Upper Cretaceous abyssal claystones in the North Atlantic and Western Tethys: current status of biostratigraphical correlation using agglutinated foraminifers and palaeceanographic events

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The biostratigraphic correlation scheme of Upper Cretaceous multicoloured claystones in the Polish and Romanian External Carpathians using agglutinated deep-water foraminifers can be extended to onshore localities in the Gibraltar Arch area (Morocco, Spain) and DSDP/ODP sites in the North Atlantic. In all studied areas, taxonomic turnovers in deep-water agglutinated foraminifers are observed at the Cenomanian-Turonian boundary and in the early/middle Campanian. Additionally, a remarkable decrease in abundance and diversity of benthic agglutinated foraminifers is observed at the same levels in continuous sections of North Atlantic DSDP sites. These datum levels correspond to inter-regional and time-constant palaeceanographic events, and may facilitate the direct correlation of the biozonalation of agglutinated foraminifers to the standard geomagnetic polarity time scale.

KEY WORDS: Upper Cretaceous; abyssal claystones; biostratigraphy; agglutinated foraminifers; palaeceanographic events; North Atlantic; Gibraltar Arch; Carpathians.

1. Introduction

Red or multicoloured claystones, deposited below the CCD (calcite compensation depth) are among the most widespread sediments in the abyssal zones of the Late Cretaceous ocean. These sediments characterize the North Atlantic abyssal DSDP/ODP sites, and their proximal equivalents can be observed in the Tethyan-Alpine flysch basins of southern and central Europe and North Africa. Despite their wide geographic distribution, there is still no reliable standard method of biostratigraphic correlation within these largely carbonate-free, organic-lean sediments. Planktonic foraminifers and calcareous nannoplankton are generally dissolved away, palynomorphs are oxidized, and radiolarians are rare and often diagenetically altered to zeolitic moulds. The only fossil group occurring in large numbers in diverse, well preserved assemblages are deep-water agglutinated foraminifers (DWAF).

A recent biogeographic survey of DWAF assemblages in the North Atlantic region (Kuhnt & Kaminski, 1990) revealed that at least 209 common species are present in the Upper Cretaceous to Paleocene deep-water sediments. This estimate must be viewed as conservative, since the taxonomy of many generic groups is still poorly known. The majority of the observed species are long-ranging (i.e. range through three stages or more) and others have a strongly environment-dependent distribution. As a result DWAF have been used for biostratigraphic correlation only
locally. For example, several species of DWAF appear to have correlative first or last occurrence levels in various basins of the Carpathian Mountain chain, and have been used for stratigraphic correlation in central Europe for over 30 years (Geroch, 1959; Neagu, 1968, 1970, 1990; Myatlik, 1970; Hanzlikova, 1972, 1973; Sandulescu, 1973; Morgiel & Olszewska, 1981, 1982; Geroch & Nowak, 1984; Geroch & Koszarski, 1988; Malata & Osyczypko, 1990).

A number of these taxa have been recently observed to possess similar stratigraphic ranges in the Gibraltar Arch area (Kuhnt, 1987; Kuhnt & Kaminski, 1989), in the Umbrian Apennines and the Betic Cordillera (Kuhnt, 1990), and in the North Atlantic (Moullade et al., 1988; Kuhnt et al., 1989; Kuhnt & Moullade, 1991). The encouraging results of the recent work in the North Atlantic have stimulated interest in the possible use of DWAF for global stratigraphic correlation in the sub-CCD realm, especially for future studies of Ocean Drilling Program material. In this paper, we review the biostratigraphy of DWAF in key stratigraphic sections in the North Atlantic and Western Tethys, and discuss the potential for developing a well calibrated, robust, biostratigraphic scheme as envisaged under the goals of IGCP Project 262.

2. Biostratigraphy of Upper Cretaceous deep-water agglutinated foraminifers (DWAF)

The key requirement for the development of a reliable biostratigraphic zonation is the availability of continuous, stratigraphically well calibrated sections. This is an elusive goal in areas of collisional tectonics, such as the Carpathians and North Africa, and the biostratigraphic schemes for these areas are necessarily based on composite sections. DSDP material benefits from generally uncomplicated tectonics and good preservation of DWAF, but equally frustrating are the presence of large coring gaps in older DSDP sites from the North Atlantic. For example, DSDP Hole 137 contains perhaps the best preserved abyssal agglutinated assemblage of any North Atlantic site, but the assemblage is known from only two cores, spaced 50 m apart. Continuous stratigraphic sections from the oligotrophic central gyre areas of the Late Cretaceous oceans constitute an unfortunate gap in the geographic coverage of DSDP/ODP sites.

The best available stratigraphic data from the North Atlantic are from DSDP holes 386 (western North Atlantic) and 398D (eastern North Atlantic). Although Hole 386 has a 30 m gap in the upper part of the section, it contains a relatively complete Cenomanian–Turonian boundary and Turonian–lower Campanian. Range-charts of the most important stratigraphic marker species in the Polish and Romanian Carpathians, the Gibraltar Arch area and at these two key North Atlantic sites are presented in Figures 1–4.

Among those species of agglutinated foraminifers that have been demonstrated to be of use for local correlation, several show correlative first or last occurrence levels in more than one basin. Stratigraphic ranges of some of these important markers and a preliminary inter-regional zonal scheme for Late Cretaceous DWAF have been compiled in Figure 5. The following datum levels appear to be useful for supra-regional correlation:

1. The taxa *Hippocrepina depressa, Pseudobolvina variabilis, Plectorecurvirooides irregularis, Trochammina abrupta, Recurvoides imperfectus,* and *Haplophragmoides falcatusuralis* have their last occurrences near the Cenomanian–Turonian boundary. Their extinction was possibly caused by oxygen-depletion of the deep ocean.
Figure 1. Lithology, sampled sections and stratigraphy of the Romanian Eastern Carpathians and the Polish External Carpathians (compiled section). Species with an asterisk occur only in shallower parts of the basin with deposition above the local CCD (e.g. in the Sub-Silesian unit). Compiled using data from Jurkiewicz (1961), Geroch & Nowak (1984), Geroch & Koszarski (1988), Neagu (1990) and unpublished data of T. Neagu and W. Kuhnt. Legend applies to both this figure and Figures 2–5.
Figure 2. Synthetic lithological section, ranges of important marker species of DWAF, and palaeoceanographic events in the Gibraltar Arch area (Tellian and Massilian 'Flysch' units). Compiled using the data of Kuhnt (1987). For legend, see Figure 1.

during the palaeoceanographic event at the Cenomanian–Turonian boundary (CTBE).

(2) The characteristic well oxygenated red clay facies above the Cenomanian–Turonian boundary contain Bulbobaculites problematicus as a biostratigraphic indicator. The total range of B. problematicus is given as lower Cenomanian to lowermost Campanian (Neagu, 1970; Kuhnt, 1990). Its partial range and optimum occurrence characterizes the Turonian Bulbobaculites problematicus Zone of Geroch & Nowak (1984) (=the H. lueckeii Zone of Moullade et al., 1988).

(3) The first occurrence of Uvigerinammina jankoi is noted immediately above the benthic-free interval of the Cenomanian–Turonian boundary event. The highest occurrence of U. jankoi is known from the middle/upper Campanian. The species Hormosina ovulum gigantea is restricted to the middle/upper Campanian and Maastrichtian (Moullade et al., 1988). The first occurrence of this species is a reliable indicator of the middle Campanian in the flysch- and deep-sea environments below the CCD. In abyssal sediments below the CCD, the overlap zone of U. jankoi and H. gigantea is easy to distinguish and is probably the most reliable correlation horizon in the mid-Campanian.
Figure 3. Quantitative composition of agglutinated foraminiferal assemblages, organic-carbon content, ranges of important marker species and palaeoceanographic events at DSDP Site 386 (modified after Kuhnt & Moullade, 1991). For legend, see Figure 1.
Figure 4. Quantitative composition of agglutinated foraminiferal assemblages, ranges of important marker species, and palaeoceanographic events in DSDP Hole 398D (modified after Kuhnt & Moullade, 1991). For legend, see Figure 1.
(4) The last occurrence of *Praecystammina globigerinaeformis* is useful for determining a datum level close to the Coniacian/Santonian boundary in abyssal assemblages of DSDP Site 603 and ODP Site 641 (Moullade et al., 1988), but this species ranges into younger levels at bathyal depths and in the tropical abyssal DSDP Hole 543A (Hemleben & Tröster, 1984).

Several species have their first occurrence in the interval between the lower/middle Campanian and the Cretaceous–Tertiary (K-T) boundary (e.g. *Rzehakina inclusa, R. epigona, Hormosina velascoensis, Glomospira diffundens*). It remains to be tested whether or not these first occurrences are coeval benthic foraminiferal events (at the resolution provided by planktonic foraminiferal zonations) in different basins.

The zonation of Geroch & Nowak (1984) also includes a lower Campanian *Goesella rugosa* Zone. However, this species utilizes calcareous cement for agglutinating its test, and its occurrence is, therefore, restricted to environments above the CCD. At bathyal onshore localities and shallower DSDP sites (e.g. Site 398, Vigo Seamount), the first occurrence of *Goesella rugosa* is an excellent indicator for the Santonian–Campanian boundary. Another calcareous cemented form, *Remesella varians*, is an indicator of middle Maastrichtian and younger strata in bathyal and
abyssal assemblages above the CCD. In sediments deposited below the CCD these species are absent.

A possible faunal turnover in deep-water benthic foraminifers at the Cretaceous–Tertiary boundary is reflected by the first occurrence of several new species in the early Paleocene. Characteristic new Danian species are: Budashevaella cf. multicamerata, Clavulinoides paleocenica, Conotrochammina whangai, Dorothisa indentata, Eggerella trochoide, Phenacophragma beckmanni, Reticulophragnum spp., Reticulophragmoides jarvisi, Spiroplectammina spectabilis (acme), Spiroplectammina excolata and Trochammina ruthveni murrayi. However, the position of the K–T boundary is not precisely delineated in the abyssal sediments of the North Atlantic Plantagenet Formation and the Alpine-Carpathian flysch-trenches, and the study of changes in DWAF across this important boundary is still at an early stage.

The use of first and last occurrences of DWAF for stratigraphic correlation between different basins is not without some persistent problems, due to differences in palaeoceanographic conditions or the local sedimentary environment. (1) Migration barriers may delay the first occurrence of a species in different basins. For example, Conotrochammina whangai was originally described from the Campanian of New Zealand (Finlay, 1940), whereas in the Western Tethys we observe the first occurrence of this species as late as the Danian (Kuhnt & Kaminski, 1990). (2) Many marker species show regionally inconsistent first and last occurrences owing to local differences in detritic supply and deep-water oxygenation (faunal groups 2–4 in Table 1). (3) Fluctuations of the CCD affect marker species which use calcareous cement (faunal group 5 in Table 1). These species consequently have differing stratigraphic ranges depending on the palaeo-water depth of the respective sites.

When using first and last occurrences of DWAF for biostratigraphic correlation, we need to be aware of environmental limitations for different species (Table 1). Future studies of more localities on a global scale are no doubt required before we can detect the true first and last appearance datum levels of stratigraphically important DWAF and calibrate them to the standard geomagnetic polarity reversal time scale. On a more local scale, a probabilistic biostratigraphic approach may help to make better use of deep-water agglutinated foraminifers for biostratigraphic

<table>
<thead>
<tr>
<th>Group</th>
<th>Characteristics species</th>
<th>Suggested habitat</th>
<th>Limiting environmental factors</th>
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<tbody>
<tr>
<td>1</td>
<td>Ueigerammina jankoi</td>
<td>Shallow infaunal</td>
<td>Few environmental limitations</td>
</tr>
<tr>
<td></td>
<td>Recurvoides spp.</td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>Hormosina ovum ovum</td>
<td>Infunal</td>
<td>Occur more frequently on</td>
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<td></td>
<td>Hormosina ovum gigantea</td>
<td></td>
<td>carbonate-poor substrates</td>
</tr>
<tr>
<td></td>
<td>Praeystammina globigerinaformis</td>
<td></td>
<td>Absent in sequences with high</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>terrigenous detrital input</td>
</tr>
<tr>
<td>3</td>
<td>Bulbocacites problematicus</td>
<td>Deep infaunal</td>
<td>Rare or absent in slightly</td>
</tr>
<tr>
<td></td>
<td>Trochammina gyroideaformis</td>
<td></td>
<td>oxygen-deficient environments</td>
</tr>
<tr>
<td>4</td>
<td>Rzhashkina epiopia</td>
<td>Epifaunal</td>
<td>Rare in well oxygenated,</td>
</tr>
<tr>
<td></td>
<td>Glomopirella grisbovskii</td>
<td></td>
<td>oligotrophic environments</td>
</tr>
<tr>
<td>5</td>
<td>Goezella rugosa</td>
<td>Infunal</td>
<td>Uses carbonate cement, absent</td>
</tr>
<tr>
<td></td>
<td>Remesella varians</td>
<td></td>
<td>in sub-CCD environments</td>
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<tr>
<td></td>
<td>Spiroplectammina subhaeringensis</td>
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<td></td>
<td>Clavulinoides subparisiensis</td>
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correlation. Probabilistic biostratigraphic methods have been demonstrated useful for constructing local biostratigraphic schemes in sedimentary basins such as the central North Sea (Gradstein et al., 1988).

3. Palaeoceanographic events

During the mid- to Late Cretaceous, the evolution of oceanic biota was profoundly influenced by two major global palaeoceanographic events, the Cenomanian–Turonian Boundary Event (CTBE) and a lower–middle Campanian Event (LMCE). In the deep-sea environment, both events are characterized by radiolarian blooms (Kuhnt et al., 1986; Thurow, 1988). These may indicate periods of enhanced upwelling and siliceous plankton productivity in the surface waters, which may have led to expanded and intensified short-term oxygen minima. Both these events also coincide with significant changes in abundance and diversity of deep-water agglutinated foraminiferal assemblages (Figures 3, 4).

The CTBE is characterized by predominating biosiliceous sedimentation and shows distinct and marked anoxic facies with enhanced preservation of organic carbon in the deep-sea (compare Figure 3). In the North Atlantic Plantagenet Formation, beds corresponding to the CTBE are devoid of benthic foraminifers, and directly overlying beds are characterized by rare and low-diversity agglutinated assemblages (mainly indeterminable ‘tubes’ and species of the family ammodiscidae). Radiolarians dominate the microfossil assemblages of this period (Thurow & Kuhnt, 1986). In the Polish External Carpathians, the Cenomanian–Turonian boundary is characterized by the occurrence of green shales with radiolarians and radiolarite beds (Bieda et al., 1963; Geroch et al., 1967), which correspond to the CTBE. This palaeoceanographic event is also observed in the Pieniny Klippen Belt, Internal Carpathians, where radiolarian-bearing black shales occur within the upper part of the Rotalipora cushmani planktonic foraminiferal Zone (Birkenmajer & Jednorowska, 1987). Benthic foraminifers re-occur during the Turonian, and abundant and highly diversified benthic assemblages can be observed in the late Turonian–Santonian Bulbocaculites problematicus and Uvigerinammina jankoi Zones (Figures 3, 4).

The LMCE is characterized by the intercalation of a biosiliceous facies in the Tethyan pelagic realm (Herm, 1962; Neagu, 1968; Dumitrice, 1970; Butt, 1981; Empson-Morin, 1984; Kuhnt, 1987). A predominantly radiolarian biofacies has also been observed across this interval in the zeolitic clays (sub-CCD deposits of the Plantagenet Formation) of the North Atlantic Ocean (Empson-Morin, 1984; Moullade et al., 1988; Thurow, 1988). In both cases, this biosiliceous event coincides with a decrease in abundance and diversity and a major taxonomic change in agglutinated foraminifers (Kuhnt et al., 1989): the Uvigerinammina jankoi assemblage, which dominated the Turonian–Santonian sequences, is replaced by a Hormosina ovulum gigantea assemblage, which characterizes upper Campanian and Maastrichtian biofacies in flysch series and zeolitic claystones deposited below the CCD.

The effects of the K–T boundary event on deep marine benthic organisms are still poorly understood. It is clear, however, that this event is associated with an extended period of reduced surface-water productivity throughout the world’s oceans (Zachos & Arthur, 1986). A number of researchers have pointed out that there were either few extinctions among deep-water benthic foraminifers at the end of the Cretaceous (Beckmann, 1960; Hillebrandt, 1965; Kuhnt & Kamiński, 1989) or that
extinctions occurred not suddenly, but over a longer period of time (Webb, 1973; Dailey, 1983). Moullade et al. (1988) observed a significant faunal break in deep-water agglutinated foraminifers coinciding with the K–T boundary in the North Atlantic Plantagenet Formation. In the sites studied, however, the Paleocene portion of the sequence revealed sparse foraminiferal assemblages. Similarly at DSDP Site 543, biostratigraphic control across the upper Maastrichtian to Paleocene interval is poor. Hence, the available data are still ambiguous as to whether or not the evolution of the deep-sea benthos had been strongly affected by the K–T boundary event.

4. Conclusions

New biostratigraphic studies of deep-water agglutinated foraminifers in North Atlantic sequences deposited below the CCD enable us to geographically extend the currently used zonal schemes established in the Carpathian and Alpine areas. The taxa *Uvigerinammina jankoi* and *Hormosina gigantea* are regarded as the most distinctive Upper Cretaceous species in the Tethyan flysch-type assemblages and the North Atlantic abyssal claystones. The first and last occurrences of these species coincide with major palaeoceanographic events at the Cenomanian–Turonian boundary (first occurrence of *U. jankoi*), in the early-middle Campanian (last occurrence of *U. jankoi*, first occurrence of *H. gigantea*) and at the Cretaceous–Tertiary (K–T) boundary (last occurrence of *H. gigantea*). Assuming the global nature of these oceanic events, the associated microfossil datum horizons are thought to be isochronous and to constitute reliable datum horizons for the global biochronology of deep-sea sediments.

The calibration of the agglutinated foraminiferal biozonation to a standard time scale, however, is still problematic. The chronostratigraphy of the deep-sea sequences is insufficiently known owing to the lack of autochthonous calcareous microfossils and only local preservation of radiolarians and palynomorphs. Direct calibration to the geomagnetic polarity time scale is difficult, since most of the mid- and Upper Cretaceous abyssal claystones were deposited during the mid-Cretaceous magnetic long normal period. Additionally, most of the DSDP Sites in the North Atlantic recovered only a patchy record of these sediments, and the sediments themselves are often remagnetized.

Changes in faunal density and diversity, which display clear trends in Upper Cretaceous deep-sea cores, also show potential for stratigraphic correlation. However, these parameters have not been recorded from the Western Tethys, since quantitative studies of complete onshore sections containing agglutinated foraminifers have yet to be carried out in a systematic manner.

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