OSTRACODS AS MARKERS OF THE
PERMIAN/TRIASSIC BOUNDARY IN THE KHUFF
FORMATION OF SAUDI ARABIA

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Abstract: Ostracods are described for the first time from Permian–Triassic shallow marine sediments of the Khuff Formation of central Saudi Arabia. They were collected using a modified acetolysis technique for releasing calcareous shells from limestones that is described herein. Thirty-four species belonging to 17 genera are recognized. Two new species are described: Arqoviella arabica sp. nov. and A. khartamensis sp. nov. The ostracod fauna supports a Late Permian age for the lower Khartam Member and a probable Early Triassic age for the upper Khartam Member of the Khuff Formation of central Saudi Arabia. This suggests that the Permian/Triassic boundary is located within the Khartam Member, rather than at the major lithological break between the Midhnab and Khartam members. Palaeoecological analysis suggests that the palaeoenvironment of the Khuff Formation was shallow marine (between 1 and 50 m deep) on an internal shelf.

Key words: Ostracods, Late Permian, Permian/Triassic boundary, Khuff Formation, Saudi Arabia, acetolysis.

At the end of the Permian it is estimated that 51 per cent of marine families, 82 per cent of marine genera and 96 per cent of marine species became extinct (Sepkoski 1992; Erwin 1993; Jablonski 1994). As with other marine organisms, the benthic ostracods were greatly affected by the end-Permian crisis, and an estimated 98 per cent of the ostracod species disappeared (Crasquin-Soleau et al. 2004). However, ostracods from the Permian/Triassic boundary interval are poorly known outside of South China. The only available data are from Guizhou Province, China (Wang 1978; Hao 1992, 1994), Western Australia (Jones 1970), Pakistan (Sohn 1970) and the western part of the Palaeo-Tethys, in Western Taurus (Turkey) (Crasquin-Soleau et al. 2002, 2004a, b). Ostracod faunas described herein from the Khuff Formation in Saudi Arabia, and particularly its lower Khartam Member, provide a new insight into ostracod faunas before the most dramatic biological event of the Phanerozoic.

GEOLOGICAL SETTING

The Permian–Triassic Khuff Formation crops out in central Saudi Arabia (Text-fig. 1) along a 1200-km-long, north–south trending, belt. The Khuff Formation always rests with major unconformity (‘the pre-Khuff unconformity’) on earliest Palaeozoic or older shield rocks (Powers et al. 1966; Powers 1968), and is conformably overlain by the Early Triassic (Scythian) Sudair Shale Formation. In northern central Saudi Arabia the Khuff Formation is divided into five members (Delfour et al. 1982; Vaslet et al. 1985; Manivit et al. 1986); from oldest to youngest these are: the Unayzah, Huqayl, Duhaysan, Midhnab and Khartam members (Text-fig. 2). Lithostratigraphy, biostratigraphy and palaeoenvironmental reconstructions of this Permian–Triassic unit have been summarized by Le Nindre et al. (1990a, b). More recent interpretations, in terms of sequence stratigraphy, have been proposed by Al-Aswad (1997) and Sharland et al. (2001).

The Unayzah Member (sensu Delfour et al. 1982) consists of terrigenous sediments and secondary clayey dolomite. Palaeoenvironments range from continental to transitional and supratidal. A flora has been described from the lower part, and rare benthic foraminifers occur in the upper part of this member. A possible Middle Permian age is proposed (Hill and El-Khayal 1983; El-Khayal and Wagner 1985; Vachard in Le Nindre et al. 1990a; Broutin et al. 1995).

The Huqayl Member is divided into two units containing calcarenite, gypsiferous claystone and solution breccias related to subsurface evaporites. It is a transgressive
The study of ostracod faunas presented here suggests a Late Permian rather than an Early Triassic age for the marine event located at the base of the lower Khartam Member. This is in agreement with the former interpretation of Le Nindre et al. (1990a, b), based upon benthic foraminifers. The Early Triassic depositional sequence may start with the littoral to tidal–intertidal deposits of the Duhaysan Member and ended with the regressive supratidal to continental deposits of the upper part of the Midhnab Member.

According to Sharland et al. (2001), MFS Tr10, defined as the basal part of the Khartam Member, is related to a depositional sequence that includes the entire Khartam Member and a part of the Early Triassic Sudair Shale Formation.

The Khartam Member is a marine carbonate sequence that is divided into two units. The lower Khartam Member consists of claystones, dolomites and sands deposited in supratidal to tidal environments. The upper Khartam Member consists of oolites, peloids and bioclastic dolomitized limestones representing littoral to tidal and intertidal environments. The lower Khartam Member has yielded rare benthic foraminifers, nautiloid embryos and abundant bactritids. The Early Triassic depositional sequence that includes the entire Khartam Member, is related to a depositional sequence corresponding to MFS P30 may include both the Unayzah and the Huqayl members.

MFS P30, defined in the subsurface, is tentatively correlated within the Huqayl Member at outcrop. It corresponds to the first Late Permian flooding event over the 'pre-Khuff unconformity', and is followed by the regressive evaporitic environments in the upper part of the Huqayl Member. The depositional sequence corresponding to MFS P30 may include both the Unayzah and the Huqayl members.

OSTRACOD PROCESSING

Fossil ostracods are studied on the basis of external and internal characters of the carapace, and have to be released from the enclosing matrix to allow observation of the carapace. Methods of ostracod isolation vary according to the nature of fossil-bearing sediments (e.g. lithology) and the mode of preservation of the fossils. Ostracods contained in soft sediments are easily released using classical mechanical or chemical methods (such as hydrogen peroxide or various acids) (see e.g. Grekoff 1956; Sohn 1961). Problems arise, however, when microfossils composed of calcium carbonate are preserved in hard, compact calcareous rocks (thus precluding acid disaggregation). Bourdon (1957) suggested the use of ‘crystallizable’ pure acetic acid (also called ‘glacial’ acetic acid) in the disaggregation of such rocks,
and later (Bourdon 1962) described this method, which he termed 'hot acetolysis'. Costa de Moura et al. (1999) published another method that utilizes hydrogen peroxide and dilute acid (HCl or CH₃COOH). However, this method was originally described for use on Upper Cretaceous and Palaeocene samples, and requires that the rock is powdered. Extensive crushing is not practical for hard compact rocks owing to the risks of fracturing the microfossils during powdering, particularly large Palaeozoic forms.

Over the last 20 years we have tested the method of Bourdon on thousands of Devonian–Triassic samples, and it has proved extremely successful in a modified form. An account in French was published by Lethiers and Crasquin-Soleau (1988). However, the method remains relatively unknown. This account provides us with the opportunity to present this seldom used method, which enables successful recovery from highly lithified rocks of ostracods varying from small (0.2 mm) to large (2–3 mm)
size, in addition to foraminifera, brachiopod larvae, ossicles, vertebrate elements and sometimes conodonts.

Processing method

There are four steps in the method.

1. Crushing (Text-fig. 3A). In order to increase the reaction surface 400–500 g of rock is reduced to pieces of several cm³. We observed that the best way is first to saw the samples and then to use a hammer to crush them. A mechanical press should be avoided because the stress can lead to breakage of the carapaces, particularly in large specimens. It is useful to surround the sample beforehand with paper to limit shard loss.

2. Dehydration (Text-fig. 3B). The crushed sample must be dried, and all the water within the sample removed, to avoid a later acid attack. To achieve this the sample is put into a heatproof glass receptacle and placed in a drier, a heating store or on a heated sand-bath for 48–72 h. The temperature should not exceed 100°C in order to avoid clay burning. Drying should be prolonged if the sample is initially very wet. Pyrex bottles are suitable, as are recycling glass pots from foodstuffs. The latter often have plastic or metallic caps which are useful for the next step.

3. Acetolysis (Text-fig. 3C). Wait until the sample has cooled down (30 min) to avoid breakage of the glass. The sample is then totally covered with pure acetic acid. *No effervescence should occur.* Effervescence is either a result of impure acid or incomplete drying. The pots should be closed, but not totally so as to let acid vapours escape. The life duration of caps (particularly metallic ones) can be prolonged by covering the opening of the pot with aluminium foil before closing. The pot is placed on a heating sand-bath at a temperature of 60–80°C, i.e. without reaching boiling. It is essential to proceed under an extractor hood because of acid vapours. After some time (varying from one day up to several weeks) a muddy deposit should form at the bottom of the jar. If this has not occurred after three weeks, it is necessary to proceed to the next step and then repeat the operation.

4. Settling and washing (Text-fig. 3D–E). When sufficient muddy deposit is present, i.e. without waiting for complete disaggregation, the excess acid is filtered off. The acid acquires a rust colour but can be re-used with the same efficiency. The samples are then washed. For ostracods a battery of three sieves is used: the 2-mm mesh retains undisaggregated sediment, the 0.5-mm mesh retains adults and large forms, and the 0.1-mm sieve retains small specimens and larvae. The washing should be quick and the samples rinsed out thoroughly to limit acid attack, which begins immediately.

**Text-fig. 3.** Diagrammatic illustration of the main steps of the modified acetolysis processing technique.
The operator should beware of the strong acid vapours that are released during sieving. The residues, collected in porcelain or Teflon cups, are dried on a sand-bath or in a heating-store. They are then ready for picking.

Advice and explanation of the method

Duration of acetolysis. Duration of acetolysis varies according to the microfacies. We observed durations from 12 h to three weeks. Marly limestones react very quickly. A sediment rich in clay may disintegrate in 12 h. In general we noted that the coarser the crystallinity of the cement the easier is the acetolysis, with a bio- or oosparite reacting quicker than a biomicrite.

Successive acetolyses. Generally we undertake two successive acetolyses on the same sample. The residue of the coarse mesh is returned to the drying step and the operation repeated. We observed that we generally obtained more specimens from the second than from the first acetolysis.

### TABLE 1. Stratigraphical distribution of ostracods in the Khuff Formation

<table>
<thead>
<tr>
<th>Khuff Formation</th>
<th>Permian</th>
<th>Triassic</th>
<th>Family or superfamily (see Text-fig. 4)</th>
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<td>Duhaysan Mbr</td>
<td>L. Midnab Mbr</td>
<td>Lower Khartam Member</td>
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<td>Bairdiacea</td>
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<td>Bairdia sp. 1</td>
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<td>Kloedenellacea</td>
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<td>Kloedenellacea</td>
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<td>Paraparchitacea</td>
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<tr>
<td>Langdaia cf. suboblonga Wang</td>
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<td>X</td>
<td>Kloedenellacea</td>
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</tbody>
</table>

Number of species | 8 | 1 | 4 | 12 | 10 | 4 | 1
Acid grade. The acetic acid should be ‘crystallizable pure’ (also called ‘glacial’), i.e. it is at least 95 per cent and crystallizes below 16°C. The use of very refined anhydrous products for chemical analysis is not recommended. These very expensive products often induce setting, i.e. the muddy deposit hardens into a compact block from which the fossils cannot easily be extracted.

Disaggregation mechanism. We do not understand exactly the mechanism by which pure acetic acid disaggregates the rock. It is probable that the acid attacks at a very fine scale, most likely at a thickness of several angstroms, at the boundary of crystals and particularly at the boundaries of the cement or element matrix. This phenomenon may be linked to the presence of a water film, which remains in spite of the drying phase, adsorbed on the surfaces. This infinitesimally small quantity of water might be necessary for initiating and maintaining the reaction.

OSTRACOD FAUNA

Productive samples

A total of 39 samples were processed using the method described above. Thirty-four samples are from a composite section (base 26°06’N, 43°58’E, top 25°57’N, 44°12’E) located in the Buraydah and Al-Faydah quadrangles of north-central Saudi Arabia. Twelve samples were productive (Table 1) but only six of them have sufficient preservation for analysis (02KH07, 11, 22, 23, 27, 29). Four samples are from Jal al Watah (26°28’N, 44°00’E) in the eastern part of the Buraydah quadrangle. Only sample Jalwa-1b yielded a significant ostracod fauna (Table 1). One sample is from the Ad Dawadimi quadrangle (24°43’N, 44°49’E), in the lower Khartam Member (02KH35).

The specimens recovered are mostly poorly preserved and deformed. Nevertheless, we recognized 37 species (of which two are new: Arqaviella arabica sp. nov. and A. khartamensis sp. nov.) belonging to 17 genera. The assemblage is similar to those described from Oman (Crasquin-Soleau et al. 1999) and Turkey (Crasquin-Soleau et al. 2002, 2004a, b), and is particularly closely related to those described from the Late Permian of Israel (Arqov Formation) by Gerry et al. (1987). Interestingly, these authors proposed a lithostratigraphical correlation between the Arqov Formation (Israel) and Khuff Formation (Saudi Arabia) (Gerry et al. 1987, p. 199).

Age of the samples studied

The lower part of the Khuff Formation (Unayzah and Huqayl members) did not yield an ostracod fauna, and the earliest ostracods are from the middle part of the Duhyasan Member (Sample 02KH07). The following stratigraphically useful ostracods are present in this sample. Sulcella sulcata Coryell and Sample was originally described from the Late Carboniferous of Texas, and subsequently reported from the Wordian of Tunisia (Lethiers et al. 1989) and the Wordian of the Khuff Formation of Oman (Crasquin-Soleau et al. 1999). ?Knoxiella infirma Shi was originally described from the Changhsingian of Hubei, South China (Chen and Shi 1982; Shi and Chen 1987) and has also been reported from the Late Permian of Tunisia (Said-Benzarti et al. 1998), and is particularly useful ostracods are present in this sample. Sulcella sulcata Coryell and Sample was originally described from the Late Carboniferous of Texas, and subsequently reported from the Wordian of Tunisia (Lethiers et al. 1989) and the Wordian of the Khuff Formation of Oman (Crasquin-Soleau et al. 1999).?Knoxiella infirma Shi was originally described from the Changhsingian of Hubei, South China (Chen and Shi 1982; Shi and Chen 1987) and has also been reported from the Late Permian of Tunisia (Said-Benzarti et al. 1998), and is particularly useful ostracods are present in this sample. Sulcella sulcata Coryell and Sample was originally described from the Late Carboniferous of Texas, and subsequently reported from the Wordian of Tunisia (Lethiers et al. 1989) and the Wordian of the Khuff Formation of Oman (Crasquin-Soleau et al. 1999).

EXPLANATION OF PLATE 1

Fig. 1. Shemonella sp. 1. Right lateral view, P6M1577, sample 02KH22, lower Khartam Member. Fig. 2. Shemonella sp. 2. Right lateral view, P6M1578, sample 02KH23, lower Khartam Member. Fig. 3. Knoxiella infirma Shi, 1982. Right lateral view, P6M1579, sample 02KH27, lower Khartam Member. Fig. 4. Paraparchites sp. 1. Right lateral view, P6M1580, sample 02KH23, lower Khartam Member. Fig. 5. Paraparchites sp. 2. Right lateral view, P6M1581, sample 02KH27, lower Khartam Member. Fig. 6. ?Knoxiella infirma Shi, 1982. Right lateral view, P6M1582, sample 02KH07, Duhyasan Member. Figs 7–8. Paraparchites sp. 3. 7, left lateral view, P6M1583, sample 02KH22, lower Khartam Member. 8, left lateral view, P6M1584, sample 02KH22, lower Khartam Member. Fig. 9. Knoxiella cf. oblonga Wang, 1978. Left lateral view, P6M1585, sample 02KH22, lower Khartam Member. Figs 10–14. Hollinella (H.) herrickana Girty, 1909. 10, right lateral view, P6M1586, sample 02KH22, lower Khartam Member. 11, right lateral view, P6M1587, sample 02KH11, Midhnab Member. 12, left lateral view, P6M1588, sample 02KH22, lower Khartam Member. 13, right lateral view, P6M1589, sample 02KH22, lower Khartam Member. 14, left lateral view, P6M1590, sample 02KH22, lower Khartam Member. Fig. 15. Hollinella sp. 2. Left lateral view, P6M1591, sample 02KH23, lower Khartam Member. All specimens from the Khuff Formation, Saudi Arabia. Scale bars represent 100 µm.
The following stratigraphically useful ostracod is present in the Lower Midhnab Member (sample 02KH11). *Hollinella herrickana* Girty has been reported from the USA (see synthesis in Bless and Jordan 1972), the Caucasus (Belousova 1965), Tunisia (Lethiers *et al.* 1989; Said-BenZarti and Crasquin-Soleau 1998) and Oman (Crasquin-Soleau *et al.* 1999). It has a stratigraphical range of Early Permian–Wordian.

A number of stratigraphically useful ostracods are present in the Lower Khartam Member (samples 02KH22, 23, 27). The presence of species of Paraparichitidae (*Paraparchites* *spp.*) and Kloedenellacea (*Knoxiella* and *Kloedenellitina*) suggests a Permian age. *Sulcella suprapermiana* Kozur, previously reported from Hungary, Oman and Greece, indicates a Wordian–Wuchiapingian age. *Arqoviella permiana* Gerry and Honigstein has been reported from the Upper Permian (Wuchiapingian) of Israel. *Knoxiella infirma* Shi is reported from South China and suggests a Late Permian age (Chen and Shi 1982).

In summary, based on the ostracod fauna, the lower Khartam Member is most likely to be of Late Permian age. Only one productive sample was recovered from the Upper Khartam Member (Sample 02KH29), and this contains only one species (*Langdaia cf. suboblonga* Wang), close to the species described by Wang (1978) from the Lower Triassic of South China. This suggests that the Upper Khartam Member may also be of Triassic age. Thus the Permian/Triassic boundary is most likely located between the Lower and Upper Khartam members.

**SYSTEMATIC PALAEONTOLOGY**

All the specimens figured are stored in the collection of the Micropaleontology Laboratory of Pierre et Marie Curie University (Paris); collection numbers P6M. Only newly erected species are described.

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**EXPLANATION OF PLATE 2**

Figs 1–7. *Sargentina transita* Kozur, 1981. All specimens from sample 02KH07, Duhaysan Member. 1, right lateral view, P6M1592. 2, left lateral view, P6M1593. 3, dorsal view, P6M1594. 4, left lateral view, P6M1595. 5, left lateral view, P6M1596. 6, left lateral view, P6M1597. 7, left lateral view, P6M1598. 8. *Sargentina* sp. 2. Right lateral view, P6M1599, sample 02KH07, Duhaysan Member.

Figs 9–12. *Kloedenellitina* sp. 1. All specimens from lower Khartam Member. 9, right lateral view, P6M2089, sample 02KH22. 10, right lateral view, P6M2090, sample 02KH27. 11, dorsal view, P6M2091, sample 02KH27. 12, dorsal view, P6M2092, sample 02KH27.

Figs 13–14. *Haworthinae* sp. 1. Lower Khartam Member. 13, dorsal view, P6M2093, sample 02KH22. 14, left lateral view, P6M2094, sample 02KH22.

Figs 15. *Fabalicypris* sp. Right lateral view, P6M2095, sample 02KH22, lower Khartam Member.

Fig. 16. *Spinocypris* sp. Right lateral view, P6M2096, sample 02KH22, lower Khartam Member. All specimens from the Khuff Formation, Saudi Arabia. Scale bars represent 100 μm.
CRASQUIN-SOLEAU et al., Permo-Triassic ostracods
Remarks. We consider the presence of reticulate ornament to be a generic rather than specific characteristic (see above). Therefore, we emend the specific diagnosis of *A. permiana* to exclude ornament details.

**Argoviella arabica** sp. nov. Crasquin-Soleau
Plate 4, figures 1–3

*Derivation of name.* After Saudi Arabia where the type locality is located.

*Types.* Holotype: one complete carapace (Pl. 4, fig. 1), collection number P6M2114; paratype: one complete carapace (Pl. 4, fig. 2), P6M2115.

*Material.* Two complete carapaces, five isolated valves and numerous fragments.

*Type horizon.* Sample Jalwa-1b; lower Khartam Member, Jal al Watah (26°28′N, 44°00′E), Buraydah quadrangle, Saudi Arabia; Late Permian.

*Diagnosis.* A species of *Arqoviella* Gerry and Honigstein, 1987 with dorsal border strongly arched in median part.

*Description.* Carapace of medium size; anterior border regularly arched with maximum curvature at mid-height; ventral border straight to gently convex; posterior border with small radius of curvature; dorsal border nearly straight in anterior and posterior parts, strongly arched in central part, sticking out the hinge line; left valve larger than right; the reticulated part of the ornamentation located in antero-median part of the carapace. Dimensions: length, 0.69–0.79 mm; height, 0.41–0.50 mm.

*Remarks.* *A. arabica* sp. nov. differs from *A. permiana* Gerry and Honigstein, 1987 because of its arched dorsal border.

**Distribution.** Upper Permian of Saudi Arabia.

**Argoviella khartamensis** sp. nov. Crasquin-Soleau
Plate 4, figures 4–5

*Derivation of name.* After Jal al Khartam, the type-locality for the Khartam Member of the Khuff Formation.

*Types.* Holotype, one complete carapace (Pl. 4, fig. 4), collection number P6M2117; paratype, one complete carapace (Pl. 4, fig. 5), P6M2118.

*Material.* Five complete carapaces, ten isolated valves and numerous fragments.

*Type horizon.* Sample 02KH23; Lower Khartam Member, Jal al Khartam (25°57′N, 44°12′E), Al Faydah quadrangle, Saudi Arabia; Late Permian.

*Diagnosis.* A species of *Arqoviella* Gerry and Honigstein, 1987 with an elongated carapace (0.43 < H/L < 0.51).

*Description.* Long carapace with low ratio H/L; anterior border regularly arched with small radius of curvature; ventral border long and gently convex; posterior border with small radius of curvature (very small for larva stages and more or less equivalent to anterior border in adult stages); dorsal border nearly straight to gently convex; left valve larger than right, with maximum of overlapping at anterior and posterior borders; the reticulated part of the ornamentation located in antero-median part of the carapace. Length, 0.41–1.03 mm; height, 0.21–0.55 mm.

*Remarks.* *A. khartamensis* sp. nov. differs from other species of the genus because of its elongate carapace.

*Distribution.* Upper Permian of Saudi Arabia.

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**EXPLANATION OF PLATE 3**

Fig. 1. *Cavellina cf. rotunda* Cooper, 1946 sensu Shi and Chen, 1987. Right lateral view, P6M2131, sample Jalwa1b, lower Khartam Member.

Figs 2–3. *Sulcella* sp. Sample 02KH23, lower Khartam Member. 2, right lateral view, P6M2097. 3, left lateral view, P6M2098.

Fig. 4. *Sulcella sulcata* Coryell and Sample, 1935. Right lateral view, P6M2099, sample 02KH07, Duhashan Member.

Figs 5–6. *Haworthina?* sp. 3. Sample 02KH22, lower Khartam Member. 5, left lateral view, P6M2100. 6, left lateral view, P6M2101.

Figs 7–12. *Haworthina?* sp. 2. Sample 02KH22, lower Khartam Member. 7, right lateral view, P6M2102. 8, right lateral view, P6M2103. 9, right lateral view, P6M2104. 10, right lateral view, P6M2105. 11, left lateral view, P6M2106. 12, right lateral view, P6M2107.

Figs 13–15. *Haworthina?* sp. 4. Sample 02KH22, lower Khartam Member. 13, right lateral view, P6M2108. 14, right lateral view, P6M2109. 15, right lateral view, P6M2110.

Fig. 16. *Acratia?* sp. 2. Right lateral view, P6M2111, sample 02KH22, lower Khartam Member.

Fig. 17. *Bairdiacypris* sp. 1. Right lateral view, P6M2112, sample 02KH22, lower Khartam Member.

Fig. 18. *Bairdia* sp. 1. Right lateral view, P6M2113, sample 02KH22, lower Khartam Member.

All specimens from the Khuff Formation, Saudi Arabia. Scale bars represent 100 μm.
CRASQUIN-SOLEAU et al., Permo-Triassic ostracods
PALAEOENVIRONMENTAL SETTING

General comments

The palaeoecology of ostracod families and/or superfamilies is now relatively well known because of studies on the relationships between facies and fauna, analysis of functional morphology and present-day comparisons. For the Late Palaeozoic, such work has been undertaken by, among others, Peterson and Kaesler (1980), Babinot and Lethiers (1984), Crasquin (1984), Costenzo and Kaesler (1987) and Melnyk and Maddocks (1988). Thus, based on the ostracod fauna, palaeoecological interpretation of the Khuff Formation may be attempted.

Based on the work of the above-mentioned authors, we summarize here the main characteristics of the ostracod families and superfamilies recovered from the Khuff Formation. An initial observation is that all of the ostracod genera encountered are known to be benthic, shallow-marine forms. The Bairdiacea are present in shallow to deep, open carbonate environments with normal salinity. The Cavellinidae appear to be ubiquitous: the large, robust cavellinids seem to be adapted to nearshore environments, whereas the smaller forms are found slightly further offshore. The Kloedenellacea are inhabitants of very shallow, euryhaline environments. The Paraparchitidae are fundamentally marine inhabitants, although some species show tolerance to brackish environments or even hypersalinity; this group is absent in the external parts of the platform. The large species of Hollinacea with developed adventral structures can characterize environments such as interdistributary bays, prodelta and interdeltaic embayments, and lagoons.

All the ostracods reported from the Khuff Formation are typical of warm waters of the intertropical zone, as are those from the Middle–Late Permian faunas of the Khuff Formation in Oman (Crasquin-Soleau et al. 1999), the Arqov Formation in Israel (Gerry et al. 1987) and the Bükk Mountains in Hungary (Kozur 1985). It is also important to note the relatively low diversity of the assemblages per sample. It is now well known that diversity is lower in brackish, marginal marine environments than in open-sea environments (see Whatley 1983).

Some taphonomic characteristics are of interest. The majority of the specimens are represented by closed carapaces. This indicates limited transportation, a soft substratum and a relatively high rate of sedimentation (Oertli 1971). The species are present generally only as adults or the final larval stage. Following Whatley (1983, 1988) and Brouwers (1988), this indicates a high energy biocoenosis or thanatocoenosis.

From all these observations, we can deduce that the Late Permian palaeoenvironment of the Khuff Formation was shallow marine (between 1 and 50 m deep) located on an internal shelf. The ostracods inhabited a soft substratum under a high rate of sedimentation.

Detailed observations

In the depositional sequence corresponding to the MFS P30, ostracods have not been found. This lack of fauna is attributed to two reasons. Firstly, the evaporitic environments that prevail in the Unayzah and Huqayl members would not have been favourable for the development of life in general, even if ostracods could withstand a high salinity. Secondly, there is a high level of recrystallization in dolomites, which is likely to have destroyed any enclosed ostracod carapaces.

The older ostracods recovered are from the subtidal limestones of the Duhaysan and Midhnab members. These are related to the marine flooding event of the depositional sequence corresponding to MFS P40, and are attributed to the Late Permian according to foraminiferal data (Vachard in Le Nindre et al. 1990a).

Sample 02KH07 (Duhaysan Member) yielded an ostracod assemblage containing the highest percentage of Bairdiacea (44-45% observed in the Khuff Formation (Text-fig. 4). This could be linked to the marine flooding event of MFS P40. The other components of the assemblage (Kloedenellacea, Hollinacea and Cavellinidae; 55-59%) are adapted to euryhaline shallow marine environments.

EXPLANATION OF PLATE 4

Figs 1–3. Arqoviella arabica sp. nov. Sample Jalwa1b. 1, holotype, left lateral view, P6M2114. 2, paratype, left lateral view, P6M2115. 3, left lateral view, P6M2116.

Figs 4–6. Arqoviella khartamensis sp. nov. Sample 02KH23. 4, left lateral view, P6M2117. 5, left lateral view, P6M2118. 6, right lateral view, P6M2119.

Figs 7–16. Arqoviella permiana Gerry and Honigstein, 1987. Sample 02KH23. 7, left lateral view, P6M2120. 8, right lateral view, P6M2121. 9, right lateral view, P6M2122. 10, dorsal view, P6M2123. 11, right lateral view, P6M2124. 12, left lateral view, P6M2125. 13, right lateral view, P6M2126. 14, right lateral view, P6M2127. 15, dorsal view, P6M2128. 16, right lateral view, P6M2129.

Fig. 17. Arqoviella sp. 4. Left lateral view, P6M2130, sample 02KH23.

All specimens from the Khuff Formation, lower Khartam Member, Saudi Arabia. Scale bars represent 100 μm.
CRASQUIN-SOLEAU et al., Arqoviella
Hence, we consider that the depositional environment was located in a subtidal zone, below wave base. Sample 02KH11 (lower Midhnab Member) yielded only one species (*Hollinella herrickana*), which suggests a very shallow, restricted, brackish environment: littoral to brackish zone.

An abundant ostracod fauna is related to the clayey calcareous subtidal environment of the marine episode (MFS Tr10) of the lower Khartam Member. Sample Jalwa 1b is located in the dolomites at the base of the member, just above the continental deposits of the upper Midhnab Member. The assemblage is composed mainly of Cavellinidae, which are ubiquitous in marine environments, and clearly indicate the arrival of the marine transgression. In sample 02KH22 the assemblage is at its most diverse, with dominant Bairdiacea, Paraparchitidae and Cypridacea. The abundance and diversity of specimens indicates more favourable conditions for life, in a deeper and higher energy environment than previously. The environment is interpreted as subtidal, with conditions of life less favourable than previously.

Sample 02KH29 (upper Khartam Member) contains only shallow marine inhabitants indicative of salinity variations. The environment is interpreted as intertidal.

The ostracod faunas in the lower Khartam Member reflect the transgressive sequence, with maximum water depth at the level of sample 02KH22. This is followed by shallowing from sample 02KH23 up to the break with the upper Khartam Member.

**CONCLUSIONS**

Ostracods are described for the first time from the Permian Khuff Formation of central Saudi Arabia. Although only a small number of samples were productive, it is an important step towards understanding the ostracod fauna of the Khuff Formation, and enables palaeoenvironmental interpretation. The facies are not favourable for ostracod preservation (gypsiferous and dolomitic claystone, dolomite and evaporitic facies). However, a modified acetolysis technique described herein enabled recovery of relatively well-preserved ostracods. The ostracod fauna supports the location of the Permian/Triassic boundary.
between the Lower and Upper Khartam members of the Khuff Formation and not, as previously suggested, between the Midhnab and Khartam members where lithological and sequence stratigraphical breaks occur. A similar feature was observed in the Western Taurus (Crasquin-Soleau et al. 2002, 2004a, b). Here the lowest level of the Early Triassic sediments contain survival forms belonging to the Kloedenellacea, a long-ranging group considered until very recently to have become extinct at the end of the Palaeozoic. The central Arabian Plate data confirm the survival of palaeocopids through the Permian/Triassic boundary. We also confirm the absence of nanism in ostracod faunas at the end of Permian (although it is observed in other groups such as foraminifera). This indicates that the palaeoenvironment is not stressed, at least up to the lower Midhnab Member. We have a gap in the ostracod record in the upper levels of the Midhnab Member, and the data obtained from the supposed Early Triassic Khartam Member are so far insufficient to discuss the processes of extinction and re-conquest after of the end-Permian mass-extinction.

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