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Cretaceous–Paleogene boundary problem in Libya: the occurrence of the foraminiferal species *Abathomphalus mayaroensis* (Bolli) in the Western Sirt Basin

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The position of the K/P boundary in wells in the Western Sirt Basin of Libya is problematic. The biostratigraphic definition of the K/P boundary in the subsurface is based on the extinction of the eponymous taxon of the standard latest Maastrichtian foraminiferal *Abathomphalus mayaroensis* Zone. We have unambiguously recognised this taxon from the Sirt Basin subsurface sections for the first time. All the latest Maastrichtian foraminiferal assemblages are dominated by planktonic foraminiferids. Some of specimens are pyritised, indicating organic flux to the basin floor, causing oxygen deficiency in the depositional environment. The occurrence of characteristic bathypelagic and some epipelagic species indicates that the environment of deposition is outer shelf–middle continental slope.

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INTRODUCTION

Identification of the Cretaceous/Paleogene (K/P) boundary in the subsurface and its correlation with the surface of the western margin of the Sirt Basin was recognised as an important problem in the 1960's (*cf.* the discussion between A. Desio and E. P. Lehmann in: Lehmann, 1964). Despite many attempts (Jordi and Lonfat 1963; Lehmann, 1964; Barr and Berggren, 1980; Tmalla, 1992) the exact position of the Cretaceous–Tertiary boundary in the Sirt Basin remains uncertain. This was due largely to the absence of *Abathomphalus mayaroensis* (Bolli), the eponymous taxon of the standard latest Maastrichtian foraminiferal zone in the Sirt Basin (Tmalla, 1992, 1996). This absence has made the correlation of the open marine deposits of the basin with the world stratigraphic standards for the K/P boundary insecure. Shallow marine deposits of the western margin of the Sirt Basin also contain fossil records too scarce to precisely establish a boundary. Moreover, neither the iridium anomaly nor any other symptom of a catastrophic event at the K–T boundary has been found in the deposits of the Sirt Basin studied to date (Eliagoubi and Powell, 1980).

Identification of the K/P boundary has been one of the purposes of the Western Sirt Basin project (WSB Project no. 2383), carried out by Petroleum Research Centre of Libya and Teknica Petroleum Services Ltd. of Calgary, Canada. This paper summarises the attempt to establish the position of the K/P boundary in wells located in the Western Sirt Basin (Fig. 1). Biostratigraphic definition of the K/P boundary in the subsurface is based on the presence and extinction of the eponymous taxon of the standard latest Maastrichtian foraminiferal *Abathomphalus mayaroensis* Zone. The K/P boundary in the Sirt Basin is a Type 1 sequence boundary (Jerzykiewicz *et al.*, 2002), making it extremely useful for stratigraphic correlation across the basin. An attempt at such high-resolution correlation is presented in this paper.

Preliminary results of the Late Cretaceous of the Western Sirt Basin (Tshakreen *et al.*, 2002) indicated that foraminiferids from the samples studied are abundant, diverse and relatively well preserved. The most recent studies of the Sirt Basin reveals the presence of earliest Paleocene deposits.

K/P BOUNDARY IN LIBYA

The Cretaceous–Paleogene boundary has been recognised in Libya as one of the most important stratigraphic boundaries as early as in 1960's (Jordi and Lonfat, 1963; Lehmann, 1964).

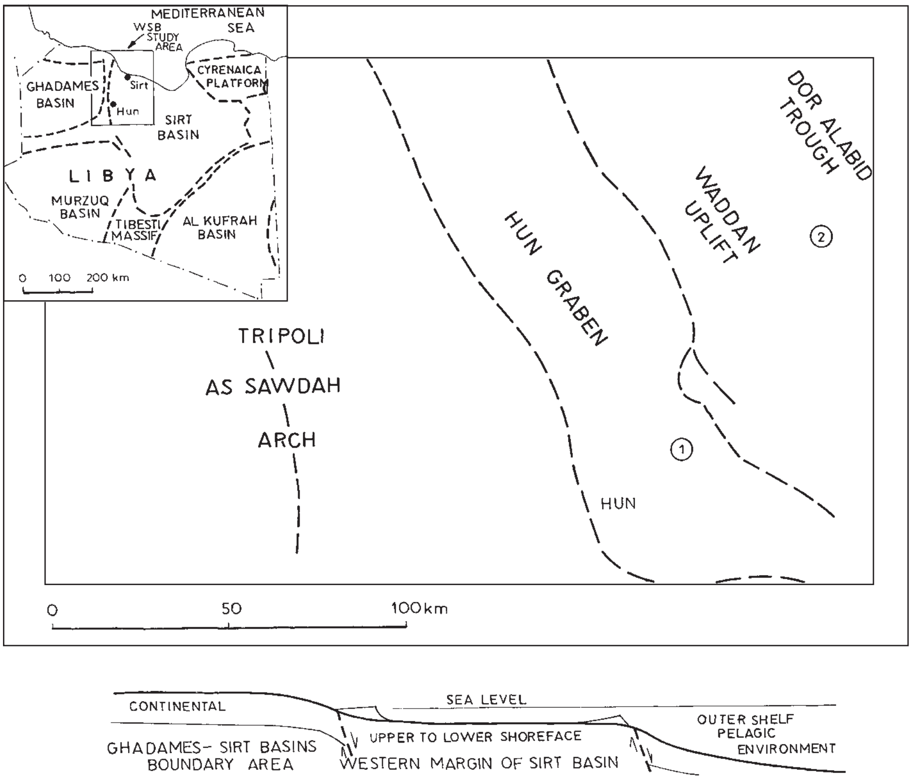

Fig. 1. A location of hinterland and open marine environments within the Western Sirt Basin

Upper left corner — the position of the study area in relation to the major sedimentary basins in Libya; 1, 2 — location of the studied wells; below — the depositional environments which developed on the eastwards sloping margin of the Western Sirt Basin. The subaerial environment (hinterland) developed on the emergent margin of the basin. Further eastward, the environment of deposition changes to a tidally-dominated inner shelf followed eastwards by outer shelf and then to the distal part of the basin marked by pelagic facies (partly after Jerzykiewicz *et al.*, 2002)

Subsequently, Barr and Berggren (1980) and Tmalla (1992) discussed the problem of the K/P boundary and established its approximate position.

Barr and Berggren (1980) placed the Cretaceous/Tertiary (Maastrichtian/Danian) contact at the base of the Socna Mollusc Bed in surface exposures, along the western margin of the Sirt Basin (i.e. between the Lower and the Upper Tar members of the Zmam Formation). According to them, the microfossils from the western margin of the basin indicate that there was a marked shallowing of the seas at the end of Maastrichtian time but no break in deposition has been postulated. Moreover, the K/P boundary in the deeper parts of the Sirt Basin is marked by an abrupt lithological change, reflecting a widespread and sudden shift in depositional environment. According to Barr (1972) this change is the result of shallowing of the Late Maastrichtian seas and a subsequent strong transgressive surge at the beginning of the Danian. However, such changes may result from global eustatic fluctuations as well as local tectonic events (Gasiński, 1997; Arenillas *et al.*, 2000; Dupuis *et al.*, 2001). Accordingly, the Maastrichtian/Danian boundary in the subsurface of Sirt Basin has been placed at the boundary between the Kalash Limestone and the Hagfa Shale (*cf.* Barr and Weegar, 1972).

Tmalla (1996) questioned the correctness of placing the K/P boundary at the contact between the Kalash Limestone and the Hagfa Shale in the Northern Sirt Basin (well A1a-NC29A). In absence of *Abathomphalus mayaroensis*, Tmalla used other planktonic species to establish the position of the K/P boundary. He proposed a local *Eoglobigerina minutula* Zone for the earliest Paleogene biostratigraphic interval which lies between the Cretaceous–Tertiary boundary and the *Subbotina pseudobulloides* Zone. As a result, Tmalla (1996) concluded that the K/P boundary should be placed within the uppermost part of the Kalash Limestone.

According to Tmalla (1992, 1996) *Abathomphalus mayaroensis* is virtually absent from subsurface sections in Libya. This fact makes the correlation of the open marine deposits of the basin with the world stratigraphic standards for the K/P boundary problematic.

GEOLOGICAL SETTING

The geology of the Western Sirt Basin has been summarised by Shakoor and Shagroni (1984) as well as by Gumati and Kanes (1985) and Gundobin and Yevdokimov (1985). Most recently, the geology of Sirt Basin has been described by Jerzykiewicz *et al.* (2002).

About 200 samples collected from ditch cuttings of two wells located in the Western Sirt Basin (Fig. 1) have been examined in the interval between 685–1203 m depth (Fig. 2). Stratigraphically, these sediments belong to the Kalash Limestone and the Hagfa

Shale (Barr and Weegar 1972; see above) and are composed of black and grey marlstones, marly shales and shales (Fig. 2).

METHODS

Sample disintegration by heating and freezing in Glaubert salt was applied. Some, very soft samples were only washed. The residue was washed through a set of sieves (100–65 μm in diameter). Specimens were identified under stereoscopic and SEM microscopes. All laboratory analyses were undertaken at the Micropalaeontological Laboratory of the Institute of Geological Sciences of the Jagiellonian University. Studied specimens of *A. mayaroensis* are housed at the Jagiellonian University Geological Museum (coll. WSB/ING UJ/2001).

MICROPALAEONTOLOGICAL PART

Description of the nominal species:

Abathomphalus mayaroensis (Bolli, 1951)
(Fig. 3a–e)

Globotruncana mayaroensis Bolli, 1951, pp. 190, 198, pl. 35, figs. 10–12.
Abathomphalus mayaroensis (Bolli), Bolli, Loeblich and Tappan, 1957, p. 43, pl. 11, figs. 1a–c.

Holotype. — Subsurface section in the Guayaguayare area, County of Mayaro, Southeastern Trinidad.

Remarks. — Specimens of *A. mayaroensis* resembling Bolli's holotype were found in the Sirt Basin (Fig. 3a, b). These forms possess the beaded keel structure (Fig. 3d, e), characteristic flat morphology of the test and spinose/rugose surface. Rugosities are arranged in parallel rows (Fig. 3e). The diameters of the forms studied are similar to the holotype from Trinidad. However, some specimens have been identified as "cf." because they possess features of *Abathomphalus mayaroensis* as well as of *Globotruncana arca* ("intermediate forms"?; Fig. 3f–h). These specimens of *A. mayaroensis* are quite similar to those recently described from the Polish Carpathians (Gasiński *et al*., 2001).

This species is rare in the studied samples; they only sometimes exceed of 2% of the total planktonic assemblages. In general, planktonic associations constitute about 80% of the whole foraminiferal assemblages.

Following Postuma (1971, pp. 50–51), *A. mayaroensis* has two beaded keels; the primary apertures are interiomarginal, umbilical, covered by a tegillum. Barr (1972, pp. 26–27, pl. 5, figs. 1–2) noted that *A. mayaroensis* chambers on the umbilical side are ornamented by short irregular radial costae. According to him, this species is never abundant in Libya, although rare specimens have been found from the Upper Maastrichtian chalk in a number of wells in the N-Sirt Basin and from outcrops in N Cyrenaica.

Robaszynski *et al*. (1984, p. 274, pl. 45, figs. 5, 6, 9, pl. 46, figs. 4–5) characterise *A. mayaroensis* as having: an extraumbilical-umbilical primary aperture, chamber surfaces ornamented with rugosities arranged in a meridional pattern. The spiral side shows chambers gradually increasing in size as added. In lateral view, this species has a very low trochospire and two keels composed of radially arranged rugosities. According to these authors, this species differs from the Late Maastrichtian *Abathomphalus intermedius* (Bolli) in the presence of two keels on all chambers.

Caron (1985, p. 42, fig. 21.10–11) noted that *A. mayaroensis* posses two peripheral keels which are composed of short, radially oriented costellae. This species differs from *A. intermedius* (Bolli) in the presence of a double keel on all chambers of the last whorl.

Hart *et al*. (in: Jenkins and Murray, 1989, p. 308) characterise this species by its "bow-tie" morphology and ornamentation.

Lybian micropalaeontologists have attempted to describe this species. Ashour (1996) illustrated (pl. 2, fig. 2) *A. mayaroensis* from the Sirt Basin, but this specimen do not resemble *Abathomphalus mayaroensis* (the illustrated specimen has a solid keel and does not indicate any traces of the characteristic test ornamentation of *A. mayaroensis*).

Tmalla (1996) mentioned that *A. mayaroensis* had never been encountered in the well A1a-NC29A. Hence, he adapted the *G. conica* Zone of Eliagoubi and Powell (1980) as the equivalent of the *A. mayaroensis* Zone in the latest Maastrichtian. He also noted the scarcity of *A. mayaroensis* in the El Kef section (following cited authors). According to Eliagoubi and Powell (1980), *A. mayaroenis* has never been recovered from any of the localities studied by them in Libya. Therefore, they established the *Globotruncana contusa* Subzone (within the *G. conica* Assemblage Zone) as the biostratigraphical equivalent of the *A. mayaroensis* standard Zone.

Shakoor and Shagroni (1984) did not list *A. mayaroensis* within the Maastrichtian foraminiferal assemblages of Libya.

Most recently, Arenillas *et al*. (2000) and Dupuis *et al*. (2001), describing the K/P boundary in Tunisia (Aïn Settara section), noted the scarcity or absence of *A. mayaroensis* in high latitude sections, including also El Kef, which is the K/P type section (*cf*. Keller *et al*., 1995; MacLeod, 1996). According to them this is related to bathymetry, i.e. a shallow-water environment. Therefore, following other authors, they used *Plummerita hantkeninoides* (Brönnimann) as a Late Maastrichtian marker. Following Ion (1993), Keller *et al*. (1995), Molina *et al*. (1996), Arenillas *et al*. (2000) and others, they established the *P. hantkeninoides* Biozone as a zone above the *A. mayaroensis* Zone in the latest Maastrichtian.

Caron (1985) and Robaszynski and Caron (1995) do not mention *P. hantkeninoides* either as taxa or biozone. However, Dupuis *et al*. (2001) used the *P. hantkeninoides* zone as a Total Range Zone because of the scarcity of *A. mayaroensis* in the Aïn Settara section in Tunisia. Following the stratigraphic range of *P. hantkeninoides* given by Robaszynski *et al*. (1984) it is evident that the stratigraphical range of this taxa is greater than that of *A. mayaroensis* (FO — before FO of *A. mayaroensis* and LO similar to *A. mayaroensis*).

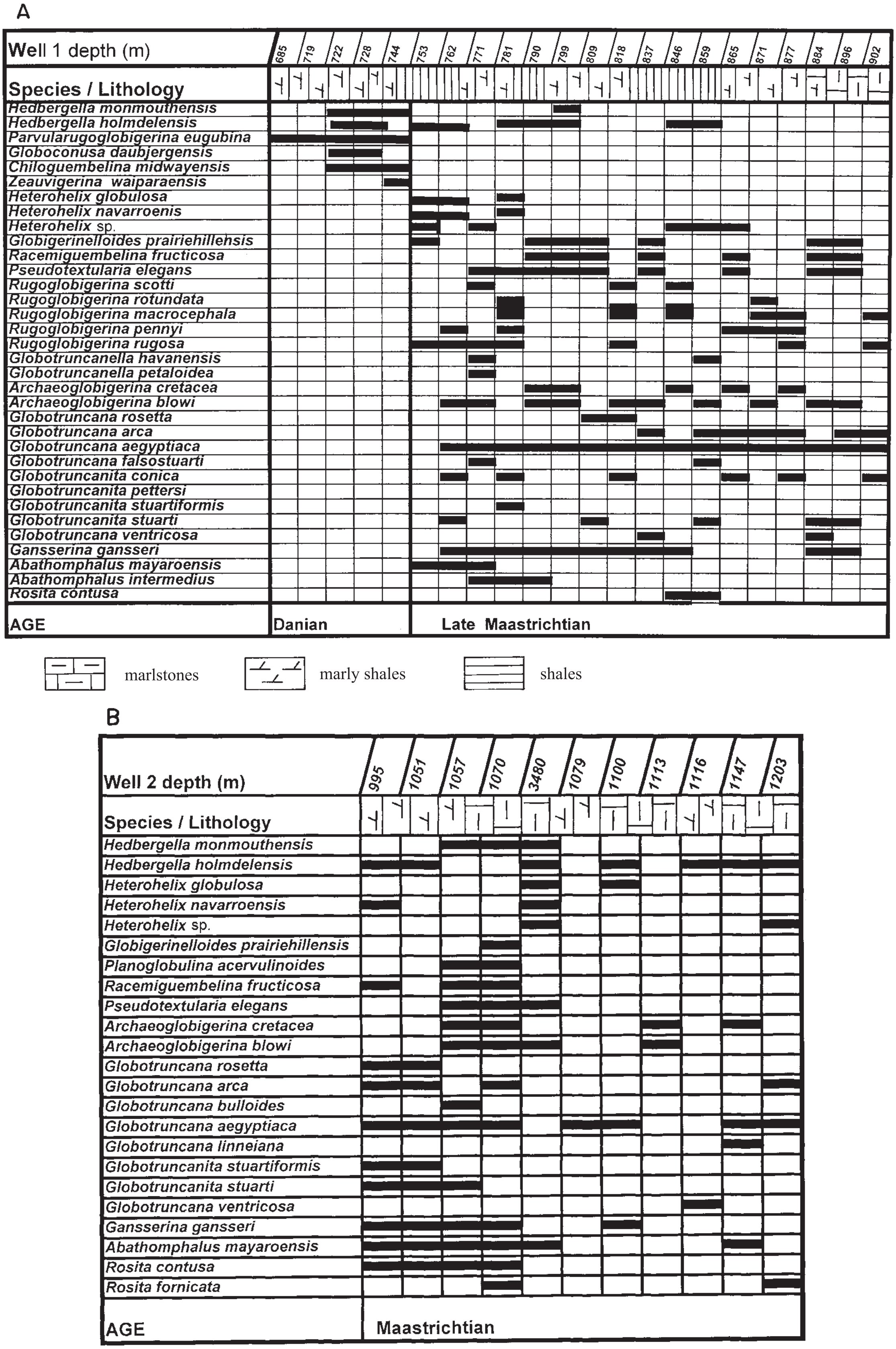

Fig. 2. Summarised biostratigraphic chart of planktonic foraminiferids

A — well 1; B — well 2

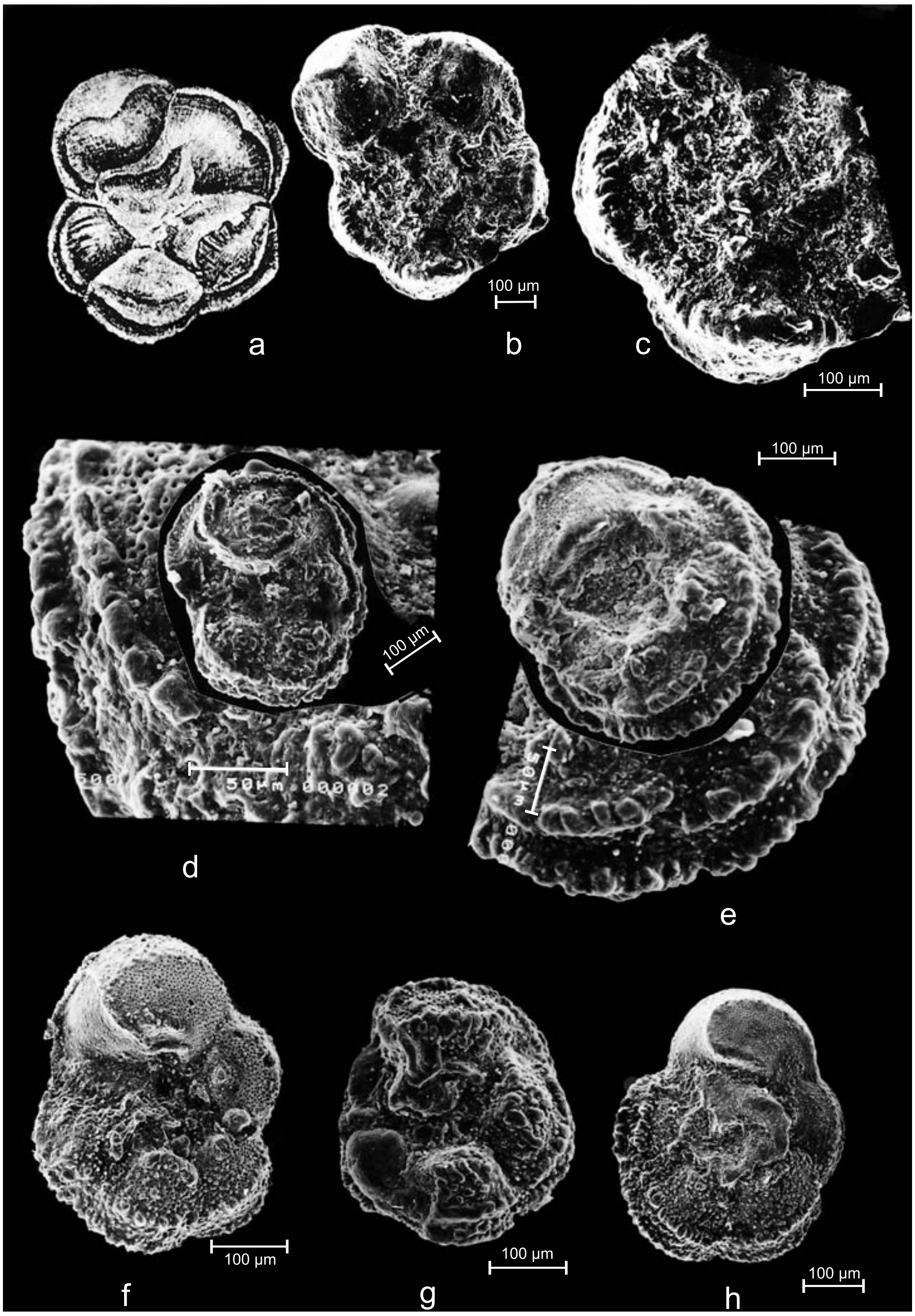

Fig. 3. **a** — *Globotruncana mayaroensis* Bolli, holotype from Guayaguayare area, Trinidad, (reprinted from Caron, 1985) × 60 (?); **b**–**e** — *Abathomphalus mayaroenis* (Bolli); all specimen magnifications × 150–200 (see bars): **b**, **c** — well no. 1, **c** × 250 visible structure of keels, composed of radially arranged rugosities, **d** — well no. 1, **e** — well no. 1; **f**–**h** — *Abathomphalus* cf. *mayaroensis* ("intermediate"? forms between *G. arca* and *A. mayaroensis*): **f**, **h** — well no. 2, **g** — well no. 1

LATEST MAASTRICHTIAN FORAMINIFERAL ASSEMBLAGES

The following foraminiferids are typical taxa accompanying *A. mayaroensis*: keeled-taxa: *Globotruncana aegyptiaca* Nakkady, *Globotruncana arca* (Cushman), *Globotruncana ventricosa* White, *Globotruncana rosetta* (Carsey), *Gansserina gansseri* (Bolli), *Globotruncana bulloides* Vogler, *Globotruncanita stuarti* (de Lapparent), *Globotruncanita stuartiformis* (Dalbiez), *Rosita contusa* (Cushman), *Rosita fornicata* (Plummer), and non-keeled taxa: *Hedbergella holmdelensis* Olsson, *Hedbergella monmouthensis* (Olsson), *Heterohelix globulosa* (Ehrenberg), *Heterohelix navarroensis* Loeblich, *Globigerinelloides prairiehillensis* Pessagno, *Archaeoglobigerina cretacea* (d'Orbigny), *Archaeoglobigerina blowi* Pessagno, *Pseudotextularia elegans* (Rzehak), *Planoglobulina acervulinoides* (Egger), *Racemiguembelina fructicosa* Egger (Fig. 2). All the latest Maastrichtian foraminiferal assemblages are dominated by planktonic foraminiferids.

Benthic assemblages are scarce and dominated by calcareous specimens. Agglutinated forms are very rare. Some of the infauna and semi-infauna forms in the foraminiferal assemblages are pyritised, indicating organic flux to the basin floor, which caused oxygen deficiency in the depositional environment. The occurrence of species such as *A. mayaroensis* and other keeled *Globotruncana* taxa along with some epipelagic (non-keeled, r-strategists) taxa such as: *Heterohelix, Pseudotextularia, Hedbergella, Archaeoglobigerina, Rugoglobigerina, Globigerinelloides* indicates that the environment of deposition is outer shelf–middle continental slope.

CONCLUSIONS

The latest Maastrichtian zonal marker *Abathomphalus mayaroensis* (Bolli) has been recognised in two wells of the Western Sirt Basin in samples collected from 744 m depth in well 1 and above 995 m in well 2.

Foraminiferal assemblages indicated outer shelf–upper slope of the latest Maastrichtian studied sediments influenced by organic flux to the basin floor, which caused oxygen deficiency in the depositional environment

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