A refined foraminiferal biostratigraphy for the Late Campanian–Early Maastrichtian succession of northeast Iraq

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ABSTRACT

Species of the benthonic foraminiferal genus Bolivinoides provide a refined biostratigraphic biozonation for the Late Campanian to Early Maastrichtian (Late Cretaceous) Shiranish Formation in NE Iraq. Three biozones and two subzones are identified: the Bolivinoides decoratus Biozone (Late Campanian) subdivided into a lower B. decoratus Subzone and upper B. laevigatus Subzone; the B. miliaris Biozone (Earliest Maastrichtian); and the B. draco Biozone (late Early Maastrichtian). These zones can be related to the biostratigraphical interval of the Globotruncana aegyptiaca (Late Campanian), Gansserina gansseri (latest Campanian–Early Maastrichtian) and Contusotruncana contusa (late Early Maastrichtian) planktonic foraminiferal biozones. Combined, the benthonic and planktonic foraminiferal biostratigraphy enables the informal recognition of lower and upper intervals within both the Globotruncana aegyptiaca and Gansserina gansseri biozones that may be important for more refined inter-regional correlation in the Middle East and North Africa. The new Bolivinoides biozonation precisely locates the Campanian–Maastrichtian boundary in NE Iraq. The foraminiferal assemblages also constrain the timing of a shallowing marine trend in the Shiranish Formation beginning from the latest Campanian that is consistent with shallowing facies noted globally at this time.

INTRODUCTION

The Shiranish Formation is the most geographically widespread lithostratigraphic unit of the Late Campanian–Early Maastrichtian succession in Iraq and contains rich and diverse benthonic and planktonic foraminifer assemblages, including species of the benthonic foraminiferal genus Bolivinoides that can be used for high-resolution biostratigraphy. The Dokan and Azmer localities of the Kurdistan region, NE Iraq, have been selected for this study because they provide nearly complete successions through the Shiranish Formation (Figure 1). The lithostratigraphy and planktonic foraminifer biostratigraphy of the Shiranish Formation have been described by several authors, most recently by Al-Banna (2010) and Hammoudi (2011). None of these studies have identified the biostratigraphic significance of Bolivinoides species in the Shiranish Formation.

Here we identify stratigraphically important Bolivinoides species, establish a biozonation that is useful for regional and interregional correlation, and more precisely define the Campanian–Maastrichtian boundary in NE Iraq. The newly refined biostratigraphy provides temporal constraint on the shallowing marine trend identified in NE Iraq, and enables regional comparisons with sea-level change on the Arabian Plate and globally.

MATERIALS AND METHODS

Two stratigraphic rock successions, one at Dokan (latitude 35° 56' 15"N and longitude 44° 57' 21"E) and the other at Azmer (latitude 35° 37' 30"N and longitude 45° 31' 45"E; see Figure 1) have been chosen for analysis. These sections present near-complete Late Cretaceous successions of the Shiranish Formation that contain rich and diverse planktonic and benthonic foraminifer assemblages, especially of Bolivinoides. Samples were taken at a spacing ranging from 0.5 m in the soft marlstones to 2 m in the indurated marlstones and marly limestones. For indurated rock samples, thin-section analysis was used for planktonic foraminiferal identifications. For friable samples, a freeze-thaw
method of processing was used (Mogaddam, 2002). Approximately 200–300 g of each friable sample was repeatedly frozen and thawed in a supersaturated solution of sodium sulphate until the rock disaggregated. Disaggregated sediments were then washed thoroughly through a 63 µm sieve and the residues separated by filtration and dried overnight with an oven temperature of 50ºC. Dried residues were sorted using sieves from 500 µm down to 63 µm. Foraminifera were picked and studied from the residue in the 63–300 µm size fractions. The foraminifera were studied using a Hitachi S-3600N Scanning Electron Microscope (SEM) at the University of Leicester, UK.

Figure 1: Geological context for the Azmer and Dokan sections of the Shiranish Formation in the Kurdistan region of NE Iraq (map after Sissakian, 2000). The Dokan section runs parallel to the left bank of the Dokan Dam, near the Dokan tourist village. The Azmer section is located about 15 km to the NE of Sulaimani city.
LITHOSTRATIGRAPHY

The Shiranish Formation represents marine shelf-deposited carbonates and mudstones that are rich in microfossil and macrofossil taxa (van Bellen et al., 1959-2005; Buday, 1980; Jassim and Goff, 2006). The Shiranish Formation unconformably overlies the marine limestones of the Kometan Formation (Mid Turonian–Early Campanian), and is succeeded conformably by marine clastic deposits of the Tanjero Formation (Late Maastrichtian) (Figure 2). van Bellen et al. (1959-2005) informally subdivided the Shiranish Formation into a ‘lower unit’, characterised by alternating foraminifer-rich marly limestone and calcareous marlstone, and an ‘upper unit’ that is dominated by blue marlstone in which the abundance of foraminifera decreases. The Shiranish Formation in the Dokan and Azmer areas is about 260 m and 144 m thick respectively. There is a glauconitic pebbly sandstone bed of about 0.5 m at the base of the Shiranish Formation (base of the ‘lower unit’) in the Dokan area (Figure 3) that may indicate a very slow rate of deposition or period of non-deposition. In the Dokan area the uppermost part of the ‘upper unit’ of the Shiranish Formation includes a massive bed of marly limestone that is about 1 m thick, bearing a mass of rudist bivalves near the contact with the overlying Tanjero Formation: this rudist bed is only locally developed and hence is not differentiated as a separate member in the Shiranish Formation.

BOLIVINOIDES BIOZONATION

Bolivinoides species provide one of the most highly resolved biostratigraphic subdivisions of Late Cretaceous strata globally (e.g. El-Nady, 2006). In order to place the Kurdistan assemblages into the context of this global stratigraphy, a total of 118 specimens of Bolivinoides have been collected from the Azmer and Dokan sections. Dimensions of the test and the number of lobes on the final chamber on the 114 complete specimens are shown in Table 1. We have not identified any intraspecific temporal

![Figure 2: Simplified lithostratigraphy of the Late Cretaceous succession in Iraq (after van Bellen et al., 1959-2005; Jassim and Goff, 2006) with some modifications.](http://pubs.geoscienceworld.org/geoarabia/article-pdf/19/1/161/5447209/jaff.pdf)

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trends in individual *Bolivinoides* species from our morphological analyses that would enable subdivision of zonal intervals. Nevertheless, the temporal succession in discrete *Bolivinoides* species can be used to establish three biozones and two subzones in the Shiranish Formation (Figure 3).

**Late Campanian Bolivinoides decoratus Biozone**

In NE Iraq this biozone is defined as the interval from the first to the last appearance datum of the nominate species and it is therefore a total range zone. It is identified in the 'lower unit' of the Shiranish Formation through a thickness of 158.5 m in the Dokan section and nearly 65 m in the

![Diagram of Bolivinoides biozonation for the Shiranish Formation in the Kurdistan region, NE Iraq. The 'lower' and 'upper' units of the Shiranish Formation are informally defined (see van Bellen et al., 1999-2005; Buday, 1980). First occurrences of key planktonic foraminifera are also shown.](image-url)

Figure 3: *Bolivinoides* biozonation for the Shiranish Formation in the Kurdistan region, NE Iraq. The 'lower' and 'upper' units of the Shiranish Formation are informally defined (see van Bellen et al., 1999-2005; Buday, 1980). First occurrences of key planktonic foraminifera are also shown.
Azmer section (Figure 3). Bolivinoides decoratus (Jones) is common at both localities and is restricted to Late Campanian strata (Figures 4 and 5). It was previously recorded with the same stratigraphical range in Europe (Hiltermann and Koch, 1950, 1955, 1962; Hofker, 1958; Hiltermann, 1963; Barr, 1966a, b; van Hinte, 1967), Atlantic Coastal Plain of New Jersey (Petters, 1977) and North Africa (Barr, 1970; Khalil, 1998; El-Nady, 2006). The first appearance datum of B. laevigatus Marie within the B. decoratus Biozone of NE Iraq enables subdivision of this interval into a lower B. decoratus Subzone and an upper B. laevigatus Subzone (see Figure 5). Based on co-occurring planktonic foraminifera in the Shiranish Formation (see Figure 6), the B. decoratus Biozone represents an equivalent stratigraphical interval to the Globotruncanana aegyptiaca and lower part of the Gansserina gansseri planktonic foraminiferal biozones (see Robaszynski, 1998; Premoli Silva and Sliter, 1999; Robaszynski et al., 2000; Premoli Silva and Verga, 2004; Sari, 2006, 2009). The combined benthonic and planktonic foraminiferal biostratigraphy for the B. decoratus Biozone also enables the informal recognition of lower and upper Globotruncanana aegyptiaca and lower Gansserina gansseri intervals that may be important for more refined inter-regional correlation in the Middle East and North Africa (see Figures 5 and 6).

Earliest Maastrichtian Bolivinoides miliaris Biozone

The lower boundary of the B. miliaris Biozone has been defined in Egypt (Khalil, 1998; see also El-Nady, 2006) by the last appearance datum (LAD) of B. decoratus, while the upper boundary of the zone is identified by the last appearance of B. miliaris (Hiltermann and Koch). In Egypt, B. miliaris and B. decoratus have overlapping ranges through much of the upper decoratus Biozone as recognised there (El-Nady, 2006), through an interval assigned to the Late Campanian (El-Nady op cit., Figure 3). Therefore, the base of the miliaris Biozone as it is recognised in Egypt is also identified by the FADs of Bolivinoides draco giganteus (Hiltermann and Koch) and B. draco draco (Marsson). However, El-Nady (2006, p. 685) stated, in contradiction to his range chart, that B. miliaris is an excellent marker for the Campanian/Maastrichtian boundary. In this paper we define the B. miliaris Biozone as a total range zone, with no overlap with B. decoratus. We believe that the decoratus-miliaris biozonal boundary equates to the Campanian/Maastrichtian boundary, as this level is also associated with the FAD of Bolivinoides draco in Iraq, and with the FADs (Figure 6) of the planktonic foraminifera Rugoglobigerina hexacamerata Bronnimann, R. penuji Bronnimann and Planoglobulina acervulinoideis (Egger), which are regarded as markers for the basal Maastrichtian in other regions (Zepeda, 1998; Li et al., 1999; Guray, 2006; Beiranvand and Ghasemi-Nejad, 2013; see Figure 6). The B. miliaris Biozone is identified in the uppermost part of the ‘lower unit’ and the lower part of the ‘upper unit’ of the Shiranish Formation (Figure 3), in the Dokan succession occupying a stratigraphic thickness of 39 m. However, in the Azmer section, the biozone is confirmed only through 26 m of strata: this is due to the rapid disappearance of foraminiferal assemblages upwards in the rock succession at Azmer (Figure 3). Bolivinoides miliaris occurs rarely in Iraq and is restricted to the earliest Maastrichtian. B. miliaris is recorded from the same stratigraphical range in Europe (Hiltermann and Koch, 1950), Atlantic Coastal Plain of New Jersey (Petters, 1977), North Africa (Le Roy, 1953; Said and Kenawy, 1956; Barr, 1970; Khalil, 1998; El-Nady, 2006), and the Caribbean (Beckmann and Koch, 1964). In NE Iraq the B. miliaris Biozone represents an equivalent stratigraphical interval to the middle part of the Gansserina gansseri planktonic foraminiferal Biozone (for which, see Robaszynski, 1998; Premoli Silva and Verga, 2004; Sari, 2006, 2009): this is based on the co-occurrence of B. miliaris with G. gansseri, and on its stratigraphic position above the B. decoratus Biozone. Combining the benthonic and planktonic foraminifer occurrences allows the informal recognition of an upper Gansserina gansseri interval in the Iraqi succession (see Figure 6).

Late Early Maastrichtian Bolivinoides draco Biozone

In Iraq, the B. draco (Marsson) Biozone is a partial range zone that is defined as the interval from the last appearance datum of B. miliaris to the last appearance datum of B. draco. B. draco is rare in its lowermost range in Iraq, where it overlaps with B. miliaris, and becomes abundant after the extinction of B. miliaris. The B. draco Biozone is identified in the upper part of the ‘upper unit’ of the Shiranish Formation in the Dokan section through nearly 37 m of strata. A succeeding biozone is not recognised in the Dokan section, while the B. draco Biozone is absent at Azmer (Figure 3), probably as a consequence of environmental change caused by the rapid shallowing-up succession and the concomitant
Table 1
Dimensions of the test (in millimetres) and number of lobes on the final chamber of *Bolivinoides* recorded in the Shiranish Formation, NE-Iraq.

| No. | Length L | Breadth B | L/B | No. of lobes on last chamber | Species name |
|-----|----------|-----------|-----|-----------------------------|--------------|
| 1   | 59.6     | 31.4      | 1.9 | 4                           | *B. decoratus* |
| 2   | 58.8     | 36.4      | 1.6 | 4                           | *B. decoratus* |
| 3   | 57.3     | 34.1      | 1.7 | 4                           | *B. decoratus* |
| 4   | 60.3     | 36.4      | 1.7 | 4                           | *B. decoratus* |
| 5   | 59.1     | 36.9      | 1.6 | 4                           | *B. decoratus* |
| 6   | 57.2     | 30.5      | 1.9 | 4                           | *B. decoratus* |
| 7   | 60.4     | 33        | 1.8 | 3                           | *B. decoratus* |
| 8   | 56.1     | 31        | 1.8 | 3                           | *B. decoratus* |
| 9   | 59       | 37.1      | 1.6 | 4                           | *B. decoratus* |
| 10  | 58.8     | 32.4      | 1.8 | 4                           | *B. decoratus* |
| 11  | 59.4     | 28.7      | 2.1 | 4                           | *B. decoratus* |
| 12  | Broken   | No        | No  | No                          | No           |
| 13  | 61.5     | 30.5      | 2   | 4                           | *B. decoratus* |
| 14  | 55.8     | 30.8      | 1.8 | 3                           | *B. decoratus* |
| 15  | 61.5     | 31.5      | 2   | 4                           | *B. decoratus* |
| 16  | 61.6     | 30.5      | 2   | 4                           | *B. decoratus* |
| 17  | 57.5     | 34.7      | 1.7 | 4                           | *B. decoratus* |
| 18  | 56.9     | 36        | 1.6 | 4                           | *B. decoratus* |
| 19  | 57.8     | 32.6      | 1.8 | 4                           | *B. decoratus* |
| 20  | 60       | 34.4      | 1.7 | 4                           | *B. decoratus* |
| 21  | 56.7     | 31.5      | 1.8 | 4                           | *B. decoratus* |
| 22  | 56.5     | 33.9      | 1.7 | 4                           | *B. decoratus* |
| 23  | 55.2     | 30.4      | 1.8 | 4                           | *B. decoratus* |
| 24  | 57.5     | 31.7      | 1.8 | 3                           | *B. decoratus* |
| 25  | 58.7     | 32        | 1.8 | 4                           | *B. decoratus* |
| 26  | Broken   | No        | No  | No                          | No           |
| 27  | 55.1     | 32.7      | 1.7 | 3                           | *B. decoratus* |
| 28  | 56.2     | 33        | 1.7 | 3 or 4                      | *B. decoratus* |
| 29  | 55.2     | 30.7      | 1.8 | 3                           | *B. decoratus* |
| 30  | 57.6     | 29.9      | 1.9 | 4                           | *B. decoratus* |
| 31  | Broken   | No        | No  | No                          | No           |
| 32  | 56.2     | 30.5      | 1.8 | 4                           | *B. decoratus* |
| 33  | 57.7     | 29.4      | 2   | 4                           | *B. decoratus* |
| 34  | 57.5     | 31.1      | 1.8 | 3                           | *B. decoratus* |
| 35  | 57.4     | 34.3      | 1.7 | 3                           | *B. decoratus* |
| 36  | 55.5     | 32.1      | 1.7 | 4                           | *B. decoratus* |
| 37  | 58.2     | 32        | 1.8 | 4                           | *B. decoratus* |
| 38  | 59.1     | 30.9      | 1.9 | 4                           | *B. decoratus* |
| 39  | 58.9     | 32.2      | 1.8 | 4                           | *B. decoratus* |
| 40  | 56.4     | 27.7      | 2   | 4                           | *B. decoratus* |
| 41  | 60.2     | 35.9      | 1.7 | 4                           | *B. decoraevaegatus* |
| 42  | 60.8     | 27.4      | 2.2 | 3                           | *B. praelaevigatus* |
| 43  | 60.7     | 26.3      | 2.3 | 3                           | *B. praelaevigatus* |
| 44  | 60       | 27.3      | 2.2 | 3                           | *B. praelaevigatus* |
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|    |    |    |    |    |      |
|----|----|----|----|----|------|
| 93 | 55.6 | 39.6 | 1.4 | 5 | B. draco |
| 94 | 55.2 | 36.7 | 1.5 | 5 | B. draco |
| 95 | 52.2 | 36.6 | 1.4 | 5 | B. draco |
| 96 | 53.1 | 38.1 | 1.4 | 5 | B. draco |
| 97 | 54.2 | 41.3 | 1.3 | 5 | B. draco |
| 98 | 54 | 41.7 | 1.3 | 5 | B. draco |
| 99 | 56.1 | 37 | 1.5 | 5 | B. draco |
| 100 | 45.8 | 37.5 | 1.2 | 5 | B. miliaris |
| 101 | 43.5 | 38.5 | 1.1 | 5 | B. miliaris |
| 102 | 42.3 | 38.4 | 1.1 | 5 | B. miliaris |
| 103 | 51.8 | 46.7 | 1.1 | 5 | B. miliaris |
| 104 | 52.7 | 47 | 1.2 | 5 | B. miliaris |
| 105 | 55 | 46.2 | 1.2 | 5 | B. miliaris |
| 106 | 55.2 | 46.3 | 1.2 | 5 | B. miliaris |
| 107 | 50.7 | 42 | 1.2 | 5 | B. miliaris |
| 108 | 53 | 44.3 | 1.2 | 5 | B. miliaris |
| 109 | 51.4 | 42.3 | 1.2 | 5 | B. miliaris |
| 110 | 55.3 | 45.1 | 1.2 | 5 | B. miliaris |
| 111 | 58.5 | 57.6 | 1 | 5 | B. miliaris |
| 112 | 58.5 | 56.5 | 1 | 5 | B. miliaris |
| 113 | 55.7 | 50.8 | 1.1 | 5 | B. miliaris |
| 114 | 55.9 | 35.6 | 1.6 | 5 | B. australis |
| 115 | 58.1 | 40.6 | 1.4 | 5 | B. australis |
| 116 | 59 | 41.2 | 1.4 | 5 | B. australis |
| 117 | 59.5 | 42.1 | 1.4 | 5 | B. australis |
| 118 | 59.4 | 42 | 1.4 | 5 | B. australis |

(continued)

disappearance of foraminifera. In Egypt, El-Nady (2006) recognised the incoming of Bolivinoides paleocenicus (Brotzen) and B. peterssoni Brotzen at the base of the B. draco Biozone as he defined it, though we have not identified these taxa in Iraq. El-Nady (2006) also recorded B. miliaris as rare in the lowermost B. draco Biozone. Therefore, the base of the B. draco Biozone as we define it in Iraq most likely lies at a lower stratigraphic level than in Egypt (see Figure 4).

THE CAMPANIAN/MAASTRICHTIAN BOUNDARY

At the Global Stratotype Section and Point (GSSP) at Tercis, southwestern France, the first appearance of the ammonite Pachydiscus neubergicus is taken as the marker of the Campanian/Maastrichtian (C-M) boundary, and this level also coincides with the first occurrences of the planktonic foraminifera Rugoglobigerina scotti and Contusotruncana contusa (Odin, 1996; Odin and Lamaurelle, 2001). At the GSSP the evolutionary lineages of the genus Bolivinoides have also been used to recognise the C-M boundary, the base of the Maastrichtian coinciding with the FAD of Bolivinoides specimens with 5 lobes on the last chamber (Odi and Lamaurelle, 2001). Bolivinoides with 5 lobes on the final chamber also characterise the base of the Maastrichtian in NE Iraq, but the first occurrences of R. scotti and C. contusa appear later in the Iraqi succession (see Figure 6), a situation apparently repeated in Iran (Darvishzad and Abdolalipour, 2009), Tunisia (Li and Keller, 1998a, b; Li et al., 1999) and NE Iraq (Sharbazheri, 2010; Ismael et al., 2011). The relative ranges, therefore, of the key planktonic and benthonic foraminifer species differ between the type section at Tercis and Iraq. Thus, the planktonic species R. scotti, C. contusa and the benthonic 5-lobed Bolivinoides species appear simultaneously at Tercis, but in Iraq the first occurrence of the planktonic species post-dates the appearance of 5-lobed Bolivinoides. Here, based on the total succession of foraminifera in our assemblages, we take the appearance of 5-lobed Bolivinoides as the more reliable marker for the C-M boundary and infer that the appearances of R. scotti and C. contusa are diachronous globally.

Before the selection of the GSSP, the extinction of the planktonic foraminifer Radotruncana calcarata had long been used to define the C-M boundary (van Hinte, 1965; Postuma, 1971; Wonders, 1980; Robaszynski et al., 1984; Olsson and Nyong, 1984; Caron, 1985; Sliter, 1989); however, several subsequent studies have shown that the LAD of R. calcarata significantly pre-dates the FAD of the
Late Cretaceous
Maestrichtian
Late

Chrono-
stratigraphy

Bolivinoides decoratus
Bolivinoides miliaris
Bolivinoides draco

Late Campanian–Late Maastrichtian Bolivinoides biozones from different regions of the world. The ranges of the Bolivinoides zones in western Europe and Libya are based on Barr (1970) and for Egypt on El-Nady (2006).

Figure 5: Ranges of recorded Late Campanian–Early Maastrichtian Bolivinoides species in the Kurdistan region, NE Iraq. The Bolivinoides biozonation in Egypt is based on Khalil (1998) and El-Nady (2006). Note that our definition of the B. draco Biozone is based on the first occurrence of the nominate species in abundance, which places our zone at an earlier chronostratigraphic level than in Egypt, but is compatible with the zonation in Libya and western Europe (Barr, 1970). The informal subdivisions of the planktonic foraminifer biozones (horizontal dashed lines) represent the combined ranges of Bolivinoides and planktonic foraminifer species.
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### Figure 6: Biostratigraphic interval recognised in the Shiranish Formation using both Bolivinoides and planktonic foraminifera. Key Bolivinoides and planktonic foraminiferal occurrences are indicated. In successions where both Bolivinoides and planktonic foraminifera are present, it is possible to recognise informally a ‘lower Gansserina gansseri’ interval, which represents the latest Campanian, and may therefore be of value for correlation in other Tethyan successions.

The boreal belemnite species *Belemnella lanceolata* (Burnett et al., 1992; Hancock et al., 1992) which has been regarded as another index for the C–M boundary. Based on these findings, Hancock et al. (1992) suggested that the position of the C–M boundary in Tethyan sections was best placed at the FAD of the planktonic foraminifera *Gansserina gansseri*. However, recent studies show that the FAD of *Gansserina gansseri* also pre-dates the C–M boundary (Robaszynski, 1998; Premoli Silva and Sliter, 1999; Robaszynski et al., 2000; Premoli Silva and Verga, 2004; Sari, 2006, 2009; also Figures 5 and 6).

Li et al. (1999) informally used the FAD of the planktonic foraminifer *Rugoglobigerina hexacamerata* for the C–M boundary based on biostratigraphic correlation with the geomagnetic time scale at Deep Sea Drilling Project (DSDP) site 525 in northwest Tunisia. Zepeda (1998) used the FAD of *Rugoglobigerina pennyi* for defining the C–M boundary in the Exmouth Plateau, northwest Australia and eastern Indian Ocean. In NE Iraq we use the first occurrences of the planktonic foraminifera *Planoglobulina acervulinoides*, *R. pennyi*, and *R. hexacamerata* within the *Gansserina gansseri* Biozone (Li and Keller, 1998a, b; Li et al., 1999; Zepeda, 1998; Robaszynski, 1998; Guray, 2006; Esmeray, 2008; Beiranvand and Ghasemi-Nejad, 2013) as additional evidence to identify the C–M boundary. These first occurrences coincide with the FAD of *Bolivinoides* with 5 lobes, especially *B. miliaris*.

### PALAEOENVIRONMENTAL SIGNIFICANCE OF THE FORAMINIFERA

Foraminifer assemblages in the Shiranish Formation indicate a gradual decrease in marine shelf water depth through the succession. High diversity foraminiferal assemblages characterise the ‘lower unit’ of the Shiranish Formation and include agglutinated species. These assemblages comprise species of the benthonic foraminifera *Ammodiscus*, *Allomorphina*, *Clavulinoides*, *Glomospira*, *Pleurostomella*, *Praebulimina*, *Pullenia*, *Osangularia* and *Quadrimorphina*, and in particular the taxa *Bathysiphon*, *Dorothia* and *Gaudryina* that suggest a middle slope environment with water depths of at least 600 m (Sliter and Baker, 1972; Sliter, 1973). This ‘lower unit’ of the Shiranish Formation also contains the benthonic
foraminifera Clavulinoides trilatera (Cushman), Marginulina bullata Reuss, Nuttallides truempyi (Nuttall), Gyroidinoides globosus (Hagenow) and Praebulimina kickapooensis (Cole) that are useful indicators for middle slope environments (Sliter and Baker, 1972; Olsson and Nyong, 1984; Alegret and Thomas, 2001): the 'lower unit' is also characterised by rich planktonic assemblages of Globotruncanana species. Towards the top of the B. decoratus Biozone the benthonic foraminifer assemblages are dominated by species of Gavelinella, Gyroidinoides, Gaudryina, Lenticulina, Marginulinopsis, Neoflabellina, Osangularia, Praebulimina and Spiroplectammina species, which suggest an upper slope environment with water depths ranging between 400 to 300 m (Sliter, 1972; Sliter and Baker, 1972). The top of the B. decoratus Biozone of the Shiranish Formation contains Bathysiphon vita Nauss, Gaudryina pyramidata Cushman, Massionella oxycona (Reuss), Nuttallinella florealis (White) and Osangularia cordieriana (d’Orbigny) that are useful indicators for upper slope environments (Sliter and Baker, 1972; Olsson and Nyong, 1984; Alegret and Thomas, 2001).

Foraminiferal assemblages in the topmost part of the 'lower unit' in the Azmer section and the 'upper unit' in the Dokan section of the Shiranish Formation suggest shallower marine conditions. The benthonic foraminifer assemblages at the level of B. miliaris and B. draco biozones are species of Bolivina, Dentalina, Fissurina, Gyroidinoides, Nodosaria and Oolina which indicate an outer neritic shelf environment of about 200 m water depth (Sliter, 1972; Sliter and Baker, 1972). This unit also includes Bolivina incrassata gigantea Wicher and Praebulimina caseya (Plummer) that are useful indicators for outer neritic shelf environments (Sliter and Baker, 1972; Olsson and Nyong, 1984). Planktonic foraminiferal assemblages are characterised by Rugoglobigerina, Globigerinelloides, Hedbergella and Heterohelix species; according to Sliter (1972) and Hart (1980) species of these genera most likely characterised shallow marine depths.

**SEA-LEVEL CHANGE IN THE SHIRANISH FORMATION**

The intra-Campanian unconformity recognised across the Arabian Plate is represented in the Dokan and Azmer sections at the cessation of deposition of pelagic limestones of the Kometan Formation (Early Campanian) followed by deposition of glauconitic pebbly sandstone at the base of the overlying Shiranish Formation (see van Bellen et al., 1959-2005; Jassim and Goff, 2006; Aqrawi et al., 2010; Lawa et al., 2013). The marine erosional surface represents a gap of the mid to early Late Campanian in which the biostratigraphically useful species Globotruncana ventricosa, Rodotruncana calcarata and Globotruncanella hawaiiensis are not recorded.

The lithofacies of the Shiranish Formation suggest the combined influence of eustasy and local subsidence on sea-level change, the latter resulting from structural loading of the Arabian Plate by obducted Neo-Tethyan margin rocks (Jassim and Goff, 2006). The lower part of the 'lower unit' of the Shiranish Formation (within the Bolivinoides decoratus Subzone) represents a major deepening upwards succession indicated by an increasing planktonic to benthonic foraminifer ratio. The middle part of the 'lower unit' of the Shiranish Formation (that part assignable to the Bolivinoides laevigatus Subzone) is marked by a maximum flooding surface with palaeodepths of at least 600 m (Figure 7) and is characterised by marl beds associated with the predominance of a planktonic lime-mudstone facies. Thereafter, in the upper part of the 'lower unit', foraminiferal evidence suggest that sea level begins to fall (see Figure 7).

In the B. miliaris Biozone the Shiranish Formation is characterised by continued sea-level fall that is identified by increasing dominance of benthonic foraminifera, a sudden drop in the abundance of globotruncanids, and an increase in the heterohelicid population associated with the presence of Pseudotextularia and Planoglobulina species. Collectively these suggest decreasing marine shelf depths to some 200 m (Sliter, 1972; Abdel-Kireem, 1983; Darvishzad and Abdolalipour, 2009; see Figure 7).

Haq et al. (1987) and Hardenbol et al. (1998) proposed a major marine regression in the Early Maastrichtian that coincided with major global cooling phases at 71.2–69.2 Ma (Figure 7). Moreover, Barrera (1994) noted that the Early Maastrichtian was the coolest interval of the Cretaceous following the peak warmth of the earlier Late Cretaceous. Therefore, sea-level change in the Iraq succession might relate to Late Cretaceous climate change, as indicated by correlation from the Bolivinoides biozonation.
Late Campanian–Early Maastrichtian foraminiferal biostratigraphy, northeast Iraq

Figure 7: Correlation of sea level reconstructed globally (Haq et al., 1987) and for the Arabian Plate (Sharland et al., 2001). The global mean surface temperature is based on Pucéat et al. (2003). The Campanian/Maastrichtian boundary was adapted from Gradstein et al. (2012). Question marks represent uncertainty for the first appearance datum of *Globotruncana aegyptiaca* and the last appearance datum of *Contusotruncana contusa*.

The same period of sea-level regression is also recorded in Iran (Darvishzad and Abdolalipour, 2009), Turkey (Sari, 2006, 2009) and in other parts of Iraq (El-Anbaawy and Sadek, 1979; Abdel-Kireem, 1983; Al-Banna, 2010; Fayyadh, 2010). In this study the sea-level curve for NE Iraq is generally consistent with the Haq et al. (1987) global sea-level curve, but it is substantially different from the Arabian Plate sea-level curve of Sharland et al. (2001), suggesting strong regional (tectonic?) controls on relative sea level on the Arabian Plate during the Late Cretaceous.

**TAXONOMIC NOTES ON SPECIES OF BOLIVINOIDES**

Here we highlight key morphological characters that we have used to diagnose *Bolivinoides* species in the Shiranish Formation, comparing our material with the original descriptions of the species. Specimens figured in Plates 1 to 3 are deposited in the collections of the British Geological Survey, Keyworth, Nottingham, UK and are identified by the prefix MPK.

*Bolivinoides australis* Edgell (Plate 1, Figs 1 and 2) was originally described from the Late Cretaceous succession of NW Australia (Edgell, 1954). Our material is conspecific with that of Edgell (op. cit.) based on its pyriform lateral shape and ovate cross-section; its smooth initial chambers, while later chambers are pustulate; and in possessing a final chamber that typically has between 5 and 6 thick, closely spaced lobes. The length/breadth ratio of the Iraqi material is between 1.4 and 1.6, thereby differentiating *B. australis* from *B. decoratus*, which has a smaller length/breadth ratio, a different shape, and more closely spaced lobes on the final chambers.

*Bolivinoides decoratus* (Jones) (Plate 1, Figs 3–9; Plate 2, Figs 1–5) was originally described and illustrated in Wright (1886) from the Chalk Group at Keady Hill, County Derry, Northern Ireland. However, the name had been used before by Jones in unpublished work and for that reason, Wright graciously attributed Jones with authorship of *Bolivina [= Bolivinoides] decorata*. The Iraqi material is typical of this species in being kite-shaped in lateral view, with an elliptical cross-section. The earliest chambers are smooth or weakly lobed; ornamentation on later chambers is more prominent, with 3 to 4 thick, distinct lobes on the final chambers. The length/breadth ratio is between 1.5 and 2.1, most commonly between 1.7 and 1.9.
Plate 1: Scale bars 100 µm.

(1, 2) *Bolivinoides australis* Edgell. Uppermost part of the ‘lower unit’, Shiranish Formation, earliest Maastrichtian: Fig. 1, MPK14381, from the Azmer section, sample number ASH-52; Fig. 2, MPK14382, from the Dokan section, sample number DSH-90.

(3-9) *Bolivinoides decoratus* (Jones). The ‘lower unit’ of the Shiranish Formation, Late Campanian: Fig. 3, MPK14383 and Fig. 4, MPK14384, from the Azmer section, sample number ASH-15; Fig. 5, MPK14385 and Fig. 6, MPK14386, from the Dokan section, sample number DSH-05; Fig. 7, MPK14387, from the Dokan section, sample number DSH-15; Fig. 8, MPK14388 and Fig. 9, MPK14389, from the Dokan section, sample number DSH-36.

(10-12) *Bolivinoides draco* (Marsson). The ‘upper unit’ of the Shiranish Formation, late Early Maastrichtian, Dokan section: Fig. 10, MPK14390 and Fig. 11, MPK14391, sample number DSH-116; Fig. 12, MPK14392, sample number DSH-117.

(13, 14) *Bolivinoides laevigatus* Marie. The ‘lower unit’ of the Shiranish Formation, Late Campanian, Dokan section: Fig. 13, MPK14393 and Fig. 14, MPK14394, sample number DSH-48.

(15, 16) *Bolivinoides miliaris* (Hiltermann and Koch). Uppermost part of the ‘lower unit’, Shiranish Formation, earliest Maastrichtian, Azmer section: Fig. 15, MPK14395 and Fig. 16, MPK14396, sample number ASH-62.
Marsson (1878) described Bolivina [=Bolivinoides] draco (Plate 1, Figs 10–12; Plate 2, Figs 6 and 7) from the Maastrichtian of Rügen Island in the Baltic Sea, Germany. The material from the Shiranish Formation possesses the typical diamond-shaped lateral morphology of this species and the test also has a compressed cross-section. The ornament comprises two, species-diagnostic, centrally positioned
Plate 3: Scale bars 100 µm.

(1-4) *Globotruncana aegyptiaca* Nakkady. The ‘lower unit’ of the Shiranish Formation, Late Campanian: 1 and 3 umbilical views, 2 and 4 spiral views, from the *Globotruncana aegyptiaca* Biozone: Figs 1, 2, MPK14409, Azmer section, sample number ASH-02; Figs 3, 4, MPK14410, Dokan section, sample number DSH-05.

See caption facing page for continuation.
parallel ribs extending along the entire length of the test, separated by a central depression. In larger forms, the ribs are intersected by overlapping side-ribs at an angle of about 35° to 40° in the later part of the test. The length/breadth ratio of the test is generally between 1.3 and 1.5.

The type material of *Bolivinoides laevigatus* Marie (Plate 1, Figs 13 and 14; Plate 2, Fig. 8) is from the Late Campanian of the Paris Basin (Marie, 1941). Iraqi specimens have the characteristic narrow, slowly expanding test and elliptical cross-section of Marie’s material. Earlier chambers are smooth or with up to two lobes, later chambers become weakly lobate, and there are three lobes on the final chambers. Lobation weakens towards the periphery. The length/breadth ratio is between 1.9 and 2.0. *Bolivinoides laevigatus* can be distinguished from *B. decoratus* by its smaller test and more weakly developed ornamentation.

*Bolivinoides miliaris* Hiltermann and Koch (Plate 1, Figs 15 and 16; Plate 2, Figs 9 and 10) is a distinctive taxon with its broad rhomboidal lateral shape and elliptical to ovate cross-section. The ornament comprises long irregular lobes, numbering five on the last pair of chambers. The maximum breadth of *B. miliaris* is near the mid-point of the test. The length/breadth ratio is between 1.0 and 1.2, most commonly 1.2. *Bolivinoides miliaris* is most similar to *B. draco*, but is distinguishable by its long, irregular, discontinuous lobes, the absence of central ribs, and by its broader rhomboidal shape. Our material possesses the characteristic morphology of the German material described by Hiltermann and Koch (1950).

*Bolivinoides prae laevigatus* Barr (Plate 2, Figs 11 and 12) was described from the Late Cretaceous of Britain (Barr, 1966a). It has a very distinctive, gradually tapering, narrow test, with a compressed shape in cross-section. The test surface is smooth to weakly lobed, with 2 or 3 lobes on the final chambers. Its length/breadth ratio is very distinctive at between 2.1 and 2.3.

Plate 3 (continued):

(5, 6) *Gansserina gansseri* (Bolli). The ‘upper unit’ of the Shiranish Formation, Early Maastrichtian: 5, umbilical view, 6, spiral view, from the *Gansserina gansseri* Biozone, MPK14411, Dokan section, sample number DSH-88.

(7, 8) *Globotruncanina lineana* d’Orbigny. The ‘lower unit’ of the Shiranish Formation, Late Campanian: 7, umbilical view, 8, spiral view, from the *Gansserina gansseri* Biozone, MPK14412, Azmer section, sample number ASH-40.

(9, 10) *Rugoglobigerina hexacamerata* Bronnimann. Uppermost part of the ‘lower unit’, Shiranish Formation, Early Maastrichtian: 9, umbilical view, 10, spiral view, from the *Gansserina gansseri* Biozone, MPK14413, Dokan section, sample number DSH-86.

(11, 12) *Contusotruncanina walischensis* (Todd). The ‘upper unit’ of the Shiranish Formation, late Early Maastrichtian: 11, spiral view, 12, side view, from the *Contusotruncanina contusa* Biozone, MPK14414, Dokan section, sample number DSH-117.

(13, 14) *Contusotruncanina contusa* (Cushman). The ‘upper unit’ of the Shiranish Formation, late Early Maastrichtian: 13, umbilical view, 14, side view, from the *Contusotruncanina contusa* Biozone, MPK14415, Dokan section, sample number DSH-117.

(15) *Planoglobulina acerulinoides* (Egger). Lower part of the ‘upper unit’, Shiranish Formation, Early Maastrichtian: from the *Gansserina gansseri* Biozone, MPK14416, Dokan section, sample number DSH-88.

(16) *Rugoglobigerina pennyi* Bronnimann. Lower part of the ‘upper unit’, Shiranish Formation, Early Maastrichtian: from the *Gansserina gansseri* Biozone, MPK14417, Dokan section, sample number DSH-88.

(17) *Rodotruncanana subsinosa* (Pessagno). The ‘upper unit’ of the Shiranish Formation, Early Maastrichtian: from the *Gansserina gansseri* Biozone, MPK14418, Dokan section, sample number DSH-88.

(18) *Globotruncanita stuarti* (de Lapparent). The ‘upper unit’ of the Shiranish Formation, Early Maastrichtian: from the *Gansserina gansseri* Biozone, MPK14419, Dokan section, sample number DSH-80.
CONCLUSIONS

The Late Campanian–Early Maastrichtian succession of NE Iraq can be subdivided into three Bolivinoides biozones: the B. decoratus Biozone (Late Campanian), subdivided into lower B. decoratus and upper B. laevigatus biosubzones; the B. miliaris Biozone (Earliest Maastrichtian) and the B. draco Biozone (late Early Maastrichtian). This zonal scheme provides greater precision in the regional correlation of the Shiranish Formation in NE Iraq, firmly establishes the Campanian/Maastrichtian boundary, and constrains the timing of sea-level fall from the latest Campanian onwards, which is consistent with evidence for marine regression globally.

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APPENDIX 1

Stratigraphic position of sample numbers given in plates 1-3.
The specimens illustrated in this paper are deposited in the British Geological Survey, Keyworth, Nottingham. The MPA numbers are the British Geological Survey numbers for the samples from which the fossil specimens come.

Azmer section
ASH-02, MPA63960, 1.5 m above the base of the Shiranish Formation.
ASH-10, MPA63961, 15 m above the base of the Shiranish Formation.
ASH-15, MPA63962, 22 m above the base of the Shiranish Formation.
ASH-25, MPA63963, 37 m above the base of the Shiranish Formation.
ASH-40, MPA63964, 57 m above the base of the Shiranish Formation.
ASH-52, MPA63965, 73 m above the base of the Shiranish Formation.
ASH-62, MPA63966, 87 m above the base of the Shiranish Formation.

Dokan section
DSH-05, MPA63967, 12.5 m above the base of the Shiranish Formation.
DSH-08, MPA63968, 17.5 m above the base of the Shiranish Formation.
DSH-15, MPA63969, 29.5 m above the base of the Shiranish Formation.
DSH-36, MPA63970, 64 m above the base of the Shiranish Formation.
DSH-48, MPA63971, 85 m above the base of the Shiranish Formation.
DSH-80, MPA63972, 148.5 m above the base of the Shiranish Formation.
DSH-86, MPA63973, 162 m above the base of the Shiranish Formation.
DSH-88, MPA63974, 167 m above the base of the Shiranish Formation.
DSH-90, MPA63975, 171 m above the base of the Shiranish Formation.
DSH-103, MPA63976, 195.5 m above the base of the Shiranish Formation.
DSH-110, MPA63977, 212 m above the base of the Shiranish Formation.
DSH-116, MPA63978, 226.5 m above the base of the Shiranish Formation.
DSH-117, MPA63979, 228 m above the base of the Shiranish Formation.

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