Correlation of events at the Cenomanian/Turonian boundary: Evidence from Southern England and Colorado

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Abstract: The events at the Cenomanian-Turonian boundary are reviewed and the various causes of the Late Cenomanian extinction event considered. There is now overwhelming evidence to suggest that many of the geochemical, faunal and floral changes recorded in this interval are synchronous world-wide. This is particularly evident if one compares the successions in Southern England with that of the Rock Canyon Anticline, Pueblo (Colorado). Despite a wealth of data, the cause of the extinction event is still not known. The recently discovered "ejecta horizon" at Nazaré (Portugal) is described and its importance evaluated.

Keywords: Foraminifera, Bonarelli Event, Cenomanian, Turonian, Eastbourne, Pueblo, Nazaré

1. INTRODUCTION

The Late Cenomanian (or Cenomanian/Turonian boundary) event is one of those identified by RAUP & SEPKOSKI (1982) in their analysis of periodic extinctions. The event has long been recognised as one of the major features of the Cretaceous succession on all continents and, in many localities, is associated with dark/black mudstones (SCHLANGER & JENKYNS, 1976). The Bonarelli Event, as it is known in parts of Europe (or CTBE in others) records a moderate turnover of both macrofauna and microfauna. It has been estimated that approximately a quarter of marine invertebrate genera were affected (HARRIES, 1993), ranging from shallow-water rudist bivalves to nektobenthic ammonites. The composition of planktonic foraminiferal assemblages also changed significantly (CARON, 1985; JARVIS et al., 1988; HALLAM & WIGNALL, 1999; PAUL et al., 1999) although BANERJEE & BOYAJIAN (1996) have argued that only 17% of foraminiferal genera became extinct; the changes being mainly at the specific level. Associated with these extinctions and associated biodiversification events are a number of isotopic and geochemical signals, including the occurrence of rare earth elements and iridium.

In recent years there have been many suggestions as to the cause of the faunal changes and the marked change in the sedimentary record adjacent to the "event".

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These include:

- Expansion of the O_2 minimum zone within the water column leading to the development of an "anoxic event" (SCHLANGER & JENKYNS, 1976; ARTHUR et al., 1987; JARVIS et al., 1988; KAIHO and HASEGAWA, 1994; CAUS et al., 1997; HART, 1996);
- Oceanographic changes (GALE et al., 2000);
- Bolide impact (MONTEIRO et al., 1998a,b);
- Multiple bolide/meteoritic impact (HUT et al., 1987);
- Changes in the food chain (PAUL & MITCHELL, 1994; PAUL et al., 1999; HART, 1996);
- Sea level changes (HANCOCK & KAUFFMAN, 1979; HALLAM & WIGNALL, 1999);
- Global cooling with an associated fall in sea level (JEANS et al., 1991);
- Major volcanism around Madagascar (COURTILLOT, 1992); and
- Changes in carbonate production (CAUS et al., 1997).

The above list is not intended to present a comprehensive summary of all the possible causes, nor can it provide a listing of all the relevant publications. It is clear, however, that a number of key features can be identified in many sections around the world and these include:

- A pattern of stepwise extinctions and biodiversification events (at both generic and specific level);
- A positive $\delta^{13}C$ isotope excursion;
- A number of iridium-rich horizons;
- A number of other geochemical anomalies (cromium, scandium, etc.);
- The presence of clay-rich sediments, often containing enhanced levels of organic carbon;
- Sediments which are generally indicative of a transgressive event; and
- A pattern of Milankovitch Cycles which can provide an indication of the duration of the "event".

In the United Kingdom the first detailed investigation of the event was that of JEFFERIES (1962, 1963) who documented the distribution of foraminifera in the Plenus Marls at Merstham in Surrey. That analysis is still valid today, although the section is no longer available. Recently research on the Plenus Marls in the UK has concentrated on Dover (JARVIS et al., 1988; LAMOLDA et al., 1994) or Eastbourne (PAUL et al., 1999; GALE et al., 2000; KELLER et al., 2001). There is no doubt that Eastbourne is the most complete (and thickest) succession, despite recent engineering works partially covering the Holywell section in coarse shingle. In the 1970's CARTER & HART (1977) documented a number of Plenus Marls sections in SE England, the Isle of Wight, Dorset and Devon. Later, HART et al. (1991, 1993) described the foraminiferal succession and stratigraphy of the Black Band in NE England.

2. THE EASTBOURNE SUCCESSION

The Eastbourne succession across the Cenomanian/Turonian boundary is exposed at two locations; Gun Gardens (by the headland) and Holywell, just SW of the western end of the Eastbourne promenade. In recent publications PAUL et al. (1999), GALE et al. (2000)

and KELLER et al. (2001) have described these sections in some detail and those interested in the sedimentology, foraminifera, ostracoda, calcareous nannofossils, macrofauna, stable isotopes, etc., are directed to these papers. Figure 1 provides a summary of some of our data, which includes geochemistry, carbon isotopes and the distribution of some important, zonally significant, foraminifera. It can be seen that the extinction of *Rotalipora cushmani* marks the end of the *R. cushmani* Taxon Range Zone and that the first appearance of *Helvetotruncana helvetica* marks the base of the *H. helvetica* Taxon Range Zone (or Interval Zone). The *Whiteinella archaeocretacea* Zone of ROBASZYNSKI & CARON (1995) is, in reality, an inter-biohorizon zone between the extinction of *R. cushmani* and the appearance of *H. helvetica*. The extinction of *R. greenhornensis* is a distinctive horizon, while the rare occurrence of *R. deeckei* in Bed 1 of the Plenus Marls (PAUL et al., 1999, fig.8) is much less reliable as an extinction datum. Many workers record (possibly incorrectly) *R. reicheli* up to this stratigraphical level; confusing these two rather similar species. The extinction of most of the typical Cenomanian benthonic taxa occurs at the top of Bed 1. Figure 1 also includes data on the maximum size of *R. cushmani* (and to a lesser extent *R. greenhornensis*) in the lower part of the Plenus Marls. HART & LEARY (1989) used these measurements as a proxy for water depth in shallow water environments or, more significantly, the depth of the habitable water column. This implies that, prior to the final extinction of the genus, individuals attained a reasonable size for some 80,000 years (using the GALE et al. [2000] time-scale). Over a period of the following 50,000–60,000 years individuals became quite small prior to the final disappearance of the genus at the first iridium level. The geochemistry of the succession, kindly provided by Carl ORTH (pers. comm., 1990) shows the presence of rare earth elements and other indications of oceanic perturbation. WILDE & BERRY (1984, 1986) have suggested that a major "overturn" of the oceanic system might cause extinction events by bringing anoxic water rich in metals and other elements into the surface waters. The occurrence of iridium in two distinct levels (both of which are just above omission surfaces) just at, and above, the extinction of *R. cushmani* and close to the maximum $\delta^{13}C$ excursion points to a potential relationship. The calcisphere flood (Fig. 1) begins just after an increased abundance of *Heterohelix* spp. (although this was not reported by PAUL et al., 1999, fig.10). This "*Heterohelix* shift" has been described from the Western Interior Seaway of the USA (WEST et al., 1998) and, more recently, been highlighted by KELLER et al. (2001, fig.13). In his pioneering work on the foraminifera of the Plenus Marls, JEFFERIES (1962) also reported the occurrence of an unusual species of *Reophax* in Bed 1. The occurrence of this flask-shaped *Reophax* is shown in Figure 1. This genus is often an early immigrant following a change in sedimentation pattern and, while this may be partly true in this case, it is associated with a very diverse benthonic assemblage. Although PAUL et al. (1999, fig.6) record *Reophax* sp. A, they do not illustrate the species. In all probability it is the same species as we indicate in Figure 1. In their analysis, PAUL et al. (1999, fig.6) use the morpho-group model of KOUTSOUKOS & HART (1990) to document the changes through the event. PAUL et al. (1999) highlight changes at the:

- Sub-Plenus erosion surface;
- Base of Bed 2 (where most of the epifaunal elements disappear; and
- Base of the *H. helvetica* Zone (approximately) where the typical assemblage of the Lower to Middle Turonian appears.

This agrees with our information at Eastbourne, Dover (JARVIS et al., 1988), Merstham (JEFFERIES, 1962) and Shillingstone (CARTER & HART, 1977).

While the senior author has studied the Cenomanian/Turonian boundary event in France, Germany, Portugal, Brazil, Oman and in SE India (TEWARI et al., 1996) it is perhaps the succession at Pueblo (Colorado) that is the most significant.

3. THE SUCCESSION OF THE ROCK CANYON ANTICLINE, PUEBLO, COLORADO

A limited number of samples from the Rock Canyon anticline succession have been investigated and compared to those from UK and European successions. The foraminifera are relatively well preserved and, although the names applied to the taxa are often different to those in use in the UK, the same "morphogroups" are present. Following the earlier work on the foraminifera by EICHER (1969) and EICHER & WORSTELL (1970) a number of other authors have described the macrofauna, microfauna, sedimentology, geochemistry and isotope stratigraphy of the succession. Almost all of the references to this work are documented in the recently published volume on the Cretaceous Western Interior Seaway (DEAN & ARTHUR, 1998). Several European workers have also studied the succession (BEAUDOIN et al., 1995; MOREL, 1998; DODSWORTH, 2000), often using material collected by others. This sucession, along with others in the Cretaceous Western Interior Seaway, have been described in detail by WEST et al. (1998).

One of the problems with this section is the distribution of the planktonic foraminifera. There are a number of discrepancies in the presented ranges of *R. cushmani, R. greenhornensis* and *H. helvetica*. The zonation that is so clear in the Eastbourne succession is complicated by the presence of atypical individuals of each species as well as the general rarity of *H. helvetica*. In our opinion most of the beds with records of *H.helvetica* contain only *H.praehelvetica* and the appearance of "*helvetica*" is probably not a reliable datum to use in correlation. The increased abundance of *Heterohelix* spp. is also present (see KELLER et al., 2001), but the flood of *Reophax* sp. (comparable to that at Eastbourne) has not been recorded. The changes in the benthonic foraminifera, though distinctive, are probably less dramatic than those recorded in the UK. This is probably due to the more extreme changes in sedimentary environment recorded in the European successions. There are two principal iridium anomalies (ORTH et al., 1988) together with a range of other rare earth elements. An $\delta^{13}C$ excursion has been documented by PRATT & THRELKELD (1984) and PRATT et al. (1993), and while it has many similarities with that recorded at Eastbourne, does show some differences in detail. We do not have sufficient material with which to undertake a morphometric analysis of the *Rotalipora* population but the descriptions of other authors seem to indicate a similar pattern (see MOREL, 1998).

4. UK – COLORADO COMPARISONS

It is generally agreed that the Late Cenomanian-Early Turonian interval marks the maximum sea levels of the Cretaceous (HAQ et al., 1988; JACQUIN & GRACIANSKY, 1998) as well as the warmest temperatures (JENKYNS & WILSON, 1999). The water depth changes

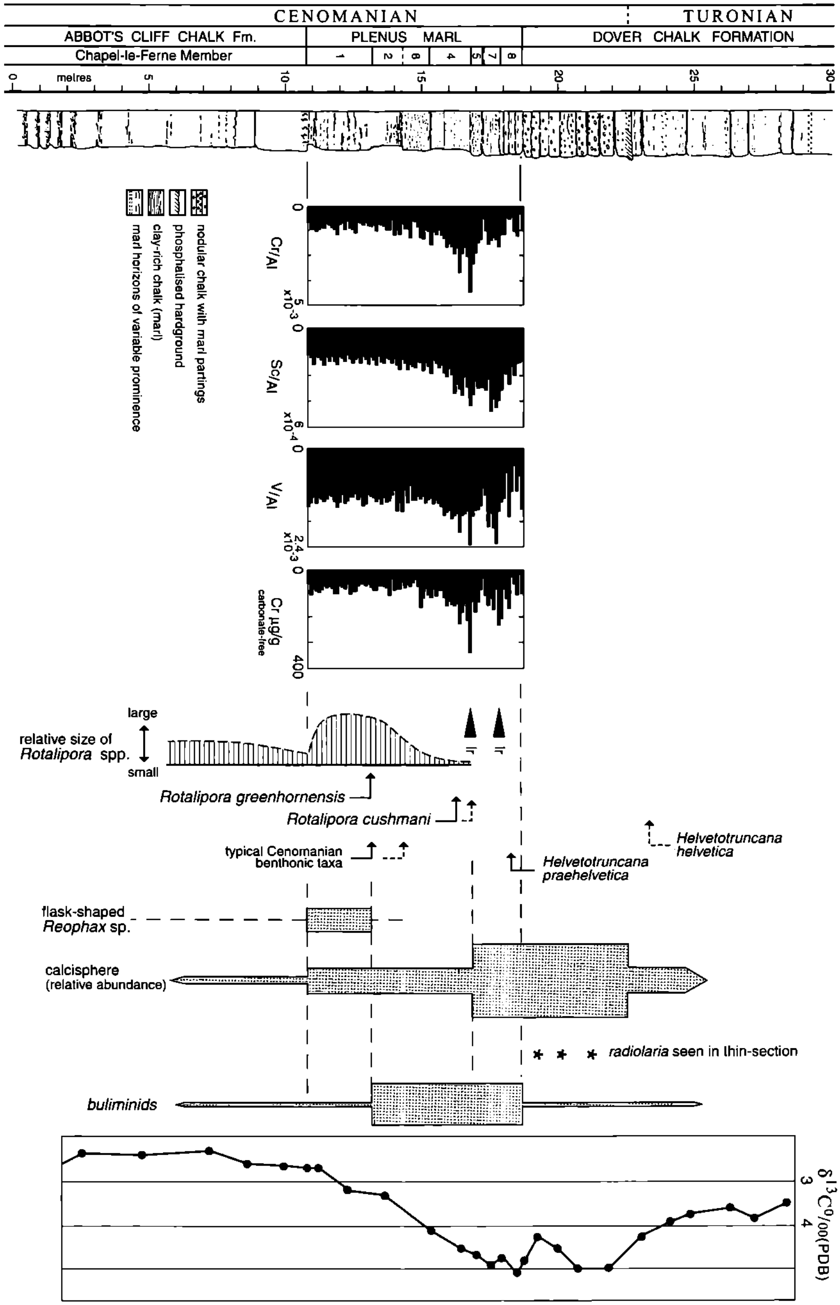

Fig. 1: The Upper Cenomanian to Lower Turonian succession at Eastbourne, Sussex, England. The geochemical data were kindly provided by C.J. Orth (Los Alamos, New Mexico, USA). The log was provided by Ian Jarvis (University of Kingston, UK), together with the samples used in the micropalaeontological analysis.

across the critical part of the succession are, however, a little more difficult to determine. Hallam & Wignall (1999) show a very general sea level rise across this interval while Gale et al. (2000, fig.1) present a postulated curve that records a fall in sea level across the sequence boundary at the sub-Plenus erosion surface followed by a general rise well into the Early Turonian. The transgressive surface is indicated at the Bed 3/4 boundary. Our, admittedly limited, biometric analysis indicates the presence of larger individuals of *Rotalipora* in Beds 1 and 2 and it is interesting that Paul et al. (1999, fig.11) also record an increase in absolute numbers of planktonic foraminifera at this level. Our interpretation indicates that, above the sub-Plenus erosion surface there was a rise in sea level; the transgressive surface being coincident with the sequence boundary. The maximum level of the $\delta^{13}C$ isotope excursion is coincident with the maximum condensation of the sedimentary succession and this may be, very approximately, what could be regarded as the zone of maximum flooding. This is, however, only 160,000 – 180,000 years above the sequence boundary and, on that basis, probably represents a parasequence (4th Order sequence) in the terminology of Van Wagoner et al., 1988). In their work on the Pueblo succession West et al. (1998, fig.8) indicate both a major cycle (the Greenhorn Cycle) and smaller cycles that are very closely mirrored by our data, especially at higher levels in the Turonian (Hart, 1997). The "strong Tethyan influence" recorded by West et al. (1998, fig.8) is at precisely the same level in the Turonian succession at which Hart (1997) records the most abundant – and diverse – planktonic foraminiferal assemblage in the UK. The distribution pattern of planktonic foraminifera in the Bounds Core (Scott et al., 1998, fig.10) matches that in SW England (Hart, 1997) in almost every detail, aside from the fact that in the UK keeled taxa are more abundant. The replacement of the planktonic-dominated fauna by one dominated by benthonic taxa in the mid-Late Turonian is also common to both areas (UK/Colorado), as well as other parts of the world; e.g., Cauvery Basin, SE India (Tewari, 1996; Tewari et al., 1998).

5. THE LATE CENOMANIAN EVENT

Having considered all the various faunal changes, chemical anomalies, sea level changes, etc., around – and across – the Late Cenomanian extinction event, are we any nearer identifying a cause? The iridium and rare earth element data were regarded by Orth (pers.comm.) as indicative of terrestrial origin rather than extra-terrestrial origin. The iridium anomaly, spherules and other exotics recorded by Monteiro et al. (1998a,b) at Nazaré (Portugal) have been interpreted as an impact ejecta horizon. The locality described by Monteiro et al. is located (Fig.2) at Praia da Vitoria, north of Nazaré (Portugal). The succession is located below shifting sands and, at many times of year, very little of the key section is exposed. Figure 3 shows a sketch log of the succession. The *in-situ* shelfal carbonates are of mid-Late Cenomanian age (Callapez, 1998, 1999; Berthou, 1984a,b) on the basis of the contained macrofauna and microfauna. Detailed work on the limited foraminiferal assemblage has failed (thus far) to produce a more accurate assessment of the age. The in-situ carbonates pass laterally into a monomictic breccia. The base of the breccia appears to cross a number of beds of the shelfal limestones and is irregular in nature. The shelfal limestones are steeply dipping, an orientation that appears to be related to the numerous salt diapirs that punctuate the

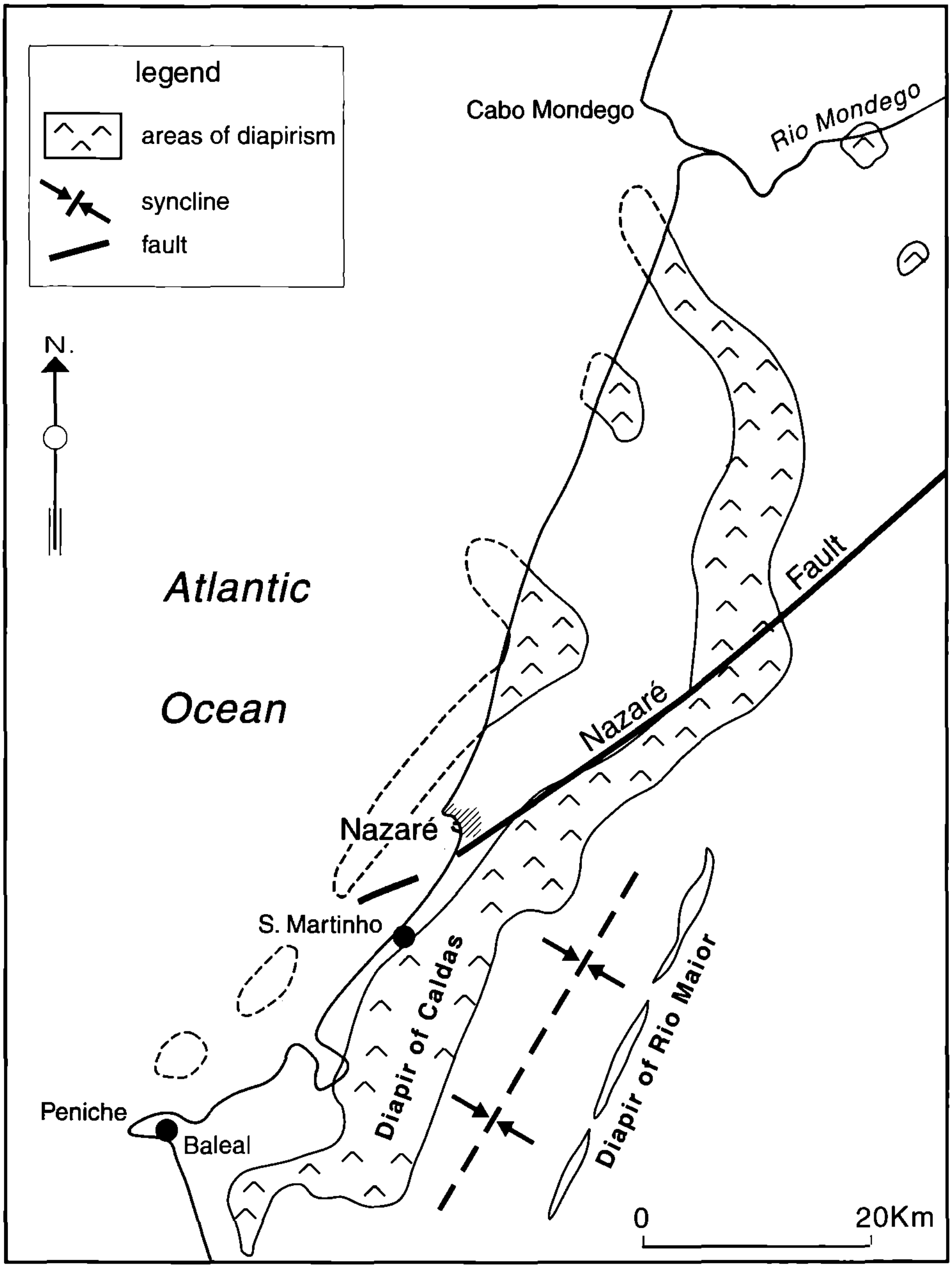

Fig. 2: Location of Nazaré and the distribution of known salt diapirs in the area.

area (see Fig. 2). The upper surface of the monomictic breccia contains the "ejecta horizon" and contains limestone fragments, cherts, sandstones, assorted metamorphic rocks, iron oxide fragments, diaplectic glass and large rounded blocks (up to 80 cm diameter) of basalt. MONTEIRO et al. (1998a) describe the glasses and other spherules in some detail and provide the results of geochemical analyses. The "ejecta horizon" is completely different to the underlying monomictic breccia and it is difficult to explain its presence in this succession. The "ejecta horizon" is immediately overlain by a soft grey clay (which contains the main iridium anomaly) which, in turn, grades up into sands that have been described as Turonian(?) – Maastrichtian (or even Palaeogene). In the base of these sands (immediately above the clay layer) are large sandstone and siltstone blocks that are presently being investigated for their microfossil and palynological content. Within the shelfal carbonate succession of the Nazaré area there are no other horizons that contain such an admixture of exotic material and this clearly indicates an "unusual" event. While the monomictic breccias could well be attributed to movement of semi-cemented carbonates on the flanks of an active salt diapir it is very difficult to explain the "ejecta horizon" by such a process. The basalts, and all the other exotics, are sub-rounded to rounded and appear to be water transported. The size of the basalt boulders implies a relatively close source and it is well known that there are late Cretaceous volcanics in the Lisbon area.

In their 1998a paper, MONTEIRO et al. suggest that the Tore Sea Mount (LAUGHTON et al., 1975) may be a potential impact site SW of the Portugal coastline. While this must be regarded as a possibility, none of the DSDP/IPOD/ODP drill sites (641 and others) off the Portuguese coast and on the flanks of the Galicia Bank (BOILLOT et al., 1987) show any disturbance within the sediments of Late Cenomanian or Turonian age. If the Tore Sea Mount *was* an impact site in the Late Cenomanian then some disturbance would be expected.

6. SUMMARY

Deatiled analysis of the Late Cenomanian extinction event at many localities around the world indicate a distinct paralellism of the faunal, floral, geochemical and isotopic signals preserved in the geological record. As to a cause of the event, there are almost as many suggestions as authors! The suggested ejecta horizon at Nazaré certainly records an unusual geological event, although it is imprecisely dated at the present time. Work on the biostratigraphy continues, and once this is known – and the horizon dated – it will be possible to decide if it is a part of the Late Cenomanian story, or whether we must continue the quest for an overall explanation.

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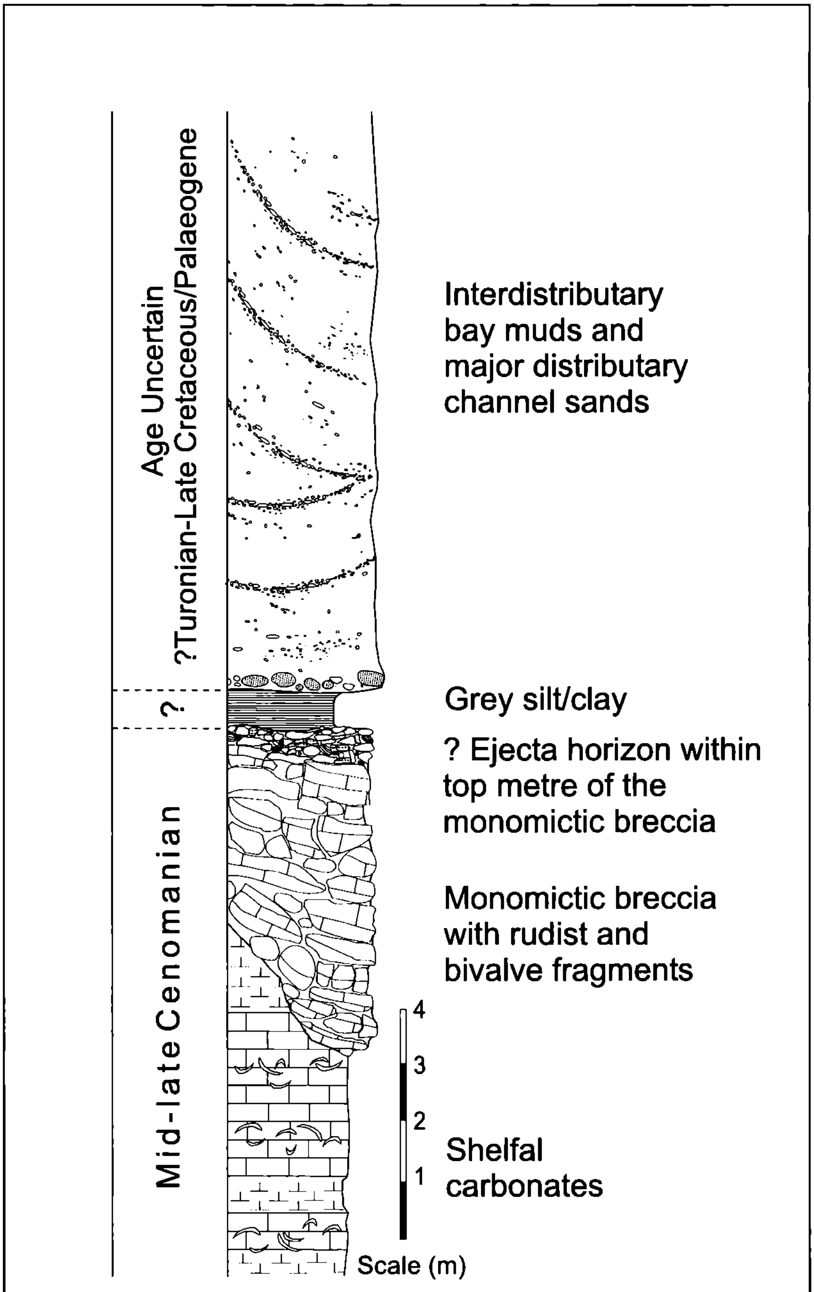

Fig. 3: Schematic log of the Praia da Vitória succession based on field work by the authors.

References

ARTHUR, M. A., SCHLANGER, S. O. & JENKYNS, H. C. 1987: The Cenomanian-Turonian oceanic anoxic event II. Palaeoceanographic controls on organic-matter production and preservation. – In: BROOKS, J. & FLEET, A. J. (Eds.): Marine Petroleum Source Rocks. – Geol. Soc. London, Spec. Pub., **26**: 401–420.

BANERJEE, A. & BOYAJIAN, G. 1996: Changing biologic selectivity of extinction in the foraminifera over the past 150 my. – Geology **24**: 607–610.

BEAUDOIN, B., MOREL, L., CARON, M. & RENARD, M. 1995: Periodicity of sedimentary signals on the Cenomanian-Turonian boundary in the Pueblo section (CO). IAS – 16th Regional Meeting of Sedimentology – 5me Congrès Français de Stratigraphie – ASF, Paris, 22, 170.

BERTHOU, P.-Y. 1984a: Albian-Turonian stage boundaries and subdivisions in the western Portuguese Basin with special emphasis on the Cenomanian-Turonian boundary in the ammonite facies and rudist facies. – Bull. Geol. Soc. Denmark **33**: 41–55.

BERTHOU, P.-Y. 1984b: Répartition stratigraphique actualisée des principaux foraminifères benthiques du Crétacé moyen et supérieur du bassin occidental portugais. – Benthos '83, 2nd Int. Symp. On Benthic Foraminifera, Pau, 1983, 45–54.

BOILLOT, G., WINTERER, E. L., MEYER, A. W. et al. 1987: Proc., Init. Repts (Pt.A), ODP, 103.

CALLAPEZ, P. 1998: Estratigrafia e Paleobiologia do Cenomaniano-Turoniano. O significado do eixo da Nazaré-Leiria-Pombal. Unpublished D.Phil. Thesis, Coimbra University, 491pp.

CALLAPEZ, P. 1999: The Cenomanian-Turonian of the Western Portuguese Basin: Stratigraphy and Palaeobiology of the Central and Northern Sectors. European Palaeontological Association (EPA) Workshop (Lisbon), Field Trip Guide No. 2, 45pp.

CARON, M. 1985: Cretaceous planktic Foraminifera. –In: BOLLI, H. M., SAUNDERS, J. B. & PERCH-NIELSEN, K. (Eds.), Plankton Stratigraphy, 17–86 Cambridge (Cambridge University Press).

CARTER, D. J. & HART, M. B. 1977: Aspects of mid-Cretaceous stratigraphical Micropalaeontology. – Bull. British Mus. Nat. Hist. (Geol.) **29**: 1–135.

CAUS, E., TEIXELL, A. & BERNAUS, J. M. 1997: Depositional model of a Cenomanian-Turonian extensional basin (Sopeira Basin, NE Spain): interplay between tectonics, eustacy and biological productivity. – Palaeogeogr. Palaeoclimat. Palaeoecol. **129**: 23–36.

COURTILLOT, V. 1992: Mass extinctions in the last 300 million years: One impact and seven flood basalts? – Israel J. Sci. **43**: 255–266.

DEAN, W. A. & ARTHUR, M. A. (Eds.) 1998: Stratigraphy and Paleoenvironments of the Cretaceous Western Interior Seaway, USA. – SEPM Concepts in Sedimentology and Palaeontology, **6**: 255pp.

DODSWORTH, P. 2000: Trans-Atlantic dinoflagellate cyst stratigraphy across the Cenomanian-Turonian (Cretaceous) stage boundary. – J. Micropalaeont. **19**: 69–84.

EICHER, D. L. 1969: Cenomanian and Turonian planktonic foraminifera from the western interior of the United States. –In: BRÖNIMANN, P. & RENZ, H. H. (Eds.), Proceedings of the First International Conference on Planktonic Microfossils, E. J.Brill, Leiden, **2**: 163–174.

EICHER, D. L. & WORSTELL, P. 1970: Cenomanian and Turonian foraminifera from the Great Plains, United States. – Micropaleont. **16**: 269–324.

GALE, A. S., SMITH, A. B., MONKS, N., YOUNG, J. R., HOWARD, A. W., WRAY, D. S. & HUGGETT, J. M. 2000: Marine biodiversity through the Late Cenomanian-Early Turonian: Palaeoceanographic controls and sequence stratigraphic biases. – J. Geol. Soc. London **157**: 745–757.

HALLAM, A. & WIGNALL, P. B. 1999: Mass extinctions and sea-level changes. – Earth-Sci. Rev. **48**: 217–250.

HANCOCK, J. M. & KAUFFMAN, E. G. 1979: The great transgressions of the Late Cretaceous. – J. Geol. Soc. London **136**: 175–186.

HAQ, B. U., HARDENBOL, J. & VAIL, P. R. 1988: Mesozoic and Cenozoic chronostratigraphy and eustatic cycles. –In: WILGUS, C. K., HASTINGS, B. S., ROSS, C. A., POSAMENTIER, H. W., VAN WAGONER,

J. & Kendall, G. St. C. (Eds.): Sea-level Changes: An Integrated Approach. – SEPM, Spec. Publ. **42**: 39–45.

Harries, P. J. 1993: Dynamics of survival following the Cenomanian-Turonian (Upper Cretaceous) mass extinction event. – Cretaceous Res. **14**: 563–583.

Hart, M. B. 1996: Recovery of the food chain after the Late Cenomanian extinction Event. – In: Hart, M. B. (Ed.), Biotic Recovery from Mass Extinction Events. – Geol. Soc. London, Spec. Pub., **102**: 265–277.

Hart, M. B. 1997: The application of micropalaeontology to sequence stratigraphy; an example from the chalk succession of south-west England. – Proc.Ussher Soc. **9**: 158–163.

Hart, M. B., Dodsworth, P., Ditchfield, P. W., Duane, A. M. & Orth, C. J. 1991: The late Cenomanian event in Eastern England. – Hist. Biol. **5**: 339–354.

Hart, M. B., Dodsworth, P. & Duane, A. M. 1993: The Late Cenomanian event in Eastern England. – Cretaceous Res. **14**: 495–508.

Hart, M. B. & Leary, P. N. 1989: The stratigraphic and palaeogeographic setting of the Late Cenomanian anoxic event. – J. Geol. Soc. London **146**: 305–310.

Hut, P., Alvarez, W., Elder, W. P., Hansen, T. A., Kauffman, E. G., Keller, G., Shoemaker, E. M. & Weisman, P. R. 1987: Comet showers as causes of mass extinctions. – Nature **329**: 118–126.

Jacquin, T. & de Graciansky, P.-C. 1998: Major transgressive/regressive cycles: the stratigraphic signature of European Basin development. – In: de Graciansky, P.-C., Hardenbol, J., Jacquin, T. & Vail, P. R. (Eds.), Mesozoic and Cenozoic Sequence Stratigraphy of European Basins – SEPM Spec. Publ. **60**: 15–29.

Jarvis, I., Carson, G. A., Cooper, K., Hart, M. B., Leary, P., Tocher, B. A., Horne, D. & Rosenfeld, A. 1988: Microfossil assemblages and the Cenomanian-Turonian (Late Cretaceous) oceanic anoxic event. – Cretaceous Res. **9**: 3–103.

Jeans, C. V., Long, D., Hall, M. A., Bland, D. J. & Cornford, C. 1991: The geochemistry of the Plenus Marls at Dover, England: evidence of fluctuating oceanographic conditions and of glacial control during the development of the Cenomanian-Turonian $\delta^{13}C$ anomaly. – Geol. Mag. **128**: 603–632.

Jefferies, R. P. S. 1962: The palaeoecology of the *Actinocamax plenus* Subzone (Lowest Turonian) in the Anglo-Paris Basin. – Palaeontology **4**: 609–632.

Jefferies, R. P. S. 1963: The stratigraphy of the *Actinocamax plenus* Subzone (Turonian) in the Anglo Paris Basin. – Proc. Geol. Assoc. **74**: 1–33.

Jenkyns, H. C. & Wilson, P. A. 1999: Stratigraphy, paleoceanography, and evolution of Cretaceous Pacific guyots: relics from a greenhouse Earth. – Am. J. Sci. **299**: 341–392.

Kaiho, K. & Hasegawa, T. 1994: End-Cenomanian benthic foraminiferal extinctions and oceanic dysoxic events in the northwestern Pacific Ocean. – Palaeogeogr. Palaeoclimat. Palaeoecol. **111**: 29–43.

Keller, G., Han, Q., Adatte, T. & Burns, S. J. 2001: Palaeoenvironment of the Cenomanian-Turonian transition at Eastbourne, England. – Cretaceous Res. **22**: 391–422.

Koutsoukos, E. A. M. & Hart, M. B. 1990: Cretaceous foraminiferal morphogroup distribution patterns, palaeocommunities and trophic structures: a case study from the Sergipe Basin, Brazil. – Trans. Roy. Soc. Edinburgh **81**: 221–246.

Lamolda, M. A., Gorostidi, A. & Paul, C. R. C. 1994: Quantitative estimates of calcareous nonnofossil changes across the Plenus Marls (latest Cenomanian), Dover, England: implications for the generation of the Cenomanian-Turonian boundary event. – Cretaceous Res. **15**: 143–164.

Laughton, A. S., Roberts, D. G. & Graves, R. 1975: Bathymetry of the northeast Atlantic. Sheet 3: Mid-Atlantic Ridge to southwest Europe. – Deep-Sea Research **22**: 792–810.

Monteiro, J. F., Munha, J. & Ribeiro, A. 1998a: Impact ejecta horizon near the Cenomanian-Turonian boundary, north of Nazaré, Portugal. – Com. V Congresso Nacional de Geologia, Novembro 1998, 4pp. [not numbered]

MONTEIRO, J. F., MUNHA, J. & RIBEIRO, A. 1998b: Impact ejecta horizon near the Cenomanian-Turonian boundary, north of Nazaré, Portugal. – Meteoritics Planet. Sci. **33**: A112–A113.

MOREL, L. 1998: Stratigraphie à Haute Resolution du Passage Cénomanien-Turonien. – Thèse de Doctorat de l'Université Paris VI-Pierre et Marie Curie, 223pp.

ORTH, C. J., ATTREP, M., MAO, X., KAUFFMAN, E. G., DINER, R. & ELDER, W. P. 1988: Iridium abundance maxima in the Upper Cenomanian extinction interval. – Geophys. Res. Lett. **15**: 346–349.

PAUL, C. R. C. & MITCHELL, S. F. 1994: Is famine a common factor in marine mass extinctions? – Geology **22**: 679–682.

PAUL, C. R. C., LAMOLDA, M. A., MITCHELL, S. F., VAZIRI, M. R., GOROSTIDI, A. & MARSHALL, J. D. 1999: The Cenomanian-Turonian boundary at Eastbourne (Sussex, UK): a proposed European reference section. – Palaeogeogr. Palaeoclimat. Palaeoecol. **150**: 83–121.

PRATT, L. M. & THRELKELD, C. N. 1984: Stratigraphic significance of $\delta^{13}C/\ \delta^{12}C$ ratios in mid Cretaceous rocks of the Western Interior. – Mem. Can. Soc. Petrol. Geol. **9**: 305–312.

PRATT, L. M., ARTHUR, M. A., DEAN, W. E. & SCHOLLE, P .A. 1993: Paleoceanographic cycles and events during the Late Cretaceous in the Western Interior Seaway of North America. – In: CALDWELL, W. G. E. & KAUFFMAN, E. G. (Eds.), Evolution of the Western Interior Basin. – Geol. Assoc. Canada, Spec. Pap., **39**: 333–353.

RAUP, D. M. & SEPKOSKI, J. J. 1982: Periodicity of extinctions in the geological past. – Proc. Nat. Acad. Sci., U.S.A., **81**: 801–805.

ROBASZYNSKI, F. & CARON, M. 1995: Foraminifères planctoniques du Crétacé: commentaire de la zonation Europe-Méditerranée. – Bull. Soc.Géol. France **166**: 681–692.

SCHLANGER, S. O. & JENKYNS, H. C. 1976: Cretaceous oceanic anoxic events: causes and consequences. – Geol. Mijnb. **55**: 179–184.

SCOTT, R. W., FRANKS, P. C., EVETTS, M. J., BERGEN, J. A. & STEIN, J. A. 1998: Timing of Mid-Cretaceous relative sea level changes in the Western Interior: AMOCO No.1 Bounds Core. – In: DEAN, W. E. & ARTHUR, M. A. (Eds.), Stratigraphy and Paleoenvironments of the Cretaceous Western Interior Seaway, USA. – SEPM Concepts in Sedimentology and Palaeontology, **6**: 11–34.

TEWARI, A. 1996: The Middle to late Cretaceous microbiostratigraphy (foraminifera) and lithostratigraphy of the Cauvery Basin, Southeast India. – Unpubl. PhD Thesis, Univ. Plymouth, 380pp.

TEWARI, A., HART, M. B. & WATKINSON, M. P. 1996: Foraminiferal recovery after the mid-Cretaceous oceanic anoxic events (OAE's) in the Cauvery Basin, southeast India. – In: HART, M. B. (Ed.), Biotic Recovery from Mass Extinction Events. – Geol. Soc. London, Spec. Pub., **102**: 237–234.

TEWARI, A., HART, M. B. & WATKINSON, M. P. 1998: *Teredolites* from the Gardudamangalam Sandstone Formation (late Turonian – Coniacian), Cauvery Basin, Southeast India. – Ichnos **6**: 75–98.

VAN WAGONER, J. C., POSAMENTIER, H. W., MITCHUM, R. M., VAIL, P. R., SARG, J. F., LOUTIT, T. S. & HARDENBOL, J. 1988: An overview of the fundamentals of sequence stratigraphy and key definitions. – In: WILGUS, C. K., HASTINGS, B. S., KENDALL, C. St. C., POSAMENTIER, H. W., ROSS, C. A. & VAN WAGONER, J. C. (Eds.): Sea-Level Changes: An Integrated Approach. – SEPM Spec. Pub. **42**: 39–46.

WEST, O .L. O., LECKIE, R. M. & SCHMIDT, M. 1998: Foraminiferal paleoecology and paleoceanography of the Greenhorn Cycle along the southwestern margin of the Western Interior Sea. – In: DEAN, W. E. & ARTHUR, M. A. (Eds.), Stratigraphy and Paleoenvironments of the Cretaceous Western Interior Seaway, USA. – SEPM, Concepts in Sedimentology and Paleontology, **6**: 79–99.

WILDE, P. & BERRY, W. B. N. 1984: Destabilization of the oceanic density structure and its significance to marine 'extinction events'. – Palaeogeogr. Palaeoclimat. Palaeocol. **48**: 143–162.

WILDE, P. & BERRY, W. B. N. 1986: The role of oceanographic factors in the generation of global bioevents. –In: WALLISER, O. H. (Ed.), Global bio-events. A critical approach. – Lect. Notes Earth Sci. **8**: 75–91, Berlin (Springer-Verlag).