Planktonic foraminiferal turnover across the Cenomanian–Turonian boundary (OAE2) in the northeast of the Tethys realm, Kopet-Dagh Basin

BEHNAZ KALANAT¹, MOHAMMAD VAHIDINIA¹,², HOSSEIN VAZIRI-MOGHADDAM² and MOHAMAD HOSSEIN MAHMUDY-GHARAIE¹

¹Department of Geology, Faculty of Science, Ferdowsi University of Mashhad, Mashhad, Iran; Be.kalanat@stu.um.ac.ir, ²vahidinia@ferdowsi.um.ac.ir, mahmudygharaie@gmail.com

Abstract: Two Late Cenomanian–Early Turonian (C–T) intervals of the eastern part of the Kopet-Dagh basin, NE Iran have been investigated to evaluate the response of planktonic foraminifera to the geological event OAE2. The Gharesu and Taherabad sections with the thicknesses of 30 m and 22.5 m are composed of shale and marl interbedded with glauconitic sandstone. Three biozones Rotalipora cushmani, Whiteinella archaeocretacea and Helvetoglobotruncana helvetica were recognized based on study of planktonic foraminifera, in these sections. We observed the patterns of planktonic foraminiferal assemblage changes around the C–T boundary and divided this succession into several successive intervals. This study confirms that OAE2 was a long term event. A gradual perturbation in the study successions starts in the interval 1 with low abundance and diversity of planktonic foraminifera. An enhanced oxygen minimum zone (OMZ) occurs in the interval 3 which coincides with a temporary absence of planktonic foraminifera and sedimentation of framboidal pyrite. High diversity of planktonic foraminifera and appearance of new genera in the interval 5 indicate return of normal conditions to the basin. A significant short-term sea surface temperature cooling is also indicated by planktonic foraminiferal turnover and carbonate contents in the interval 2 which is comparable with other parts of the Tethys Ocean, Boreal sea and Atlantic region.

Keywords: biostratigraphy, palaeoecology, planktonic foraminifera, Cenomanian–Turonian boundary, OAE2, Tethyan realm, Kopet-Dagh basin.

Introduction

Oceanic anoxic events (OAEs) were episodes of widespread marine anoxia. There were arguably between two and seven OAEs during the Mid-Cretaceous (Leckie et al. 2002). The most prominent and widespread of these OAEs spans the Cenomanian–Turonian boundary interval and is called Cenomanian–Turonian Boundary Event (CTBE) or OAE2 (Schlanger & Jenkyns 1976; Leckie et al. 2002).

The Cenomanian–Turonian boundary (~93.5 Ma) was a time of transition in the nature of the ocean-climate system. This interval is known as a typical greenhouse period caused largely by increased CO₂ from elevated global igneous activity (Jones & Jenkyns 2001; Poulsen et al. 2001). It is marked by a major warming peak and globally averaged surface temperatures more than 14 °C higher than those of today (Tarduno et al. 1998), ~100–200 m higher sea level than that of today (Haq et al. 1987; Miller et al. 2005), a lack of permanent ice sheets and oceanic circulations (Frakes et al. 1992).

These conditions could have increased the rate of chemical weathering, flux of nutrient to the ocean and biological productivity (Pedersen & Calvert 1990). Production of a lot of organic matter during the time of decreasing oceanic circulations leads to an anoxic condition and superimposition of three crises during the event: wide scale occurrence of black shales (Arthur & Premoli Silva 1982; Luciani & Cobianchi 1999; Coccioni & Luciani 2005), faunal turnovers (Leckie et al. 1998; Keller et al. 2001, 2008; Keller & Pardo 2004; Caron et al. 2006; Soua et al. 2009, 2011) and a positive δ¹³C excursion (Paul et al. 1999; Keller et al. 2004).

The C–T boundary has been studied worldwide (Luderer & Kuhn 1997; Leckie et al. 1998; Luciani & Cobianchi 1999; Keller et al. 2001, 2004, 2008; Coccioni & Luciani 2005; Mort et al. 2008 among others) but this boundary was little known in Iran. Only a few studies have been conducted in the Kopet-Dagh basin. Previous reports from the Shurab and Hmam-Ghale sections in the east of the Kopet-Dagh basin have suggested the presence of oxygen-restricted deposition in the region, based on the presence of dark shale and marl sediments and foraminiferal turnovers (Abdoshahi et al. 2010; Ghoorchaei et al. 2011). Other studies described this boundary as a disconformity (Afshar-Harb 1994; Sadeghi & Forughi 2004) or paraconformity (Vahidinia et al. 1999) in the Kopet-Dagh basin.

The investigated sections in the Gharesu and Taherabad localities are the only well described Cenomanian–Turonian boundary intervals in the northeastern part of Tethys. It is therefore a unique opportunity to study the changes in fossil
content across the Cenomanian–Turonian boundary and the palaeoceanographic development in this part of the Mid-Cretaceous world.

The turnover of the planktonic foraminifera, is a particular focus of this study because their perturbation has been a sensitive monitor of events during the Cenomanian–Turonian boundary in the previous studies.

Geographical and geological setting of the studied areas

The Kopet-Dagh basin, which stretches over nearly 700 kilometres from the east of the Caspian Sea to NE Iran, Turkmenistan and north Afghanistan (Fig. 1C) is composed of a 5000–7000 m thick sequence of gently folded rocks of Middle Jurassic to Eocene age (Afshar-Harb 1994). The Cretaceous sediments were deposited on the northern shelf of a deeper marine basin separating the Iran Plate from Eurasia (Turan) Plate in the northeast of the Tethys realm (Fig. 1A, B). This sequence reaches more than 3000 m in thickness and seems to represent all stages of the Cretaceous (Stocklin 1968). The Aitamir and Abderaz formations are two major lithostratigraphic units in the Kopet-Dagh basin with Lower to Upper Cretaceous age (Afshar-Harb 1994).

The Late Cenomanian to Early Turonian interval in the Gharesu and Taherabad sections spans the upper part of the Aitamir Formation and lower part of the Abderaz Formation. The Gharesu section is located a few kilometres west of the city of Kalat (Fig. 1D). This section is composed of 30 m of shale and marl interbedded with glauconitic sandstone. The Taherabad section is 22.5 m thick and is located along the Mashhad-Kalat main road (Fig. 1D). The lithology of this section is similar to the Gharesu section except that the Gharesu section has more sandstone beds than the Taherabad section.

Material and methods

After preliminary sampling to locate the C–T interval, 22 samples spanning 30 m of the Gharesu section and 49 samples spanning 22.5 m of the Taherabad section were finally collected. The samples were taken at 20–50 cm intervals close to the C–T boundary and at 1–2 m intervals farther away from the boundary.

In the laboratory, samples were crushed and put into a mixture of water and a small amount of H₂O₂, then washed through a 53 µm sieve. For planktonic foraminiferal studies, about 250–300 specimens were counted and identified except in the samples around the C–T boundary where foraminifera are rare or absent. Species identification follows that of Caron (1985) and Premoli-Silva & Verga (2004) (Figs. 2, 3). The carbonate contents were measured using the calcimeter method in the laboratory.

Fig. 1. A — Palaeogeographic map of the Late Cretaceous (Late Cretaceous; © Blakey R.; http://jan.ucc.nau.edu/~rcb7/RCB.html) showing the location of investigated sections in the Kopet-Dagh basin (1, 2) and important sections referred in the text (3 — Pont d’Issole, 4 — Eastbourn, 5 — Tarfaya). The area of map B is outlined; B — Cenomanian palaeogeographic map of the Middle East (modified after Philip & Floquet 2000); C — structural units of Iran and location of the Kopet-Dagh basin in northeast Iran, southwestern Turkmenistan and north Afghanistan (after Berberian & King 1981); D — the Gharesu and Taherabad sections along the Mashhad-Kalat main road.
Fig. 2. SEM illustrations of planktonic foraminifera from the Taherabad section (‘a’ for spiral side, ‘b’ for lateral side, ‘c’ for umbilical side). 1a, b, c — Rotalipora cushmani (Morrow), sample T4. 2a, b, c — Rotalipora appenninica (Renz) sample T14. 3a, b, c — Praeglobotruncana gibba Klaus, sample T48. 4a, b, c — Helvetoglobotruncana helvetica (Bolli), sample T46. 5a, b, c — Whiteinella prae­ helvetica (Trujillo), sample T46. 6a, b, c — Dicarinella hagni (Scheibnerova), sample T46. 7a, b, c — Whiteinella archaeocretacea Pessagno, sample T47.
Fig. 3. SEM illustrations of planktonic foraminifera from the Taherabad and Gharesu sections ('a' for spiral side, 'b' for lateral side, 'c' for umbilical side).

1a, b, c — Marginotruncana pseudolinneiana Pessagno, sample gh21.
2a, b, c — Rotalipora appenninica (Renz), sample gh5.
3a, b, c — Helvetoglobotruncana helvetica (Bolli), sample gh21.
4a, b, c — Helvetoglobotruncana helvetica (Bolli), sample gh22.
5a, b, c — Praeglobotruncana stephani (Gandolfi), sample gh6.
6 — Heterohelix globulosa (Ehrenberg), sample T47.
7 — Heterohelix moremani (Cushman), sample T48.
8 — Guembelitria cenomanana Keller, sample T46.
9 — Guembelitria cenomanana Keller, sample gh21.
10 — frambooidal pyrite, sample T2.
Biostratigraphy

Despite ammonites, changes in the planktonic foraminiferal assemblages are less indicative and seem to occur over a broad interval of time coeval with the contemporary oceanic environmental perturbation across the Cenomanian–Turonian boundary.

The foraminiferal biostratigraphy of the Cretaceous has been studied in great detail by many authors. Wonders (1980) proposed that C–T boundary corresponds to the base of the *Whiteinella archaeocretacea* zone. But subsequent studies (Caron 1985; Robaszynski et al. 1993; Robaszynski & Caron 1995; Hardenbol et al. 1998; Premoli-Silva & Verga 2004; Zaghib-Turki & Soua 2013) indicated that this boundary is placed in the middle of the *W. archaeocretacea* zone (Fig. 4).

28 species belonging to 11 genera and 22 species belonging to 10 genera of planktonic foraminifera were recognized respectively in the Taherabad and Gharesu sections. The stratigraphic distributions of these planktonic foraminifera are plotted in Figs. 5 and 6.

Based on the planktonic foraminiferal zonal scheme of Premoli-Silva & Verga (2004), the following planktonic foraminiferal biozones were identified in the sections:

**Rotalipora cushmani Total Range Zone:** This zone is defined by the first and last occurrences of *Rotalipora cushmani* and corresponds to the Middle–Late Cenomanian. Premoli-Silva & Verga (2004) divided this zone into two subzones (*Rotalipora greenhornensis* and *Dicarinella algeriana*) which are differentiated by the first appearance of *D. algeriana*.

Rotaliporidae are not present from the base of this zone in our sections, but this group appears from a height of 2.5 m in the Taherabad section and 10.5 m in the Gharesu section. Rotaliporidae (*R. cushmani, R. appenninica*) are scarce in this biozone and are associated with whiteinellids, heterohelicids, muricohedbergellids and dicarinellids.

In the Gharesu section the first appearance of rotaliporids coincides with the first appearance of dicarinellids, but in the Taherabad section *D. algeriana* appears before rotaliporids. The absence of rotaliporids and dicarinellids in the base of sections resulted from eutrophic condition and/or low oxygen content or by shallower marine environmental conditions. So we suggest the interval from the base of sections to the last occurrence of *R. cushmani* belongs to the *D. algeriana* subzone.

**Whiteinella archaeocretacea Partial Range Zone:** This zone spans the interval from the last occurrence of *R. cushmani* to the first occurrence of *H. helvetica* and extends from the latest Cenomanian to earliest Turonian.

This biozone appears from a height of 6.5 m in the Taherabad section and 14 m in the Gharesu section. Assemblages in this interval, if present, consist of whiteinellids, muricohedbergellids, heterohelicids and guembelitriids.

**Helvetoglobotruncana helvetica Total Range Zone:** The base and top of the zone coincide respectively with the first and last occurrences of the index-species *H. helvetica*. This zone ranges from Early to Middle Turonian.

We recognized the species about 19.5 m and 29 m above the base of the Taherabad and Gharesu sections, respectively. The most important and common foraminifera in this zone are: dicarinellids, whiteinellids, muricohedbergellids, heterohelicids and praeglobotruncanids. Also Marginotruncanidae species are present in the Gharesu section.

**Palaeo-ecology and planktonic foraminiferal turnover**

In the past 20 years, the palaeo-ecology of foraminifera became a dominant field of micropalaeontology. Significant changes in foraminiferal assemblages can be interpreted as reflecting an ecological response to palaeo-oceanographic variations. Among other foraminifera the ecology of planktonic foraminifera plays an important role in the study of oceanic systems (Nebrigic 2006).

Recent planktonic foraminifera reach their highest diversity within a stratified water column with normal salinity,
nutrient and oxygen content (Hart 1980a, b; Leckie et al. 1998; Hallock et al. 1991; Keller et al. 2001; Keller & Pardo 2004). In these conditions large, keeled, deep-water dwelling forms (K strategists, such as: *Rotalipora* and *Helvetoglobotruncana*) increase. But when environmental conditions are more extreme, diversity is low and opportunistic taxa (r strategists, such as: *Heterohelix* and *Muricohedbergella*) are common (Keller et al. 2001; Coccioni and Luciani 2005). These simpler morphotypes with little surface ornamentation and thin test walls generally occupy the surface mixed layers (above thermocline), or shallow waters with generally unstable and/or eutrophic conditions (Hart 1980a, b; Caron & Homewood 1983; Leckie et al. 1998; Keller 1988; Li & Keller 1998; Keller et al. 2001).

In order to interpret foraminiferal distribution across the C–T transition, Coccioni and Luciani (2005) summarized published data on stable isotopic analysis together with depth ranking based on environmental inferences (morphology and palaeobiogeographic distribution) in their article (Fig. 7).

![Fig. 5. Distribution and species richness of planktonic foraminifera in the Gharesu section.](image)

Based on changes in planktonic foraminiferal distribution and diversity, we divided the Gharesu and Taherabad sections into 5 discrete intervals:

**Interval 1:** This interval (samples gh1–gh4 in Gharesu section and T0–T3 in the Taherabad section, the lower part of *R. cushmani* zone) is characterized by low species diversity and abundance and low carbonate content (Fig. 8). In the Gharesu section planktonic foraminifera are not present or too scarce to be counted. In the Taherabad section simple morphotype of planktonic foraminifera with globular chambers and trochospiral, biserial and triserial test (*Whiteinella*, *Murico hedbergella*, *Heterohelix* and *Guembelitria*) are present. Keeled forms (*Dicarinella algeriana*) are present in very low abundance in sample T1 (Fig. 9).

We propose this interval was deposited in a marine environment with high terrigenous influx and eutrophic condition. Framboidal pyrite (Fig. 3–10) is also present in all samples of this interval. These framboids are 50–150 µm in diameter and are composed of tiny crystallites of 2–5 µm which are spheroidal, cubic, octahedra or irregular in shape. The formation of framboidal pyrite in sediments or during sedimentation requires an anaerobic environment (Schallreuter 1982). Under low oxygen content conditions, sulphate-reducing bacteria produce hydrogen sulphide which reacts with available iron to form microconcretions of pyrite, possibly by the mechanisms suggested by Berner (1969).

**Interval 2:** At the onset of this interval (samples gh5–gh7 in the Gharesu section and T4–T14 in the Taherabad section, the upper part of the *R. cushmani* zone), rotaliporids appear in both sections. A marked increase in diversity and abundance of planktonic foraminifera occurs in this interval, as the number of species in the Gharesu section increases from 1 to 10 and in the Taherabad section from 6 to 15 (Fig. 9), this is accompanied by a relative increase of CaCO₃ content (Figs. 8, 9) which suggests, terrigenous input decreases in
this interval. However, the condition in this interval is more stable, a relatively high percentage of Whiteinella, Muricochedbergella and Guembelitria and low abundance of keeled forms (2–5% in samples which are present) indicate a general mesotrophic regime in interval 2.

**Interval 3:** This interval (samples gh8–gh16 in the Gharesu section and T15–T39 in the Taherabad section, the lower part of the *W. archaeocretacea* zone) starts with the disappearance of rotaliporids and ends with a thick glauconitic sandstone. At the base of this phase, a dramatic

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**Fig. 6.** Distribution and species richness of planktonic foraminifera in the Taherabad section.

**Fig. 7.** Inferred life strategy of upper Cenomanian and lower Turonian planktonic foraminifera derived mainly from latitudinal distribution, abundance and depth ranking based on environmental inferences (morphology and biogeographic distribution), and stable isotopic data, plotted against the oceanic surface trophic resources continuum (modified after Coccioni & Luciani 2005).
decrease in diversity and abundance of planktonic foraminifera occurs. Planktonic foraminifera are absent except for sample gh11 in the Gharesu section and samples 17–19, 22–26 in the Taherabad section. The assemblage contains dwarfed and scattered Guembelitria and Whiteinella in the Gharesu section and Guembelitria, Heterohelix, Whiteinella and Muricohedbergella in the Taherabad section. Keeled morphotypes are present in very low abundance (almost 2%) in samples 23, 24, 26 in the Taherabad section (Fig. 9).

All the above, low percentage of carbonate, presence of sandstone beds and frambooidal pyrite in the sediments, indicate sedimentation occurs in a marine environment with high productivity and low oxygen content.

The presence of benthic foraminifera in samples where planktonic foraminifera disappear temporarily indicates that the water column and bottom water is not extremely depleted in oxygen content and absence of planktonic foraminifera is a result of a high detrital input and productivity beside a developed oxygen minimum zone (OMZ).

Interval 4: At the onset of this interval (samples gh17–gh20 in the Gharesu section and samples T40–T45 in the Taherabad section, the upper part of the W. archaeocretacea zone) planktonic foraminifera reappear with higher abundance and diversity. Heterohelicids dominate the assemblage. Whiteinella and Muricohedbergella are present with high abundance. Guembelitria are very rare in this interval. Keeled forms are present in all samples from the Taherabad section and in...
sample 18 from the Gharesu section (although with low abundance ~4–5 %) (Fig. 9).

This interval coincident with maximum Heterohelix abundance. This event (the so called Heterohelix shift) was also observed at the same stratigraphic interval in the world (Leckie et al. 1998; Keller et al. 2001, 2008; Keller & Pardo 2004; Zaghib-Turki & Soua 2013) and is an excellent biomarker for global correlations. Heterohelix shift appears to be associated with a global expansion of the oxygen minimum zone (Keller & Pardo 2004, Zaghib-Turki & Soua 2013).

Increasing of planktonic foraminiferal abundance and carbonate content, show that terrigenous input is low in this interval.

Interval 5: This interval (samples gh21–gh22 in the Gharesu section, samples T46–T49 in the Taherabad section, H. helvetica zone) starts with the appearance of Helvetoglobotruncana helvetica. The diversity and abundance of planktonic foraminifera are higher than in other intervals (Fig. 9).

The appearance of new genera (Helvetoglobotruncana and Marginotruncana in the Gharesu section and Helvetoglobotruncana in the Taherabad section) and abundance of keeled forms indicate this interval is deposited under a relatively normal salinity, oxygen content and oligotrophic condition.

Guembelitria disappear in this interval because this genus thrived in eutrophic surface waters of shallow marginal marine environments with variable salinities at times of severe ecological stress (Keller 2002; Keller et al. 2002).

Correlation and discussion

Lower abundance and number of species of planktonic foraminifera, lower keeled forms and more sandstone intercalation in the Gharesu section suggest that this section was deposited in a shallower water environment than the Taherabad section but all other changes in the sea level and appearance and disappearance of species are comparable in these sections (Fig. 9).

In the Gharesu and Taherabad sections, decrease of oxygen content starts in interval 1 and continues in intervals 2, 3 and 4, as is revealed by the presence of framboidal pyrite in the deposits and planktonic foraminiferal content. High numbers of the opportunists and Heterohelix shift suggest that the environmental perturbation related to the CTBE did not end during interval 3 but continued into interval 4.

It seems that, recovery phase occurs in the Helvetoglobotruncana helvetica zone (interval 5) and is marked by an...
increase of both abundance and diversity of planktonic foraminifera.

Good correlation between diversity of planktonic foraminifera and CaCO$_3$ content suggests that detrital input and productivity beside oxygen content are effective factors in patterns of change in planktonic foraminiferal assemblages in the Gharesu and Taherabad sections, as in the intervals 1 and 3, high detrital input leads to an eutrophic condition and decreases the diversity of planktonic foraminifera (Fig. 9).

The Late Cenomanian sea surface temperature cooling

On a global scale, the C–T boundary is characterized by its warm climate interval accompanied by a major sea level transgression (Hancock & Kauffman 1979; Haq et al. 1987; Uličný et al. 1993; Hardenbol et al. 1998). However, many authors have described an ephemeral but significant decrease in sea surface temperatures at the onset of OAE2 in some CTB sections (Lamolda et al. 1994; Forster et al. 2007; Jarvis et al. 2011; Kaito et al. 2014 among others). This cooling has been attributed to a drop in atmospheric pCO$_2$ (Symbol for the negative decadic logarithm of the CO$_2$ concentration) levels which in turn was caused by enhanced carbon sequestration by burial of organic matter (Hasegawa et al. 2003; Forster et al. 2007). This event was first recognized as an incursion of boreal fauna in the shelf seas of NW Europe (e.g., Jefferies 1962; Gale & Christensen 1996; Voigt et al. 2004) and called the Plenus Cold Event. In the Western Interior Seaway of North America and in the equatorial proto-Atlantic, this interval was characterized by repopulation of the seafloor by benthic foraminifera (the Benthic Oxic Event), indicating regional reoxygenation of bottom waters (Lekie et al. 1998; Keller et al. 2001, 2008; Keller & Pardo 2004).

This short-lived cooling event in the Gharesu and Taherabad sections is characterized by a decreased detrital input and increased carbonate production and diversity of planktonic foraminifera in interval 2, at the end of the R. cushmani zone (Fig. 9).

This event is compared with those at Pont d’Issole (France, Tethys Ocean), Eastbourne (England, Boreal sea) and Tazra (Morocco, Atlantic region) in Figure 8.

The record of Pont d’Issole in France (Tethys Ocean) (Grosheny et al. 2006; Jarvis et al. 2011) displays two prominent black shale intervals within an interbedded limestone-grey marl succession. This succession is similar to Gharesu and Taherabad in many ways (increase of carbonate and planktonic foraminiferal diversity in cooling interval) but differs from Gharesu and Taherabad by its further depth and sedimentation of black shale before and after the cold event.

The CTB interval at Eastbourne section in England (Boreal sea) consists of chalk and rhythmically bedded marls (Plenus Marls Formation) (Gale et al. 1993). In the Plenus marls, the relative abundance increase of keeled taxa and increase of planktonic foraminiferal diversity, coincident with decreased Heterohelix abundances, suggest a well-stratified water mass and reduced oxygen minimum zone (Keller et al. 2001).

In contrast to Gharesu and Taherabad (Tethys realm), marls and marly chalk deposits at Eastbourne (Boreal Sea), with decreased calcite, increased phyllo-silicates, quartz and feldspar were deposited in the Plenus Cold Event period (Keller et al. 2001). This difference in carbonate content of the Plenus Cold Event interval may be explained by the different palaeo-latitude of sections. The Gharesu and Taherabad sections with their lower palaeo-latitude are less effected by sea-level lowstand periods, increased erosion and accelerated detrital input.

As before mentioned, synchronous with the Plenus Cold Event, a period of extensive bottom water reoxygenation occurred throughout the Atlantic region. In this interval at the Tazra section (Morocco, Atlantic Ocean), the low oxygen tolerant Heterohelix populations dramatically decreased in response to more oxygenated waters throughout the water column, Guembelitira thrived and the surviving rotaliporids species rapidly disappeared (Keller et al. 2008). Low Calcite/Detritus ratios in the cooling event indicate increased detrital input, linked to intensified upwelling in the western African margin (Keller et al. 2008).

In fact, this cooling event is an unusual interlude in the long-term trend of oceanic anoxia during the Cenomanian–Turonian interval. At the start of OAE2, higher sea surface temperature together with enhanced runoff and nutrient input resulted in burial of organic matter. Burial of organic matter (OM) lowered pCO$_2$, cooling the greenhouse climate. At the end of the OAE2, when carbon burial rates were reduced, pCO$_2$ increased again (van Bentum et al. 2012). In all described sections, faunal turnover suggests the expansion of the oxygen minimum zone before and after the cold event (Fig. 8).

Conclusion

The two Cenomanian–Turonian sections at Gharesu and Taherabad in the Kopet-Dagh basin coincide with the upper part of the Aitamir Formation and lower part of the Abderaz Formation. The C–T boundary in these two sections is conformable based on presence of the three following zones: Rotalipora cushmani Total Range zone, Whiteinella archaeo­cretacea Partial Range Zone and Helvetoglobotruncana helvetica Total Range Zone. Planktonic foraminiferal assemblage changes show five intervals with different degrees of environmental perturbation associated with the OAE2. In the two sections, the most dramatic changes took place during interval 3. Temporary disappearance of all planktonic foraminifera in some samples, low carbonate content and presence of frambooidal pyrite indicate an increased detrital input, surface productivity and an enhanced OMZ in interval 3. High abundance of simple planktonic morphotypes especially heterohelicids shows that low oxygen
content continues into interval 4. Appearance of the new genera *Helvetoglobotruncana* and *Marginotruncana* in the upper part of sections indicates that this part of the sediments was deposited under more normal and stable condition. A decreased run off also coincides with increased carbonate contents and diversity of planktonic foraminifera in interval 2 (at the end of the *R. cushmani* zone) can be interpreted as evidence of a short-term cooling in the studied succession, which is comparable to the Plenus Cold Event in the Tethys realm and benthic oxic zone in the Atlantic Ocean.

References


