Zeitschrift: Eclogae Geologicae Helvetiae

Herausgeber: Schweizerische Geologische Gesellschaft

Band: 91 (1998)

Heft: 2

Artikel: Stratigraphy, sedimentology and depositional environments of the Permian to uppermost Cretaceous Batain Group, eastern-Oman

Autor: Immenhauser, Adrian / Schreurs, Guido / Peter, Tjerk

DOI: https://doi.org/10.5169/seals-168419

0012-9402/98/020217-19 $1.50 + 0.20/0
Birkhäuser Verlag, Basel, 1998

Eclogae geol. Helv. 91 (1998) 217–235

Stratigraphy, sedimentology and depositional environments of the Permian to uppermost Cretaceous Batain Group, eastern-Oman

ADRIAN IMMENHAUSER[1], GUIDO SCHREURS[2], TJERK PETERS[2], ALBERT MATTER[2], MARC HAUSER[2] & PAULIAN DUMITRICA[3]

Key Words: Oman, Neo-Tethys, sediments, volcanic rocks, Cretaceous-Paleogene transition

ABSTRACT

Permian to Late Cretaceous allochthonous sedimentary and volcanic rocks exposed in the Batain area (eastern Oman Margin) have received comparably little attention in the past. They largely were considered as part of the Hamrat Duru Group (Hawasina Complex) of the northern Oman Mountains. Structural, kinematic and biostratigraphic results from our mapping campaign in the Batain area have now revealed, that emplacement of these units occurred in a WNW direction during latest Cretaceous/Early Paleogene time. This clearly contrasts with previous models that postulated a S-ward directed obduction in Campanian times such as recorded from the Hawasina Complex and Semail Ophiolite in the Oman Mountains. We herewith establish the "Batain Group" comprising all Permian to Late Cretaceous allochthonous units in the Batain Area. These are: 1.) the Permian Qarari Formation deposited in the toe of a slope setting; 2.) the Late Permian to late Liassic Al Jil Formation comprising periplatform detritus and very coarse breccias; 3.) the Scythian to Norian Matbat Formation formed by slope deposits; 4.) the Early Jurassic to early Oxfordian Guwayza Formation with high energy platform detritus; 5.) the Mid-Jurassic to earliest Cretaceous Ruwaydah Formation seamount; and 6.) the Oxfordian to Santonian Wahrah Formation, mainly radiolarites; and 7.) the Santonian to latest Maastrichtian Fayah Formation built by flysch-type sediments. These sedimentary and volcanic rocks represent deposits of the former "Batain basin" off eastern-Oman, destroyed by compressional tectonics at the Cretaceous/Paleogene transition. For tectono-stratigraphic reasons the Batain Group does *not* form part of the Hawasina Complex.

ZUSAMMENFASSUNG

Allochthone Einheiten entlang der Ostküste von Oman (Batain Gebiet), namentlich Sedimente und vulkanische Gesteine von permischem bis spätkretazischem Alter, wurden bislang als Teil der Hamrat Duru Gruppe (Hawasina Komplex) interpretiert, die zum Teil die nördliche Gebirgskette von Oman bilden. Neue strukturelle, kinematische und biostratigraphische Resultate unserer Kartierung zeigen, dass diese allochthonen Einheiten an der Kreide/Paleogen-Grenze in WNW Richtung obduziert wurden. Das steht im klaren Gegensatz zu bisher postulierten Modellen. Diese schlagen eine SW-gerichtete Obduktion während des Campan vor, wie beim Hawasina Komplex und beim Semail Ophiolit aus dem nördlichen Gebirge von Oman. Wir haben eine «Batain Gruppe» neu geschaffen, die alle permischen bis oberkretazischen Gesteine im Batain Gebiet umfasst. Dies sind: 1.) Qarari Formation: Perm, mit distalen Abhangsedimenten; 2.) Al Jil Formation: spätes Perm bis später Lias, beinhaltet Plattformschutt und sehr grobe Brekzien; 3.) Matbat Formation: Scyth bis Nor, beinhaltet kieselige und quarzführende Abhangsedimente; 4.) Guwayza Formation: früher Jura bis frühes Oxford, Schüttungen einer hochenergetischen Plattform; 5.) Ruwaydah Formation: Mitteljura bis Unterkreide, Fragmente eines unterseeischen Vulkans; und 6.) Wahrah Formation: Oxford bis Santon, vor allem Radiolarite; und 7.) Fayah Formation: Santon bis spätestes Maastricht, beinhaltet Flysche und Megabreccien. Sedimentgesteine sowie Vulkanite wurden im «Batain Becken» entlang der Ostküste Omans abgelagert. Es wurde im Zuge kompressiver Tektonik an der Kreide/Paleogen-Grenze zerstört. Aufgrund struktureller sowie stratigraphischer Argumente bildet die Batain Gruppe *keine* Untereinheit des Hawasina Komplexes.

1. Introduction

The Batain area in eastern Oman extends roughly 130 km in NE-SW and 40 km in E-W-direction (Fig. 1). As most of Oman's eastern coast it has received comparably little attention in the past.

Allochthonous units (Batain Group) in the Batain area comprise Permian to uppermost Maastrichtian marine sediments, volcanics and ophiolitic rocks of the Neo-Tethyan Batain basin which formerly was located along eastern Oman. The closure of the Batain basin and the obduction of the Batain Group took place in a WNW-ward direction around the Cretaceous-Paleogene transition. The Batain Group was thrust onto Proterozoic crystalline basement rocks and autochthonous sedimentary units and is, in turn, overlain by neoautochthonous Paleocene to Pliocene marine and continental deposits.

The first part of this paper documents litho-, and biostratigraphic results of our 1:20,000 scale mapping campaign in the Batain area, whereas the second part deals with the interpreta-

[1] Corresponding author, present address: Adrian Immenhauser, Vrije Universiteit/Earth Sciences, De Boelelaan 1085, NL–1081 HV Amsterdam, fax: 0031-(0)20.646.24.57; e-mail. imma@geo.vu.nl
[2] Geologisch-Mineralogische Institute, Universität Bern, Baltzerstrasse 1, CH–3012 Bern
[3] Könitzstrasse 39, CH–3008 Bern

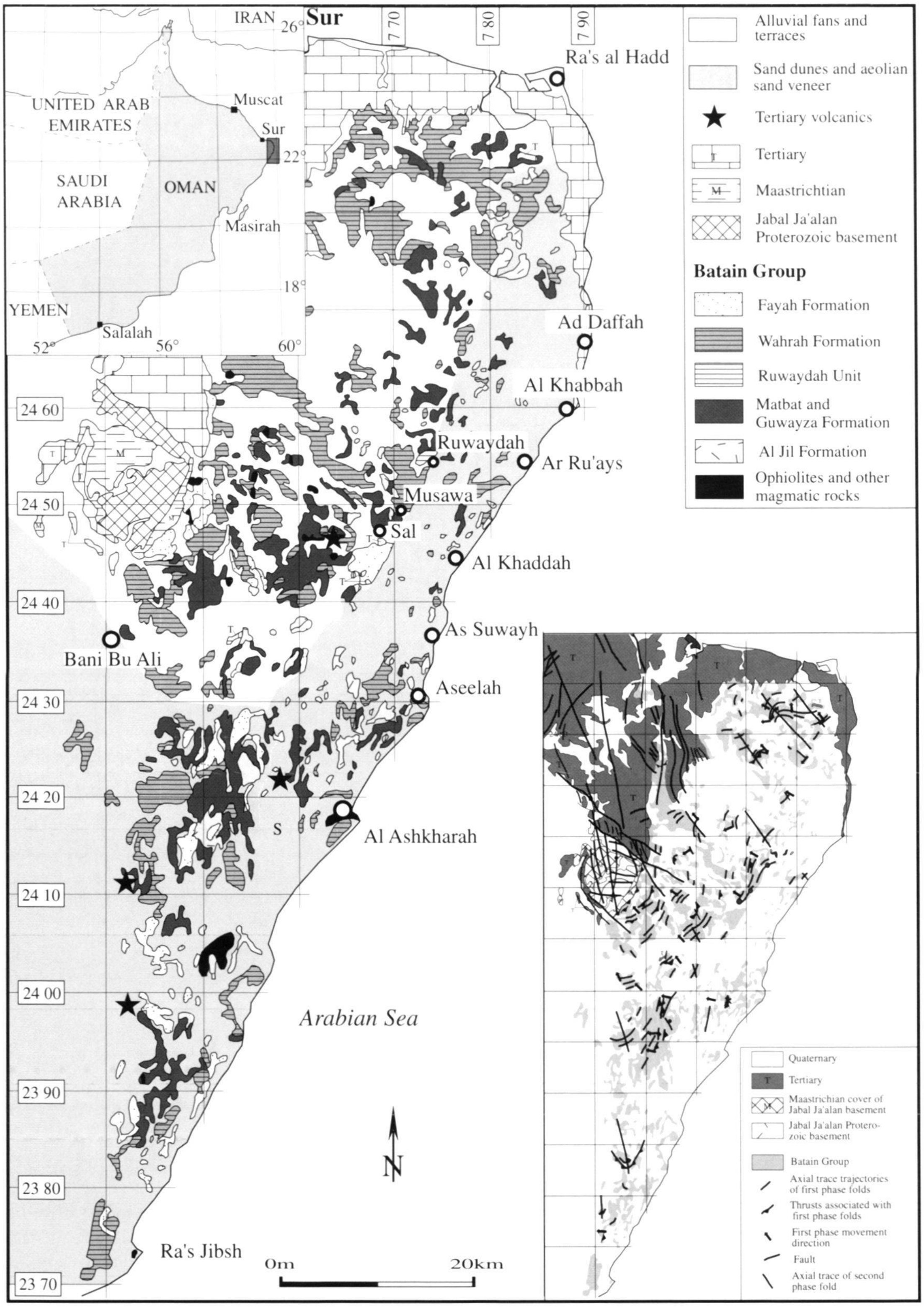

Fig. 1. Geotectonic overview map of the Batain coast, showing the distribution of allochthonous (Batain Group) and autochthonous units, and localities and UTM coordinates mentioned in this contribution. The lower right structural map shows axial trace trajectories of the obduction-related F1 folds, the associated thrusts and their movement direction.

tion of the depositional environments. The structural and kinematic framework, summarized in chapter 2, is documented in detail in a twin-paper (Schreurs & Immenhauser in press).

1.1 Previous studies

The Batain area was first investigated by Glennie et al. in 1974 and tentatively interpreted as part of the "Hawasina allochthonous unit" exposed in the Oman Mountains (Béchennec 1987; Cooper 1990; Le Métour et al. 1995). When Glennie et al. (1974) and, later, the geologists of the Bureau de Recherches Géologiques et Minières (BRGM; Roger et al. 1991; Béchennec et al. 1992; Wyns et al. 1992) started fieldwork in the Batain Region, they largely found lithologies comparable in age and facies as they knew from the Oman Mountains. Based on this observation and on their structural interpretation, they postulated that allochthonous sedimentary units in the Batain region form part of the tectono-stratigraphic Hawasina Complex previously attributed to the northern Oman Mountains (for summary see Robertson et al. 1990).

Other workers focused on the very complex structural setting and considered the allochthons in the Batain region as melange "... primarily tectonic but probably composite in origin ..." (Shackleton et al. 1990). In 1982, the geologists of the Metal Mining Agency of Japan investigated manganese-bearing radiolarites in the northern Batain area. Beauchamp et al. (1995) presented a seismic interpretation of the subsurface geology in the Batain area and proposed it to be underlain by what they termed the "Masirah Graben".

2. New structural and kinematic key evidence in the Batain area

In the course of our project on Masirah Island to the south of the Batain area (Fig. 1; Peters et al. 1995) we were able to demonstrate that the obduction of the Masirah Ophiolite was NW-directed and took place at the Cretaceous/Paleogene transition (Marquer et al. 1995; Immenhauser 1996).

These kinematic and stratigraphic findings from Masirah Island were later discussed within their plate tectonic framework by Gnos et al. (1997), who postulated that fragments of oceanic lithosphere along the east Oman Margin – including those in the Batain area – were emplaced due to transpressional motions between the Indo-Pakistani and the Afro-Arabian plates at about 65 Ma.

Results of new structural investigations in the Batain area (Schreurs & Immenhauser in press) differ in several aspects from previous work (e.g. Shackleton et al. 1990; Ries and Shackleton 1990; Béchennec et al. 1992) and have important regional implications. Most important differences concern timing of obduction and associated tectonic transport direction. Schreurs & Immenhauser (submitted) distinguish two compressional deformation phases, separated from one another by an extensional phase.

During a first compressional phase the Permian to Late Cretaceous sediments and volcanic rocks of a basin along the east Oman Margin – including the Fayah Formation of (Coniacian?) Santonian to Maastrichtian age – were detached from their unknown substratum and affected by intense deformation, resulting in a thin-skinned fold-and-thrust belt (Batain Group). This deformation led to the obduction of the allochthonous units onto the Arabian continental margin. The Batain nappes are unconformably overlain by neo-autochthonous Late Paleocene to Miocene sediments, which show no emplacement related deformation. This places the age of obduction in latest Maastrichtian and/or Early Paleocene times, which is coeval with the timing of emplacement of the Masirah ophiolite (Marquer et al. 1995). Removing the effects of later, Paleogene/Neogene deformation, reveals that kinematic indicators associated with obduction and formation of the Batain nappes indicate a WNW-directed tectonic transport and an initially NNE-SSW-trending fold-and-thrust belt (Fig. 1). The WNW-directed obduction is similar to the transport direction of the Masirah Ophiolite (Immenhauser 1995).

Thus, our new structural evidence, supported by sedimentologic and biostratigraphic data, indicates that obduction of the Batain Group and Masirah Ophiolite occurred from SE to NW onto the east Oman continental margin at about 65 Ma, i.e. about 15–20 m.y. later than the SW-directed emplacement of the Semail Ophiolite and Hawasina Complex onto the northern continental margin of Oman (e.g. Allemann & Peters 1972; Glennie et al. 1974). This has important consequences for paleogeographic reconstructions. Our new findings indicate that the Permian to Late Cretaceous sediments and volcanics now contained within the Batain nappes were originally deposited in a basin off the eastern margin of Oman. This basin will be referred to as the "Batain basin" in order to distinguish it from the Hawasina basin.

The post-emplacement Tertiary evolution of the Batain area consisted of an extensional and a compressional episode. Numerous extensional normal faults cross-cut both the Batain nappes and the overlying Tertiary neo-autochthonous sediments. Limited to the scale of the outcrop in the Batain area, these extensional structures are tentatively linked to extensional intraplate deformation reflecting the Gulf of Aden rifting and progressive opening, which commenced in Late Eocene times (e.g. Beydoun 1982; Platel & Roger 1989). Both Late Paleocene to Mid-Miocene autochthonous cover and the underlying Batain fold-and-thrust belt are affected by open N-S to NW-SE-trending folds, reflecting Late Miocene roughly NE-SW-directed shortening. This Neogene deformation is thought to be related to the collision of Arabia with Eurasia. It is responsible for reorientation of the initially NNE-SSW trending Batain nappes and associated WNW transport direction (both on outcrop and map scale).

The overprinting of an intense obduction-related deformation and post-emplacement Paleogene/Neogene deformation of a complex paleogeographic realm resulted locally in apparently irregular, disjointed and chaotic structures, especially in areas where continuous outcrop is lacking. However, in our opinion there is far more structural coherence than previously

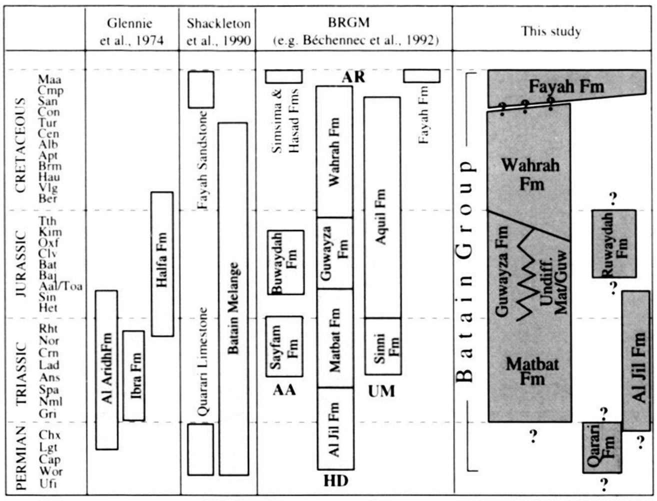

Fig. 2. Overview of the Permian to Quaternary stratigraphy in the Batain area as proposed by Glennie et al. (1974); Shackleton et al. (1990), and the BRGM (e.g. Béchennec et al. 1992) compared to the stratigraphy of the Batain Group as proposed in this study. AA = Al Arid Group, HD = Hamrat Duru Group, UM = Umar Group, AR = Aruma Group.

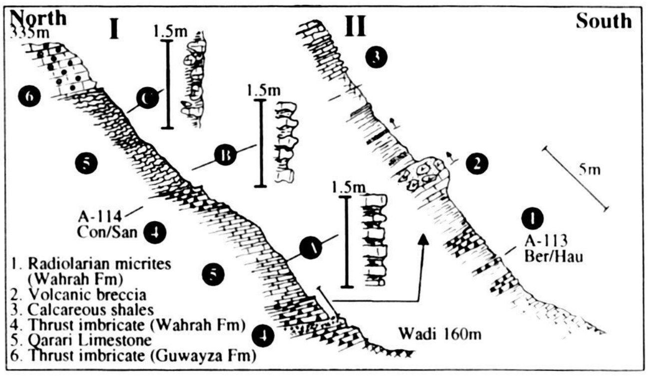

Fig. 3. Locality: 755311/2422988. (I) Tectono-stratigraphic overview section of the Qarari Formation at Jebel Qarari with intercalated thrust imbricates. (II) A section of Berriasian/Hauterivian radiolarites at the base of Jebel Qarari is shown. The Qarari Formation, displays a trend from platy (A) to highly nodular limestones (C). A Coniacian/Santonian radiolarite thrust imbricate (4) is intercalated and the peak of Jebel Qarari is formed by an thrust slice of the Guwayza Formation (5). Note the differences in scale.

believed and that the term "Batain Mélange" as put forward by Shackleton et al. (1990) should be abandoned.

3. The Batain Group

Previous biostratigraphic data of the Batain Group (e.g. Shackleton et al. 1990) were largely obtained from biota in calcareous lithologies, whereas key data from siliceous, radiolarian-rich rocks, were underrepresented. We therefore focused on dating the radiolarian-rich lithologies and combined these findings with the biostratigraphic results of previous authors. We dated about 100 radiolarian samples, of which 44 of the most important ones are discussed below and summarized in the appendix. In some localities also conodonts (determined by L. Krystin) and ammonites (determined by R. A. Gygi and Ch. Meyer) were used for dating (data to be presented in forthcoming papers).

For reasons of simplicity, we largely use the pre-existing stratigraphic nomenclature for the Batain area (Roger et al. 1991; Béchennec et al. 1992; Wyns et al. 1992), but lay emphasis on the point that all of these formations/units are attributed to the Batain Group defined herein (Fig. 2). Throughout this report, we follow Harland et al. (1989) with regard to the Mesozoic time-scale, whereas the Permian time-scale is adapted from Ross et al. (1994). All coordinates refer to the UTM (Universal Transverse Mercator) system.

3.1 Qarari Formation

Jebel Qarari (755189/2422887), northwest of Al Ashkharah (Fig. 1), is the type locality of what was informally termed "Qarari Limestone" by Shackleton et al. (1990). Béchennec et al. (1992) assigned the Qarari Limestone to the Al Jil Formation previously defined in the Oman Mountains. Based on lithologic arguments, we herewith establish a Qarari Formation and separate it from the Al Jil Formation (Fig. 2). The Qarari Formation is, to our knowledge, only known from the Batain area.

Besides the main exposure at Jebel Qarari (Fig. 3), this formation is present in a number of small, isolated outcrops and boulders within the Al Jil Formation (e.g. locality 77500/2439250) throughout the Batain plain. Boulders of Qarari limestone are also found at the base of large thrust sheets. The base and top of most Qarari Formation exposures is generally bounded by thrust planes. Béchennec et al. (1992) reported a mean thickness of about 180 m for the Qarari Limestone exposed at the southern slope of Jebel Qarari. This probably is an overestimation since individual thrust slices do not exceed 60 to 80 m in thickness (Fig. 3).

Facies – The Qarari Formation (Fig. 3) is characterized by a non-cyclic bedset of fine peloidal, partly silicified, gray argillaceous limestones (mudstones and rare wackestones) with fine allochems such as bivalve debris and siliceous sponge spiculae. Beds are 10 to 30 cm thick and platy to nodular. These gray limestones alternate with retreating shaly, yellowish and greenish interbeds. A trend from platy limestones (A in Fig. 3), at the base of Jebel Qarari, to very nodular limestones (C in Fig. 3) in the upper third of sections is observed. This nodular appearance is probably due to diagenetic overprint but locally burrowing was also observed.

Coquina horizons of dissociated bivalves and gastropods and

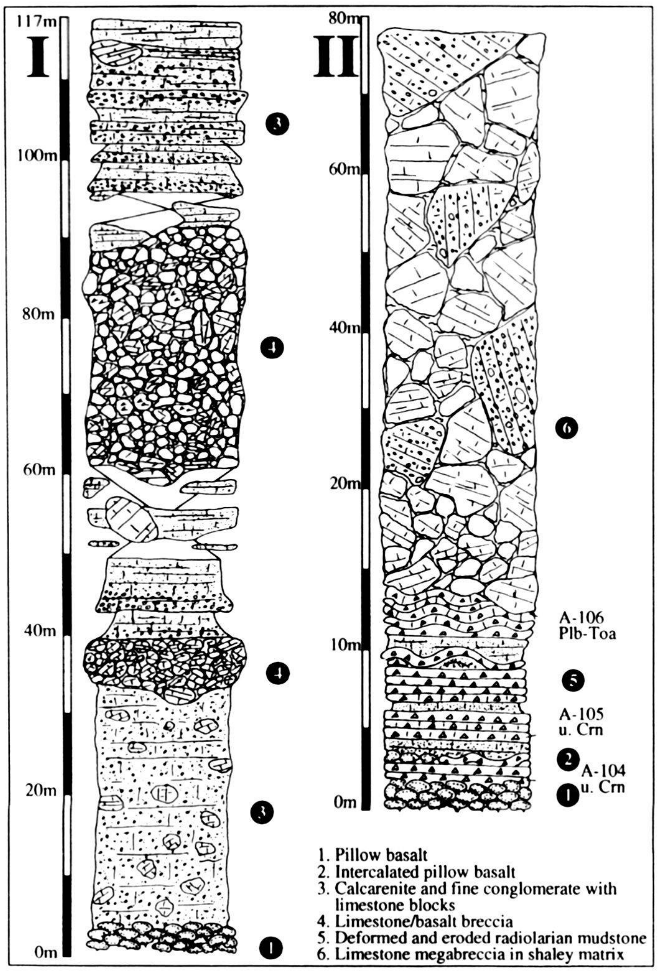

Fig. 4. Stratigraphic columns of the Type I (locality: 765774/2432936) and II (locality: 763508/2427249) of the Al Jil Formation. Both facies-types rest on a basaltic basement (1) and basalts are occasionally intercalated in higher levels of type II (2). Type I: Basalts are overlain by limestones and volcanic breccias, conglomerates and calcarenites. Reworked limestones are of Permian to Triassic age. Type II: A radiolarite/calcarenite assemblage is truncated by a limestone megabreccia. The age of the underlying radiolarites ranges from upper Carnian to Pliensbachian/Toarcian. Note the different scale.

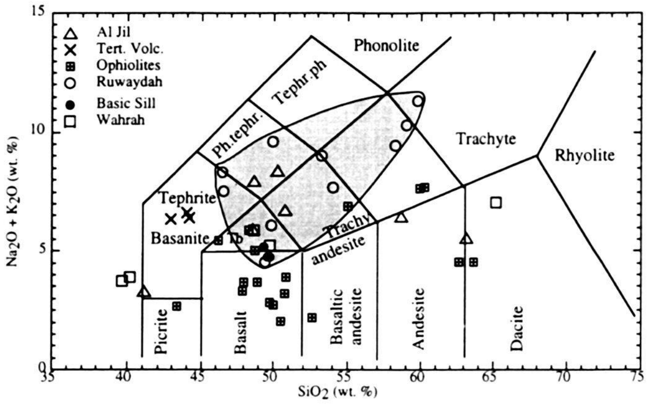

Fig. 5. TAS diagram (Le Maître 1984) showing the geochemical composition of the volcanic and ophiolitic rocks in the Batain Group.

subordinate brachiopod shells, bryozoans, small solitary corals, and crinoid stems are common at upper bedding planes. Locally, bivalves were found in situ (A. Pillevuit, pers. commun., 1996). Occasionally well preserved ammonite assemblages are also present (data to be presented in a forthcoming paper). A number of isolated outcrops with intraformational conglomerates are exposed on the southern slope of Jebel Qarari.

At Jebel Qarari, the gray limestones are imbricated with thrust slices comprising greenish and red, silicified radiolarian limestones, radiolarian-rich clays, volcanic microbreccias and coarse limestone conglomerates with basaltic components (Fig. 3). The top of Jebel Qarari is formed by a thrust sheet of the Guwayza Formation yielding exotic blocks of fusulinid limestones (Fig. 3). The base of Jebel Qarari, radiolarite thrust slices with interlayered volcanic ash, consists of coarse arenites and polymict conglomerates including Qarari Formation components (Fig. 3/II). The relation between the Qarari Formation and the radiolarite thrust imbricates is thus probably tectonic (non-stratigraphic contacts between Qarari limestones and radiolarian thrust imbricates) *and* stratigraphic (Qarari limestone components in conglomerates within thrust imbricates) in origin.

Age – Shackleton et al. (1990) reported Permian bivalves and fusulinid foraminifera obtained from the gray limestones at Jebel Qarari. Our own age data are based on ammonites found at Jebel Qarari and indicate a Wordian age (Ch. Meyer, pers. commun., 1997) at least for this part of the Qarari Formation. Thrust imbricates at the base of Jebel Qarari yield a Berriasian to Hauterivian radiolarian fauna (Appendix: A-113). The depositional age of thrust imbricates – alternating with Qarari Formation limestones further upsection – was dated as Coniacian-Santonian by radiolarian assemblages (Appendix: A-114). These imbricates do not form part of the Qarari Formation, but probably belong to the Wahrah Formation (chapter 3.5).

3.2 Al Jil Formation

The Al Jil Formation was established by Béchennec in 1987 as part of the Hamrat Duru Group (Hawasina) in the central Oman Mountains (Fig. 2). This formation was later introduced in the Batain area by Roger et al. (1991), Béchennec et al. (1992), and Wyns et al. (1992) and also considered as part of the Hawasina.

The Al Jil Formation of the Batain Group, as defined herein, is exposed throughout the Batain plain in characteristic whitish ridges and numerous small exposures of which base and top are very often tectonised. Following Béchennec et al. (1992) the top of the Al Jil Formation is made up of thin, platy limestones in stratigraphic contact with the Matbat Formation.

The base of a complete section through the Matbat Formation at locality 762478/2449654 (top Al Jil Formation sensu Béchennec et al. 1992) contained a rich conodont facies of Scythian age (L. Krystin, pers. commun., 1997). The primary stratigraphic thickness of the Al Jil Formation is difficult to estimate due to the tectonised nature of most formation boundaries, but locally 100 meters and more of continuous section is found (e.g. 765774/2432936; Fig. 4/I).

Large exposures in the northern Batain plain, attributed to the Sayfam Formation by Wyns et al. (1992), are also interpreted as Al Jil Formation of the Batain Group. The lithologies forming these exposures differ neither in facies, nor in biostratigraphic age nor inferred depositional environment from the Al Jil Formation as defined herein. In the Batain area, the facies types I and II were distinguished:

Facies – Type I (Fig. 4/I) is characterized by a succession of structureless whitish and reddish beds, one meter to tens of meters thick, formed by moderately sorted arenitic limestones, poorly sorted polymict conglomerates and breccias with large limestone blocks. Wherever exposed, this succession rests on a volcanic basement ranging from phonotephrites over trachyandesites and andesites to dacites (Fig. 5). Radiolarites are rare. Breccia components are either of reworked shoalwater facies such as dolomites, algal laminites, bioclastic limestones with corals, bivalves (megalodonts), bryozoans, oolitic limestones or slabs of basaltic rocks. Limestones with numerous small bivalve "filaments" are present.

A number of exposures in the northern Batain plain (783682/2475796; Sayfam Formation in the sense of Wyns et al. 1992) are made up of 5 to 10 meters of partly nodular radiolarites alternating with dolomitized fine-grained calcarenites atop highly vesicular, green-brown pillow basalts. This succession grades into 20 m of russet calcarenites with pebbles of fine-grained limestones yielding bivalve "filaments" and is overlain by 30 m of massive, silicified limestone conglomerates devoid of macroscopic visible bioclasts.

Type I sections are often found near or atop exposures with strongly tectonised, hydrothermally overprinted serpentinites and ophicalcites (i.e. brecciated and veined, silicified or serpentinized peridotites).

Type II sections (Fig. 4/II) show reddish, very porous radiolarites (referred as "porcellanites" herein) and radiolarian-rich shales that overlie greenish-brown amygdaloidal pillow basalts and andesites (Fig. 5). The radiolarites are interbedded with an upward-increasing amount of calcareous arenites, fine limestone breccias and radiolarian limestones. The volcanic rocks and the overlying radiolarite-limestone range from 5 to 30 m in thickness. The radiolarite-limestone sequence is truncated by a massive, white limestone megabreccia, several tens of meters in thickness, with a calcareous to reddish clay matrix. Components are strongly recrystallized, but a coarse shallow marine facies, such as found in the type I sections, is still recognized. Some of the boulders are reworked limestone breccias (Fig. 4/II).

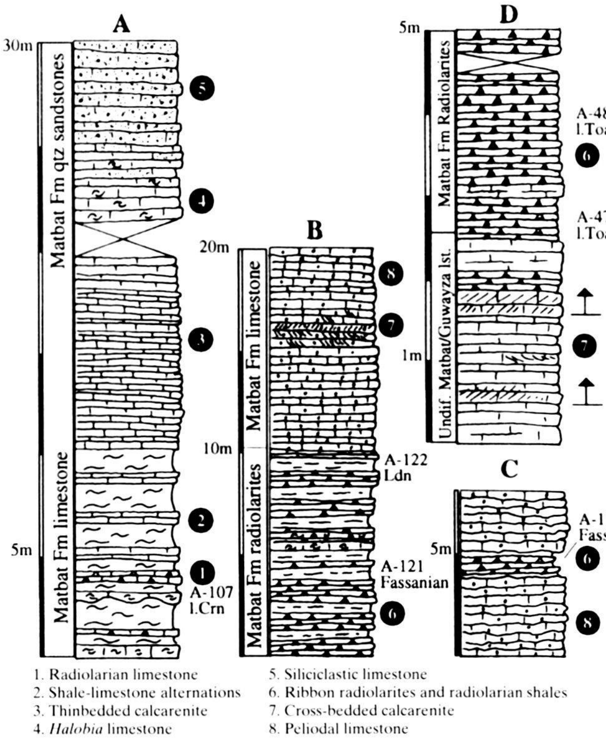

Fig. 6A. Locality: 763233/2427123. Stratigraphic section of the Matbat Formation showing the lower limestone member (1–4) and the upper siliciclastic member (5). B/C.) (B: locality 772282/2475593; C: locality 759332/2444846) Matbat Formation radiolarites and limestones. 10 m of Fassanian radiolarites (6) are found in B, whereas the same interval is less than 1 m in C. D.) Locality: 757289/2446605. Lower Toarcian contact between undifferentiated Matbat/Guwayza Formation limestones and radiolarites. Arrows indicate stratigraphic polarity. Note the different scale of section D.

Age – Béchennec et al. (1992) reported Upper Permian radiolarian assemblages at the base of the Al Jil Formation in an exposure near Al Ashkharah (Fig. 1). This locality, however, could not be found. Wyns et al. (1992) found Ladinian-Carnian ages for Al Jil Formation radiolarites in the northern Batain plain (Sayfam Formation sensu Wyns et al. 1992). Pillevuit (1993) dated Anisian/Ladinian radiolarites.

Our radiolarian data support a Ladinian (type I; Appendix: A-123), Carnian (type II, Appendix: A-104, A-105) and Norian age (type II, Appendix: A-125) for the radiolarites at the base of the Al Jil Formation. Radiolarian limestones found above radiolarites, directly underneath the megabreccia, may be as young as Pliensbachian/Toarcian at some locations (type II, Appendix: A-106).

The shallow marine biota in reworked blocks were dated Permian by Shackleton et al. (1990), Lee (1990), Béchennec et al. (1992), Wyns et al. (1992), and Permian to Triassic by Pillevuit (1993). The matrix of the megabreccia is not dated, but a maximum age for its deposition is given by the stratigraphically underlying Middle to Upper Triassic and Lower Jurassic radiolarites.

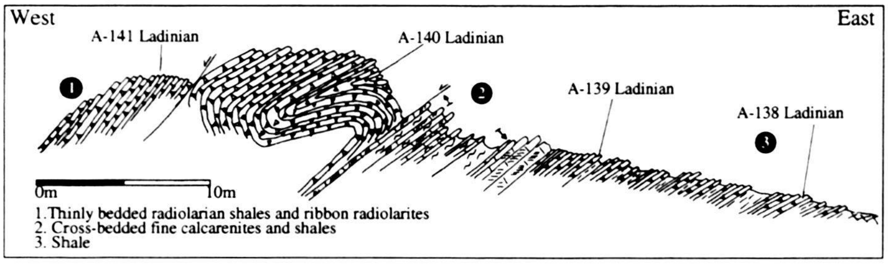

Fig. 7. Locality: 761156/2444708. Folded and thrusted section of Ladinian Matbat Fm radiolarites (1). A small portion of silicified, cross-bedded calcarenites and shales (2) is exposed at the base of the radiolarites, whereas the contact to the overlying Matbat Fm limestones is not exposed. Arrows indicate stratigraphic polarity.

3.3. Matbat Formation and Guwayza Formation

The Matbat and Guwayza formations (Fig. 2) were both established by Béchennec (1987) in the central Oman Mountains. In the Batain plain, the Matbat and Guwayza formations were described as part of the Hamrat Duru Group (Hawasina) by Roger et al. (1991), Béchennec et al. (1992), and Wyns et al. (1992).

Some exposures in the Batain plain are clearly assigned to the Matbat or Guwayza Formation (sensu Béchennec 1987) but most outcrops are neither formed by a clearly mappable Matbat nor Guwayza Formation facies (Fig. 2).

The base of the Matbat Formation (Batain Group; Fig. 6A) is locally made of platy limestones (e.g. 762478/2449654; Al Jil Formation of Béchennec et al. 1992), but most contacts are tectonic in nature. The upper formational boundary of the Matbat Formation is not exposed in the Batain plain. The upper, siliciclastic member of the Matbat Formation is mostly tectonically truncated or shows a gradual transition into the Guwayza Formation (Fig. 2). The contact between the Guwayza and overlying Wahrah Formation is equally gradational.

A stratigraphic thickness between a few tens of meters and at least 130 m (e.g. 762478/2449654) was measured for the Matbat Formation. The stratigraphic thickness of the Guwayza Formation is unclear since the contact to the underlying Matbat Formation is poorly exposed and gradual. However, a minimum of 25 m was measured, whereas Béchennec et al. (1992) suggest it 50 to 60 m thick.

Facies – The basal part of the Matbat Formation consists of grayish, platy limestones (uppermost Al Jil Formation of Roger et al. 1991; Béchennec et al. 1992; Wyns et al. 1992). Further upsection, the Matbat Formation comprises dark, purple marls, ochre, platy micrites and siliceous shales. A few meters upsection this facies gives way to about 10 m of reddish and greenish radiolarian shales, calcarenites and marls (Figs. 6A, B, C, 7). The radiolarites are overlain by a thick succession of brownish, platy limestones, in beds of 5 to 20 cm in thickness. These shaly limestones yield particularly abundant thin-shelled, pelagic bivalve "filaments" of the *Halobia*- and *Daonella*-type (Shackleton et al. 1990; Béchennec et al. 1992). Brecciated micritic limestones become prominent further up in the sequence. Basaltic sills and lava flows of up to 8 meter in thickness are locally present.

The predominant internal sedimentary structures are cm to dm scale cross-bedding, convolute bedding and hummocky-cross-bedding. Paleocurrent analysis of ripples and flute casts, corrected for deformation, indicates that the dominant flow was unidirectional and to the southeast. Small channels, several decimeters in width and few centimeters in depth, were recognized. Slumped beds are present in several exposures (e.g. 746366/2391646).

In location 762167/2427031 and at a few other exposures, the uppermost meters of the section consist of thickly bedded greenish, medium to coarse-grained quartz sandstones with a calcareous matrix and laminae of reworked muscovite and biotite (Fig. 6A). Isolated exposures of black and dark-brown, quartz-rich calcarenites are frequently found and were also attributed to the Matbat Formation.

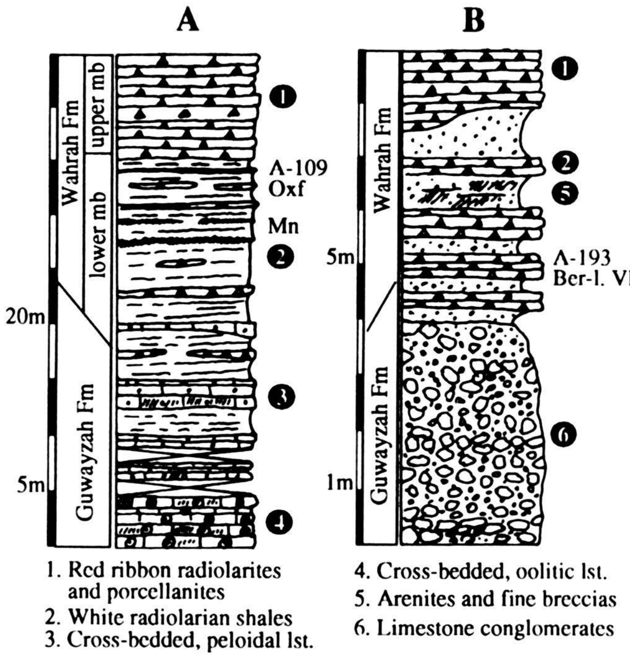

Fig. 8A. Locality: 771075/2455747. Wahrah Formation (northern facies) overlying the limestones (3 & 4) of the Guwayza Formation. Note the gradual change of whitish radiolarian shales and porcellanites (2) of the lower member, into red-brown ribbon radiolarites (1) of the upper member. B.) Locality: 77500/2439300. Guwayza Formation conglomerates (6) stratigraphically overlain by Barremian to lower Valanginian radiolarites of the Wahrah Formation.

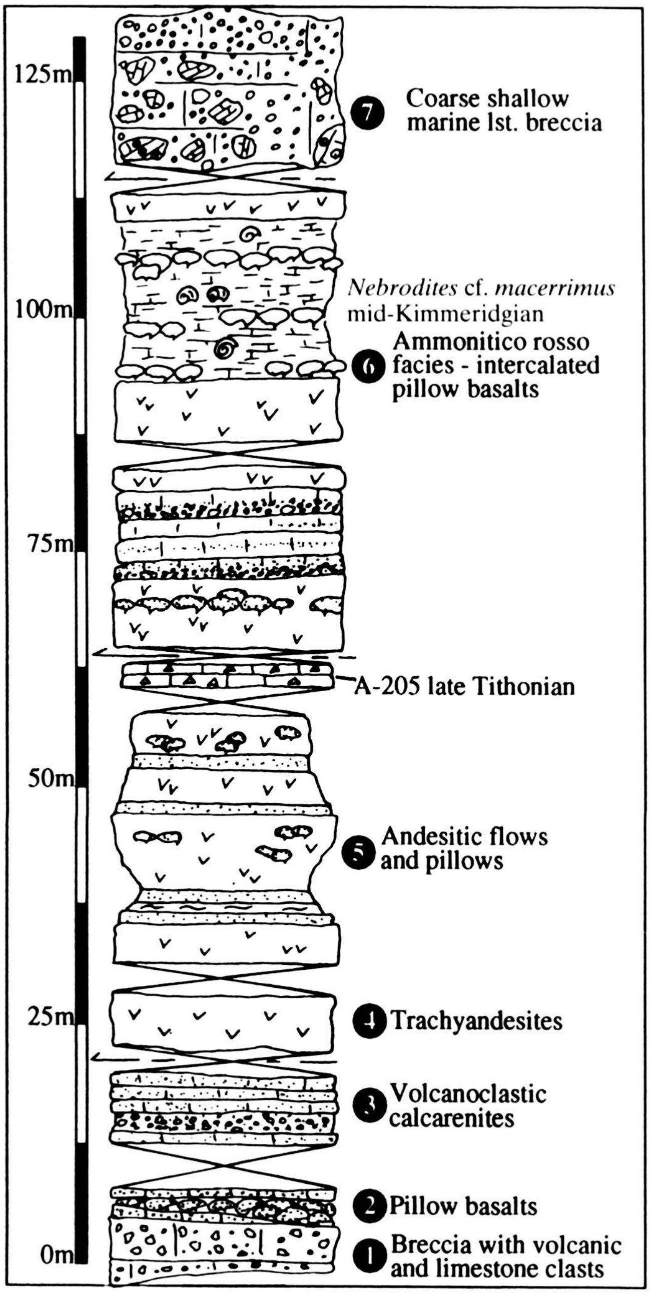

Fig. 9. Locality: 773265/2454988. Lithostratigraphic column of the Ruwaydah Formation across four thrust slices. The column shows (2, 5) volcanic intervals alternating with (3) volcanoclastic calcarenites, (A-205) radiolarian micrites, (6) Ammonitico rosso-facies and (7) shallow marine limestones breccia.

Facies – The Guwayza Formation is composed by decimeter-, to meter-bedded, gray and ochre, oolitic, peloidal and bioclastic packstones and grainstones (Fig. 8A). Calcarenites with reworked carbonate (extra-) clasts are equally common. Allochems include fine-grained bivalve detritus and occasionally crinoid fragments. Fining-up facies successions occasionally contain up to an estimated 10% quartz grains (up to several mm in diameter) and are capped by fine-grained bioclastic calcarenites. Thin beds of fine-grained, silicified radiolarian limestones (diagenetically altered) appear sporadically in most sections. Occasionally, the Guwayza Formation carries exotic limestone boulders with abundant fusulinids of a Permian age. Towards its top, the Guwayza Formation becomes gradually finer grained with an increasing number of radiolarian-rich shales.

Occasionally, conglomerate-filled channels up to several meters in thickness are present (e.g. 77500/2439300; cf. Fig. 8B). Clasts consist of, in order of decreasing abundance, gray lime-mudstones, laminated limestones, wackestones, black, quartz-rich biomicrites, dark, calcareous sandstones, silex nodules, and red micrites.

The above descriptions of the Matbat and Guwayza formations refer to the "end-member-types". Besides these, a large number of exposures are found with platy to thick bedded calcarenites, oo-micrites and radiolarian limestones with varying amounts of detrital quartz. Béchennec et al. (1992) referred to these exposures as "undifferentiated Matbat Formation". However, based on our biostratigraphic age data we believe that a number of these exposures should be attributed to the Guwayza Formation or take an intermediate position between those two formations. We therefore prefer the term "undifferentiated Matbat/Guwayza Formation".

Age – Radiolarites of the Matbat Formation were dated as Ladinian by Roger et al. (1991), Béchennec et al. (1992), and Wyns et al. (1992); and *Halobia* "filaments" as Middle to Late Triassic in age (Shackleton et al. 1990). Well preserved radiolarian assemblages in radiolarites of the Matbat Formation indicate a Ladinian age (Appendix: A-121, A-122, A-131, A-138, A-139, A-140, A-141), but also Carnian was observed (Appendix: A-107). Reliable conodont biostratigraphy indicates a Scythian to lower Norian age for the Matbat Formation limestones (L. Krystin, pers. commun., 1997). The youngest radiolarian assemblages found in the Matbat Formation, were of upper Pliensbachian/lower Toarcian age (Appendix: A-47, A-48, A-147).

Quartz sandstone deposition was dated latest Triassic to Early Jurassic (Glennie et al. 1974; Bernoulli & Weissert 1987) in the upper Matbat Formation of the Hamrat Duru Group of the Hawasina Basin farther north. A similar depositional age for the Matbat Formation siliciclastics in the Batain plain is suggested by the conformably underlying Upper Triassic limestones.

The Guwayza Formation in the Batain plain could not be dated by us nor, to our knowledge, by any previous workers. Thus, any interpretation of the depositional age must rely on a maximum age – the Late Triassic and possibly Early Jurassic age for the top of the underlying Matbat Formation – and a minimum age – the Mid- to Late Jurassic at the base of the overlying Wahrah Formation. As shown below, the Guwayza-Wahrah formations boundary is probably diachronous.

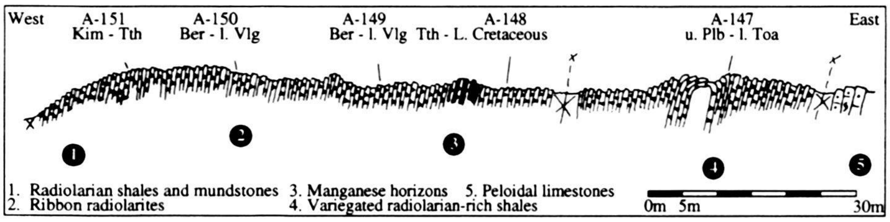

Fig. 10. Locality: 741002/2382640. Stratigraphic section through two thrust slices of the lower and of the upper member of the Wahrah Formation (southern facies). (3) Manganese horizons within the upper member are indicated.

3.4 *Ruwaydah Formation*

The Ruwaydah Formation is introduced here for rocks nearby the village of Ruwaydah (Fig. 1). This exposure was previously considered as Buwaydah Formation (Al Arid Group by Wyns et al. 1992; Fig. 2) of the Hawasina Complex.

The Ruwaydah Formation is exposed in a horse-shoe shaped outcrop about 1000 m in length and 600 m in width. The primary depositional thickness is difficult to estimate since the exposure consists of several thrust slices (Fig. 9). There is no stratigraphic contact observed with any of the other formations of the Batain Group.

Facies – A section measured from SW to NE into the center of the "Ruwaydah horse-shoe" included four thrust slices (Fig. 9). The succession commences with gray limestone breccias associated with a dark-gray pillow basalt horizon (1 & 2 in Fig. 9). The calcareous matrix contains mm-sized volcanic clasts and displaced gastropod and coral fragments. The breccia/pillow basalt interval is overlain by a thin-bedded, fining-upward succession of pale-gray calcarenites, and ends with dark-gray, cross bedded calcirudites and conglomerates with reworked basalt (3 in Fig. 9).

The carbonate facies is overlain by several thrust-sheets containing dark green basaltic-andesitic and trachyandesitic flows and dark green amygdaloidal pillow horizons. Gray-purple and red radiolarian micrites and calcarenites are interbedded within the volcanic rocks (4 & 5 in Fig. 9).

Towards the interior of the exposure poorly bedded reddish wackestones, packstones and dark-green "smiling pillow" horizons are present. The limestones are of Ammonitico rosso facies, containing ammonites, nautilids, gastropods and belemnites (6 in Fig. 9). The ammonite assemblage consists of *Phylloceras* sp., *Lytoceras* sp., *Perisphinctes* sp. and *Nebrodites* cf. *macerrimus* (R.A. Gygi, pers. commun., 1997). The center of the exposure is formed by massive silicified limestone breccias of shallow water facies including oolitic and bioclastic carbonates (7 in Fig. 9).

Age – Wyns et al. (1992) recognized Bathonian-Oxfordian biota in the calcarenites and Callovian-Oxfordian radiolarian biota in the micrites. Shackleton et al. (1990) reported Late Jurassic or Cretaceous nerineid gastropods. These findings are more or less in concert with our Late Tithonian radiolarian assemblages (Appendix: A-205) and the ammonite *Nebrodites* cf. *macerrimus* indicating a Mid-Kimmeridgian age. The precise depositional age of the Ruwaydah Formation is difficult to determine, because of strong imbrication within the exposure, but biostratigraphic evidence and correlation with Upper Jurassic/Lower Cretaceous volcanic activity recorded in the Wahrah Formation suggests a Mid- to Late Jurassic and probably earliest Cretaceous age.

3.5 *Wahrah Formation*

Large areas of the Batain plain are dominated by radiolarites (Wahrah Formation, Hawasina Complex; sensu Roger et al. 1991; Béchennec et al. 1992; and Wyns et al. 1992; cf. Fig. 2).

The Wahrah Formation of the Batain Group is made entirely by ribbon radiolarites, radiolarian porcellanites and radiolarian clays with argillaceous bedding planes. The lower stratigraphic contact of the Wahrah Formation is gradually and defined by the transition into the underlying calcareous Guwayza Formation, or undifferentiated limestones (Figs. 8A/B). An upper stratigraphic boundary was not found and is probably always tectonic. The stratigraphic thickness of the Wahrah Formation is difficult to reconstruct, all sections are intensively imbricated, folded and truncated.

Facies – Two informal Wahrah Formation facies types, each with two members are distinguished:

Northern Facies: This facies type is dominant north of an east/west line running approximately through Al Ashkharah (Fig. 1). The lower member, atop of the Guwayza Formation, comprises whitish and occasionally ochre bedded radiolarites, porcellanites and radiolarian-rich shales (Fig. 8A). Beds are about 5 to 20 cm thick and alternate with argillaceous interbeds some mm to 5 cm thick. This lower, whitish member of the northern facies type reaches about 20 m thickness. Mn-dendrites, Mn-crusts and Mn-filled fissures are common. However, these black weathering siliceous sediments are not to be mistaken for the manganese enrichments in the upper member. East of Jebel Ja'alan this member is conspicuously ochre to yellow (e.g. 754120/2445536).

Basaltic sills and layers of volcanic ash are found near the village of Musawa (770877/2450486; Fig. 1) and in thrust imbricates at the base of Jebel Qarari (Fig. 3). Their chemistry is tephritic to trachytic and lies on the same alkaline trend as the volcanic rocks of the Ruwaydah Formation (Fig. 5).

The lower member gradually changes upsection into an

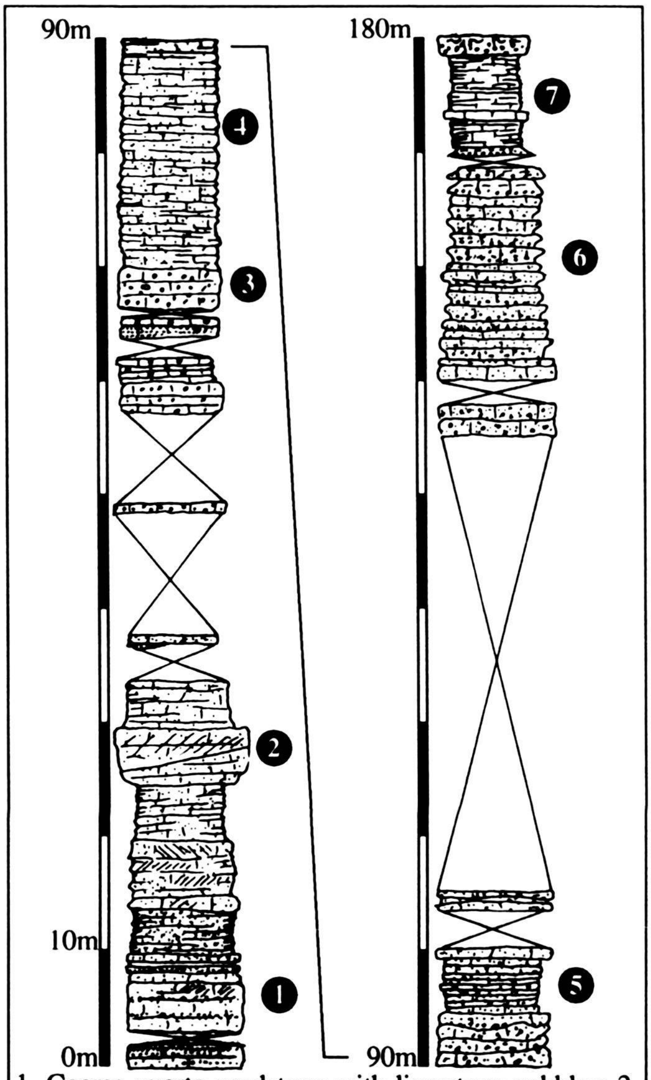

Fig. 11. Locality: 744750/2397600. The Upper Maastrichtian (Béchennec et al. 1992) Fayah Formation at the type locality. The exposures show a rich spectrum of (1) quartz-dominated sandstones and (3) fine conglomerates with reworked components. Towards its top the quartz-sandstones grade into (7) reddish, platy micrites.

upper member comprising 10 to 20 cm-thick beds, vividly colored in red to red-brown, with an upward increasing number of silex nodules and stringers (Fig. 8A). Finally, it grades into brick-red, brownish-red and purple ribbon cherts and porcellanites with shaly partings. Radiolarian tests are often destroyed by silica diagenesis, but some beds retain well preserved assemblages. Occasionally, burrows are preserved at lower bedding planes. Black and dark brownish chert-hosted manganese occurrences, up to 25 m thick, are common. These stratiform manganese horizons are built up of several manganese zones. In these zones, different types of enrichment can be recognized: i) brown muddy cherts with dispersed fine-grained manganese ore particles; ii) layered Mn-chert where the Mn is concentrated in up to 3 cm-thick layers; iii) black cherts of up to 30 cm thick that stand out as massive beds, and iv) nodular shaped segregation's without any concentric textures. These Mn-enrichments are similar to those described by Kickmaier & Peters (1990) in the Jebel Hammah range to the northwest of the Batain area. A thickness of 40 m was measured for most of the upper member (Fig. 8A). The northern facies of the Wahrah Formation is common around Sal and Musawa and near Ra's al Hadd (Fig. 1).

Southern Facies: The southern facies of the Wahrah Formation is most common in the southern domains of the Batain plain and near Al Ashkharah (Fig. 8A). Two members are distinguished: The lower member comprises a succession of variegated reddish, yellowish, greenish, grayish and ochre radiolarites and radiolarian-rich clays. This facies is easily distinguished from the whitish lower member of the northern facies type. Beds are between 5 and 20 cm thick and have shaly partings. Well preserved radiolarian tests are found in great number in some sections. The lower member reaches 10–20 m in thickness and rests often on an undifferentiated Matbat/Guwayza Formation.

The upper member of the southern facies, characterized by dark-red ribbon cherts, is similar in appearance to the upper member of the northern facies of the Wahrah Formation. Occasionally, successions of greenish, grayish or brown radiolarite beds and thin manganese horizons are intercalated.

Age – The lower member of the Wahrah Formation (northern facies) was dated as Oxfordian (Appendix: A-14.3, A-109) to Late Tithonian-Berriasian (Appendix: A-46). Locally (77500/2439300) even a Berriasian to early Valanginian age was obtained (Appendix: A-193).

The upper member of the northern facies spans a wide time interval ranging from the Jurassic/Cretaceous transition (Appendix: A-2.1, A-24.1, 24.2, 24.3), to the mid-Cretaceous (Appendix: A-14.1 or A-1.1, A-115). Coniacian to Santonian ages (e.g. Appendix: A-114).

The lower member of the southern facies is somewhat older than its northern equivalent; Mid-, Late Jurassic (Appendix: A-151, A-192) to Berriasian-Early Valanginian (Appendix: A-149) radiolarian faunas were recovered. Radiolarian assemblages in the upper member of the southern facies indicate a latest Jurassic to Early Cretaceous age (Appendix: A-57.1, A-57.2, A-57.3, A-58, A-59).

Radiolarian faunas near manganese enrichments were dated as Oxfordian (Appendix: A-109); Tithonian to Early Cretaceous (Appendix: A-148); but most of them are of Berriasian/Valanginian age (e.g. A-110). The youngest fauna was of late Hauterivian age (A-102). The oldest manganese horizon was dated as Ladinian (Appendix: A-120; Al Jil Formation?).

These age data are in agreement with Shackleton et al.

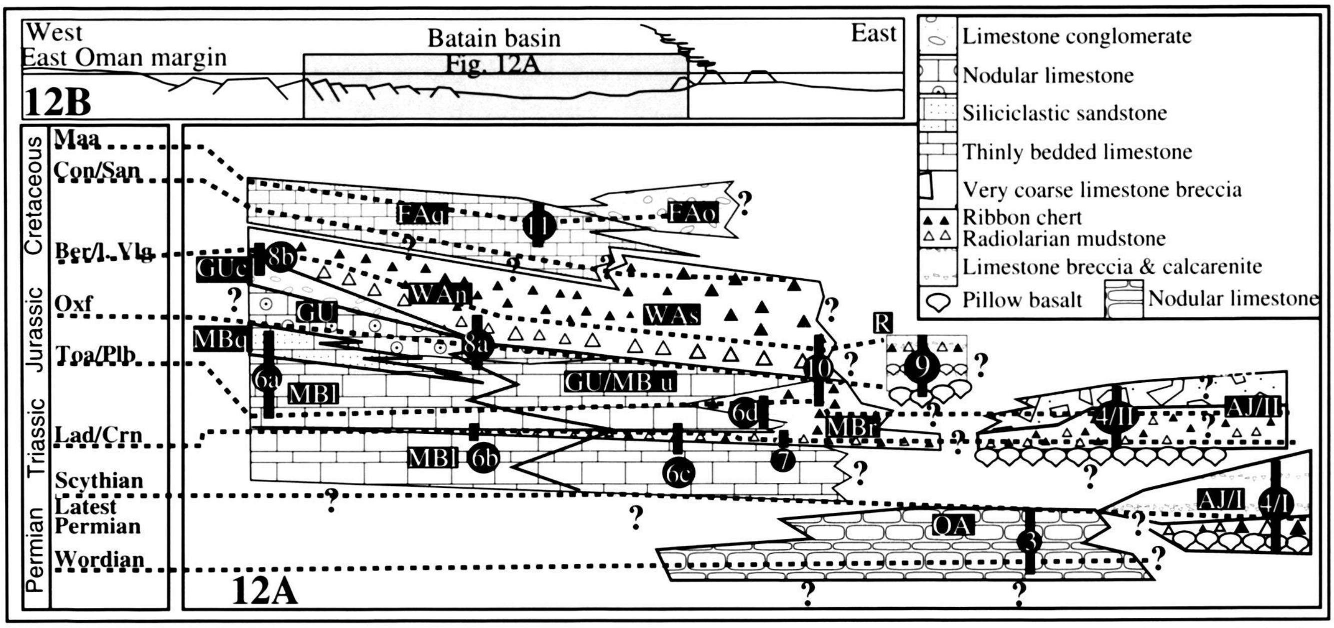

Fig. 12A-B. Litho- and chronostratigraphic overview of the Batain Group. A.) shows the formations in their inferred spatial and temporal context. Timelines dashed. Thick vertical lines give the approximate positions of lithologic sections. Numbers refer to the figure numbers. B.) shows a simplified overview of a possible setting for the Batain Basin in Mesozoic times. QA = Qarari Fm, AJ/I = Type I Al Jil Fm, AJ/II = Type II Al Jil Fm, R = Ruwaydah Fm, MBr = Matbat Fm radiolarites, MBl = Matbat Fm limestones, MBq = Matbat Fm quartz sandstones, GU = Guwayzah Fm, GUc = Guwayzah Fm conglomerates, WAn = northern facies Wahrah Fm, WAs = southern facies Wahrah Fm, FAq = Fayah Fm quartz sandstones, FAo = Fayah Fm olistostromes.

(1990), who reported Late Jurassic to Cenomanian ages for the entire sequence, whereas Béchennec et al. (1992) and Wyns et al. (1992) dated late Berriasian to Coniacian radiolarites only. Pillevuit (1993) found Valanginian to Barremian ribbon cherts.

3.6 Fayah Formation

The Fayah Formation ("Fayah Sandstone" of Shackleton et al. 1990; "Fayah Formation" of Roger et al. 1991; Fig. 2) is found along the entire eastern Oman margin but has no equivalent in the Oman Mountains. It overlies the Ra's Madrekah Ophiolite to the south (Gnos et al. 1997), is intercalated between the Masirah Ophiolite nappes (Fayah Unit, Immenhauser 1995; 1996), and forms part of the Batain Group.

Facies – The most common facies of the Fayah Formation is an ochre to greenish siliciclastic sandstone with layers of detrital mica (muscovite and biotite) in calcareous matrix. Intraclasts of reworked carbonates are present but remain small in size (< 5 mm). They are interlayered with red and gray clay and marl beds. This facies is common near Sal (Fig. 1) and at the type locality, Jebel Fayah, in the southern Batain plain (Fig. 1; 744750/2397600) where the Fayah Formation reaches at least 180 m in stratigraphic thickness (Fig. 11B).

At Jebel Fayah, fine- to coarse-grained, graded, well sorted quartz sandstones with a calcareous matrix are present. They alternate with beds of polymict conglomerates. Clasts are commonly cm-sized grayish mudstones, fine-grained biomicrites and brownish wackestones with coarse bivalve debris. Fining-upward cycles, cross-bedding (current-ripples) and locally convolute bedding are present. An unidirectional ENE-ward sediment transport direction (corrected for deformation) was determined from flute casts. Bedding planes are occasionally covered by subhorizontal burrows and other trace fossils. Exotic blocks, mainly granites and rhyolites, appear sporadically within these sandstones and are very similar to those exposed in the Huqf area (Dubreuilh et al. 1992).

Another typical facies of the Fayah Formation are red and ochre clays and marls, occasionally with fragmented calcareous sandstone beds. These marls, found along wadi banks, are always sheared and deformed due to their incompetent nature.

Age – The Fayah Formation was dated Coniacian to Campanian near Jebel Ja'alan, but otherwise Campanian to Maastrichtian (Shackleton et al. 1990; Table 1 p. 683) and late Maastrichtian by Béchennec et al. (1992). Olistostrome deposits near Sal were dated for its youngest (?) component, an uppermost Maastrichtian radiolarite and considered as part of the Fayah Formation by Roger et al. (1991).

These age data agree with the Coniacian to latest Maastrichtian nannoplankton in the Fayah Formation on Masirah Island (Immenhauser 1995, 1996) and the Late Maastrichtian foraminifera on Ra's Madrekah (Gnos et al. 1997).

4. Interpretation of depositional environments

The stratigraphic setting of sedimentary and volcanic units in the former Batain basin has been disrupted by extensive deformation during obduction and the array of sedimentary and volcanic rocks exposed in the Batain Group is far from complete. The carbonate platforms from which e.g. the clasts of the Al Jil Formation, the oolites of the Guwayza Formation, or the calcareous sandstones of the Fayah Formation were shed, are not exposed and remain unknown.

The nature of the basement, on which the Batain Group was deposited is crucial for any reconstruction of the paleogeographic setting but most successions were detached from their basement and most of the evidence is indirect. An interpretation of the large-scale depositional setting and a chronostratigraphic overview is shown in figure 12.

4.1 Qarari Formation

The depositional environment of the Qarari Formation is assigned to the toe of a slope/basinal setting well below the storm wave base (50 to 100 m), but still above the calcite compensation depth (CCD). This interpretation is based on the following arguments: the argillaceous/micritic facies of the limestones, the clay-rich interbeds, sponge spiculae and ammonites testify to an open water depositional setting. Coquina beds in the Qarari Formation were probably winnowed by bottom currents. Intraformational conglomerates exposed at Jebel Qarari as well as blocks of Qarari Formation limestones in Al Jil Formation conglomerates testify to the existence of nearby topographic highs from which these conglomerates were shed.

A present-day equivalent to the Qarari Formation may be the lower slope north of Little Bahama. There, ahermatypic corals form mounds at water depths of 1000–1300 m. Amongst other organisms ophiuroids, crinoids, gastropods, bivalves and sponges were recovered (Mullins et al. 1981).

4.2 Al Jil Formation

Reconstructing the depositional environment of the Al Jil Formation is difficult since only the sedimentary aprons of unknown shallow marine carbonate sources are present (Fig. 4).

There are, in fact, two indirect arguments supporting a seamount, or at least an offshore, origin for the Al Jil Formation: Firstly, the tectonically highest position in the nappe stack of the Batain fold-and-thrust belt hold by thrust imbricates of the Al Jil Formation may reflect a distal position. Secondly, Carnian/Norian and even Pliensbachian/Toarcian radiolarites of the Matbat Formation and radiolarite/limestone assemblages at the base of the Type II Al Jil Formation were deposited contemporaneously (Fig. 12). But why was there no commingling of the Matbat and Al Jil Formations? The Matbat Formation is attributed to the slope of the continental margin of eastern Oman, or at least to a continental basement, as demonstrated by its siliciclastic upper member (Fig. 6A). In contrast, the Al Jil Formation yields no continental detritus but basaltic components. It thus seems likely to locate the Al Jil platforms further basinward, i.e. on seamounts.

However, analyzing the spectrum of lithologies found in the Al Jil Formation breccias allows indirect reconstruction of these carbonate platforms: dolomites and algal laminites are expected in restricted to evaporitic domains. Wackestones and packstones with worn and coated bioclasts may reflect lagoonal domains. Blocks with reefal biota and (sparse) oolites probably document the organic build-up belt. Fine-grained packstones rich in bivalve "filaments", and reddish shaly sediments with juvenile ammonites (Hallstatt facies, cf. Pillevuit 1993) are expected on the slope. These limestones were deposited on or near a volcanic basement as indicated by reworked slabs of basalts. The basement on which the platform derived detritus was shed contained basalts too. The basement, however, of these basalts remains unknown.

There is a fundamental difference in the type I and type II facies of the Al Jil Formation: Type I (Fig. 4/I) was deposited as a sedimentary apron of material derived from a topographic feature, such as described from the slope to the north of Little Bahama Bank (cf. Mullins et al. 1984). It reflects the permanent down-slope transport and deposition of reworked shallow marine detritus quasi-coeval to the growth of one or several platforms. The age of components and their matrix is similar to the age of their radiolarite basement. The periplatform radiolarian oozes intercalated between calcarenites and breccias and their basaltic basement are comparably thin or even absent. This may be explained by either: i) a rapid onset of periplatform detritus shedding after the formation of the underlying basalts (little time for deposition of radiolarian oozes onto these basalts) or ii) erosion of the radiolarian oozes and deposition of coarse-grained calcareous carbonates. The (youngest?) detritus of the Type I Al Jil Formation is found in the northern Batain plain and was shed in Ladinian/Carnian times as demonstrated by the age of the directly underlying radiolarites.

Type II (Fig. 4/II) is different because its components, forming a mega-breccia, are of Permo-Triassic age, but the matrix inbetween these blocks and their Late Triassic to Late Liassic radiolarite basement is markedly younger. Thus, the Type II Al Jil Formation formed as much as 35 m.y. after the deposition of its shallow marine components. In conclusion, the Type II facies of the Al Jil Formation have the aspect of a very coarse debris flow possibly triggered by seismic events and/or instabilities of Permo-Triassic carbonate platform edges during Late Triassic to Late Liassic time.

4.3 The Matbat and Guwayza formations

Matbat Formation – In the Early Triassic, a semi-evaporitic regime was established on the Arabian platform and deposition in the marginal basins of Oman was slow (cf. Murris 1980; Béchennec 1987). The radiolarian interval at the base of the

Matbat Formation may reflect a decreased influx of carbonate. Further causes are probably of a paleo-oceanographic and tectonic nature. The global sea-level rose in Mid-Triassic time and reached its maximum in late Carnian/early Norian time (Murris 1980; Haq et al. 1987). The subsequent elevation in calcite depositional depth (CCD) would favor the deposition of radiolarian-rich clays. This is consistent with a generally elevated Triassic CCD (Bernoulli et al. 1990) and a global occurrence of Carnian-Norian radiolarites (e.g. Jones & Murchey 1986).

The interpretation of the hummocky cross-stratification, characteristic for the Matbat Formation, is problematical. Duke (1985) argued that hummocky cross-stratification forms only during tropical hurricanes and heavy winter storms. However, Eyles and Clark (1986) reported hummocky cross-stratification in lacustrine sediments as shallow as 2 m. We thus prefer to base our interpretation on the slumps and small channels, which indicate deposition in a slope setting and probably in the lower slope domains. This is also supported by intercalated sponge-radiolarian and *Halobia* limestones. Whether heavy waves (tsunamy or storms) formed the hummocky cross-stratification and triggered slumping remains unclear.

Continent-derived wedges of quartz sandstones reached the marginal setting of the Batain basin in Jurassic time. Exposures with quartz-sandstones are uncommon, but quartz-bearing limestones of the Matbat Formation appear in large numbers especially to the south of the Batain area. This may reflect a somewhat more distal position relative to the source of the detrital material. Bernoulli & Weissert (1987) relate turbiditic quartz arenites in the Hawasina basin to a Rhaetian regression (Murris 1980) and the subsequent emersion of the continental hinterland.

In eastern Oman, the Huqf-Haushi high trends parallel to the continental margin. This high was active from Infracambrian time onward (Ries & Shackleton 1990) and may have acted as a source area for clastic detritus in the Batain basin (cf. Fayah Formation). However, many of the pre-Jurassic continental deposits of the Arabian craton are quartz-rich (e.g. the Mid-Cambrian to Mid-Silurian Haima Group or the Carboniferous to Permian Haushi Group, Le Métour et al. 1995 and references therein) and erosion and redeposition of these units would similarly result in siliciclastic turbidites.

Guwayza Formation – The locally oolite-rich interval of the Guwayza Formation is in contrast to the paucity of ooids in all other formations of the Batain Group. Variations in the abundance of ooids correlate with eustatic changes of the global sea-level (Wilkinson et al. 1985). The Jurassic age inferred for the Guwayza Formation of the Batain Group corresponds well with a global peak in ooid formation.

The impact of ooid-rich lithologies suggests that a high energy carbonate shelf or ramp (cf. Murris 1980) along the eastern Oman margin shed debris into the Batain basin. Shallow marine, high energy environments are constantly moved by wave action and thus lethal for most biota (Hottinger 1988). This possibly explains the paucity of age-indicative biota in the oolite facies of the Guwayza Formation.

The overall depositional environment of the oolite-facies of the Guwayza Formation is most likely turbiditic. This conclusion is based on the observation of sedimentary structures such as fining-upward cycles, flute casts and the alternation character of ooid-rich intervals with fine-grained, muddy open-water facies (back-ground sedimentation). Occasionally, calcareous conglomerate avalanches reached the base of slope setting. Their formation probably was triggered by regional destabilization of the shelf edge (cf. Cooper 1990; Al-Suleimani 1992).

We assume, that the strong (vertical and lateral) facies changes observed in numerous sections reflect a gradual transition from a proximal facies (oolites and conglomerates; Figs. 8A/B) into an intermediate facies, characterized by oolitic sands alternating with fine-grained peloidal mudstones. Finally, oolitic limestones disappear towards the proximal domains where the fine-grained pelagic equivalent of the Guwayza Formation predominates. This distal facies of the Guwayza Formation becomes indistinguishable from the Matbat Formation in depositional age and facies (Fig. 6D).

The reworked fusulinid-rich exotic blocks within the Guwayza Formation probably reflect submarine erosion but their origin remains unknown. Autochthonous Artinskian fusulinid-bearing limestones of the Khuff Formation are known from the Huqf-Haushi area to the south of the Batain coast but this facies is markedly different (A. Pillevuit, pers. commun., 1996).

4.4 Ruwaydah Formation

The Ruwaydah Formation is tentatively interpreted as an assemblage of thrusted seamount fragments. Supporting evidence is mainly the characteristic array of facies types such as the Ammonitico rosso facies (Jenkyns 1970) of Mid-Kimmeridgian age, the upper Tithonian radiolarian micrites (A-205), and the shallow marine limestone breccia of unknown age. These sedimentary rocks are repeatedly interlayered with basalt-, andesite-, and trachyandesite-breccias, pillowed basalts and flows indicating ongoing volcanic activity from Late Jurassic into probably Early Cretaceous time.

This assemblage of volcanic and sedimentary rocks cannot be explained readily by invoking a depositional setting near a mid-ocean-ridge, such as the one described by Immenhauser (1996). It is more characteristic for an off-ridge seamount setting (e.g. Meyer et al. 1997). However, the Ruwaydah seamount should be interpreted in the framework of a Mid-Jurassic/earliest Cretaceous volcanic event also recorded in the Wahrah Formation.

4.5 Wahrah Formation

The unique appearance of Mesozoic ribbon radiolarites related to orogenic belts has no parallels in those radiolarites cored from ocean basins (Jenkyns & Winterer 1982). During late Jurassic and Cretaceous time, the CCD of the Neo-Tethys was moderately shallow and rose to a shallow maximum (Van Andel 1975). Consequently, the causes for the change from prevailing calcareous deposits during the Permian, Triassic and Early Jurassic, into radiolarian dominated sediments during Mid- to Late Jurassic time, reflects an important turnover in paleoceanographic parameters. However, there is probably a strong basin-related influence on the facies and spatial distribution of the Wahrah Formation superimposed on Tethyan paleoceanographic signals. The informal subdivision of the Wahrah Formation into a northern and southern facies type most likely reflects a subdivision of the Batain basin into a number of sub-basins (with different facies types each characteristic for an individual sub-basins) and/or probably a proximal-distal trend (Fig. 12). The northern facies of the Wahrah Formation, resting commonly upon the proximal ooid-rich facies of the Guwayza Formation, probably was in a more proximal position with respect to the source area of the ooids. The southern facies of the Wahrah Formation, overlying the distal facies of either the Guwayza and/or the Matbat Formation, may reflect domains of the Batain basin which were more distant (distally or laterally) to shallow marine. This agrees with the Pliensbachian/Toarcian age for the lower formational boundary of the southern facies and the Oxfordian age of the same boundary in the northern facies.

Ribbon radiolarites of the Jurassic Wahrah Formation and those of the Cretaceous Wahrah Formation should, however, not be interpreted in the same manner. Fertility and productivity of surface waters and, linked to this, the amount of siliceous and calcareous plankton produced, influence on the position of the CCD and, consequently, on the facies distribution of calcareous versus siliceous sediments (e.g. Bossellini & Winterer 1975; Baumgartner 1987). These and other physical paleoceanographic parameters, such as basin morphology, upwelling cycles, and sea-level fluctuations, changed markedly during the Jurassic and Cretaceous periods (e.g. Jenkyns & Winterer 1982; Baumgartner 1984, 1987).

The Jurassic sections of both types of the Wahrah Formation (lower members) are more clayey – locally also micritic – than the red ribbon radiolarites of the upper Cretaceous members. This trend is also observed in the Hawasina basin further north where at least in certain domains radiolarian shales were laid down from Early Jurassic into Early Cretaceous time (Yanqul Formation; cf. Bernoulli & Weissert 1987; Sid'r Formation of Glennie et al. 1974). From late Mid-Cretaceous up to Coniacian/Santonian time, sedimentation in the Batain basin remained essentially radiolarian and the genuine ribbon radiolarites of the upper members were deposited.

A major magmatic event in Early Cretaceous time in the Batain Basin (Berriasian/Valanginian; Wyns et al. 1992) is recorded by layers of volcanic tuffaceous ash, and basaltic dikes and sills, both at Jebel Qarari and near Musawa (Fig. 1). The restriction of the basaltic sills and tuffs to the lower member of the Wahrah Formation and their chemistry allow to relate them to the Late Jurassic magmatic event which also caused the Ruwaydah seamount.

The manganese horizons are similar in age and geochemistry (high Mn/Fe ratio without trace metal enrichment) to those of the Wahrah Formation in the Jebel Hammah range, and the region of Ibra to the northwest of the Batain plain. Kickmaier and Peters (1990; 1991) proposed hydrodynamically controlled enrichment of manganese and separation from clay minerals and radiolaria at sea-water/sediment interface as well as a hydrothermal origin and a two step continental derived source. It is hardly an accident that the time interval of significant Mn-enrichment coincided with the opening of the Somali basin and the formation of the proto-Owen transform fault during Late Jurassic and Early Cretaceous time respectively (e.g. Gnos et al. 1997 and references therein).

4.6 Fayah Formation

Most of the Fayah Formation is interpreted to be deposited by turbidity currents, alternating with debris flows and grain flows in a deep water environment, the whole deposited during early stages of compressional tectonism and obduction of the Batain fold-and-thrust belt (Gnos et al. 1997). Sections taken at Jebel Fayah (Fig. 11) show mainly the A, B, and C divisions of turbidite deposits of Bouma (1962). The climax of turbidite deposition in the Batain basin was in the Maastrichtian and especially the late Maastrichtian (Béchennec et al. 1992). Chaotic debris flows (olistostrome) with blocks up to several tens of meters across near Sal (Fig. 1) were equally assigned to late Maastrichtian time (Wyns et al. 1992).

The (initial) deep-water environment in which the Fayah Formation was deposited is demonstrated by the coeval Coniacian/Santonian radiolarites of the Wahrah Formation exposed at Jebel Qarari (Fig. 3). The Coniacian/Santonian and Campanian equivalents, however, of the Fayah Formation, well exposed on the Masirah Ophiolite further south (Immenhauser 1996), are less prominent (or difficult to date) in the Batain region (Shackleton et al. 1990). The continental source of the Fayah Formation is demonstrated by the abundance of detrital material.

Detailed structural investigations (Schreurs & Immenhauser in press) clearly demonstrate that the Fayah Formation at Jebel Fayah, as well as in other locations, has undergone the same, emplacement-related deformation as all the other rocks of the Batain Group. This interpretation is fundamentally different from those of previous authors (Roger et al. 1991; Béchennec et al. 1992; Wyns et al. 1992) who suggested that the Fayah Formation post-dates the emplacement of the Batain allochthons.

5. Summary and conclusions

1. The allochthonous units in the Batain area were obducted in a WNW-ward direction around the Cretaceous/Paleogene transition. This contrasts with the direction (south-

ward) and timing (early Campanian) of emplacement of the allochthonous units in the Oman Mountains (Hawasina Complex, Semail Ophiolite; Glennie et al. 1974).

2. The paleo-depositional realm of the Batain allochthons, the "Batain basin", was formerly located along the present-day eastern Oman margin, whereas the Hawasina basin was located along the northern Oman margin. Both basins recorded the tectonic evolution of the margins of the Arabian plate and Neo-Tethyan paleo-oceanographic signals.
3. We establish the "Batain Group" for all allochthonous units in the Batain area but largely use the pre-existing formation names (Roger et al. 1991; Béchennec et al. 1992; Wyns et al. 1992). For tectono-stratigraphic reasons the Batain Group does not belong to the Hawasina Complex. The Batain Group is built by the Permian Qarari Formation, the Late Permian to Late Liassic Al Jil Formation, the Scythian to Norian (Early Jurassic?) Matbat Formation, the Early Jurassic to Oxfordian Guwayza Formation, the Mid-Jurassic to probably earliest Cretaceous Ruwaydah Formation, the Late Jurassic (Oxfordian) to Coniacian/Santonian Wahrah Formation, and the (Coniacian?) Santonian to latest Maastrichtian Fayah Formation.
4. The depositional environment of the argillaceous Qarari Formation limestones is attributed to the toe of a slope setting. The shallow marine carbonate detritus of the Al Jil Formation was probably shed from offshore carbonate platforms, and reflects two fundamentally different depositional models: Type I is interpreted as periplatform detritus shed during platform growth; Type II comprises Lower Jurassic platform breccias. The shaly/siliceous Matbat Formation yields slope deposits recording regressive-transgressive trends on the Arabian platform. The partially oolitic Guwayza Formation documents the re-establishment of a Jurassic carbonate platform along eastern Oman. The distal portions of the Guwayza Formation interfinger with the Matbat Formation and becomes indistinguishable in facies. The Ruwaydah Formation is interpreted as a dismembered seamount structure. The Wahrah Formation displays a complex variety of radiolarian dominated siliceous sediments reflecting the paleo-oceanographic evolution of the Neo-Tethys overprinted by local paleogeographic effects. The siliciclastic flysch sediments and debris flows of the Fayah Formation were shed during Senonian compressive tectonism leading to the emplacement of the Batain fold-and-thrust belt near the Cretaceous/Paleogene transition.

Acknowledgements

This research was supported by the Swiss National Foundation (project No. 20-33562.92). Work along the east Oman Margin was possible due to the help of the Ministry of Petroleum and Minerals of Oman, especially Mohammed Bin Hussein Bin Kassim, Director General of Minerals and Hilal Al Azri, Director of the Geological Survey who provided logistical help and support. PDO (Petroleum Development of Oman) is acknowledged for providing insight in an unpublished report and seismic cross-sections. We acknowledge critical comments and remarks of A. Baud, F. Béchennec, D. Bernoulli, B. Garrison, R. Loosveld, H. Oterdoom, I. Mercolli, J. Meyer, A. Pillevuit, W. Schlager and J. Terken. Comments on an earlier version of the manuscript by Eclogae reviewers B.P. Pratt and B.C. Burchfiel improved the paper.

REFERENCES

Allemann, F. & Peters, T. 1972: The ophiolite-radiolarite belt of the north-Oman Mountains. Eclogae geol. Helv. 65, 657–697.

Al-Suleimani, Z. 1992: Geology of the Jabal Aswad map area (Oman Mountains) with emphasis on the sedimentology of the Guwayza Formation. Diploma thesis, University of Bern, 45 p.

Baumgartner, P. O. 1984: A Middle Jurassic-Early Cretaceous low-latitude radiolarian zonation based on unitary associations and age of Tethyan radiolarites. Eclogae geol. Helv. 77, 729–837.

Baumgartner, P. O. 1987: Age and genesis of Tethyan Jurassic radiolarites. Eclogae geol. Helv. 80, 831–879.

Beauchamp, W. H., Ries, A. C., Coward, M. P. & Miles, J. A. 1995: Masirah graben, Oman: A hidden Cretaceous rift system? Bull. amer. Assoc. Petroleum Geol. 79, 864–879.

Béchennec, F. 1987: Géologie des nappes Hawasina dans les parties orientale et centrale des Montagnes d'Oman. Thèse Doct. d'État, Université P. et M. Curie, Paris VI, Bur. Rech. Géol. Min., Document n° 127, Orléans, France, 417 p.

Béchennec, F., Roger, J., Chevrel, S. & Le Métour, J. 1992: Geological map of Al Ashkharah, sheet NF 40-12, scale 1:250,000, with explanatary notes. Director General of Minerals, Oman Ministry of Petroleum and Minerals, Muscat.

Bernoulli, D. & Weissert, H. 1987: The upper Hawasina nappes in the central Oman Mountains: stratigraphy, palinspastics and sequence of nappe emplacement. Geodyn. Acta 1, 47–58.

Bernoulli, D., Weissert, H. & Blome, C. D. 1990: Evolution of the Triassic Hawasina basin, central Oman Mountains. In: The geology and tectonics of the Oman region. (Ed. by Robertson A. H. F., Searle, M. P. & Ries, A. C.). Spec. Publ. geol. Soc. London 49, 189–202.

Beydoun, Z. R. 1982: The Gulf of Aden and NW Arabian Sea. In: 6 The Indian Ocean. (Ed. by Nairn A. E. M. & Stehli, F. G.), Plenum Press, 253–313.

Bosselini, A. & Winterer, E. L. 1975: Pelagic limestone and radiolarite of the Tethyan Mesozoic: A genetic model. Geology 3, 279–282.

Bouma, A. H. 1962: Sedimentology of some flysch deposits. Amsterdam, Elsevier.

Cooper, D. J. W. 1990: Sedimentary evolution and palaeogeographic reconstruction of the Mesozoic continental rise in Oman: evidence from the Hamrat Duru Group. In: The geology and tectonics of the Oman region. (Ed. by Robertson A. H. F., Searle, M. P. & Ries, A. C.). Spec. Publ. geol. Soc. London 49, 161–188.

Duke, W. L. 1985: Hummocky cross-stratification, tropical hurricanes, and intense winter storms. Sedimentology 32, 167–194.

Eyles, N. & Clark, B. M. 1986: Significance of hummocky and swaley cross-stratification in late Pleistocene lacustrine sediments of the Ontario basin, Canada. Geology 14, 679–682.

Glennie, K. W., Boeuf, M. G. A., Hughes Clarke, M. W., Moody-Stuart, M., Pilaar, W. F. H. & Reinhardt, B. M. 1974: Geology of the Oman Mountains. Verh. geol.-mijnbouwkd. Genoot. Nederl., Transactions 31, The Hague, Shell Research BV.

Gnos, E., Immenhauser, A. & Peters, T. 1997: Late Cretaceous/Early Tertiary collision between the Indian and Arabian plates recorded in ophiolites and related sediments. Tectonophysics 271, 1–19.

Haq, B. U., Hardenbol, J. & Vail, P. R. 1987: Chronology of the fluctuating sea levels since the Triassic. Science 235, 1156–1167.

Harland, W. B., Armstrong, R. L., Cox, A. V., Craig, L. E., Smith, A. G. & Smith, D. G. 1989: A geologic time scale 1989. New York: Cambridge University Press, 263 p.

Hottinger, L. 1988: Significance of diversity in shallow benthic foraminifera. In: Atti del Quattro Simposio di Ecologiae Palecologia della Comunità

Bentoniche in Sorrento. Museo Regionale di Science Naturali – Torino. 35–51.

IMMENHAUSER, A. 1995: The autochthonous Mesozoic sediment record on the Masirah Island ophiolite (Sultanate of Oman) - sedimentology, stratigraphy, bathymetry, structures and paleogeographic implications. Ph.D.-thesis, University of Bern, 260 pp.

– 1996: Cretaceous sedimentary rocks on the Masirah ophiolite (Sultanate of Oman): evidence for an unusual bathymetric history. J. geol. Soc. (London) 153, 539–551.

JENKYNS, H. C. 1970: Fossil manganese nodules from the west Sicilian Jurassic. Eclogae geol. Helv. 63, 741–774.

JENKYNS, H. C. & WINTERER, E. L. 1982: Palaeoceanography of Mesozoic ribbon radiolarites. Earth and planet. Sci. Lett. 60, 351–375.

JONES, D. L. & MURCHEY, B. 1986: Geologic significance of Paleozoic and Mesozoic chert. Ann. Rev. Earth and planet. Sci. 14, 455–492.

KICKMAIER, W. & PETERS, T. 1990: Manganese occurrences in the Al Hammah Range – Wahrah Formation, Oman Mountains. In: The geology and tectonics of the Oman region. (Ed. by ROBERTSON A. H. F., SEARLE, M. P. & RIES, A. C.). Spec. Publ. geol. Soc. London 49, 239–249.

– 1991: Chert-hosted manganese deposits in the Wahrah Formation: A depositional model. In: Ophiolite genesis and evolution of the oceanic lithosphere. Proceedings of the ophiolite conference (Muscat, Oman, 1990). (Ed. by PETERS T., NICOLAS, A. & COLEMAN, R. G.), Kluwer Academic Publishers.

LEE, C. W. 1990: A review of platform sedimentation in the Early and Late Permian of Oman, with particular reference to the Oman Mountains. In: The geology and tectonics of the Oman region. (Ed. by ROBERTSON A. H. F., SEARLE, M. P. & RIES, A. C.). Spec. Publ. geol. Soc. London 49, 39–47.

LE MAITRE, R.W. 1984: A proposal by the IUGS subcommission on the systematics of igneous rocks for a chemical classification of volcanic rocks based on the total alkali silica (TAS) diagram. Austral. J. Earth Sci. 31, 243–255.

LE MÉTOUR, J., MICHEL, J. C., BÉCHENNEC, F., PLATEL, J. P. & ROGER, J. 1995: Geology and mineral wealth of the Sultanate of Oman. Muscat: Ministry of Petroleum and Minerals, Directorate General of Minerals, Sultanate of Oman and Bur. Rech. Géol. Min., Muscat.

MARQUER, D., PETERS, T. & GNOS, E. 1995: A new structural interpretation for the emplacement of the Masirah Ophiolites (Oman): A main Paleocene intra-oceanic thrust. Geodyn. Acta 8, 13–19.

METAL MINING AGENCY OF JAPAN 1982: Report on geological survey of the Sultanate of Oman. Metal Mining Agency of Japan.

MEYER, J., MERCOLLI, I. & IMMENHAUSER, A. 1997: Off-ridge alkaline magmatism and seamount volcanoes in the Masirah island ophiolite, Oman. Tectonophysics 267, 187–208.

MULLINS, H. T., NEWTON, C. R., HEATH, K. & VANBUREN, H. M. 1981: Modern deep-water coral mounds north of Little Bahama Bank: criteria for recognition of deep-water coral bioherms in the rock-record. J. Sediment. Petrol. 51, 999–1013.

MULLINS, H. T., GARDULSKI, A. F., HINCHEY, E. J. & HINE, A. C. 1984: Anatomy of modern open-ocean carbonate slope: northern Little Bahama Bank. Sedimentology 31, 141–168.

MURRIS, R. J. 1980: Middle east: Stratigraphic evolution and oil habitat. Bull. amer. Assoc. Petroleum Geol. 64, 597–618.

PETERS, T., IMMENHAUSER, A., MERCOLLI, I. & MEYER, J. 1995: Geological map of Masirah north and Masirah south with explanatory notes, sheet K768-north and sheet K768-south, scale: 1:50,000, Directorate General of Minerals, Ministry of Petroleum and Minerals, Oman, Muscat.

PILLEVUIT, A. 1993: Les blocs exotiques du Sultanate d'Oman. Evolution paléogéographique d'une marge passive flexurale. Ph.D., Mém. géol. (Lausanne), 249.

PLATEL, J.-P. & ROGER, J. 1989: Evolution géodynamique du Dhofar (Sultanate d'Oman) pendant le Crétacé et le Tertiaire en relation avec l'ouverture du golfe d'Aden. Bull. Soc. géol. France 8, 253–263.

RIES, A. C. & SHACKLETON, R. M. 1990: Structures in the Huqf-Haushi uplift, east central Oman. In: The geology and tectonics of the Oman region. (Ed. by ROBERTSON A. H. F., SEARLE, M. P. & RIES, A. C.). Spec. Publ. geol. Soc. London 49, 653-664.

ROBERTSON, A. H. F., BLOME, C. D., COOPER, D. W. J., KEMP, A. E. S. & SEARLE, M. P. 1990: The northern Oman Tethyan continental margin: stratigraphy, structure, concepts and controversies. In: The geology and tectonics of the Oman region. (Ed. by ROBERTSON A. H. F., SEARLE, M. P. & RIES, A. C.). Spec. Publ. geol. Soc. London 49, 213–224.

ROGER, J., BÉCHENNEC, F., JANJOU, D., LE MÉTOUR, J., WYNS, R. & BEURRIER, M. 1991: Geological map of Ja'alan with explanatory notes, sheet NF 40-8E, scale: 1:100,000, Directorate General, Ministry of Petroleum and Minerals, Oman, Muscat.

ROSS, C. A., BAUD, A. & MENNING, M. 1994: A time scale for project Pangea. In: Pangea: Global environments and resources. Canad. Soc. Petrol. Geol. Mem. 17, 81–83.

SCHREURS, G. & IMMENHAUSER, A. (accepted): WNW-directed obduction of the Batain Group on the E-Oman margin at the Cretaceous-Tertiary boundary. Tectonics.

SHACKLETON, R. M., RIES, A. C., BIRD, A. C., FILBRANDT, J. B., LEE, C. W. & CUNNINGHAM, G. C. 1990: The Batain melange of NE Oman. In: The geology and tectonics of the Oman region. (Ed. by ROBERTSON A. H. F., SEARLE, M. P. & RIES, A. C.). Spec. Publ. geol. Soc. London 49, 673–696.

VAN ANDEL, T. H. 1975: Mesozoic/Cainozoic calcite compensation depth and the global distribution of calcareous sediments. Earth and planet. Sci. Lett. 26, 187–194.

WILKINSON, B. H., OWEN, R. M. & CARROLL, A. R. 1985: Submarine hydrothermal weathering, global eustasy, and carbonate polymorphism in Phanerozoic marine oolites. J. sediment. Petrol. 55, 171–183.

WYNS, R., LE MÉTOUR, J., ROGER, J. & CHEVREL, S. 1992: Geological map of Sur with explanatory notes, sheet NF-40-08, scale 1:250,000, Directorate General of Minerals, Oman, Muscat.

Manuscript received October 20, 1997
Revision accepted April 28, 1998

Appendix. Overview of the radiolarian assemblages and their age mentioned in this contribution. A complete list may be ordered from the corresponding author.

Sample	UTM Coord.	Taxa determined	Age	Form. Unit
A-1.1	760656/ 2441293	*Archaeodictyomitra lacrimula* (FOREMAN), *Aurisaturnalis carinatus perforatus* (DUMITRICA & DUMITRICA)	A fragment of *Aurisaturnalis carinatus perforatus* indicates an **upper Barremian - lower Aptian**, the upper part of the *A. carinatus* Zone.	Wahrah
A-2.1	760185/ 2441599	*Obesacapsula cetia* (FOREMAN); *Obesacapsula lucifer* (BAUMGARTNER); *Parvicingula dhimeniaensis* (BAUMGARTNER); *Protunuma japonicus* (MATSUOHA & YAO); *Zhamoidellum ovum* (DUMITRICA)	**Tithonian**	Wahrah
14.1	770045/ 2449604	*Aurisaturnalis carinatus carinatus* (FOREMAN); *Eucyrtis columbaria* (RENZ; younger morfotype, without apical horn); *Sethocapsa orca* (FOREMAN); *Stylospongia titirez* (JUD)	**Lower Barremian - lower part of Upper Barremian**, (lower part of *Aurisaturnalis carinatus* Zone), on the basis of *Aurisaturnalis carinatus carinatus*.	Wahrah
A-14.3	770045/ 2449604	*Archaeospongoprunum imlayi* (PESSAGNO); *Cinguloturris carpatica* (DUMITRICA); *Emiluvia orea* (BAUMGARTNER); *Eucyrtidiellum ptyctum* (RIEDEL & SANFILIPPO); *Mirifusus dianae* (KARRER); *Mirifusus guadalupensis* (PESSAGNO); *Podobursa* aff. *helvetica* (RÜST); *Transhsuum maxwelli* (PESSAGNO); *Triactoma cornuta* (BAUMGARTNER); *Triactoma jonesi* (PESSAGNO)	**Oxfordian**, **U.A.8-10** of Baumgartner, 1995.	Wahrah
A-24.1	740428/ 238312	*Emiluvia chica* (FOREMAN); *Pantanellium squinaboli* (TAN); *Sethocapsa kitoi* (JUD)	**Uppermost Tithonian - lower Valanginian**, on the basis of *Sethocapsa kitoi*.	Wahrah
A-24.2	740428/ 238312	*Archaeospongoprunum patricki* (JUD); *Eucyrtidiellum pyramis* (AITA); *Hemicryptocapsa agolarium* (FOREMAN); *Neorelumbra* sp. A of (KIESSLING); *Sethocapsa kitoi* (JUD); *Sethocapsa leiostraca* (FOREMAN, large morphotype); *Wrangellium* (?) *depressum* (BAUMGARTNER)	**Uppermost Tithonian - lowermost Berriasian**, on the basis of the co-occurrence of *E. pyramis* and *Neorelumbra* sp. A.	Wahrah
A-24.3	740428/ 238312	*Emiluvia chica* (FOREMAN); *Neorelumbra* sp. A of (KIESSLING); *Ristola cretacea* (BAUMGARTNER); *Tricolocapsa campana* (KIESSLING)	**Berriasian**, on the basis of the occurrence of *Neorelumbra* sp. A and *T. campana*.	Wahrah
A-46	754120/ 2445536	*Emiluvia* cf. *sedecimporata* (WISNIOWSKI) - fragment; *Obesacapsula cetia* (FOREMAN); *Paronaella tubulata* (STEIGER); *Parvicingula cosmoconica* (FOREMAN); *Parvicingula dhimeniaensis* (BAUMGARTNER); *Wrangellium* (?) *depressum* (BAUMGARTNER)	**Upper Tithonian - Berriasian**	Wahrah
A-47	768750/ 2446515	*Bagotum* cf. *mandense* (PESSAGNO & WHALEN); *Bagotum* cf. *modestum* (PESSAGNO & WHALEN); *Bistarkum bifurcum* (YEH); *Neowrangellium* cf. *pessagnoi* (YEH); *Pseudoristola obesa* (Yeh)	The age of the sample is most probably **Lower Toarcian**.	Wahrah
A-48	757289/ 2446605	*Bagotum* aff. *mandense* (PESSAGNO & WHALEN); *Bistarkum bifurcum* (YEH); *Bistarkum rigidum* (YEH); *Bagotum* aff. *mandense* (PESSAGNO & WHALEN); *Canutus indomitus* (PESSAGNO & WHALEN); *Canutus rockfishensis* (PESSAGNO & WHALEN); *Pseudoristola megalobosa* (YEH); *Pseudoristola obesa* (YEH)	The assemblage is very similar to that of sample A-47. The most probably age of the sample is **Lower Toarcian**.	Wahrah
A-57.1	765600/ 2430450	*Canoptum banale* (JUD); *Emiluvia chica* (FOREMAN); *Eucyrtidiellum pyramis* (AITA); *Obesacapsula bullata* (STEIGER); *Parapodocapsa furcata* (STEIGER); *Sethocapsa kitoi* (JUD); *Tricolocapsa campana* (KIESSLING); *Wrangellium* (?) *depressum* (BAUMGARTNER)	**Uppermost Tithonian - ? lowermost Berriasian**, on the basis of co-occurrence of *Parapodocapsa furcata* with *Eucyrtidiellum pyramis*.	Wahrah
A-57.2	765600/ 2430450	*Archaeodictyomitra minoensis* (MIZUTANI); *Cinguloturris* cf. *carpatica* (DUMITRICA); *Emiluvia* cf. *chica* (FOREMAN); *Eucyrtidiellum pyramis* (AITA); *Williriedellum carpaticum* (DUMITRICA)	**Tithonian**, on the basis of the occurrence of *A. minoensis*, *C. carpatica*, *E. pyramis* and others.	Wahrah
A-57.3	765600/ 2430450	*Cinguloturris cylindra* (KEMKIN & RUDENKO); *Emiluvia chica* (FOREMAN); *Eucyrtidiellum pyramis* (AITA); *Paronaella tubulata* (STEIGER); *Parvicingula cosmoconica* (FOREMAN); *Parvicingula sphaerica* (STEIGER); *Ristola cretacea* (BAUMGARTNER); *Sethocapsa concentrica* (STEIGER); *Sethocapsa zweilii* (JUD); *Tricolocapsa campana* (KIESSLING); *Wrangellium* (?) *depressum* (BAUMGARTNER)	**Uppermost Tithonian - lowermost Berriasian**.	Wahrah
A-58	766500/ 2431300	*Emiluvia chica* (FOREMAN); *Stichomitra pulchella* (RÜST)	Very probably **Valanginian**, on the basis of the co-occurrence of *E. chica* with *S. pulchella*.	Wahrah
A-59	766250/ 2429300	*Parvicingula cosmoconica* (FOREMAN); *Sethocapsa kitoi* (JUD)	**Berriasian - Lower Valanginian**, on the basis of *Sethocapsa kitoi*.	Wahrah
A-102	766744/ 2434675	*Aurisaturnalis variabilis* (SQUINABOL); *Caneta usotanensis* (TUMANDA); *Cecrops septemporatus* (PARONA); *Crolanium bipodium* (PARONA); *Hemicryptocapsa agolarium* (FOREMAN); *Sethocapsa orca* (FOREMAN); *Sethocapsa uterculus* (PARONA); *Wrangellium columnarium* (JUD); *Wrangellium puga* (SCHAAF)	**Upper Hauterivian, UA28-32** of Jud (1994) The assemblage is a typical Tethyan Lower Cretaceous radiolarian assemblage. The co-occurrence of *A. variabilis* (UA24-32) with *S. orca* (UA28-35) restrains its age to Upper Hauterivian, UA28-32 of Jud (1994) respectively.	Wahrah
A-104	763508/ 2427249	*Spongopallium* (?) sp. B of Gorican and Buser (1990) (1 specimen); *Pseudoheliodiscus* cf. *triassicus* (KOZUR & MOSTLER; one entire specimen and several fragments).	**Upper Carnian**. The former species is known from the Fassanian, the latter from the Upper Carnian. Possibly the specimen of *Spongopallium* is reworked or has a longer range than presently known.	Al Jil

A-105	763508/ 2427249	*Archaeocenosphaera* (?) spp., similar to those of sample A-104 *Crucella* sp.; 2 twisted spines of spumellarians.	**Carnian.** The age should be similar to that of sample A-104 because of *Crucella* sp. and of twisted spines.	Al Jil
A-106	763582/ 2427063	*Archaeocenosphaera* sp.; *Lupherium* spp.; *Lantus* spp.; *Fantus* spp.; *Santonaella* spp.; *Praeconocaryomma* sp.	**Pliensbachian-Toarcian.** Although the species are indeterminable the assemblage resembles those of samples A-47 and A-48, the age of which is Upper Pliensbachian-Lower Toarcian.	Al Jil
A-107	763233/ 2427123	*Tritortis kretaensis* (KOZUR & KRAHL) - common; *Baumgartneria stellata* (DUMITRICA); *Spongoserrula rarauana* (DUMITRICA)	**Lower Carnian**. *Tritortis kretaensis* Zone. The great frequence of *Tritortis kretaensis* permits to assign this assemblage to the *T. kretaensis* Zone of Kozur & Mostler (1994) which practically corresponds to the Lower Carnian.	Matbat
A-109	771075/ 2455747	*Archaeospongoprunum imlayi* (PESSAGNO); *Caneta dhimenaensis* (BAUMGARTNER); *Caneta mashitaensis* (MIZUTANI); *Cinguloturris carpatica* (DUMITRICA); *Dicerosaturnalis angustus* (BAUMGARTNER); *Mirifusus* cf. *guadalupensis* (PESSAGNO); *Ristola altissima altissima* (RÜST); *Protunuma japonicum* (MATSUOKA & YAO); *Tetratrabs zealis* (OZVOLDOVA); *Transhsuum brevicostatum* (OZVOLDOVA)	**Oxfordian.** This assemblage is common at the level of the Oxfordian from the Carpathians and Alps.	Wahrah
A-110	771064/ 2455584	*Archaeospongoprunum patricki* (JUD); *Emiluvia chica* (FOREMAN); *Parapodocapsa furcata* (STEIGER)	**Berriasian-lowermost Valanginian**. The age is base on the presence of *Parapodocapsa furcata* the range of which comprises the interval of UA5-13 of Jud (1994).	Wahrah
A-113	755078/ 2422535	*Archaeodictyomitra* cf. *excellens* (TAN); *Dicerosaturnalis dicranacanthos* (SQUINABOL); ?*Wrangellium depressum* (BAUMGARTNER)	**Berriasian-Hauterivian**. Radiolarians are few and extremely poorly preserved but sponge spicules are common.	Wahrah
A-114	755189/ 2422887	*Alievium* cf. *gallowayi* (PESSAGNO); *Alievium* cf. *superbus* (SQUINABOL); *Dictyomitra formosa* (SQUINABOL) sensu Pessagno 1976; *Patellula planconvexa* (PESSAGNO); *Pseudoaulophacus* aff. *lenticulatus* (WHITE); *Pseudodictyomitra hornatissima* (SQUINABOL); *Stichomitra pulchra* (SQUINABOL)	**Coniacian-Santonian**. The presence of evolved forms of *Alievium* (*A.* cf. *gallowayi*) suggests an age around the Coniacian/Santonian boundary.	Wahrah
A-115	754114/ 2423530	*Dactyliosphaera maxima* (PESSAGNO); *Pseudodictyomitra lodogaensis* (PESSAGNO); *Pterospongus* cf. *alatus* (DUMITRICA); *Tubilustrium transmontanum* (O'DOGHERTY); Twisted spines of *Tritortis* or *Muelleritortis*	**Upper Albian-Cenomanian**, with species reworked from the **Upper Ladinian.**	Wahrah
A-120	772194/ 2474998	*Archaeocenosphaera* (?) spp.	**Ladinian**	Al Jil
A-121	772282/ 2475593	*Baumgartneria retrospina* (DUMITRICA); *Eptingium manfredi* (DUMITRICA); *Oertlispongus inaequispinosus* (DUMITRICA, KOZUR & MOSTLER); *Pseudostylosphaera* sp.	**Fassanian** On the basis of the 3 species determinated the assemblage can be considered to be Fassanian in age.	Matbat
A-122	772282/ 2475593	*Archaeocenosphaera* (?) ssp.; *Muelleritortis* (?) aff. *cochleata* (NAKASEKO & NISHIMURA)	**Ladinian**, possibly **Upper Ladinian**. The type of *Archaeocenosphaera* (?) and the colour and type of preservation are similar to those of samples A-119, A-131, A-139, A-199, all of them determined as Ladinian.	Matbat
A-123	783682/ 2475796	*Baumgartneria* sp.; *Eptingium manfredi* (DUMITRICA); *Oertlispongus inaequispinosus* (DUMITRICA, KOZUR & MOSTLER); *Paroertlispongus multispinosus* (KOZUR & MOSTLER)	**Fassanian.** The assemblage is very poor but the few species determined permit to establish the age.	Al Jil
A-125	783722/ 2475604	*Capnodoce anapetes* (DE WEVER); *Capnuchosphaera tricornis* (DE WEVER); *Capnuchosphaera puncta* (DE WEVER); *Capnuchosphaera lea* (DE WEVER); *Spongostylus* cf. *carnicus* (KOZUR & MOSTLER); *Xiphoteca karpenissionensis* (DE WEVER)	**Lower Norian.** The assemblage is similar to that described by De Wever et al. (1979) from Greece and considered to be Lower Norian in age.	Al Jil
A-131	759068/ 2443667	*Baumgartneria bifurcata* (DUMITRICA); *Eptingium manfredi* (DUMITRICA); *Oertlispongus inaequispinosus* (DUMITRICA, KOZUR & MOSTLER); *Pseudostylosphaera coccostyla* (RÜST)	**Fassanian.** This assemblage is characteristic of the Fassanian, and especially of its lower part.	Matbat
A-137	761156/ 2444708	*Capnuchosphaera* sp.; *Eptingium manfredi* (DUMITRICA); *Pseudostylosphaera* sp.; *Tritortis kretaensis* (KOZUR & KRAHL)	**Late Carnian.** Although very poorly preserved, the assemblage contains *Tritortis kretaensis*.	Matbat
A-138	761156/ 2444708	*Archaeocenosphaera* (?) spp. - common; *Pseudostylosphaera* ex gr. *coccostyla* (RÜST)	**Ladinian**	Matbat
A-139	761156/ 2444708	The assemblage consists especially of large spherical forms assigned to *Archaeocenosphaera* (?) spp. and of forms with external shell formed of polygonal meshes. These forms seem to represent cortical shells of *Pseudostylosphaera* with the two spines broken off.	**Ladinian.** By comparison with the samples A-119 (Upper Ladinian), A-131 (Lower Ladinian) and A-199 (Lower Ladinian) the age can be estimated as Ladinian.	Matbat
A-140	761156/ 2444708	*Archaeocenosphaera* (?) sp.; *Oertlispongus inaequispinosus* (DUMITRICA, KOZUR & MOSTLER) - a single fragment	**Ladinian**, possibly Lower Ladinian.	Matbat

A-141	761156/ 2444708	*Archaeocenosphaera* (?) spp. - most common; *Pseudostylosphaera* sp. with spines broken off.	**Ladinian**	Matbat
A-147	7410002/ 2382640	*Katroma inflata* (YEH); *Neowrangellium* cf. *pessagnoi* (YEH); *Pseudoristola obesa* (YEH); *Santonaella* sp. E of YEH.	**Upper Pliensbachian-Lower Toarcian**. The assemblage is similar in type of preservation and composition to that of samples A-47 and A-48.	Matbat
A-148	7410002/ 2382640	*Acaeniotyle* (?) with spines broken off or *Praeonosphaera* sp.; *Archaeodictyomitra* sp. of Tithonian-Lower Cretaceous type; *Wrangellium* (?) sp.	**Tithonian?-Lower Cretaceous**.	Wahrah
A-149	7410002/ 2382640	*Alievium picum* (KIESSLING); *Neorelumbra kiesslingi* (DUMITRICA) n.sp.; *Praecaneta longa* (JUD); *Pseudodictyomitra leptoconica* (FOREMAN); *Sethocapsa zweilii* (JUD); *Spongacapsula banala* (JUD)	**Berriasian-lower Valanginian**.	Wahrah
A-150	741002/ 2382640	*Cinguloturris cylindra* (KEMKIN & RUDENKO); *Emiluvia chica* (FOREMAN); *Podocapsa amphitreptera* (FOREMAN); *Pseudodictyomitra carpatica* (LOZYNIAK); *Sethocapsa leiostraca* (FOREMAN); *Spongacapsula banala* (JUD)	**Berriasian-?Lower Valanginian**. The age of the assemblage can be established as Berriasian-lower Valanginian (UA5-17 of Jud, 1994).	Wahrah
A-151	741002/ 2382640	*Archaeodictyomitra minoensis* (MIZUTANI); *Caneta mashitaensis* (MIZUTANI); *Dicerosaturnalis angustus* (BAUMGARTNER); *Mirifusus dianae* (KARRER); *Podocapsa amphitreptera* (FOREMAN); *Protunuma japonicus* (MATSUOKA & YAO); *Ristola altissima altissima* (RÜST)	**Kimmeridgian-Tithonian**. The age is based on the presence of *H. angustus*, *C. mashitaensis* and *A. minoensis*.	Wahrah
A-192	766270/ 2428990	*Emiluvia premyogii* (BAUMGARTNER); *Obesacapsula morroensis* (PESSAGNO); *Stichocapsa robusta* (MATSUOKA); *Stylocapsa catenarum* (MATSUOKA); *Transhsuum brevicostatum* (OZVOLDOVA)	**Upper Bathonian-Lower Callovian.** These species have ranges extended either to Bathonian or Bajocian, or to early Callovian, Oxfordian or Kimmeridgian-Tithonian, but they co-occur in the Upper Bathonian-Lower Callovian.	Wahrah
A-193	77500/ 2439300	*Cinguloturris cylindra* (KEMKIN & RUDENKO); *Podocapsa amphitreptera* (FOREMAN); *Praecaneta cosmoconica* (FOREMAN); *Sethocapsa uterculus* (PARONA); *Wrangellium depressum* (BAUMGARTNER)	**Berriasian-Lower Valanginian, UA5-18.** The age is primary based on the co-occurrence of *W. depressum* (UA5-24) and *C. cylindra* (UA3-18).	Wahrah
A-205	773369/ 2455467	*Archaeodictyomitra apiarium* (RÜST); *Archaeodictyomitra minoensis* (MIZUTANI); *Mirifusus dianae* (KARRER); *Ristola procera* (PESSAGNO); *Wrangellium depressum* (BAUMGARTNER)	**Late Tithonian.** The age is based on the co-occurrence of *A. minoensis* and *R. procera*.	Ruwaydah