

## EVIDENCE OF A GUADALUPIAN AGE FOR THE KHUFF FORMATION OF SOUTHEASTERN OMAN: PRELIMINARY REPORT (with Paleontological Appendix by A. Nicora)

LUCIA ANGIOLINI\*, ALDA NICORA\*, HUGO BUCHER\*\*, DANIEL VACHARD\*\*\*, ALAIN PILLEVUIT\*\*\*\*, JEAN-PIERRE PLATEL°, JACK ROGER°,°°, AYMON BAUD°°°, JEAN BROUTIN#, HAROUB AL HASHMI## & JEAN MARCOUX'''

Received March 3, 1998; accepted May 21, 1998

*Key-words:* SE Oman, Khuff Fm., Brachiopods, Conodonts, Foraminifers, Guadalupian, Wordian.

*Riassunto.* La successione sedimentaria di età Guadalupiana, che affiora nella regione di Huqf (Sultanato di Oman), comprende la Formazione Gharif, terrigena e di ambiente fluviale e la soprastante Formazione Khuff che rappresenta la trasgressione marina sulla formazione precedente. La F. Khuff è costituita da marne e calcari bioclastici ed è stata suddivisa in quattro membri. Essa contiene una ricca fauna a brachiopodi, conodonti, foraminiferi, bivalvi, gasteropodi, ostracodi e cefalopodi. La fauna a brachiopodi della F. Khuff comprende soprattutto generi appartenenti agli ordini Strophomenida, Productida, Orthida e Terebratulida. I conodonti (le cui descrizioni sistematiche sono riportate nell'Appendice paleontologica) sono rappresentati da *Hindeodus excavatus* Behnken, 1975, *Merrilina* sp., *M. praedivergens* Kozur & Mostler, 1976 e *Sweetina* n. sp. I foraminiferi sono rappresentati da specie di *Miliolina* and *Rotaliina*. La fauna a brachiopodi e conodonti permette di datare la F. Khuff al Wordiano.

L'ambiente deposizionale della F. Khuff dell'Oman sudorientale corrisponde alla parte esterna di una vasta piattaforma carbonatica che ricopre la maggior parte della Piattaforma Arabica. La F. Khuff testimonia un ciclo trasgressivo-regressivo dovuto a subsidenza differenziale.

*Abstract.* The Guadalupian succession of the Huqf area (Sultanate of Oman) represents a mega-sequence comprising the fluvial terrigenous Gharif Formation and the overlying marine Khuff Formation. The Khuff Fm. is subdivided into four members and is composed of marls and bioclastic limestones. The Khuff Fm. yields a rich fauna of brachiopods, conodonts, foraminifers, bivalves, gastropods, ostracods and cephalopods. The brachiopod fauna of the Khuff Fm. includes strophomenids, productids, orthids and terebratulids. The associated conodont fauna includes *Hindeodus excavatus* Behnken, *Merrilina* sp., *M. praedivergens* Kozur & Mostler, and *Sweetina* n. sp. (sy-

stematic descriptions of conodonts are given in the Paleontological Appendix). Foraminifers are represented by species of *Miliolina* and *Rotaliina*. The Khuff Fm. is given a Wordian age, based on brachiopods and conodonts.

The depositional environment of the Khuff Fm. of southeastern Oman corresponds to the outer shelf of a large carbonate platform covering most of the Arabian Platform. The Khuff Fm. is interpreted as a major transgressive-regressive cycle related to differential subsidence.

### Introduction.

The Guadalupian Khuff Formation from southeastern Oman was deposited on the Arabian Shelf in a shallow carbonate platform facing the Neotethys spreading ocean. The Khuff Fm. is characterized by white and grey marly and bioclastic limestones containing a very rich and varied faunal assemblage, including bivalves, brachiopods, conodonts, foraminifers, gastropods, nautiloids, ostracods and trilobites.

A first description of the Khuff fauna from southeastern Oman was given by Hudson & Sudbury (1959), who named it as the Lusaba fauna, a name derived from the Wadi where this fauna was collected.

The present preliminary report deals with the description of the Khuff Formation and part of its fauna (brachiopods, conodonts and foraminifers) from the Huqf area in southeastern Oman (Fig. 1). Systematic descriptions and plates of the Khuff conodonts are provi-

\* Dip. Scienze della Terra, Via Mangiagalli 34, Milano, Italy, lucia@e35.gp.terra.unimi.it

\*\* Centre des Sciences de la Terre, CNRS UMR 5565, Université Claude Bernard Lyon I, 27-43 Bd. du 11 Novembre, F-69622 Villeurbanne Cedex, France

\*\*\* Univ. des Sciences et Technologie de Lille, 59655 Villeneuve D'ascq, France

\*\*\*\* Institut de Géologie, Université de Lausanne, UNIL-BFSH2, CH-1015 Lausanne

° BRGM SGR/AQI F-33600 Pessac, France

°° BRGM SGN/I2G, B.P. 6009, F-45060 Orleans Cedex 2, France

°°° Musée Cantonal de Géologie, UNIL-BFSH2, CH-1015 Lausanne, Suisse

# UPMC, Paléobotanique et Paléoécologie, 12 Rue Cuvier, Paris, F-75005, France

## Directorate of Petroleum and Minerals, Muscat, P.O. Box 551, Oman

''' Université Denis Diderot-Paris 7 et IGP Géologie, 2 Place Jussieu, F-75251, Paris, France

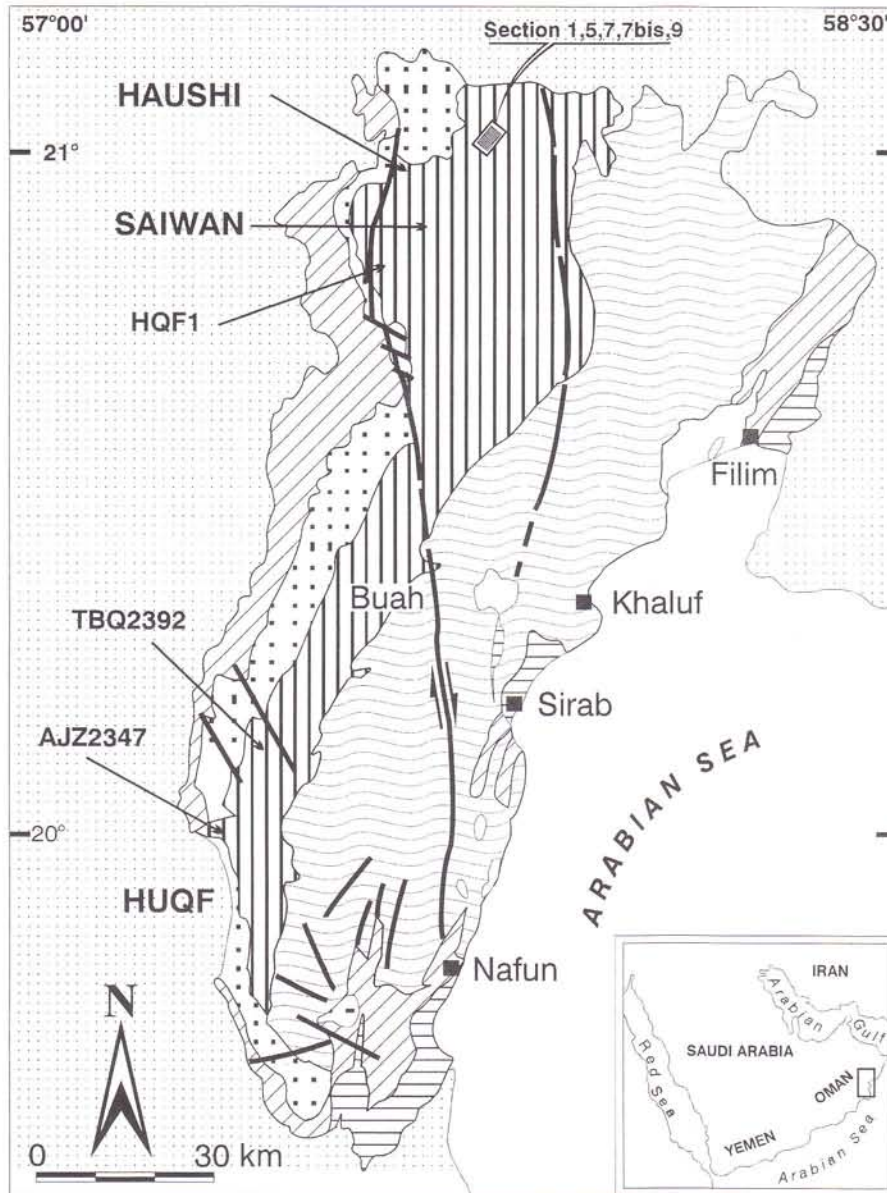


Fig. 1 - Geologic sketch map of the Haushi-Huqf area, southeastern Oman (modified from Broutin et al. 1995). The square indicates the area represented in Fig. 2.

Bucher, H. Al Hashmi, J. Marcoux, J.-P. Platel and J. Roger) supported by the Peri-Tethys Programme, whereas limited collections have been done by A. Pillevuit, J.P. Platel and J. Roger in 1991.

Bivalves and ostracods from the Khuff Fm. of southeastern Oman are being described by Dickins (submitted) and Craquin et al. (submitted), respectively.

**Geological setting.**

The Sultanate of Oman forms the southeastern margin of the Arabian Plate, delimited by the oceanic crust of the Arabian Sea and Gulf of Oman. The Huqf area is located in the southeastern Interior Oman (Fig. 1) and belongs to the autochthonous sedimentary cover of the Arabian Platform.

Late Paleozoic rocks are well exposed along the western side of the uplifted Huqf massif (Le Metour et al., 1994) and their stratigraphy has been revised in detail by Dubreuilh et al. (1992) and Roger et al. (1992). According to these authors and to more recent papers (Broutin et al., 1995; Angiolini et al., 1996; Angiolini et al. 1997; Craquin et al. submitted, and Cru-meyrolle et al., 1997), the Carboniferous to Permian succession of the Huqf area consists

ded in the Paleontological Appendix by A. Nicora. Systematic descriptions of the Khuff brachiopods will be published as a separate paper (Angiolini & Bucher, in progress), whereas a brief account on foraminifers by D. Vachard is here included.

Most of the fauna presently studied was sampled in 1995 by a team (L. Angiolini, A. Baud, J. Broutin, H.

of two mega-sequences separated by a regional unconformity, recording two major transgressive events respectively controlled by the last phase of the Gondwanan deglaciation and by the opening of the Neotethys.

The first mega-sequence (Haushi Group) comprises the Lower Permian glacio-lacustrine deposits of the Al Khlata Formation overlaid by the transgressive mari-

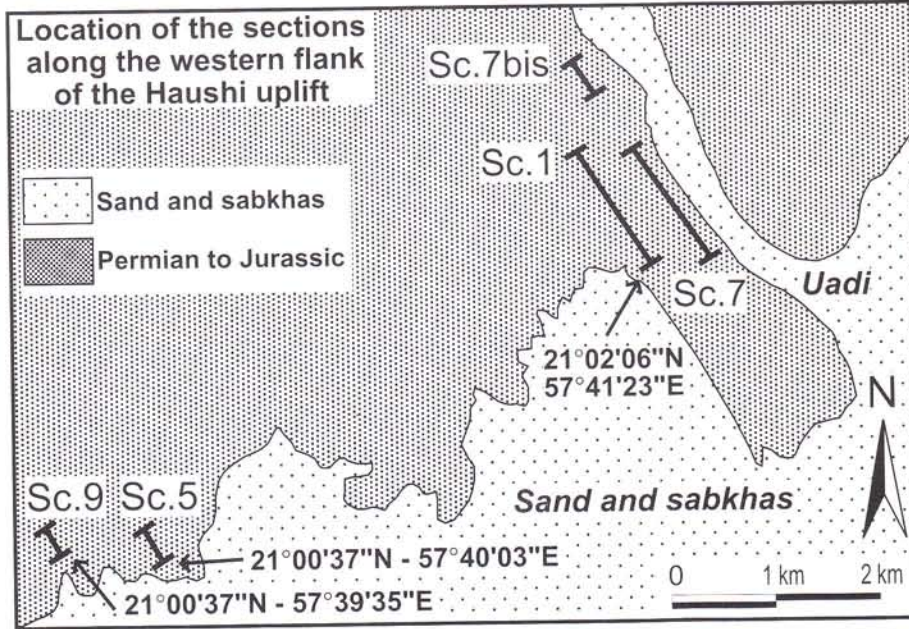


Fig. 2 - Geographic location of the 5 stratigraphic sections on which the composite section of Fig. 3 is based (drawn from aerial photograph).

- five sections (from west to east: section 9, section 5, section 1, section 7 and section 7bis), located between  $21^{\circ}00'37''$  N- $57^{\circ}39'35''$  E and  $21^{\circ}02'06''$  N- $57^{\circ}41'23''$  E, along the north-western flank of the Haushi uplift (Fig. 2).

The best outcrops of the Khuff Fm. are represented by the latter five sections, which have been correlated by conspicuous lithological markers in the composite section of Fig. 3.

ne sandstones and limestones of the Saiwan Formation, Sakmarian in age (Angiolini et al., 1997). This mega-sequence disconformably overlies the Lower Paleozoic series.

The second mega-sequence (Akhdar Group), rests unconformably on the Haushi Group and includes the fluvial shales and sandstones of the Gharif Formation followed by the marine marls and bioclastic limestones of the Khuff Formation. The age of this mega-sequence spans the ?Roadian to Wordian time interval (Broutin et al., 1995; this paper). The Gharif Fm. represents a hydrocarbon reservoir of the Ghaba salt basin, one of the major petroliferous region of Oman (Crumeyrolle et al., 1997). In the Huqf area, the Khuff Fm. is capped by the continental sandstones and siltstones of the Minjur Fm, whose age is poorly constrained (Triassic to Jurassic). The sharp transition between the Khuff and the Minjur Fms. corresponds to an angular unconformity.

#### The Khuff Formation in southeastern Oman.

The Khuff Formation was formally introduced by Steineke et al. (1958) to encompass Late Permian carbonate rocks of Central Arabia. A synthesis of the Khuff Fm. of south-central Saudi Arabia has been recently published by Al-Aswad (1997).

The Khuff Fm. of the Huqf area (southeastern Oman) has been studied along several sections (Fig. 1):

- section HQF1 located 8 km south-west of the Saiwan 1 oil well, along the jeep trail to Ghaba;
- section TBQ2392 located about 90 km south of Saiwan;
- section AJZ2347 located 12 km south of the previous one;

#### Lithology.

In the Huqf area, the Khuff Fm. conformably overlies the bioturbated sandstones of the uppermost Gharif Fm. The Khuff Fm. reaches a maximum thickness of 30 to 40 m and consists of sandstones, marls and bioclastic limestones very rich in brachiopods, conodonts, foraminifers, ammonoids, trilobites, gastropods, bivalves and ostracods. The sharp base of the non marine sandstones and claystones of the Minjur Fm. cuts across the Khuff Fm. with a regional angular unconformity.

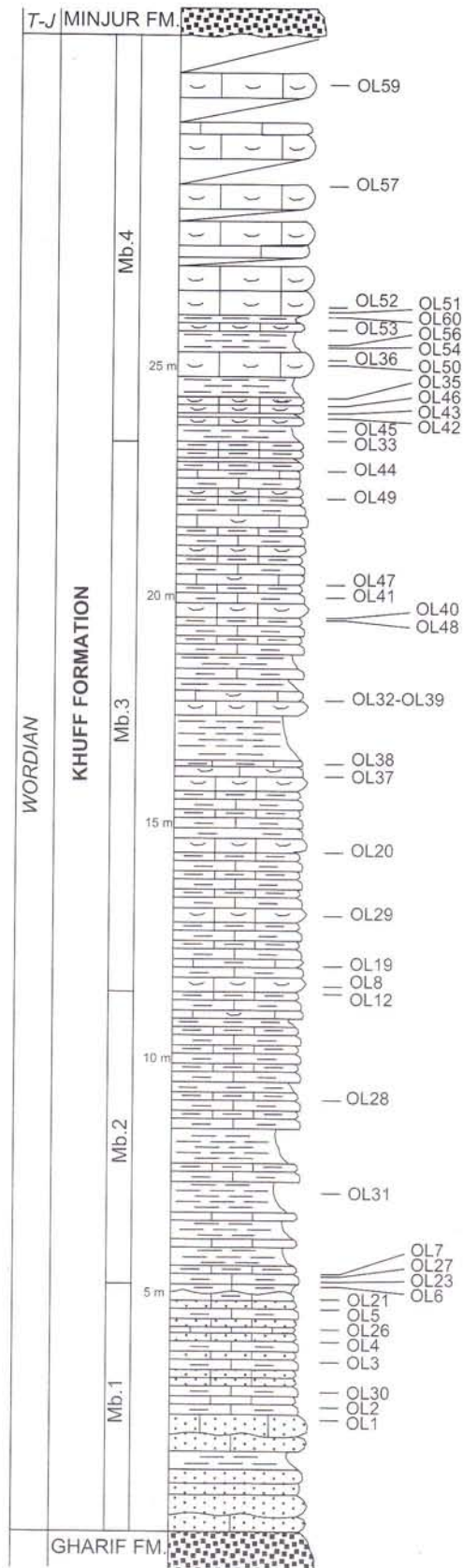
The Khuff Fm. is subdivided into four members, from bottom to top:




- bioclastic quartzarenites with wave ripples, passing upward to marly and bioclastic limestones (Mb. 1);
- laminated and bioturbated marls and marly limestones (Mb. 2);
- marls, marly limestones and cross-bedded bioclastic limestones (Mb. 3);
- coarse bioclastic limestones with bioturbated silty and quartzose marls (Mb. 4).

The fossiliferous levels are widespread throughout all the members and are particularly abundant in the first and fourth members.

#### Brachiopods.

The brachiopod fauna of the Khuff Fm. is numerically dominated by the quasi-infaunal productids *Celebetes* sp., *Dyschrestia* sp., *Juresania omanensis* Hudson & Sudbury, 1959 and *Linoproductus* aff. *kaseti* Grant, 1976. Terebratulids belonging to the genus *Dielasma* are also common. The productids *Kozlowskia tescorum* (Hudson & Sudbury, 1959), *Bilotina* sp. and *Grandaurispina* sp., the orthid *Orthotichia* cf. *bistriata* Reed, 1944, the stro-



-  Limestones
-  Bioclastic limestones
-  Marly limestones

phomenids *Perigeyerella* sp. and *Derbyia* cf. *diversa* Reed, 1944 and the chonetid *Neochonetes* (*Sommeriella*) *arabicus* (Hudson & Sudbury, 1959) are subordinated. Specimens of *Haydenella* sp., *Calliprotonia* sp., *Magniplicatina* sp., *Cyclacantharia* sp., *Acritosia* sp., *Cleiothyridina* cf. *seriata* Grant, 1976, and *Hemiptychina* sp. are very rare. This fauna shows strong affinities with the brachiopods of the Amb Fm. of Salt Range, Pakistan (Waagen, 1882-1885; Reed, 1944) and those of the Rat Buri Limestone of South Thailand (Grant, 1976).

The Khuff brachiopod fauna is a mixed/transitional fauna in the sense of Shi et al. (1995), comprising wide-ranging (*Orthotichia*, *Derbyia*, *Linoproductus*, *Cleiothyridina*, and *Dielasma*), Tethyan (*Perigeyerella*, *Haydenella*, *Kozłowskaia*, *Calliprotonia*, *Grandawispina*, *Cyclacantharia*, *Acritosia*), Gondwanan (*Sommeriella* and *Dyschrestia*) and endemic genera (*Celebetes* and *Bilotina*). The dominance of Tethyan genera suggests warm/sub-tropical climate conditions.

#### Conodonts.

The conodont fauna described by A. Nicora in the Paleontological Appendix was obtained from very small samples, mostly derived from the matrix of brachiopods. Although conodonts are rare, possibly because of sample size, some biostratigraphically significant species have been recovered. The conodont assemblage detected in samples OL7, OL8, OL9, OL12, OL27 (Fig. 2) consists of *Hindeodus excavatus* Behnken, 1975 *sensu* Wardlaw & Collinson (1984), *Merrillina* sp., *M. praedivergens* Kozur & Mostler, 1976, and *Sweetina* n. sp. of Wardlaw (pers. comm., 1998). This assemblage is mostly similar to that of the Amb Fm. of Salt Range (Pakistan) described by Wardlaw & Pogue (1995).

As for the Khuff brachiopods, also the conodonts record a mixing of cool water (*Merrillina*) and Tethyan (*Sweetina*) faunal elements.

#### Foraminifers.

Bioclastic packstones of the Khuff Fm. contain the following assemblage:

- a) Metazoa remains: gastropods, bivalves, conularia, bryozoa, spines of brachiopods (productids and athyridids), ostracodes, crinoids and bone fragments;
- b) Algae: *Permocalculus* cf. *tenellus* (Pia, 1935);
- c) Pseudo-algae: *Stacheoides* sp.
- d) Foraminifera:

Fig. 3 - Composite section of the Khuff Fm. along the north-western flank of the Haushi uplift. OL numbers represent fossiliferous levels. Sample OL9 is not shown on the composite section, being collected in the scree of level OL8.

## Endothyrida:

- *Diplosphaerina* ex gr. *inaequalis* (Derville, 1931)
- *Earlandia* ex gr. *minor* (Rauzer, 1948);

## Miliolina:

- *Calcitornella* sp.
- *Hemigordius* ex gr. *permicus* (Grozdilova, 1956)

## Rotaliina Nodosariacea:

- *Nodosaria* sp.
- *Geinitzina* spp.
- *Pachyphloia robusta* Miklukho-Maclay, 1954
- *Dentalina* cf. *ampullaeformis* Zolotova & Shiryaeva, 1982
- *Rectoglandulina salebra* Baryshnikov, 1982
- *Langella lepida* Wang, 1988
- *Langella elongata* Wang, 1988

This assemblage is relatively similar to that of the Chihhsia Fm. of South China and of the Kungurian of Urals.

## Depositional environment and cyclicity.

The Khuff Fm. represents the onset of a carbonate shelf, on top of the coastal-plain deposits of the Gharif Fm. More precisely, the first member represents a transgressive shallow water marine environment with flood sediments reworked by waves and/or tidal currents; the second member records a significant drowning below storm wave base, in a depositional setting of the outer shelf; the third member suggests deposition above wave base, occasionally affected by storms; the fourth member suggests a shallow-water carbonate shelf.

The entire Khuff Fm., with the exception of the base of the first member, has been probably deposited on the outer shelf of a large carbonate platform. This is in accordance with the conodont distribution (Kozur, 1995; Wardlaw, 1995) and it is also supported by the palaeoecological analyses of the brachiopod fauna: the first member, with abundance of chonetids, represents the marine transgression on the continental Gharif Fm.; the second and third member, dominated by quasi-infaunal productids and cool water conodont elements, suggest rather deep muddy bottoms, occasionally affected by storm action, reworking and accumulating brachiopods and molluscs; the fourth member, with increase of attached forms (e.g. terebratulids) mostly disarticulated, indicates shallow-water, turbulent sandy bottom conditions.

This interpretation agrees with the Khuff Fm. depositional models by Al Jallal (1994, p. 113) and Al-Aswad (1997, p. 319), with an inner shelf in the west (covering most of the Saudi Arabia), an outer shelf in the east (Oman) and a shelf margin (coral-algal buildups), slope and basin in the Oman Mountains (Hawasina nappes) and Iran, the Huqf area being located in the outer shelf.

Facies evolution of the Khuff Fm. indicates an asymmetric transgressive-regressive cycle, with a distinctively rapid drowning phase of the carbonate shelf

(abrupt transition from the shore face Mb. 1 to the offshore Mb. 2). In fact, according to Broutin et al. (1995, p. 1073), the uppermost Gharif Fm. and the basal Khuff Fm. (i.e. the Mb. 1 and the lower part of Mb. 2) represent the Transgressive Systems Tract, the Maximum Flooding Surface being recorded in the lower part of the second member of the Khuff Fm, whereas the third to fourth members are interpreted as Highstand Systems Tract. This transgressive-regressive cycle may corresponds in part to the first of the four third-order cycles recognized by Al-Aswad (1997) in the Khuff Fm. of Saudi Arabia. According to Al-Aswad (1997), Cycle 1 lasts 4,08 million year and, as the other three cycles, is related to differential tectonic subsidence associated with the opening of the Neotethys.

## Age.

In the present paper, the nomenclature of Permian series and stages approved by the Permian Subcommission of ICS and published by Jin et al. (1997) is followed. As the correlation of the newly proposed classification (Jin et al., 1997) and the Tethyan Scale (Leven, 1980; 1981) needs clarification, the references to the Tethyan stages by previous authors are preserved in their original forms. However, a tentative correlation of the Guadalupian with the Kubergandian-Midian stages of the Tethyan Scale (Leven, 1980) is attempted in Table 1. According to the revision of Kotlyar & Pronina (1995), the mid-Permian Tethyan stages *sensu* Leven show inconsistencies in their own definitions and the Murgabian must be restricted only to the *Neoschwagerina craticulifera* Zone. In fact, the Midian *sensu* Leven (1980) is partially overlapping with the Murgabian *sensu* Leven (1980) (i.e. the lower *Yabeina-Lepidolina* Zone coincides with the *N. margaritae* Zone) and the interpretation of the Kubergandian has been changed several times (Kotlyar & Pronina, 1995, p. 26).

The age of the Khuff Fm. from southeastern Oman was considered Late Artinskian or not younger than Early Permian by most authors (e.g. Hudson & Sudbury, 1959; Archbold & Burrett, 1990; Grant, 1976; Shi et al., 1995; Archbold & Shi, 1995), while Dubreuilh et al. (1992), Roger et al. (1992), Dickins (1992), Le Metour et al. (1994), Broutin et al. (1995) and Al-Aswad (1997) assumed a Late Permian age.

In the present paper, the Khuff Fm. from southeastern Oman is dated as middle Guadalupian and more precisely as Wordian [roughly corresponding to Murgabian *sensu* Kotlyar & Pronina (1995) (*Neoschwagerina craticulifera* Zone) of the Tethyan scale (see Table 1)], as indicated by the brachiopods, conodonts, foraminifers and bivalves (see Dickins, submitted, for the age of the bivalves).

Leven 1980	Kotlyar & Pronina 1995	Fusulinids	Jin et al. 1997
MIDIAN	MIDIAN	<i>Lepidolina</i> <i>Y. globosa</i>	CAPITANIAN
		<i>N. margaritae</i> <i>Y. archaica</i>	WORDIAN
MURGABIAN	MURGABIAN	<i>N. craticulifera</i>	
KUBERG.	KUBERGANDIAN	<i>N. simplex</i> <i>Cancellina</i> <i>Armenina</i>	

Tab. 1 - Mid-Permian (Guadalupian) correlations among the Tethyan scale *sensu* Leven (1980, 1981), the Tethyan scale as revised by Kotlyar & Pronina (1995) and the Permian chronostratigraphic subdivisions by Jin et al. (1997). As the Tethyan scale is based on fusulinids, also the fusulinid zones are reported. IR is the position of the Illawarra Reversal according to Glenister & Wardlaw (1998). The dotted area represents the overlapping between the late Murgabian and the early Midian in the Tethyan scale *sensu* Leven (1980).

The brachiopods of the Khuff Fm. are dated to the late Roadian-Wordian on the basis of the occurrence of:

- taxa similar to those of the Roadian-Wordian Amb Fm. (age assignment according to Wardlaw & Pogue, 1995; Wardlaw, pers. comm.), such as *O. cf. bistrifurcata*, *D. cf. diversa*, the genus *Bilotina* and species of the genera *Dielasma* and *Hemiptychina*;

- taxa similar to those of the Rat Buri Lmst. of South Thailand (Kubergandian to Dzhulfian in age according to Fontaine & Suteethorn (1988) with a Kubergandian age for the brachiopod beds) such as *L. aff. kaseti*, *C. cf. seriata* and the genera *Celebetes* and *Dyschrestia*;

- *Perigeyerella*, which is confined to the Late Permian (Williams et al., 1965);

- *Haydenella*, widespread in the mid to Late Permian Amb, Wargal and Chhidru Fms. of Salt Range (Pakistan) (Waagen, 1882-1885; Reed, 1944; Grant, 1976) and in the Late Permian of South and East Asia (Diener, 1915; Yanagida, 1964; Fantini Sestini, 1965; Ruzhentsev & Sarycheva, 1965; Grant, 1976);

- *Cyclacantharia*, restricted to the Guadalupian of West Texas (Cooper & Grant, 1975);

- the tiny species *N. (S.) arabicus*, as small representatives of *Neochonetes* are characteristic of the Kungurian and subsequent stages, according to Archbold (1981);

- *Cleiothyridina* of the sulcate type, which, according to Dickins et al. (1989), indicates a Kazanian age.

The conodont assemblage detected in the lower-middle part of the Khuff Fm. (samples OL7, OL8, OL9, OL12, OL27) suggests a late Wordian to Capitanian age (Wardlaw & Pogue, 1995; Kozur, 1995; Wardlaw and Kozur, pers. comm.). In particular, the Oman specimens of *Hindeodus excavatus* are mostly similar to those described by Wardlaw & Collinson (1984) from the Word and Capitan Fms. of West Texas and to a species of *Hindeodus* found in the Amb and Wargal Fms. of Salt Range, Pakistan (Wardlaw & Pogue, 1995; Wardlaw, pers. comm.), whereas *M. praedivergens* ranges from the late Wordian to the Capitanian.

According to Dickins (submitted), the bivalve assemblage suggests a Kubergandian to Murgabian age.

Due to the lack of fusulinids, the foraminifer assemblage cannot support a more precise age than Artinskian to early-Wordian. The oldest age (i.e. Artinskian) is constrained by the occurrence of genus *Langella*, which appears in the Artinskian in South China; the younger age (i.e. early Wordian) is inferred by the absence of strong modifications in the Nodosariacean assemblage, which occur later in the Wordian.

#### PLATE 1

(All specimens x 100).

Fig. 1-3 - *Hindeodus excavatus* Behnken *sensu* Wardlaw & Collinson (1984) - 1a, b Pa element, lateral and oblique/lower view; 2, 3 Sc elements, lateral view (OL7).

Fig. 4-6 - *Merrillina* sp. - Sc elements, lateral views (OL7).

Fig. 7-8 - *Hindeodus* sp. - Pa element, lateral view and Pb element, lateral view (OL8).

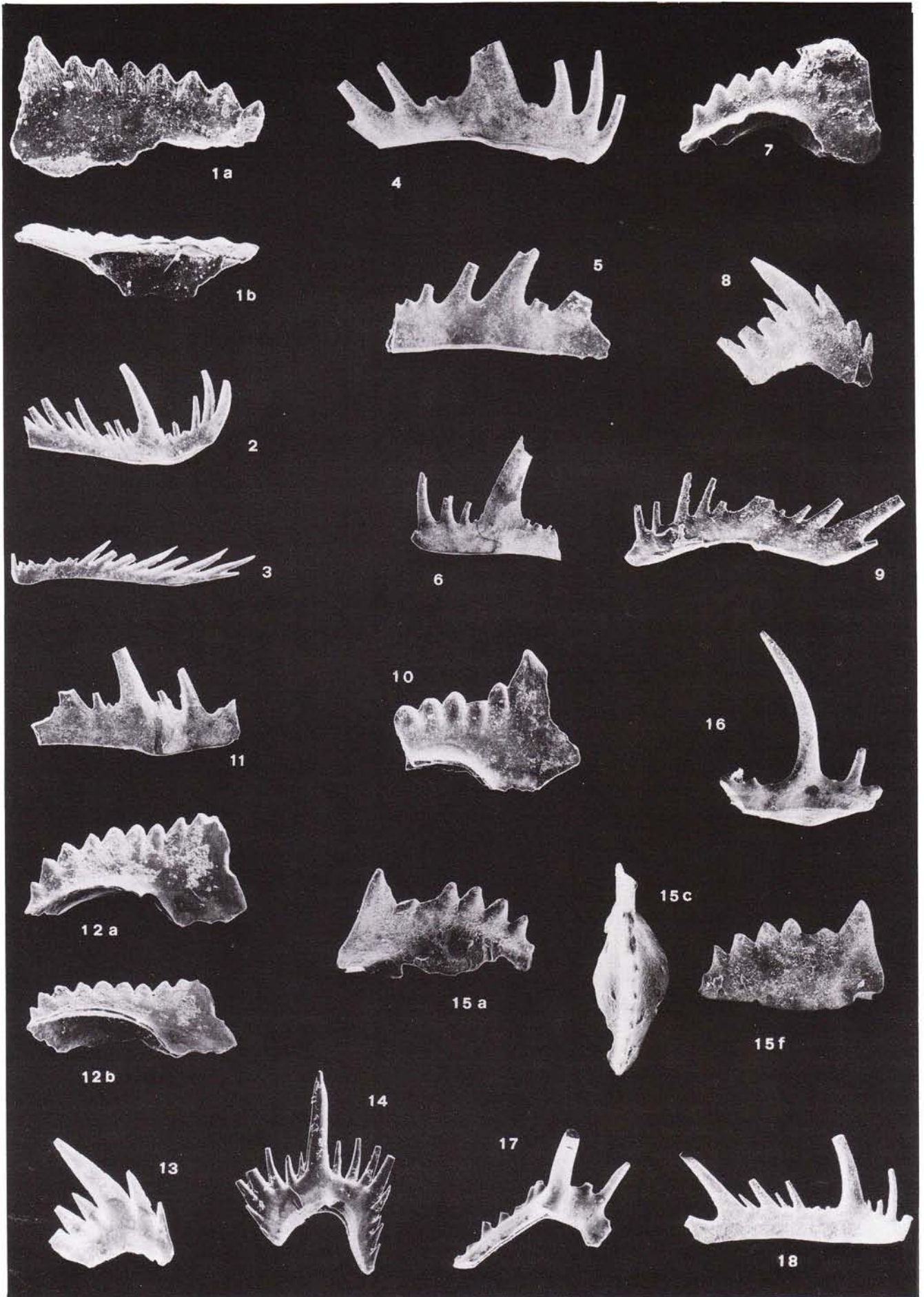
Fig. 9 - *Merrillina* sp. - Sb element, inner lateral view (OL8).

Fig. 10 - *Hindeodus* sp. - Pa element, lateral view (OL9).

Fig. 11 - *Merrillina* sp. - Sa element, lateral view (OL9).

Fig. 12-15 - *Hindeodus excavatus* Behnken *sensu* Wardlaw & Collinson (1984) - 12a, b, Pa element, lateral and oblique/lower view; 13, Pb element, lateral view; 14, Sa element, posterior view; 15a, c, f, Pa element, inner, upper and outer views (OL12).

Fig. 16-18 - *Merrillina* sp. - 16 Sc element, inner view; 17, M element, posterior view; 18, Sc element, lateral view (OL12).



In conclusion, if the brachiopods and the bivalves both support a Roadian-Wordian age, the conodonts and the foraminifers point out an age difference: the former indicating an age no older than late Wordian and the latter suggesting an age no younger than early Wordian. As this is only a preliminary report and the Guadalupian correlations are not yet firmly established, we prefer at present to suggest a general Wordian age for the Khuff Fm.

### Conclusions.

The marine marls and bioclastic limestones of the Khuff Fm. of southeastern Oman record the marine transgression on the continental Gharif Fm. with the installation of a large carbonate platform which drows rapidly below storm wave base and then return to shallow

water conditions. Both brachiopods and conodonts record a mixing of cool water and warm faunal elements: the dominance of Tethyan genera suggest subtropical climate conditions.

The rich fauna of the Khuff Fm. indicates a Wordian age, thus dating in southeastern Oman the mid-Permian global regression and subsequent transgression recognized by Dickins (1997) and associated by the author to the Hunter-Bowen Orogenic Phase.

The varied fauna of the Khuff Fm. is of particular importance in establishing mid-Permian correlation. In fact, the concomitant occurrence of conodonts, brachiopods, molluscs and foraminifers make correlation easy both with the paleotropical and the high latitude regions. The southeastern Oman fauna can thus be correlated with the mid-Permian faunas from Iran to South Thailand and with the Guadalupian of West Texas.

## PALEONTOLOGICAL APPENDIX

by A. Nicora

### Conodont systematic descriptions.

All the described specimens are housed in the Paleontological Museum of the University of Milan, Italy. Field numbers of single fossiliferous beds [OL prefixed (Fig. 3)] are reported.

#### Genus *Merrillina* Kozur, 1975

Type-species. *Merrillina divergens* (Bender & Stoppel, 1965)

#### *Merrillina praedivergens* Kozur & Mostler, 1976.

Pl. 2, fig. 1, 4-6.

1971 *Neospathodus divergens* - Clark & Behnken, p. 436-437, pl. 2, fig. 6.

1976 *Merrillina praedivergens* Kozur & Mostler, p. 11, pl. 1, fig. 8.

1984 *Merrillina divergens* - Wardlaw & Collinson, p. 269, pl. 3, fig. 1-3.

Material - 2 Pa elements and several ramiforms: OL27.

Occurrence and age - Section 7: OL27. Khuff Fm., Wordian.

Description - A species of *Merrillina* characterized by a Pa element with a thick, long cusp posteriorly directed and weakly inclined toward the base; with 3 massive, thick, short denticles, partly fused the two in the middle, decreasing in size anteriorly. Basal cavity broad, laterally expanded, with roughly triangular-shape. The ramiform elements of the apparatus that are similar to those of *M. galeata* and partly of *Stepanovites* (in the latter form larger, more robust and with stronger flaring basal cavities) are illustrated on plates 1 and 2.

Discussion - The species is represented in the material at hand only by two Pa elements. With respect to the compared or illustrated material, the unit seems to be broader, has no posterior denticles, the cusp is considerably larger and longer than following denticles and slightly inclined. With respect to *M. divergens* (Bender & Stoppel), the cusp is conspicuously longer and the blade is longer and lower. Originally Kozur & Mostler

### PLATE 2

(All specimens x 100).

Fig. 1, 4-6 - *Merrillina praedivergens* Kozur & Mostler - 1a, b, Pa element, lateral and oblique/lower views; 1d, enlargement of 1b; 4-5, Pb elements, lateral views; 6, Sc element, lateral view (OL27).

Fig. 2-3, 7, 9-11 - *Hindeodus excavatus* Behnken *sensu* Wardlaw & Collinson (1984) - 2a, c, f, Pa element, inner lateral, upper and outer lateral views; 3a, b, Pa element, outer lateral and upper views; 7, Sc element, lateral view; 9, Sc element, lateral view; 10, M element, posterior view; 11, Sc element, lateral view (OL27).

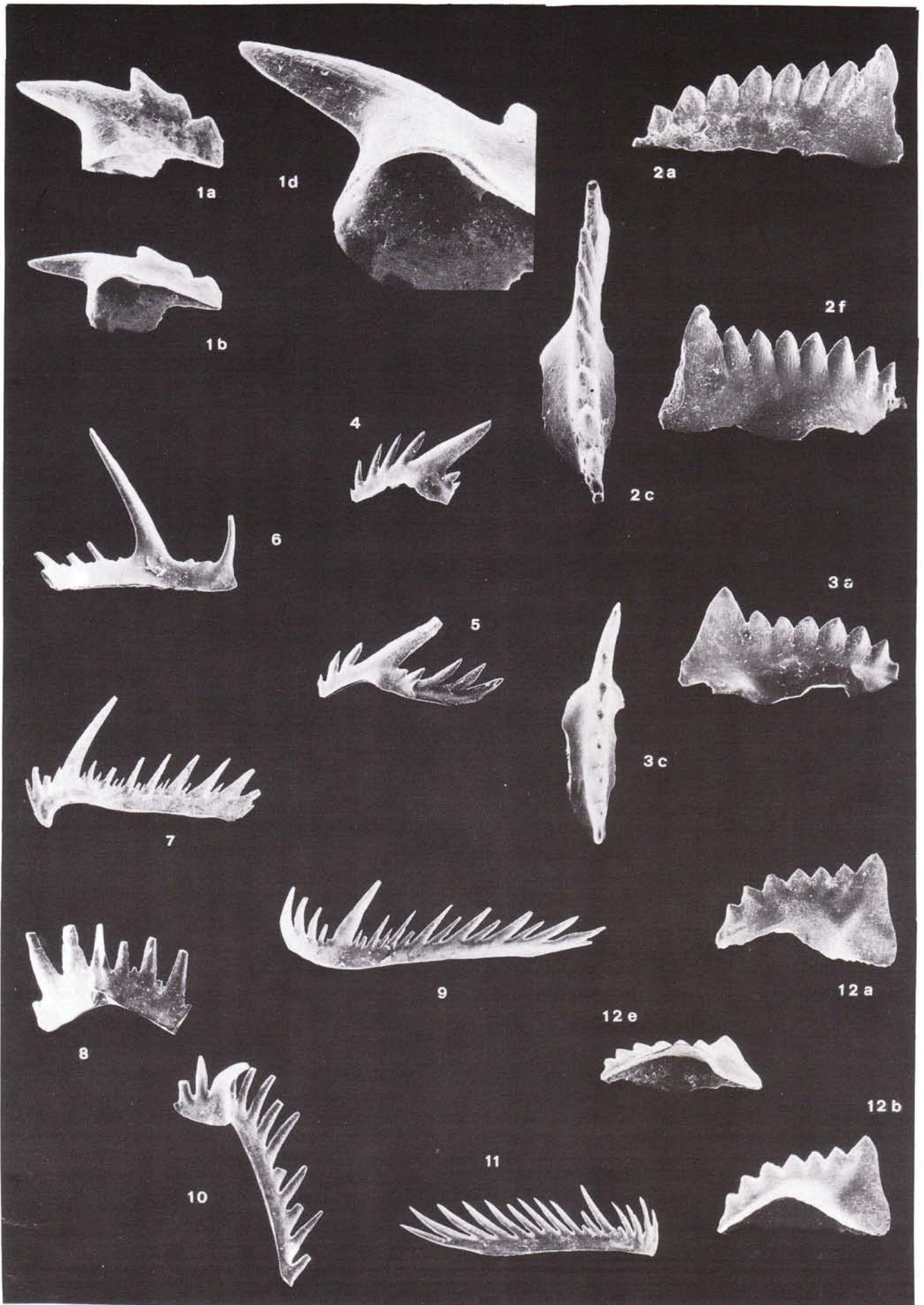
Fig. 8 - *Sweetina* n. sp. of Wardlaw (pers. comm., 1998) - Pa element, inner view (OL27).

Fig. 9, 10 - *Merrillina praedivergens* Kozur & Mostler - 9, Sc element, lateral view; 10 M element, posterior view (OL27).

Fig. 11 - *Merrillina* sp - Sc element (OL27).

Fig. 12 - *Hindeodus excavatus* Behnken *sensu* Wardlaw & Collinson (1984) - 12a, b, e, Pa element, juvenile form, lateral, lateral/lower and lower views (OL50).





(1976) included only specimens with 1-2 denticles behind the cusp in the species, but this feature is variable and there occur also forms of *M. praedivergens* without denticles behind the cusp (Kozur pers. comm.). Furthermore, Wardlaw & Collinson (1984) illustrate forms with and without a denticle behind the cusp from the same sample suggesting this is not a diagnostic feature for this species.

Other occurrences - *Merrillina praedivergens* was originally described by Kozur & Mostler (1976) for a specimen figured by Clark & Behnken (1971) from the upper Gerster Formation (Capitanian) of Nevada. Wardlaw & Collinson (1984) reported the species under *Merrillina divergens* (Bender & Stoppel) from the upper Wordian part of the Phosphoria Formation of Wyoming. In this material one specimen has a denticle behind the cusp as in the holotype, whereas two specimens have no denticles behind the cusp as in the present material from southeastern Oman. According to Kozur (1995) the species-range is late Wordian to Capitanian.

#### Genus *Hindeodus* Rexroad & Furnish, 1964

Type-species. *Hindeodus cristulus* (Youngquist & Miller, 1949)

#### *Hindeodus excavatus* (Behnken, 1975)

Pl. 1, fig. 1-3, 12-15; Pl. 2, fig. 2-3, 7, 9-12.

1975 *Ellisonia excavata* Behnken, p. 302, pl. 1, fig. 9-14.

1975 *Anchignathodus minutus* - Behnken, p. 297, pl. 1, fig. 16-18.

1984 *Hindeodus excavatus* - Wardlaw & Collinson, p. 268-269, pl. 5, fig. 1, 2, 4-9.

Material - 7 Pa elements and several ramiforms: OL7, OL12, OL27, OL50.

Occurrence and age - Section 1: OL7; section 5: OL12; section 7: OL27. Khuff Fm., Wordian.

Description - A species of *Hindeodus* characterized by Pa element with a relatively short posterior blade that bears 6-8 short, massive conical denticles, fused at the base but distinctly separated at apex, that gradually and slowly decrease in size toward the posterior end. Cusp large, but not thickened, about one-third longer than the denticles. In juveniles and in stratigraphically higher specimens the basal cavity is wide beneath the posterior blade.

Discussion - According to personal communication of Dr. Wardlaw, this species belongs to a new species from the Word and Capitan Fms. of West Texas. However, as this new species has not been published yet, it was suggested to refer the Oman specimens to *Hindeodus excavatus* Behnken as figured by Wardlaw & Collinson (1984), in order to avoid the introduction of *nomina nuda*. The apparatus of this species is represented, in our material, by few broken Pa and ramiform elements. Pa elements of this species differ from those of *H. latidentatus* Kozur, Mostler & Rahimi-Yazd, 1975 because denticles are less discrete, the cusp is shorter and relatively fused to the anteriormost denticle.

Other occurrences - According to Wardlaw (pers. comm.) the specimens of *Hindeodus excavatus* from southeastern Oman are similar to those found in the Roadian-Capitanian formations of West Texas by Wardlaw & Collinson (1984) and in the Amb and Wargal Fms. of Salt Range, Pakistan (Wardlaw & Pogue, 1995). According to Kozur (1995) *H. excavatus* ranges from the Artinskian to the Capitanian.

#### Acknowledgements.

H. Kozur and B. Wardlaw are warmly thanked for discussion on the Khuff conodonts. M. Gaetani, H. Brunton and P. Racheboeuf gave precious advises on an early version of this paper. Finally, the manuscript deeply benefited of the review by F. Hirsch and B. Wardlaw.

## REFERENCES

- Al-Aswad A.A. (1997) - Stratigraphy, sedimentary environment and depositional evolution of the Khuff Fm. in south-central Saudi Arabia. *Journ. Petr. Geol.*, v. 20, n. 3, pp. 307-326, London.
- Al-Jallal I.A. (1994) - The Khuff formation. Its regional reservoir potential in Saudi Arabia and other Gulf Countries; depositional and stratigraphic approach. In Al-Husseini M.I. (Ed.) - Middle East Petroleum Geosciences (Goe94): Selected papers from the Middle East Geosciences Conference, pp. 103-119, Bahrain.
- Angiolini L., Bucher H., Pillecuit A., Platel J.P., Roger J., Broutin J., Baud A., Marcoux J., & Al Hashmi H. (1997) - Early Permian (Sakmarian) brachiopods from Southeastern Oman. *Geobios*, v. 30, n. 3, pp. 379-405, Lyon.
- Angiolini L., Nicora A., Bucher H., Baud A., Vachard D., Platel J.P., Pillecuit A., Roger J., Broutin J., Marcoux J., Al Hashmi H. (1996) - Late Permian fauna from the Khuff Formation, South Oman. *Permophiles*, 29, pp. 62-64. A Newsletter of SCPS. Ottawa.
- Archbold N.W. (1981) - Studies on Western Australian Permian brachiopods. 2 The Family Rugosochonetidae Muir-Wood 1960. *Proc. R. Soc. Victoria*, v. 93, pp. 109-120, Melbourne.
- Archbold N.W. & Burret C.F. (1990) - Re-assessment of the Arabian Permian chonetid brachiopod *Chonetes arabi-*

- cus Hudson & Sudbury, 1959. *Proc. R. Soc. Victoria*, v. 102, pp. 121-122, Melbourne.
- Archbold N.W. & Shi G.R. (1995) - Permian brachiopod faunas of Western Australia: Gondwanan-Asian relationships and Permian climate. *Journ. Southeast Asian Earth Sc.*, v. 11, pp. 207-215, London.
- Behnken F.H. (1975) - Leonardian and Guadalupian (Permian) conodont biostratigraphy in western and South-Western United States. *Journ. Paleont.*, v. 49, pp. 284-315, Boulder.
- Broutin J., Roger J., Platel J.P., Angiolini L., Baud A., Bucher H., Marcoux J. & Al Hashmi H. (1995) - The Permian Pangea. Phytogeographic implications of the new paleontological discoveries in Oman (Arabian Peninsula). *Compt. Rend. Acad. Sci.*, v. 321, IIa, pp. 1069-1086, Paris.
- Clark D.L. & Behnken F.H. (1971) - Conodonts and biostratigraphy of the Permian. In Sweet W.C. and Berstrom S.M. (Eds.) - Conodont Biostratigraphy. *Geol. Soc. Amer. Mem.* v. 127, pp. 415-439, Boulder.
- Cooper G.A. & Grant R.E. (1975) - Permian Brachiopods of West Texas, V. *Smithsonian Contributions to Paleobiology*, v. 19, pp. 795-1920, Washington.
- Crasquin-Soleau S., Broutin J., Roger J., Platel J.P., Al Hashmi H., Angiolini L., Baud A., Bucher H. & Marcoux J. - First Permian ostracod fauna from the Arabian Plate (Khuff Formation - Sultanate of Oman). Submitted to *Micropaleontology*, New York.
- Crumeyrolle P., Razin P., Roger J., Platel J.P. and Broutin J. (1997) - Le complexe transgressif Permien superieur du Huqf (Oman): sedimentologie, stratigraphie et geometrie des reservoirs. 6<sup>e</sup> Congres Francais de Sedimentologie. Livre des resumes, 27, 293 pp., Paris.
- Dickins J.M. (1992) - Permian geology of Gondwana countries: an overview. *Int. Geol. Riv.*, v. 34, n. 10, pp. 986-1000, Silver Spring.
- Dickins J.M. (1997) - The mid-Permian: major changes in geology, environment and faunas and some evolutionary implications. In J.M. Dickins, Yang Zunyi, Yin Hongfu, S.G. Lucas (Eds.) - Late Paleozoic and Early Mesozoic Circum-Pacific events and their global correlation, Cambridge Univ. Press, pp. 118-124, Cambridge.
- Dickins J.M. - Mid Permian (Kubergandian-Murgabian) Bivalves from the Khuff Formation, Oman: implications for world events and correlation. Submitted to *Riv. It. Paleont. Strat.*, Milano.
- Dickins J.M., Archbold N.W., Thomas G.A. & Campbell H.S. (1989) - Mid Permian correlations. XI Congres International de Stratigraphie et Géologie du Carbonifère, Compte Rendu, v. 2, pp. 185-198, Beijing.
- Diener C. (1915) - The Anthracolithic Faunas of Kashmir, Kanaur and Spiti. *Palaeont. Indica N.S.*, v. 5, n. 2, pp. 1-135, Calcutta.
- Dubreuilh J., Platel J.P., Le Metour J., Roger J., Wyns R., Bhechennech F. & Berthiaux A. (1992) - Explanatory notes to the Geological map of Khaluf, Sheet NF 40-15, scale 1:250000. Directorate General of Minerals, Oman Ministry of Petroleum and Minerals, Muscat.
- Fantini Sestini N. (1965) - Permian fossils of Shaksgam Valley. In A. Desio (Ed.) - Italian expeditions to the Karakorum (K2) and Hindu Kush. IV. *Paleontology, Zoology, Botany*, v. 1, n. 1, pp. 149-192, Leiden.
- Fontaine H. & Suteethorn V. (1988) - Late Palaeozoic and Mesozoic fossils of West Thailand and their environments. *CCOP Technical Bulletin*, v. 20, pp. 1-211.
- Glenister B.F. & Wardlaw B.R. (1998) - Permian Chronostratigraphic Subdivisions. *Permophiles*, 31, pp. 35-36. A Newsletter of SCPS. Ottawa.
- Grant R.E. 1976 - Permian brachiopods from southern Thailand. *Paleont. Soc. Mem.*, 9, pp. 1-254, Tulsa.
- Hudson R.G.S. & Sudbury M. (1959) - Permian Brachiopoda from south-east Arabia. *Notes et Mémoires Moyen-Orient*, v. 7, pp. 20-53, Paris.
- Jin Y., Wardlaw B.R., Glenister B.F. & Kotlyar G.V. (1997) - Permian chronostratigraphic subdivisions. *Episodes*, v. 20, n. 1, pp. 10-15, Beijing.
- Kotlyar G.V. & Pronina G.P. (1995) - Murgabian and Midian Stages of the Tethyan realm. *Permophiles*, v. 27, pp. 23-26. A Newsletter of SCPS. Ottawa.
- Kozur H. (1995) - Permian Conodont zonation and its importance for the Permian Stratigraphic Standard Scale. *Geol. Palaont. Mitt. Innsbruck*, v. 20, pp. 165-205, Innsbruck.
- Kozur H. & Mostler H. (1976) - Neue Conodonten aus dem Jungpalaeozoikum und der Trias. *Geol. Palaont. Mitt. Innsbruck*, v. 6, pp. 1-33, Innsbruck.
- Kozur H., Mostler H. and Rahimi-Yazd A. (1975) - Beitrage zur Mikropalaontologie permotriadischer Schichtfolgen. teil II: Neue Conodonten aus dem Oberperm und der basalen Trias von Nord- und Zentraliran. *Geol. Palaont. Mitt. Innsbruck*, v. 5, pp. 1-23, Innsbruck.
- Le Metour J., Bechennech F., Platel J.P., & Roger J. (1994) - Late Permian birth of the Neo-Tethys and development of its southern continental margin in Oman. The Middle East Petroleum Geoscience, Selected papers from the Middle East Geosciences Conference, pp. 642-654, Bahrain.
- Leven E. Ya. (1980) - Explanatory notes to the stratigraphic scale of Permian deposits of the Tethys area. *Izdat. VSEGEI*, pp. 1-15, St. Petersburg (In Russian).
- Leven E. Ya. (1981) - Permian Tethys Stage Scale and correlation of sections of the Mediterranean-Alpine folded belt. In Karamata S. & Sassi F.P. (Eds.) - *IGCP No. 5, Newsletter*, v. 3, pp. 100-112, Padova.
- Reed F.R.C. (1944) - Brachiopods and Mollusca from the Productus Limestone of the Salt Range. *Palaeont. Indica N.S.*, v. 23, n. 2, pp. 1-678, Calcutta.
- Roger J., Chevrel S., Platel J.P., Bechennech F., Dubreuilh J., Le Metour J. & Wyns R. (1992) - Geological Map of Mafraq Sheet NF 40-11, scale 1:250.000. Directorate General of Minerals, Oman Ministry of Petroleum and Minerals, Muscat.
- Ruzhentsev V.E. & Sarycheva T.G. (Eds.) (1965) - Evolution and succession of marine organism at the Permo-Triassic boundary. *Akad. Nauk SSSR Trudy Paleontological Institut*, v. 108, pp. 1-430, Moskva.
- Shi G.R., Archbold N.W. & Zhan L.P. (1995) - Distribution and characteristics of mixed (transitional) mid-Permian (Late Artinskian-Ufimian) marine faunas in Asia and

- their palaeogeographical implications. *Palaeogeogr., Palaeoclim., Palaeoecol.*, v. 114, pp. 241-271, Amsterdam.
- Steineke M., Bramkamp R. & Sander N.J. (1958) - Stratigraphic relations of Arabian Jurassic oil. In Weeks L.G. (Ed.) - *Habitat of oil*. AAPG, pp. 1294-1339, Tulsa.
- Waagen W.H. (1882-1885) - Salt Range fossils. Part 4 Brachiopoda. *Palaeont. Indica*, ser. 13, v. 1, n. 1-5, pp. 329-770, Calcutta.
- Wardlaw B.R. (1995) - Permian conodonts. In: Scholle P.A., Peryt T.M., Ulmer-Scholle D.S. (Eds.) - *The Permian of Northern Pangea*. Springer Verlag, pp. 186-195, Berlin.
- Wardlaw B.R. & Collinson J.W. (1984) - Conodont paleoecology of the Permian Phosphoria Formation and related rocks of Wyoming and adjacent areas. In Clark D.L. (Ed.) - *Conodont Biofacies and Provincialism*. *Geol. Soc. Amer. Sp. Paper.*, v. 196, pp. 263-281, Boulder.
- Wardlaw B.R. & Pogue K.R. (1995) - The Permian of Pakistan. In Scholle P.A., Peryt T.M., Ulmer-Scholle D.S. (Eds.) - *The Permian of Northern Pangea*. Springer Verlag, pp. 215-224, Berlin.
- Williams A., Rowell A.J., Muir-Wood H.M., Pitrat C.W., Schmidt H., Stehli F.G., Ager D.V., Wright A.D., Elliott G.F., Amsden T.W., Rudwick M.J.S., Hatai K., Biernat G., McLaren D.J., Boucot A.J., Johnson J.G., Staton R.D., Grant R.E. & Jope H.M. (1965) - In Moore R.C. (Ed.) - *Treatise on Invertebrate Paleontology*. Part H: Brachiopoda, *Geol. Soc. Amer., Univ. Kans. Press*, pp. 1-927, Lawrence.
- Yanagida J. (1964) - Permian Brachiopods from Central Thailand. *Contr. Geol. Palaeont. SE Asia*, IX, Mem. Fac. Sci., Kyushu University, v. 15, n. 1, pp. 1-22.