

DEVELOPING BEST PRACTICE IN MICROPALAEONTOLOGY: EXAMPLES FROM THE MID-CRETACEOUS OF THE ZAGROS MOUNTAINS

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Abstract Micropalaeontological studies can provide important information on how strata correlate, age calibration, palaeoenvironmental determination, palaeobiology, evolutionary relationships of the taxa being studied, palaeogeography, and the recognition of global or regional geological events in a local succession. However, the value of micropalaeontological studies is constrained by the accuracy with which taxa are identified, the accuracy of their age interpretation, and the use of up-to-date taxonomic concepts, supported by modern research literature. Best practice implies attention to these and other details, which we illustrate with reference to published research on larger benthic foraminifera (especially orbitolinids) from the mid-Cretaceous succession of the Zagros Mountains in the Middle East. It is demonstrated that whilst there are many excellent studies, a significant number could offer more value if they were to use precise, modern taxonomic concepts applied to well-illustrated and documented unequivocal material. Poorly founded age assignments and misidentifications can lead to confusion on assessment of true stratigraphic ranges and evolutionary patterns. Moreover, they can lead to miscorrelation and erroneous modelling of the subsurface in a hydrocarbon-rich region. Integrated studies of larger benthic foraminifera with other age-diagnostic fossil groups or chemostratigraphic methods would further enhance their utility. These recommendations are applicable to micropalaeontological studies on microfossils of any type and age, from any part of the world, but we hope will promote additional rigour in studies on the micropalaeontology of the Mesozoic and Cenozoic succession of the Zagros that still have much to impart.

Keywords: Micropalaeontology, biostratigraphy, orbitolinids, Zagros Mountains, Cretaceous

1. INTRODUCTION

The Permian, Mesozoic, and Cenozoic stratigraphic succession in the Zagros Mountains of the Middle East is dominated by tropical carbonate sediments (e.g., van Belen et al., 1959; Setudehnia, 1972; Falcon, 1974; Motiei, 1993; Sharland et al., 2001; Aqrabi et al., 2010). These rocks can be extremely rich in microfossils, not least, larger benthic foraminifera (LBF), typically identified in thin-sections. These have the potential to be extremely useful for correlation, age calibration, and palaeoenvironmental determination, along with associated sequence stratigraphic interpretation (Simmons & Aretz, 2020). Collection of material for study is facilitated by the spectacular outcrops in the region. Moreover, given the economic importance of the succession because of the presence of hydrocarbons (e.g., James & Wynd, 1965; Aqrabi et al., 2010; Bordenave, 2014; Grabowski Jr., 2014; Esrafil-Dizaji & Rahimpour-Bonab, 2019), numerous wells have been drilled, providing abundant subsurface material for study.

It is not surprising therefore, that micropalaeontological studies on the carbonate rocks of the Zagros have a long history, partially documented by Elliott (1983) and Hughes (2013). Many of the earliest studies were carried out by the pioneering micropalaeontologists of the historical petroleum companies active in Iraq and Iran. These include P.T. Cox (e.g., Cox, 1937), F.R.S. Henson (e.g., Henson, 1948) and J.G. Wynd (e.g., James & Wynd,

1965). Monographs and publicly available theses such as those by Bozorgnia & Banafiti (1964), Gollestaneh (1965), and Sampò (1969) provided illustrations of the microfauna present, a tradition that has continued with workers from national oil companies and academic institutes (e.g., Kalantari, 1976, 1986, 1992).

More recently there has been a proliferation of publications on Zagros LBF micropalaeontology, some of it in international journals, alongside papers in local journals. More than 300 papers have been published referring to the occurrence of Cretaceous LBF in the Zagros in the last 10 years alone. Many are excellent, but a significant number could offer more value if they were to use precise, modern taxonomic concepts applied to well-illustrated and documented unequivocal material. Without such, the consequent biostratigraphic interpretations can be undermined, which at a local or regional scale is important because biostratigraphy remains the basis for correlation and building an understanding of sequence stratigraphy, palaeogeography, and the stratigraphic architecture of the subsurface. Such studies require firm foundations. Erroneous biostratigraphy based on uncertain identifications and outdated taxonomy can thus have profound implications. Errors also reduce the value for globally applicable studies in biozonation, taxonomy, and evolution.

Therefore, there are issues regarding fossil identification and interpretation to be addressed. These are the subject of this paper that we illustrate with examples from the

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mid-Cretaceous (Aptian, Albian, and Cenomanian) LBF from the Zagros, especially the orbitolinids (Orbitolinidae). Notwithstanding recent publications (e.g., Hosseinzadeh et al., 2020; Dousti Mohajer et al., 2021a), the identity, stratigraphic range, and evolutionary trends of mid-Cretaceous alveolinids (Alveolinidae) from the Zagros also require revision and commentary, but this is largely beyond the scope of this paper. By highlighting these challenges and their potential solutions, we hope to encourage all workers on Zagros micropalaeontology to add additional rigour and best practice to their studies so that the value of their research can be maximised.

We wish to stress that the recommendations for best practice made herein could be applied to any micropalaeontological study in any part of the world, and the issues highlighted here have been documented from outside the Zagros (Schlagintweit 2021a, b) and outside the Cretaceous (Benedetti, 2021). We use the mid-Cretaceous LBF micropalaeontology of the Zagros as an example because (a) we are familiar with the stratigraphy and the fossils; and (b) so much literature is appearing on the subject, some of which is excellent and some of which falls short of expectations. It therefore seems timely to review the “state of the art”. In the spirit of “people in glass houses shouldn’t throw stones” we freely acknowledge that not all our work has always strictly adhered to the principals expressed here. We all have room for improvement!

2. ISSUES

2.1 Fossil Identifications

At the risk of stating the obvious, not every fossil specimen can be precisely identified, even by very experienced specialists. Preservation may be poor and/or key features may be missing or obscured. Unfortunately, it takes time and experience to develop the skills to identify fossils correctly, not least avoiding the temptation to simply match a fossil to an image from the literature. Confident identification requires knowledge of the morphological features used in taxonomy, and how they appear in different cross-sections, when, as is the case with LBF, they are viewed in thin-section (Figure 1).

Thin-sections of carbonate rocks from the Zagros (and other parts of the Middle East) are often rich in LBF and other microfossils. Unfortunately, not all specimens can be readily identified from random sections. Cuttings samples from wells may be particularly problematic, because of sample size. In extreme cases, sedimentary grains that are not fossils at all are sometimes identified as fossils with precise taxonomic names (see Granier, 2020 and Simmons, 2020 for examples of the identification of this practice). Recent publications by Abedpour et al. (2020a) and Arampour et al. (2021) contain poorly illustrated material identified as distinct species, although many of the illustrations provided cast doubt on if even the fossil group suggested is present.

Our key point is that if only random thin-sections are available, then identifications often carry doubt and this should be indicated by a question-mark, or identification to only a higher taxonomic level (e.g., genus or family). Bengtson (1988) can be consulted for best practice in the use of open nomenclature. The authors recognise that such strict considerations are not always applied, and indeed have been guilty themselves (e.g., Simmons, 1994) of attempting precise identifications based on inadequate material. However, the consequences can be significant. Without adequate material and a strict approach to identification, misidentifications are possible, and this in turn can lead to confusion regarding the stratigraphic range of a species or falsely challenge established phylogenetic (e.g., ancestor-descendant) relationships.

LBF have complex internal morphology, and a single random section, or even several random sections, may not reveal sufficient information for specimens to be identified at the species or even genus level. Hottinger (1967) provides seminal illustrations of how random sections through certain Cretaceous LBF can vary markedly. Often of critical importance is the structure and size of the initial embryonic chambers. For example, Schroeder (1962, 1963, 1975), Arnaud-Vanneau (1980), Schroeder et al. (2010), and Cruz Abad (2018) demonstrated that the nature of the embryonic apparatus of the Orbitolinidae (subfamily Orbitolininae) is a key feature for identification and thus for taxonomic classification, and that external morphology is the least important feature, although it may have some value in palaeoenvironmental interpretation (Vilas et al., 1995; Simmons et al., 2000). Exhibiting almost identical internal structure, specimens of *Palorbitolina* Schroeder, *Mesorbitolina* Schroeder and *Orbitolina* d’Orbigny cannot be differentiated in sections not showing the embryo. These genera variously range from the intra-Barremian to the intra-Cenomanian and therefore can lead to a wide range of misleading stratigraphic conclusions if not correctly determined.

Even if a key feature such as the embryonic apparatus is visible, confident identification requires the study of multiple specimens from a sample to obtain a range of measurements of the initial chambers or other key features (see Vicedo & Piuze (2017) for a good example of this approach regarding Cretaceous alveolinids). Some features are subtle and require expertise to interpret correctly, for example to differentiate a peri-embryonic ring (genus *Palorbitolina*) and subembryonic zone (genus *Mesorbitolina*) in some transverse sections (for terminology see Schroeder, 1962; 1963; an example of confusion has been documented by Schlagintweit, 2021a). Ideally, multiple oriented thin-sections should be made from disaggregated material. Of course, there are practical limitations regarding sample material and costs, and these may preclude precise identification.

Differences in the structure of the embryonic apparatus allow for several evolutionary lineages to be recognised, with each lineage typically containing several stratigraphically restricted species with partly overlapping ranges

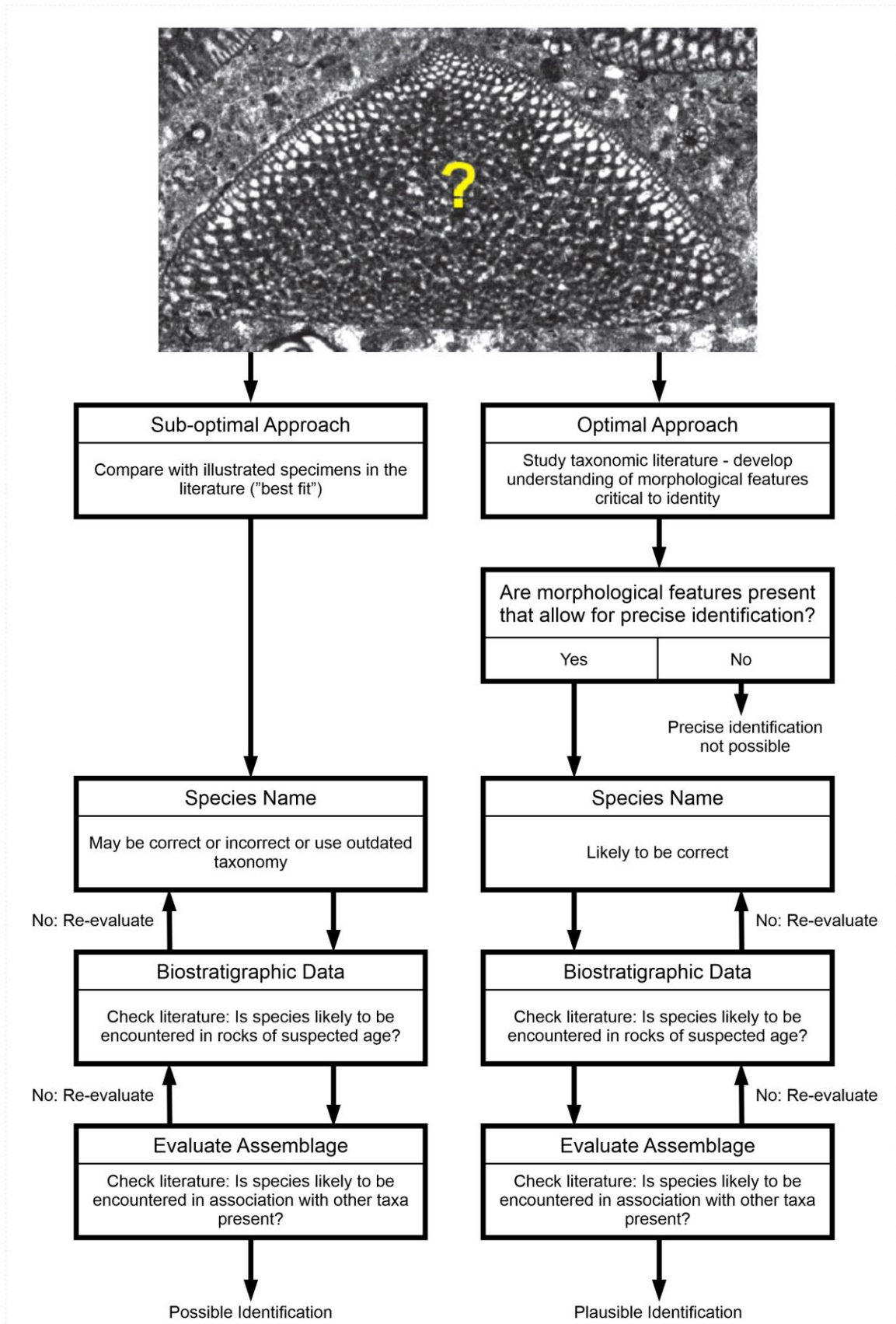


Fig. 1 Optimal and sub-optimal workflows for the identification of larger benthic foraminifera. Following a review of identification, the identity of a specimen can be confirmed or downgraded to a non-specific identity. If the identification is confident based on morphological features, stratigraphic range extension is possible, but should be evaluated carefully if the vast majority of well-established records suggest a different age.

(e.g., Schroeder, 1975; Schroeder et al., 2010). If applied correctly, this makes orbitolinids of immense practical value for biostratigraphic studies of the sediments in which they occur. This has been adopted by a number of workers on Zagros biostratigraphy (e.g., Yazdi Moghadam et al., 2008; Safari et al., 2010; Parvaneh Nejad Shirazi & Abedi, 2013; Moosavizadeh et al., 2014, 2015, 2020), but not by all. Herein we remark upon a number of significant misidentifications, use of archaic taxonomy, and implausible suggested stratigraphic ranges. These records add confusion to the identity and biostratigraphy of the species concerned.

The importance of credible illustrations to support detailed species identifications cannot be overstated. By doing so, identifications can be verified during the refereeing process, or by subsequent researchers. These illustrations should be of sufficient quality to confirm any suggested identification. Key features for identification (such as the embryonic apparatus in orbitolinids) should be visible and provided at an adequate magnification. Noori et al. (2016) in a paper that otherwise uses up to date taxonomic names and presents a reasonable list of orbitolinids to support a late Albian – early Cenomanian age for the Maaddud Formation in eastern Iraq, provide illustrations of which none are suitable for confirming the identity of the taxa mentioned. A similar problem reduces the value of an otherwise important publication on orbitolinids and other LBF from the Qamchuqa Formation of Iraq (Daoud, 2021), in which the identify of many taxa cannot be confirmed by the illustrations provided, or there is confusion as to the sample locations (figures 6a and 9d therein are clearly from the same thin-section, but are said to come from different samples with different ages). The fossil illustrated (Daoud, 2021, figs. 6a and 9d) is *Iraqia simplex* Henson, not *Orbitolinopsis cenomaniensis* Schlagintweit & Yazdi-Moghadam.

In addition to misidentifications because of poor material, they may be due to an apparent lack of familiarity with the morphological features that form the basis of identity. For LBF, key publications that help ensure knowledge of key morphological features include Loeblich and Tappan (1987), Hottinger (2006), and BouDagher-Fadel (2018).

Confusion is inevitable when wholly inappropriate taxonomic names are utilised, or genera or species are reported from rocks of ages in which they should not occur. For example, records of the well-known Early Cretaceous genus *Choffatella* Schlumberger (Arnaud-Vanneau, 1980; Zghal et al., 1988) in the Cenomanian Sarvak Formation of the Zagros (Parvaneh Nejad Shirazi et al., 2009; Rahimpour-Bonab et al., 2012, 2013; Afghah & Dookh, 2014; Omidvar et al., 2014a, b) are very likely mistaken and none are supported by convincing illustration.

Tables 1 and 2 provide examples of orbitolinid assemblages described from the mid-Cretaceous Sarvak Formation (Table 1) and Kazhdumi and Dariyan formations (Table 2) of the Zagros, each assemblage is listed under the biozone defined by the authors, with an interpretation of age by the authors. Comments on modern taxonomy,

stratigraphic range and likely identity are provided. It can be seen that issues identified include archaic taxonomy, incompatible known stratigraphic ranges of taxa versus age implied, taxa unlikely to co-occur in an assemblage, lack of substantiation by illustration, and misidentifications.

The assemblage described from the alleged early Cenomanian *Praealveolina iberica* – *Praealveolina pennensis* Assemblage Zone of Afghah & Fadaei (2014) illustrates problems that misidentifications or use of material inadequate to make certain identifications can create. In addition to reasonably established early Cenomanian species such as *Praealveolina iberica* Reichel and *Praealveolina pennensis* Reichel (Schroeder and Neumann, 1985, Calonge et al., 2002), a number of somewhat surprisingly species are reported as co-occurring. For example, *Mesorbitolina texana* (Roemer) (late Aptian – early Albian; Schroeder et al., 2010) and *Cisalveolina fraasi* (Guembel) (late Cenomanian; Schroeder and Neumann, 1985; Frijia et al., 2015). The identity of these taxa cannot be confirmed from the illustrations provided. *M. texana* is also reported from the early Cenomanian by Afghah & Dookh (2014) as is *Cisalveolina fallax* Reichel, a synonym of *C. fraasi* (Schroeder & Neumann, 1985). An unfortunate consequence might be that an inexperienced worker might assume from Afghah & Fadaei (2014) and Afghah & Dookh (2014) that the range of *M. texana* and *C. fraasi* (plus other taxa) be (incorrectly in our opinion) extended into the early Cenomanian.

Afghah & Fadaei (2014) report *Orbitolina concava* Lamarck and *Neorbitolinopsis conulus* (Douville) from their alleged late Cenomanian *Chrysalidina gradata* - *Cuneolina pavonia* Assemblage Zone (see Table 1 herein). *O. concava* is not illustrated and that of *N. conulus* is indeterminate, but if present these records would represent a remarkable extension of the range of these taxa which are known to be much older (Schroeder and Neumann, 1985). For example, *O. concava* is a typically early Cenomanian species (Schroeder and Neumann, 1985). The record of *Orbitolina* alongside late Cenomanian markers such as *C. fraasi* by Ghabeishavi et al. (2010) is also problematic.

We can further illustrate this issue with other examples from the mid-Cretaceous orbitolinids of the Zagros. There are several reports of Lower Cretaceous taxa in the Cenomanian Sarvak Formation such as *Dictyoconus? pachymarginalis* Schroeder, *Palorbitolina lenticularis* (Blumenbach) or *Montseciella? arabica* (Henson) (Table 1). For example, a non-determinable orbitolinid with reduced marginal zone and septules in the central zone (*Mesorbitolina* sp. or *Orbitolina* sp.) has been illustrated as *Dictyoconus? pachymarginalis* Schroeder by Dehghanian and Afghah (2021, Fig. 7.4) from the early Cenomanian of the Sarvak Formation (Figure 2A herein). On the other hand, *Dictyoconus pachymarginalis* (an Aptian species; Schroeder, 1965) illustrated by Afghah et al. (2014: fig. 11A; Figure 2D herein) from the early Cenomanian (and reported by them from the late Cenomanian)

Table 1 Examples from recently published biozonations of the Sarvak Formation, that record orbitolinids. Issues include archaic taxonomy, incompatible known stratigraphic ranges of taxa versus age implied, lack of substantiation by illustration, and misidentifications.

Orbitolinid Taxa Listed as Present	Current Taxonomic Status	Current Biostratigraphic Range	Probable Identity of Species Described
<i>Orbitolina concava</i> Zone (“early Cenomanian”); Dehghanian and Afghah (2021)			
<i>Orbitolina concava</i>	<i>Orbitolina concava</i>	early Cenomanian (Schroeder & Neumann, 1985)	Not illustrated
<i>Orbitolina conica</i>	<i>Conicorbitolina conica</i> fide Schroeder & Neumann (1985)	early-middle Cenomanian (Schroeder & Neumann, 1985)	Not illustrated
<i>Orbitolina conidia</i> (= <i>conoidea</i>)	junior synonym of <i>Palorbitolina lenticularis</i> fide Schroeder (1963)	late early Barremian-basal late Aptian (Schroeder, 1963; Grani-er et al., 2017)	Not illustrated
<i>Orbitolina discoidea</i>			Not illustrated
<i>Orbitolina lenticularis</i>	<i>Palorbitolina lenticularis</i> fide Schroeder (1963)		Not illustrated
<i>Orbitolina kurdica</i>	<i>Mesorbitolina texana</i> fide Simmons et al. (2000)	late Aptian – early Albian (Schroeder et al., 2010)	Not illustrated
<i>Dictyoconus pachymarginalis</i>	<i>Dictyoconus? pachymarginalis</i>	late Bedoulian-Gargasian (Schroeder, 1965)	<i>Mesorbitolina</i> or <i>Orbitolina</i> sp. (Late Aptian – Early Cenomanian)
<i>Chrysalidina gradata-Cuneolina pavonia</i> Assemblage Zone (“late Cenomanian”); Afghah & Fadaei (2014)			
<i>Orbitolina concava</i>	<i>Orbitolina concava</i>	early Cenomanian (Schroeder & Neumann, 1985)	Not illustrated
<i>Neorbitolinopsis conulus</i>	<i>Neorbitolinopsis conulus</i>	late Albian (Schroeder & Neumann, 1985)	<i>Praetaberina bingistani</i> (middle – late Cenomanian)
<i>Praealveolina iberica – Praealveolina pennensis</i> Assemblage Zone (“early Cenomanian”); Afghah & Fadaei (2014)			
<i>Mesorbitolina texana</i>	<i>Mesorbitolina texana</i>	late Aptian – early Albian (Schroeder et al., 2010)	Indeterminate
<i>Nezzazata concava-Praealveolina cretacea</i> Assemblage Zone (“late Cenomanian”); Afghah et al. (2014)			
<i>Dictyoconus pachymarginalis</i>	<i>Dictyoconus? pachymarginalis</i>	late Bedoulian-Gargasian (Schroeder, 1965)	<i>Persiconus sarvaki</i> (Cenomanian)
<i>Pseudolituonella reicheli-Pseudorhipidionina</i> sp.- <i>Chrysalidina gradata</i> Assemblage Zone (“late Cenomanian”); Afghah et al. (2014)			
<i>Dictyoconus pachymarginalis</i>	<i>Dictyoconus? pachymarginalis</i>	late Bedoulian-Gargasian (Schroeder, 1965)	<i>Persiconus sarvaki</i> (Cenomanian)
<i>Dictyoconus arabicus</i>	<i>Montseciella arabica</i> fide Cherchi & Schroeder (1999)	late Barremian-earliest Aptian (Schroeder et al., 2010)	Not illustrated
<i>Nezzazata-Alveolinides</i> Assemblage zone (“middle-late Cenomanian”); Ahmadi et al. (2008)			
<i>Dictyoconus arabicus</i>	<i>Montseciella arabica</i> fide Cherchi & Schroeder (1999)	late Barremian-earliest Aptian (Schroeder et al., 2010)	<i>Persiconus sarvaki</i> fide Yazdi-Moghadam & Schlagintweit (2020) (Cenomanian)

Table 2 Examples from recently published biozonations of the Kazhdumi and Dariyan formations, that record orbitolinids. Issues include archaic taxonomy, incompatible known stratigraphic ranges of taxa versus age implied, lack of substantiation by illustration, and misidentifications.

Orbitolinid Taxa Listed as Present	Current Taxonomic Status	Current Biostratigraphic Range	Probable Identity of Species Described
<i>Conicorbitolina conica</i> Zone (“early Albian”); Arampour et al. (2021)			
<i>Conicorbitolina conica</i>	<i>Conicorbitolina conica</i>	early-middle Cenomanian (Schroeder & Neumann, 1985; Husinec et al., 2000)	? <i>Mesorbitolina texana</i> (early late Aptian-middle Albian)
<i>Dictyoconus arabicus</i> Zone (“Late Aptian” or “Aptian/Albian transition”); Arampour et al. (2021)			
<i>Dictyoconus arabicus</i>	<i>Montseciella arabica</i> fide Cherchi & Schroeder (1999)	Late Barremian-earliest Aptian (Schroeder et al., 2010)	Indeterminate orbitolininae
<i>Conicorbitolina conica</i>	<i>Conicorbitolina conica</i>	early-middle Cenomanian (Schroeder & Neumann, 1985; Husinec et al., 2000)	? <i>Mesorbitolina texana</i> (early late Aptian-middle Albian)
<i>Conicorbitolina conica-Mesorbitolina parva</i> Zone (“late Albian”); Keshavarzi et al. (2020, 2021)			
<i>Neorbitolinopsis conulus</i>	<i>Neorbitolinopsis conulus</i>	late Albian (Schroeder & Neumann, 1985)	Not illustrated
<i>Mesorbitolina subconcava</i>	<i>Mesorbitolina subconcava</i>	latest Aptian-early late Albian (Schroeder & Neumann, 1985)	<i>Mesorbitolina subconcava</i> (latest Aptian-early late Albian) and ? <i>Palorbitolinoides</i> sp.
<i>Conicorbitolina conica</i>	<i>Conicorbitolina conica</i>	early-middle Cenomanian (Schroeder & Neumann, 1985; Husinec et al., 2000)	<i>Mesorbitolina texana</i> (early late Aptian – middle Albian)
<i>Mesorbitolina parva</i>	<i>Mesorbitolina parva</i>	late Aptian (Schroeder et al., 2010; Cherchi & Schroeder, 2013)	<i>Mesorbitolina texana</i> (early late Aptian – middle Albian)
<i>Mesorbitolina texana</i>	<i>Mesorbitolina texana</i>	early late Aptian-middle Albian (Schroeder & Neumann, 1985)	Indeterminate
<i>Mesorbitolina aperta</i>	<i>Mesorbitolina aperta</i>	late Albian – early Cenomanian (Schroeder & Neumann, 1985)	Not illustrated
<i>Orbitolina concava</i>	<i>Orbitolina concava</i>	early Cenomanian (Schroeder & Neumann, 1985)	Indeterminate
<i>Orbitolina discoidea-Mesorbitolina subconcava</i> Subzone (“early Albian”); Keshavarzi et al. (2020, 2021)			
<i>Orbitolina discoidea</i>	junior synonym of <i>Palorbitolina lenticularis</i> fide Schroeder (1963)	Late early Barremian-basal late Aptian (Schroeder, 1963; Granier et al., 2017)	Indeterminate
<i>Mesorbitolina subconcava</i>	<i>Mesorbitolina subconcava</i>	latest Aptian-early late Albian (Schroeder & Neumann, 1985)	<i>Mesorbitolina subconcava</i> and ? <i>Palorbitolinoides</i> sp.
<i>Conicorbitolina conica</i>	<i>Conicorbitolina conica</i>	early-middle Cenomanian (Schroeder & Neumann, 1985; Husinec et al., 2000)	<i>Mesorbitolina texana</i> (early late Aptian – middle Albian)
<i>Mesorbitolina parva</i>	<i>Mesorbitolina parva</i>	late Aptian (Schroeder et al., 2010; Cherchi & Schroeder, 2013)	<i>Mesorbitolina texana</i> (early late Aptian – middle Albian)
<i>Mesorbitolina texana</i>	<i>Mesorbitolina texana</i>	early late Aptian-middle Albian (Schroeder & Neumann, 1985)	<i>Mesorbitolina texana</i> (early late Aptian – middle Albian)
<i>Mesorbitolina aperta</i>	<i>Mesorbitolina aperta</i>	late Albian – early Cenomanian (Schroeder & Neumann, 1985)	Not illustrated
<i>Orbitolina concava</i>	<i>Orbitolina concava</i>	early Cenomanian (Schroeder & Neumann, 1985)	Indeterminate
<i>Orbitolina kurdica</i>	<i>Mesorbitolina texana</i> fide Simmons et al. (2000)	early late Aptian-middle Albian (Schroeder & Neumann, 1985)	Not illustrated
<i>Mesorbitolina aperta</i> Zone (“late Albian”); Afghah et al. (2020)			
<i>Mesorbitolina aperta</i>	<i>Mesorbitolina aperta</i>	late Albian – early Cenomanian (Schroeder & Neumann, 1985)	? <i>Mesorbitolina subconcava</i> (latest Aptian-early late Albian)
<i>Conicorbitolina conica</i>	<i>Conicorbitolina conica</i>	early-middle Cenomanian (Schroeder & Neumann, 1985; Husinec et al. 2000)	? <i>Mesorbitolina</i> sp.
<i>Orbitolina concava</i>	<i>Orbitolina concava</i>	early Cenomanian (Schroeder & Neumann, 1985)	Not illustrated
<i>Hemicyclammina sigali – Mesorbitolina subconcava</i> Zone (“early Albian”); Afghah et al. (2020)			
<i>Mesorbitolina subconcava</i>	<i>Mesorbitolina subconcava</i>	latest Aptian-early late Albian (Schroeder & Neumann, 1985)	<i>Mesorbitolina subconcava</i> (latest Aptian-early late Albian)
<i>Mesorbitolina texana</i>	<i>Mesorbitolina texana</i>	early late Aptian-middle Albian (Schroeder & Neumann, 1985)	? <i>Mesorbitolina texana</i> (early late Aptian – middle Albian)

<i>Conicorbitolina conica</i>	<i>Conicorbitolina conica</i>	early-middle Cenomanian (Schroeder & Neumann, 1985; Husinec et al. 2000)	? <i>Mesorbitolina</i> sp.
<i>Mesorbitolina parva</i>	<i>Mesorbitolina parva</i>	late Aptian (Schroeder et al., 2010; Cherchi & Schroeder, 2013)	<i>Mesorbitolina texana</i> (early late Aptian – middle Albian) or <i>Mesorbitolina subconcava</i> (latest Aptian-early late Albian)
<i>Orbitolina concava</i> – <i>Hemicyclammina sigali</i> Zone (“late Albian – Early Cenomanian”); Haftlang et al. (2020)			
<i>Orbitolina concava</i>	<i>Orbitolina concava</i>	early Cenomanian (Schroeder & Neumann, 1985)	Uncertain from illustration
<i>Palorbitolina lenticularis</i> Zone (“Aptian”); Haftlang et al. (2020)			
<i>Palorbitolina lenticularis</i>	<i>Palorbitolina lenticularis</i>	Late early Barremian-basal late Aptian (Schroeder, 1963; Granier et al., 2017)	Uncertain from illustration
<i>Mesorbitolina subconcava</i> Zone (“late Aptian”) Shirzade et al. (2019)			
<i>Dictyoconus arabicus</i>	<i>Montseciella arabica</i> fide Cherchi & Schroeder (1999)	Late Barremian-earliest Aptian (Schroeder et al., 2010)	? <i>Orbitolinopsis</i> n. sp.
<i>Mesorbitolina parva</i> – <i>Mesorbitolina texana</i> Zone and <i>Mesorbitolina texana</i> – <i>Orbitolina</i> sp. Zone (“late Aptian”); Afghah & Shaabanpiur Haghighi (2014)			
<i>Conicorbitolina conica</i>	<i>Conicorbitolina conica</i>	early-middle Cenomanian (Schroeder & Neumann, 1985; Husinec et al., 2000)	Not illustrated
<i>Mesorbitolina lotzei</i>	<i>Mesorbitolina lotzei</i>	late early Aptian (Schroeder et al., 2010; Cherchi & Schroeder, 2013)	Not illustrated
<i>Mesorbitolina parva</i>	<i>Mesorbitolina parva</i>	late Aptian (Schroeder et al., 2010; Cherchi & Schroeder, 2013)	<i>Mesorbitolina texana</i> (early late Aptian – middle Albian)
<i>Mesorbitolina texana</i>	<i>Mesorbitolina texana</i>	early late Aptian-middle Albian (Schroeder & Neumann, 1985)	<i>Mesorbitolina texana</i> (early late Aptian – middle Albian)
<i>Mesorbitolina subconcava</i>	<i>Mesorbitolina subconcava</i>	latest Aptian-early late Albian (Schroeder & Neumann, 1985)	Not illustrated
<i>Palorbitolina lenticularis</i>	<i>Palorbitolina lenticularis</i>	Late early Barremian-basal late Aptian (Schroeder, 1963; Granier et al., 2017)	Not illustrated
<i>Orbitolina kurdica</i>	<i>Mesorbitolina texana</i> fide Simmons et al. (2000)	early late Aptian-middle Albian (Schroeder & Neumann, 1985)	? <i>Mesorbitolina</i> sp.
<i>Dictyoconus arabicus</i>	<i>Montseciella arabica</i> fide Cherchi & Schroeder (1999)	Late Barremian-earliest Aptian (Schroeder et al., 2010)	Indeterminate orbitolinid
<i>Iraqia simplex</i>	<i>Iraqia simplex</i>	Aptian (Yazdi Moghadam et al., 2021)	Indeterminate orbitolinid
<i>Valdanchella decourti</i>	“ <i>Valdanchella</i> ” <i>decourti</i>	Late Albian – Early Cenomanian (Schroeder & Neumann, 1985)	Indeterminate orbitolinid
<i>Orbitolina subconcava</i> Zone (“Albian”); Parvaneh Nejad Shirazi et al. (2009, 2011)			
<i>Orbitolina concava</i>	<i>Orbitolina concava</i>	early Cenomanian (Schroeder & Neumann, 1985)	? <i>Orbitolina</i> sp.
<i>Orbitolina conica</i>	<i>Conicorbitolina conica</i>	early – middle Cenomanian (Schroeder & Neumann, 1985)	? <i>Conicorbitolina conica</i> (early – middle Cenomanian)
<i>Orbitolina subconcava</i>	<i>Mesorbitolina subconcava</i>	latest Aptian-early late Albian (Schroeder & Neumann, 1985)	? <i>Mesorbitolina subconcava</i> (latest Aptian-early late Albian)
<i>Dictyoconus arabicus</i> Zone (“Aptian”); Parvaneh Nejad Shirazi et al. (2009, 2011)			
<i>Dictyoconus arabicus</i>	<i>Montseciella arabica</i> fide Cherchi & Schroeder (1999)	Late Barremian-earliest Aptian (Schroeder et al., 2010)	Not illustrated
<i>Mesorbitolina texana</i>	<i>Mesorbitolina texana</i>	early late Aptian-middle Albian (Schroeder & Neumann, 1985)	<i>Mesorbitolina texana</i> (early late Aptian – middle Albian) <i>Mesorbitolina subconcava</i>
<i>Palorbitolina lenticularis</i>	<i>Palorbitolina lenticularis</i>	Late early Barremian-basal late Aptian (Schroeder, 1963; Granier et al., 2017)	Not illustrated
<i>Nezzazata</i> – <i>alveolines</i> Zone (“middle – late Cenomanian”); Ahmadi et al. (2008)			
<i>Dictyoconus cf. arabicus</i>	<i>Montseciella arabica</i> fide Cherchi & Schroeder (1999)	Late Barremian-earliest Aptian (Schroeder et al., 2010)	Indeterminate Dictyoconinae
<i>Hemicyclammina</i> – <i>Orbitolina</i> Zone (“early to middle Albian”); Ahmadi et al. (2008)			
<i>Orbitolina concava</i>	<i>Orbitolina concava</i>	early Cenomanian (Schroeder & Neumann, 1985)	Uncertain
<i>Orbitolina parva</i>	<i>Mesorbitolina parva</i>	late Aptian (Schroeder et al., 2010; Cherchi & Schroeder, 2013)	Not illustrated

<i>Neoiragia convexa</i>	<i>Neoiragia convexa</i>	Late Albian – Early Cenomanian	<i>Orbitolinopsis cenomaniensis</i> fide Schlagintweit and Yazdi-Moghadam (2020) (Cenomanian)
<i>Simplorbitolina cf. conulus</i>	<i>Neorbitolinopsis conulus</i>	late Albian (Schroeder & Neumann, 1985)	Not illustrated
<i>Orbitolina – Iraqlia Zone</i> (“Aptian”); Ahmadi et al. (2008)			
<i>Orbitolina concava</i>	<i>Orbitolina concava</i>	early Cenomanian (Schroeder & Neumann, 1985)	Uncertain

and in Dousti Mohajer et al. (2021b, pl. 2r) correspond to (sub)axial sections of the Cenomanian *Persiconus sarvaki* Yazdi-Moghadam & Schlagintweit (Figure 2E-F herein) (see also “*Dictyoconus pachymarginalis*” of Rahiminejad et al., 2006, Figure 5e, Jamalpour et al., 2017, Plate 1h; Jamalpour et al., 2018, Plate 2/4; Kiarostami et al., 2019, Plate 2d). Several other specimens of *P. sarvaki* from the Sarvak Formation have been referred to *Dictyoconus* sp., “*Dictyoconus arabicus*” or “*Dictyoconus pachymarginalis*” (see synonymy in Yazdi-Moghadam and Schlagintweit (2020).

Dictyoconus sp. in Assadi et al. (2016: fig. 6-a16) represents a medium-conical orbitolinid with septules (instead of pillars), and crosswise oblique (instead of straight) foramina as in *Orbitolina* or *Mesorbitolina*. Wynd (1965) mentioned the occurrence of *Dictyoconus* sp. and *Orbitolinopsis* sp. in the Cenomanian “*Nezzazata*-alveolinid assemblage zone” most likely referring to the recently described species *Persiconus sarvaki* Yazdi-Moghadam & Schlagintweit and *O. cenomaniensis*.

The early-early late Aptian *D.?* *pachymarginalis* Schroeder (Fig. 2B-C herein) is well known from the Taft and Tirgan formations of Central Iran (e.g., Schlagintweit & Wilmsen, 2014; Bucur et al., 2019) and has (very rarely) been described from the Aptian of the Zagros (Hamedanian et al., 2017: pl. 1D).

In summary, the orbitolinid assemblages reported from the Sarvak Formation (Table 1) represent a mixture of species that can be valid and plausible (e.g., *O. concava* group), species that have so far not been reliably recorded (e.g., *N. conulus*), and incorrectly identified older Cretaceous taxa.

2.2 Use of outdated or inappropriate taxonomy

Taxonomic studies are the foundation upon which sound identifications are built, which in turn leads to robust biostratigraphic or palaeoenvironmental interpretation. Cretaceous LBF suffer from a proliferation of taxonomic nomenclature. This includes species or genera defined by inadequate material, including archaic names with uncertain definitions; species or genera defined by features (e.g., external shape) that have no or limited taxonomic value, or defined by very minor morphological variations of key features; and synonyms of established taxa (Schlagintweit, 2020; Consorti & Schlagintweit, 2021).

Orbitolinids particularly suffer in these respects with archaic names such as “*Orbitolina discoidea*” still being used by some workers, even though such taxa have been shown to be *nomina nuda* or synonyms of more established taxa. Likewise, other names such as *Orbitolina lenticularis* are used in an archaic loose sense when the taxonomy of that species has long been established precisely (Schroeder, 1963). If new taxa are to be introduced, they need to be illustrated by material that is sufficient to determine the identity. For example, the Early Cretaceous orbitolinid genus *Sayyabellus* introduced by Mohammed (2003), is supported by illustrations that are wholly undiagnostic to define a new orbitolinid taxon (Schlagintweit, 2020).

For most Cretaceous LBF there are useful key publications that establish an up-to-date taxonomy of many key species – for example, the seminal publication edited by Schroeder and Neumann (1985) alongside more recent publications on other non-orbitolinid key species or genera (e.g., Banner et al., 1991, Consorti et al., 2015). These publications are well established and available online, so that ignorance of their existence is hard to excuse in modern micropalaeontological studies. Whilst not exhaustive, the World Foraminifera Database as part of WORMS (for further information see Hayward et al., 2020) provides a researcher with the currently valid taxonomic names and further information on key references. That is not of course to say that the taxonomy of many key species likely to be encountered in Zagros stratigraphy is unequivocally established. There are still challenges to establish the exact taxonomic identify (and stratigraphic range) of many species likely to be encountered. However, this cannot excuse using outdated or misguided taxonomic concepts that only lead to confusion in biostratigraphic interpretation and evolutionary or palaeobiological studies. Poor taxonomy sits alongside poor fossil identification as causing confusion to subsequent workers hoping to extract value from any given micropalaeontological study.

Examples of the difficulties presented by some recent studies on the micropalaeontology of the Zagros can be illustrated by reference to publications on the mid-Cretaceous Dariyan, Kazhdumi and Sarvak formations that refer to orbitolinids (Tables 1 and 2). In such papers, species names can still be found that have long been regarded as synonyms or invalid. These include *Orbitolina discoidea* Gras, *Orbitolina kurdica* Henson, and *Orbitolina conoidea* Gras (Dehghanian and Afgah, 2021; Keshavarzi et al., 2020, 2021). *O. conoidea* has also been

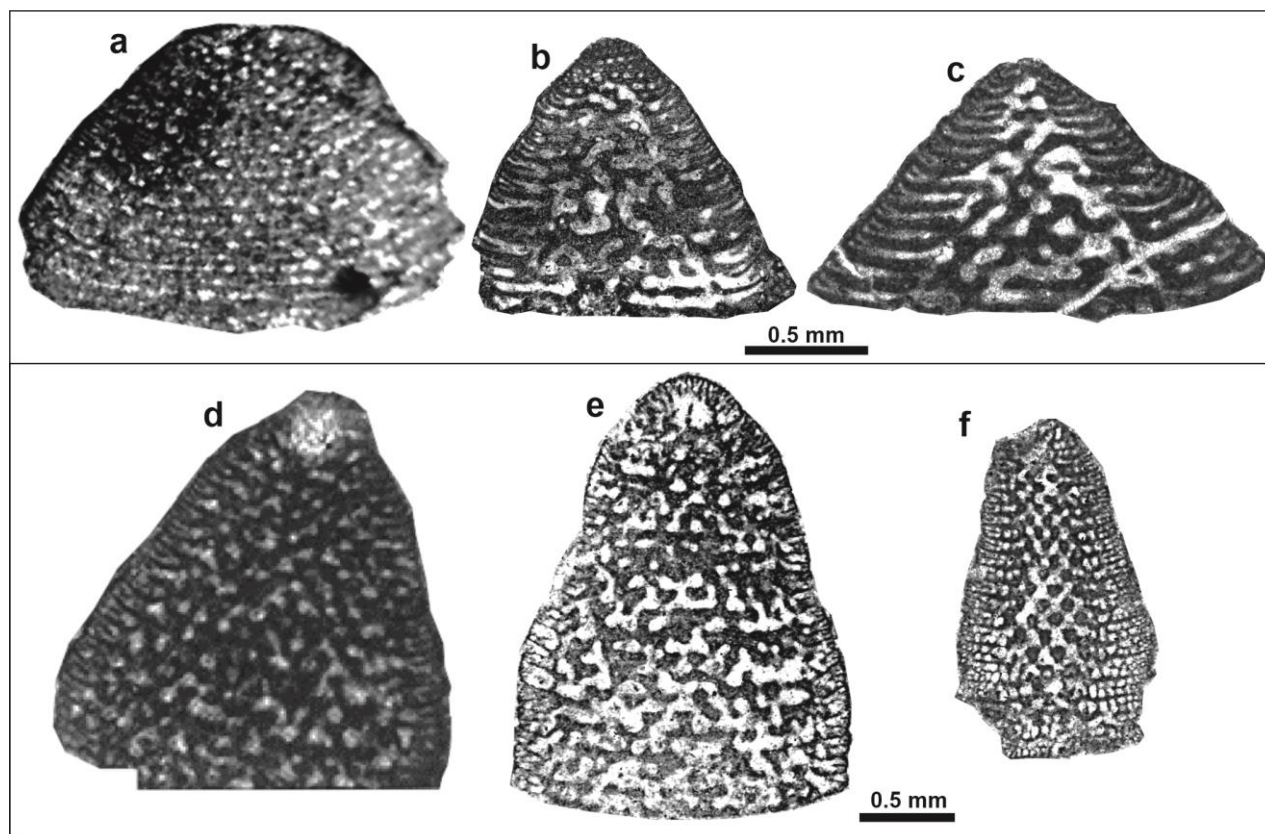


Fig. 2 Lower- to mid-Cretaceous Orbitolinidae from Iran. **a** Subaxial section of *Mesorbitolina* sp. or *Orbitolina* sp. (= *Dictyoconus pachymarginalis* Schroeder in Dehghanian and Afghah, 2021, Fig. 7.4, Albian Kazhdumi Formation SW Iran). **b–c** *Dictyoconus pachymarginalis* Schroeder, subaxial sections, Aptian Taft Formation, Central Iran. **d** “*Dictyoconus pachymarginalis* Schroeder” axial section (extracted from Afghah et al., 2014, fig. 11A), Cenomanian Sarvak Formation of SW Iran. **e–f** *Persiconus sarvaki* Yazdi-Moghadam & Schlagintweit, axial and tangential sections, Cenomanian Sarvak Formation of SW Iran.

reported from Lower Cretaceous formations (e.g., Khodashenas et al., 2014; Abyat et al., 2016). Henson (1948) used such species concepts, as did Sampò (1969) and Kalantari (1976, 1986, 1992) (often with very little obvious consistency), but taxonomic revision was carried out from the 1960’s onwards (Schroeder, 1963, 1975; Simmons et al., 2000; Schroeder et al., 2010) that placed such taxa into synonymy. Historically, terms such as *Orbitolina discoidea* and *Orbitolina conoidea* were respectively used to designate flat and conical gross morphologies of *Orbitolina* (*sensu lato*). As previously noted, gross morphology is not a key taxonomic feature (see again example of *M. texana* in Fig. 4), and in any case, both *O. discoidea* and *O. conoidea* are synonyms of *P. lenticularis* (Schroeder, 1963). The use of such archaic species names should thus be discouraged.

With respect to *O. kurdica*, Simmons et al. (2000) who re-studied the type and figured material of Henson (1948), noted that a previously unillustrated syntype (designated by them as lectotype) refers without any doubt to *M. texana* (Simmons et al., 2000, pl. 1, fig. 1). On the other hand, in the type-description Henson (1948: fig. 11a) provided a schematic drawing of an embryo that corresponds to *P. lenticularis* with peri-embryonic ring and lacking a subembryonic zone. Another syntype specimen of “*O. kurdica*” (Henson, 1948, pl. 1, fig. 10)

shows a coiled initial part and can neither belong to *Palorbitolina* nor *Mesorbitolina*; most likely it is a section of *Paleodictyoconus*. Therefore, the original *O. kurdica* concept of Henson appears to be a mixture of different species and the use of this species name should be avoided.

2.3 Biozonation schemes and age calibration

Biozonation schemes are the typical means of conveying the potential of fossils for correlation. Such schemes typically use the evolutionary or local inception and extinctions of key fossils to define the limits of each biozone, although abundance peaks and overall assemblage characteristics may also be used (McGowran, 2005; Gladenkov and Gladenkov, 2021). Very often, the successive inceptions of species within an evolutionary plexus of a particular fossil group may be used (as in typical planktonic foraminifera biozonation schemes, or those of some Cenozoic LBF, or for mid-Cretaceous orbitolinids).

For biozonation schemes to be effective, they mostly rely on the demonstrable repetition of the defining events or characteristics in multiple geographically spaced successions. A zonation scheme that is newly created for a single stratigraphic succession or a few very closely spaced successions is of limited value as it may not assist in

AGE	WYND (1965)	SAMPÒ (1969)	KALANTARI (1976)	SISSINGH (1977)	AMEEN & GHARIB (2014)
TURON.	<i>Valvulammina - Dicyclina</i>	<i>Valvulammina - Nummoloculina - Dicyclina</i>			
CENOM.	<i>Nezzazata - alveolinid</i>	<i>Nezzazata</i>	<i>Nezzazata - Dicyclina</i>	B 10	<i>Orbitolina</i> (s.l.) ▼
	<i>Praealveolina - algae</i>	<i>Praealveolina - Ovalveolina</i>	<i>Trocholina lenticularis - T. altispira</i>		<i>Ovalveolina ovum</i> (s.l.) ▼
ALBIAN	<i>Trocholina - Orbitolina</i>	<i>Oligostegina - Hedbergella washitensis</i>			<i>Orbitolina concava</i>
	<i>Hemicyclammina - Orbitolina</i>				<i>Orbitolina sefini</i>
	Conical <i>Orbitolina</i>	<i>Orbitolina concava</i> subspp. ("large <i>Orbitolina</i> ")	<i>Hedbergella washitensis & Hemicyclammina sigali</i>	B 9	<i>Orbitolina qatarica</i>
APTIAN		<i>Orbitolina discoidea - conoidea</i>			<i>Mesorbitolina subconcava</i>
					<i>Mesorbitolina texana</i>
	<i>Hensonella - Orbitolina - Choffatella</i>	<i>Choffatella decipiens</i>	<i>Orbitolina discoidea - conoidea & Orbitolina lenticularis</i>	B 8	<i>Salpingoporella dinarica</i> ▼
				B 7	<i>Choffatella decipiens</i> ▼
NEOCOM.					<i>Palorbitolina lenticularis / Choffatella decipiens</i>
					<i>Choffatella decipiens</i>
	<i>Choffatella - Cyclammina</i>	<i>Dictyoconus arabicus</i>	<i>Choffatella decipiens & Pseudocyclammina rugosa</i>	B 6	▲ <i>Ovalveolina ovum</i> (s.l.)
				B 5	▲ common <i>Orbitolina</i> (s.l.)
	<i>Pseudocyclammina lituus - Trocholina</i>	<i>Pseudocyclammina lituus</i>	<i>Pseudocyclammina lituus & Pseudochrysalidina arabica</i>	B 4	▲ common <i>Choffatella decipiens</i>
			B 3	▲ <i>Salpingoporella dinarica</i>	
		<i>Munieria - Salpingoporella</i>	<i>Cyclammina cf. greigi</i>	B 2	<i>Pseudocyclammina lituus</i> ▼
				B 1	<i>Salpingoporella annulata</i> ▼

Fig. 3 Early – mid-Cretaceous Zagros biozonations (mostly assemblage zones or biofacies) utilising larger benthic foraminifera. The Wynd (1965) zonation and Sissingh (1977) zonations are based on data presented in Motiei (1993). Sampò (1969) and Kalantari (1976) are published schemes, whilst that of Ammen & Gharib (2014) is a scheme using more modern taxonomic concepts. LAD = Last Appearance Datum. FAD = First Appearance Datum. s.l. = sensu lato. No numerical scaling of the geological timescale is implied. The age assignments and taxonomic nomenclature are often outdated, and the uncertainty precludes precise calibration of stage boundaries and the precise relationship of one zonal scheme to another.

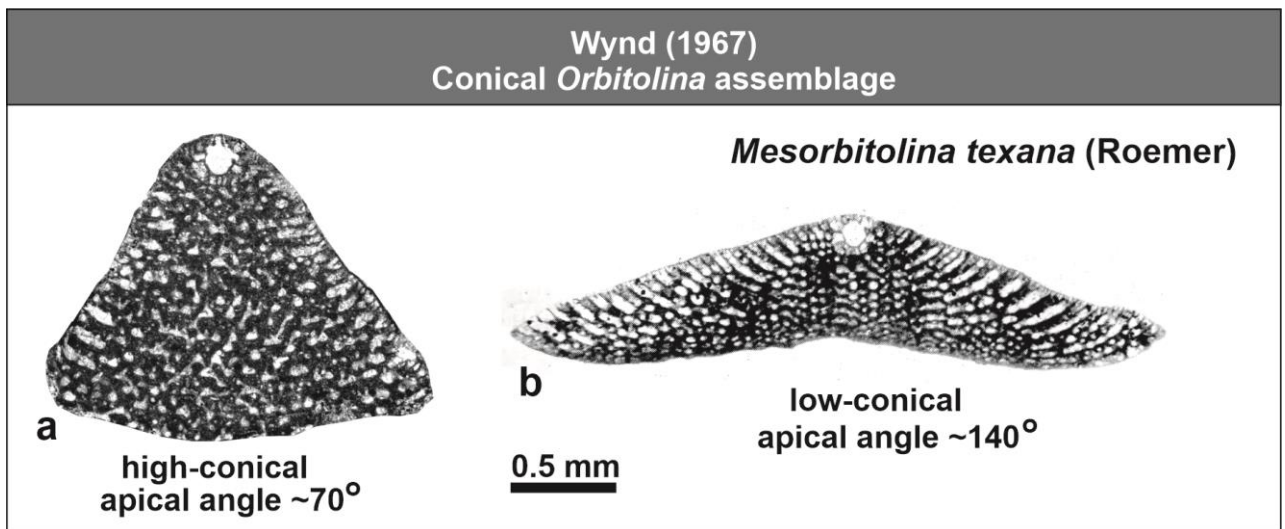


Fig. 4 Morphological variability (apical angle, test height and diameter) of the late Aptian – middle Albian *Mesorbitolina texana* (Roemer). **a** late Aptian Taft Formation of Central Iran. **b** late Aptian of Lebanon (from Schroeder and Neumann, 1985, pl. 36, fig. 2, topotype of *Orbitolina discoidea* var. *libanica* Henson; coll. F.R.S. Henson). Also note the convex test base in **a** and the central depression in **b** with a few final annular chambers.

wider correlation or in calibration to international standard zonations and the chronostratigraphic scale. Within the Zagros stratigraphic succession, a local biozonation scheme that remains persistently referred to, despite its vintage, is that of Wynd (1965). Moreover, this reference is an unpublished report, although the essence of it (Fig. 3) can be gleaned from subsequent publicly available publications including those of James and Wynd (1965) and Motiei (1993). Strictly speaking, the Wynd (1965) scheme is not a biozonation scheme. It describes “biofacies”, assemblages of microfossils that characterise a particular episode of deposition and related depositional environment. As such, the boundaries of each biofacies or assemblage zone are likely to be diachronous. The persistence of this zonation (e.g., Ghabeshavi et al., 2010; Piryaei et al., 2010; Rahimpour-Bonab et al., 2012, 2013; Omidvar et al., 2014a, b; Rikhtegarzadeh et al., 2016, 2017; Kazemzadeh & Loftpoor, 2016; Saedi Razavi et al., 2021) relates to its use by the National Iranian Oil Company (NIOC), where the broad assemblage zones have some proven utility in correlation and recognising stratigraphic intervals. Other effectively unpublished zonations exist (e.g., Sissingh, 1977, Fig. 3), intended for use by NIOC but have failed to become established. Notwithstanding its ongoing usage, the zonation of Wynd (1965) is based on often archaic taxonomy (see Section 2.2) and age assignments of the formations it relates to (see Section 2.4), leading to confusion when this zonation is used to define the stratigraphic range of key fossils. For example, a “Conical *Orbitolina* Assemblage Zone” has been established for the Albian stratigraphy. A term such as “Conical *Orbitolina*” has very limited meaning and value in terms of modern micropalaeontology. For example, the late Aptian-middle Albian species *Mesorbitolina texana* may show both high-conical to low-conical (almost discoidal) test morphologies (Fig. 4). So several orbitolinids (with complex embryo) may be conical, such as *Mesorbitolina*, *Conicorbitolina* Schroeder, and also many dictyoconinids (with simple embryo). As previously noted, the shape of orbitolinids has no taxonomic value, instead being related to palaeoecology (Henson, 1948; Vilas et al., 1995; Simmons et al., 2000). Furthermore, here the genus name “*Orbitolina*” relates to archaic usage, rather than the precise usage in practice today (e.g., Schroeder & Neumann, 1985; Simmons et al., 2000; Schroeder et al., 2010). Consequently, it is impossible to derive any interpretation of age calibration from such a zonal definition, or even recognise it with confidence. Notwithstanding the persistence of the Wynd (1965) zonation, there have been proliferation of mid-Cretaceous LBF biozonations in recent literature, often relating to individual or closely spaced sections (e.g., Afghah & Dookh, 2014; Toulabi & Roozbahani, 2015; Abyat et al., 2016; Haftlang et al., 2020; Dousti Mohajer et al., 2021a, b; Abedpour et al., 2021). Tables 1 and 2 and Figures 5 and 6 refer to examples of this practice. These schemes appear to be of limited value for two reasons. Firstly, the schemes often seem to be based upon

archaic taxonomic nomenclature and/or implausible stratigraphic ranges. Secondly, the very proliferation of schemes, notwithstanding taxonomy or stratigraphic range issues, suggests each scheme is of limited value. Whilst endemic LBF do occur in the Cretaceous stratigraphy of the Zagros and Arabian Plate, there are many species that are present across wider Neotethys, and it is these that are recommended for biozonation purposes, unless there is a compelling reason to create a local biozonation (for the use in biosteering hydrocarbon wells for example).

The value of these schemes is substantially undermined by the use of out-of-date taxonomy and the implied co-occurrence of species that are not known to co-exist elsewhere in the mid-Cretaceous stratigraphy of Neotethys. Examples are documented in Tables 1 and 2. Such errors could easily be avoided by a review of readily available literature. In some cases, the ranges of taxa with well-established ranges such as *Praeorbitolina cormyi* Schroeder (see Schroeder et al., 2010; Cherchi and Schroeder, 2013) and *O. concava* (see Schroeder & Neumann, 1985; Simmons et al., 2000) have incorrectly been extended by as much as an additional stage, or *P. lenticularis* (see Schroeder et al., 2010; Cherchi and Schroeder, 2013; Mohammed, 2017) incorrectly extended to encompass all of the Aptian (Parvaneh Nejad Shirazi et al., 2013; Afghah and Shaabanpour Haghighi, 2014; Haftlang et al., 2020) or even Albian – Cenomanian (Afghah & Fanati Rashidi, 2007). Moreover, there are misleading applications of references with regard to stratigraphic ranges of key fossils. Keshavarzi et al. (2020, p. 108) remarked that the “*presence of Orbitolina discoidea and Mesorbitolina subconcava implies early Albian age*” and in doing so referring among others to Schroeder et al. (2010). The latter authors (p. 63) however clearly stated that names such as *O. discoidea* “*are now obsolete...and therefore not applicable*”. According to Schroeder (1963), *O. discoidea* Gras represents a junior synonym of *P. lenticularis* known from the late early Barremian-basal late Aptian interval (Schroeder, 1963; Schroeder et al., 2010; Taherpour-Khalil-Abad et al., 2015; Mohammed, 2017; Granier et al., 2017). For *M. subconcava*, Schroeder et al. (2010, p. 69) indicate a latest Aptian to early middle Albian for the eastern Arabian and north-eastern African plates. Put simply, *O. discoidea* (= *P. lenticularis*) and *M. subconcava* cannot occur together.

Haftlang et al. (2020) also misquote the literature suggesting that Schroeder et al. (2010) indicated that *O. concava* is an Albian species (and thereby justifying a possible Albian age for rocks they find this species in – the illustrations are equivocal). *O. concava* is well established as a useful early Cenomanian species (Schroeder & Neumann, 1985; Simmons et al., 2000) and there is no such statement that *O. concava* is an Albian species in Schroeder et al. (2010).

Arapour et al. (2021) provide some confusing interpretations of microfossil assemblages from the Kazhdumi Formation. An early Albian *Conicorbitolina conica* Total

AGE	AHMADI et al. (2008)	PARVANEH NEJAD SHIRAZI et al. (2009, 2011)	AFGHAN & FADAEI (2014)	SHIRZADE et al. (2019)
TURON.				
CENOM.	<i>Nezzazata</i> - <i>Alveolinides</i>	<i>Lithocodium aggregatum</i>	<i>Chrysalidina gradata</i> - <i>Cuneolina pavonia</i>	
	<i>Ticinella madecassiana</i> - <i>Rotalipora</i>		<i>Nezzazata conica</i> - <i>Nezzazata simplex</i>	
ALBIAN	<i>Hemicyclammina</i> - <i>Orbitolina</i>	<i>Nezzazatinella picardi</i>	<i>Praealveolina iberica</i> - <i>Praealveolina pennensis</i>	
		<i>Orbitolina subconcava</i>		
APTIAN	<i>Orbitolina</i> - <i>Iraqia</i>	<i>Hemicyclammina sigali</i>		<i>Favusella washitensis</i>
		<i>Salpingoporella annulata</i>		<i>Mesorbitolina subconcava</i>
NEOCOM.		<i>Dictyoconus arabicus</i>		<i>Mesorbitolina texana</i>
				<i>Hedbergella</i> - Orbitolinids

Fig. 5 Examples of relatively recent Zagros mid-Cretaceous biozonation schemes that utilize larger benthic foraminifera. No numerical scaling of the geological timescale is implied. The age assignments and taxonomic nomenclature are often outdated, and the uncertainty precludes precise calibration of stage boundaries and the precise relationship of one zonal scheme to another.

Range Zone is defined (despite the species being recorded above and below this zone). As justification for the age interpretation, they incorrectly claim that an early Albian age was assigned to *C. conica* by Schroeder et al. (2010). They also record “*Dictyoconus arabicus*” and “*Montseciella arabica*” from the rocks they interpret as late Aptian or Aptian/Albian transition. *D. arabicus* and *M. arabica* are synonyms and late Barremian – earliest Aptian in age (Schroeder et al., 2010). Many taxa cannot be substantiated by illustration and some do not even belong to the fossil group indicated (for example the illustrated “*Neomeris cretacea*” and “*Clypeina occidentalis*” are echinoderm spines).

A particularly troublesome example is the late Albian *Conicorbitolina conica*-*Mesorbitolina parva* Zone of Keshavarzi et al. (2020, 2021). The first-named species ranges from early-middle Cenomanian (Schroeder and Neumann, 1985; Husinec et al., 2000), while the latter is restricted to the early late Aptian (Schroeder et al., 2010). In fact, the *M. parva* orbitolinid biozone of Schroeder et

al. (2010, fig. 10) refers to the early Gargasian (= *E. subnodosom-costatum* ammonite zone). Hence, *Mesorbitolina parva* is also incorrectly included in the early Albian “*Hemicyclammina sigali* and *Mesorbitolina subconcava* zone” of Afghah et al. (2020) (specimens illustrated are of a more advanced species of *Mesorbitolina*). Note that records of *O. concava* and *Mesorbitolina aperta* in the early Albian, *M. texana*, *Conicorbitolina conica*, *Mesorbitolina parva* in the late Albian by Keshavarzi et al. (2021, Figure 12) are all contrary to the accepted ranges of these taxa and are not substantiated by illustration. As previously noted, the use of the names *O. discoidea* and *O. kurdica* is inappropriate.

A similar unlikely assemblage of supposedly contemporaneous LBF is reported from the Dariyan Formation by Shaabanpour Haghighi & Sahraeyan (2014): “*P. lenticularis*, *Mesorbitolina parva*, *M. texana*, *M. subconcava*, *Conicorbitolina conica*, *M. lotzei*, *M. ovalis-pervia*, *Orbitolina kurdica*, *I. simplex*, *Valdanchella decourti* ...and *Pseudocyclammina lituus*”. Additionally, *Pseudocyclammina rugosa* (d’Orbigny) is mentioned elsewhere in

AGE	KESHAVARZI et al. (2020, 2021)	HAFTLANG et al. (2020)	DOUSTI MOHAJER et al. (2020, 2021)	DEGHANIAN & AFGHAH (2021)	ARAMPOUR et al. (2021)
TURON.			<i>Dicyclina schlumbergeri</i> Nezzazatinella picardi - Mangashtia - Dicyclina		
CENOM.		<i>Stomiosphaera conoidea</i> Praealveolina cretacea Taberina bingistani	<i>Cisalveolina fraasi</i> - <i>Cisalveolina lehneri</i> - <i>Praetaberna bingistani</i> <i>Chrysalidina gradata</i> - <i>Cisalveolina fraasi</i> - <i>Cisalveolina lehneri</i> Praealveolina iberica - Chrysalidina gradata	<i>Pseudolituonella reicheli</i> Nezzazatinella picardi	
	<i>Conicorbitolina conica</i> & <i>Mesorbitolina parva</i>	<i>Orbitolina concava</i> - <i>Hemicyclammina sigali</i>	<i>Muricohedbergella</i> - <i>Globigerinelloides</i>	<i>Orbitolina concava</i>	
ALBIAN	<i>Hemicyclammina sigali</i> <i>Favusella washitensis</i> <i>Mesorbitolina subconcava</i> - <i>Orbitolina discoidea</i>	[no zone]			<i>Hemicyclammina sigali</i> <i>Conicorbitolina conica</i>
APTIAN		<i>Palorbitolina lenticularis</i>			<i>Dictyoconus arabicus</i> <i>Hedbergella trocoidea</i> <i>Globigerinelloides ferreolensis</i> <i>Ticinella primula</i>
NEOCOM.					

Fig. 6 Further examples of relatively recent Zagros mid-Cretaceous biozonation schemes that utilize larger benthic foraminifera. No numerical scaling of the geological timescale is implied. The age assignments and taxonomic nomenclature are often outdated, and the uncertainty precludes precise calibration of stage boundaries and the precise relationship of one zonal scheme to another.

their text. There is little doubt that the Dariyan Formation is a mostly Aptian-aged formation and only locally extends into the early Albian (van Buchem et al., 2010) and some taxa mentioned (*P. lenticularis*, *M. parva*, *M. texana*, *M. subconcava*) are not incompatible with this (see Yavari et al., 2017 for an excellent, well-illustrated study on orbitolinids and associated LBF from the Dariyan Formation). However, the records of *C. conica* and *P. rugosa* (Cenomanian taxa: Schroeder & Neumann, 1985; Husinec et al., 2000, Simmons et al. 2020) and *P. lituus* (no younger than Valanginian: Bassoulet, 1997; Velić, 2007; Hosseini et al., 2016) add confusion to the literature records of these species (see also Parvaneh Nejad Shirazi et al., 2009; 2011; Afghah & Shaabanpiur Haghghi, 2014; Dehghani et al., 2014; Afghah et al., 2016). As already mentioned, *O. kurdica* is not a useful taxonomic entity.

Abedpour et al. (2020b) interprets the Dariyan Formation in sections close to Shiraz as early Albian. The following microfossil assemblage is offered as support: *Choffatella desipencis* [*decipiens*], *Orbitolina texana*, *Orbitolina* sp., *Dictyoconus* [*Dictyoconus*] sp., *Chrysalidina* sp., *Nezzazata* sp., *Milolida*, *Pseudochrysalidina conica*, *Pseudochrysalidina* sp., *Lituonella* sp., *Pseudolituonella* sp., *Salpingoporella* sp., *Orbitolina lenticularis*, *Orbitolina kurdica*, *Orbitolina conica*, *I. simplex*, and *Pseudochrysalidina arabica*. No aspect of this confusing assem-

blage is compatible with an early Albian age. Several species are no younger than Aptian (*C. decipiens*, *P. lenticularis*, *I. simplex*), others are much older (*Pseudochrysalidina arabica* = *Paravalvulina arabica*; Banner et al., 1991), others are much younger (*Orbitolina conica* = *Conicorbitolina conica* - see discussion elsewhere herein). Moreover, none of the illustrations provided to support the identifications offer confirmation of identity. In summary, the age assignment of the Dariyan Formation in this paper cannot be justified, and confusion is added to the stratigraphic ranges and identity of important microfossils.

Although *Dictyoconus arabicus* (= *Montseciella? arabica*) is a commonly encountered and useful stratigraphic marker for late Barremian – earliest Aptian strata across the Middle East (Schroeder et al., 2010), it seems to be widely misidentified and assigned misleading ages ranging from Aptian to Cenomanian (e.g., Ahmadi et al., 2008; Parvaneh Nejad Shirazi et al., 2013; Afghah & Shaabanpiur Haghghi, 2014). Shirzade et al. (2019) illustrate a specimen from the late Aptian which appears to be a possibly new species of *Orbitolinopsis*. It is worth mentioning, however, that *M.? arabica* might be confused with *Rectodictyoconus giganteus* Schroeder, an early Aptian species.

Iraqia simplex appears to be another species prone to uncertain identification and age interpretation. This is an early Aptian species (see review by Masse, 2003, and Yazdi-Moghadam et al., 2021), although is reported from Albian and Cenomanian stratigraphy, often without illustration (e.g., Sayyab & Mohammed, 1985; Shapourikia et al., 2021). It seems that Henson (1948) included both Aptian and Albian-Cenomanian material in his description and collection of types, perhaps representing two different taxa pending a detailed review of this species and its occurrences.

An updated regionally applicable LBF biozonation for the Zagros and Arabian Plate is long-overdue and it is good to see steps underway to rectify this (e.g., Schroeder et al., 2010; Hughes, 2018). The zonations of Ameen and Gharib (2014) (Figure 3) (see also Al-Mamory & Al-Dulaimi, 2020) and Hamedanian et al. (2017) are a step in the right direction of establishing regionally applicable zones on the basis of key LBF (especially orbitolinids) in the mid-Cretaceous stratigraphy of the Zagros, although the precise age calibration of some zones requires further research and the identification of the species mentioned is often unsubstantiated because of undiagnostic illustrations.

2.4 Working towards a new synthesis

Notwithstanding issues with identification and taxonomy in the previous sections, LBF have the potential to provide reasonably precise age calibration for many of the sedimentary successions in the Zagros and the wider Arabian Plate. Many of the taxa present are well known in other parts of Tethys from reasonably age-calibrated stratigraphy (see for example the range charts in Schroeder and Neumann, 1985; Velić, 2007 and Chiocchini et al., 2008).

However, as noted by Frijia (2015), the stratigraphic ranges of many mid-Cretaceous LBF are poorly constrained, because of the lack of independent age control from planktonic microfossils, ammonites, or stable isotopes. Thus, the occurrences of LBF in the Zagros should help provide further information on stratigraphic ranges for species for which this needs to be better constrained. The realisation of this is however seldom accomplished. If one were to synthesise the ranges of many Cretaceous LBF from publications that document their occurrence in the Zagros, often the result would be overly-long “smeared” ranges, or ranges that are at odds with their established ranges in other parts of Neotethys. Indeed, this is a problem when attempting to document the stratigraphic range of many Cretaceous LBF from across Neotethys (see Figure 5 of Sari et al., 2009 and Figure 8 of Solak et al., 2020). This is partly because of misidentifications or unproven identifications (see Section 2.1) or because of the use of inappropriate taxonomy (see Section 2.2). Even where this is not the case, confusion may be introduced because the age interpretation of the rock unit the fossils are occurring in requires revision. The

ages of some formations in the Zagros are tied to stratigraphic concepts dating back to the work of pioneers such as Henson (1948) and James and Wynd (1965). Notwithstanding some exceptions (e.g., Vincent et al., 2010; Yavari et al., 2018; Sharifi et al., 2021; Raisossadat et al., 2021), ammonites can be scarce in Cretaceous Zagros stratigraphy, and will not be encountered at all in most well material. Consequently, the ages of many formations were loosely constrained in many older works and such concepts can be deeply ingrained.

In particular, arguments that the upper part of the Sarvak Formation in Iran and its equivalents in other parts of the Zagros (e.g., the Mishrif Formation in Iraq; Mahdi & Aqrabi, 2014) extend into the Turonian (e.g., Razin et al., 2010; Mehmandsoti et al., 2021), need more substantiation by either more age-diagnostic LBF faunas and/or other calibration methods. For example, Razin et al. (2010) cite the presence of *Taberina bingistani* Henson (= *Praetaberina bingistani*) as evidence for Turonian age, but Consorti et al. (2015) convincingly argue that this is a Cenomanian-restricted species.

The presence of Turonian stratigraphy is an old debate (van Bellen et al., 1959) and is complicated because differential erosion at sequence boundaries may mean that Turonian strata are missing locally (Davies et al., 2002; van Buchem et al., 2011). Rahimpour-Bonab et al. (2012, 2013) and Omidvar et al. (2014a,b) have summarised some of the evidence, for at least local extension of the Sarvak Formation into the Turonian, and in more open marine facies the Sarvak is undoubtedly Turonian in its upper part (Sharp et al., 2010; Navidtalab et al., 2019; Kalanat et al., 2021). Suggestions by Al-Dulaimy & Al-Sheikhly (2013) that certain well known mid-Cretaceous LBF such as *Chrysalidina gradata*, *C. fallax* (= *C. fraasi*), *Praealveolina simplex* (= *Simplalveolina simplex*) and *Taberina bingistani* (= *Praetaberina bingistani*) might range up into a Turonian portion of the Mishrif Formation of Iraq (notwithstanding issues regarding fossil identification) need independent age verification, since these taxa are typically thought to be Cenomanian restricted (Schroeder & Neumann, 1985; Sari et al., 2009; Frijia et al., 2015; Consorti et al., 2015; Simmons et al., 2020; Solak et al., 2020). Their extinction is linked to a major demise in carbonate platform biota around the Cenomanian/Turonian boundary (Philip & Airaud-Crumiere, 1991) relating to unfavourable oceanographic conditions associated with global Ocean Anoxic Event 2 (Parente et al., 2008).

In summary, much work needs to be undertaken to delineate the age ranges of many Cretaceous LBF occurring in the Zagros and other parts of the Middle East. Fortunately, studies are emerging that integrate LBF occurrences with ammonite occurrences and chemostratigraphic (stable isotope and strontium isotope) age calibration, providing encouragement that the biostratigraphic potential of the Cretaceous LBF occurrences can be fully realised. Parente et al. (2007) and Frijia et al. (2015) provide examples of this approach from another part of Neotethys.

Chemostratigraphic studies on the Cretaceous stratigraphy of the Zagros are becoming more commonplace (e.g., Piryaei et al., 2010; Hajkazemi et al. 2012; Navidtalab et al., 2019). Reports of mid-Cretaceous LBF in association with age diagnostic planktonic foraminifera from the Zagros succession (Afghah & Shaabanpiur Haghghi, 2014; Kiarostami et al., 2019; Bahrami et al., 2021) and carbon isotope data (e.g., Moosavizadeh et al., 2014) or strontium isotope data (e.g., Hosseini et al., 2016) are a welcome development, provided taxa are identified correctly (see Section 2.1).

2.5 Documentation

In all micropalaeontological studies, presentation of raw data is key. Clearly drawn range charts in which the occurrence of fossils are documented on a sample-by-sample basis are important (ideally alongside associated sedimentology, etc), as are illustrations of key fossils to provide confidence in the interpretations. As noted in Section 2.1, these should be of sufficient quality, orientation, and magnification to verify identity. Sample numbers relating to the image should always be provided. When dealing with subsurface material it is important to document the sample type being studied (Simmons, 2020). Core material has much more stratigraphic fidelity than material from cuttings.

By providing this data additional insights may be gleaned – for example, that certain taxa occur together (creating “assemblage zones”) or are associated with particular facies and palaeoenvironments.

CONCLUSIONS

The occurrences of LBF in the Cretaceous stratigraphy of the Zagros have great potential to enrich our knowledge of this fossil group - evolutionary trends, palaeobiogeography, biostratigraphy and palaeoecology. Moreover, their study can illuminate the depositional history of the stratigraphy of the rocks they occur in – age calibration, correlation, and relationships to global events. Biostratigraphy is important to building an understanding of palaeogeography, sequence stratigraphy, and the character of the subsurface. It thus needs to be built on sound foundations.

The following considerations (which can be applied to similar studies anywhere) are therefore important:

- The fossils need to be identified correctly and uncertainty in identification expressed. Not every specimen can be identified precisely.
- Up to date taxonomy needs to be used and introduction of inadequately described or unnecessary new taxa (i.e. synonyms of existing species) should be avoided
- Biozonation schemes created or employed should, ideally, have genuine value for correlation and be

based on the likely stratigraphic ranges of the fossils incorporated.

- Independent age calibration of the rocks LBF occur in should be sought and less reliance placed on older interpretations which lacked the benefits of modern age calibration methods.
- Fossil distribution data should be provided alongside unequivocal illustrations of key fossils.

As noted in the introduction, issues such as misidentification or inadequate illustration to confirm identify of orbitolinids and associated LBF are not confined to publications on the Zagros. Rahiminejad and Hassani (2016) in an otherwise thoughtful paper on the palaeoecology of orbitolinid-bearing sediments from the Early Cretaceous of Central Iran misidentify several taxa (e.g., “*Praechrysalidinina*”, “*Pseudolituonella*”, “*Ovalveolina crassa*”, “*Pseudocyclamina*”, “*Mesorbitolina parva*” and “*Simplorbitolina*”, or provide equivocal illustrations, for example, of “*Praeorbitolina cormyi*”. They also use archaic names (e.g., *Orbitolina discoidea*). The net result is adding confusion to the identity of certain taxa along with inappropriate range extensions. For example, *Ovalveolina crassa* is unlikely to occur in the Aptian, being no older than latest Albian (Schroeder and Neumann, 1985).

The advent of the internet means that key literature is no longer so hard to search for and obtain. Relevant modern studies are available to all. Moreover, many experts are willing to share their expertise. If nowhere else, expertise should be utilised in pre-publication reviews by journal editors. It goes without saying that studies that include micropalaeontology should be reviewed by at least one micropalaeontological expert and their reviews acted upon.

We encourage continued study of the micropalaeontology of the Zagros – there is much to be learnt from this geological wonderland.

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