Ostracods of the Permian-Triassic Khuff Formation, Saudi Arabia: palaeoecology and palaeobiogeography

Sylvie Crasquin-Soleau, Denis Vaslet and Yves-Michel Le Nindre

ABSTRACT

Ostracods were recovered for the first time from outcrops of the Permian-Triassic Khuff Formation in central Saudi Arabia. The fauna is exceptional in that the Khuff lithofacies were not considered favourable for their development and preservation. This ostracod fauna positions the Triassic-Permian Boundary between the Lower and Upper Khartam members of the Khuff Formation. The palaeoecological analysis shows that the Saudi Arabian Permian ostracods are typical of a shallow, intertropical, warm-water setting. The evolution of the ostracods is directly linked with variations of sea level, and particularly the two Late Permian maximum flooding events: (1) at the base of the Midhnab Member (MFI PKm), and (2) within the Lower Khartam Member (MFI PKk). Some of the species discovered in the Saudi Arabian outcrops are known from other countries. The provincialism index (PI) was used to establish the palaeobiogeographic relationships between different Palaeo-Tethyan areas. A schematic model of oceanic currents is proposed to explain the spreading of species.

INTRODUCTION

Permian to Triassic sedimentary rocks of the Khuff Formation are exposed in central Saudi Arabia along a North-South belt, some 1,200 km long (Figure 1). The Khuff Formation rests everywhere unconformably (Pre-Khuff Unconformity - PKU) over Lower Palaeozoic or Proterozoic shield rocks (Powers et al., 1966; Powers, 1968). The Khuff Formation is conformably overlain by the clayey and evaporitic Lower Triassic (‘Scythian’) Sudair Shale Formation. Le Nindre et al. (1990a, b) published the first synthesis of field work and extensive systematic geological mapping, conducted in the 1980s by the Saudi Arabian Deputy Ministry of Mineral Resources (DMMR) and the French Geological Survey (BRGM), including lithostratigraphy, biostratigraphy and palaeoenvironmental reconstructions. More recent compilations from central Saudi Arabia, were interpreted in terms of sequence stratigraphy by Alsharhan and Nairn (1995), Al-Aswad (1997) and Sharland et al. (2001). A complete revision, including new field acquisitions, and compilation of local studies for oil exploration (Senalp and Al-Duaiji, 1995, 2001), was prepared by Vaslet et al. (2005). It includes a reassessment of the biostratigraphy based on foraminifers and algae (Vachard et al., 2002, 2003, 2005), ostracods (Crasquin-Soleau et al., 2004a,b 2005, this paper) and palaeofloras (Broutin et al., 2002; Berthelin et al., 2006). Vaslet et al. (2005) divided the central Saudi Arabian outcrops of the Khuff Formation (some 200 m thick) into five members, from oldest to youngest: Ash Shiqqah, Huqayl, Duhaysan, Midhnab and Khartam members (Figure 2).

Ostracod fauna from the Khuff Formation was first recorded by Le Nindre et al. (1990b), and mentioned by Al-Aswad (1997). The study of ostracod tests in thin sections, however, did not allow their specific identification. More recently, in 2002, a systematic field study for ostracod research was conducted by D. Vaslet and Y.-M. Le Nindre. It involved sampling ostracod fauna from the base to the top of the Khuff Formation in central Saudi Arabian outcrops. These samples were processed and the extracted fauna was analysed by S. Crasquin-Soleau. The aim of this paper is to build a precise biostratigraphy and systematically describe, for the first time, the ostracod fauna of the Khuff Formation in Saudi Arabia. The paper also presents our interpretations of the palaeoecologic and palaeogeographic settings implied by the ostracod fauna.
Figure 1: Simplified Khuff Formation outcrop, central Saudi Arabia (modified after Vaslet et al., 2005). A total of 39 samples were collected by D. Vaslet and Y.-M. Le Nindre for this study; 34 samples from the vicinity of Unayzah town, 4 samples from Jal al Watah located between Buraydah town and Ash Shiqqah, and one sample from the south of Khuff town. In Figure 2 the stratigraphic positions of the 34 samples collected near Unayzah town are shown relative to the type section of the Khuff Formation in the Ad Dawadimi quadrangle.
LITHOSTRATIGRAPHY, BIOSTRATIGRAPHY AND SEQUENCE STRATIGRAPHY OF THE KHUFF FORMATION

The Ash Shiqqah Member (Senalp and Al-Duaiji, 1995, 2001) (nearly equivalent to the obsolete Unayzah member of the Khuff Formation of Delfour et al., 1982) consists of terrigenous sediments with secondary clayey dolomite and local evaporite in the upper part of the unit. The palaeoenvironments range from transitional to continental and supratidal. The Unayzah Flora (Hill and El-Khayal, 1983; El-Khayal and Wagner, 1985; Broutin et al., 1995), formerly described in the lower part of the Khuff Formation, is now attributed to the underlying Unayzah Formation (Vaslet et al., 2005). Rare benthic smaller foraminifers occur locally in the upper part of the Ash Shiqqah Member, indicating a possible Middle Permian Capitanian (late Midian) age for this lowest unit of the Khuff Formation (Vachard et al., 2002; Vaslet et al., 2005).

The Huqayl Member is subdivided into two sequential units containing calcarenite, gypsiferous claystone, dolomite, and solution breccias related to subsurface evaporites. This marine transgressive unit is tentatively assigned a Late Permian ?Wuchiapingian (Dzhulfian) age according to its benthic foraminiferal content (Vachard et al., 2002, 2005; Vaslet et al., 2005). The Duhaysan Member is the first true calcareous subtidal to littoral unit of the Khuff Formation (Le Nindre et al., 1990b), and is interpreted as the transgressive unit of the overlying Midhnab Member (Vaslet et al., 2005). The Duhaysan Member has yielded benthic foraminifers, gastropods and abundant bacritids. A Late Permian Wuchiapingian to Changhsingian age is tentatively assigned to the Duhaysan Member (Vaslet et al., 2005).

The Midhnab Member displays a succession ranging from marine fossiliferous limestones at the base, toward gypsiferous and dolomitic rocks deposited in restricted palaeoenvironments, in the upper part. The lower part of the Midhnab Member is dated by benthic foraminifers as Late Permian Changhsingian (Dorashamian) by Vachard et al. (2002, 2005). Locally, in northern central Saudi Arabia, the topmost part of the Midhnab Member presents continental facies including lacustrine limestone, sandstone channels and claystone in meandering river systems and swamps. These facies contain drifted wood and plant remains (Hill and El-Khayal, 1983; Vaslet et al., 1985; Le Nindre et al., 1990b; Vaslet et al., 2005). Recent descriptions of the Midhnab Flora indicate a Late Permian mixed flora including Cathaysian, Euramerican and Gondwanan plant remains (Broutin et al., 1995, 2002; Berthelin, 2002; Berthelin et al., 2006).

The Khartam Member, the uppermost mainly carbonate unit of the Khuff Formation, is subdivided into two marine units characterised by littoral to tidal and intertidal palaeoenvironments. The Lower Khartam Member consists of claystone, dolomite and sands, deposited in supratidal to tidal palaeoenvironments. The Upper Khartam Member is an oolitic, peloidal and bioclastic limestone, locally dolomitised, deposited in littoral to tidal and intertidal palaeoenvironments. The Lower Khartam Member yielded rare benthic foraminifers possibly dated as late Late Permian (late Changhsingian) by Vachard et al. (2002, 2005), while the Upper Khartam Member, consisting principally of reworked Dasycladacean algae ooids, is characterised by the appearance of *Spirorbis phylactea*na Brönniman and Zaninetti, a serpulid that is particularly abundant in the Early Triassic rocks in Neo-Tethyan areas.

According to Vaslet et al. (2005), the Khuff Formation consists of four main depositional sequences (DS PKh, DS PKm, DS PKk and DS TrS, see Figure 2). The last depositional sequence starts with the Khuff Formation and continues in the overlying Sudair Shale Formation. The DS PKh (named after Permian-Khuff-Huqayl) includes the Ash Shiqqah and the Huqayl members. Its basal sequence boundary (SB) corresponds to the Pre-Khuff Unconformity (PKU) and it contains the maximum flooding interval MFI PKh that represents the first Late Permian flooding event over central Saudi Arabian outcrop areas. This flooding interval is located in the basal part of the Huqayl Member and is followed by the regressive evaporitic palaeoenvironments of the Huqayl Member (Le Nindre et al., 1990b; Vaslet et al., 2005).

The DS PKm (named after Permian-Khuff-Midhnab) started with the deposition of subtidal to littoral Duhaysan Member above an erosive surface at the top of DS PKh, and ended with the regressive
## Local Stratigraphy

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<th>Early</th>
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<th>Littoral</th>
<th>Restricted Continental Lagoonal</th>
<th>Salt Marsh</th>
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### Environment

- Intertidal
- Littoral
- Sub- to intertidal
- Restricted Continental Lagoonal
- Salt Marsh

### Sequence Stratigraphy and Marine Influence

- High Relative Sea Level
- Low Relative Sea Level

- DS TrS
- DS PKk
- MFI PKk
- DS PKm
- MFI PKm
- DS PKh
- MFI PKh

**Figure 2:** Section of Khuff Formation in northern central Saudi Arabia, Ad Dawadimi quadrangle (modified after Vaslet et al., 2005) showing stratigraphic positions of ostracod samples.
supratidal to continental deposits of the upper part of the Midnab Member. A maximum flooding interval (MFI PKm) is clearly located in the outcrops at the base of the Midnab Member, with abundant marine fauna including cephalopods, brachiopods (Vaslet et al., 2005; Angiolini et al., 2006; Chirat et al., 2006) associated with the ostracod fauna (Crasquin-Soleau et al., 2005).

The DS PKk corresponds to the Lower Khartam Member (Permian-Khuff-Khartam), and represents the terminal Late Permian Depositional Sequence in the outcrops of central Saudi Arabia. The basal SB is marked by a return to marine subtidal conditions after the continental break at the end of DS PKm. It contains a maximum flooding interval (MFI PKk) that contains the remains of marine fauna, including abundant Permian ostracods (Crasquin-Soleau et al., 2005, this paper), bactritids and locally cephalopods (Chirat et al., 2006).

Table 1: Stratigraphic distribution of ostracods in the Khuff Formation.

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<th>Family or Superfamily</th>
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Number of Species 8 1 4 12 10 4 1
The DS TrS (named after the Sudair Shale Formation) starts with the littoral, tidal to intertidal deposits of the Early Triassic Upper Khartam Member of the Khuff Formation, and ends with the closed-basin, clayey to evaporitic rocks of the Lower Triassic Sudair Shale Formation (Le Nindre et al., 1990b; Vaslet et al., 2005).

**OSTRACOD FAUNA OF THE KHUFF FORMATION**

A total of thirty-nine samples were processed using the method described in Crasquin-Soleau et al. (2005). Thirty-four samples were collected from a composite section (base 26°06'N, 43°58'E, top 25°57'N, 44°12'E) located in the Buraydah and in the Al-Faydah quadrangles of northern central Saudi Arabia, where twelve samples gave fauna (Table 1). Six samples yielded ostracods (02KH07, 02KH11, 02KH22, 02KH23, 02KH27 and 02KH29). Another set of four samples came from Jal al Watah (26°28'N, 44°00'E) in the eastern part of the Buraydah quadrangle, from which the sample Jalwa-1b yielded significant ostracod fauna (Table 1). A single sample was taken from the Lower Khartam Member (02KH35) in the Ad Dawadimi quadrangle (24°43'N, 44°49'E).

In most cases, the specimens are often poorly preserved and deformed. Nevertheless, we recognised 37 species (two of which are new: *Arqoviella arabica* Crasquin-Soleau, 2004; and *Arqoviella khartamensis* Crasquin-Soleau, 2004) belonging to 17 genera (Table 1; Crasquin-Soleau et al., 2005).

The fauna of the Khuff Formation is similar to that of Oman (Crasquin-Soleau et al., 1999; Crasquin-Soleau, 2003; Angiolini et al., 2004) and Turkey (Crasquin-Soleau et al., 2002, 2004a,b). It is also very closely related to the Upper Permian ostracods from Negev (boreholes in Arqov Formation; Gerry et al., 1987). Due to their lithological similarity, Gerry et al. (1987, p. 199) proposed a correlation between the Arqov and Khuff formations.

**AGE OF STUDIED SAMPLES**

The lower part of the Khuff Formation (Ash Shiqqah and Huqayl members) did not yield ostracods. The oldest ostracods were found in the middle part of the Duhaysan Member (sample 02KH07, Figure 2). *Sulcella sulcata* Coryell & Sample (1932; Late Carboniferous of Texas) was also discovered in the Wordian of Tunisia (Lethiers et al., 1989), in Hungary (Kozur, 1985) and in the Khuff Formation of Oman (Wordian, Crasquin-Soleau et al., 1999) (Plate 5.10). ?*Knoxiella insfra* (Plate 3.9) described by Shi in the Changhsingian of Hubei (South China; Chen and Shi, 1982; Shi and Chen, 1987) is also present in the late Wordian of Tunisia (Said-Benzarti and Crasquin-Soleau, 1998, pl. 1, fig. 17, as "Shemonella aff. dutroi") and gives a late Middle to Late Permian age. *Sargentina transita* (Kozur) (Plates 4.1–4.7), from the late Middle Permian of the Bükk Mountains (Hungary; Kozur, 1981, 1985), was also recognised by Gerry et al. (1987) in the Late Permian of Negev, and by Crasquin-Soleau et al. (1999) in the Wordian of Oman.

In the Lower Midhnab Member (sample 02KH11, Figure 2), *Hollinella herrickana* (Girty) (Plates 4.8–4.12) described in the USA (see synthesis in Bress and Jordan, 1972), Caucasus (Belousova, 1965), Tunisia (Lethiers et al., 1989; Said-Benzarti and Crasquin-Soleau, 1998) and Oman (Crasquin-Soleau et al., 1999) has a stratigraphic range from Early Permian to Wordian.

In the Lower Khartam Member (samples 02KH22, 02KH23, 02KH27, Figure 2), the presence of Paraparchitidae (*Paraparchites* spp.) (Plates 3.1–3.4) and Kloedenellacea species belonging to *Knoxiella* and *Kloedenellitina* suggests a Permian age. *Sulcella suprapermiana* Kozur (Hungary; Kozur, 1985; Oman, Crasquin-Soleau et al., 1999; Negev, Gerry et al., 1987 and Greece, Crasquin-Soleau and Baud, 1998) indicates a Wordian-Wuchiapingian age. *Arqoviella permiana* Gerry and Honigstein (Plates 7.7–7.9) was described in the Late Permian (Wuchiapingian) of Negev (Gerry and Honigstein, 1987). *Sulcella insfra* Shi (Plate 3.8) suggests a Late Permian age (South China, Chen and Shi, 1982). Therefore, according to the ostracod fauna, the Lower Khartam Member is Late Permian in age.

In the Upper Khartam Member (sample 02KH29, Figure 2), only one species (*Langdaia cf. suboblonga* Wang) is similar to the species described by Wang (1978) in the Early Triassic of South China. Therefore, the Triassic-Permian Boundary is located between the Lower and the Upper Khartam members (Figure 3).
The palaeoecological requirements of families and/or superfamilies are relatively well known due to the studies of the relationships between facies and fauna, the analysis of functional morphology and to comparisons with modern fauna. For the Late Palaeozoic, publications on this subject include: Peterson and Kaesler (1980), Babinot and Lethiers (1984). Crasquin (1984), Costanzo and Kaesler (1987) and Melnyk and Maddocks (1988). The palaeoecological interpretations for the benthic and shallow-marine ostracod genera of the Khuff Formation is based on the studies of these authors (Figure 4).

The Bairdiacea represent shallow to deep, open-marine carbonate environments with normal salinity. The Cavellinidae appear to have been ubiquitous. The large, robust cavellinids seem to have adapted to nearshore environments, while the smaller forms lived slightly further offshore. The Kloedenellacea inhabited very shallow, euryhaline environments. The Paraparchitidae were fundamentally marine inhabitants, though some species showed tolerance to brackish environments or even hypersalinity;

![Figure 3: Stratigraphic occurrence of ostracod markers in the five Khuff members, in relation to Algae, Foraminifera and Cyanobacteria markers.](image-url)
this group is absent in the external parts of the platform. The large species of Hollinacea (with developed adventral structures) could characterise environments such as interdistributary bays, prodelta and interdeltaic embayments and lagoons.

All the ostracods of the Khuff Formation that are reported here, are typical of the warm waters of the intertropical zone. They are similar to those found in the Middle-Late Permian of the Khuff Formation in Oman (Crasquin-Soleau et al., 1999), the Arqov Formation in Negev (Gerry et al., 1987) and the Bükk Mountains in Hungary (Kozur, 1985).

Some taphonomic characters can be added. Except for sample 02KH27, almost all 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 generally represented only by adults and the last larval stage. Following Whatley (1983, 1988) and Brouwers (1988), these observations indicate a high-energy biocoenosis or thanatocoenosis. It is also important to note the relatively low
Ostracods of the Permian-Triassic Khuff Formation, Saudi Arabia

The diversity of the assemblages per sample; diversity is lower in brackish, marginal-marine environments than in the open sea (see Whatley, 1983). These observations imply that the Late Permian environment of the Khuff Formation was a shallow-marine internal shelf (between one and 50 m deep), and that the species lived on a soft substratum under a high rate of sedimentation.

In Depositional Sequence DS PKh (Ash Shiqqah and Huqayl members) ostracods are absent. This may be due to the evaporitic environments that prevailed during the deposition of DS PKh. The high salinity concentration associated with these environments is not generally favourable for the development of life. Even if ostracods did prevail in this hostile environment, the high level of recrystallisation in dolomites would have minimised the likelihood of their preservation.

The oldest ostracods discovered in the Khuff Formation occur within the subtidal limestones of the Duhaysan and Midhnab members. They are concentrated in the marine flooding interval MFI PKm, and attributed a Late Permian age based on foraminifers (Vachard et al., 2003, 2005; Vaslet et al., 2005). In the sample 02KH07 (Duhaysan Member; Figure 5), the ostracod assemblage shows the highest percentage of Bairdiacea (44.4%) in the Khuff Formation. This could be related to the flooding event represented by MFI PKm. The other components of the assemblage (Kloedenellacea, Hollinacea and Cavellinidae, 55.5%) were adapted to euryhaline shallow-marine environments. Hence, the depositional environment of MFI PKm was subtidal and below wave base. The sample 02KH11 (Lower Midhnab Member; Figure 5) yielded only one species (Hollinella herrickana), which suggests a very shallow, restricted, brackish environment (littoral to brackish).

An abundant ostracod fauna is related to the marine flooding interval MFI PKk (Figure 2) located in the clayey calcareous subtidal palaeoenvironments of the Lower Khartam Member. Sample Jalwa-1b was taken from the basal dolomites of the marine Khartam Member - just above the continental deposits of the Upper Midhnab Member (characterised by their exceptional flora, Broutin et al., 2002; Berthelin, 2002, 2006). The assemblage is mainly composed of Cavellinidae, which are ubiquitous in clearly marine environments and represent a transgression.

Figure 5: Distribution of ostracod families and superfamilies in the samples of the Khuff Formation. The six samples (Duhaysan: 02KH07; lower Midhnab: 02KH11; Lower Khartam: 02KH22, 02KH23 and 02KH27; and Upper Khartam: 02KH29) are located in the Buraydah and in the Al-Faydah quadrangles (Figures 1 and 2) of northern central Saudi Arabia. Sample Lower Khartam Jalwa-1b is located in the eastern part of the Buraydah quadrangle (Figure 1).
The assemblage in Lower Khartam sample 02KH22 is the most diversified, with dominant Bairdiacea, Paraparchitidae and Cypridacea. It indicates more stable living conditions, a deeper-water environment, higher energy, and more favourable conditions for life (high specific diversity and numerous specimens), i.e. a deep subtidal zone.

Lower Khartam Sample 02KH23 contains a mixture of Paraparchitidae, Cavellinidae and Cytherissinellidae. The habitat of the Cytherissinellidae family is not known, but its association with the other two families suggests that it could have inhabited shallow-water zones: a subtidal environment with favourable conditions (as indicated by the relatively high specific diversity and numerous specimens). Lower Khartam Sample 02KH27 only contains shallow-water inhabitants indicative of salinity variations.
Plate 3: Khuff Formation ostracods. All specimens from the Khuff Formation, Saudi Arabia. Scale bar 100 µm.

3.1: *Paraparchites* sp. 1. Right lateral view, P6M1580, sample 02KH23, Lower Khartam Member.
3.2: *Paraparchites* sp. 2. Right lateral view, P6M1581, sample 02KH27, Lower Khartam Member.
3.3, 3.4: *Paraparchites* sp. 3. (3.3) Left lateral view, P6M1583, sample 02KH22, Lower Khartam Member. (3.4) Left lateral view, P6M1584, sample 02KH22, lower Khartam Member.
3.5: *Shemonaella* sp. 1. Right lateral view, P6M1577, sample 02KH22, Lower Khartam Member.
3.6: *Shemonaella* sp. 2. Right lateral view, P6M1578, sample 02KH23, Lower Khartam Member.
3.8: *Knoxiella infirma* Shi, 1982. Right lateral view, P6M1579, sample 02KH27, Lower Khartam Member.
3.9: *Knoxiella infirma* Shi, 1982. Right lateral view, P6M1582, sample 02KH07, Duhaysan Member.
3.10–3.13: *Kloedenellitina* sp. 1. Lower Khartam Member. 3.10: Right lateral view, P6M2089, sample 02KH22. 3.11: Right lateral view, P6M2090, sample 02KH27. 3.12: Dorsal view, P6M2091, sample 02KH27. 3.13: Dorsal view, P6M2092, sample 02KH27.
Plate 4: Khuff Formation ostracods. All specimens from the Khuff Formation, Saudi Arabia. Scale bar 100 µm.
4.1–4.7: *Sargentina transita* Kozur, 1981. Sample 02KH07, Duhaysan Member. 4.1: Right lateral view, P6M1592. 4.2: Left lateral view, P6M1593. 4.3: Dorsal view, P6M1594. 4.4: Left lateral view, P6M1595. 4.5: Left lateral view, P6M1596. 4.6: Left lateral view, P6M1597. 4.7: Left lateral view, P6M1598. 4.8–4.12: *Hollinella (H.) herrickana* Girty, 1909. 4.8: Right lateral view, P6M1586, sample 02KH22, Lower Khartam Member. 4.9: Right lateral view, P6M1587, sample 02KH11, Midhnam Member. 4.10: Left lateral view, P6M1588, sample 02KH22, Lower Khartam Member. 4.11: Right lateral view, P6M1589, sample 02KH22, lower Khartam Member. 4.12: Left lateral view, P6M1590, sample 02KH22, Lower Khartam Member.
Plate 5: Khuff Formation ostracods. All specimens from the Khuff Formation, Saudi Arabia. Scale bar 100 µm.

5.1: *Hollinella* sp. 2. Left lateral view, P6M1591, sample 02KH23, lower Khartam Member. 5.2: *Sargentina* sp. 2. Right lateral view, P6M1599, sample 02KH07, Duhaysan Member. 5.3: *Cavellina cf. rotunda* Cooper, 1946 *sensu* Shi and Chen, 1987. Right lateral view, P6M2131, sample Jalwa-1b, lower Khartam Member.

5.4: *Spinocypris* sp. Right lateral view, P6M2096, sample 02KH22, lower Khartam Member. 5.5–5.6: *Haworthina?* sp. 1. Lower Khartam Member. 5.5: Left lateral view, P6M2094, sample 02KH22. 5.6: Dorsal view, P6M2093, sample 02KH22.

5.7–5.8: *Sulcella* sp. Sample 02KH23, Lower Khartam Member. 5.7: Right lateral view, P6M2097. 5.8: Left lateral view, P6M2098.

5.9: *Fabalicypris* sp. Right lateral view, P6M2095, sample 02KH22, Lower Khartam Member.

5.10: *Sulcella sulcata* Coryell and Sample, 1935. Right lateral view, P6M2099, sample 02KH07, Duhaysan Mbr.

5.11: *Bairdia* sp. 1. Right lateral view, P6M2113, sample 02KH22, Lower Khartam Member. 5.12: *Acratia?* sp. 3. Right lateral view, P6M2110, Sample 02KH22, Lower Khartam Member.

5.13: *Bairdiacypris* sp. 1. Right lateral view, P6M2112, sample 02KH22, Lower Khartam Member.
The conditions of life were more stressful than previously (numerous specimens and few species). In this sample, all the carapaces are disassociated and this could be due to currents.

The evolution of ostracods gathered from the Lower Khartam Member reflects a transgressive sequence, with the maximum depth attained at the level of sample 02KH22 (Figure 2), followed by a shallowing from sample 02KH23 up to the break with the Upper Khartam Member. Upper Khartam Member Sample 02KH29 yielded only one species of Kloedenellacea, which indicates an intertidal zone. Le Nindre et al. (1990b, p. 96) noted that the tests of the ostracods were thinner in the Upper Khartam Member than in the Lower Khartam Member. This relationship also suggests that more confined palaeoenvironments prevailed during the deposition of the Early Triassic Upper Khartam Member.
Regional Palaeobiogeographical Relationships

All the Khuff ostracods in our study are benthic and their larvae had a similar way of life. In order to interpret the palaeobiogeography of the Khuff ostracods we used the binary similarity coefficient Provincialism Index, PI of Johnson (1971). The PI (PI = C/2E) compares the number of common taxa (C) in two regions (with samples of different sizes) relative to the number of endemic taxa to the region of the lower diversity (E). We use here the specific level for comparison. This systematic level is, for us, the only significant one.

There are 28 endemic species in the Khuff Formation (Plate 1). Six that were discovered here exist in other Palaeo-Tethyan regions (Plate 2). Three other species are compared to species described in other...
Figure 6: Ostracod Provincialism Index (PI) in the main sites of the southern Palaeo-Tethyan margin. Western Taurus (Crasquin-Soleau et al., 2002, 2004a, b); Oman (Crasquin-Soleau et al., 1999, 2001; Angiolini et al., 2004); Negev (Gerry et al., 1987); South China (Shi and Chen, 1987; Shi, 1982; Wang, 1978); Tunisia (Lethiers et al., 1989; Said-Bencharti and Crasquin-Soleau, 1998); Hungary (Kozur, 1985); Greece (Crasquin-Soleau and Baud, 1998); Saudi Arabia (Crasquin-Soleau et al., 2005, this paper); USA and Caucasus (in Lethiers et al., 1989).

Table 2

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regions. These nine Khuff species are present in Western Taurus (Turkey), Oman, Negev, South China, Tunisia, Hungary, North America, Greece and/or Caucasus. The results in Figure 6 and Table 2 show that ostracod palaeobiogeography of Saudi Arabia is closest to that of the Taurus, Oman, Negev and South China.

The high coefficient PI between Saudi Arabia and far-away Tunisia (0.042) and Hungary (0.054) is also significant (Figure 6, Table 2). By showing these regions on a palinspastic reconstruction (Figure 7, Gaetani et al., 2000), it becomes clear that they were all situated on the shelf of Pangea Continent. The lower PI value of Saudi Arabia with Greece (Figure 6, Table 2) could be due to the presence of a deeper zone between them, and to the influence of currents from the northeast. The Palaeo-Tethys
warm surface currents coming from the east, spread along the southern margins of the continent, furthering faunal exchanges (Figure 7). The relative isolation of the Caucasus could be explained by the existence of an inverse current that came from northeast, thus restricting the faunal exchanges.

The relationships with Cathaysia could also be explained by the presence of surface currents that allowed the spreading of fauna. This would be easier to explain if a configuration of the Pangea B type is favoured for the reconstruction of this super-continent. In the same way, we consider the presence of trans-oceanic currents, as proposed by Lethiers and Crasquin-Soleau (1995), to explain the common species with the North American platform (Figure 8).

CONCLUSIONS

The ostracod fauna discovered in the Permian-Triassic Khuff Formation of Saudi Arabia is here described for the first time. The occurrence of ostracods in this formation was unexpected because its facies (gypsiferous and dolomitic claystone, dolomite and evaporites) is not generally favourable for their preservation. The ostracod fauna supports the positioning of the Triassic-Permian Boundary between the Lower and Upper Khartam members of the Khuff Formation, where lithological and sequence stratigraphic breaks occur. A similar pattern was observed in the Western Taurus (Crasquin-Soleau et al., 2002, 2004a, b). Here the lowest level of the Lower 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 data from central Saudi Arabia confirm the survival of palaeocopids through the Triassic-Permian Boundary. We also confirm the absence of nanism in ostracod faunas at the end of the Permian Period (although it is observed in other groups like foraminifers). This indicates that the palaeoenvironment was not stressed, at least up to the Lower Midhnab Member. The presence in the Khuff Formation of six species that are common in other areas of the Palaeo-Tethys Ocean, implies a palaeobiogeographic link. The Provincialism Index (PI) emphasises the close relationships of the Arabian Plate with the southwestern Palaeo-Tethys and also with South China. This could be explained by the presence of warm surface currents coming from the southeast.
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REFERENCES


ABOUT THE AUTHORS

**Sylvie Crasquin-Soleau** is a Micropalaeontologist at the French National Centre of Scientific Research in Paris, France. She received a PhD in Palaeontology from Lille University in 1986 where her research focused on Lower Carboniferous ostracodes from North of France and the Rocky Mountains in Canada. Sylvie’s work presently focuses on Permian and Triassic marine ostracodes of the Palaeo-Tethys area. Her emphasis is on ostracod palaeoecology, palaeobiogeographic analysis and palaeoenvironment reconstructions in Oman, Turkey, Saudi Arabia, Iran, Thailand and south China.

crasquin@ccr.jussieu.fr

**Denis Vaslet** is Head of the Geology and Geoinformation Division at the Bureau de Recherches Géologiques et Minières (BRGM), the French Geological Survey. He has 30 years of experience in the geology of the Middle East. From 1977 to 1979 Denis was involved in geological mapping and phosphate prospecting in Iran for the Geological Survey of Iran and the National Iranian Oil Company. From 1979 to 1991, he was responsible for the Cover Rocks mapping program in Saudi Arabia for the Saudi Arabian Deputy Ministry for Mineral Resources. Denis has been involved in the complete lithostratigraphic revision of the Phanerozoic rocks of central Saudi Arabia, for which he received his Doctorate of Sciences from the University of Paris in 1987. He is currently in charge of geological and geophysical mapping both in France and overseas, and for the production and distribution of digital geological information at BRGM. Denis remains involved in several research projects in the sedimentary geology and stratigraphy fields within the Arabian Peninsula.

d.vaslet@brgm.fr

**Yves-Michel Le Nindre** has more than 10 years of experience in the geological mapping of the Phanerozoic rocks of Saudi Arabia. He received his Doctorate of Sciences from the University of Paris in 1987. Yves-Michel’s dissertation was on the sedimentation and geodynamics of Central Arabia from the Permian to the Cretaceous. He is currently working with the Bureau de Recherches Géologiques et Minières on sedimentary basin analysis and modelling, particularly in hydrogeology, and is also involved in present-day littoral modelling.

ym.lenindre@brgm.fr

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