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# Cretaceous sea level changes and global eustatic curves; evidence from SW England

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Recently published global eustatic curves for the Cretaceous have provided a target against which "real" data can be tested. Sea level curves for Southern England, and the event stratigraphy so generated, can be traced into Devon and tested with reference to shoreline facies, remaniée flint, chert and fossil occurrences. Calculations on the rates of change of sea level indicate that crustal subsidence may have been more important than previously recognised, even in SW England - an area currently used as a stable platform against which other subsidence and sea level rise could be calibrated.

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## Introduction

Publication of the Vail *et al.* (1977) and Haq *et al.* (1987) eustatic curves and sequence stratigraphy have revived an interest in global sea level changes. In 1969 Hancock presented a review of the way in which SW England was affected by the Late Cretaceous transgression(s) and, twenty years on, it would seem appropriate to review the situation as it relates to this area. As a summary to the 1979 Geological Society of London thematic volume on sea level changes Donovan and Jones (1979) reviewed the perceived wisdom on mechanisms and rates of change. Their data, together with more recent work, suggests the following mechanisms as controlling global sea level.

1. Changes in the volume of the hydrosphere - probably largely unchanged since 1500Ma (Mackenzie 1975).

2. Changes in the volume of LAND ice. Such calculations must ignore the loss of ice shelves, pack ice and icebergs, as these are floating and already displacing much of their volume of water. Melting of the land ice is the process of glacio-eustacy in the normal sense and provides for a maximum range of 150m. (Shumskiy 1969) at a rate of 1mm $a^{-1}$ or 1km $Ma^{-1}$. These figures allow for thermal expansion of the water column in a non-glacial world and also for the lowering of the oceanic crust by loading caused by the extra water.

3. Changes in the volume of the ocean basins. These can have variable tectonic causes but to have any global affect there must be full interconnection of the various ocean basins. One such mechanism might be the destruction of old, deep, ocean floor and its replacement by a new, shallower, ocean basin. This might well have been a contributing cause in the early development of the S Atlantic Ocean in the mid-Late Cretaceous. Such changes are, however, probably unquantifiable.

4. Changes in the volume of the mid-oceanic ridge systems. Changes in ridge volume, especially during enhanced spreading rates (Menard 1964; Hays and Pitman 1973) are thought to have been a particularly important mechanism, especially during a period such as the Cretaceous where little, if any, land ice was present on the Earth. The present volume of the oceanic ridge systems (Menard 1964) is quoted as 1.6x $10^8$km$^3$, which must be balanced against a present oceanic water volume of 1.35x $10^9$km$^3$. These figures indicate that the volume of the ridge systems, above the level of the deep oceanic basins, occupy a significant proportion of the space required by water. Any expansion or contraction of the ridge volume would therefore have a significant effect on overall sea level. The total range of such changes could be as high as 300m but with a rate of change being only around 10mm $ka^{-1}$ or 1km 100$Ma^{-1}$. Thus as far as the present discussion is concerned this mechanism produces *a maximum* rate of change of 10m $Ma^{-1}$.

Basin dessication may have a slight, short-lived affect (±15m), as may local sedimentation (probably largely negated by crustal subsidence). Changes in Earth radius and possible changes in the geoid have, for the purposes of this paper, been discounted or regarded as incalculable.

## Interpretation of data

Vail *et al.* (1977) and Haq *et al.* (1987) have based most, if not all, of their work on commercial seismic data. Such information is not usually available to the average field geologist, most of whom cannot agree on the interpretation of their raw field data. This problem was admirably demonstrated by Hancock and Kauffman (1979, fig. 3), using the example of a Late Cretaceous cyclothem from the Western Interior Seaway (USA). The majority of workers proposing such sea level changes, generally ignore still-stands, basin subsidence, sediment compaction and the *source* of the sediment (pelagic v. terrestrial). If the interpretation of the initial data is suspect, then attempts at the correlation of such sea level curves (Matsumoto 1977; Christensen 1984; Young 1986) must be treated with total suspicion. Very few of the authors who's data were compared by Young (1986) actually regarded sea level changes as being a cumulative process. Hancock and Kauffman (1979), however, have provided a cumulative curve for the mid-Late Cretaceous which many have found to be generally acceptable. Hancock (1989) has recently produced a more detailed update of his mid-Late Cretaceous curve, again using only relative sea level values. The distinct peak in the latest Campanian that was prominent in his 1976 curve is still easily identifiable. In their 1979 paper, however, Hancock and Kauffman suggest, by a number of arguments, that rates of change can be calculated and to do so they made use of the data provided by the residual flint gravels on the Haldon Hills and at Orleigh Court, both of which are in SW England. The rates of change they obtained include figures of 27m $Ma^{-1}$, 95m, $Ma^{-1}$, 90m $Ma^{-1}$, 46m $Ma^{-1}$, 10.5m $Ma^{-1}$and 170m $Ma^{-1}$. All of these, apart from the figure of 10.5m $Ma^{-1}$, are well in excess of anything the available mechanisms could produce, and certainly well beyond those predicted by Cretaceous seismic stratigraphy.

## Relative sea level changes in the mid-Late Cretaceous

Relative changes in sea level, as indicated above, are notoriously difficult to document. Hart and Bailey (1979) and Hart (1980) used a *combination* of planktonic:benthonic ratios coupled with planktonic foraminiferal morphogroups to attempt to model sea level changes in the mid-Cretaceous. The actual planktonic:benthonic ratios have never been used by the author to calculate depth of deposition, partly because such a direct interpretation is probably flawed, but also because it is well-known that some planktonic foraminifera are preferentially destroyed during preservation (Curry 1982) and even during sample preparation. In general terms, however, there is an indication that an abundance of planktonic individuals, coupled with the presence of appropriate deeper-water morphotypes, indicates deeper water conditions. The planktonic:benthonic ratios can also be influenced (=distorted) by a lack of benthonic taxa, as may well be the case in the Turonian (Leary and Wray 1989). At the same time however we have the occurrence of a diverse, keeled, deeper-water, fauna which can be taken to indicate deeper-water conditions on its own merit.

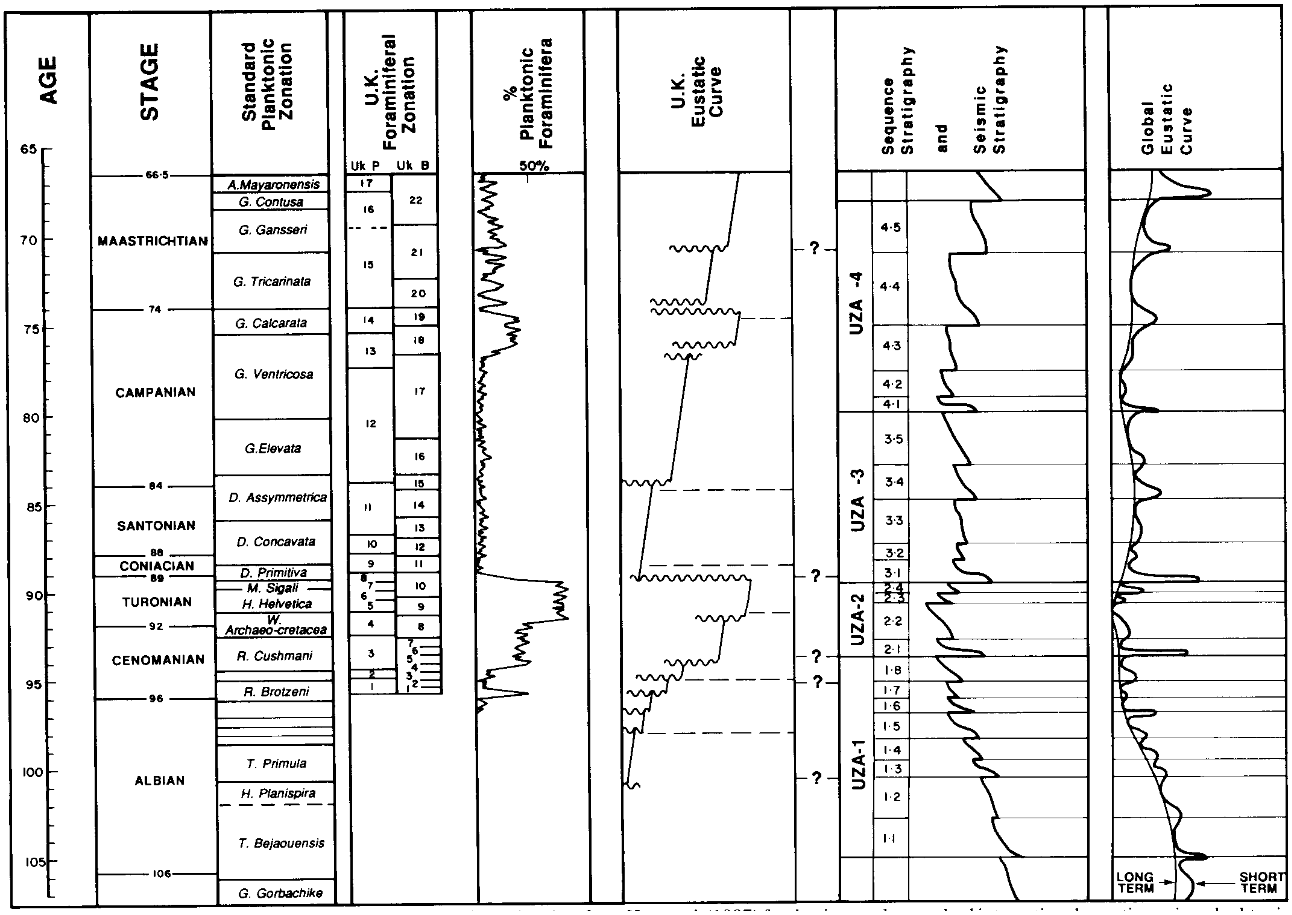


Figure 1. Compilation of the mid-Late Cretaceous succession using data from Haq *et al.* (1987) for the time scale, standard international zonation using planktonic foraminifera, sequence stratigraphy and global eustatic curve. The UKB (Benthonic foraminifera) and UKP (planktonic foraminifera) zonations are based on the definitions in Hart *et al.* (1989). The planktonic:benthonic ratio is a composite succession based on sections in the Isle of Wight, Kent, Norfolk and boreholes immediately off-shore Norfolk. Correlations between sections in southern England have confirmed that the pattern, as presented, is characteristic of the UK. The total number of samples used in the plot is over 750, with the planktonic:benthonic ratio plot being based on counts of 500 specimens in the 250-500μm grain size fraction of every sample (i.e. over 375,000 specimens). Using the other size fractions to obtain data for the palaeoecological interpretations has raised the total data base for the sea level curve to over 1,500,000 specimens.

As indicated by Hart (1980) and the present data (Fig. 1) the mid-Late Cretaceous is characterised by long periods during which the planktonic:benthonic ratio (and other indicators) remain constant. These intervals appear to indicate a relatively constant water depth and this situation is confirmed by the gradualistic changes seen in the benthonic fauna. To maintain a constant water depth either sea level is rising gradually to accommodate sedimentation or the basin is subsiding at a comparable rate. In the chalk succession there are known omission surfaces and faint dissolution surfaces (clay wisps) but in general the sediment (under the SEM) shows little evidence of strong compaction; particularly in the on-shore successions. Clearly the curve shown in Fig. 1 is the resultant of all these controls. The planktonic:benthonic ratio plot is based on suites of samples at 1m (or less) intervals throughout the whole UK succession, all of which were located within microfossil and macrofossil zonations. In all these samples counts of foraminifera (normally 300 to 500 in each size fraction) have provided the data for the interpretation of planktonic foraminiferal morphogroups and indications of palaeoecological change in the benthonic fauna. The methodology used in the constructions of the lower part of the resulting sea level curve was described in detail by Hart (1980) and this has been extended using data from the Santoniun-Maastrichtian interval. The percentage of planktonic foraminifera in the Late Cretaceous shows a tremendous change in the Middle and Late Cenomanian, with a maximum level being attained in the Early to mid-Turonian. In the latest Cenomanian a mid-layer oxygen minimum zone (Jarvis *et al.* 1988, and references therein) expanded right across the NW European Continental Shelf. This was the only time at which this occurred (Hart and Duane 1989) in the Cretaceous succession. In the Late Campanian there is an increase in the planktonic component, and this continues into the Maastrichtian. In this case, unlike the Turonian, the planktonic population is composed largely of *Archaeoglobigerina spp.* and *Rugoglobigerina spp.* and not typically deeper-water taxa such as *Globotruncanita, Contusotruncana* and *Gansserina,* all of which are known from coeval sediments just off the Continental Shelf of SW England (Ball 1985).

As a result of these considerations a UK sea level curve has been produced (Fig. 1) which does not have the customary Late Campanian maximum, but in many other respects closely mirrors the data of Haq *et al.* (1987). It must be remembered, however, that interpretations based on foraminiferal distributions and those based on the seismic response to sedimentary onlap-offlap successions are likely to be slightly (or even significantly) different.

## Evidence from SW England

In SW England (Fig. 2) the mid-Late Cretaceous successions were deposited in relatively shallow water and for a part of this interval some of the area may have been an island or a series of islands. There have been several attempts at documenting the submergence of this area. Smith (1961) used data from detrital mineral assemblages to argue that the Dartmoor granite was exposed during the deposition of the Foxmould Sands but that the whole area was below sea level from the Early Turonian onwards. Hancock (1969) accepted nearly all

Smith's data, but claimed that the granites of SW England were not a major source of sediment during the Late Cretaceous. He concluded, however, that the whole of Devon and Cornwall were below sea level during the latter part of the Late Cretaceous. The evidence for this comes from the well-known flint gravels of the Haldon Hills and Orleigh Court.

The Haldon Hill flint gravels, of presumed Eocene age, contain a wide variety of macrofossils (Jukes-Browne 1902; Jukes-Browne and Hill 1904, pp. 132-133; Wood, in Selwood *et al.* 1984) which range in age from the *Terebratulina lata* Zone to the *Belemnitella mucronata* Zone (Fig. 2). At Orleigh Court, in North Devon, Rogers and Simpson (1937) have described an extensive fauna that includes elements from all the zones between the *Sternotaxis planus* Zone and the *Belemnitella mucronata* Zone. Hancock (1969) and Hancock and Kauffman (1979) used the elevation of both these localities, added onto which was an allowance for water depth and an estimate of the thickness of the zones represented (in Norfolk!) in order to calculate the eventual height of sea level at the maximum transgression (Late Campanian). While Hancock (1969) appeared to accept the errors involved in such calculations, Hancock and Kauffman (1979) used them to calculate the very rapid rates of sea level change outlined above. The assumption in all these predictions is that there was little or no crustal subsidence in SW England. Recent work in Southern England, the Western Approaches Basin and the North Sea Basin indicates that this assumption is invalid.

## Basin analysis

In his account of the petrology of the chalk Hancock (1976, table III) listed the thicknesses of chalk in the various zones and calculated rates of sedimentation. Fig. 3 shows a sediment thickness plot for the Late Turonian-Maastrichtian interval, based on the Culver CliffWhitecliff Bay section on the Isle of Wight. This plot commences after the Late Turonian regressive event in the *S.planus* Zone. In total some 290m of chalk are present in the section, which terminates in the *B.mucronata* Zone. The maximum rate of sea level rise allowable by *a continuous* increase in oceanic ridge volume would be 10m $Ma^{-1}$ operating over a period of 13 Ma. This would give a total sea level rise of 130m, unless some other mechanism was operative. The change in physical water depth (sea level to sediment interface) between the Late Turonian and the mid-Campanian is estimated (on microfaunal data) as being about 150m and this, added to the sediment thickness (290m) gives a total sea level rise of 440m. As only 130m can be found from oceanic ridge expansion, this leaves approximately 310m to be obtained from compaction, dissolution and crustal subsidence.

Using these data and the predicted sea level curve based on the foraminifera (Fig. 1) it is possible to plot a subsidence history. Fig. 4 shows an imaginary section from Dartmoor (plotted as present day height), Haldon Hill, and the Isle of Wight. The baseline of the diagram is the bottom of the Cenomanian. This is located at the base of the uppermost Upper Greensand on the Haldon Hills (cf. Hamblin and Wood 1976) and the base of the chalk succession at Culver Cliff, Isle of Wight. To make these plots comparable the datum for the Isle of Wight succession (at 150m) is based on the sea level for the earliest Cenomanian, determined by the Haldon Hills succession. Using the sea level changes determined by the microfaunas and the general rate of sea level rise calculated from the ridge expansion model, it is anticipated that sea level would rise, fall and rise again to the levels recorded across the diagram. This gives a maximum mid-Campanian value at about 530m. When one adds the total thickness of the Cenomanian to mid-Campanian strata to the water depth anticipated for the mid-Campanian the level for the *B.mucronata* Zone rises to 840m. The difference, 310m, must be the crustal subsidence. It is impossible to say if the whole of Southern England, including

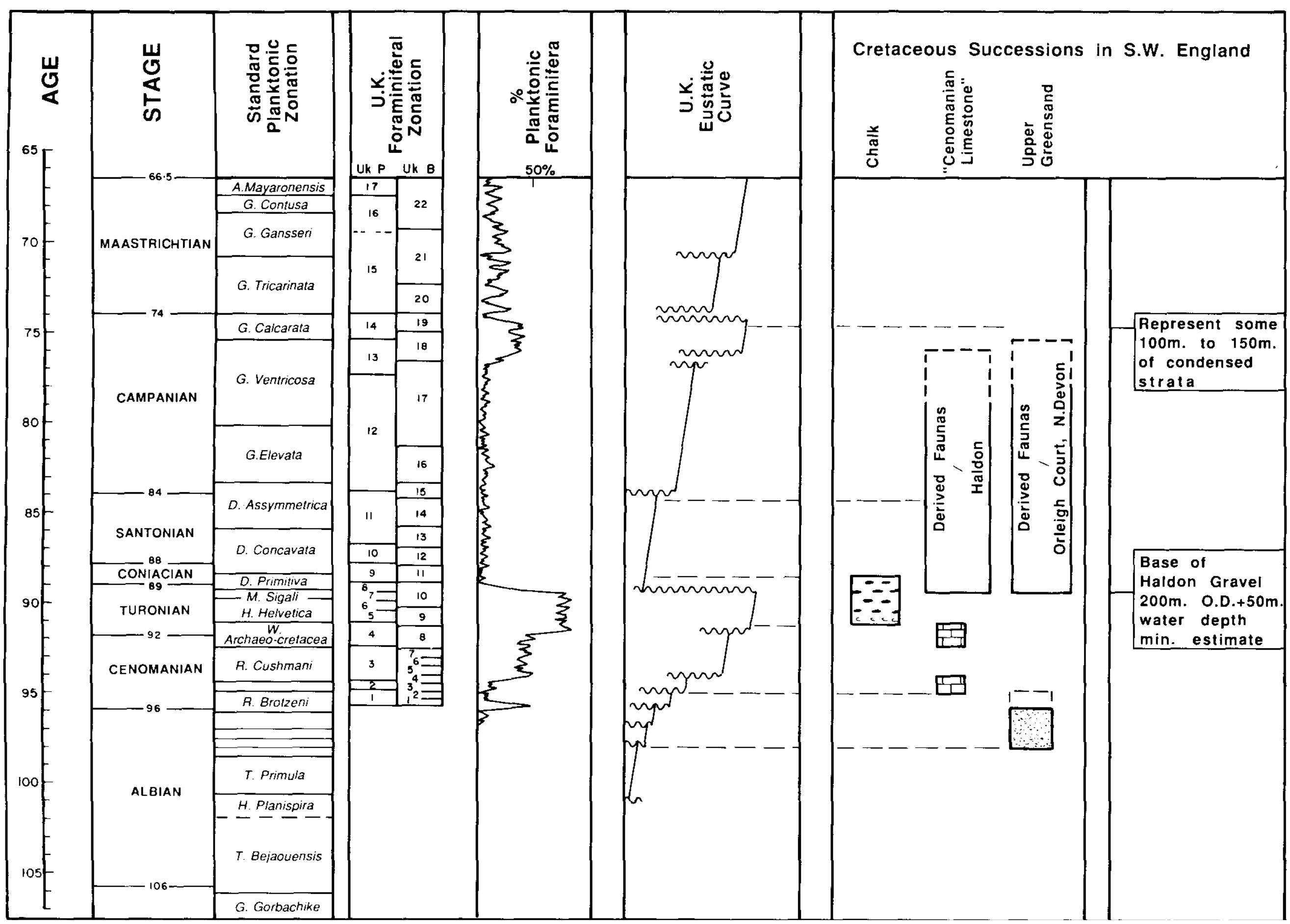


Figure 2. Data from Fig. 1 incorporated with data from the Cretaceous successions of SW England (including the derived faunas of the Haldon Hills and Orleigh Court).

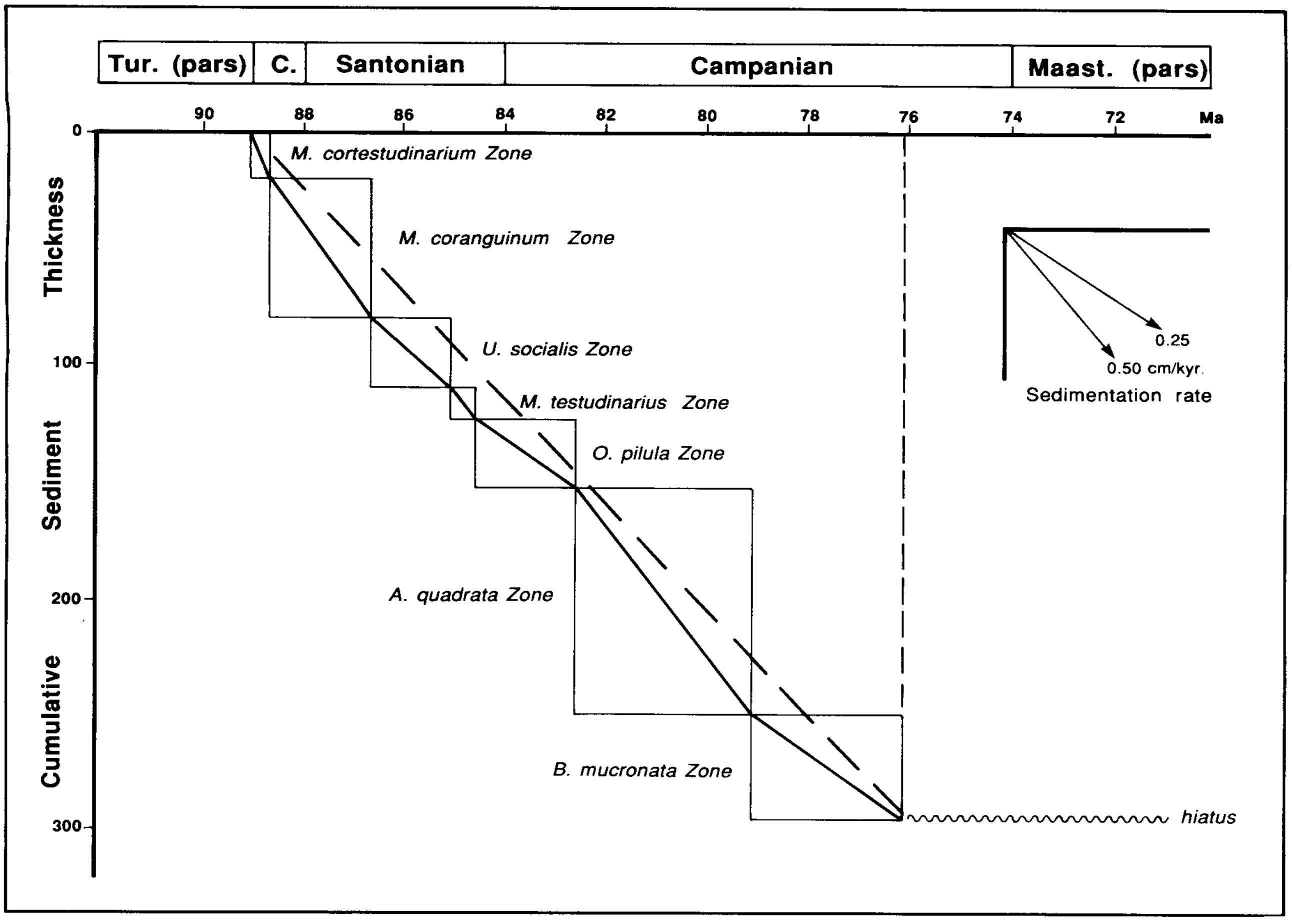


Figure 3. Time-subsidence curve for part of the chalk succession at Culver Cliff-Whitecliff Bay (Isle of Wight). For full description see text.

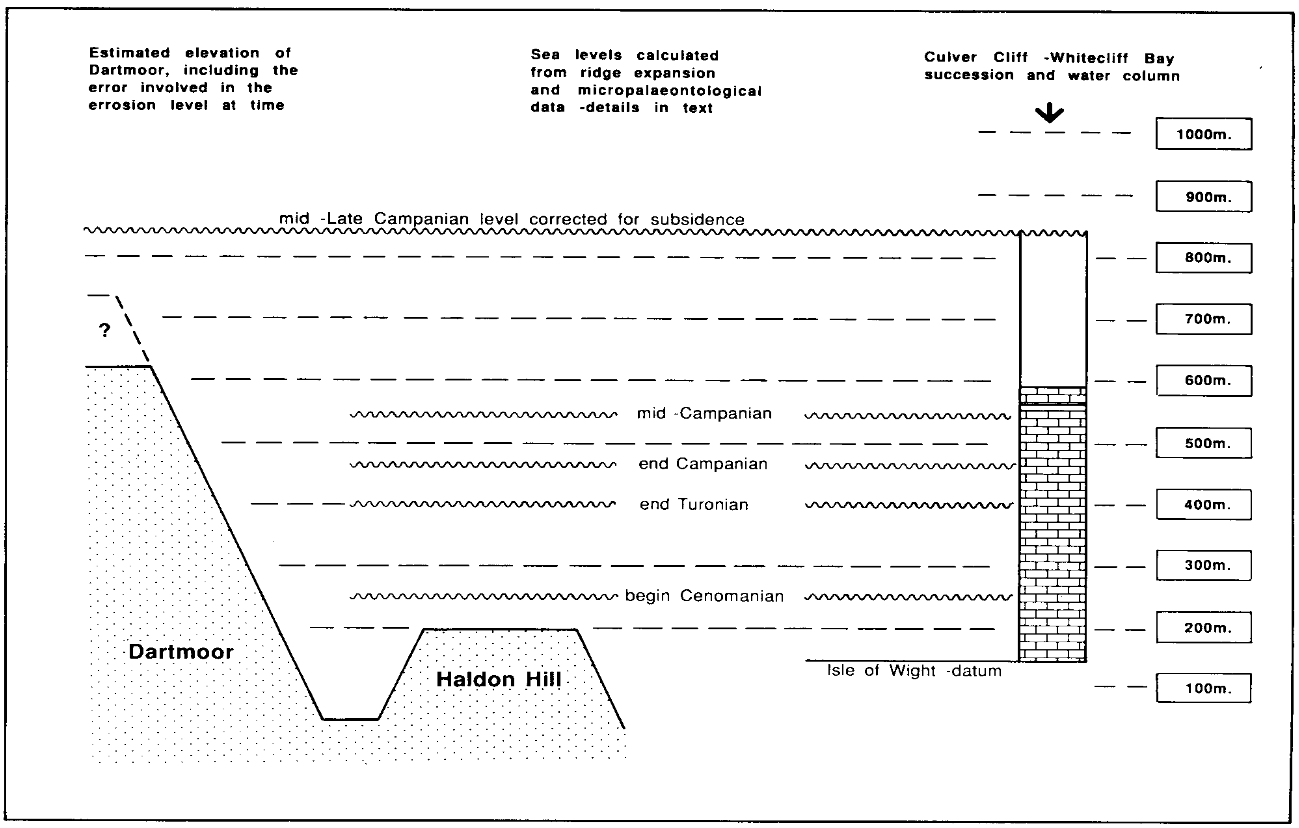


Figure 4. Sea level change, water depth predictions and basin subsidence model for southern England.

Dartmoor, subsided at this rate. If it has done so then the mid-Campanian sea level was some 225m above the present topographical height of the granite. These figures are probably meaningless, especially as Dangerfield and Hawkes (1969) have estimated that present erosion has penetrated some 50-200m into the granite. What level of erosion was present during the Cretaceous is therefore impossible to determine. As indicated in Fig. 4, Dartmoor may have been inundated by as much as 100-200m depending on the topographical height of the granite batholith.

The predicted subsidence of 310m over the Isle of Wight gives a rate of 17mm $ka^{-1}$. Sediment accumulation diagrams drawn in the same way by the author for the Tertiary sediments of the Whitecliff Bay (Isle of Wight) succession give rates of approximately 35mm $ka^{-1}$. Clearly it is difficult to make comparisons with the Cretaceous figure as the sediments are very different and the time-scales involved rather shorter. Geophysics will have to show if the subsidence figure of 17mm $ka^{-1}$ is a realistic value, but that is beyond the scope of this paper.

## Summary

A sea level curve for the mid-Late Cretaceous has been constructed using micropalaeontological data and compared to published eustatic curves and sequence stratigraphy data. Using this information and data from the marginal successions in SW England, a model for Cretaceous sea level rise and crustal subsidence has been constructed. This indicates that crustal subsidence is more important to the development of the succession than simple sea level rise. In SW England it is very difficult to say how the granite batholith and surrounding country rocks would have behaved in terms of subsidence and/or uplift. The model developed here would lead to the area being a series of dwindling islands throughout the Turonian-Early Campanian interval, with total submergence being possible in the Campanian and Early Maastrichtian. It is interesting to speculate on what effect this would have had on the kaolinisation process and the hydrothermal circulation process demanded by Durrance and Bristow (1986) for kaolin formation.

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