Read at the Annual Conference of the Ussher Society, January 1991

Sea-level changes across the Albian-Cenomanian boundary in south-west England

M.D. SIMMONS, C.L. WILLIAMS and M.B. HART

Simmons, M.D., Williams, C.L. and Hart, M.B. 1991. Sea-level changes across the Albian-Cenomanian boundary in south-west England. *Proceedings of the Ussher Society, 7,* 408-412.

The marginal Albian-Cenomanian sediments of south-west England provide an ideal succession in which to study sea-level changes. The recognition of maximum onlap, facies variations and hardground surfaces, has enabled a sea-level curve to be established for the late Albian-Middle Cenomanian of this area. The curve shows a gradual sea-level rise during the *inflatum* Zone, reaching a peak in the basal *rostratum* Subzone *(dispar* Zone). A sea-level fall throughout the majority of the *dispar* Zone reaches a trough in the basal Cenomanian *(carcitanensis* Subzone). A subsequent rise in sea-level reaches a peak in the lower part of the *saxbii* Subzone. Sea-level falls to a low in the *dixoni* Zone and there is a short transgressive-regressive cycle in the *costatus* Subzone, after which a general sea-level rise is indicated. This sea-level curve is compared with the global curve of Haq *et al.* (1987) and the more localised curve for Britain by Hancock (1989). Whilst there are some similarities with the Haq *et al.* curve, there is less similarity with that of Hancock. The curve for south-west England compares favourably with the transgressions and regressions documented in the Paris Basin and Armorican Massif regions by Juignet (1980).

M.D. Simmons, Exploration Technology Branch, BP Research Centre, Sunbury-on-Thames, Middlesex TW16 7LN.
C.L. Williams, Tethyan Consultants, Branshaw House, Downgate, Callington, Cornwall PL17 8JX. M.B. Hart, Department of Geological Sciences, Polytechnic South West, Plymouth, PL4 BAA.

Introduction

In the 1970's stratigraphers in EXXON developed a new way of looking at sedimentary successions. Initially using relationships seen in seismic sections, but later also using outcrop and well data, the method breaks a rock succession up into packages or "sequences". The basic premise of this technique is that sea-levels have fluctuated throughout geological time, either due to glaciations or through volumetric changes caused by plate movements and variations in sea-floor spreading rates. Cycles of sea-level change occur at several orders of magnitude. Short-term fluctuations lead to the development of sequences, the fundamental unit within the EXXON method. A sequence is a genetically related package of rock bounded by unconformities or their correlative conformities (Van Wagoner *et al.* 1988). A sequence can be further subdivided into systems tracts. These show the distribution of facies across the shelf and basin during given periods of the sea-level change (eustatic) cycle. Each systems tract is characterised by particular sedimentary and seismic geometries, facies relationships and fossil biota. Three main systems tracts can be recognised within a given sequence: a lowstand systems tract developed during a eustatic fall in sea-level; a transgressive systems tract developed during sea-level rise; and a highstand systems tract developed at and directly after sea-level has risen to its maximum in that cycle. Also of importance is the maximum flooding surface. This represents the time of maximum transgression. It is often represented by condensed sedimentation.

Notwithstanding certain reservations about the methodology and global applicability of sea-level change, "Sequence Stratigraphy" became widely publicized following publication of AAPG Memoir 26 (Payton 1977) and the technique was widely accepted and utilized in the oil industry. It is fair to say that its employment by academic geologists has been slower, perhaps because they do not have access to as complete a seismic dataset as industry geologists. The technique is an exciting one for two main reasons. Firstly, it draws all the different types of data on a sedimentary succession (seismic, sedimentology, biostratigraphy, etc) together, and allows for a lucid picture of basin history to be drawn. Secondly it is a highly predictive technique. Fades out of the area of study can be predicted by reference to the systems tracts they will fall in.

As noted above, one of the fundamental tenets of sequence stratigraphy is that sea-levels have fluctuated in a given manner world-wide through geological time. A number of so-called "sealevel curves" have been produced documenting this, with the most important recent work being that of Haq *et al.* (1987). This shows a global pattern of synchronous sea level changes and thus a myriad of systems tracts which theoretically should be recognisable world-wide, assuming no local tectonic controls and suitable marine successions in a passive margin setting. Hancock (1989) has produced a sea-level curve specifically for the Cretaceous of the British region, and there are several others some of which are referred to below. A problem with the Haq *et al.* (1987) curve is that it is often based on observations made on basinal successions. It is better to document sea-level changes from marginal areas where even small fluctuations in sea-level are likely to result in major facies changes. During the Albian - Cenomanian period, south-west England was such a marginal area. It therefore provides an ideal opportunity to develop a sea-level curve and compare this against those already published for this time period. However, it should be noted that any local sea-level curve is a function of the combination of subsidence, sediment supply and eustatic sea-level change. Each of these factors will be of varying significance, although in this particular instance most significance is placed on the eustatic variation. It is also interesting to re-examine the Albian - Cenomanian succession of south-west England within the context of sequence stratigraphy. This may shed light on the depositional environment and correlation of these problematic deposits.

The south-west England succession

Early studies on the Albian - Cenomanian succession of south-west England (eg. Jukes-Browne and Hill 1900, 1903) recognised that it was more marginal in nature than the basinal succession seen in south-east England. This has been confirmed and expanded upon in later, more detailed studies of sedimentology and fossil faunas (eg. Smith 1957,1961, 1965; Tresise 1960; Hancock 1969; Kennedy 1970; Hart 1973. 1982, 1983; Ali 1975, 1976; Hamblin and Wood 1976; Carter and Hart 1977; Jarvis and Woodroof 1984; Williams 1986; Garrison *at al.* 1987; Williams *et al.* 1988; Hart and Williams 1990).

In south-west England the Late Albian - Middle Cenomanian is represented by the Upper Greensand and the Cenomanian Limestone, and their equivalents (Fig. 1).

The Upper Greensand of the south-east Devon coast is divided into the Foxmould Sands, Chert Beds and Top Sandstones (Jukes Browne and Hill 1900; Tresise 1960) and has recently been described by Williams (1986), Garrison *et al.* (1987) and Williams *et al.* (1988). A new formal lithostratigraphy is in preparation. The Foxmould Sands are burrowed, glauconitic fine sands and silts with occasional limestone beds. They are separated from the overlying Chert Beds by a hardground. The Chert Beds are mud-free carbonate-cemented sandstones with large chert nodules and large burrow systems. Phosphatic pebble beds also occur. The Top Sandstones are a thin, coarse carbonate-cemented sandstone or loosely cemented limestone. The age of the Upper Greensand is not well established. Ammonites are scarce, but Late Albian *auritus* and *varicosum* subzone faunas are known from the Foxmould Sands (Hancock 1969; Williams *et al.* 1988). Micropalaeontological evidence suggests that the Foxmould Sands may be as young as *rhotomagense* Subzone (Willians *et al.* 1988) (Fig. 1). Suggestions by Hart (1971, 1973) and Carter and Hart (1977) that the Chert Beds are Cenomanian, using microfauna, have been refuted by the record of a *dispar* Zone ammonite fauna near the top of the Chert Beds at Shapwick Grange Quarry, south-west Dorset (Hamblin and Wood 1976). This fauna is most likely from the higher part of the *dispar* Zone (H.G. Owen, pers. comm.). It is probable that the highest part of the Chert Beds and the Top Sandstones extend into the basal Cenomanian *carcitanensis* Subzone. Orbitoline foraminifera from this level provide only equivocal evidence (Simmons and Williams, in press).

The Cenomanian Limestone (Smith 1957) has been renamed the Beer Head Limestone formation by Jarvis and Woodroof (1984) and the classic Al, A2, B and C divisions first described by Jukes-Browne and Hill (1903) (but following Meyer 1874), formally redescribed and renamed the Pounds Pool, Hooken, Little Beach and Pinnacles Members respectively. Each member is bounded by a hardground, and each member also shows marked thickness variations, perhaps related to local tectonic controls (Smith 1957, 1961,1965; Drummond 1970; Hart 1971,1982; Jarvis and Woodroof 1984). The Beer Head Limestone Formation has been thoroughly described by Jarvis and Woodroof (1984). It consists of bioclastic detritus-rich limestones and locally intraformational conglomerates and phosphatic pebble beds. The age of the constituent members of the Beer Head Limestone is well established by ammonite faunas (Kennedy 1970; Juignet and Kennedy 1976; Wright and Kennedy 1981; Jarvis and Woodroof 1984). The Pounds Pool Member can be referred to the higher part of the *carcitanensis* Subzone, the Hooken Member to the *saxbii* subzone, and the Little Beach Member to the upper *dixoni* Zone and lower *costatus* Subzone. The Pinnacles Member contains a fauna indicating a position between the *geslinianum* Zone and *judii* Zone (uppermost Cenomanian - *gracile* Zone of authors). As noted by Carter and Hart (1977) and Hancock (1989) the ammonite faunas of the Beer Head Limestone are often in a phosphatised condition and may be reworked. Carter and Hart (1977) went as far as to question some of the ages suggested by the ammonite faunas, noting that foraminifera are more likely to be indigenous. However, for the purposes of this study we accept the ammonite evidence (largely documented by Kennedy 1970) which is also supported by other macrofossil data (Kennedy and Hancock 1976).

To the east and north of the south-east Devon coast, the Beer Head Limestone is locally replaced by the Wilmington Sands. Kennedy (1970) has demonstrated that these sands are broadly equivalent to the Pounds Pool and Hooken Members of the Beer Head Limestone. The Wilmington Sands overlie coarse, shelly Upper Greensand similar to the Eggardon Grit of farther east (and thus probably basal Cenomanian). The lower Wilmington Sands probably equate to the Pounds Pool Member and can be referred to the upper *carcitanensis* Subzone, whilst the overlying "grizzle" equates to the Hooken Member and contains ammonites suggesting a *saxbii* Subzone - lower *dixoni* Zone age (Kennedy 1970). Overlying the Wilmington Sands is a thin limestone equivalent to the Little Beach Member, followed by the latest Cenomanian basal chalk/Pinnacles Member equivalent.

In west Dorset the Upper Greensand can be divided into the Eggerdon Grit (a lateral equivalent of the Top Sandstones), the Chert Beds and Foxmould Sands, the latter passing downward into a Gault facies. In this area the onset of Gault/Upper Greensand is

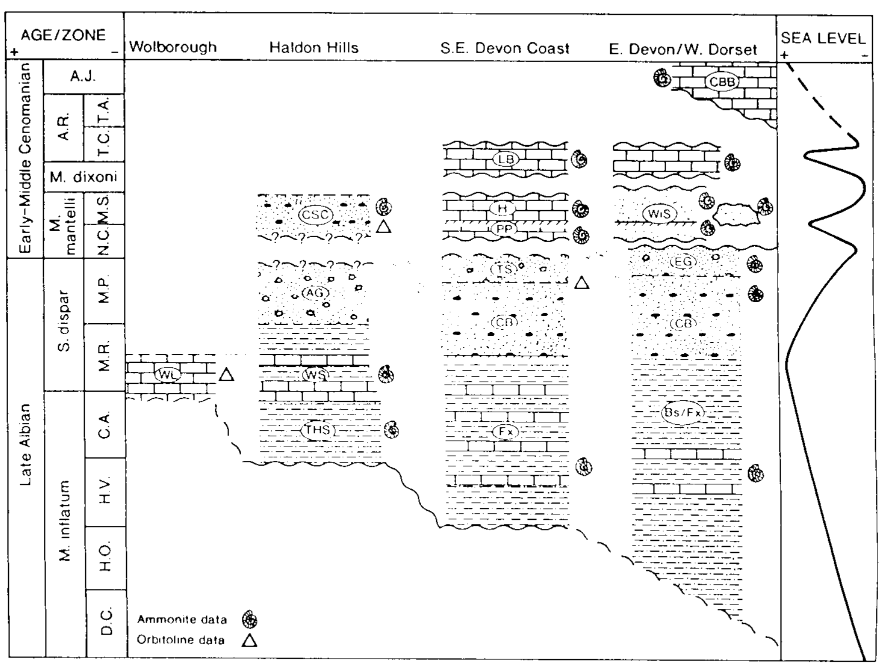

Figure 1. *Chronostratigraphic* summary chart for the Late Albian - Middle Cenomanian of south-west England. Ammonite zonation follows Owen (1984), Wright *et al.* (1984) and Hancock (1989). A.J. = A. *jukesbrownei,* T.A. = T. *acutrus, T.C. = T. costatus,* A.R = A. *rhotomagense,* M.S. = M. *saxbii,* N.C. = N. *carcitanensis, M.* P. = M. *perinflatun,* M.R. = M. *rostratum,* C.A. = C. *auritus,* H.V. = H. *varicosum,* H.O. = H. *orbignyi, D.C. = D. crestatum. Lithostratigraphy* abbreviations are as *follows: Wl* = Wolborough Limeston, THS = Telegraph Hill Sands Member, WS = Woodlands Sands Member, AG = Ashcombe Gravels Member, CSC = Cullum Sands with Cherts Member, Fx = Foxmould Sands, CB = Chert Beds, *TS = Top* Sandstones, PP = Pounds Pool Member, H = Hooken Member, LB = Little Beach Member, Bs = Blackdown Sands, EG = Eggardon Grit, WiS = Wilmington Sands, CBB = Chalk Basement Beds. Sea-level change curve is generaliced and shows relative magnitude of onlap.

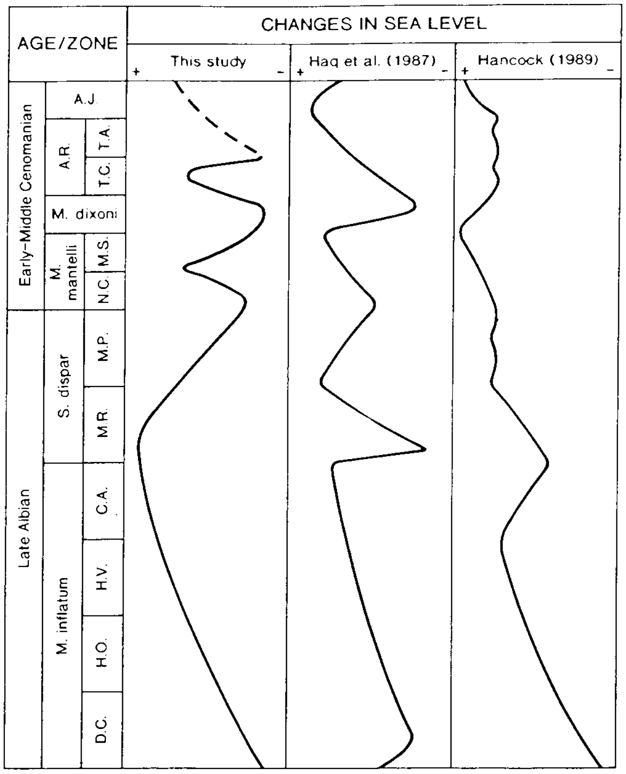

Figure 2. Comparison of sea-level curves for the Late Albian - Middle Cenomanian. Ammonite zonation as for Fig. 1. Sea-level changes shown are relative not absolute.

at least as old as *creistatum* subzone, perhaps *latus* Zone (Rawson *et al.* 1978; Hancock 1989). The Eggardon Grit is of upper *dispar* Zone - basal *carcitanensis* subzone age (Kennedy 1970). Often the Eggardon Grit is overlain directly by the Chalk Basement Beds which are usually of Middle Cenomanian *acutus* subzone or *jukesbrownei* Zone age and becomes younger to the west (Kennedy 1970; Carter and Hart 1977 - see also Fig. 1). Occasionally, a thin remanié deposit or conglomerate is present which may contain ammonites indicating *a saxbii* Subzone age (Kennedy 1970). Unusually, considering the age of the Little Beach Member, *dixoni* Zone or *costatus* Subzone faunas are absent in this area, perhaps indicating the presence of a local high, although the Hooke Valley Conglomerate may be of this age.

Westerly Upper Greensand outliers occur at the Haldon Hills and at Wolborough near Newton Abbot (Selwood *et al.* 1984). The Haldon Hills succession has been described by Hamblin and Wood (1976) who introduced the term Haldon Sands Formation with four members: (in ascending order) Telegraph Hill Sands; Woodlands Sands; Ashcombe Gravels; and Cullum Sands with Cherts. The Telegraph Hill Sands Member contained an *auritus* Subzone ammonite fauna, whilst the overlying Woodlands Sands Member (including limestones and the Haldon Coral Bed) was dated as *dispar* Zone (presumably lower *rostratum* Subzone). The Ashcombe Gravels Member contains no age-diagnostic fauna but is interpreted as being of *dispar* Zone age. The overlying Cullum Sands with Cherts Member contains early Cenomanian ammonites (Hamblin and Wood 1976). An early Cenomanian age is also suggested by the presence of orbitolinids referable to *Orbitolina* cf. *concava* (Simmons and Williams, in press). Hamblin and Wood (1976) suggested that the Cullum Sands with Cherts Member might correlate with the lower part of the Cenomanian Limestone (=Beer Head Limestone Formation). This seems likely given the age of the two units. The Ashcombe Gravels Member has a lithological affinity with the Top Sandstones, although this coarse lithofacies is likely to be diachronous (Fig. 1). A break in sedimen tation is suggested between the Ashcombe Gravels and the Cullum Sands with Cherts Members. This is supported by the marked lithological change between the two units observed in the field and the coarse, kaolinised base of the Cullum Sands with Cherts Member.

The Wolborough Limestones (Edwards 1979) represent the most westerly onshore outcrop of Upper Greensand equivalents. They have been correlated by Hamblin and Wood (1976) to the Woodlands Sands Member of Haldon Hill, indicating that they are of *rostratum* Subzone age. This Late Albian age is supported by the rich orbitoline fauna they contain (Schroeder *et al. 1986)* which is most likely of *dispar* Zone age (Simmons and Wiiliams, in press).

The recognition of sequences and sea-level change in outcrop

The recognition of sequence boundaries, systems tracts and sea-level changes in outcrop has been the subject of some debate in recent years (eg. Wilgus *et al.* 1988; Hancock 1989). Sequences, as defined by Van Wagoner *et al.* (1988) (following Mitchum 1977) are bounded by unconformities (caused by a downward shift in coastal onlap) or their correlative conformities. It therefore follows that sequence boundaries will be recognised by missing biozones and marked facies changes.

The recognition of sea-level changes (and hence systems tracts) is more complex. Hancock (1989) has suggested the use of hardgrounds to recognise periods of maximum regression (following Juignet 1980; Francis 1984). The subject of why and how hardgrounds form is a complex one (for example, see discussions of Fischer and Garrison 1967; Kennedy and Garrison 1975; Bromley 1978; Garrison *et al.* 1987) and beyond the scope of this article. However, whilst accepting Hancock's premise that hardgrounds form in response to an interruption in sedimentation, this may not always relate to regression. In chalk facies hardgrounds will form in response to a reduction in nannofossil accumulation. This could simply relate to a shallowing caused by a regressive eustatic event. Alternatively (and as noted by Hancock 1989), it may relate to winnowing by local bottom currents. These could occur in almost any environmental setting and not be a function of eustatic change. Hancock (1989, p. 569) notes the need to distinguish between hardgrounds which are the result of a general lowering of sea-level and those which are "local accidents of winnowing currents over, say, a diapiric uplift". But hardgrounds may also develop during periods of transgression. Indeed, Hancock (1989, p. 577) notes that courses of phosphatic nodules in the Gault, the equivalent of chalk hardgrounds, may form in response to "...a transgression that carried the shoreline further from the basin. Deposition of sediment was also moved further from the basinal region which was then starved of clay". In a marginal setting, such as that represented by the Late Albian - Cenomanian sediments of south-west England, an increase in water depth caused by a transgression may cause a marked drop in sedimentation and the formation of a hardground. In terms of sequence stratigraphy, condensed deposition is associated with the maximum flooding surface, or height of transgression (Van Wagoner *et al.* 1988; Loutit *et al.* 1988). Thus at the peak of transgression, a hardground may develop, particularly on the shelf, with biozones being condensed or apparently missing. In contrast to Hancock (1989), we would argue that this condensed sequence will not always overly the regressive hardground (although it may sometimes, perhaps as in the case of some of the Beer Head Limestone Formation hardgrounds which are multiple (Jarvis and Woodroof, 1984). Rather it will overlie the lowstand and lower transgressive systems tracts which will onlap onto the shelf. Thus in conclusion, some hardgrounds are associated with regression and unconformity (eg. that at the top of the Top Sandstones), but some are the function of condensation during maximum transgression (eg. that at the top of the Foxmould Sands).

In the Late Albian - Cenomanian succession in south-west England we recognise transgressions and eustatic sea-level rises by periods of maximum onlap (as documented in Fig. 1). We also consider the distribution of facies variations, the diachroneity of facies and the presence of hardgrounds and unconformities.

Sea-level changes in south-west England

As shown by Fig. 1, there is a gradual east to west onlap of the Upper Greensand and equivalents during the Late Albian, The basal Foxmould Sands are at least as old as *cristatum* Subzone in west Dorset, in south-east Devon they are of *varicosum* Subzone. The base of the Haldon Sands Formation is *auritus* Subzone, but the period of maximum transgression is indicated by the Wolborough Limestones which are thought to be *rostratum* Subzone age. Within the *varicosum* - *auritus* succession in south-west England there are no major facies changes or depositional breaks to indicate a cessation of the transgression. Thus sea-level was rising throughout the *inflatum* Zone and the time of maximum eustatic rise was in the lower part of the *rostratum* Subzone *(dispar* Zone). Interestingly, this sea-level rise led to the establishment of a carbonate shelf with orbitoline-rich limestone in the inner shelf, with local coral bioherms basinward of this (the Haldon Coral Bed, Woodlands Sands Member). The limestones in the Foxmould Sands have an outer shelf fauna. The hardground at the top of the Foxmould Sands corresponds to condensation at the time of maximum transgression.

There then followed a gradual regression throughout the remainder of the *dispar* Zone. This is indicated by the shallowing of facies throughout the Chert Beds and Top Sandstones (Tresise 1960; Williams 1986). The Ashcombe Gravels, Top Sandstones and Eggerdon Grit represent a diachronous regressive, coarse, shallow water facies which become progressively younger eastwards. The maximum regression occurs in the basal Cenomanian in the lower part of the *carcitanensis* Subzone, as evidenced by the unconformity and hardground at the top of the Top Sandstones and Eggardon Grit. However, one should also be aware that this apparent regression may in part be due to increased sediment supply, although this itself often occurs during a eustatic sea-level fall (highstand systems tract).

Rapid eustatic rise and transgression occurred in the upper part of the *carcitanensis* Subzone as evidenced by the onlap of the lowermost Cenomanian Limestone (Pounds Pool Member, Beer Head Limestones Formation) and equivalents (lower Wilmington Sands and Cullum Sands with Cherts Member) across south Devon. Garrison *et al.* (1987) also recognise an increase in water depth at this time. As with the Late Albian transgression, this leads to the establishment of a carbonate shelf and orbitoline rich inner shelf limestone (Cullum Sands with Cherts Member). The hardground at the top of the Pounds Pool Member (basal *saxbii* Subzone) is probably the result of condensation associated with transgression. A shallowing-up trend in the Hooken Member overlying the hardground at the top of the Pound Pool Member, and also within the upper Wilmington Sands indicates a regression and eustatic sea-level fall taking place throughout the majority of the *saxbii* Subzone. This culminates in the unconformity seen at the top of the Hooken Member and Wilmington Sands, the latter being within the *dixoni* Zone.

The succession of facies within the Little Beach Member indicates a further relatively rapid transgressive - regressive cycle. A eustatic sea-level high occurred during the lower part of the *costatus* Subzone, and a regression in the upper part of this subzone. A gradual recovery of sea-level is indicated in the *acutus* subzone and continues into the *jukesbrownei* Zone, as indicated by the gradual westerly onlap of the Chalk Basement Beds. This transgression may have continued throughout the Late Cenomanian, culminating in the deposition of the Pinnacles Member of southeast Devon, This is the lateral equivalent of the Plenus Marls of south-east Devon (Carter and Hart 1977; Jarvis *et al.* 1988), which is associated with a eustatic sea-level high (Hancock 1989).

Comparison with other Sea-level curves

Fig. 2 compares the sea-level curve we have developed for the Late Albian - middle Cenomanian of south-west England with the global curve of Haq *et al.* (1987) and more localized curve developed for the British region by Hancock (1989).

There are some similarities between our curve and that of Haq *et al.* (1987). On both, Sea-levels are shown to be rising throughout most of the *inflatum* Zone. As noted by Hancock (1989) this in fact corresponds to the global onset of the major "Cenomanian Transgression" of Suess (1906). Haq *et al.* (1987) have a eustatic high at the *auritus* - *rostratum* Subzone boundary. Ours is slightly higher, in the lower part of the *rostratum* Subzone, but perhaps within the range of error in both methods. A subsequent sharp eustatic fall is indicated by Haq *et al.* (1987). This may have initiated and correspond to the onset of a fall on our curve, but unlike Haq *et al.,* we observe sea-levels to be falling throughout the *dispar* Zone. As noted by Morner (1980), such a dramatic sea-level fall as that indicated by Haq *et al.* (1987) within the lower *rostratum* Subzone is difficult to explain, Haq *et al.* (1987) have a recovery of sea-level during most of the *rostratum* Subzone and a fall during the *perinflatum* Subzone. This culminates in a regressive trough during the basal part of the *carcitanensis* subzone, which is in agreement with our work. Haq *et al.* (1987) show the subsequent eustatic rise culminating at the top of the *saxbii* Subzone; we show it to culminate slightly lower. Once again there is agreement with the following regressive trough: it lies within the *dixoni* Subzone. Haq *et al.* (1987) then gave a eustatic rise taking place through to within the *jukesbrownei* Zone. They do not recognise the cycle which we see within the *costatus* Subzone.

Surprisingly, given that it is more directly relevant than the curve of Haq *et al.* (1987), there is only slight agreement between our curve and that of Hancock (1989). They both show a eustatic rise during the early part of the *inflatum* Zone. However, Hancock (1989) shows the eustatic peak to be at the base of the *auritus* subzone. This cannot be reconciled with the clear evidence for continued onlap during the *auritus* Subzone at Haldon and at Wolborough. Following a regression during the *auritus* Subzone, Hancock (1989) shows sea-level to be rising or in a state of stillstand during *dispar* Zone times. This contradicts the evidence he himself cites, that there was a Late Albian shallowing of the sea in Devon. However, the possibility of increased sediment supply - must be taken into account, although this is most likely to occur during eustatic sea-level fall (highstand systems tract). Within the Early - Middle Cenomanian Hancock (1989) shows a rise culminating at the top of the *saxbii* Subzone, followed by slight regression, still-stand and then transgression during *jukesbrownei* Zone times. This is quite different to our curve (although the eustatic peak at the top of the *saxbii* Zone is close to our result, and in agreement with Haq *et al.* (1987). Perhaps one problem in comparing our curve to that of Hancock (1989) is that he uses zonal boundaries as datums for placing his minima and maxima of sealevel change, whilst we have tried to place ours within zones where appropriate.

Other workers' data on sea-level change are often too generalized to be compared directly to ours. However, a regression culminating at, or very near, the Albian - Cenomanian boundary is indicated by Morner (1980) and Matsumoto (1980) for a number of localities world-wide, and by Juignet (1980) for the Paris Basin and the Armorican Massif. This is in agreement with our work. Juignet (1980) recorded sea-level highs during the *inflatum* Zone, the *saxbii* Subzone and *jukesbrownei* Zone. Again, this agrees with our results. Cooper (1977) indicated that the Late Albian transgression began during *orbignyi* Subzone times. This is slightly later than our work. Cooper also noted that the strata across the Albian - Cenomanian boundary are typically represented by regressive deposits worldwide. He mentioned that the *dispar* Zone is regressive in the Western Interior of North America, in Brazil, Peru and around Africa. This matches our results. His discussion of transgressive peaks in the Cenomanian shows similarities with our work. Using the results of Hart and Tarling's (1974) study of Cenomanian palaeogeograpy, he is unusual in that like us, he recognizes a sea-level rise during the *costatus* Subzone.

Differences between our curve and those of other workers could be ascribed to local tectonic and isostatic controls on sedimentation (Hart 1990). That there were mid-Cretaceous tectonic movements in south-west England has been suggested by a number of workers (eg. Smith 1957; Drummond 1970; Hart 1971). To what degree tectonic/isostatic controls overprint eustatic controls in the area (if indeed at all) remains a subject for further investigation.

Acknowledgements. We wish to thank BP Research for assistance with diagram drafting and for permission to publish. Toine Wonders (BP) is thanked for his helpful advice.

References

Ali, M.T. 1975. Environmental implications of infillings in the Upper Greensand of the Beer district, south Devon. *Proceedings of the Geologists' Association, 85,* 519-531.

Ali, M.T. 1976. The significance of a mid-Cretaceous cobble conglomerate, Beer district, south Devon. *Geological Magazine, 113,* 151-158.

Bromley, R.G. 1978. Hardground diagenesis. *In:* Fairbridge, R.W, and Bourgeois, J. (eds.) *The Encyclopedia of Sedimentology*. Downden, Hutchinson and Ross, 397-400.

Carter, D.J. and Hart, M.B. 1977. Aspects of mid-Cretaceous stratigraphic micropalaeontology. *Bulletin of the British Museum (Natural History), Geology, 29,* 1-135.

Cooper, M.R. 1977. Eustacy during the Cretaceous: its implications and importance. *Palaeogeography, Palaeoclimatology and Palaeoecology,* 22, 1-60.

Drummond, P.V.O. 1970. the mid-Dorset swell. Evidence of Albian-Cenomanian movements in Wessex. *Proceedings of the Geologists' Association, 81,* 679-714.

Edwards, R.A. 1979. Diagenesis of limestones from the Upper Greensand at Wolborough, south Devon. *Proceedings of the Ussher Society, 4,* 326-340.

Fischer, A.G. and Garrison, R.E. 1967. Carbonate lithification of the sea floor. *Journal of Geology,* 75, 488-496.

Francis, 1.H. 1984. Correlation between the north temperate and Tethyan realms in the Cenomanian of western France and the significance of hardground horizons. *Cretaceous Research, 5,* 259-269.

Garrison, R.E., Kennedy, W.J. and Palmer, T.J. 1987. Early lithification and hardgrounds in Upper Albian and Cenomanian calcarenites, southwest England. *Cretaceous Research, 8,* 103-140.

Hamblin, R.J.O. and Wood, C.L 1976. The Cretaceous (Albian - Cenomanian) stratigraphy of the Haldon Hills, south Devon, England. *Newsletters in Stratigraphy, 4,* 135-149.

Hancock, J.M. 1969. The transgression of the Cretaceous sea in south-west England. *Proceeding of the Geologists' Association, 100,* 565-594.

Haq, B.U., Hardenbol, J. and Vail, P.R. 1987. Chronology of fluctuating sealevels since the Triassic. *Science, 235,* 1156-1167.

Hart, M.B. 1971. Micropalaeontological evidence of mid-Cenomanian flexuring in south-west England. *Proceeding of the Ussher Society, 2,* 315-325.

Hart, M.B. 1973. Some observations on the Chert Beds (Upper Greensand) of south-west England. *Proceedings of the Ussher Society, 2,* 599-608. Hart, M.B. 1982. The marine rocks of the Mesozoic, In: Durrance, E.M. and Laming, D.J.C. (eds) *The Geology of Devon.* Exeter University Press, 179-203.

Hart, M.B. 1983. Planktonic foraminifera from the Cenomanian of the Wilmington quarries (SE Devon). *Proceedings of the Ussher Society, 5,* 406-410.

Hart, M.B. 1990. Cretaceous sea level changes and global eustatic curves; evidence from SW England. *Proceedings of the Ussher Society, 7, 268-272.* Hart, M.B. and Tarling, D.H. 1974. Cenomanian palaeogeography of the North Atlantic and possible mid-Cenomanian eustatic movements and theit implications. *Palaeogeography, Palaeoclimatalogy and Palaeoecology,* 15, 95-108.

Hart, M.B. and Williams, C.L. 1990. The Upper Greensand in East Devon: new data but old problems. *Proceedings of the Ussher Society, 7,* 273-278. Jarvis, I. and Woodroof, P.B. 1984. Stratigraphy of the Cenomanian and basal Turonian (Upper Cretaceous) between Branscombe and Seaton, SE Devon, England. *Proceedings of the Geologists' Association, 95,* 193-215. Jarvis, I, Carson, G.A., Cooper, M.K.E., Hart, M.B., Leary, P.N., Tocher, B.A., Horne, D. and Rosenfeld, A. 1988. Microfosil assemblages and the Cenomanian - Turonian (Late Cretaceous) oceanic anozic event. *Cretaceous Research, 9,* 3-103.

Juignet, P. 1980. Transgressions-régressions, variations eustatiques et influences tectoniques de I'Aptien au Maastrichtien dans le Bassin de Paris occidental et sur la bordure du Massif Armoricain. *Cretaceous Research,* 1, 341-357.

Juignet, P. and Kennedy, W.J. 1976. Faunas d'ammonites et biostratigraphie comparée du Cenomanien du nord-ouest de la France (Normandie) et du sud du I'Angleterre. *Bulletin de Societe Geologie de Normandie et Amis Museum, 63, 1-132.*

Jukes-Browne, A.J. and Hill, W. 1900. The Cretaceous rocks of Britain. 1. The Gault and Upper Greensand of England. *Memoir of the Geological Survey of Great Britain,* 499pp.

Jukes-Browne, A.J. and Hill, W. 1903. the Cretaceous rocks of Britain. 2. the Lower and Middle chalk of England. *Memoir of the Geological Survey of Great Britain,* 568pp.

Kennedy, W.J. 1970. A correlation of the uppermost Albian and Cenomanian of south-west England. *Proceedings of the Geologists' Association, 81,* 613-677.

Kennedy, W.J. and Garrison, R.E. 1975. Morphology and genesis of nodular chalks and hardgrounds in the Upper Cretaceous of southern England. *Sedimentology, 22,* 311-386.

Kennedy, W.J. and Hancock, J.M. 1976. The mid-Cretaceous of the United Kingdom. *Annales du Museum d'histoire Naturelle de Nice, 4, v.* 1-v.72. Loutit, T.S., Hardenbol, J., Vail, P.R. and Baum, G.R. 1988. Condensed sections: the key to age determination and correlation of continental margin sequences. *In:* Wilgus, C.K., Hastings, B.S., Kendall, C.G.St.C., Posamentier, H.W., Ross, C.A. and Van Wagoner, J.C. *(eds) Sea-level Changes: An Integrated Approach*. SEPM Special Publication 42, 183-213.

Matsumoto, T. 1980. Inter-regional correlation of transgressions and regressions in the Cretaceous period. *Cretaceous Research, 1,* 359-373. Meyer, C.J.A. 1874. On the Cretaceous rocks of Beer Head and the adjacent cliff section, and on the relative horizons therein of the Warminster and Blackdown fossiliferous deposits. *Quarterly Journal of the Geological Society, London, 30,* 369-393.

Mitchum, T.M. 1977. Seismic stratigraphy and global changes of sea-level. Part 1: glossary of terms used in seismic stratigraphy. *In:* Payton, C.E. (ed.) *Seismic Stratigraphy-Applications to Hydrocarbon Exploration*. American Association of Petroleum Geologists Memoir, 26, 205-212.

Morner, N.A. 1980. Relative sea-level, tectono-eustacy, geoidal eustacy and geodynamics during the Cretaceous. *Cretaceous Research, 1,* 329-340. Owen, H.G. 1984. The Albian stage: European province chronology and ammonite zonation. *Cretaceous Research,* 5, 329-344.

Payton, C.E. (ed.) 1977. *Seismic Stratigraphy -Applications to Hydrocarbon Exploration.* American Association of Petroleum Geologists Memoir. 26.

Rawson, P.F., Curry, D., Dilley, F.C., Hancock, J.M., Kennedy, W.J., Neale, J.W., Wood, C.J. and Worssam, B.C. 1978. A correlation of Cretaceous rocks in the British Isles. *Special Report of the Geological Society, London, 9,* 70pp.

Schroeder, R., Simmons, M.D., Hart, M.B. and Williams, C.L. 1986. A note on the occurrence of *Orbitolina (Orbitolina) sefini* Henson, 1948 (Foraminiferida) in the Upper Greensand of SW England. *Cretaceous Research, 7,* 381-387.

Selwood, E.B., Edwards, R.A., Simpson, S., Chesher, J.A., Hamblin, R.J.O., Henson, M.R., Riddols, B.W. and Waters, R.A. 1984. Geology of the country around Newton Abbot. *Memoir of the Britian Geological Survey*. Simmons, M.S. and Williams, C.L. in press. Cretaceous Orbitolinidae (Foraminifera) from onshore south-west England. *Journal of Micropalaeontology.*

Smith, W.E. 1957, The Cenomanian Limestone of the Beer district, south Devon. *Proceedings of the Geologists' Association, 68,* 115-133.

Smith, W.E. 1961. The Cenomanian deposits of south-east Devonshire: the Cenomanian Limestone east of Seaton. *Proceedings of the Geologists' Association, 76,* 121-136.

Suess, W. 1906. *The Face of the Earth* (English translation of *Das Antlitz der Erde),* 2, 566pp. Clarendon Press, Oxford.

Tresise, G.R. 1960. Aspects of the lithology of the Wessex Upper Greensand. *Proceedings of the Geologists' Association, 71,* 316-339.

Van Wagoner, J.C., Pasamentier, H.W., Michum, R.M., Vail, P.R., Sarg, J.F., Loutit, T.S. and Hardenbol, J. 1988. An overview of the fundamentals of sequence stratigraphy and key definitions. *In:* Wilgus, C.K., Hastings, B.S., Kendall, C.G.St.C., Posamentier, H.W., Ross, C.A. and Van Wagoner, J.C. (eds) *Sea-level Changes: An Integrated Approach.* SEPM Special Publication 42. 39-45.

Wilgus, C.K., Hastings, B.S., Kendall, C.G.St.C., Posamentier, H.W., Ross, C.A. and Van Wagoner, J.C. (eds) 1988. *Sea-level Changes: An Integrated Approach.* SEPM Special Publication 42, 407pp.

Williams, C.L. 1986. The cherts of the Upper Greensand (Cretaceous) of south-east Devon. *In:* Sieveking, G. de G. and Hart, M.B. (eds) *The Scientific Study of Flints and Cherts.* Cambridge University Press, 63-70. Williams, C.L., Hart, M.B. and Leary, P.N. 1988. Foraminifera and correlation of the Upper Greensand, Branscombe, south-east Devon. *Proceedings of the Ussher Society, 7,* 97-99.

Wright, C.W. and Kennedy, W.J. 1981. The ammonoidea of the Plenus Marls and Middle Chalk. *Palaeontographical Society Monograph, 560,* 1-148 Wright, C.W., Kennedy, W.J. and Hancock, J.M. 1984. Stratigraphic introduction. *In:* Wright, C. W. and Kennedy, W.J.: The ammonoidea of the Lower Chalk, Part 1. *Palaeontographical Society Monograph, 567,* 1-37.