

## KIMMERIDGIAN PALAEOENVIRONMENTS; A MICROPALAEONTOLOGICAL PERSPECTIVE

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The Kimmeridge Clay Formation of the Dorset Coast is a classic example of a succession of mudstones, claystones and muddy limestones deposited in a range of dysaerobic or anoxic environments. The various models presently available draw on both macro- and micropalaeontological data but fail to present a convincing picture of what is undoubtedly a complex depositional setting. It is suggested here that only by considering the complete structure of the food chain will it be possible to resolve some of the difficulties.

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### INTRODUCTION

The Late Jurassic Kimmeridge Clay Formation comprises a succession of organic-rich calcareous mudstones, claystones and siltstones. The stratigraphy of the succession is well known and has been divided into 48 "beds" on palaeontological and lithological grounds (Gallois and Cox, 1974, 1976; Gallois, 1979; Cox and Gallois, 1981). Deposition occurred during a period of eustatic rise with transgressive sediments being recorded in many areas. Water depths of 10-100 m are estimated over much of north-west Europe (Gallois, 1976). Because of the limited (probably silled) nature of the connections to the open ocean, the water column or the water/sediment interface became depleted in oxygen, leading to the deposition of organic-rich sediments. The Kimmeridge Clay Formation is also characterised by rhythmic alternations of lithologies that appear to indicate a variation in the intensity of the oxygen depletion. These have been attributed to Milankovitch cyclicality by House (1985, 1987). At the present time there are three principal palaeoenvironmental models which explain this complex depositional environment. These can be summarised as follows:-

- productivity model (Gallois, 1976);
- preservational model (Tyson *et al.*, 1979);
- palaeoceanographic model (Oschmann, 1988 or Miller, 1990).

Good summaries of all these models are available in Wignall (1989, 1994) and Scotchman (1989). Wignall (1994), gives a complete review of all the models related to black shale palaeoecology, including those produced by Rhoads and Morse (1971), Byers (1977) and Savrda *et al.* (1984). Wignall (1994, Fig.3.2) also provides a new model for oxygen-restricted environments and this will be further developed in this paper. The current limitation of nearly all such models is that there is minimal consideration of the lower levels of the food chain and this is now addressed.

### THE FOOD CHAIN

While the majority of oxygen-deficient models describe the macrofauna, few consider the mesofauna and fewer still describe the microfauna/flora, nanofauna/flora and picofauna/flora. The structure of the planktonic community is of critical importance and a useful summary is provided by Laybourn-Parry (1992). This community largely controls the supply of nutrients to the benthonic community, and - eventually - the more regularly recorded elements of the preserved macrofauna. This complex food web is still not fully understood (see Ducklow and Taylor, 1991) and, in applying it to the geological record, another level of uncertainty is added. A possible version of the microbial food web is shown in Figure 1. It is clear that, in the geological situation, there are two additional variables; the

preservation of the individual components and the evolutionary stage of the flora and fauna represented by the age under debate. Although many parts of the food chain will not be represented in the fossil record because of a lack of a preservable skeleton, shell, test or other structures, the presence of some parts of the chain will indicate that other components *must* have been present in the original environments.

In the Kimmeridge Clay Formation it is known that Foraminiferida, Ostracoda, dinoflagellates, calcareous nannofossils, spores, and pollen represent the preservable elements of the microfauna and microflora. Ciliates have not been recorded, and neither have diatoms, ebridians and silicoflagellates. The Foraminiferida are relatively little understood, having been studied only by Lloyd (1958, 1959, 1962) and Shipp (1989). Figure 2 shows the ranges of the four most important genera and the overall distribution of the Foraminiferida, plotted as the diversity of the non-nodosariacean fauna. Including the Nodosariacea generates a parallel curve with the major changes being at about the same levels. This diagram shows that the foraminiferal diversity decreases steadily from the Corallian (with more than 30 species represented) to a level of approximately 8 species by the lower part of the *Aulacostephanus eudoxus* Zone. This relatively poor fauna of *Ammobaculites* spp. and *Trochammina* spp. continues up to Cattle Ledge Stone Band, above which the fauna recovers slowly, although it never attains the diversity values of the Corallian. One can therefore identify four assemblages (A - D) in the Kimmeridge Clay Formation:-

- D - diverse fauna with miliolid foraminifera re-appearing
- C - reduced fauna dominated by *Ammobaculites* spp. and *Eoguttulina* spp.
- B - very reduced fauna with only *Ammobaculites* spp. and *Trochammina* spp.
- A - very diverse fauna with all groups present, including *Epistomina* spp.

Within any of these assemblages there are cyclical variations in response to changes in substrate generated by the Milankovitch-induced changes.

Within the Kimmeridge Clay Formation there are numerous coccolith-rich beds that can be recognised by their pale colour and reduced specific gravity. These bands are laterally persistent (Gallois, 1976) and can be correlated in many well sections across southern England. They are generally composed of only one species, *Ellipsagelosphaera britannica* (Stradner) as reported by Gallois and Cox (1974). Gallois (1976) used the presence of these coccolith "blooms" to develop his model of the Kimmeridge Clay environment.

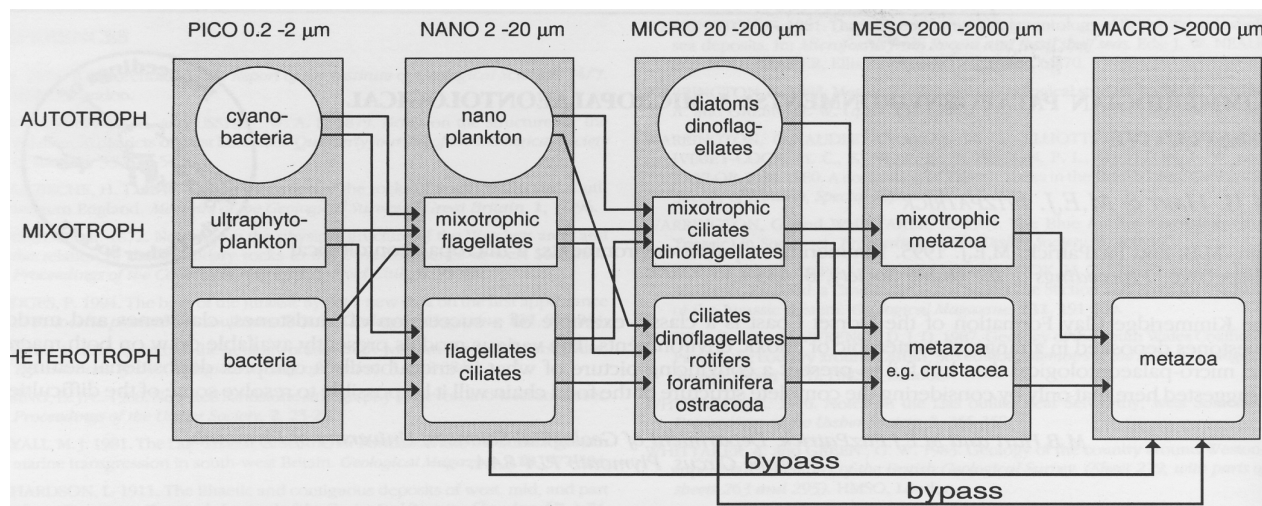


Figure 1. The microbial food web used in our work, which is a modified and extended form of that proposed by Ducklow and Taylor (1991).

The micropalaeontology (largely dinoflagellates) of the Kimmeridge Clay Formation have been described by Downie (1957), Ioannides *et al.* (1977), Riding (1984), Durr (1988) and Tyson (1989). It has been recognised that towards the margins of the basin there are more diverse floras, while in the central, more anoxic parts of the basin, there is a restricted flora with fewer taxa being represented. This may be a result of redeposition of cysts from the less hydrographically stable basin margins (Tyson, 1987). Durr (1988) also identified a difference in the predominant cyst morphology between southern Germany (chorate cysts) and the Boulonnais (proximate cysts), which may also reflect the differences in hydrographic regimes.

The Ostracoda of the Kimmeridge Clay Formation have been thoroughly studied by Kilenyi (1969), with Barker (1966a,b) producing data on the transition upwards into the Portland succession. The distribution of the ostracod fauna very closely mirrors that of the Foraminiferida. The *P. baylei* - *A. mutabilis* Zones have a rich and diverse fauna which declines progressively upwards. This exactly parallels the reducing foraminiferid fauna seen in assemblage "A" (see Figure 2). The *A. eudoxus* - *P. scitulus* Zones are almost barren - corresponding almost exactly to the "B" assemblage identified in Figure 2. The *P. pectinatus* - *P. rotunda* Zones contain a completely new assemblage that is less rich and diverse than that recorded from the lowermost Kimmeridge Clay. This fauna equates with the "C" and "D" assemblages shown in Figure 2. The ostracod faunas of the lowermost Kimmeridge Clay and those of the uppermost Kimmeridge Clay have only one species in common, so great is the change across the barren interval.

#### PALAEOENVIRONMENTAL MODELS

There are three basic models for the palaeoenvironment of the Kimmeridge Clay Formation. The models of Gallois (1976) and Tyson *et al.* (1979) derive their origin from analyses of the microfioras. The Gallois model relies on sudden "blooms" of coccospheres and dinoflagellates, which when sedimented, drained the oxygen from the waters immediately above the sediment/water interface. Recent work by Honjo (1976) and Haq (1978) indicates that coccospheres (with their coccoliths) are largely ingested by copepods within the water column, and are deposited as faecal pellets. Once within the sediment, bacterial activity will release the coccoliths into the sediment. As the coccoliths arrive at the sea floor already digested, the greater part of their organic content must surely have been extracted by the copepods. It would seem unlikely, therefore, that the process of sedimenting the coccospheres could occur without the intervention of the copepods and that the process would not generate, on its own, the oxygen-depleted environments postulated by Gallois.

The model of Tyson *et al.* (1979) is based on a full geochemical analysis of the sediments, a study of the organic-walled microfossils and on palynofacies analysis. It relies on comparisons with the modern Black Sea, where a highly stratified water column has developed widespread anaerobic bottom conditions. The Kimmeridgian palaeoenvironment was, however, much shallower than the Black Sea, but once a stratified water column has been developed, the depth to substrate below the postulated  $O_2$  -  $H_2S$  interface is largely irrelevant. As Wignall (1989) has shown, many of the beds within the Kimmeridge Clay Formation exhibit sedimentary structures indicative of storm events, and these limit the water depth available to the model.

The evidence from the distribution of the Foraminiferida appears to indicate that, within the *Aulacostephanus eudoxus* - *Pectinatites elegans* Zones, there was a fauna (Assemblage B) characterised by only *Ammobaculites* spp. and *Trochammina* spp.. Such agglutinated assemblages are often associated with low oxygen environments (see Koutsoukos and Hart, 1990, for a review of the literature). The immediately overlying Assemblage C is characterised by a fauna dominated by *Ammobaculites* spp. and *Eoguttulina* spp., another assemblage often associated with a reduced level of oxygen at the sediment/water interface. Assemblage C coincides with the "oil shales" in the Dorset succession. These are indicative of the highest levels of organic preservation within the sediment. As Assemblages B and C existed for a considerable period of time, it is unlikely that they were generated by the reduced oxygen conditions formed by the "blooms" postulated by Gallois (1976). Rather, the foraminiferid data supports the concept of a stratified water column. The different assemblages, therefore, record the presence of dysaerobic/anoxic water masses above the sea floor. The reduced diversity of dinoflagellates is also reminiscent of the stressed flora recorded in the Late Cenomanian by Hart *et al.* (1991). In the Late Cenomanian the dinoflagellate flora comprised few taxa but the stratified water mass associated with the Late Cenomanian global bioevent (Jarvis *et al.*, 1988) produced exceptional preservation in the Black Band of north-east England. Hart *et al.* (1991) show a close relationship between the reduction in the dinoflagellates and the increase in the abundance of calcispheres in the Late Cenomanian. Within the Kimmeridge Clay Formation, calcispheres are also abundant at certain levels (McQuaker, *pers. comm.*), although we have not observed these.

#### CONCLUSIONS

The micropalaeontological data available suggest that the productivity model of Gallois (1976), although perhaps important for

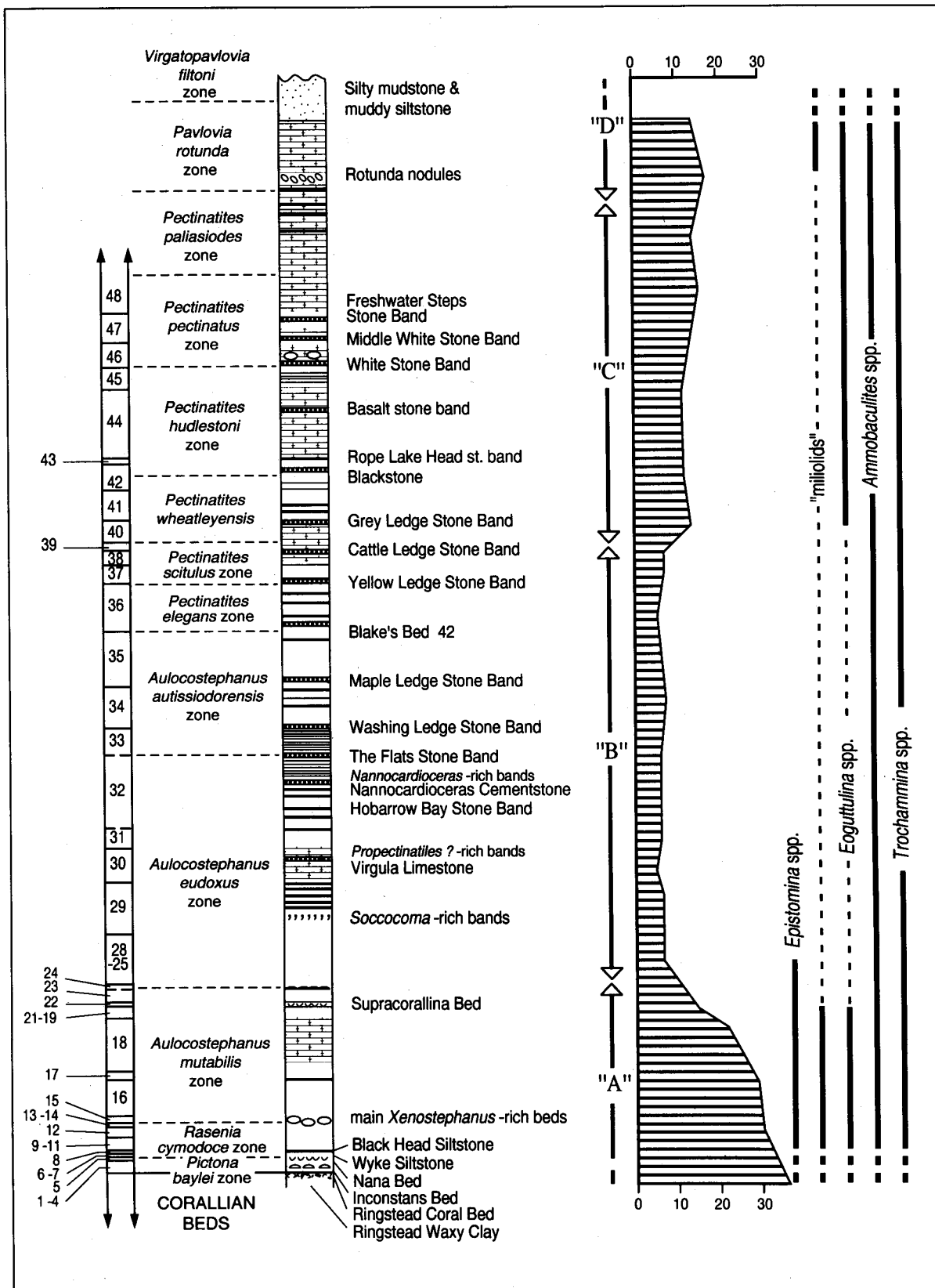


Figure 2. The lithological succession of the Kimmeridge Clay Formation using the standard notation described in the text. The diversity (total number of species present) graph is based on the non-nodosariacean Foraminiferida. The foraminiferal ranges shown are those of the four most common genera, together with the occurrence of the miliolids. Their distribution shows that between "beds" 21 and 40 there is only a reduced fauna of *Ammobaculites* spp. and *Trochammina* spp. For a full guide to the lithological succession refer to Scotchman (1989).

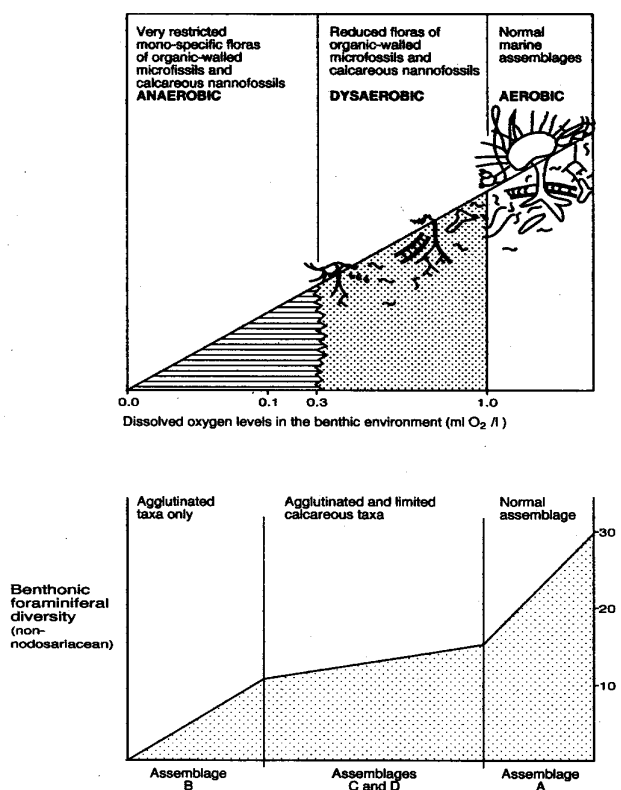


Figure 3. Palaeoenvironmental model adapted from that described by Rhoads and Morse (1971).

the formation of specific beds, is not the cause of a stratified water column. The local submarine configuration of the basin encouraged stagnation between the depositional highs, locally exacerbated by a lack of water column mixing, except at particular horizons (Wignall, 1989). The new depositional model proposed by Wignall (1994), which was developed from that of Rhoads and Morse (1971) can therefore be extended to include the micropalaeontological data shown in Figure 3. This model needs to be tested further using a more detailed sample set from the Kimmeridge Clay Formation and from other Jurassic organic-rich clays such as the Jet Rock Member of the Yorkshire coast. The additional work will involve the close sampling of some key cycles, especially those with a range of lithological types

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