

New records and new taxa of Permian brachiopods from the Khuff Formation, Midhnab Member, central Saudi Arabia

Lucia Angiolini, Denis Vaslet, Yves-Michel Le Nindre and Miriam Zarbo

ABSTRACT

Brachiopods are described for the first time from outcrops of the lower part of the Midhnab Member of the Khuff Formation in central Saudi Arabia. The very rare fauna discovered includes *Kotlaia* sp. ind. of the order Orthida and *Omanilasma husseini* n. gen. n. sp. of the order Terebratulida. Besides this new taxon, another new species *Omanilasma desertica* n. gen. n. sp. from the Khuff Formation of Interior Oman is here erected. The brachiopods were collected from an open-marine horizon and are associated with nautiloids, baccitrids, bivalves, foraminifers, algae, and ostracods. A probable Late Permian age is assigned to the lower part of the Midhnab Member based on foraminifers. The brachiopods are compared to similar faunas from the Middle Permian Khuff Formation of Interior Oman, Amb Formation of Salt Range (Pakistan) and Rat Buri Limestone of Southeast Thailand.

INTRODUCTION

The Permian-Triassic Khuff Formation (Steineke and Bramkamp, 1952; Steineke et al., 1958; Powers, 1968; Vaslet et al., 2005) crops out in central Saudi Arabia along a N-S belt that is some 1,200 km in length (Figure 1). The 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, now the Saudi Geological Survey - SGS) and the French geological survey (BRGM), including lithostratigraphy, biostratigraphy and palaeoenvironment 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, 2004).

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., 2004, 2006) and palaeoflora (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).

Up to now few records of Permian brachiopods have been reported from Saudi Arabia and they consist mainly in the mention of brachiopod debris in the Khuff Formation in the Al Faydah quadrangle (Vaslet et al., 1985, p. 16) (Figure 1). In a compilation made by Le Nindre et al. (1990b, p. 53) brachiopod fragments have been recorded from several horizons within the upper Huqayl, Duhaysan, Midhnab and Khartam members of the Khuff Formation. Al-Aswad (1997, pages 316 and 318) also reported brachiopod fragments from the lower part of the Midhnab Member and from the lower part of the Khartam Member. These scattered findings in Saudi Arabia make a striking contrast with the rich brachiopod faunas described from the Khuff Formation of the Al Huqf and Jabal Gharif regions of Interior Oman by Angiolini and Bucher (1999) and Angiolini et al. (1998, 2001, 2003, 2004).

The brachiopod fauna that is examined here was discovered in the Khuff Formation of Saudi Arabia, during a field trip led by D. Vaslet and Y.-M. Le Nindre in 2002. The fossiliferous site is located in the Buraydah quadrangle (Vaslet et al., 1985) at 26°07'01"N, 44°02'26"E, 5 km to the north of Midhnab

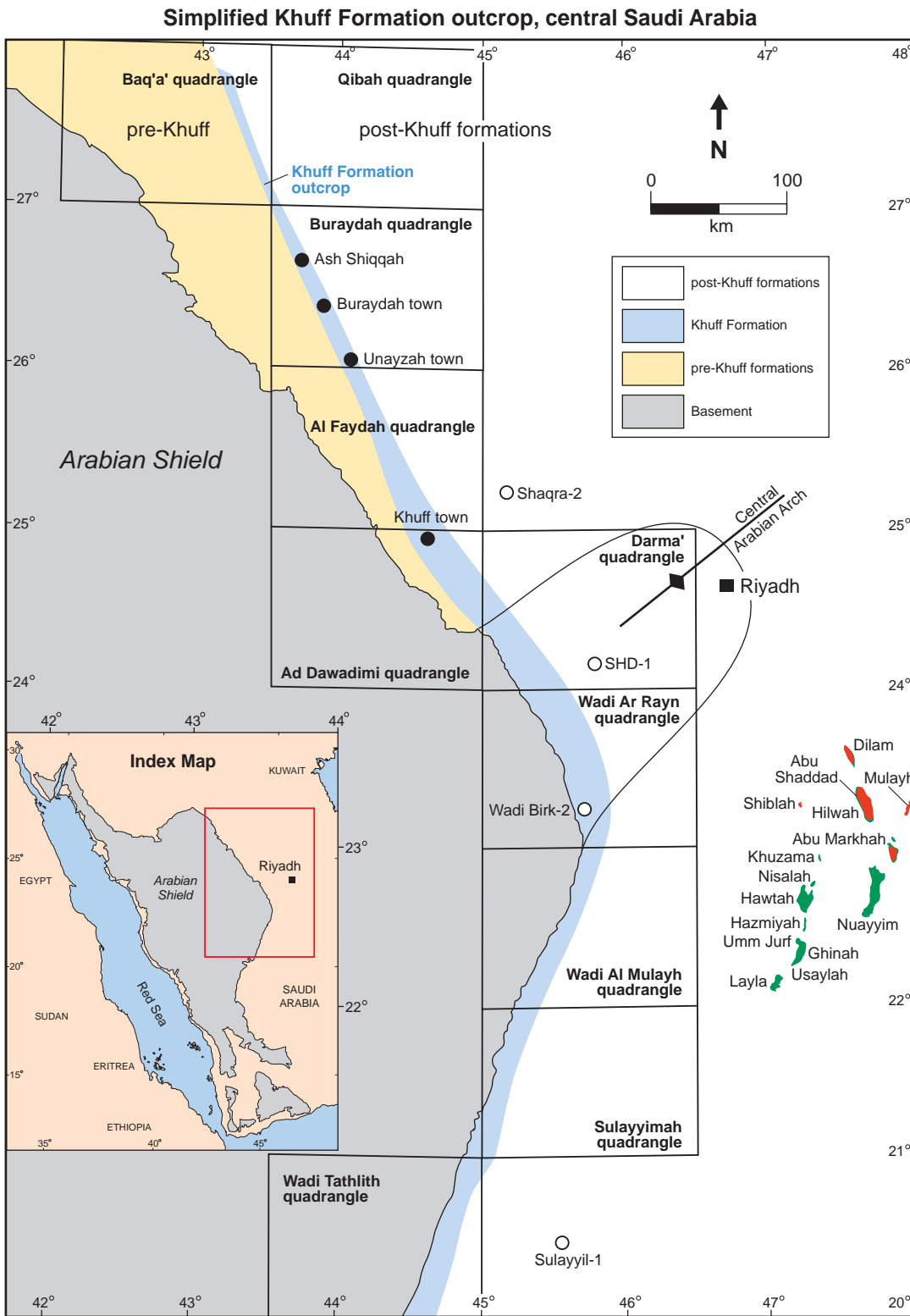


Figure 1: Simplified Khuff Formation outcrop, central Saudi Arabia (modified after Vaslet et al., 2005).

town. The brachiopods occur in the lowest part of the subunit 2 of the Midhnab Member (Vaslet et al., 2005), in bluish bioclastic platy limestones rich in marine fauna, alternating with yellow clayey limestones (Figures 1 and 2). This unit corresponds to the maximum flooding interval (MFI) in central Saudi Arabia in the Late Permian times (Le Nindre et al., 1990b; Sharland et al., 2001, 2004; Vaslet et al., 2005).

Khuff Formation, Buraydah quadrangle, Saudi Arabia

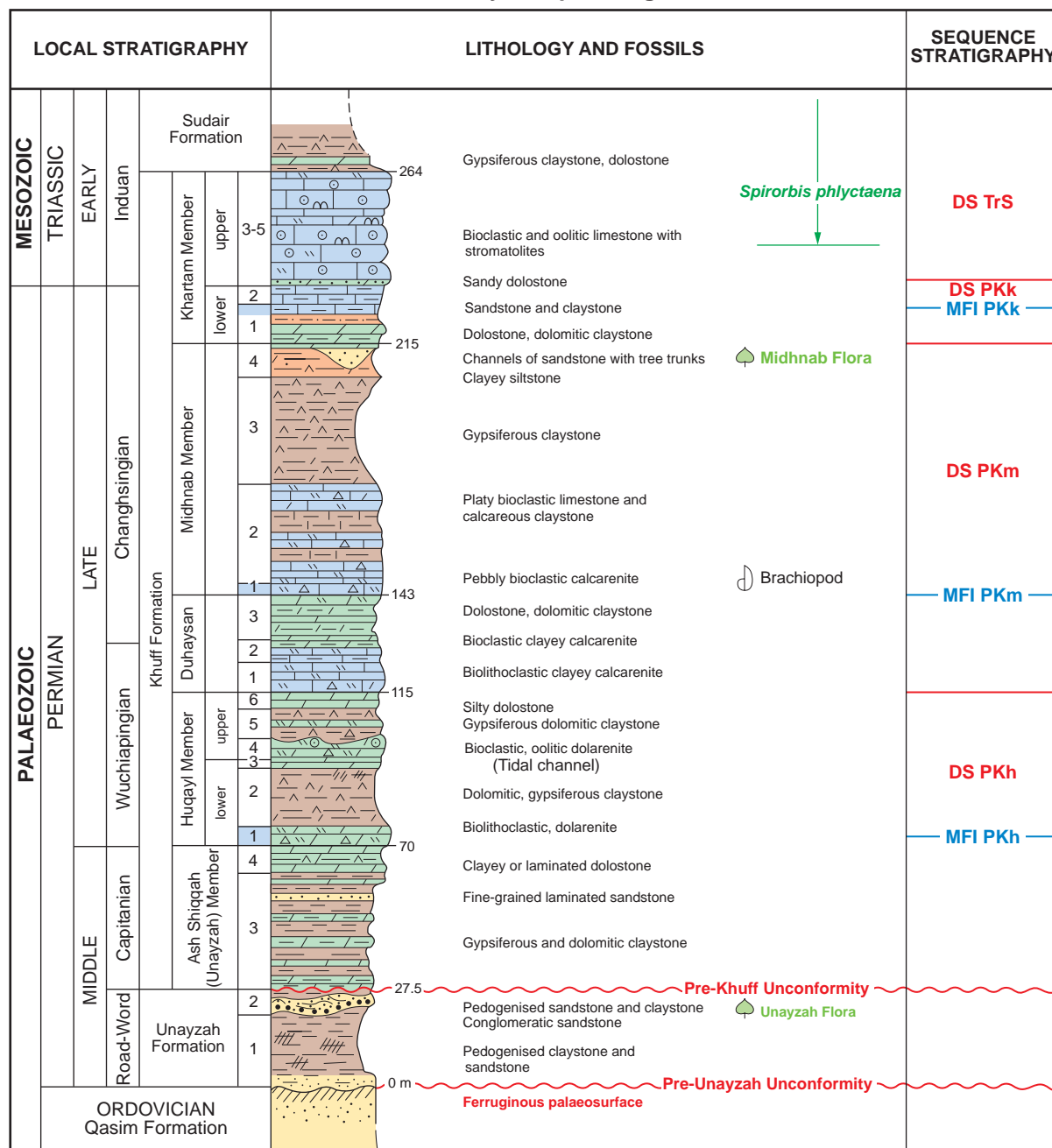


Figure 2: Generalized section of Khuff Formation in the Buraydah quadrangle, northern central Saudi Arabia (modified after Manivit et al., 1986, and Vaslet et al., 2005).

The aim of this paper is to describe in a systematic manner the brachiopod fauna recently discovered in the lower part of the Midhnab Member of the Khuff Formation in central Saudi Arabia, and to assess their biostratigraphical, palaeoecological and palaeogeographical implications.

LITHOSTRATIGRAPHY, BIOSTRATIGRAPHY AND SEQUENCE STRATIGRAPHY OF THE KHUFF FORMATION

The Ash Shiqqah Member (nearly equivalent to the obsolete Unayzah member of Delfour et al., 1982) of the Khuff Formation consists of terrigenous sediments with secondary clayey dolostone, and local evaporites in the upper part of the member. 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 age for this lowest member 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, dolostone, and solution breccias related to subsurface evaporites. This marine transgressive unit has been tentatively assigned a Late Permian ?Wuchiapingian (?Dzhulfian) age according to its benthic foraminifers content (Vachard et al., 2003, 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 interpreted as the transgressive unit of the overlying Midhnab Member (Vaslet et al., 2005). The Duhaysan Member has yielded benthic foraminifers, nautiloids, gastropods, and abundant baccitrids. A Late Permian Wuchiapingian to Changhsingian age has been tentatively assigned to the Duhaysan Member (Vaslet et al., 2003, 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 has been dated by benthic foraminifers as Late Permian Changhsingian by Vachard et al. (2003, 2005). However, a conodont specimen recently discovered in the lower part of the Midhnab Member indicates a late Capitanian age (Nicora et al., 2006). Moreover, ongoing isotope analyses on Midhnab brachiopod shells (done by the first author in cooperation with M.H. Stephenson of BGS, Nottingham and D.P.F. Darbyshire and M.J. Leng of NERC Isotope Geosciences Laboratory, Nottingham) suggest a late Capitanian or early Wuchiapingian age. Locally, in northern central Saudi Arabia, the topmost continental facies of Midhnab Member include lacustrine limestone, sandstone channels and claystone in meandering river systems and swamps. These facies contain drifted woods 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, Euramerian and Gondwanan plant remains (Broutin et al., 1995, 2002; Berthelin, 2002, 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, dolostone and sandstone, deposited in supratidal to tidal palaeoenvironments. The Upper Khartam Member is an oolitic, peloidal and bioclastic limestone locally dolomitized, deposited in littoral to tidal and intertidal palaeoenvironments. The Lower Khartam Member yielded rare benthic foraminifers possibly dated as latest Permian (Changhsingian) by Vachard et al. (2003, 2005). The Upper Khartam Member, consisting principally of reworked Dasycladacean algae ooids, is characterised by the appearance of *Spirorbis phlyctaena* 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 first Late Permian flooding event over central Saudi Arabian outcrop areas (MFI PKh). 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., 1990a, b; Vaslet et al., 2005).

The DS PKm (named after Permian-Khuff-Midhnab) starts with the deposition of subtidal to littoral Duhaysan Member above an erosive surface at the top of DS PKh, and ends with the regressive supratidal to continental deposits of the upper part of the Midhnab Member. A maximum flooding surface (MFS PKm) is clearly located in the outcrops at the base of the Midhnab Member; it is characterised by abundant open-marine fauna including cephalopods and brachiopods (Chirat et al., 2006; Vaslet 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 is manifested by marine fauna, including abundant Permian ostracods (Crasquin-Soleau et al., 2004, 2005), bactritids and locally cephalopods (Chirat et al., 2006).

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).

BRACHIOPOD FAUNA

The brachiopod fauna collected at the base of the Midhnab Member consists of 13 specimens belonging to two species of two different orders: *Kotlaia* sp. ind. of the order Orthida and *Omanilasma husseinii* n. gen. n. sp. of the order Terebratulida. It is worth noting that both taxa also occur in the Wordian Khuff Formation of Interior Oman (Angiolini and Bucher, 1999; Angiolini et al., 2003, 2004), which however is characterised by a much more diversified brachiopod fauna comprising more than 2,000 specimens collected in outcrops and belonging to 30 species. The biostratigraphic analysis of the brachiopods of Interior Oman led to the establishment of three assemblage zones: (1) the *Neochonetes (Nongtaia) arabicus-Celebetes manarollai* Biozone; (2) the *Acritosia* sp. and *Globosobucina* sp. Biozone; and (3) the *Grandaurispina ghabaensis - Kozłowskaia tescorum* Biozone. The biozones are of Wordian age as supported by the associated conodonts and ammonoids (Angiolini et al., 2003, 2004). The two taxa that are shared by the Khuff Formation, in Oman and Saudi Arabia, do not conclusively resolve the age of the Midhnab Member. This is because *Kotlaia* is a genus spanning the Middle to Late Permian time interval and *Omanilasma* n. gen. is presently known only from Oman and Saudi Arabia. In fact, foraminifers date the Midhnab Member as Late Permian (Vachard et al., 2005).

The lithology and faunal composition of the shell beds in the lower part of the Midhnab Member is also strongly reminiscent of the bioclastic beds of the Khuff Formation in Oman. These tempestites comprise abundant mixed autochthonous and allochthonous marine fauna dominated by scaphopods, algae, crinoids, foraminifers, bryozoans, ostracods, gastropods, nautiloids, ammonoids, brachiopods, and bivalves. The latter two groups show convexity upward. Elongated forms such as scaphopods, gastropods and cephalopods show the long axis isoriented towards the palaeocurrents.

Kotlaia sp. ind. and *Omanilasma husseinii* n. gen. n. sp. are pedicle-attached brachiopod taxa in which substrate relationships are governed by the pedicle system. They are generally considered to be ubiquitous as the pedicle can be modified for several life-styles depending on the energy of the environment. The shape and size of the Saudi Arabian Khuff brachiopod shells and the position of the foramen suggest that they are close to recent articulated generalist species. These species can be found in highly variable substrates and energy regimes, with the highest population densities occurring around the shoreline (Richardson *in* Williams et al., 1997).

Angiolini (2001) has shown the strong palaeobiogeographical affinity of the Middle Permian brachiopod fauna of Interior Oman, the Salt Range in Pakistan (Amb Formation) and southeastern Thailand (Ratburi Limestone). All these faunal stations belonged to the Sibumasu Province, stretching during Middle Permian times, mainly along the southern shore of the Neo-Tethys Ocean. The two taxa found in the Midhnab Member are Gondwanan genera, which also occur in the Middle and Upper Permian succession of the Salt Range; however they represent an insufficient record to establish palaeobiogeographical ties.

SYSTEMATIC DESCRIPTION (L. Angiolini and M. Zarbo)

All described specimens are housed in the Palaeontological Museum of the Dipartimento di Scienze della Terra "A. Desio", University of Milano, Italy. Specimens are registered with the prefix MPUM

Plate 1

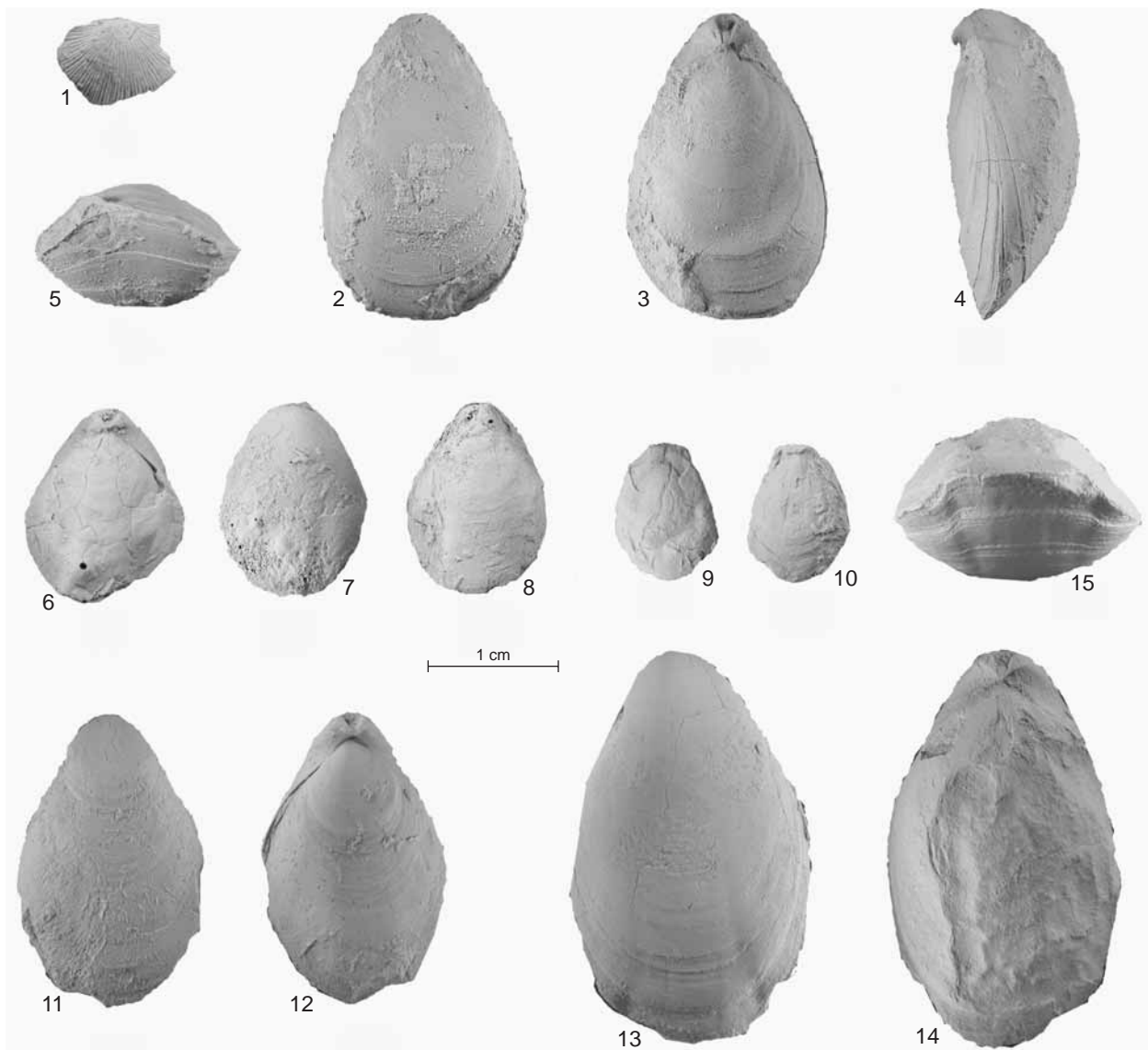


Plate 1

1.1: *Kotlaia* sp. ind., dorsal valve, MPUM9369 (KH0211-5); from the Khuff Formation, Midh nab Member of Saudi Arabia, Buraydah quadrangle, 26°07'01"N, 44°02'26"E.

1.2–1.5: *Omanilasma husseinii* n. gen. n. sp., articulated specimen, holotype MPUM9370 (AO45-16), ventral, dorsal, lateral, anterior views; from bed AO45, section K4, Khuff Formation, Member 3 of Interior Oman.

1.6: *Omanilasma husseinii* n. gen. n. sp., articulated specimen, MPUM9371 (KH0211-7), dorsal view, from the Khuff Formation, Midh nab Member of Saudi Arabia, Buraydah quadrangle, 26°07'01"N, 44°02'26"E.

1.7–1.8: *Omanilasma husseinii* n. gen. n. sp., articulated specimen, MPUM9372 (KH0211-9), ventral and dorsal views, from the Khuff Formation, Midh nab Member of Saudi Arabia, Buraydah quadrangle, 26°07'01"N, 44°02'26"E.

1.9, 1.10: *Omanilasma husseinii* n. gen. n. sp., articulated specimen, MPUM9373 (KH0211-15), ventral and dorsal views, from the Khuff Formation, Midh nab Member of Saudi Arabia, Buraydah quadrangle, 26°07'01"N, 44°02'26"E.

1.11, 1.12: *Omanilasma desertica* n. gen. n. sp., articulated specimen MPUM9378 (AO210-163) ventral and dorsal views; from bed AO/OL210, section K7, Khuff Formation, Member 3 of Interior Oman.

1.13, 1.14, 1.15: *Omanilasma desertica* n. gen. n. sp., articulated specimen, MPUM9370 (AO210-98), ventral, dorsal and anterior views; from bed AO/OL210, section K7, Khuff Formation, Member 3 of Interior Oman.

followed by a four-digit number and by the field number within brackets. This study follows the classification of Williams and Harper *in* Williams et al. (2000) for the orthids and the classification of Muir Wood et al. *in* Williams et al. (1965) for the terebratulids.

Subphylum: Rynchonelliformea Williams et al., 1996
Class: Rhynchonellata Williams et al., 1996
Order: Orthida Schuchert and Cooper, 1932
Suborder: Dalmanellidina Moore, 1952
Superfamily: Enteletoidea Waagen, 1884
Family: Schizophoriidae Schuchert & LeVene, 1929
Genus: *Kotlaia* Grant, 1993

Type-species: *Kotlaia capillosa* Grant, 1993 from the Upper Permian Chhidru Formation of Kishor Range, Pakistan.

Remarks: Among the Schizophoriidae, the Middle Permian genus *Kotlaia* Grant, 1993 is very close both to *Orthotichia* Hall & Clarke, 1892 and to *Acosarina* Cooper & Grant, 1969. *Kotlaia* differs from the Carboniferous *Orthotichia* by its sulcate to emarginate anterior commissure, divergent dental plates, ventral muscle field bisected by low median septum extending up to 2/3 of the valve length and short but strongly divergent brachiophore plates. Both genera are ornamented by tubular costellae on both valves. The Lower Permian genus *Acosarina* holds intermediate features between *Orthotichia* and *Kotlaia* suggesting an evolutive trend from the Carboniferous *Orthotichia*, through the intermediate Lower Permian genus *Acosarina*, to the Middle Permian *Kotlaia*. The genus *Kotlaia* has been reported up to now from the Middle Permian of Chios (Greece), Middle Permian of Oman and Late Permian of Salt Range (Angiolini et al., 2005).

***Kotlaia* sp. ind.** (Plate 1.1)

Material: One articulated specimen MPUM9368 (KH0211-16); 1 dorsal valve MPUM9369 (KH0211-5).

Figured material: One dorsal valve: MPUM9369 (KH0211-5).

Description: Small-sized biconvex shells, with slightly transverse outline. Maximum width 6.6 mm, corresponding length 5.7 mm. Anterior commissure rectimarginate. Ornamentation of both valves with thin tubular costellae numbering 20 per 5 mm. Interior of ventral valve with low median septum.

Discussion: Notwithstanding the small dimensions, the few available specimens show some of the distinctive features of the Middle-Upper Permian genus *Kotlaia*.

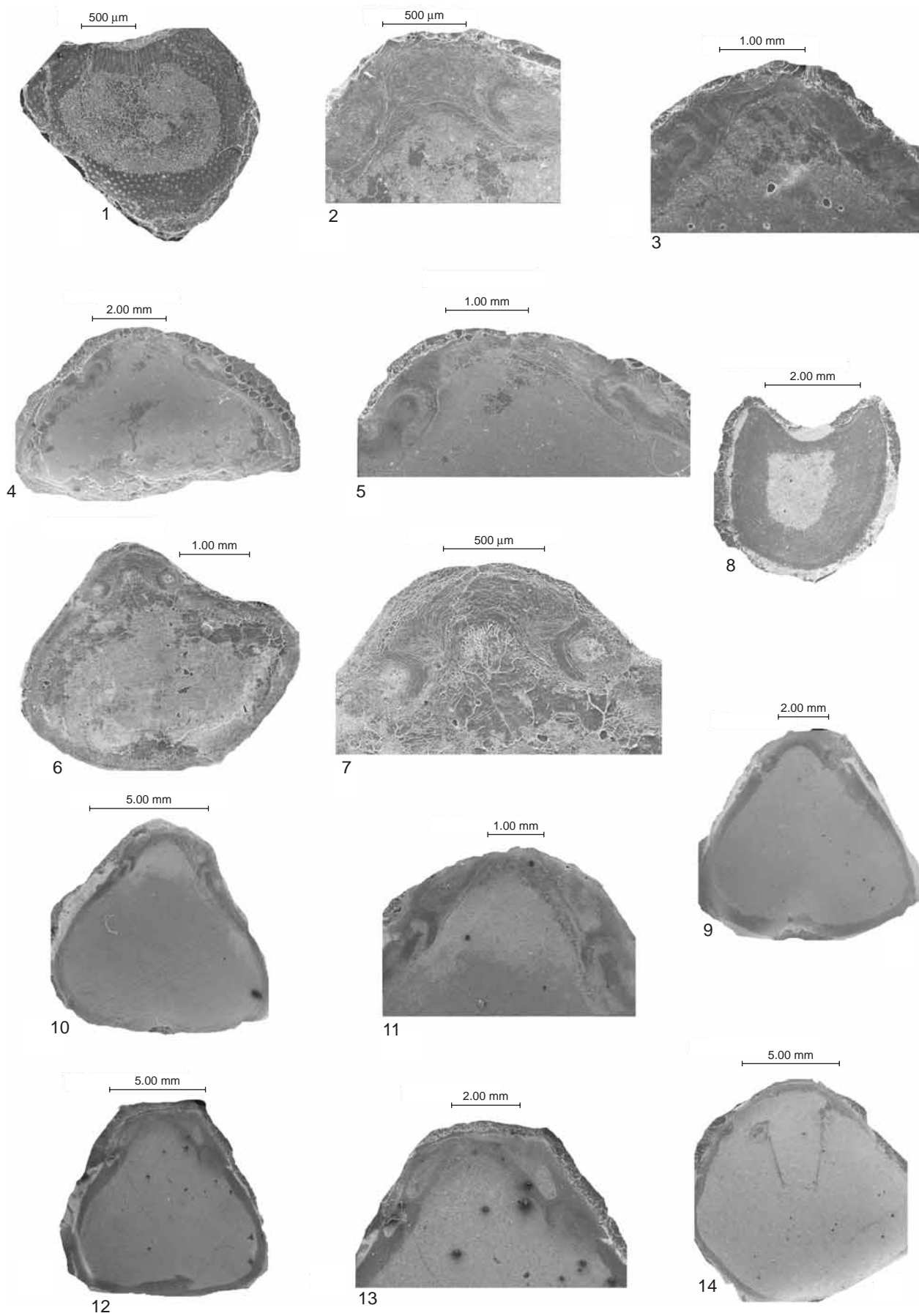
Order: Terebratulida Waagen, 1883
Suborder: Terebratulidina Waagen, 1883
Superfamily: Dielasmatoidea Schuchert, 1913
Family: Dielasmatidae Schuchert, 1913
Subfamily: Dielasmatinae Schuchert, 1913
Genus: *Omanilasma* n. gen.

Type-species: *Omanilasma husseinii* n. sp. from the Wordian (Middle Permian) Khuff Formation of Interior Oman.

Derivatio Nominis: From Oman (type region) and the allied genus *Dielasma* King, 1859.

Diagnosis: Similar to *Dielasma* King, 1956, but interior of ventral valve with reduced dental flanges fused to valve walls.

Plate 2



Discussion: *Omanilasma* n. gen. is externally very similar to *Dielasma* King, 1859, sharing its biconvex, elongate subovate shape with generally uniplicate anterior commissure and labiate foramen, but it differs from *Dielasma* by the absence of dental plates inside the ventral valve. The new genus is in fact characterised by the occurrence of reduced dental flanges supporting the teeth but not extending to the valve floor. Internally its dorsal valve shows the hinge plates forming an open 'V' between the socket ridges and the valve floor, as *Dielasma*. The latter feature differentiates *Omanilasma* n. gen. from other externally similar genera, such as *Hoskingia* Campbell, 1965.

Omanilasma husseini n. sp. (Plates 1.2–1.10; Plates 2.1–2.14)

1959 *Dielasma hochstetteri* (Toula) var. *personata* Reed – Hudson and Sudbury, p. 51, pl. 6, figs. 7-9, 12-13.

1999 *Dielasma* sp. A – Angiolini in Angiolini & Bucher, p. 692, figs. 17.20-31, table 13.

Derivatio Nominis: For Moujahed I. Al-Husseini.

Holotype: An articulated specimen, MPUM9370 (AO45-16).

Type Locality and Horizon: Interior Oman, Haushi ring, Khuff Formation, Member 3, top of section K4 in Angiolini et al. (2001, p. 27), bed AO45, 21°02'30"N, 57°42'00"E. Wordian (Middle Permian).

Other Material: Eleven articulated specimens from the Khuff Formation, Midhnab Member of Saudi Arabia: KH0211-1,-2,-3,-7,-8,-9,-10,-11,-13,-15,-18; 190 articulated specimens from the Khuff Formation, Members 2 and 3 of Oman, beds AO45, AO59, AO73, AO109, AO111, AO112, AO113, AO/OL210, OL100, OL101, OM16, OM18, OM20 from the Haushi ring (sections K4, K5, K7, I1) and from Jabal Gharif (for location see Angiolini et al., 2001, 2003).

Figured material: Four articulated specimens, holotype MPUM9370 (AO45-16), MPUM9371 (KH0211-7), MPUM9372 (KH0211-9), MPUM9373 (KH0211-15).

Diagnosis: Spatuliform *Omanilasma* with proportionately large, labiate foramen.

Description: Medium-sized, biconvex shells with spatuliform outline. Anterior commissure rectimarginate to broadly uniplicate. Maximum width at or slightly anterior to midlength. Maximum width ranging between 7.7 and 22.1 mm, corresponding length respectively 10 and 35.8 mm and thickness 4.9 and 13.5 mm. Ventral valve more convex than the dorsal one, especially in the posterior region. Ventral foramen subcircular to subtriangular, epithyrid, labiate, with pedicle collar. Dorsal valve elongate subovate. Both valves smooth except for growth lines and widely spaced growth

Plate 2

2.1–2.5: *Omanilasma husseini* n. gen. n. sp., articulated specimen, MPUM9374 (KH0211-1), dorsal valve upward. **2.1–2.4:** serial sections at 0.1 mm, 2.4 mm, 3.2 mm, 3.6 mm from the umbo; **2.5:** enlargement of fig. 4 showing hinge plates forming an open 'V' between the socket ridges and the valve floor. Specimen from the Khuff Formation, Midhnab Member of Saudi Arabia, Buraydah quadrangle, 26°07'01" N-44°02'26" E.

2.6, 2.7: *Omanilasma husseini* n. gen. n. sp., articulated specimen, MPUM9375 (KH0211-13), dorsal valve upward. Serial sections at 1.2 mm and 1.3 mm from the umbo showing absence of dental plates. Specimen from the Khuff Formation, Midhnab Member of Saudi Arabia, Buraydah quadrangle, 26°07'01"N, 44°02'26"E.

2.8–2.14: *Omanilasma husseini* n. gen. n. sp., articulated specimen, MPUM9376 (AO45-66), dorsal valve upward. **2.8–2.10, 2.12, 2.14:** serial sections respectively at 0.4 mm, 1.1 mm, 4.5 mm, 5.7 mm, 8.8 mm from the umbo. **2.11:** enlargement of figure 2.10. **2.13:** enlargement of Plate 2.12. All showing reduced dental flanges fused to valve walls and hinge plates forming an open 'V' between the socket ridges and the valve floor. Specimen from bed AO45, section K4, Khuff Formation, Member 3 of Interior Oman.

lamellae. Interior of ventral valve with reduced dental flanges fused to valve walls and short, extending anteriorly for few mm only. Interior of dorsal valve with hinge plates forming an open 'V' between the socket ridges and the valve floor.

Discussion: Additional material collected during 1997, 2000 and 2001 from the Khuff Formation in the Haushi and Jabal Gharif regions of Oman, and the new findings in the Saudi Arabian Khuff provide the opportunity to establish a new terebratulid genus and species based on the new specimens as well as on those previously determined as *Dielasma* sp. A by Angiolini (in Angiolini and Bucher, 1999). If the erection of the new genus is essentially based on the internal characters, the new species is based on its spatuliform shape and on its proportionately large and labiate foramen.

Angiolini (in Angiolini and Bucher, 1999, p. 694) pointed out the similarity of the Oman specimens to the ones from the Amb Formation of Salt Range (Pakistan) attributed to *Dielasma itaitubense* (Derby, 1974) by Waagen (1882, p. 348, pl. 26, fig. 5), of which the internal characters are unknown. The same holds true for some of the Thai specimens described as *Dielasma* species by Grant (1976, p. 244, pl. 68, figs. 6–10, 13–17, 23–27), specimens for which serial sections showing internal characters are not provided. The problem with the Thai specimens is that they show a great variability of external characters and more than one species was grouped by Grant (1976) under *Dielasma* species. For example, of the four specimens showing ventral interior with well-developed dental plates, two (Grant, 1976, pl. 68, figs. 41, 42) have different external characters from *O. husseini* n. sp., whereas the remaining two (pl. 68, figs. 29, 30) are articulated fragments of umbonal ends so that it is impossible to discern the external features.

***Omanilasma desertica* n. sp.** (Plates 1.11–1.14)

1999 *Dielasma* sp. B – Angiolini in Angiolini & Bucher, p. 695, figs. 17.14–17, table 14.

Derivatio Nominis: For the deserts of Oman.

Holotype: An articulated specimen, MPUM8495 (OL28-1) figured in Angiolini & Bucher (1999, p. 693, fig. 17.16–17).

Type Locality and Horizon: Interior Oman, Haushi ring, Khuff Formation, Member 2, composite section in Angiolini & Bucher (1999, fig. 2), bed OL28, 21°00'37"N, 57°39'35"E and 21°02'06"N, 57°41'23"E. Wordian (Middle Permian).

Other Material: 28 articulated specimens from the Khuff Formation, Member 3 of Oman, beds AO45, AO56, AO73, AO/OL210, OM18 from the Haushi ring (sections K4, K5, K7) (for location see Angiolini et al., 2001, 2003).

Figured material: Two articulated specimens: MPUM9378 (AO210-163) and MPUM9379 (AO210-98).

Diagnosis: Equibiconvex elongated oval *Omanilasma*.

Description: Medium-sized, biconvex shells with elongated oval outline. Anterior commissure slightly uniplicate. Maximum width at midlength. Maximum width ranging between 10 and 19 mm, corresponding length respectively 17 and 33.4 mm and thickness 6.9 and 14 mm. Ventral valve only slightly more convex than the dorsal one. Ventral foramen epithyrid, labiate, with pedicle collar. Ventral umbonal slopes long, usually folded above the dorsal lateral margins. Both valves smooth except for growth lines and widely spaced growth lamellae. Interior of ventral valve with reduced dental flanges fused to valve walls and short. Interior of dorsal valve with hinge plates forming an open 'V' between the socket ridges and the valve floor.

Discussion: *Omanilasma desertica* n. sp. differs from *Omanilasma husseini* n. sp. by its narrower shell, elongated oval outline and longer umbonal slopes. Its dorsal valve shows a greater convexity than

the same valve in *Omanilasma husseini* n. sp. *Omanilasma desertica* n. sp. is externally similar to *Dielasma purdoni* Reed, 1944 (p. 156, pl. 45, fig. 9; pl. 49, fig. 14) from the Amb Formation of Salt Range, of which the internal characters were not described.

CONCLUSIONS

Very rare brachiopods have been discovered in the lowest part of the subunit 2 of the Midhnab Member of the Khuff Formation in central Saudi Arabia outcrops and are described here for the first time. The discovered fauna includes *Kotlaia* sp. ind. of the order Orthida and *Omanilasma husseini* n. gen. n. sp. of the order Terebratulida. The brachiopods were collected from an open-marine bed and are associated with nautiloids, baccitrids, bivalves, foraminifers, algae, and ostracods. A probable Late Permian age is assigned to the lower part of the Midhnab Member based on foraminifers. The new brachiopods are compared to similar faunas from the Middle Permian Khuff Formation of Interior Oman, Amb Formation of Salt Range (Pakistan) and Rat Buri Limestone of Southeast Thailand. In addition the new species *Omanilasma desertica* n. gen. n. sp. from the Khuff Formation of Interior Oman is here erected.

ACKNOWLEDGEMENTS

This study is based on geological field data acquired in 2002, during a field trip organized by Saudi Aramco on the Khuff Formation outcrops. The authors wish to express their thanks to Saudi Aramco geologists R.K. Al-Dakhil, I. Al-Jallal, R.A. Kamal, A.A. Tawil, I. Billing, R.G. Demaree and G.W.G. Hughes for the help given in the field and during further discussions. Thanks also to Beicip geologists B. Murat and E. Pluchery for their contribution in the field, and to A. Rizzi and C. Malinverno for their technical assistance. N.W. Archbold, M. Stephenson and M.I. Al-Husseini are thanked for their thorough and constructive reviews. Finally the GeoArabia team is thanked for the preparation of the text and the final design of the paper.

REFERENCES

- Al-Aswad, A.A. 1997. Stratigraphy, sedimentary environment and depositional evolution of the Khuff Formation in South-central Saudi Arabia. *Journal of Petroleum Geology*, v. 20, p. 307-326.
- Alsharhan, A.S. and A.E.M. Nairn 1995. Stratigraphy and sedimentology of the Permian in the Arabian basin and adjacent areas: a critical review. In, P.A. Scholle, T.M. Peryt and D.S. Ulmer-Scholle (Eds.), *The Permian of Northern Pangea*. Springer Verlag, Berlin Heidelberg, v. 2, p. 187-214.
- Angiolini, L. 2001. Lower and Middle Permian brachiopods from Oman and Peri-Gondwanan palaeogeographical reconstructions. In, C.H.C. Brunton, L.R.M. Cocks and S.L. Long (Eds.), *Brachiopods Past and Present*. The Systematics Association Special Volume Series, v. 63, p. 352-362.
- Angiolini, L. and H. Bucher 1999. Taxonomy and quantitative biochronology of Guadalupian brachiopods from the Khuff Fm., Southeastern Oman. *Geobios*, v. 32, no. 5, p. 665-699.
- Angiolini, L., A. Nicora, H. Bucher, D. Vachard, A. Pillevuit, J.-P. Platel, J. Roger, A. Baud, J. Broutin, H. Al Hashmi and J. Marcoux 1998. Evidence of a Guadalupian age for the Khuff Formation of Southeastern Oman: preliminary report. *Rivista Italiana di Paleontologia e Stratigrafia*, v. 104, no. 3, p. 329-340.
- Angiolini, L., M. Balini, M. Berthelin, J. Broutin, S. Crasquin-Soleau, E. Garzanti, A. Nicora, J.-P. Platel, J. Roger and A. Tintori 2001. Lower to Middle Permian sedimentation on the Arabian Platform: the succession of the Haushi-Huqf area (Interior Oman). Excursion guide-book for the International Conference Geology of Oman, January 7-11, 2001, Ghaba, Oman, 37 p.
- Angiolini, L., M. Balini, E. Garzanti, A. Nicora, A. Tintori, S. Crasquin-Soleau and G. Muttoni 2003. Permian climatic and palaeogeographic changes in northern Gondwana: the Khuff Formation of Interior Oman. *Palaeogeography Palaeoclimatology Palaeoecology*, v. 191, nos. 3-4, p. 269-300.
- Angiolini, L., S. Crasquin-Soleau, J.-P. Platel, J. Roger, D. Vachard, D. Vaslet and M. Al Husseini 2004. Saiwan, Gharif and Khuff formations, Haushi-Huqf Uplift, Oman. In, M.I. Al-Husseini (Ed.), *Carboniferous, Permian and Triassic Arabian Stratigraphy*. GeoArabia Special Publication 3, p. 149-183.
- Angiolini L., L. Carabelli and M. Gaetani 2005. Middle Permian brachiopods from Chios Island (Greece) and their palaeobiogeographical significance: new evidences for a Gondwanan affinity of the Upper Unit. *Journal of Systematic Palaeontology*, v. 3, 2, pp. 169-185.

- Berthelin, M. 2002. Flore mixte du Permien de l'Oman et Pangées permienes: Dynamique de mise en place et signification paléoécologique, paléoclimatique et paléogéographique. Thèse de Doctorat, Université de Paris VI, Paris, 263 p.
- Berthelin, M., J. Broutin, D. Vaslet, Y.-M. Le Nindre and M. Halawani 2006. Mixed Late Permian floras and related palaeoenvironments in the Khuff Formation of central Saudi Arabia. *GeoArabia*, v. 11, no. 3, p. 65-86.
- Broutin, J., M. Berthelin, M. Halawani, D. Vaslet and Y.-M. Le Nindre 2002. Mixed Late Permian floras and related paleoenvironments in the upper Khuff Formation of central Saudi Arabia. *GeoArabia*, v. 7, no. 2, p. 219.
- Broutin, J., J. Roger, J.-P. Platel, L. Angiolini, A. Baud, H. Bucher, J. Marcoux and H. Al Hashmi 1995. The Permian Pangea. Phytogeographic implications of the new paleontological discoveries in Oman (Arabian Peninsula). *Comptes Rendus Académie Sciences, Paris*, v. 321, p. 1069-1086.
- Campbell, K.S.W. 1965. Australian Permian Terebratuloids. Bureau of Mineral Resources, Geology and Geophysics, Bulletin no. 68, 147 p.
- Chirat, R., D. Vaslet and Y.-M. Le Nindre 2006. Nautiloids of the Permian-Triassic Khuff Formation, central Saudi Arabia. *GeoArabia*, v. 11, no. 1, p. 81-92.
- Cooper, G. A. and R.E. Grant 1969. New Permian Brachiopoda from west Texas. *Smithsonian Contribution to Paleobiology*, v. 1, p. 1-20.
- Crasquin-Soleau, S., D. Vaslet, and Y.-M. Le Nindre 2004. Ostracods from Permian -Triassic boundary in Saudi Arabia (Khuff Formation). *Palaeontology* (in press).
- Crasquin-Soleau, S., D. Vaslet and Y.-M. Le Nindre 2006. Ostracods of the Permian-Triassic Khuff Formation, Saudi Arabia: palaeoecology and palaeobiogeography. *GeoArabia*, v. 11, no. 1, p. 55-76.
- Delfour, J., R. Dhellemmes, P. Elbass, D. Vaslet, J.M. Brosse, Y.-M. Le Nindre and O. Dottin 1982. Geologic map of the Ad Dawadimi quadrangle, sheet 24G, Kingdom of Saudi Arabia (with explanatory notes). Saudi Arabian Deputy Ministry for Mineral Resources, Geoscience Map GM60, Scale 1:250,000.
- Derby, O.A. 1874. On the Carboniferous Brachiopoda of Itaituba, Rio Tapajos, province of Para, Brazil. *Cornell University Scientific Bulletin, Series 2*, v. 1, p. 1-63.
- El-Khayal, A.A. and R.H. Wagner 1985. Upper Permian stratigraphy and megaflores of Saudi Arabia; paleogeographic and climatic implications. 10 Congreso Internacional de estratigrafica y geologia del Carbonifero. Instituto Geologico y Minero de España, Madrid, p. 17-26.
- Grant, R.E. 1993. Permian brachiopods from Khios Island, Greece. *Journal of Paleontology*, v. 67, supplement to 4, *Paleontological Society Memoir* 33, p. 1-21.
- Grant, R.E. 1976. Permian brachiopods from southern Thailand. *Journal of Paleontology*, v. 50, supplement to 3, *Paleontological Society Memoir* 9, p. 35-37.
- Hall, J. and J.M. Clarke 1892. An introduction to the study of genera of Palaeozoic Brachiopoda. *Natural History of New York, Palaeontology*, v. 8, part 1, 394 p. New York Geological Survey. Charles van Benthuysen and Son. Albany.
- Hill, C.R. and A.A. El-Khayal 1983. Late Permian plants including Charophytes from the Khuff Formation of Saudi Arabia. *Bulletin of British Museum of Natural History, Geology Series*, v. 37, p. 105-112.
- Hudson, R.G.S. and M. Sudbury 1959. Permian Brachiopoda from south-east Arabia. Notes et mémoires sur le Moyen-Orient. *Muséum National d'Histoire Naturelle Paris*, no. 7, p. 19-55.
- King, W. 1859. On *Gwynia*, *Dielasma*, *Macandrevia*, three new genera, etc. *Zoologic and Botanic Association Proceedings*, v. 1, no. 3, p. 262.
- Le Nindre, Y.-M., J. Manivit and D. Vaslet 1990a. Histoire géologique de la bordure occidentale de la plate-forme arabe, vol. 2: Géodynamique et paléogéographie de la plate-forme arabe du Permien au Jurassique. Bureau de Recherches Géologiques et Minières, Orléans, Document 192, 278 p.
- Le Nindre, Y.-M., D. Vaslet and J. Manivit 1990b. Histoire géologique de la bordure occidentale de la plate-forme arabe, vol. 3: Le Permo-Trias d'Arabie centrale. Bureau de Recherches Géologiques et Minières, Orléans, Document 193, 262 p.
- Manivit, J., D. Vaslet, A. Berthiaux, P. Le Strat and J. Fourniguet 1986. Geologic map of the Buraydah quadrangle, sheet 26G, Kingdom of Saudi Arabia (with explanatory notes). Saudi Arabian Deputy Ministry for Mineral Resource, Geoscience Map GM114, Scale 1:250,000.
- Moore, R.C., C.G. Lalicker and A.G. Fischer 1952. *Invertebrate Fossils*. McGraw-Hill, New York, 766 p.
- Nicora, A., D. Vaslet and Y.-M. Le Nindre 2006. First record of Permian conodont "Jinogondolella" cf. *altaduensis* from the Midhnab Member, Khuff Formation, Saudi Arabia. *GeoArabia*, v. 11, no. 2, p. 91-96.

- Powers, R.W. 1968. Saudi Arabia. Lexique stratigraphique international, III, fasc.10b 1. Centre National de la Recherche Scientifique, Paris, 177 p.
- Powers, R.W., L.F. Ramirez, C.D. Redmond and E.L.J. Elberg 1966. Geology of the Arabian peninsula: Sedimentary geology of Saudi Arabia. United States Geological Survey, Professional Paper 560 D, 147 p.
- Reed, F.R.C. 1944. Brachiopoda and Mollusca from the Productus Limestone of the Salt Range. Memoires of the Geological Survey of India, Palaeontologia Indica, New Series, v. 23, no. 2, 678 p.
- Schuchert, C. 1913. Class 2. Brachiopoda. In, K.A. von Zittel (2nd edition) Text-book of Palaeontology. v. 1, part 1, p. 355-420. (Translated and edited by C.R. Eastman, McMillan and Co., Ltd. London).
- Schuchert, C. and G.A. Cooper 1932. Brachiopod genera of the suborders Orthoidea and Pentameroidea. Memoirs of the Peabody Museum of Natural History, v. 4, no.1, 270 p.
- Schuchert, C. and C.M. LeVene 1929. Brachiopoda (generum et genotyporum index et bibliographia). In, W.J.F. Pompeckj (Ed.), Fossilium catalogus, volume 1, Animalia, Parts 42. Junk, Berlin, 140 p.
- Senalp, M. and A. Al-Duaiji 1995. Stratigraphy and sedimentation of the 'Unayzah Reservoir' central Saudi Arabia. In, M.I. Al-Husseini (Ed.), Middle East Petroleum Geosciences Conference, GEO'94. Gulf PetroLink, Bahrain, v. 2, p. 837-847.
- Senalp, M. and A. Al-Duaiji 2001. Sequence stratigraphy of the 'Unayzah reservoir' in central Saudi Arabia. The Saudi Aramco Journal of Technology, Summer 2001, p. 20-43.
- Sharland, R., R. Archer, D.M. Casey, R.B. Davies, S.H. Hall, A.P. Heward, A.D. Horbury and M.D. Simmons 2001. Arabian Plate Sequence Stratigraphy. GeoArabia Special Publication 2, 371 p.
- Sharland, P.R., D.M. Casey, R.B. Davies, M.D. Simmons and O.E. Sutcliffe 2004. Arabian Plate Sequence Stratigraphy. GeoArabia, v. 9, no. 1, p. 199-214.
- Steineke, M. and R.A. Bramkamp 1952. Mesozoic rocks of eastern Saudi Arabia. American Association of Petroleum Geologists Bulletin, Abstracts, v. 36, no. 5, p. 909.
- Steineke, M., T.F. Harris, K.R. Parsons and E.L. Berg 1958. Geologic map of the western Persian Gulf Quadrangle, Kingdom of Saudi Arabia. United States Geological Survey Miscellaneous Geological Investigations. Map 1-208A, Scale 1:500,000. Reprinted in 1977 as GM-208B.
- Vachard, D., M. Hauser, R. Martini, L. Zaninetti, A. Matter and T. Peters 2002. Middle Permian (Midian) foraminiferal assemblages from the Batain Plain (Eastern Oman): their significance to Neotethyan paleogeography. Journal of Foraminiferal Research, v. 32, no. 2, p. 155-172.
- Vachard, D., A. Zambettakis-Lekas, E. Skourtsos, R. Martini and L. Zaninetti 2003. Foraminifera, algae and carbonate microproblematica from the late Wuchiapingian/Dzhulfian (late Permian) of Peloponnesus (Greece). Rivista Italiana di Paleontologia i Stratigrafia, v. 109, no. 2, p. 339-358.
- Vachard, D., J. Gaillot, D. Vaslet and Y.-M. Le Nindre 2005. Foraminifers and algae from the Khuff Formation (late Middle Permian-Early Triassic) of central Saudi Arabia. GeoArabia, v. 10, no. 4, p. 137-186.
- Vaslet, D., M. Beurrier, M. Villey, J. Manivit, P. Le Strat, Y.-M. Le Nindre, J.M. Brosse, A. Berthiaux and J. Fourniguet 1985. Geologic map of the Al Faydah quadrangle, sheet 25G, Kingdom of Saudi Arabia (with explanatory notes). Saudi Arabian Deputy Ministry for Mineral Resources, Geoscience Map, GM102, Scale 1:250,000.
- Vaslet, D., Y.-M. Le Nindre, D. Vachard, J. Broutin, S. Crasquin-Soleau, M. Berthelin, J. Gaillot, M. Halawani and M. Al-Husseini 2005. The Permian-Triassic Khuff Formation of central Saudi Arabia. GeoArabia, v. 10, no. 4, p. 77-134.
- Waagen, W. 1882-1885. Salt Range fossils. Part 4 Brachiopoda. Memoirs of the Geological Survey of India, Palaeontologia Indica, Series 13, 1 (Productus Limestone fossils), v. 1-5, p. 329-770.
- Williams, A., S.J. Carlson, C.H.C. Brunton, L.E. Holmer and L. Popov 1996. A supra-ordinal classification of the Brachiopoda. Philosophical Transactions of the Royal Society of London, Series B, 351, p. 1171-1193.
- Williams, A., A.J. Rowell, H.M. Muir-Wood, C.W. Pitrat, H. Schmidt, F.G. Stehli, D.V. Ager, A.D. Wright, G.F. Elliot, T.W. Amsden, M.J.S. Rudwick, K. Hatai, G. Biernat, D.J. McLaren, A.J. Boucot, J.G. Johnson, R.D. Staton, R.E. Grant and H.M. 1965. Treatise on Invertebrate Palaeontology (Part H, Brachiopoda). Geological Society of America, Boulder, and University of Kansas Press, Lawrence, 927 p.
- Williams, A., C.H.C. Brunton, S.J. Carlson et al. (44) 1997. Treatise on Invertebrate Palaeontology. Part H (Brachiopoda Revised). Volume 1: Introduction. Geological Society of America, Boulder, and University of Kansas Press, Lawrence, 539 p.
- Williams, A., C.H.C. Brunton, S.J. Carlson et al. (44) 2000. Treatise on Invertebrate Palaeontology. Part H (Brachiopoda revised). Volume 3: Linguliformea, Craniiformea, and Rhynchonelliformea (part). Geological Society of America, Boulder, and University of Kansas Press, Lawrence, 919 p.

ABOUT THE AUTHORS

Lucia Angiolini is a Palaeontologist at the Department of Earth Sciences, University of Milano, Italy. She received a PhD in Earth Sciences from Milano University in 1994. Lucia has 10 years experience in Permian brachiopods from the Peri-Gondwana region and the Cimmerian blocks from Turkey to the Himalayas through Oman and Karakorum. Her research interests include, besides pure taxonomy, quantitative biostratigraphy, palaeobiogeography based on multivariate analyses, and Permian correlation between Gondwanan and Tethyan realms.

Lucia.Angiolini@unimi.it



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



Miriam Zarbo obtained a BSc in Natural Sciences from the Università degli Studi di Milano in February 2004. The subject of her thesis was the systematic study of brachiopods species from the Khuff Formation of Oman and Saudi Arabia. She is currently continuing her education studying for a Masters in Palaeobiology at the Università degli Studi di Milano.



Manuscript received August 25, 2004
 Revised September 14, 2005
 Accepted February 1, 2006
 Press version proofread by the authors March 11, 2006