphical level, may therefore be incorrect. At Skegness, a second coccolith-rich bed, only about 20 mm thick, was recorded 1·3 m below the first, and just below the lowest *P.* (*P.*) *eastlecottensis*. It is possible therefore that this lower bed is the true, but very attenuated equivalent of the White Stone Band, but more palaeontological control is needed before this correlation can be resolved (see also Cope 1974, p. 36).

***Pectinatites (Arkellites) hudlestoni* Zone**

The *hudlestoni* Zone was recorded in all six of the Wash area boreholes, although only part of the zone was present in the Skegness, CSU 71/65, Gayton and Marham boreholes. Where complete, it ranged in thickness from 11·1 m at Hunstanton to 12·6 m in Borehole CSU 71/66.

The highest part of the zone consists of dark grey mudstones, but the major part is made up of pale calcareous mudstones including, near the base, a persistent tabular cementstone. This same broad lithological division is also present in Dorset and at Warlingham.

The zonal index is rare and was recorded only in Borehole CSU 71/66. The dark grey mudstones in the upper part of the zone are characterized by *P.* (*V.*) *encombensis*, the pale calcareous mudstones by *P.* (*V*). *reisiformis* Cope. In Dorset, the base of the zone was formerly taken at the Rope Lake Head Stone Band, a thick coccolith limestone within a sequence of oil shales which marks the incoming of *P.* (*A.*) *hudlestoni* Cope (Cope 1967). As a result of more recent work, Cope (1974, p. 31) has redefined the zonal boundary to be taken at the incoming of *P.* (*V.*) *reisiformis*. In the Wash area, and at Warlingham (Worssam and Ivimey-Cook 1971, p. 77), the base of this zone, as thus defined, lies just below the upper limit of the range of *Saccocoma*. In Dorset, the top of the Blackstone is now taken to mark the base of the zone (Cope 1974, p. 31).

The apparent similarity in the Wash and Dorset sequences of a prominent tabular cementstone, a few metres above the base of the zone, is fortuitous. The Rope Lake Head Stone Band almost certainly occurs stratigraphically lower than the Wash area cementstone, the latter lying within pale calcareous mudstones which correlate with the thick 'dicey' clays of Dorset (Bed 25 of Blake 1875). No coccolith-rich bed was recorded at this level in the Wash area, or at Warlingham, although in both sequences, the zonal boundary falls within a prominent group of thick oil shales which correlate with similar oil shales, including the Blackstone, in Dorset.

***Pectinatites (Virgatosphinctoides) wheatleyensis* Zone**

The full thickness of this zone was proved only in Borehole CSU 71/65, where it was 15·8 m, making it the thickest of the Upper Kimmeridge Clay zones proved in the Wash area. In Dorset and Warlingham the *hudlestoni* Zone is the thickest, although the lithological sequences in the *wheatleyensis* Zone in all three areas are very similar.

The upper part of the zone contains a group of oil shales with *P.* (*V.*) *grandis* (Neaverson), *P.* (*V.*) *pseudoscruposus* (Spath), *P.* (*V.*) *wheatleyensis* (Neaverson) and *Saccocoma*. The lower part of the zone is composed of alternations of pale and dark grey mudstone with a few subordinate beds of oil shale.

In Dorset, where the base of the zone is taken at a prominent tabular cementstone, the Grey Ledge Stone Band, *P.* (*V.*) *wheatleyensis* and its associated forms are confined to the upper part of the zone (Cope 1974). In Borehole CSU 71/65, where there was no specifically determinable ammonite either in the lower part of the *wheatleyensis* Zone or in the underlying *scitulus* Zone, the boundary has been taken by tentative analogy with the Grey Ledge Stone Band, at a pale calcareous bed about 6 m below the incoming of *P.* (*V.*) *wheatleyensis*.

***Pectinatites (Virgatosphinctoides) scitulus* Zone**

Strata referred to this zone and the underlying *elegans* Zone were recorded only in Borehole CSU 71/65. The *scitulus* Zone consists of 2·1 m of medium and dark grey mudstones with thin oil shale beds. *P.* (*V.*) *sp.* was the only ammonite recorded at this level. In Dorset the base of the zone is taken at the Yellow Ledge Stone Band, a brownish grey bituminous tabular cementstone of the cemented oil shale type. The base of the zone in Borehole CSU 71/65 has been taken at 32·45 m, at the base of a lithologically very similar bed.

***Pectinatites (Virgatosphinctoides) elegans* Zone**

The *elegans* Zone in Borehole CSU 71/65 consists of 4·4 m of dark grey blocky mudstones with a few thin beds of oil shale. Determinable ammonites are rare although several specimens of the zonal index were recorded a little below the bituminous cementstone referred to above. *P.* (*Arkellites*) cf. *primitivus* Cope is present in the lower part of the zone. *Gravesia*, which occurs sparingly at this level in Dorset and at Warlingham, was not recorded. The base of the *elegans* Zone, and of the Upper Kimmeridge Clay, in Dorset is taken at another bituminous cementstone (Bed 42 of Blake 1875) which is used as a convenient lithological datum lying between the highest known *Aulacostephanus* and the lowest *Pectinatites*. The boundary in Borehole CSU 71/65 has therefore been taken at 36·81 m at the base of a thick oil shale which marks the lower limit of *Pectinatites* and is 0·9 m above the highest recorded *Aulacostephanus*.

CONCLUSIONS

Although much thinner (43 m) than the equivalent sequences in Dorset (about 150 m) and in the Warlingham Borehole (about 90 m), the Upper Kimmeridge Clay of the Wash area can be matched with them in considerable lithological and faunal detail. The apparent persistence of individual thin marker bands, such as the White Stone Band and the *Saccocoma* Band, and of broad lithological similarities over most of southern England, suggests that during the Upper Kimmeridgian, ecologically similar environments existed over large areas, despite considerable variations in the rates of subsidence within those areas.

In Norfolk and Lincolnshire, the youngest Kimmeridgian (*P.* (*P.*) *pectinatus* Zone) preserved beneath the Sandringham Sands–Spilsby Sandstone unconformity occurs in the middle of The Wash. Northwards and southwards from The Wash, the Kimmeridge Clay is progressively overstepped until it is cut out entirely at the Market Weighton axis and in the Mundford area (Gallois 1973, p. 71). It would seem more than coincidence therefore that The Wash, and its earlier continuation beneath the Recent sediments of the Fenlands, should have followed this line of maximum thickness of preserved Kimmeridge Clay.

The Recent sediments in Borehole CSU 71/65 rest on a tabular cementstone of the *P.* (*A.*) *hudlestoni* Zone and it seems likely that such cementstones form a series of ledges on the floor of The Wash (now largely hidden beneath Recent sediments) comparable to the famous Kimmeridge Ledges of Dorset. A similar situation may have occurred in Middle Volgian times, when the Sandringham Sands sea advanced across the eroded surface of the Kimmeridge Clay, since the highest Kimmeridgian in Borehole CSU 71/66 is also a tabular cementstone.

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APPENDIX

DETAILED DESCRIPTIONS OF THE BOREHOLES

The following descriptive logs of Boreholes CSU 71/65 and CSU 71/66, if taken together, provide a complete section of the Upper Kimmeridge Clay sequence in The Wash. These two boreholes are about 3·5 km apart. They can be lithologically and faunally matched in detail with the Skegness, Hunstanton, Gayton and Marham sequences: descriptions of the Upper Kimmeridge Clay in these latter four boreholes are filed in manuscript at the Institute.

In the following abbreviated logs only the more important fossils are recorded; the distribution of long-ranging forms is discussed above.

Borehole CSU 71/66

Drilled by m.v. *Whitethorn*, 13 to 14 December 1971.
National Grid reference: TF 6117 4475; Lat. 52°58·33′N, Long. 0°24·04′E.
Water depth: 19·0 to 22·0 m (tidal). Borehole datum: sea bed.
Institute Specimen Nos. CSE 423 to 806.

	Thickness m	*Depth* m
RECENT AND PLEISTOCENE		
Rock bitted, mostly loose sand .. .. about	15·00	15·00
CRETACEOUS		
SANDRINGHAM SANDS		
Rock bitted, poorly consolidated sands .. .. .. about	5·50	20·50
Core lost	1·30	21·80
?Basal Cretaceous Nodule Bed: sandstone, densely calcareously cemented, fine and very fine-grained, medium and dark grey, burrow-mottled with many rough coated almost black phosphatic nodules	0·20	22·00
JURASSIC		
Basal Nodule Bed: sandstone, densely cemented as above, fine and medium-grained, glauconite speckled and with rare chamosite ooliths, pale and medium grey, becoming sparsely shelly below 22·21 m with *Ophiomorpha* burrows and passing down at 22·40 m into very densely cemented, with patchy pyrite cement, fine-grained, shelly sandstone with bits of large thick-shelled bivalves, thin-shelled bivalves including *Entolium*, gastropods, rare chamosite ooliths; becoming increasingly pebbly with depth below 22·40 m with black lydite and phosphate pebbles up to 15 mm across, and with softer cream-coloured phosphate pebbles	0·62	22·62
KIMMERIDGE CLAY		
UPPER KIMMERIDGE CLAY		
***Pectinatites (P.) pectinatus* Zone**		
Cementstone, medium grey, muddy limestone with secondary calcite veins, clean fracture, rings to the hammer, barren;		

	Thickness *m*	*Depth* *m*
vertical, subrounded burrowfills of fine and medium-grained, shelly sand extend down from the Sandringham Sands to a *core break and probable small core loss at 22·72 m*	0·23	22·85
Core lost	0·25	23·10
Mudstone, soft, medium and dark grey, traces of calcite shell debris in winnowed patches, mostly leached and softened due to ?groundwater action; a few poorly preserved bivalves ..	0·32	23·42
Core lost	0·04	23·46
Mudstone, medium to pale grey with comminuted shell debris throughout and a few well-preserved bivalves including *Codakia* (*Epilucina*) *miniscula* (Blake) and oysters, with the brachiopod *Lingula ovalis* J. Sowerby; dark grey clay burrowfills in lower part	0·29	23·75
Core lost	0·02	23·77
Mudstone, medium grey with a few paler burrowfills; comminuted shell debris and a few well-preserved bivalves as above, perisphinctid fragment at 23·80 m, sharp but interburrowed junction with bed below	0·14	23·91
Oil shale, brownish grey, fissile mudstone, noticeably light in weight and giving off a bituminous smell when freshly broken; sparsely shelly with crushed bivalves, including *C.* (*E.*) *miniscula* and *Protocardia morinica* (de Loriol), the brachiopod *Discinisca latissima* (J. Sowerby), and fragments of finely ribbed perisphinctids including *Pectinatites sp.* at 23·95 m; foraminifera-spotted; small faecal pellets preserved in soft, pale brown phosphate; burrowfills of dark grey mudstone extend down from above; sharp base	0·06	23·97
Mudstone, pale grey, sparsely fossiliferous, foraminifera-spotted, passing down to uniformly pale grey with well-preserved bivalves as above, *Pleuromya* at 24·18 m; *Pectinatites sp.* at 24·02 m	0·58	24·55
Core lost	0·05	24·60
Mudstone, pale brownish grey, slightly more shelly and more intensely spotted than above, tending towards oil shale; sharp base	0·01	24·61
Mudstone, medium and dark grey with crushed *Codakia* and *Protocardia* from 24·61 to 24·66 m; then sparsely shelly, paler from 24·74 to 24·80 m; *Pectinatites sp.* at 24·90 m; burrowfills of comminuted shell debris throughout ..	0·46	25·07
Core lost	0·43	25·50
Mudstone, medium to dark grey as above, sparsely shelly; passing down into	0·12	25·62
Mudstone, pale to medium grey, slightly silty, becoming darker and less silty with depth, *Camptonectes* cf. *morini* (de Loriol) at 25·65 m, *Modiolus autissiodorensis* (Cotteau) at 25·68 m	0·09	25·71
Core lost	0·14	25·85
Mudstone, medium to dark grey, sparsely shelly, chondritic mottling with pale grey burrowfills; a few tiny bivalves ..	0·15	26·00
Core lost	0·10	26·10

	Thickness *m*	*Depth* *m*
Mudstone, dark grey, sparsely shelly with several *Pectinatites sp.* at 26·20 m	0·16	26·26
Mudstone, pale to medium grey, slightly silty with irregular fracture, sparsely shelly with tiny bivalves, small *Oxytoma* at 26·35 m	0·14	26·40
Core lost	0·10	26·50
Mudstone, pale grey, slightly silty as above, a few small dark burrowfills and pyritized worm trails; becoming smoother and less silty below 26·40 m; passing down into	0·10	26·60
Mudstone, medium grey as above with shell fragments and a few well-preserved bivalves, *Camptonectes* at 26·83 and 26·90 m; some paler burrowfills with a network of very fine, straight, pyritized trails at 26·83 m; passing down into ..	0·32	26·92
Mudstone, pale grey, slightly silty with irregular fracture; sparse but well-preserved fauna with *Camptonectes* at 27·15 and 27·23 m; a few dark infilled burrows	0·33	27·25
Core lost	0·25	27·50
Mudstone, medium grey, slightly silty with irregular fracture and with paler burrowfills; passing down into	0·03	27·53
Mudstone, pale grey, slightly silty as above, with scattered thin-shelled calcite fauna, mostly bivalves, some as paired valves, *Grammatodon* at 27·60 m, *Oxytoma* at 27·75 m; becoming more densely calcareously cemented between 27·60 and 27·70 m; passing down into	0·27	27·80
Mudstone, medium grey, more shelly than above, becoming fissile in lower part	0·05	27·85
Mudstone, dark grey, smooth textured, more shelly from 27·90 to 28·00 m with *Pleuromya*, *Codakia* and foraminifera-spotted surfaces; more silty below 28·10 m and becoming medium grey below 28·18 m; becoming dark grey again and tending to sub-conchoidal fracture below 28·50 m; burrow-mottled junction with bed below	0·75	28·60
Mudstone, pale grey, slightly silty with darker burrowfills, darkening to medium grey with depth; sharp change at base	0·26	28·86
White Stone Band: mudstone, very calcareous, pale and very pale brownish grey, with soft earthy texture; very coccolith-rich, shelly with crushed *Lingula*, *Discinisca*, *Codakia*, *Protocardia*, and very fine-ribbed *Pectinatites* including *P.* (*P.*) *eastlecottensis* (Salfeld) at 28·90 m; finely interlaminated in part with darker laminae and with burrowfills of more bituminous material; passing down into	0·21	29·07
Oil shale, pale brown, moderately shelly, earthy textured with fragments of *Pectinatites sp.*; interburrowed base	0·10	29·17
Mudstone, medium to dark grey, smooth textured, becoming more silty, medium grey below 29·25 m; sparsely shelly, *Chlamys* at 29·66 m; sharp base	0·67	29·84
Oil shale, fissile, shelly, as above, with *P.* (*P.*) *eastlecottensis* at 29·87 and 29·90 m, faecal pellets and fish debris; passing down into	0·10	29·94

	Thickness m	Depth m
Mudstone, fissile, shelly, with dark grey matrix; fauna as above; *core break at base*	0·06	30·00
Mudstone, dark grey, smooth textured, sparsely shelly; *core break at base*	0·33	30·33
Mudstone, dark grey, moderately shelly, softened and disturbed by drilling; *core break at base*	0·07	30·40
Oil shale, fissile, brownish grey, shelly at some levels only	0·10	30·50
Mudstone, dark grey, softened and highly disturbed	0·08	30·58
Core lost	0·07	30·65
Mudstone, fissile, very shelly with *miniscula* plasters and *P.* (*P.*) *eastlecottensis* at 30·68 m; foraminifera-spotted with rare faecal pellets; sharp base	0·04	30·69
***Pectinatites* (*Arkellites*) *hudlestoni* Zone**		
Mudstone, dark grey, more shelly in highest 10 to 20 mm; disturbed by coring	0·15	30·84
Mudstone, pale to medium grey with darker burrowfills, sparsely shelly, passing down into	0·06	30·90
Mudstone, medium to dark grey, as above; passing down into	0·05	30·95
Mudstone, slightly silty, medium grey, moderately shelly with burrowfills of oil shale in lower part; *core break at base*	0·07	31·02
Mudstone, dark grey with slightly paler, more silty burrowfills; sparsely shelly with broken bivalves and fragments of coarsely ribbed perisphinctids appearing below 31·05 m; becoming more shelly and silty from 31·08 to 31·12 m; rapid transition at base	0·35	31·37
Oil shale; *core break at base*	0·02	31·39
Mudstone, medium to dark grey with scattered shells and comminuted debris, some concentrated in burrowfills; *Pectinatites* (*Virgatosphinctoides*) *encombensis* Cope at 31·43 m; becoming paler below 31·60 m; *core break at base*	0·31	31·70
Core lost	0·05	31·75
Mudstone, pale to medium grey, slightly silty, tending to sub-conchoidal fracture, sparsely shelly with broken shell fragments; large coaly, pyritized, wood fragment at 31·83 m; *core break at base*	0·13	31·88
Mudstone, fissile, very shelly	0·01	31·89
Mudstone, dark grey becoming slightly paler and more silty with depth, sparsely shelly; *core break at base*	0·31	32·20
Mudstone, pale grey, very slightly silty with burrowfills of darker grey; rough fracture; sparsely shelly with *Pectinatites sp.* at 32·26 m; probable shelly plaster at base	0·16	32·36
Mudstone, dark grey with weak chondritic mottling in paler grey and with large paler burrowfills; passing down into	0·14	32·50
Mudstone, slightly brownish grey, very shelly with faecal pellets; passing down into	0·02	32·52
Mudstone, dark grey becoming more shelly with depth; *Pectinatites sp.* at 32·53 m, *Chlamys* at 32·53 and 32·56 m; passing down into	0·08	32·60

	Thickness *m*	*Depth* *m*
Mudstone, pale grey, slightly silty, shelly and fissile alternating with less shelly; becoming very fissile and shelly at base; *Pectinatites* (*V.*) *sp.* at 32·78 m; sharp base	0·19	32·79
Mudstone, medium and dark grey, blocky, smooth textured with burrowfills of medium grey, slightly silty, more shelly	0·25	33·04
Core lost	0·06	33·10
Mudstone, dark grey as above, passing down into	0·10	33·20
Mudstone, medium grey, passing down into slightly silty, paler grey with dark grey burrowfills; well-preserved ammonites in the lower part including *Pectinatites* (*V.*) *sp.* at 33·32 m and *P.* (*V.*) aff. *encombensis* at 33·40 m; *core break at base* ..	0·30	33·50
Mudstone, medium to pale grey, slightly silty with darker burrowfills; sparsely shelly with a few well-preserved ammonites, *Pectinatites* (*V.*) *sp.* at 33·80 m, *P. sp.* at 34·10 m and *P.* (*A.*) cf. *hudlestoni* Cope at 34·43 m; sharp base ..	1·00	34·50
Mudstone, very dark grey, passing down into dark grey at 34·64 m; sparsely shelly with a few large crushed ammonites including *Pectinatites* (*V.*) *sp.* at 34·80 and 34·90 m; *core break at base*	0·40	34·90
Mudstone, medium grey, slightly silty with rough fracture; *core break at base*	0·16	35·06
Mudstone, dark grey, blocky with smooth texture; sparsely shelly with *Pectinatites sp.* at 35·34 m	0·32	35·38
Mudstone, medium grey, slightly more shelly and silty with foraminifera spotting from 36·10 to 36·20 m; *Pectinatites sp.* 35·57 m, *P.* (*V.*) aff. *reisiformis* Cope at 35·73 m, and *P.* (*V.*) *sp.* at 35·83 m; *core break at base*	1·02	36·40
Core lost	0·30	36·70
Mudstone, dark grey with medium grey burrow mottling; *core break at base*	0·08	36·78
Core lost	0·02	36·80
Mudstone, dark grey, blocky as above with a few large ammonites, *Pectinatites* (*V.*) *sp.* at 36·91 m	0·28	37·08
Mudstone, medium to pale grey with darker burrow mottling; becoming denser and slightly more calcareously cemented below 35·50 m; becoming paler, very calcareous from 37·70 to 38·10 m then becoming slightly darker and less calcareous with depth; sparsely shelly throughout with a few well-preserved ammonites, *Pectinatites* (*V.*) *sp.* at 37·44 m, *P.* (*V.*) aff. *reisiformis* at 37·52 m, *P.* (*V.*) *reisiformis densicostatus* Cope at 37·70 m and *P.* (*V.*) cf. *reisiformis* at 37·83 m; small *Astarte* at 38·20 m; passing down into	1·27	38·35
Mudstone, medium to dark grey, sparsely shelly	0·05	38·40
Mudstone, dark grey, with pale chondritic mottling; shelly; sharp base	0·02	38·42
Mudstone, medium to pale grey, blocky tending to sub-conchoidal fracture; becoming darker with depth; a few well-preserved ammonites including *P.* (*V.*) *reisiformis* at 38·50 m, many with epizoic oysters	0·14	38·56

	Thickness m	Depth m
Mudstone, medium to dark grey, slightly silty, more shelly than above; *Pectinatites* (*V.*) *sp.* at 38·60 m; becoming paler and denser with depth	0·04	38·60
Mudstone, pale to medium grey, dense, tending to sub-conchoidal fracture, sparsely shelly with a few well-preserved ammonites; *Pectinatites* (*V.*) *sp.* at 38·78 m	0·30	38·90
Oil shale, brownish grey as above with fish debris etc.; *core break at base*	0·02	38·92
Mudstone, dark grey, sparsely shelly; *Pectinatites* (*V.*) *sp.* at 39·08 m; *core break at base*	0·18	39·10
Mudstone, pale to medium grey, blocky with sub-conchoidal fracture; sparsely shelly; becoming darker with depth and passing down into	0·59	39·69
Mudstone, dark grey, blocky, sparsely shelly; *Pectinatites sp.* at 39·85 m; *core break at base*	0·16	39·85
Mudstone, medium to pale grey, becoming denser and paler below 40·05 m; sparsely shelly with ammonite fragments, *Pectinatites sp.* at 39·95 and 40·03 m; passing down into ..	0·48	40·33
Cementstone, densely cemented, pale to medium grey, almost barren; passing down into	0·19	40·52
Mudstone, pale grey with sub-conchoidal fracture; sparsely shelly with several small oysters at 40·79 m; passing down into	0·27	40·79
Mudstone, medium to dark grey, sparsely shelly; passing down into	0·11	40·90
Mudstone, pale to medium grey, slightly silty; paler with depth, becoming tough, with sub-conchoidal fracture approaching cementstone from 41·26 to 41·38 m; darker grey with a few large ammonites and oysters from 41·50 to 41·62 m; *core break at base*	1·10	42·00
Core lost	0·20	42·20
Mudstone, fissile, shelly, slightly brownish grey, tending to oil shale	0·02	42·22
Core lost	0·03	42·25
Oil shale, interbedded with thin (10 to 20 mm thick) beds of fissile mudstone; locally only sparsely fossiliferous but mostly shelly throughout; foraminifera-spotted; faecal pellets concentrated in burrowfills; crushed bivalves and ammonites, *Pectinatites* (*V.*) cf. *wheatleyensis* (Neaverson) at 42·26 m; sharp base	0·11	42·36
Mudstone, dark grey, fissile, shelly with plasters of *Codakia*, etc.; sharp base	0·06	42·42
Oil shale, as above	0·18	42·60
Mudstone, dark grey, fissile, shelly; passing down into ..	0·06	42·66
Oil shale, including thin beds of fissile, shelly mudstone ..	0·34	43·00
Mudstone, dark grey, fissile with thin beds of oil shale interbedded	0·25	43·25

	Thickness m	Depth m
***Pectinatites (Virgatosphinctoides) wheatleyensis* Zone**		
Mudstone, dark grey, blocky, sparsely fossiliferous, becoming more shelly with depth; *Pectinatites* (*V.*) *sp.* at 43·38 m; passing down into	0·20	43·45
Mudstone, fissile, dark grey, shelly; passing down into ..	0·09	43·54
Oil shale; sharp base	0·01	43·55
Mudstone, medium to pale grey, slightly silty, becoming darker and more shelly with depth	0·06	43·61
Mudstone, medium to dark grey, sparsely shelly; becoming more shelly with depth and passing down into fissile, shelly mudstone at base; *core break at base*	0·19	43·80
Oil shale, interbedded with thin, fissile, shelly mudstone; sharp base	0·25	44·05
Mudstone, medium to pale grey; alternations of fissile, shelly and slightly silty, less shelly beds; passing down into ..	0·07	44·12
Mudstone, dark grey, blocky, sparsely fossiliferous; passing down into	0·06	44·18
Mudstone, dark grey, fissile, shelly with interbedded thin oil shale beds; sharp base	0·23	44·41
Mudstone, medium to dark grey, sparsely fossiliferous; sharp base	0·15	44·56
Mudstone, dark grey, fissile, shelly, locally passing into oil shale; sharp base	0·04	44·60
Oil shale with a few beds of fissile, shelly mudstone up to 10 mm thick and with dark grey, muddy burrowfills, mostly shelly; *Pectinatites* (*V.*) *sp.* at 44·80 and 44·85 m, *P.* (*V.*) aff. *grandis* (Neaverson) at 44·87 m, and with pyritized plates of *Saccocoma* abundant from 44·80 to 44·82 m with a single plate at 44·90 m	0·40	45·00
Final depth		45·00

Borehole CSU 71/65

Drilled by m.v. *Whitethorn*, 11 to 13 December 1971.
National Grid reference: TF 5850 4676. Lat. 52°59·66′N, Long. 0°21·71′E.
Water depth: 30·0 to 33·5 m (tidal). Borehole datum: sea bed.
Institute Specimen Nos. CSE 1 to 422.

	Thickness m	Depth m
RECENT AND PLEISTOCENE		
Rock bitted, mostly sand and gravel ..	11·50	11·50
JURASSIC		
KIMMERIDGE CLAY		
UPPER KIMMERIDGE CLAY		
***Pectinatites (Arkellites) hudlestoni* Zone**		
Cementstone, pale grey, densely calcareously cemented, barren	0·20	11·70
Mudstone, pale grey becoming less calcareous with depth; sparsely shelly with poorly preserved bivalves; *Pectinatites* (*V.*) *sp.* at 11·90 m; passing down into	0·20	11·90
Mudstone, dark grey with paler burrowfills, blocky, softened down to 12·20 m; sparsely shelly but with thin fissile, shelly		

	Thickness m	Depth m
beds; *Pectinatites* (*Virgatosphinctoides*) aff. *pseudoscruposus* (Spath) at 12·52 m; *Astarte* and small oysters at 12·52 m; *Dentalium* at 12·64 m	0·90	12·80
Core lost	0·70	13·50
Mudstone, medium grey with darker burrowfills; sparsely shelly *P.* (*V.*) aff. *pseudoscruposus* at 13·50 m	0·06	13·56
Mudstone, dark grey, blocky, sparsely shelly becoming more shelly with depth, with *Codakia*, small oysters, *Dentalium* and serpulids	0·24	13·80
Oil shale, with thin beds of dark grey, shelly, fissile mudstone containing burrowfills of oil shale; *Pectinatites* (*V.*) *sp.* at 13·84 m, *Codakia*, small oysters and *Dentalium* common throughout; *Saccocoma* abundant at 13·88 m, with a single fragment at 13·97 m; *Chemnitzia* at 14·01 m, *Protocardia* at 14·28 m, *Discinisca* at 14·37 m	0·58	14·38
Mudstone, medium to dark, slightly brownish grey; sparsely shelly	0·04	14·42
Oil shale, fissile, shelly	0·08	14·50
***Pectinatites* (*Virgatosphinctoides*) *wheatleyensis* Zone**		
Oil shale, fissile, shelly with less shelly beds; *Pectinatites* (*V.*) *sp.* at 14·62 m; passing down into	0·20	14·70
Mudstone, dark grey, fissile, shelly; intensely foraminifera-spotted becoming brownish grey, less spotted in its lower part	0·10	14·80
Mudstone, dark grey, sparsely shelly with some shelly partings; *Pectinatites sp.* at 14·95 m	0·27	15·07
Mudstone, medium grey, sparsely shelly with a few large ammonites; *P.* (*V.*) aff. *pseudoscruposus* at 15·27 m; *Lingula* at 15·15 m; becoming darker, more shelly and fissile with depth; passing down into	0·33	15·40
Oil shale, brownish grey, shelly with *Codakia* plasters.. ..	0·10	15·50
Core lost	0·50	16·00
Mudstone, brownish grey, tending to oil shale, with burrowfills of medium grey mudstone; sparsely shelly, becoming more shelly with depth, with *Dicroloma* and small oysters; passing down into	0·10	16·10
Mudstone, dark, slightly brownish grey, shelly and intensely foraminifera-spotted; alternating with foraminifera-spotted bituminous shale which tends to oil shale; passing down into	0·30	16·40
Oil shale, brownish grey with dark grey mud burrowfills; shelly with *Codakia* plasters; *Opis* at 16·44 m	0·30	16·70
Core lost	0·15	16·85
Oil shale, as above	0·15	17·00
Mudstone, dark grey, locally passing into medium grey; blocky with irregular fracture; sparsely shelly	0·40	17·40
Core lost	0·20	17·60
Oil shale, brownish grey, with dark grey mud burrowfills; sparsely shelly but silty textured due to abundant calcareous microfauna; probably coccolith-rich	0·05	17·65

	Thickness m	Depth m
Mudstone, dark grey, sparsely shelly; passing down into ..	0·25	17·90
Mudstone, medium grey, locally passing into pale grey, sparsely shelly; some carbonaceous plant debris	0·13	18·03
Core lost	0·67	18·70
Mudstone, medium to dark grey, sparsely shelly; much damaged by drilling down to 19·00 m; *P.* (*V.*) aff. *wheatleyensis ?* at 18·71 m; *core break at base*	0·60	19·30
Core lost	0·20	19·50
Mudstone, medium to dark grey, sparsely shelly down to 19·60 m; then almost barren; locally foraminifera-spotted; *Astarte* and fish scales at 19·60 m	0·50	20·00
Core lost	0·30	20·30
Mudstone, medium grey, almost barren; locally faintly foraminifera-spotted	0·80	21·10
Core lost	1·00	22·10
Mudstone, pale grey, sparsely shelly with *Pleuromya* at 22·32 m	0·50	22·60
Mudstone, medium grey, sparsely shelly	0·40	23·00
Core lost	0·10	23·10
Mudstone, medium grey, sparsely shelly becoming almost barren with depth; shelly, foraminifera-spotted plaster at 23·55 m with *Codakia* and fish debris; *Protocardia* at 24·00 m, *Nanogyra virgula* (Defrance) at 24·20 m; passing down into	1·10	24·20
Mudstone, pale grey with dark grey burrowfills; almost barren	0·10	24·30
Mudstone, fissile, sparsely shelly, foraminifera-spotted, tending to oil shale; passing down into	0·15	24·45
Oil shale, brownish grey, fissile, shelly with *Protocardia*, *Modiolus autissiodorensis* and *Codakia* at 24·56 m; passing down into	0·12	24·57
Mudstone, pale brownish grey, sparsely shelly, smooth textured; becoming more calcareous with depth and passing down into pale grey at 24·70 m with a more fissile, brownish grey bed at 24·84 m; *core break at base*	0·43	25·00
Mudstone, medium grey, sparsely shelly; fish scales at 26·00 m, *Pectinatites* (*V.*) *sp.* at 26·10 m, terebratulid and tiny *Lingula* at 26·20 m	1·75	26·75
Core lost	0·20	26·95
Mudstone, dark grey, fissile and intensely foraminifera-spotted from 26·95 to 26·96 m; then alternating sparsely shelly and almost barren, with local foraminifera-spotting and darker, sooty with comminuted plant debris; passing down into ..	0·45	27·40
Mudstone, medium grey, sparsely shelly; *Pectinatites* (*V.*) *sp.* at 27·50 m, several *Protocardia* at 27·58 m; becoming dark grey below 27·60 m	0·30	27·70
Core lost	0·15	27·85
Mudstone, dark grey, almost barren with local foraminifera-spotting and sooty plant debris; *core break at base*	0·15	28·00
Mudstone, dark brownish grey, fissile, shelly, foraminifera-spotted; *Pectinatites* (*V.*) *sp.* at 28·17 m; tending to oil shale in lower part and passing down into	0·20	28·20

	Thickness *m*	*Depth* *m*
Mudstone, dark grey, almost barren; sooty plant debris down to 28·45 m; densely foraminifera-spotted from 29·10 to 29·20 m; *Pectinatites sp.* at 29·28 and 29·50 m, *Protocardia* and oysters at 28·77 and 29·10 m, *Grammatodon* at 28·90 m, *Lingula* at 28·25 m, *Discinisca* at 29·35 m	1·45	29·65
Oil shale, moderately shelly with dark grey mud burrowfills; sharp base	0·05	29·70
Mudstone, dark grey, smooth breaking, almost barren; passing down into	0·20	29·90
Mudstone, medium grey, slightly silty in part, almost barren, weakly foraminifera-spotted in part; *Pectinatites sp.* at 30·05 m; passing down into	0·30	30·20
Mudstone, medium to pale grey, almost barren	0·10	30·30
***Pectinatites (Virgatosphinctoides) scitulus* Zone**		
Mudstone, medium grey, almost barren with smooth fracture; disturbed by coring; *core break at base*	0·20	30·50
Oil shale, shelly, with some thin beds of dark grey, shelly mudstone; *Codakia*, *Astarte* and *Protocardia* common; *Pectinatites sp.* at 30·80 m; interburrowed base	0·30	30·80
Mudstone, pale grey, smooth textured, moderately shelly rapidly becoming much less shelly with depth	0·20	31·00
Core lost	0·20	31·20
Mudstone, medium to dark grey, sparsely shelly in upper part, but becoming shelly and fissile below 31·45 m; passing down into	0·35	31·55
Oil shale, alternating shelly and sparsely shelly; interburrowed base	0·15	31·70
Mudstone, medium grey, moderately shelly; *Pectinatites sp.* at 31·79 m; passing down into	0·10	31·80
Mudstone, dark grey, moderately shelly with *Astarte* and *Protocardia* common; passing down into	0·10	31·90
Oil shale, fissile, shelly, with thin beds and burrowfills of dark grey, barren mudstone; *Pectinatites sp.* at 31·94, 32·00 and 32·17 m, *P.* (*V.*) *sp.* at 32·18 m, *Dicroloma* at 31·94 m, *Discinisca* at 32·17 m, *Dentalium* at 32·18 m, *Codakia*, *Astarte* and *Protocardia* common; passing down into ..	0·28	32·18
Mudstone, medium to dark grey, moderately shelly; becoming plant-speckled and foraminifera-spotted below 32·20 m; passing down into	0·12	32·30
Mudstone, medium grey, shelly with some comminuted shell debris; passing down into	0·06	32·36
Cementstone, greyish brown, mottled oil shale, densely calcareously cemented; sparsely shelly with a few bivalve ghosts; burrowfills of medium and dark grey mudstone; passing down into	0·09	32·45
***Pectinatites (Virgatosphinctoides) elegans* Zone**		
Oil shale and fissile, brownish grey mudstone interbedded;		

	Thickness m	*Depth* m
sparsely shelly; small belemnite at 32·51 m; *Pectinatites* (*V.*) cf. *elegans* Cope at 32·55 m; passing down into	0·10	32·55
Mudstone, medium grey, shelly with burrow concentrations of shell debris; *P.* (*V.*) cf. *elegans* at 32·56 m, *Pectinatites* (*V.*) *sp.* at 32·62 m, *P. sp.* at 33·00 m; pectinid at 32·70 m, *Protocardia* at several horizons; burrowfills of oil shale at 32·62 m; becoming darker grey with depth, with thin oil shale bed at 32·80 m; smoother, medium grey below 32·80 m	0·45	33·00
Core lost	0·10	33·10
Mudstone, medium grey, moderately shelly with oil shale burrowfills; passing down into..	0·02	33·12
Oil shale, moderately shelly with burrowfills from above ..	0·04	33·16
Mudstone, medium to pale grey, sparsely shelly; interburrowed base	0·09	33·25
Mudstone, brownish grey, shelly, tending to oil shale; burrowfills of dark grey mudstone; becoming more uniformly shelly, dark grey below 33·40 m; *Pectinatites* (*V.*) *sp.* at 33·41 m, *P.* (*V.*) *elegans* at 33·45 m; *Camptonectes* at 33·40 m, *Dicroloma* at 33·45 and 33·55 m; interburrowed base	0·40	33·65
Oil shale, shelly with dark grey burrowfills	0·05	33·70
Core lost	0·10	33·80
Oil shale, as above; *Dicroloma* common at 33·81 m	0·05	33·85
Mudstone, dark grey, almost barren, with sooty plant debris; passing down into	0·10	33·95
Mudstone, dark grey, fissile, shelly; passing down into ..	0·05	34·00
Oil shale, shelly, fissile; *Pectinatites* (*V.*) *sp.* at 34·02 m; serpulid at 34·03 m	0·10	34·10
Mudstone, dark grey, shelly, fissile with oysters and other bivalves, and fragments of large ammonites; *Pectinatites* (*V.*) *sp.* at 34·56 m, *Protocardia* at 34·15 m, *N. virgula* at 34·25 m, *Inoceramus* at 34·40 m, many with secondary gypsum encrustation; plaster of foraminifera and bivalve spat at 34·50 m; passing down into	0·65	34·75
Mudstone, medium to dark grey, slightly sooty textured, almost barren; passing down into	0·45	35·20
Mudstone, dark grey, in part fissile, shelly; oysters at 35·30 m; passing down into	0·23	35·43
Oil shale, brownish grey, fissile, muddy burrowfills, moderately shelly	0·07	35·50
Mudstone, dark grey and slightly brownish grey, in part fissile and tending to oil shale; *Pectinatites* (*V.*) *sp.* at 35·76 and 35·85 m; passing down into	0·38	35·88
Mudstone, medium grey, sparsely shelly; *Pectinatites sp.* at 35·94 and 35·96 m; passing down into	0·12	36·00
Mudstone, dark grey with irregular rough fracture; shelly with *Protocardia* at 36·03 m, fish scales, *Pectinatites* (*Arkellites?*) *sp.* at 36·08 m and *P.* (*A.*) cf. *primitivus* Cope at 36·17 m; becoming smooth-textured below 36·12 m	0·20	36·20
Core lost	0·10	36·30

	Thickness m	Depth m
Mudstone, brownish grey, moderately shelly with *Astarte* and *Protocardia*; tending to oil shale; interburrowed in part with medium grey, shelly mudstone; irregular, cream-coloured, calcitic patches at 36·45 m; thin bed of medium grey mudstone at 36·50 m; passing down into	0·30	36·60
Oil shale, fissile, shelly with *Pectinatites sp.* at 36·81 m; *core break at base*	0·21	36·81
LOWER KIMMERIDGE CLAY		
Aulacostephanus (A.) autissiodorensis Zone		
Mudstone, medium grey, blocky, sparsely shelly	0·19	37·00
Core lost	0·10	37·10
Mudstone, medium grey as above; passing down into ..	0·55	37·65
Mudstone, medium, slightly brownish grey, locally tending to oil shale; sparsely shelly with *Aulacostephanus* at 37·70, 37·71 and 37·85 m and with small crushed iridescent and smooth *Aulacostephanus* at 37·83 to 37·85 m; passing down into	0·20	37·85
Mudstone, medium grey, blocky, sparsely shelly, *Astarte* at 37·90 m, *Thracia* at 38·10 m, *Aulacostephanus (A.) autissiodorensis* (Cotteau) at 38·30 m; *core break at base*	0·45	38·30
Oil shale, fissile, shelly, with *Aulacostephanus*; *core break at base*	0·10	38·40
Mudstone, medium to pale grey, sparsely shelly; *core break at base*	0·25	38·65
Mudstone, medium to dark brownish grey and sooty grey; moderately shelly in part with *Aulacostephanus*, mostly crushed and iridescent; passing down into	0·40	39·05
Mudstone, pale brownish grey, fissile, moderately shelly, foraminifera-spotted, tending locally to oil shale; *A. (A.) autissiodorensis* at 39·07 m; passing down into	0·20	39·25
Mudstone, medium grey, sparsely shelly with smooth fracture, becoming darker with depth	0·25	39·50
Core lost	0·10	39·60
Mudstone, dark grey, sparsely shelly with smooth fracture, sooty textured in part; *Oxytoma* at 39·85 m, *Lopha* at 40·00 m; damaged by drilling at 40·00 to 40·15 m; shelly plaster with *Plicatula* and *Aulacostephanus* debris at 40·40 m; fissile, shelly bed at 40·75 m; becoming medium to dark grey below 40·80 m; *Propectinatites?* at 41·10 m; shelly bed at 41·18 m; passing down into..	1·90	41·50
Mudstone, medium to dark grey, fissile, moderately shelly; passing down into	0·40	41·90
Mudstone, medium to pale grey, sparsely shelly	0·15	42·05
Mudstone, dark grey, fissile, shelly with *Aulacostephanus*; passing down into	0·20	42·25
Mudstone, medium and dark grey, alternating sparsely and moderately shelly, with *Aulacostephanus*; *Propectinatites sp.* at 42·50 m; shelly bed at 42·80 m	0·75	43·00
Final depth		43·00