INTERNATIONAL ASSOCIATION OF SEDIMENTOLOGY
24th REGIONAL MEETING, MUSCAT JAN. 10-13, 2005

# Permo-Triassic Deposits of the Oman Mountains: from Basin and Slope to the shallow Platform

## Post-Conference Excursion No. A13 in the Oman Mountains January 14 - 17, 2001

**Leaders: Sylvain RICHOZ and Aymon BAUD,**

**With contribution of Leopold KRYSTYN, Richard TWITCHETT, the help of Jean MARCOUX, and the text adapted from François Bechenec, Fabrice Cordey and René Maury *in* Baud et al. (2001)**

# PART I STRUCTURE AND PALAEOGEOGRAPHICAL EVOLUTION OF THE OMAN PASSSIVE MARGIN DURING THE PERMO-TRIASSIC: AN INTRODUCTION TO THE FIELD TRIP.

## 1.- Structure of the Oman Mountains (Adapted from Béchennec in Baud et al. 2001)

The Sultanate of Oman is situated on the southeast margin of the Arabian Peninsula. Separated from Africa by active spreading axes in the Gulf of Aden and the Red Sea, and by transcurrent fault zone of the Gulf of Aqaba and the Dead Sea, the peninsula is bounded to the east by the Owen-Murray transcurrent fault zone; to the north she is bordered by the Eurasian plate, the boundary between the two plates being a collision zone in the Taurus and Zagros mountains and a zone of northeastward subduction in the Gulf of Oman.

Geological studies carried out in Oman by many projects have provided a profond insigh into geological history, as summarized by the 1/500000-scale map of the northern chain (Glennie et al.,1974) and by the 1/1000000-scale map of the whole Oman (Le Métour et al., 1993a; Béchennec et al., 1993a). The alpine northern Oman Mountains, extending for 700 km from the Musandam Peninsula in the north to the Batain coast in the southeast, was uplifted at the end of the Miocene along the northeastern edge of the Arabian Peninsula. Seven major structural units are identified from the base up (fig. 1- 2):

- The Crystalline Basement, of Late Proterozoic age.
- The Sedimentary Basement of latest Proterozoic to Ordovician age.
- The Middle Permian-Late Cretaceous carbonate Arabian Platform (Hajar Unit).
- The Sumeini and Hawasina nappes mainly made up of continental slope and basin. deposits thrusted onto the Arabian Platform during the Late Cretaceous.
- The Samail Ophiolite, a fragment of Neo-Tethys oceanic lithosphere obducted onto the Oman continental margin in the Late Cretaceous.
- The post-nappes sedimentary cover of End-Cretaceous-tertiary age.

The Crystalline Basement comprises gneiss and micaschist that are intruded by various plutonic rocks, such as quartzdiorite, tonalite, granodiorite and granite; radiometric dating reveal that these rocks were formed and cooled between 825 and 725 Ma; crystalline rock of the same nature and age is well known in the Arabian Shield of the Yemen and Saudi Arabia and constitute the greater part of the continental crust of the Arabian plate which formed a vast craton from the earliest Palaezoic period. The oldest deposits of the Sedimentary Basement are end-Late Proterozoic or Proterozoic/Cambrian boundary times and the youngest ones are attributed to the Early Permian. However sedimentation, in spite of the huge thickness (1000-5000m) of the series, was not continuous throughout this time: several major stratigraphic break are recorded. The Permian-Cretaceous shallow-water carbonate series are named from the vast continental shelf, the Arabian Platform, where they were deposited. In the Oman Mountains this unit, called Hajar Unit, lies unconformably on the basement and constitutes the autochthonous (or parautochthonous) structural unit which was subsequently overthrust by nappes. Its history belongs to that of the Neo-Tethys continental margin. The Sumeini and Hawasina nappes also tell the history of the southern margin of the Neo-Tethys ocean. They are mainly made of pelagic and turbiditc sediments deposited in slope to basin environment and of subordinated volcanic rocks; these units document the beginning of Neo-Tethyan extension in the Middle Permian and the beginning of the Eoalpine compressive tectonism, that leads to the destruction of the Oman continental margin, in Late Cretaceous.

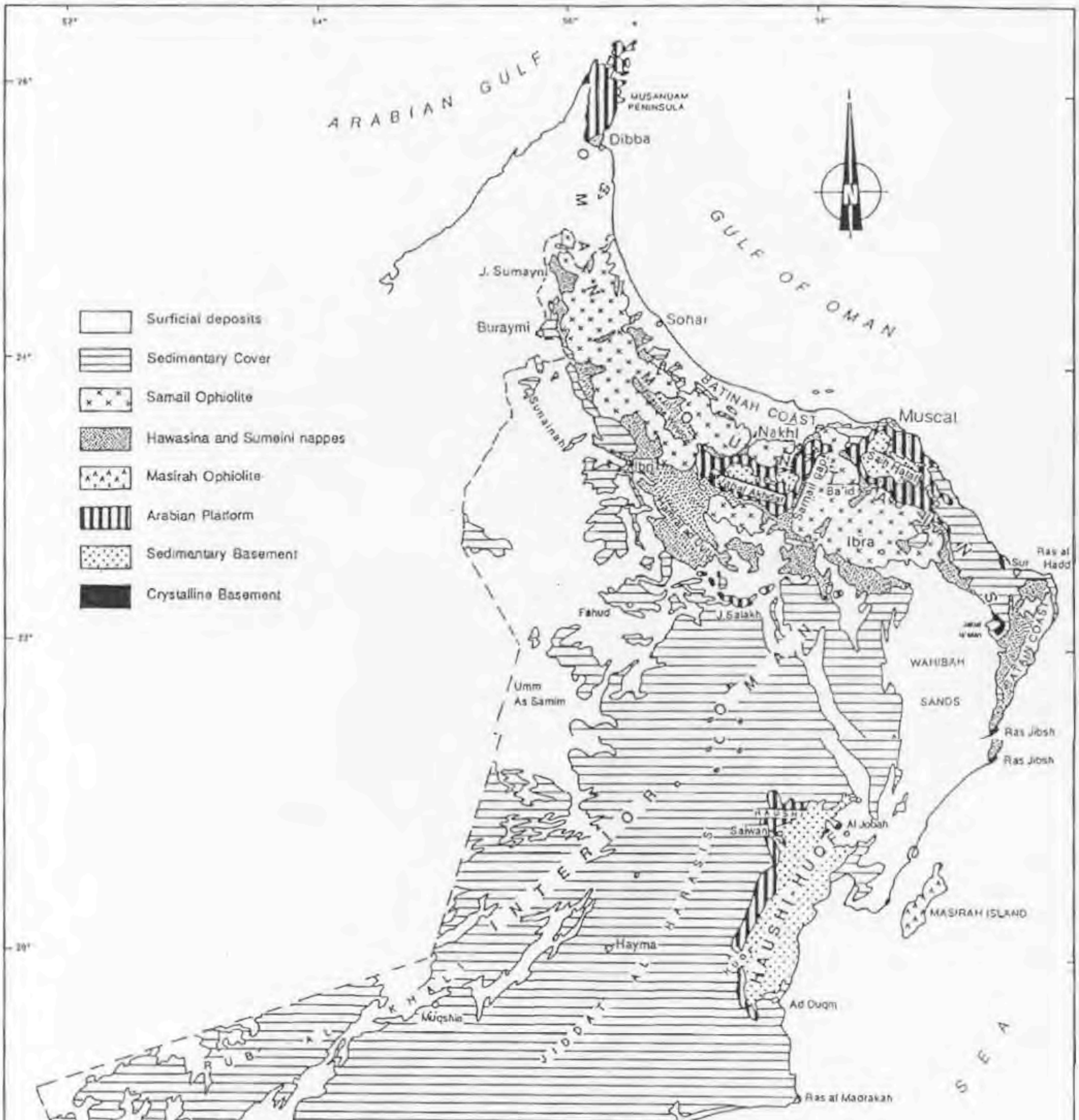



Fig. 1- Geological sketch map of the Sultanate of Oman (from Le Metour et al., 1995).

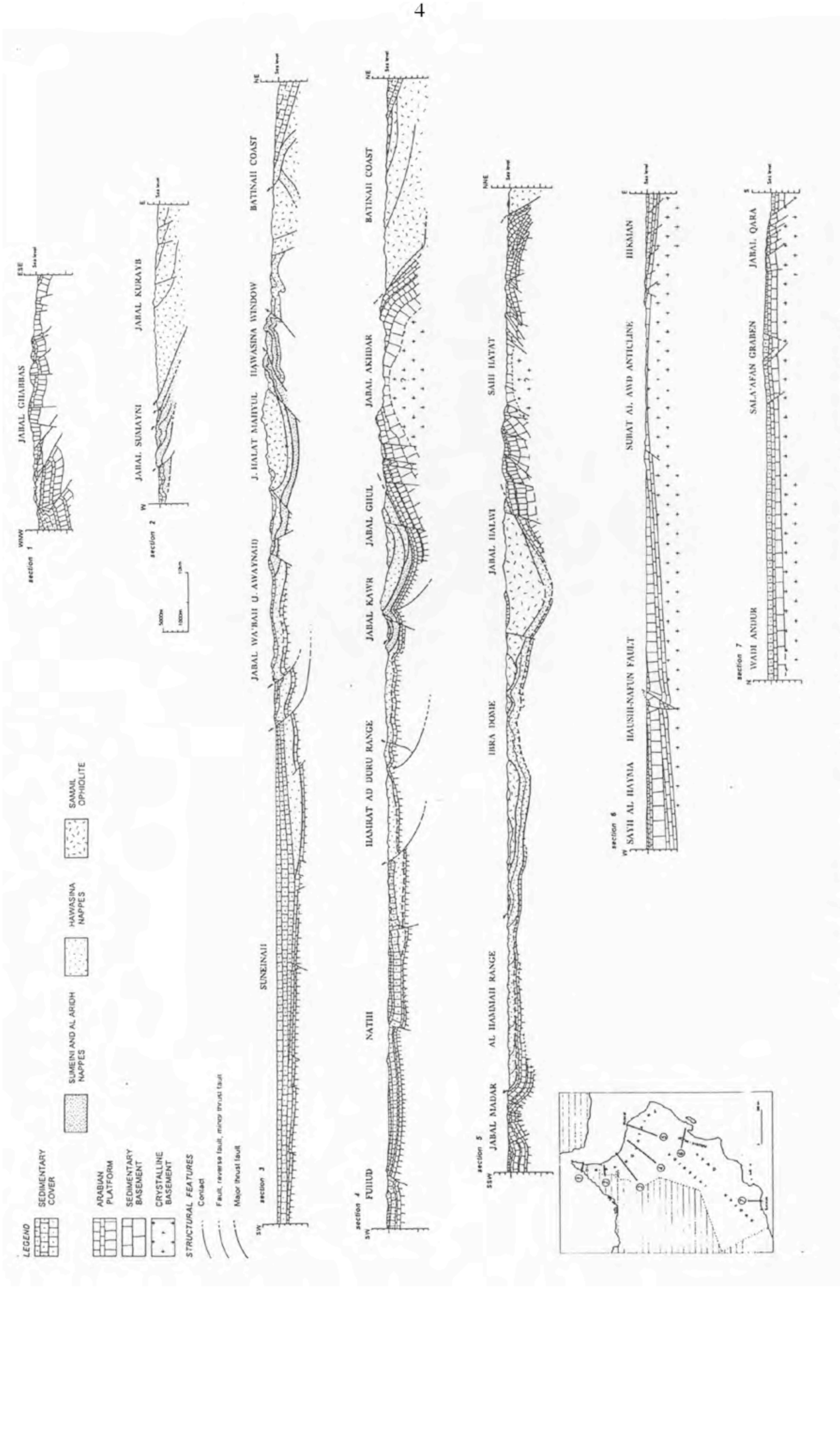
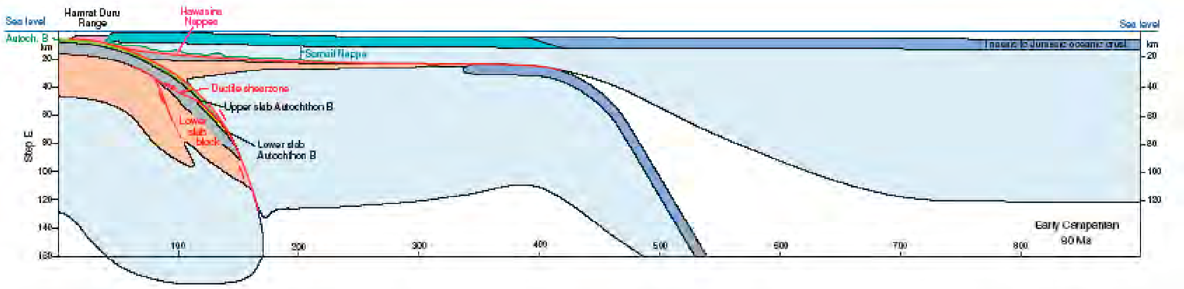



**Fig. 2- Structural cross-sections from the N to the S of Oman (from Le Métour et al., 1995)**

The Samail Nappe is a vast, extensive fragment of oceanic lithosphere created in the Neo-Tethys during the Middle to Late Cretaceous; it is structurally, the highest of the allochthonous units. The Samail Ophiolite may be subdivided in two major sequences separated by the petrographic Moho: a lower Mantle sequence and an upper Crustal sequence. The distinction of two successive magmatic suites corresponding to two distinct tectono-magmatic episodes that developed in the Neo-Tethyan oceanic floor is fundamental: the first one dated end-Albian-Early Cenomanian, was formed extension episode at an oceanic spreading ridge; the second one , dated Middle Cenomanian-Late Turonian, took place in a context of northward intra-oceanic subduction.
According to Breton et al. (2004), an intracontinental subduction zone affected the autochthon of the Arabian Platform with a basal rupture lying in the proximal part of the continental margin, to the south of the northern edge of the carbonate platform. A North Muscat microplate was created between the intra-continental subduction zone and the intraoceanic subduction that gave rise to the Samail Ophiolite; this microplate includes the outer part of the Arabian Platform, the continental slope and the entire Hawasina Basin.
From Early Turonian to Late Santonian the obduction and the intracontinental subduction were coeval and parallel. The northeast edge of the North Muscat microplate plunged below the Samail Nappe whilst the emergent southwest part overthrust the innermost parts of the Arabian Platform. The leading edge of the Samail and Hawasina Nappes advanced across the southwestern border of the North Muscat microplate just before obduction and intracontinental subduction ceased at the Santonian–Campanian boundary. Towards the end of the intracontinental subduction, the lower part of the crust of the subducted autochthon delaminated the upper part, marking the first stage of the metamorphic rocks exhumation.




From Early Campanian to Early Maastrichtian, the North Muscat microplate moved to the northeast, its northeastern edge sunking by gravity into the asthenosphere.
The subducted autochthon rose up, and came into contact with the base of the obducted units. The resulting uplift of the ophiolite nappes produced its emergence and partial erosion. Local crustal thickening, related to the lithospheric delamination, caused doming at Saih Hatat and subsequent erosion that locally extended to the pre-Permian sedimentary basement during the Early Maastrichtian.

During the Late Campanian-Maastrichtian the first continental sediments were deposited on the Oman Mountains area and the marine transgressions start again in Maastrichtian. Thus, the end-Cretaceous and Tertiary sedimentary cover represents the post-nappe unit, in reference to the Oman Mountains. The recent geological history is marked notably by the Alpine orogeny, in the Miocene, that leads to the uplift of the present Northern Oman Mountains with the formation of the present day dome shape of Jabal Akhdar.

## Permian - Triassic birth and evolution of the Arabian passive margin.

Our analysis is based on our own data (Baud et al., 2001a, b,, Richoz, 2004) and on Béchennec (in Baud et al., 2001a), Pillevuit 1993, and Pillevuit et al. (1997) .

**Summary.**
The Neotethyan opening with the northward drifting of the Iran/Mega Lhasa microcontinent ("Cimmeria", Sengör, 1984) following a rifting – extensional phase is achieved in the Sakmarian (hypothesis developed by Saidi, 1997, Besse et al., 1998, Angiolini et al., 2003a et b, and Maury et al., 2003) or achieved in the Roadian-Wordian (hypothesis presented here and developed by Baud et al., 1993, Pillevuit et al., 1997, Baud et al., 2001a, b). The following thermal subsidence with the onset of the continental margin is well recorded in the thick Wordian-Capitanian carbonate succession and continued during the Lopingian. Tectonic instability of the margin, with bock tilting, platform drowning and (fault) breccia deposits start at the dawn of the Triassic with main climax during the Dienerian and the Smithian. A renewed tectonic instability with plume related volcanism start offshore in the Carnian with the creation of atoll like isolated carbonate platforms (Kawr) and the opening of a new basin (Umar). By end of Triassic, all the known parts of the continental margin and adjacent ocean and atolls are designed.

**Before the Neotethyan rifting**
In late Palaeozoic time when all existing continents moved together to a single Pangea supercontinent, Oman and the Arabian Peninsula with Africa, India, etc…(Ricou, 1993) formed part of the Gondwana continent on its southern half. To the north the enlarged Gondwanaland (including the Cimmerian blocks) was bordered by the Palaeotethys ocean. During the Late Carboniferous-Earliest Permian period, the Gondwana continent was subjected to glaciation (Al Khlata tillite in Oman).

**The first stage of the Neotethyan rifting**
The end of the glacial period in the Early Permian resulted in a global rise in sea level, which subsequently submerged parts of the continent. This is reflected in the marine siliciclastic and carbonate deposits laid down during the Early Permian (Sakmarian-Artinskian) identified in the Haushi-Huqf area and Interior Oman (Saiwan Fm., Dubreuilh et al. 1992; Miller and Furnish, 1957; Hudson and Sudbury, 1959; Angiolini et al., 1997) and in the Jabal Qamar, north of Oman Mountains (Asfar Fm., Pillevuit, 1993, Pillevuit et al., 1997). Furthermore, reworked blocks of Early Permian (Artinskian, Kungurian) shallow-marine carbonate are also identified in the nappe units of the Batain series documenting the southeasternward extension of a rim basin (Pillevuit, 1993, Pillevuit et al., 1997, Immenhauser etc) or the opening of the northern Karoo rift system (Hauser et al. 2002) with a Permian shelf and sea-way along the southeastern coast of Oman (Hauser et al. 2000). However, such marine deposits are unknown in the central and eastern part of the Oman mountains (Jabal Akhdar and Saih Hatat) indicating that, at this time, this region constituted a positive zone; this is probably in relation with a flexural doming belonging to the Neotethyan rifting, initiating a shoulder and concomitant rim basins where the marine deposits laid down.

The first stages of the Neotethyan extension conrinued during Kungurian-Roadian time and are documented by:

- An angular unconformity between the Early Permian Saiwan Fm. and the Middle Permian Gharif Fm., in the Haushi-Huqf area;

- An angular unconformity between the Early Permian Asfar Fm. and the Late-Early/ Middle Permian Qamar Fm., in the Jabal Qamar area (Northwestern part of the Oman Mountains);
- Horst and graben tectonics as identified in the Oman Mountains (Jabal Akhdar and Saih Hatat) by the differential erosion between blocks (Le Métour, 1988; Rabu, 1988) and by the syn-rift-type siliclastic terrigenous deposits of the lower part of the Saiq Fm. (Saiq A1 unit).

Global sea level rose to a maximum during the late Early Permian (Kungurian - Haq et al., 1987) and shallow-marine carbonate of this age are found in Oman as reworked blocks in lower Triassic proximal turbiditic facies of the nappe units on the Batain Coast (Béchennec et al., 1992a, Hauser at al. 2000) witness of extensional movements between Afro-Arabia and India.
Subsequently as a result of rapid erosion of the shoulder initiated in Early Permian, the terrigenous siliciclastics deposits of the Gharif Fm. (Kungurian-Roadian, Broutin et al., 1995) and those of the base of the Qamar and Saiq Fms. were laid down in a continental environment.

**The Neotethyan opening**
At the dawn of the Wordian (Middle Permian), within a sea level rise, the "Fusulinid Sea" transgressed over most of Oman with the exception of the Jabal Ja'alan and the Huqf-Dhofar axis; this transgression enabled the establishment of a vast carbonate platform in Jabal Akhdar, a 400-700m-thick succession of cyclic shallow marine carbonate, the Saiq Fm. (Middle-Late Permian to basal Triassic, Baud et al. 2001, Richoz, 2004); a similar succession occurs in the Saih Hatat (Weidlich et al., 2003) in the Musandam (Bih and Hagil Fms.) as well as in the Interior Oman and in the Haushi area (Khuff Fm., Dubreuil et al., 1992; Angiolini et al. 1998; 2003). In our opinion, this transgression was the result of the break-up of the Neotethyan rift and the associated thermal subsidence.
This Neotethyan break-up initiated the northward drift of the Iran/Mega Lhasa microcontinent (Baud et al., 1993, 2001); the most striking effect of the climax of the Neotethyan extension in Oman, however, was the formation of a continental slope (Sumeini) and a basin (Hawasina) that built the southern continental passive margin of the Neo-Tethys along the adjacent Arabian Platform. From the latter early-rifted blocks were detached and formed isolated distal platforms along the continental slope (later they were incorporated in the Hawasina Nappes).

Continental slope deposits (with slumps and intraformational breccias) have been identified in the northwestern part of the Oman Mountains (Jebel Sumeini), where they form the basal part of the Maqam Fm. dated as Middle Permian (Wordian - Pillevuit, 1993; Pillevuit et al., 1997; or Roadian - Krystyn, oral communication). A different type of ramp(?)-related deep water gray limestone is known in the nappe units of the Batain Plain (southeastern part of the Oman Mountains), called as "Qarari Limestone" (Shackleton et al., 1990; Béchennec et al., 1992a; Wyns et al., 1992) with a base dated as Roadian (Middle Permian, Immenhauser et al., 1998) and the top Wuchiapingian (Kozur, unpublished results).

Distal isolated platforms now preserved as nappes in Baid and Jabal Qamar areas (Béchennec, 1988; Béchennec et al., 1992b; Pillevuit, 1993, Pillevuit et al., 1997) are mainly made of Middle-Late Permian open shelf carbonates. The Jabal Qamar unit includes a fragment of the pre-Permian basement (Rann, Ayim and Asfar Fms., Pillevuit, 1993) unconformably overlain by the late Early-early Middle Permian shallow-marine carbonate Qamar Fm. with a quartz-sandstone basal member. The Baid unit is truncated at the base and is made up of about 100 m of Middle-Late Permian (Capitanian-Wuchiapingian) shallow-

marine carbonate (Baid Fm., Béchennec, 1988; Pillevuit, 1993, Pillevuit et al., 1997, Baud al., 2001a). The distal paleogeographic position of these Permian tilted blocks with regard to the Arabian Platform is documented by:
(1) differences in terms of facies (open marine with **ammonoids**? versus restricted platform in others parts of the Oman Mountains, e.g. Jabal Akhdar, Saih Hatat, Musandam);
(2) The presence of reworked shelly rich and reefal boulders from these isolated platforms in the distal deeper water calcirudites of the present Hawasina Nappes.
Middle Permian basinal facies is to be found at the base of numerous tectonics units in the Hawasina Nappes, made up of formations from the Hamrat Duru Group. These successions start generally with thick volcanic sequences (basal volcanics of the Al Jil Fm); they are particularly well exposed to the north of the Hawasina Window (Buday'ah area) and of the Jabal Akhdar (Al Ajal region) and in the southern flank of the Saih Hatat (Wadi Wasit area); they have been also identified locally, near Nahkl and Rustaq and in the Batain plain near Al Ashkharah. Predominantly these volcanic rocks comprise tubular pillow basalt and subordinated andesitic and trachytic lava, hyaloclastite and tuff (Béchennec, 1988; Béchennec et al., 1991; Béchennec et al., 1992a-b-c, Pillevuit, 1993, Pillevuit et al., 1997). These volcanic rocks are either of MORB type or alkali basalt-related; however N-MORB (depleted) have not been found as most of the studied samples range from transitional MORB to enriched MORB (Maury et al., 2003). The volcanic succession is generally overlain by red radiolarian chert and shale, dated as Middle Permian (Wordian) in Buday'ah and Al Ashkharah areas (De Wever et al., 1988; Béchennec et al., 1992a-c, Cordey in Baud et al. 2001b). In the Wadi Wasit area, the volcanic series is capped by red cephalopods-bearing carbonate, dated Middle Permian (Wordian, Blendinger et al., 1992; Pillevuit et al. 1997, Baud et al. 2001b), by shales and breccia with reworked blocks of Middle Permian platform carbonate (Béchennec et al., 1992b; Pillevuit 1993). Near Nahkl the volcanic series includes blocks of Middle Permian shallow-marine carbonate and is overlain by pelagic limestone. In the Rustaq area the volcanic succession is also capped by a condensed carbonate sequence (Hallstatt facies type) dated as Middle Permian (Wordian, Blendinger et al., 1992, Pillevuit et al. 1997, Baud et al. 2001b, Kozur et al. 2003).
With the peak of the thermal subsidence in the Wordian-Capitanian, a stable carbonate platform became established on the Arabian Peninsula. At the end of the Guadalupian, probably associated with a global fall in sea level at this time (Haq et al., 1987), the Saiq, Khuff and Hagil Fms. show a strong regressive tendency with restricted environmental facies and a reduced biophase.
During the Lopingian, subsidence is renewed and as recorded in the Saiq mega-cycle B (up to 300m of shallowing upward cycles) still well active.

**The Permian-Triassic transition and the Lower Triassic deposits on the Arabian passive margin.**
At the end of the Permian, regressive conditions leading to local emersion are recorded from the Arabian carbonate platform (Jabal Akhdar, Saih Hatat, Musandam) and from the adjoining slope (shallowing in the Sumeini unit).

Carbonate breccia is the main lithology of the basal Triassic deposits in the Jabal Akhdar (Cycle C of the Saiq Formation, Griesbachian). Strong differential subsidence (renewed extensional regime) is evidenced by the varying thickness of the Cycle C: about 90m in Wadi Sathan and only 7m on the Saiq plateau. A fine grained terrigenous event with yellow to green clay deposit (Dienerian) is recorded at the base of the Mahil and the Sudair Fms., in the Saih Hatat/Jabal Akhdar and in the Interior Oman respectively.

On the slope of the continental margin, a continuous more than 1 km thick carbonate and subordinate shale sequence has been precisely dated from Changsingian to Spathian (recent unpubl. data in this guide book). Overlying the Capitanian-Wuchiapingian? deep-water cherty dolomite (upper part of the Member B of the Maqam Fm), we have discovered Changsingian shallowing and less siliceous strongly bioturbated lime mudstones. A huge facies change occurs around the P-T boundary with Griesbachian papery, laminated calcimicrobial mudstone overlying the boundary clay (base of the Member C of the Maqam Fm). The above following calcarenites, calcirudite turbidites and mass flows (Watts 1987) with shallow water Upper Permian lime clasts start with an erosional break in the late Dienerian (instability period, dated by L.K.). Smithian deposits (platy limestones, shales and megabreccia up to 900m; middle and upper Member C of the Maqam Fm.) are incredibly thick and indicate high carbonate productivity on the platform as well a very active subsidence at the base of slope (Baud et al. 2001; Richoz 2004).

On the Baid tilted block, after karstification of the Permian carbonate platform and a Griesbachian break, Dienerian-Smithian deep-water red ammonoid limestone documents a drowning of the platform thereby filling fissures and cavities (Hallstatt breccia on Djebel Rahbah, H. Bucher oral communication) within the Permian limestones (Tozer and Calon, 1990; Pillevuit, 1993; Pillevuit et al., 1997, Baud et al. 2001, Richoz 2004).

In the proximal basin (Wadi Wasit units) a late(?) Dienerian submarine mass flow breccia containing Permian to basal Triassic (mega-)blocks erodes deeply into the underlying Upper and even Middle Permian rocks. One of these blocks has preserved a unique basal Triassic fossil record unknown anywhere else (Krystyn et al.,2003; Twittchett et al.,2004). The breccia can reach local thicknesses up to 50 m and is onlapped by Smithian deep-water platy limestones.

In the distal basin (Budaya'a), the middle Permian radiolarian cherts deposits are overlain by Lopingian siliceous and calcareous shales followed in the basal Triassic by laminated platy limestones and shales.

**The Olenekian to Rhaetian evolution of the margin**

On the Arabian platform we note dolomite successions of various thickness (350m for the Sudair Fm.; 500-800m for the Mahil Fm.; 850m for the Ghail, Milaha and basal Ghalilah Fms. in Musandam). Common breaks in subsidence are indicated by shallowing upward sequences with frequent sub-aerial exposures. Emersion and laterite deposits at the end of the Triassic indicate a first order sea level fall.

On the slope of the continental margin (Sumeini), the thick Smithian deposits are overlain by Spathian-Anisian shales (Member D) and Ladinian radiolarites built under stable depositional condition. During the Carnian-Norian, episodic instability is documented by coarse calcirudites interbedded in the chert and calcarenite succession of the Member E of the Maqam Fm.

On the Baid tilted block, Triassic tectonic instability is also documented by angular unconformities and by clast-supported breccia with Late Permian remains in the Hallstatt type succession from Dienerian up to the Lower Jurassic (Tozer and Calon, 1990; Pillevuit, 1993; Pillevuit et al., 1997, Krystyn in Baud et al. 2001).

In some areas of the distal basin (Dibba ? zone and the Central Oman Mountains), volcanic rocks are interbedded in the Ladinian-Carnian chert member of the Matbat Fm. (Béchennec et al., 1992c; Le Métour et al., 1992b), interpreted as evidence of a renewed extensional regime.

The Late Triassic (Carnian) oceanic extension of the distal part of the Hawasina Basin is documented by the creation of the Misfah (=Kawr) Platform and the Umar Basin. Kawr and Umar Groups now build individual tectonic units on top of the stacked Hawasina Nappes. . Their basement consists of a thick volcanic unit that displays the characteristic of intraplate magmatic series and range from intraplate tholeiites to alkali basalt (Béchennec, 1988; Béchennec et al., 1991; Pillevuit, 1993; Pillevuit et al., 1997; Maury et al., 2001, 2003, Lapierre et al. 2004). Strong subsidence of the cooling oceanic(?) crust leads to a huge thickness of the Late Triassic shallow-marine carbonates deposited on this distal platform. In the Misfah setting the volcanic unit is overlain by a Norian marly nodular limestone (Subayb Formation,) and by a thick (600m) shallow-marine carbonate of Dachstein type (Misfah Fm., Pillevuit, 1993), Norian-Rhaetian in age (Krystyn in Baud et al., 2001b). The end of lagoonal carbonate deposition with presence of hardgrounds and, in places, microkarsts reflects the end-Triassic sea level fall. In the adjacent Umar Basin, the Late Triassic sedimentary succession consists of pelagic limestone and radiolarian chert without any terrigenous influx; rare calcareous clastic sediments are calcirudite and megabreccia made of reworked boulders of shallow-marine carbonate originating from the Misfah Platform or related atoll structures.

## PART II: INTRODUCTION AND DESCRIPTION OF THE VISITED OUTCROPS

### 1-. Introduction: Permian - Triassic stratigraphic nomenclature

| | | Stand. Stages | Tethyan Stages | Conodont zones | |
|---|---|---|---|---|---|
| TRIASSIC | LATE | RHAETIAN | | *posthernsteini*<br>*mosheri* | 201My |
| | | NORIAN | | *bidentata* *steinbergensis*<br>*serrulata*<br>*postera*<br>*elongata*<br>*spiculata*<br>*multidentata*<br>*triangularis*<br>*quadrata* *navicula*<br>*primitius* | 225My |
| | | CARNIAN | | *communisti*<br>*nodosus*<br>*polygnathiformis* | |
| | MIDDLE | LADINIAN | | *mungoensis*<br>*hungaricus*<br>*trumpyi* | 241My |
| | | ANISIAN | | *excelsa* *constricta*<br>*bulgarica*<br>*shoshonensis*<br>*germanica*<br>*timorensis* *regale* | |
| | EARLY | OLENEKIAN | | *homeri* *aff timorensis*<br>*collinsoni*<br>*triangularis*<br>*milleri*<br>*meeki* *waageni*<br>*pakistanensis* | |
| | | INDUAN | | *cristagalli*<br>*dieneri*<br>*discreta* *kummeli*<br>*sosioensis* *carinata*<br>*isarcica*<br>*parvus* | 253My |
| PERMIAN | LATE | CHANGHSINGIAN | DORASHAMIAN | *praeparvus*<br>*yini*<br>*changxinensis*<br>*subcarinata*<br>*wangi* | |
| | | WUCHIAPINGIAN | DZHULFIAN | *orientalis*<br>*transcaucasica*<br>*leveni*<br>*quangyuanensis*<br>*dukouensis*<br>*postbitteri* | |
| | MIDDLE | CAPITANIAN | MIDIAN | *altudaensis*<br>*postserrata*<br>*omanenesis* | 264My |
| | | WORDIAN | MURGABIAN | *siciliensis* | |
| | | ROADIAN | KUBERGANDIAN | *nankingensis* | 270My |
| | EARLY | KUNGURIAN | BOLORIAN | *sulcoplicatus*<br>*prayi*<br>"*exsculptus*" | |
| | | ARTINSKIAN | | *pequopensis* *pnevi*<br>*postwhitei*<br>*florensis* *whitei* | |
| | | SAKMARIAN | | *trimilus*<br>*barskovi* | |
| | | ASSELIAN | | *fusus*<br>*nevaensis*<br>*isolatus* | 298My |

Table 1- Permian-Triassic Time table with standard and Tethyan stages name. Conodont biochronology modified from Permophiles 36 and Orchard & Tozer (1997) and Richoz (2004).

In the last ten years, many changes occured in the Permian-Triassic time scale and zonation. It is why we are giving in table 1 a recent time table as adopted by the IUGS. The Tethyan stage names used in some part of this guide book are shown according to their correlative standard stages.

### 1.2 Visited localities and maps

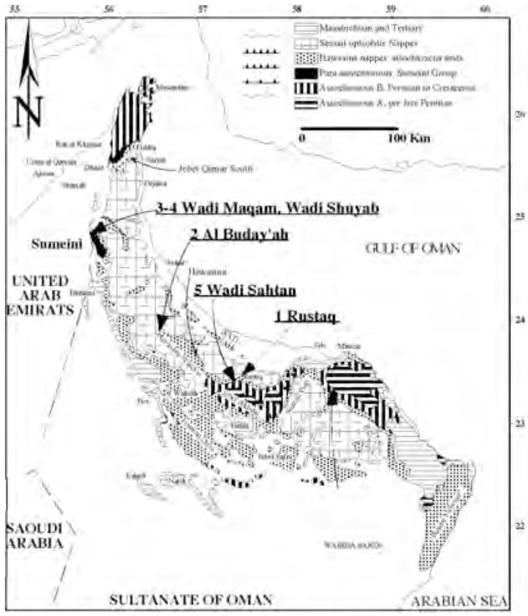



Figure 3: Geological sketch of the Oman Mountains with the main visited localities (Excursions A13, 1 - 5). Modified, from Pillevuit et al., (1997).

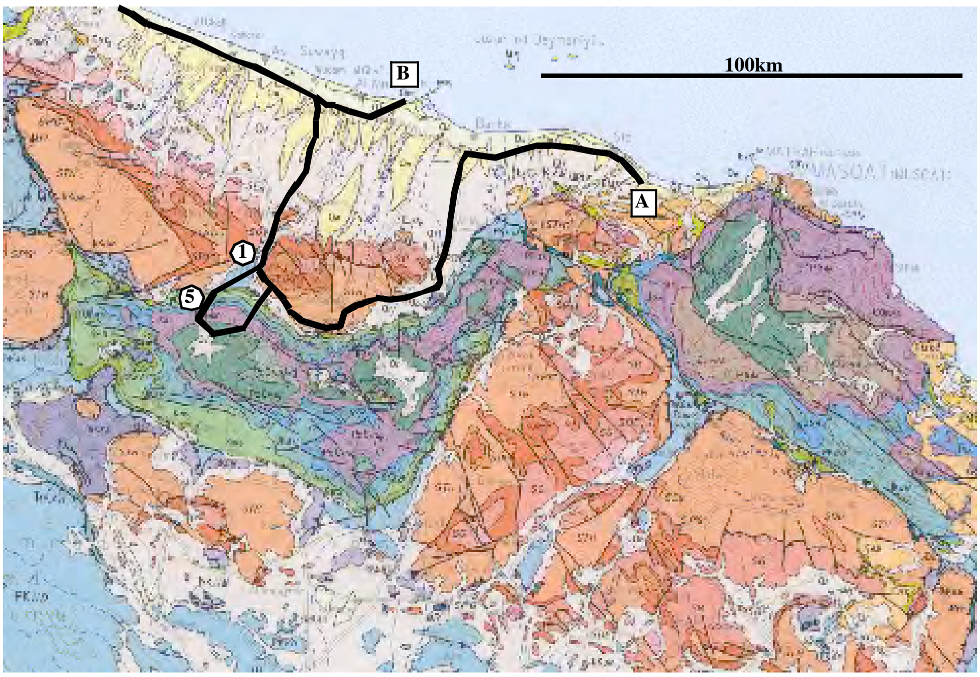



Figure 4: Geological Map of the Eastern part of the Field excursion A13, with the first and last stops (1,5) and place of the last overnight (B). Map from Le Métour et al., (1993a)

### 1.3 Magmatic evolution of the Permo-Triassic Tethyan margin in Oman *(afterR. Maury)*

Submarine basaltic flows are exposed in several areas of the Tethyan Oman margin. In some occurrences, the pillowed basaltic units are overlain by faunistically-dated Permian deposits (Rustaq, Buday'ah, Wadi Wasit, Saih Hatat, Al Ajal), whereas in other areas they are associated to Triassic sedimentary rocks (Jabal Misfah, Jabal Buwaydah, Aqil, Sinni) (cf figure 11). The pillow basalts are usually subaphyric with less than 5 modal % phenocrysts of olivine (altered to chlorite or serpentine), albitized plagioclase and clinopyroxene, the latter mineral still displaying its primary (magmatic) chemical composition. Secondary minerals are common in the groundmass of these basalts. They include albite, chlorite, calcite and less commonly quartz.

We have studied for major and trace elements carefully selected basaltic samples, the loss on ignition of which is usually less than 6 weight %. They have been analyzed by ICP-AES following the methods described by Cotten et al. (1995). Their primary major element compositions are rather well-preserved with the exception of alkali elements which display random variations linked to alteration processes. Most of them are evolved basalts, with MgO contents lower than 8%, and intermediate lavas are common,especially in the Triassic occurrences. The TiO2 contents of the basalts are very variable: they range from 0.9% to 4%. Two basaltic groups can be distinguished, with TiO2 contents respectively low (1-2%) and high (2-4%). They are equivalent to the low-Ti ("LTi") and high-Ti ("HTi") basalts recognized in rifts, plateaus and trapps (Gibson et al., 1995; Pik et al., 1998, 1999). The low-Ti basalts are rather similar to MORB from the point of view of their major element chemistry, whereas that of the high-Ti basalts recalls the intraplate (plume-related) basalts from rifts and ocean islands.

The trace element features of these basaltic types are also contrasted. Incompatible multielement spectras restricted to elements usually immobile or slightly mobile during alteration (Th, Nb, Zr, Ti, Y and the rare earth elements La, Ce, Nd, Sm, Gd, Dy, Er and Yb) display four kinds of patterns: (1) nearly flat patterns identical to those of "transitional" MORB (i.e. transitional between depleted MORB and enriched MORB); (2) slightly enriched patterns similar to those of enriched MORB; (3) moderately to consistently enriched patterns similar to those of intraplate plume-type tholeiites from rifts, plateaus and ocean islands, and finally (4) strongly enriched patterns typical of intraplate alkali basalts. It is important to notice that no depleted pattern typical of normal MORB has been found over more than 60 analyzed pillow basalt samples.

Types (1), (2) ,(3) and (4) are commonly found in plume-related occurrences, e.g. rifts and plateaus (see references above). Types (1) and (2) correspond to low-Ti basalts and are the closest to MORB, as shown by their position in the (Nb/Y)/(Zr/Y) diagram of Fitton et al. (1997). Similar compositions are also found in oceanic ridge basalts located close to hot spots (e.g. Bougault et al., 1985) and in basalts from the seaward-dipping reflector sequences in passive ocean margins (Fitton et al., 1998). The main chemical differences between those of these basalts emplaced through continental crust and those in truly oceanic position lie in their contents in large ion lithophile elements (Rb, Ba, K, Sr) which unfortunately have been modified by alteration processes in the case of the Oman basalts. Types (3) and (4) correspond to the high-Ti basalt group and are rather similar to the tholeiites and alkali basalts from ocean islands, respectively. They are not occurring in oceanic crust materials devoid of plume-hot spot influences.

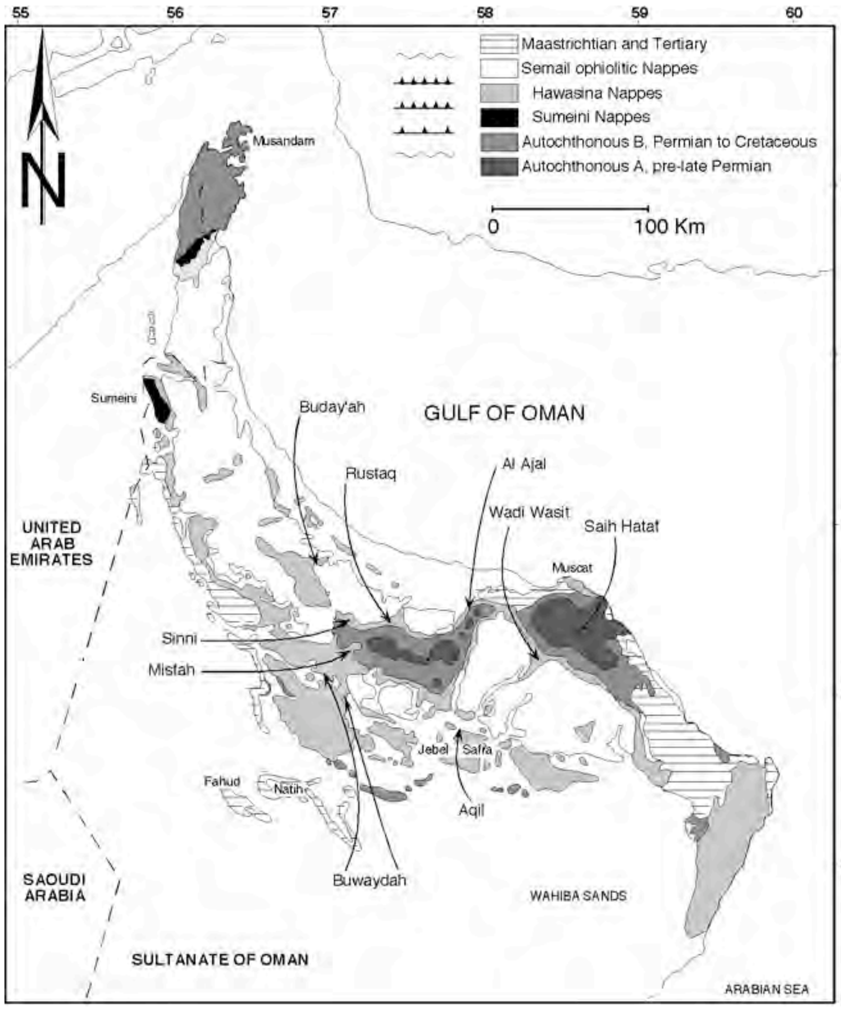



Figure 5: Geological sketch map of the Oman Mountains (after Glennie et al. 1974) with localities of Permian-Triassic volcanism cited in the text

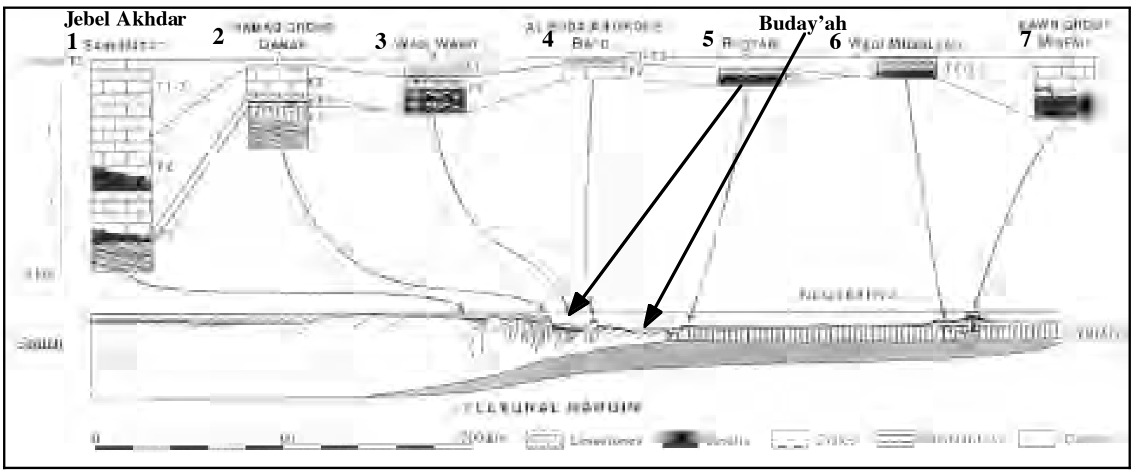



Figure 6: Oman margin in the late Triassic, from proximal (1) to distal (7) (after Pillevuit et al., 1997).

## 1.3 Carbon isotope stratigraphy *(S. Richoz)*

$\delta^{13}C$ and $\delta^{18}O$ isotope stratigraphy has been studied in 6 different sections of various environment from shallow to deep water facies zones of the Upper Permian-Lower Triassic carbonate sequences (bulk rock, new data and data from Atudorei, 1999). Wordian carbonates have in all sections high $\delta^{13}C$ values between +3‰ and +6.6‰. These high values are still present in Capitanian to Wuchiapingian carbonates. According to Baud et al. (2001) dated Changhsingian carbonates are present as resedimented pebbles or clasts in basinal Triassic to Cretaceous sediments of the Oman margin. In stratigraphic successions, they are expected to be recorded in the shelf sediments (Parautochtonous : Saih Hatat, Jabal Akhdar -Wadi Sathan section,) and in the basinal Buday'ah section but without biostratigraphic constraints. Dated Changhsingian carbonates is now proved in the Sumeini slope unit, in the Wadi Maqam section.

$\delta^{13}$Ccarb isotope values measured on Lower? and Middle Griesbachian limestones, from a block dated by conodonts (Krystyn et al., 2001) in the Wadi Wasit area, are around 1.5‰ and progressivly increase up to 3‰ in the Upper Griesbachian. Dienerian to Smithian limestones comprise low positive $\_^{13}C$ values (1.6‰ in Wadi Alwa 1 section) to low negative values (-0.7‰ in Wadi Wasit) with positive peaks up to 3.5‰. In the Wadi Musjah section, $\_^{13}C$ values of Dienerian carbonates are surprisingly high, between 2.5‰ and 3.5‰. Higher up in the section (Smithian?) they approach to more common values around 1.6‰.

The biostratigraphically poorly constrained Lower Triassic dolomites of the Mahil Formation in the Wadi Sahtan show low positive $\_^{13}C$ values between 0.4 and 2.9‰ in the lower part of unit D; the values increase up to 4 ‰ in the upper part of the sction. Within the Lower Triassic limestones of the Wadi Maqam C member, the negative $\_^{13}C$ values vary between -0.5‰ and -2.5‰. Thus, Lower Triassic carbonates show a great variability in $_^{13}$Ctot, over a range of 4.5‰, as well as inside a single section than between several.

$\delta^{18}O$ values show large variations, ranging from 0‰ to -10‰, more or less covariant with $_^{13}$Ctot values. Permian and Triassic limestones of sections studied here have been transported in front or beneath the Semail Ophiolite Nappe system and have post-depositional diagenetic histories. Hence diagenetic effect, can not be excluded here. As this would have not only increase the variability of the isotopic response but also lead to lower the values. As this is not the case for these values we assume that observed variabilty is mainly to be related to global short-term variations in seawater chemistry or local variations of $\_^{13}C$ values of the seawater related to particular paleoceanographic settings.

Despite the variability within paleogeographic domains and the poor correlation control, present

$\delta 13_C$ data allows to asume that Upper Permian carbonates are relatively constant with high positive values and are followed by a worldwide large negative shift of the $\_^{13}C$ at the Permian-Triassic boundary. During the Lower Triassic $\_^{13}C$ start at low values and then increase in the Dienerian before showing a negative trend in the Smithian limestones. This global trend however need to be consolidated by better biostratigraphic contrains.

# 2. Description of the visited outcrops (fig. x). January 14 morning: Rustaq section1, middle Permian cephalopod limestone on pillow lavas (Hawasina Nappes)

**Routing** (fig. 4)
From Seebt area we take for about 80km the highway Nr 01 to the West along the Badinah coast, then turn left Southward in direction of the village of Nakhl and again Westward to the village of Rustaq. The outcrop (fig. R1) is located about 2 km northwest of the town just south of a large waste deposit, for geological map see fig. R2.

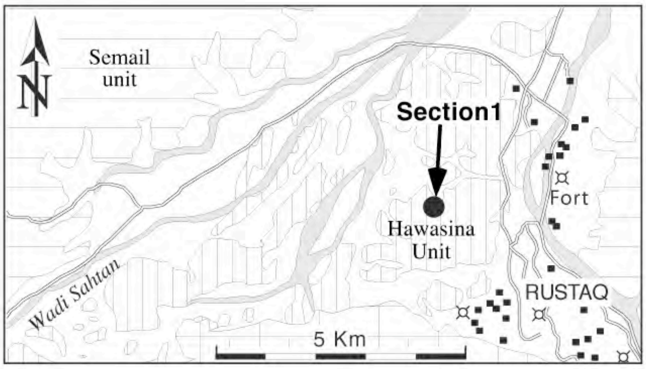



Figure R1: Sketch of the Rustaq area (see figure 4 for location). (Modified after Pillevuit et al., 1997, fig.11)

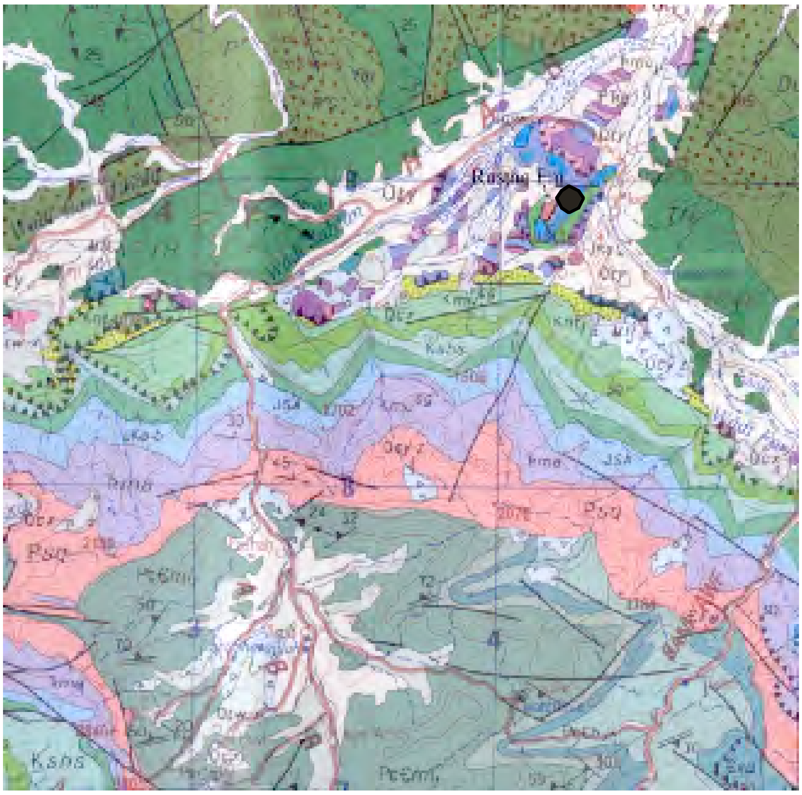


Figure R2: Geological map of Rustaq area (NW of Jabal Akhdar), Grid: 10km (Map Seeb, Béchennec et al., 1992b),

**Introduction**
The Permian cephalopod limestones of Rustaq were discovered by Béchennec (1988) who named this lithological succession the Rustaq Formation. Shortly later, in 1990 the sequence

was independently studied by Pillevuit and Blendinger with the results published in 1992 (Blendinger et al.) respectively 1993 (Pillevuit).

The Rustaq Formation occurs as tectonically isolated slabs in the hills west of the Rustaq village (Figs. R1 and R2). The base of the Formation consists of about 50m of mafic pillow basalts and green tuffites. Basalt samples analyzed by Pillevuit (1993) and Maury et al. 2003 for trace elements patterns are quite similar. They are slightly enriched in incompatible elements and classify as enriched MORB. Such patterns are found in low-Ti basalts from rifts and plateaus as well as from seaward-dipping reflector sequences in passive ocean margins. They are also found in basalts from truly oceanic settings, but located near hot spots (e.g. close to Iceland or the Azores in the North Atlantic).

## Stops

**Stop 1 -** Panorama of the Rustak Formation outcrops

**Stop 2 -** Stratigraphy of the Rustak Formation (fig. R3 and R4), sections 1 and 2.

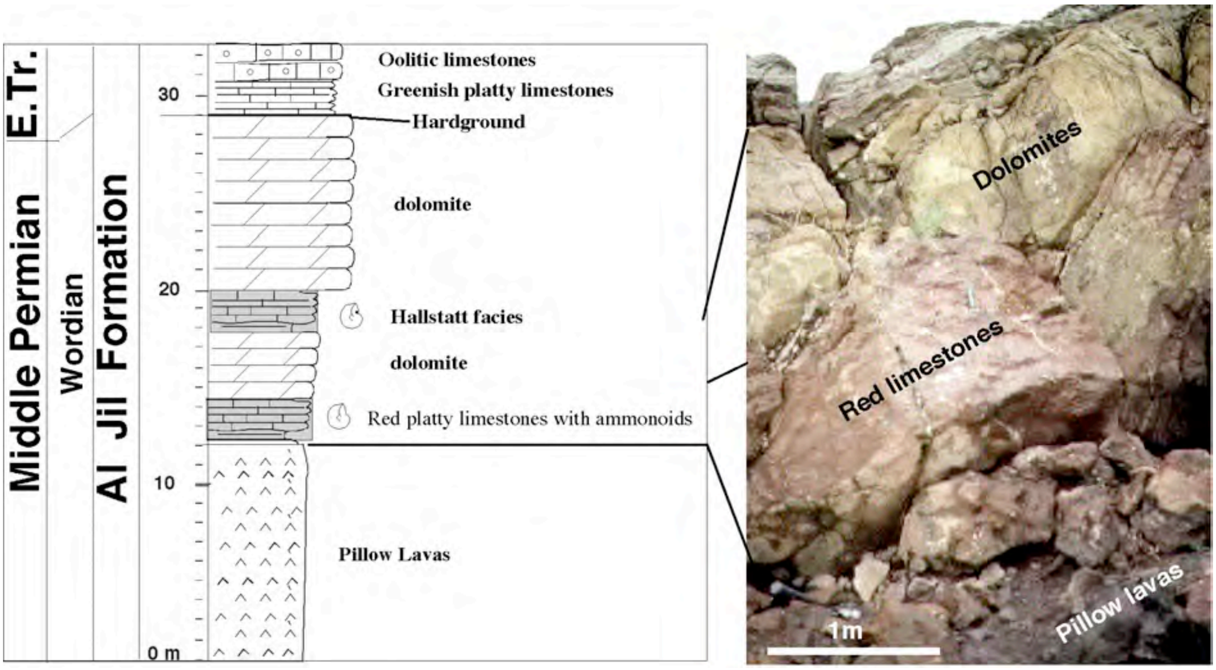



Figure R3: Stratigraphic sketch and photo of section 1 of Rustaq (description in the text, modified after Pillevuit 1993, fig. 68).

The following sequence can be observed in the Rustaq section 1 (Fig. R4). The base of the Al Jil Formation consists of about 80m of mafic pillow basalts and green tuffites (level a). In different parts of the pillow lava succession, inter-pillow cavities are filled with red lime-mudstone providing conodonts, particularly near the top (level b). A 30cm thick red nodular cephalopod argillaceous limestone fills the irregular upper surface of the pillows and contains crinoid ossicles and ammonoids (level c). The following dm-thick red crinoid- and ammonoid-rich beds (with 0.2m-1.2m lateral variation of thickness), are typical condensed pelagic cephalopod limestones known in the Triassic of the Tethys as Hallstatt facies (level d). Thin coatings of black manganese oxide minerals are lining the shells (Fig. x). The microfauna consists of foraminifers, bryozoans, conodonts, and ostracods. The lower Hallstatt Limestone of the Rustaq Member is overlain by a 1.1m-2m thick brownish to pink dolomite (level e) which may contain patches of undolomitized red limestone. The maximally 1.1 m thick upper horizon of red Hallstatt Limestone (level f) is indistinctly bedded. It contains the same fossils as the lower horizon.

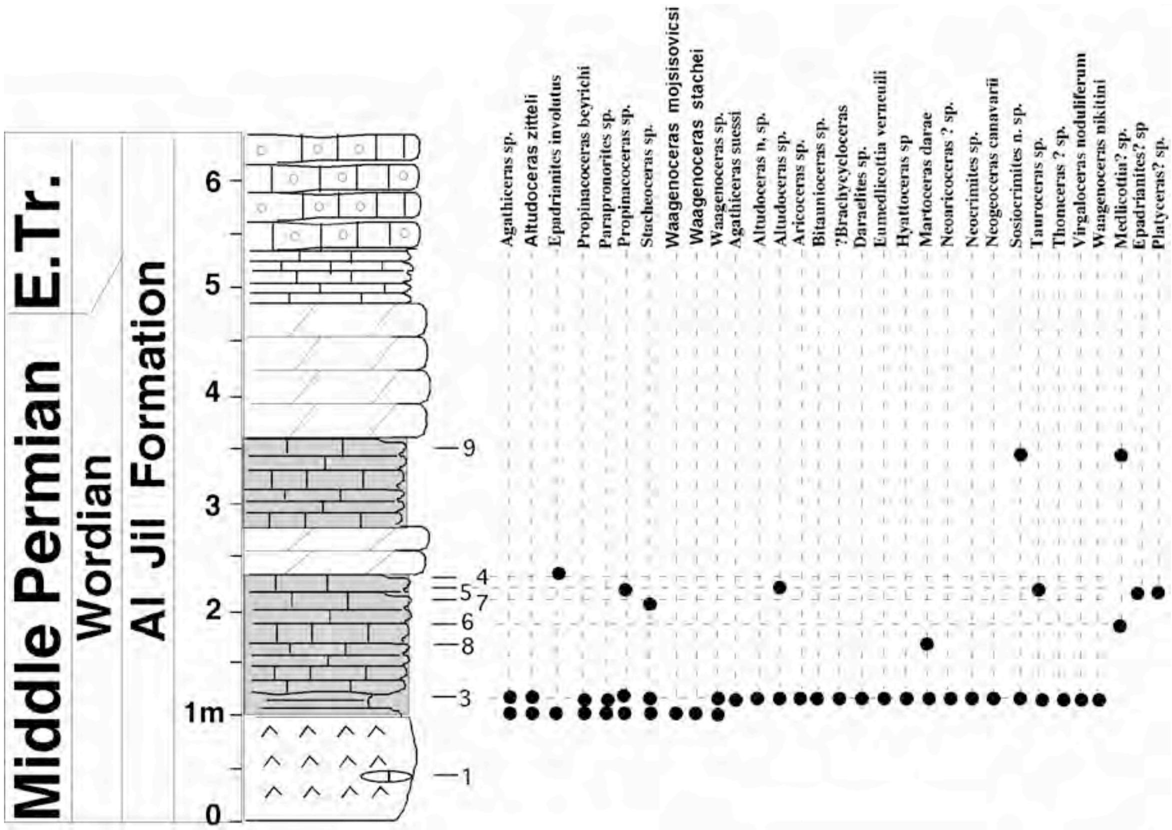


Figure R4 : Stratigraphic sketch of the Rustaq section 2 (modified from Pillevuit et al., 1997) with the ammonoid distribution.

A rather rich cephalopod fauna is recorded from the place by Blendinger et al. (1992), Pillevuit (1993, determinations by W.W. Nassichuk) and Niko et al. (1996): *Aricoceras, Neocrimites, Hyattoceras, A. suessi, Stacheoceras., Waagenoceras, W. nikitini, Altudoceras sosiense, Paraceltites hoeferi, Parapronorites beyrichi, Tauroceras, Eumedlicottia verneuili, Virgaloceras noduliferum, Sosiocrimites, Daraelites sp., Neoaricoceras ?, Hyattoceras, Martoceras, Thomceras ?, Neogeoceras canavarii, Bitaunioceras;* orthocerid - *Brachycycloceras rustaqense, Sitaunioceras* cf. *zonatum* (Gemmellaro), nautilid -*Liroceras sp.* and bactritid -*Bactrites? s*p. The trilobite *Timoraspis breviceps* (Becq-Giraudon & Pillevuit, 1995) occur in the samples 734 and 735 of Pillevuit.
Conodonts have been described by Mei & Henderson …. According to Kozur (Kozur et al. in prep), a very rich ostracod fauna is present containing both palaeopsychrosphaeric deep as well as shallow water ostracods. The palaeopsychrosphaeric ostracods disappear after 1m in the Hallstatt Limestone, re-appear in the upper level of the Hallstatt Limestone and disappear close to the thick dolomites which cover the Hallstatt Limestone. Palaeopsychrosphaeric ostracods indicate open connection to oceanic cold bottom water currents and thus a Neotethys ocean floor with Panthalassa connection for the first time. According to the different authors, the age of this unit is Wordian and is correlated with the equivalent Sosio fauna in Sicily.
The upper dolomitized cephalopod limestones are tectonically overlain by a 8 m thick series showing: (1) at the base, a sequence of grey/violet shale with subordinated beds, 30 cm thick, of fine-grained calcarenite, (2) at the top a thick sequence of oolitic calciturbidite in beds

60cm thick interbedded with shale. The latter are mapped as Jurassic Guwayza Fm. by Bechenec….

The Permian of Rustaq has been interpreted as an atoll setting within the Hawasina deep-sea basin by Pillevuit et al. (1997). An ocean-near seamount setting may be more compatible with the Hallstatt-type facies of the limestones. Their common bioclastic packstone microfacies dominated by fragmented cephalopod shells and isolated echinoderm fragments without distinct shallow water indicators may point to a stronger current-induced depositional environment on a submarine high.

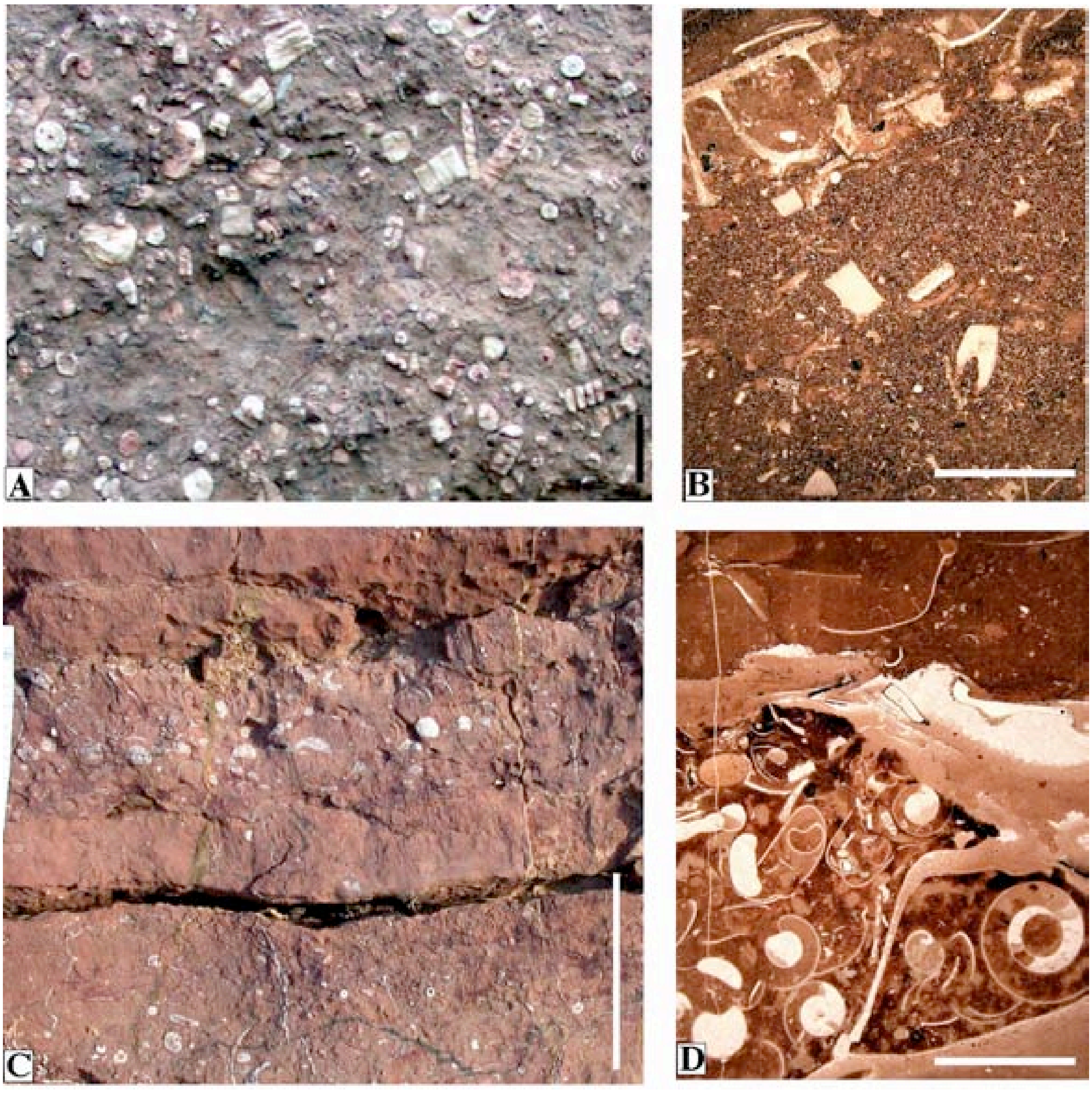



Figure R5: Main facies of the red ammonoid limestone (Hallstatt type) from the Rustaq sections.
A- Bedding plane of the red limestone with crinoids (scale 1cm).
B- Partly dolomitised crinoid wackestone (scale 5 mm).
C- Bedded red lime skeletal wackestones and mudstone.
D- Wordian ammonoids red lime packstone with cavities partly filled by lime mud.

## January 14 afternoon: Buday'ah: a Late Permian Hawasina basinal unit, MORB pillow basalt and radiolarian chert units

**Routing** (geological map at the fig. B1).
Between Buday'ah and Al Kuryah along wadi Hawasina. 250 m before sign « Al Kuryah 4 km », turn left and follow wadi along 200 m. N 23°44' 40" E 056°54'13.5", alt.: 355m.

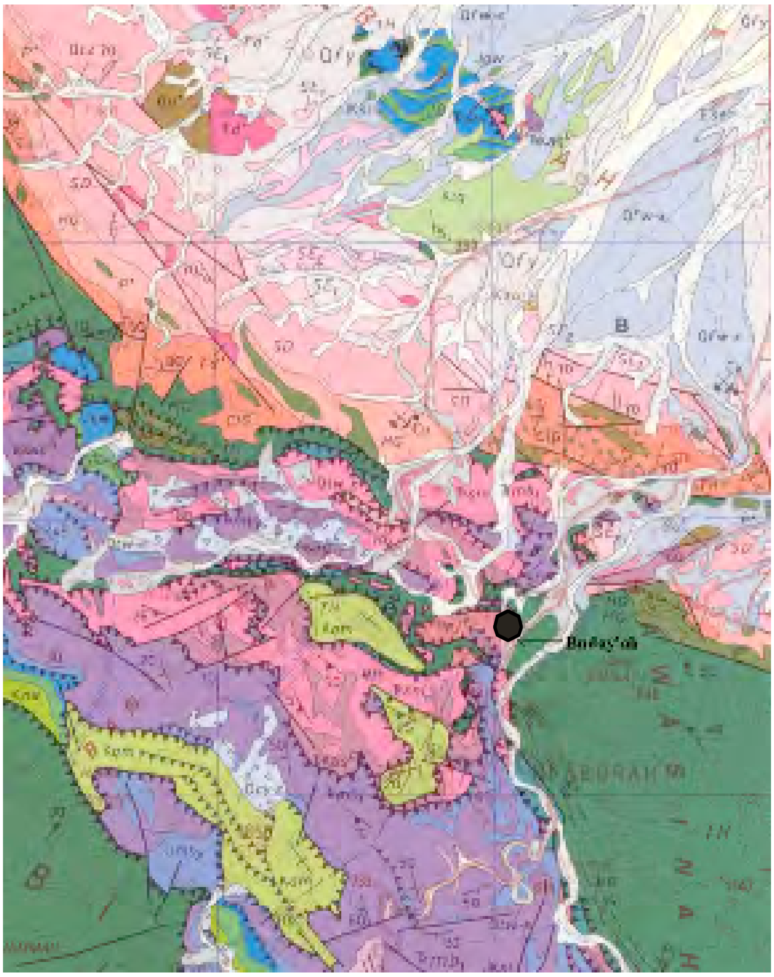



Figure B1- Geological map of Buday'ah area (Map Ibri, Béchennec et al., 1992c)

**Introduction** (After *F. Béchennec, F. Cordey and R. Maury in Baud et al. 2001*)
Located in the northeast part of the Hawasina Window (fig. x, Ibri map, Béchennec et al., 1992c), this locality is among the only places where the lower member of the **AI Jil Formation** is exposed (figs. 13, 14). Originally defined at the foot of Jabal Misht and around Taw in the central West Oman Mountains (Seeb map area, Béchennec, 1987), this formation was partly redefined in the same area during 1:250,000-scale mapping (Béchennec *et al.*, 1992a).
The **lower member** is composed of volcanic rocks, overlain by a generally rather thin sequence of shale and radiolarian chert of middle and late Permian age, and an **upper member** which is composed mainly of either calcirudite containing blocks of reworked shallow-marine carbonate, or alternatively calcilutite and fine-grained flaggy calcarenite associated with shale and locally with quartzose sandstone. The substrate of the AI Jil Formation is unknown since the lowermost part of the lower member is everywhere

tectonically truncated. The formation is conformably overlain by middle and late Triassic radiolarian chert of the Matbat Formation (fig. ).

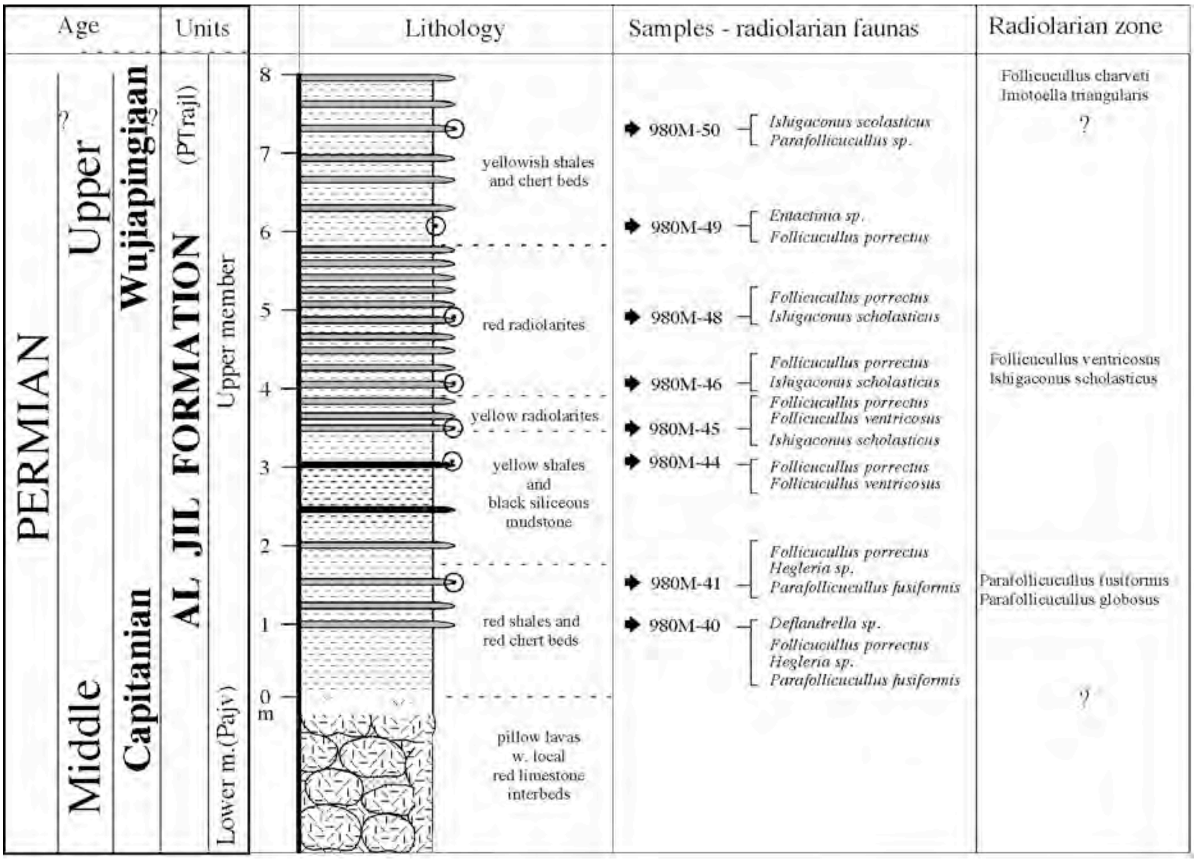



Figure B2: Stratigraphy of lower member and basal upper member of the Al Jil Formation at stops 2.1 . Radiolarian, dét. F. Cordey

**Stop 2.1** - **The lower member** (basaltic pillow lavas *.)* of the Al Jil Formation (figs. B2, B3, B4 and B5) forms two hills, one roughly 1 km across and the other several kilometres across. The basal volcanic sequence is composed of dark-green to brown, slightly amygdaloidal, pillow basalt in which the pillows range in diameter from 20 cm to 1 m and have aphyric cores and rims which locally contain plagioclase phenocrysts. Locally, interpillows are filled with red, fine-grained carbonates with unidentified ammonites.

Figure B3: View of locality. Overturned succession of MORB-type lavas (Al Jil, lower member Pajv) and Late Permian radiolarian chert and shales (base of the upper member PTrajl).

The basalt has microlitic texture, is generally spherulitic and locally porphyritic; it is composed of plagioclase mainly as sheafs of skeletal microlites but also in spherulites and in places as phenocrysts, rare clinopyroxene as fine prisms and phenocrysts replaced by carbonate and oxides, Fe- Ti oxides occuring interstitially and as elongate skeletal crystals, and carbonate in small amygdales. Data on rare earth elements (REE), Th and high field strength elements on two basalt samples at Buday'ah show transitional and enriched MORB signatures ( Maury et al., 2003); such association is found in rift and plateaus as well as fin seaward-dipping reflector sequences in passive ocean margins. They are also found in basalts from truly oceanic settings, but located near hot spots (e.g. close to Iceland or the Azores in the North Atlantic).


Figure B4: Detailed view of the studied profile. 1=Overturned succession of MORB-type lavas (Al Jil, lower member Pajv); 2=Middle to Late Permian radiolarian chert; 3=siliceous shales (base of the upper member; 4= carbonaceous shales; 5 brown weathered platy limestones and shales. The Permian-Triassic boundary is between 3 and 4. Scale given by S. Richoz (right), and H. Kozur (left).

**Stop 2.2 The upper member** (radiolarian chert, beige flaggy limestone and shale figs B2, B3, B4 and B5) The base of the upper member of the AI Jil Formation, near Buday'ah in the northeastern part of the Hawasina Window, consists of a succession of thin nodular brownish

lime mudstone, siliceous shale and radiolarian chert resting conformably on the basalt of the lower member, and dated as Wordian on the basis of radiolarians (Béchennec, 1987; De Wever *et al*, 1988). More recent studies point out the succession of the following basal units (figs B4 and B5): red shales and red chert beds (2 m), yellow shales and black siliceous mudstone (2 m), yellow radiolarites (0.5 m), red radiolarites (2 m), yellowish shales and chert beds (2 m). Radiolarians range in age from Wordian to Capitanian on the basis of 9 associations correlated with *Parafollicucullus fusiformis* - *Parafollicucullus globosus* and *Follicucullus ventricosus* - *Ishigaconus scholasticus* assemblage zones of Kozur (1989).
Ammonoids (*Waagenoceras*, *Timorites* sp.) found in the lime mudstone interval between lavas and chert indicate a Capitanian age for the base of the post-volcanic sedimentary sequence.
Compared with other Hamrat Duru successions (Wadi Wasit, Nakhl, Rustaq) Buday'ah seems the most distal and probably deepest Permian depositional sequence of the basin as it has only minor carbonate influx and misses any shallow water debris input (reefal slump blocks, calciturbites) known from the other sections.

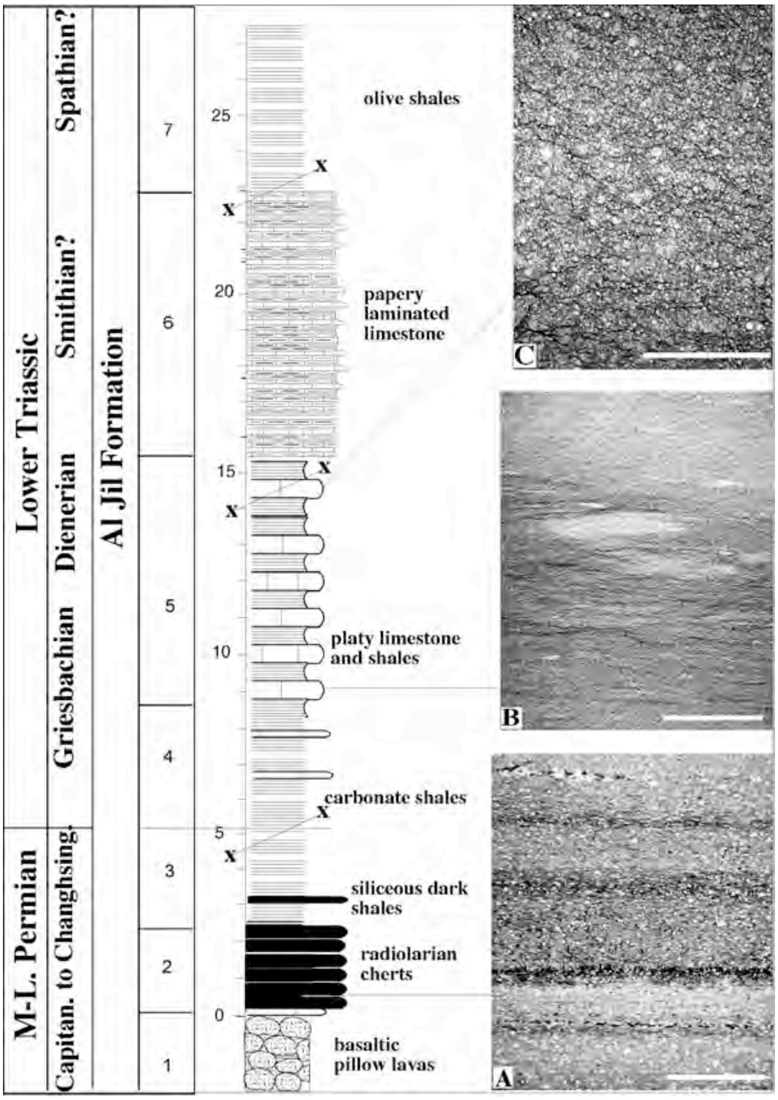



Figure B5: Sketch of the Middle Permian to Lower Triassic Stratigraphic succession of the Al Jil Formation in the Buday'ah area. Ages of the Lower part is based on radiolarian, ammonoids and conodont. For the upper part, ages are hypothetical. Microfacies (scale bar 5mm) A: laminated lime siltstone with radiolarian (Capitanian); B: lime mudstone with trace fossils; C: lime graistone-siltstone with calcispheres.

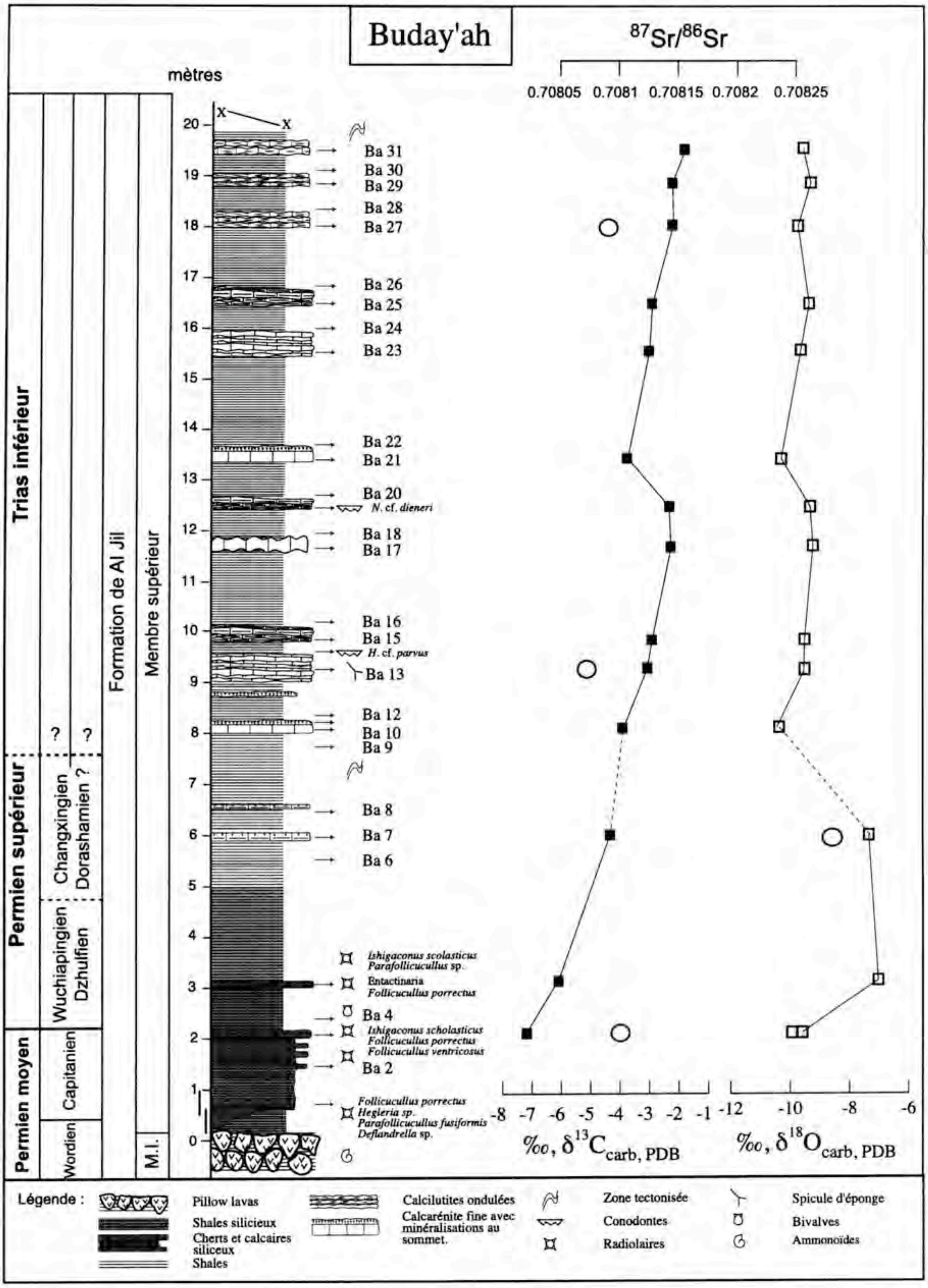



Figure B6: Litho- and isotope stratigraphy of the section at the stop 2.2. Conodontes, det. H. Kozut, Radiolarian, det. F. Cordey. Ammonoids mentioned in text are from lime mudstone band on top of lavas, det. L. Krystyn.

# January 15: The Sumeini Group in the Wadi Maqam: from middle Permian to Lower Triassic carbonate slope deposits.

The section choosen for the fieldtrip is located East of Shu'ayb village and corresponds to the section MS-6 of Watts and Garrison (1986). The lower part (Member A) is located along a small hills about 500m South of the entrance of the Wadi Maqam gorge (3 in fig. M1, fig. M5). A good profile of the Member B can be see in the gorge and the boundary with Member C that correspond to the Permian-Triassic boundary crops out on a high, on the right flanc, near the end of the Gorge (Baud et al. 2001b, Richoz 2004).

**Routing** (Fig. M1)

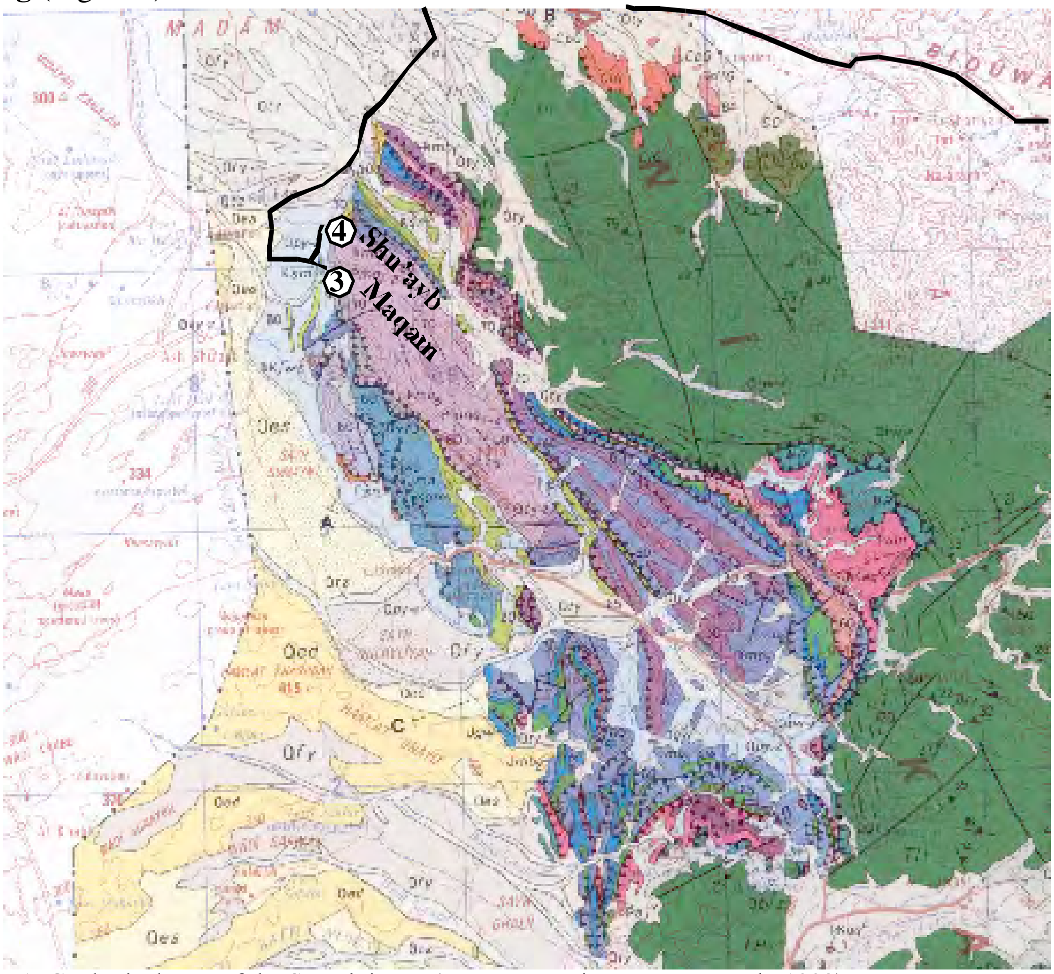



Figure M1: Geological map of the Sumeini area (Map Buraymi, Le Metour et al., 1992).

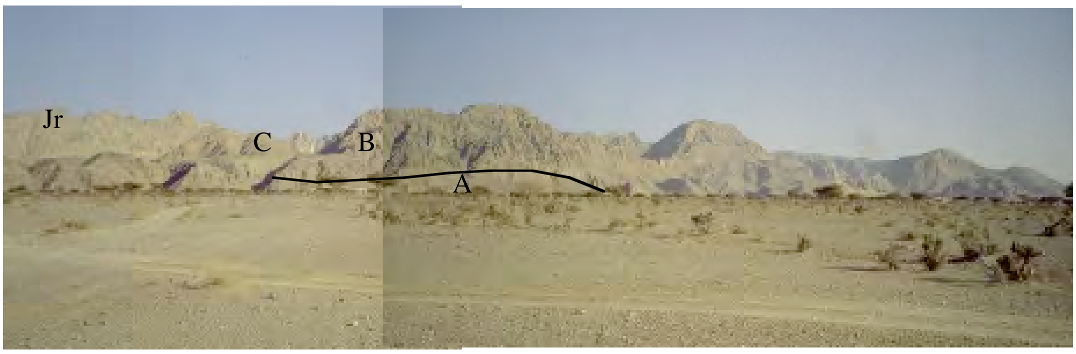



Figure M2: Panorama of Sumeini Range in the Wadi Maqam area; A, B, C, middle Permian to lower Triassic members of the Maqam Formation; Jr, crest forming Jurassic carbonates in the ground.

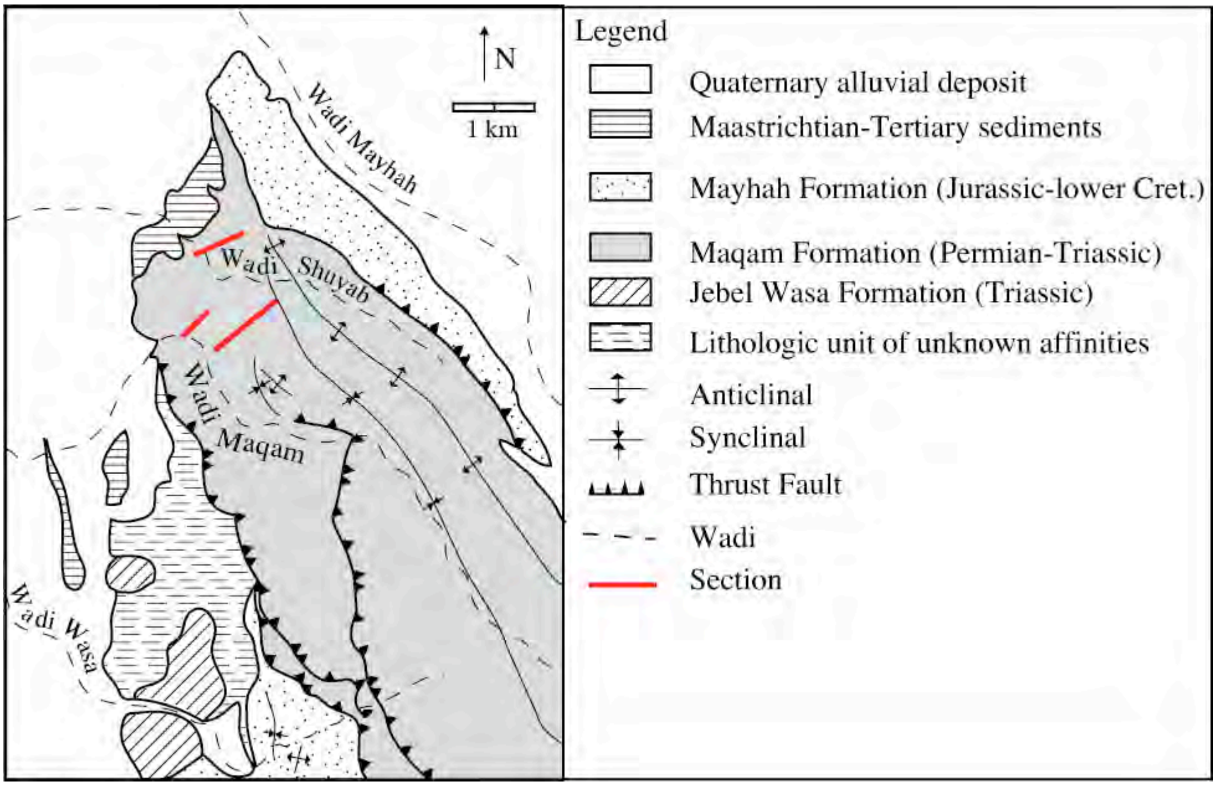



Figure M3: Simplified geological map of Sumeini Area. (After Watts & Garrison, 1986).

**Introduction**

The Sumeini Group, as defined by Glennie et al. (1974) is represented by a thick sequence (about 2500 m) of Permian to Cretaceous slope carbonate deposits and crops out (Searle et al., 1990; Le Métour et al., 1992) near the border between Oman and the United Arab Emirates (fig. M1). A comprehensive sedimentological study of the Sumeini Group has been carried out by Watts (1985, 1988, 1990) and by Watts and Garrison (1986). Detailed maping and stratigraphical studies were done by Le Métour et al, (1991) and Béchennec et al., (1993). The lower part of the Sumeini Group (about 1700 m thick) is included in the Maqam Formation (Upper Permian to lower Jurassic), further subdivided into 6 members (A, B, C, D, E and F, fig. M4).

## General overview of the Maqam Formation

**Member A**

The Member A of the Maqam Formation (figs. M4 and M5), here about 80 m thick, (but laterally up to 250m) is tectonically truncated at the base and its substratum remains unknown. Its base is made of an unknown thickness of multicolored shales with accessory tectonized thin bedded limestones or dolomites and the upper part consists of outer shelf fossiliferous limestones early middle Permian in age.

**Member B**

The member B consists of a 415 m thick sequence of predominantly thin-bedded to massive dolomites with numerous dolorudite intervals and locally abundant breccia in the lower part and cherty in the upper part. This thick dolomite succession is formed in a deep-marine environment. Overlying the synrift units this succession record the break-up and the early development of the Oman continental margin, subsidence and possible tectonic flexure or faulting. At the same time the former rift shoulder (Djebel Akdhar) is flooded by the open marine transgression (late middle Permian). The upper part of the B Member records the end Permian events and the transition to C Member the boundary events.

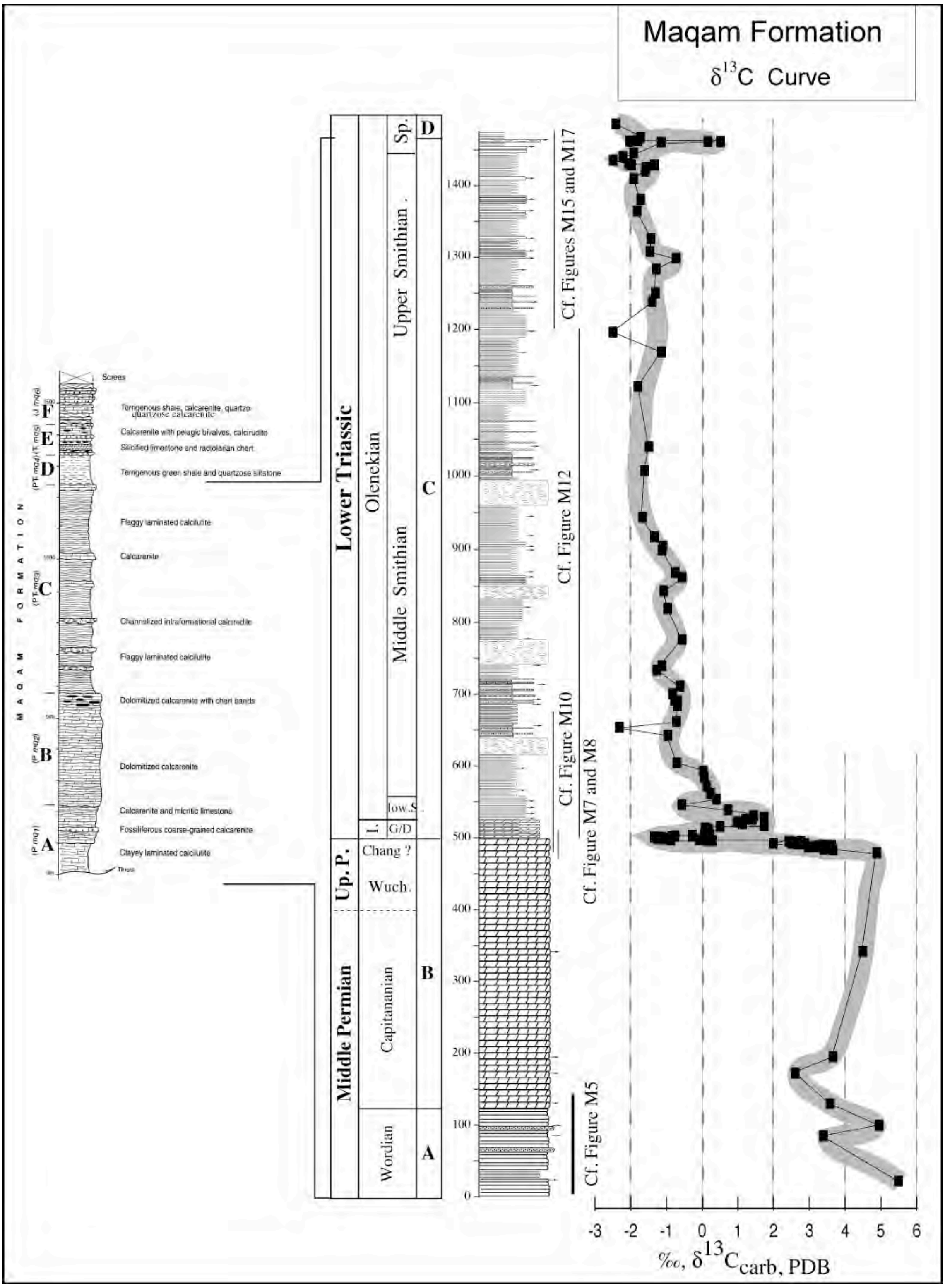



Figure M4: On the left: Stratigraphic section of the Maqam Formation from Le Métour et al., (1992a). Members A-F according to Watts and Garisson (1986). On the right: Carbon isotope profile of the Maqam Formation, member A, B, C. (Data from Atudorei, 1999, for the Members A and B and from Richoz, 2004, for the Member C).

**Member C**

The thin Griesbachian-Dienerian part of C Member (fig. M10) consists of thin bedded platy dolomite, corresponding to thin bedded lime mudstone, NW of the dolomitisation front. The first calcirudite beds of the C Member occur about

The incredible thick Smithian part of C Member (up to 900m) marks the onset on the base of slope of a deep-marine basin in which the carbonate submarine fan deposits developped This very thick unit consists essentially of platy limestones, calcarenites and calcirudites. It comprises mainly grey-beige calcilutite, laminated and flaggy, interbedded with sparse beds of fine-grained calcarenite in cm beds. Channelizing beds of intraformational calcirudite are also part in this succession which constitutes the great part of the outcrops of the Sumeini Group A detailed sedimentological survey and depositional model of carbonate submarine fans have been presented and discussed by Watts (1987).

**Member D**

Carbonate sedimentation of the C Member ended abruptly in the early Spathian, followed by deposition of a thick interval of terrigenous mudstone and siltstone of the D Member (Spathian-Anisian).

**Member E**

The Member E**,** approximatively 60m thick comprises mainly radiolarian chert, calcarenite and calcirudite (Ladinian).

**Member F**

The Member F is made of calcirudites and calcarenites with, in addition to the reworked lithoclasts of limestone, in places chert, lava and rare quartz. (Carnian-Norian).

**General overview of the carbon isotope stratigraphy in Wadi Maqam** (S. Richoz)

The present $\delta^{13}C_{carb}$ isotopic curve (fig. M4) is a compilation of data from Richoz et al. (2004) for top Member B and Member C and Atudorei (1999) for values on Member A and B.
The highest $\delta^{13}C_{carb}$ values (+5.5‰) are recorded in members A and B and correspond to the high Middle - Late Permian values recorded in the Tethys (Baud et al., 1989, Richoz 2004).
Values are around +4.9‰, 10m below the top of the Member B and drop to around +2‰ in the last gray limestones beds of Members B (fig. ). The shaly interval record a drop of 3.3‰ followed by a positive shift of 1.0‰ in the first platy limestones beds of Members C. The minimum (-1.2‰) is reached here at the level of the first appearance of *H. parvus*. The overall drop of around 6‰ in the $\delta^{13}C_{carb}$ values is one of the largest known within the PTBI in the Tethys. The isotopic values go up to +1.7‰ then in the first 20m of platy dolostone and fall to +1‰ after the fist breccia to shift again in the vermicular limstones to reach a peak at 1.7‰ at the level of the smithian conodont zone *N. waageni*. Values shift down to values globally negative (between –0.9‰ and –2.5‰) during most of the Member C in Wadi Maqam and Wadi Shuyab. Corresponding to each thick turbiditic event occuring in the platy limestones, a 0.5‰ negative shift in the isotopic curve is recorded. We can suppose that this change is due to the massive input of the platform carbonate in the slope system. 20m below the top of Member C, values are around –1.6‰ and shift down to -2.5‰ in the last meters of platy limestones. Values shift rapidly to positive values (0.5‰) in the base of the marly orange limestone interval ending Member C. At the top of this orange interval and in the some calcareous beds at the base of Member D, values are again quite negative (around -2.0‰ and –2.5‰). This short peak is believed to be equivalent to the one at the Smithain-Spathian boundary in some other sections (Atudorei, 1999; Payne et al., 2004; Richoz 2004).

$\delta^{18}O$ curves have values from -3.2‰ to -4.0‰ for Member A and B, shifting at the beginning of Member C down to -5.2‰ and then staying stable between -5.4‰ and -6.9‰. If this shift corresponds to the Permian-Triassic boundary, it corresponds also to the dolomitisation front and is certainly affected.

**Stops**

**Stop 3.1 -** The panorama at the entrance of the Wadi Maqam is presented at the fig. M2.

**Stop 3.2 - Member A** of the Maqam Formation (fig. M5). We will look at about 80 m of outer shelf carbonate.
A Wordian age was proposed by Pillevuit (1993) on the basis of the ammonoids *Stacheoceras sp., Adrianites* ? of *A. isoniorphus, Aghathiceras sp.* (Determination from W.W. Nassichuck), of the trilobites *Néoproetus indicus,* Tesch, n. subsp. *Ditomopyginae* (Becq-Giraudon and Pillevuit, 1995) and of the ostracods *Bairdia sp., Aurigerites sp., Healdianella sp., Acratia sp.* (Determinations S. Crasquin Soleau). Rugose and favositid corals, bryozoa, crinoids and Productid brachiopods also occur, some of them reworked. With a new ammonoid collection, L. Krystyn is in favor of a Roadian age for part of this Member.

Overlying an unknown thickness of shales, the lithology consists of gray and black thinly bedded limestones at the base (A1) alternating with marls and locally with sandstones. Upward, overlying a marly and shaly interval (A2), this succession, with thicker beds, also includes sparse fine-grained calcirudite (fig. M6C) and cross-bedded calcarenite (fig. M6A) in channeling beds 80-150cm thick (A3). The uppermost part is partly dolomitised (A4). Fossils were recovered from the lower half of the unit (A1).

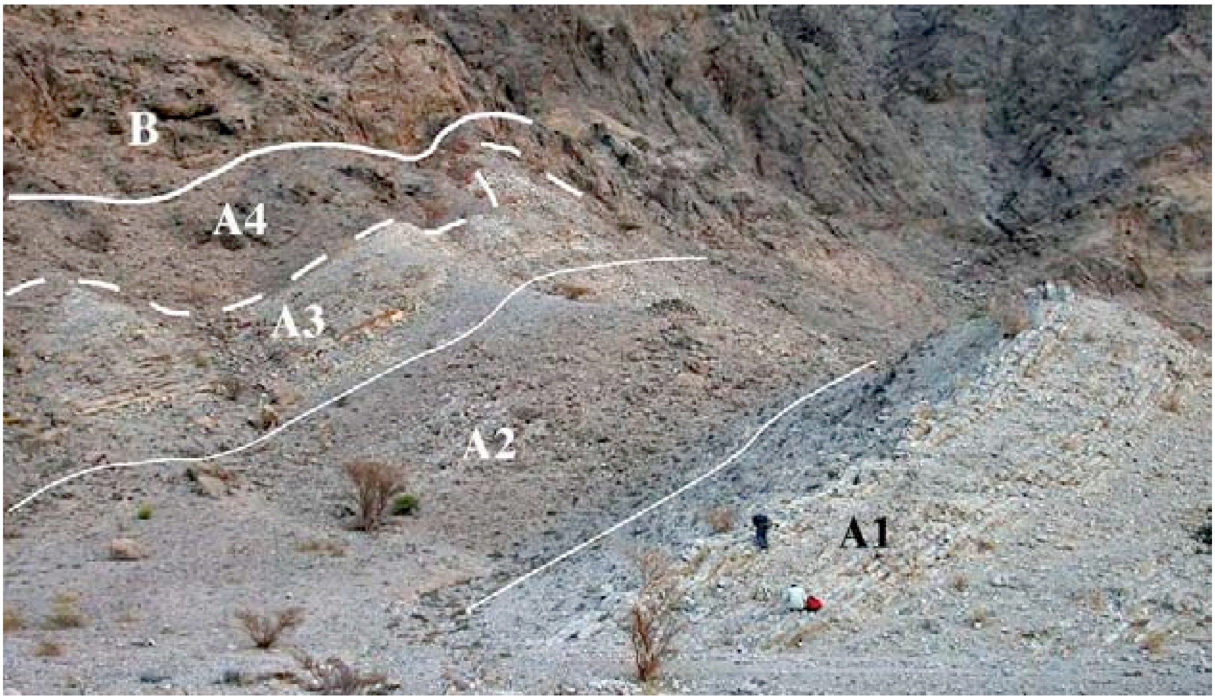



Figure M5: View on Member A of the Maqam Formation. A1 –shale and limestones unit; A2 – mainly hidden shale unit: A3 – upper limestone unit separated from A4 by an irregular front of dolomitisation. B –base of the dolomitised B unit with a thick dolorudite, clast supported bed.

This upper part (A3-4, fig. M18A) of the Member A is well bioturbated (fig. M6B) with ichnofabric indices (ii; sensu Droser and Bottjer, 1986) of 3-5, typically ii4 (fig. M18B). There is a diverse suite of ichnotaxa, which are observed in vertical section only, including

*Chondrites*, *Palaeophycus*, *Planolites*, *Teichichnus* and ?*Thalassinoides*. With the exception of *Chondrites*, burrow diameters are typically on the order of 1cm in size: *Planolites* burrows range from 5 to10 mm (mean = 7.4); *Palaeophycus* from 6 to13 mm (mean = 10.2); and ?*Thalassinoides* from 12-28 mm (mean = 16.1). The substrate was clearly well-oxygenated, with ample food supply, and supported a diverse infauna.

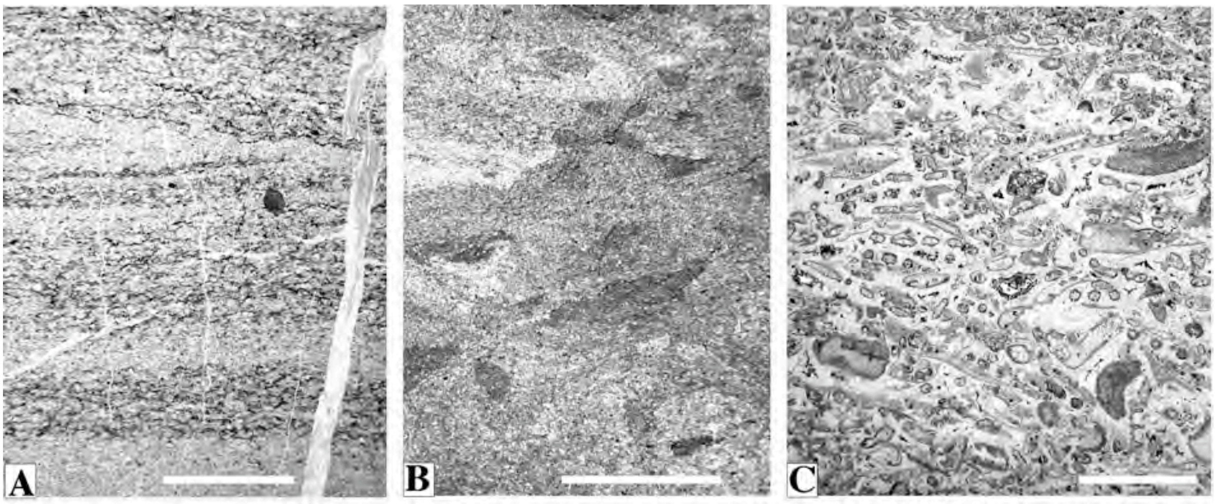



Figure M6: Microfacies of the Member A of the Maqam Formation (scale bar 5mm). A: cross laminated lime packstone near the base of the unit A1. B: Bioturbated lime wackestone, top of unit A2. C: lime grainstone with mixed lithoclasts and bioclasts, unit A3.

**Stop 3.3 - The lower part of member B** consists of a 365 m thick sequence of predominantly thin-bedded to massive dolomites with numerous dolorudite intervals and locally abundant breccia in the lower part. The contact with the underlying A4 unit is irregular (fig. M5). Corals recovered from the lower part indicate a Capitanian age (Watts and Garrison, 1986).

**Stop 3.4 - The upper part of member B** (fig. M7) consists 50m of dm sized bed of cherty dolomites and cherts rich in sponge spicules. It must be emphasized that a silica rich interval is widesprad on NW Pangea margin and also known in the Lopingian carbonate of the Tethys. Biogenic silica factories collapsed near the end of the Permian period throughout the world (Beauchamp & Baud, 2001)

**Stop 3.5a** - The Permian-Triassic transition (Figs. M7, Position: N24°46'26", E55°51'59".) has been studied in detail. and some recent results will be presented at this stop. The cherty dolomites are abruptly replaced by microbial platy limestones. This fine laminated stromatolitic facies is is typical of the basal Triassic carbonate transgression in the Tethys (Baud et al. 1996 and in press). A very important negative shift of carbone isotope takes place at the top of the member B and continues into the basal part of the member C (Richoz 2004, figs. M8 and M10). As a result, the Permian-Triassic transition can be constrained within few meters, at the very base of the member C (Baud et al., 2001b).

**Detail of the Carbon isotope stratigraphy** *(S. Richoz*

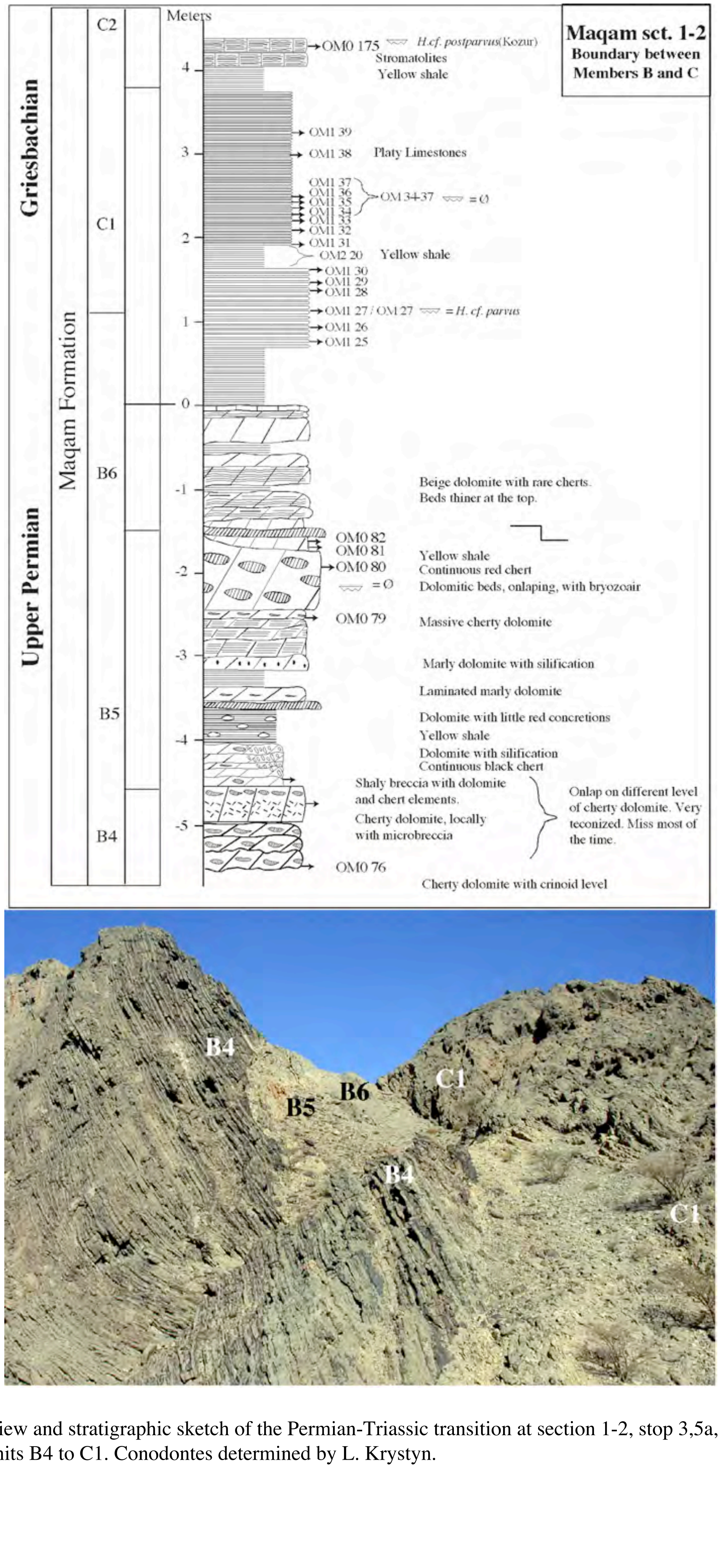



Figure M7: View and stratigraphic sketch of the Permian-Triassic transition at section 1-2, stop 3,5a, with the lithological units B4 to C1. Conodontes determined by L. Krystyn.

The topmost part of Member B (B6 in fig. M8) with well bioturbated (ii4) beds is indicating a well-oxygenated palaeowater column and a diverse infauna (Fig. M18C,D,E,F). The ichnotaxa include *Chondrites*, *Palaeophycus*, *Thalassinoides, Rhizocorallium* and possibly *Zoophycos*. The *Thalassinoides* burrows (Fig. M18C,D) are often cast by the diagenetic chert, in a similar fashion to that which occurs in the Cretaceous chalks of western Europe. Cross-cutting relationships may be observed in places, indicating that *Thalassinoides* burrows were emplaced at a shallow depth within the sediment, with *Chondrites* and ?*Zoophycos* occupying deeper tiers. This tiering relationship is also reminiscent of the Upper Cretaceous chalks of western Europe (e.g. Bromley and Ekdale, 1986). *Thalassinoides* burrows are typically 10-16 mm in diameter (mean = 14.3).
In sharp contrast to the well-bioturbated Member B, the overlying basal metres of Member C (C1 in fig, M8) are well laminated (ii1, fig. M9) with no evidence of bioturbation. This dramatic loss of the burrowing infauna indicates the appearance of oxygen-poor waters and the onset of the Permian-Triassic Superanoxic Event (Isozaki, 1997). A similar loss of bioturbation is recorded in many sections worldwide (Twitchett and Wignall, 1996; Twitchett et al., 2001; Wignall and Twitchett, 2002).

Figure M9: Microbial laminations and plastic deformations from the basal part of Member C (C1) in Wadi Maqam.

**Stop 3.5b (on the slope down towards 3.6)**
The bedding planes of the well-bioturbated, uppermost beds of Member B are exposed (B6 in fig. M8), and contain a diverse and large-sized ichnofauna. Prominent are the dramatic and beautiful *Rhizocorallium* burrows (fig. M18E,F), which range from 11 to 28 mm in diameter (mean = 20.0 mm). Rarer, large, *Thalassinoides* are also present (mean diameter = 17.2 mm; range = 12-21 mm). There is a dramatic decrease in the size of marine animals, and their associated trace fossils, through the Permian-Triassic extinction interval (e.g. Twitchett, 1999; Twitchett and Barras, 2004). This "Lilliput effect" (a phrase coined by Urbanek, 1993) is observed at many, if not all, extinction crises and is probably caused by environmental stresses such as the loss of primary productivity and decreased oxygenation. Globally, *Rhizocorallium* and *Thalassinoides* do not return to these pre-extinction sizes (diameters in excess of 20mm) in any depositional setting until the Anisian (RJT, unpublished data). Similar size changes in these ichnotaxa are also recorded through the Triassic-Jurassic extinction-recovery interval (Twitchett and Barras, 2004).

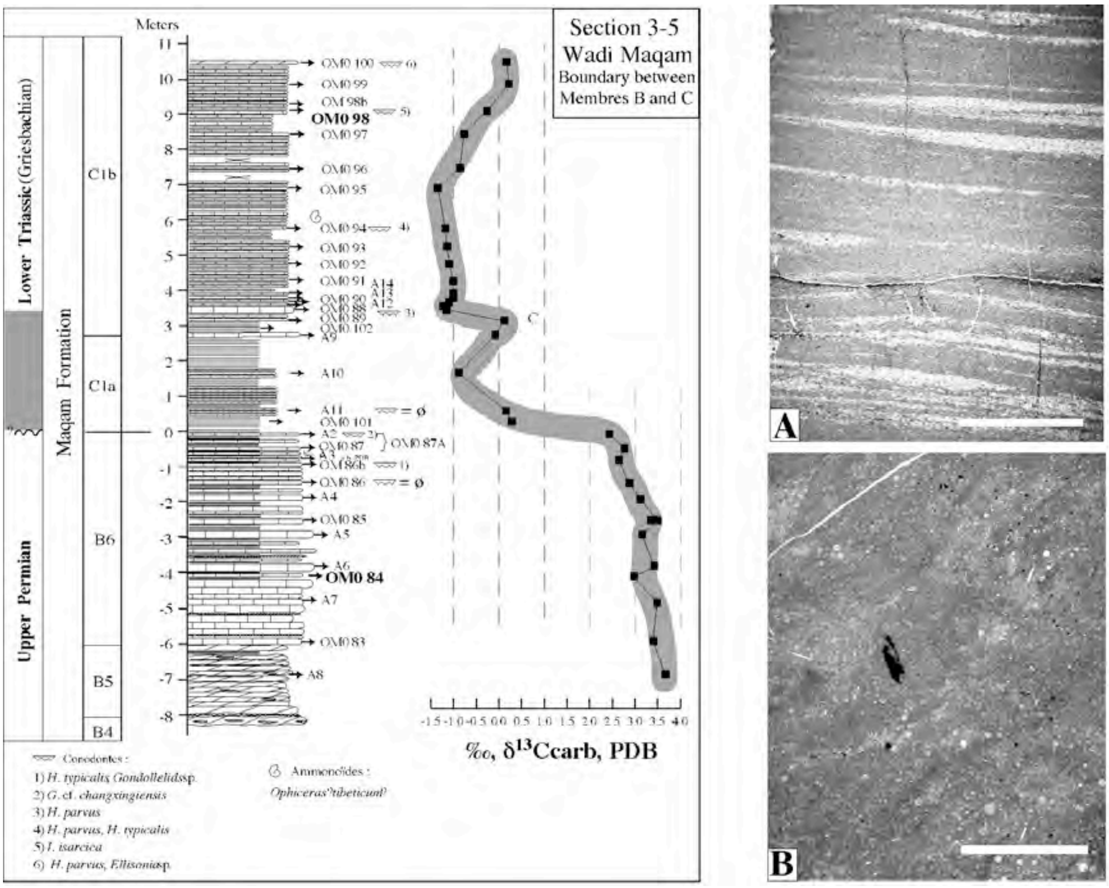



Figure M8: statigraphic sketch of the Permian-Triassic transition with Carbon isotope profile at stop 3.5b. Ammonoids and conodonts determined by L. Krystyn. A:laminated calcisiltite of the basal Triassic C1b unit. B: bioturbated lime mudstone with calcitized radiolarian, Changhsingian B6 unit. Scale bar A and B: 5mm.

**Stop 3.6 - The lower part of Member C** (figs. M8 and M10).

Although the lower part of Member C is almost entirely laminated, occasional horizons of bioturbation are present. The bioturbation is only weakly developed, and primary lamination may be only slightly disturbed (ii2) or more disturbed, resulting in slightly wavy bedding (ii3). Ichnodiversity is low and burrow diameters are much reduced compared to the underlying Member B. Common burrows are subhorizontal and unbranched *Planolites* and *Palaeophycus*, with burrow diameters typically between 2 and 6 mm (mean = 4.3). Rarer mm-sized *Arenicolites* and ?*Megagrapton* are also present. These bioturbated intervals presumably indicate that, occasionally, oxygen levels increased sufficiently to allow a limited benthos to colonise the substrate. Similar ichnofacies are recorded in the Induan worldwide (Twitchett and Wignall, 1996; Twitchett and Barras, 2004). It is interesting to note that *Chondrites*, thought by many to indicate dysaerobic environments in the Mesozoic (e.g. Bromley and Ekdale, 1984; Savrda and Bottjer, 1986), is not recorded here, nor at any other Induan section.

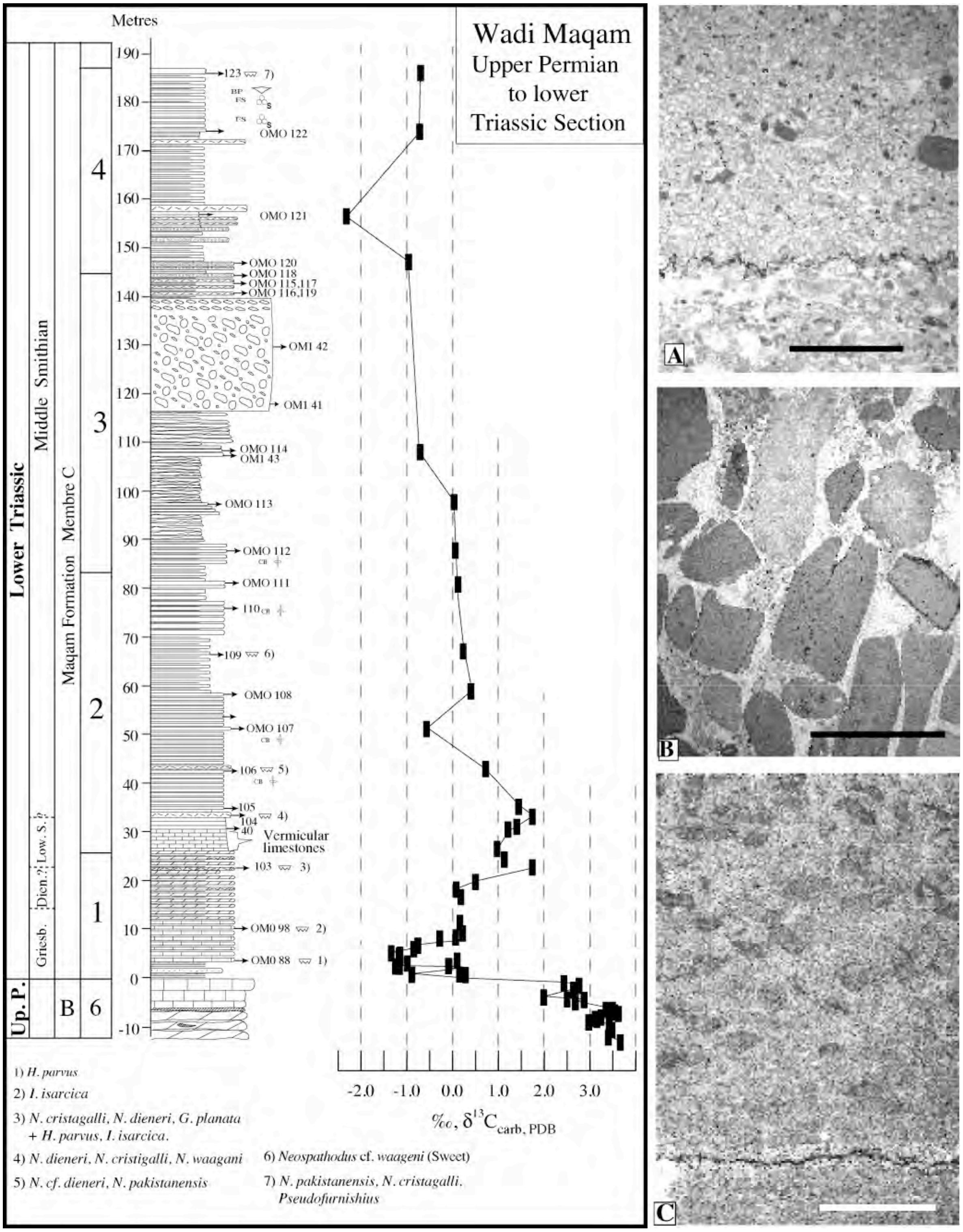



Figure M10: lower part of Member C. stratigraphy and Carbon isotope curve. A, B, C: microfacies, scale bar 5mm. A: Graded calcarenite with bioclasts in the lower part and ooids diagenetically altered in the upper part (unit C5, middle Smithian). Calcirudite showing clasts with of shallow water facies , stromatolitic, thrombolitic and clast with oolites and oncolites (base of unit C6, middle Smithian). C: Calcisiltite with tiny trace fossils (unit C2, middle Smithian).

Higher up, the calcirudites, commonly clast-supported (edge-wise conglomerates), are characterized by tabular clasts representing the sub- in situ reworking of the laminated, platy calcilutite. In places, the calcarenite becomes predominant and interbedded with calcirudite in metric beds. Some levels of the calcarenite contains reworked tangential oolitic limestone clasts and a sparse biota of silicisponge spicules, mollusc debris and benthic foraminifera *Trochammina* sp. We note also the presence of typical lower Triassic *Cyclogira* and *Earlandia* type foraminifera found about 160m above the base (unit C4).

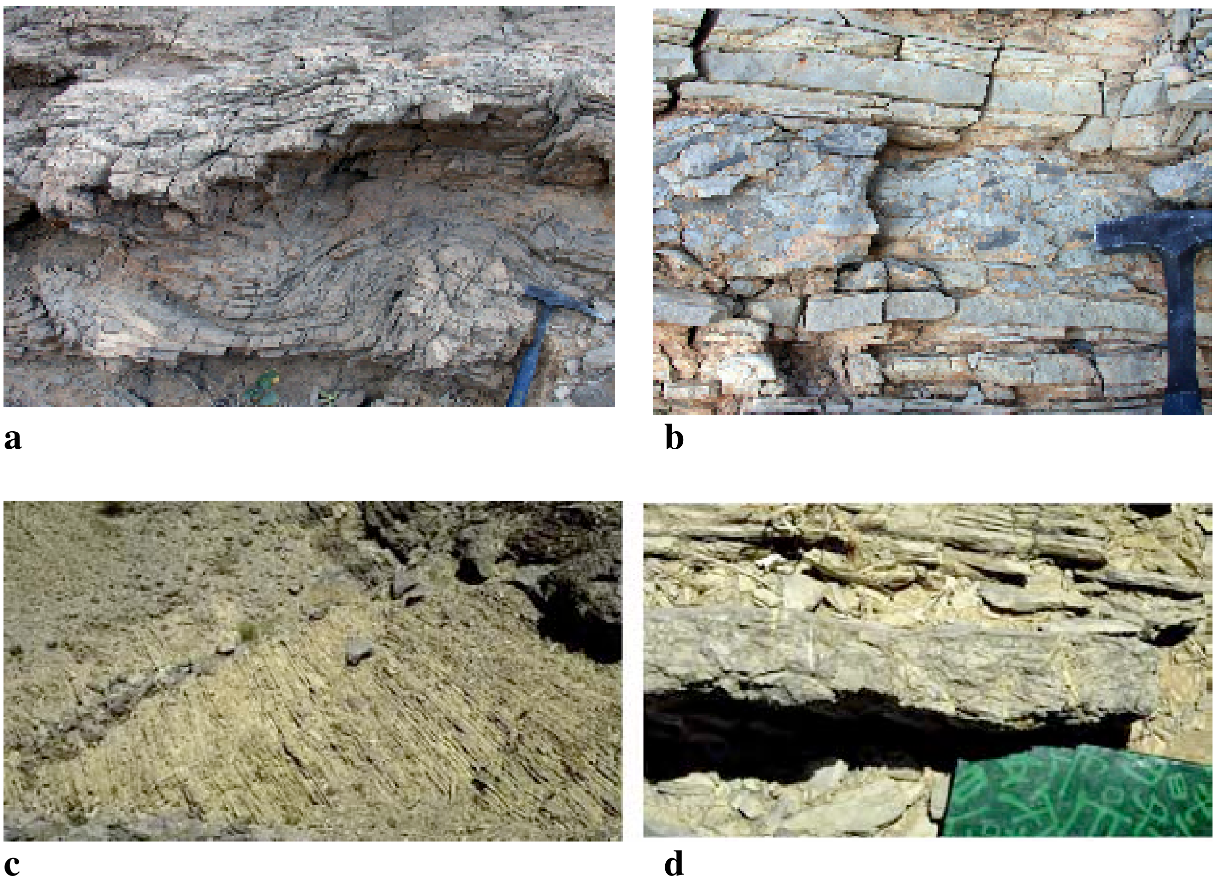
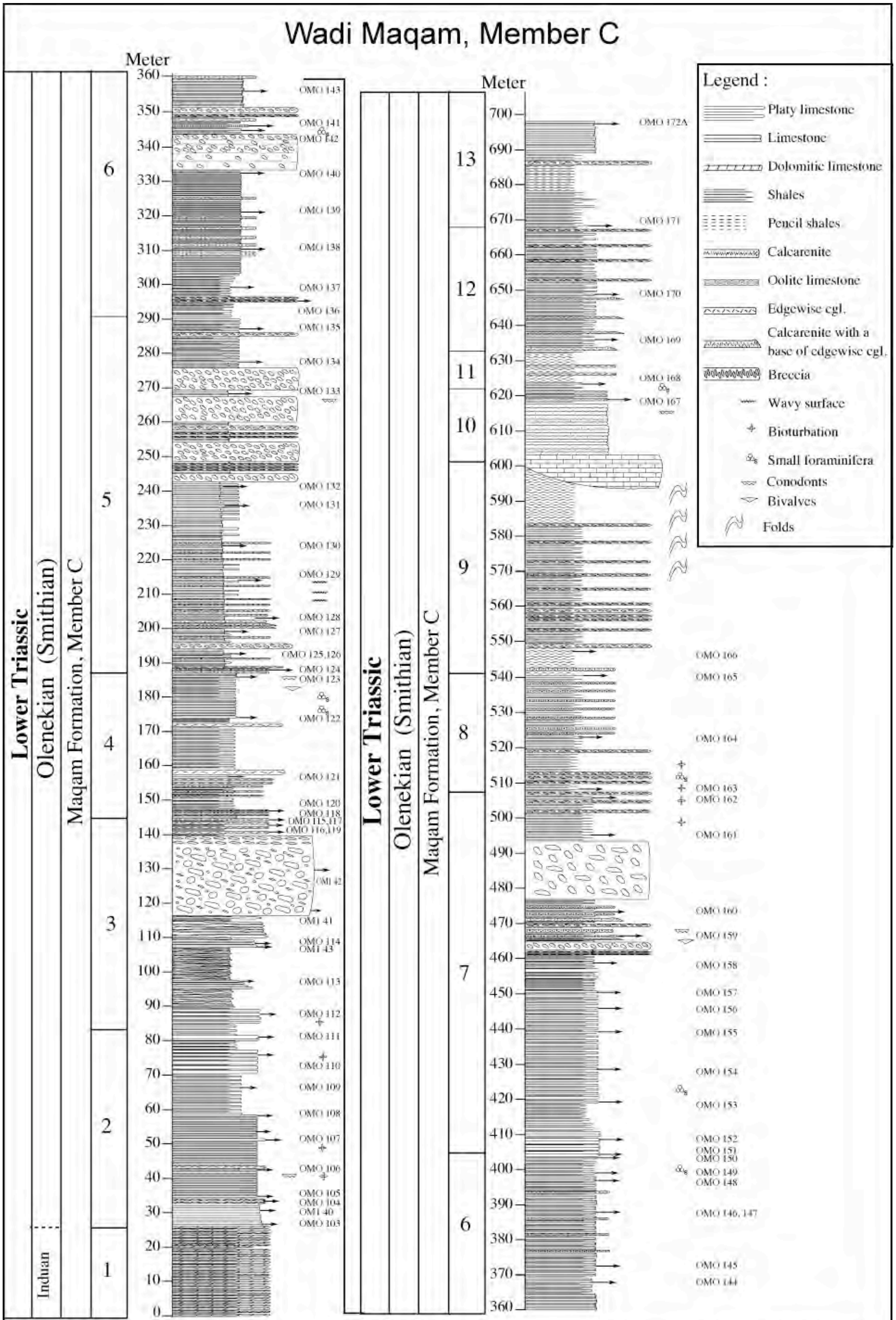



Figure M11 a: slump beds in unit C1 (Griesbachian); M11b: Late-Permian – basal Triassic polygenic lime clasts bed in platy limestone of unit C1 (late Dienerian event); M11c: platy limestone with megabreccia (calcirudite bed) at the top (unit C5, middle Smithian); M11d: monogenic flat pebble conglomerate bed in platy limestones (unit C5, middle Smithian).



Dét L. Krystyn : OMO 124 : *Neospathodus* cf. *waageni* (Sweet) OMO 133 : *Neospathodus conservatius* (Müller), *N: Cristagali* (Huckriede) OMO 159 : Robust ramiform elements OMO 167 : Robust ramiform elements

Figure M12: Lithology and stratigraphy of  Member C in Wadi Maqam.

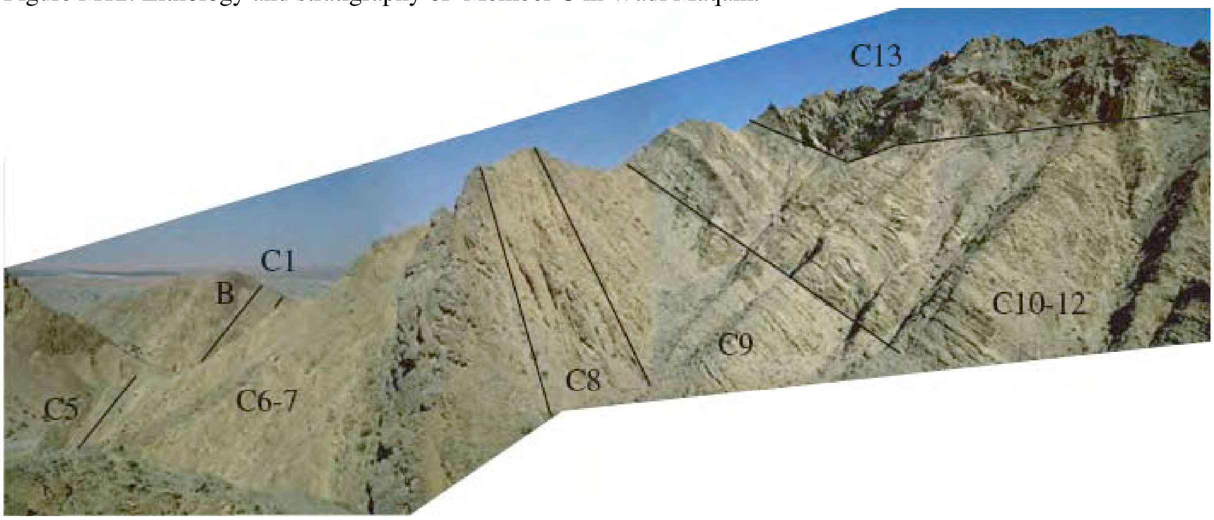



Figure M13: View of the middle part of  Member C in Wadi Maqam (Units C5 to C13).

**Stops 3.7 and 3.8 -** We will look at the calcirudites of the middle part of the member C (figs M10 and M12)**.**

## January 16: The Sumeini Group in the Wadi Shu'yab: from lower to middle Triassic carbonate slope deposits.

**Stop 4.1**- We will look at the left flank of the Wadi Shu'yab, from the top of last mega-calcirudite bed (fig. M14a,b).

**a** **b**

Figure M14a: Ripples and traces cf. Paleodictyon at the top of a calciturbidite megabreccia (upper part of Member C in Wadi Shu'yab), M14b: Cross-ripples from the same outcrop, stop 4.1.

**Stop 4.2**- The upper (Olenekian) part of Member C (fig. M15 and M17) records a gradual change in palaeo-oxygen levels as the Superanoxic Event begins to wane and the substrate becomes oxygenated for longer periods than it was during the Induan. However, the levels of bioturbation recorded in Upper Permian Member B (i.e. ii4) are never recorded in Member C, indicating suboptimal environments for at least the duration of the Early Triassic. Alternating packages of unbioturbated (ii1) and bioturbated (ii2-3) strata are typically 5-20m thick. Thus, at times the substrate was anoxic, whereas at other times it was dysoxic with slightly elevated, fluctuating, oxygen levels.

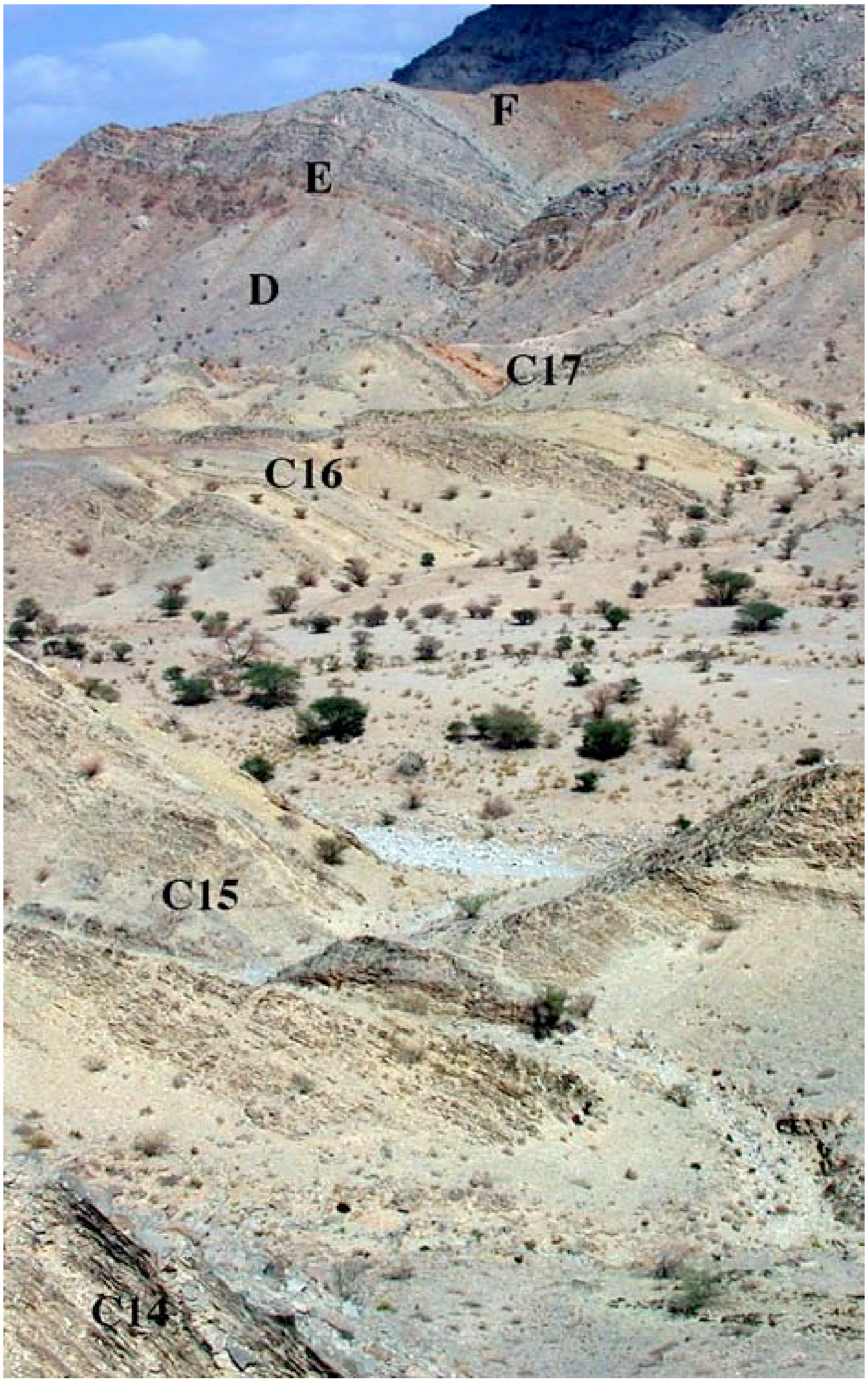


Figure M15: View of the upper part of Member C in Wadi Shu'yab, stop 4.2, and Members D, E and F in the ground.

Ichnodiversity is low. Typically, only one or two ichnotaxa (predominantly subhorizontal burrows produced by a depauperate community of deposit feeders) are present in any given bed. Occasionally, vertical *Arenicolites* are observed, indicating the presence of suspension feeders. From ca. 140m (Figure x), the bioturbated intervals begin to show an increase in ichnodiversity. *Arenicolites* and *Chondrites* are recorded at this level. However, the straight-branched form of *Chondrites* present in the upper Member C is clearly showing a unusual habit, compared to more 'typical' forms that branch downwards through the sediment. Here, *Chondrites* is largely subhorizontal in habit, possibly because the deeper levels of the substrate were completely anoxic or lacked sufficient food resources.

From ca. 155 to 180m (fig. M17), the platy limestones are reasonably well bioturbated (ii3) and contain an ichnofauna comprising *Chondrites*, *Palaeophycus* and *Phycodes*. The *Phycodes* burrows are particularly well preserved and locally common and characterise the remaining metres of Member C. The relative abundance of these ichnotaxa is variable. Rare crosscutting relationships indicate that the tracemakers all occupied the same, shallow, tier within the sediment. From ca. 190 to 215 m (fig. M17), the platy limestones are less well bioturbated (ii1-2), but where the bioturbation does occur, *Chondrites* and *Phycodes* typically dominate, with occasional *Planolites*.

The uppermost parts of Member C (from 225 to 235 m) are fairly well bioturbated (ii3) and contain the most diverse trace fossil assemblage of the Lower Triassic part of the Maqam Formation. Here, *Arenicolites*, *Chondrites*, *Palaeophycus*, *Planolites* and *Phycodes* are all recorded. Rare, subhorizontal trails ("*Scolicia*") are also present in loose slabs at this approximate level. However, the ichnofauna is still clearly different to that of the Upper Permian. *Rhizocorallium* and *Thalassinoides* are not present, the sediments are less well bioturbated and burrow diameters are typically less than 10mm (usually 2-3 mm). Environmental conditions near the end of the early Triassic were clearly very different to those of the latest Permian

**Stop 4.3**- The topmost part of Member C, the yellow dolomitic limestone with calcirudites (fig. M16, C17 in fig M15 and fig. M 18)

Figure M16: View of the top of Member C (C17) in Wadi Shu'yab, with the end of a calcirudite channel within the platy limestone.

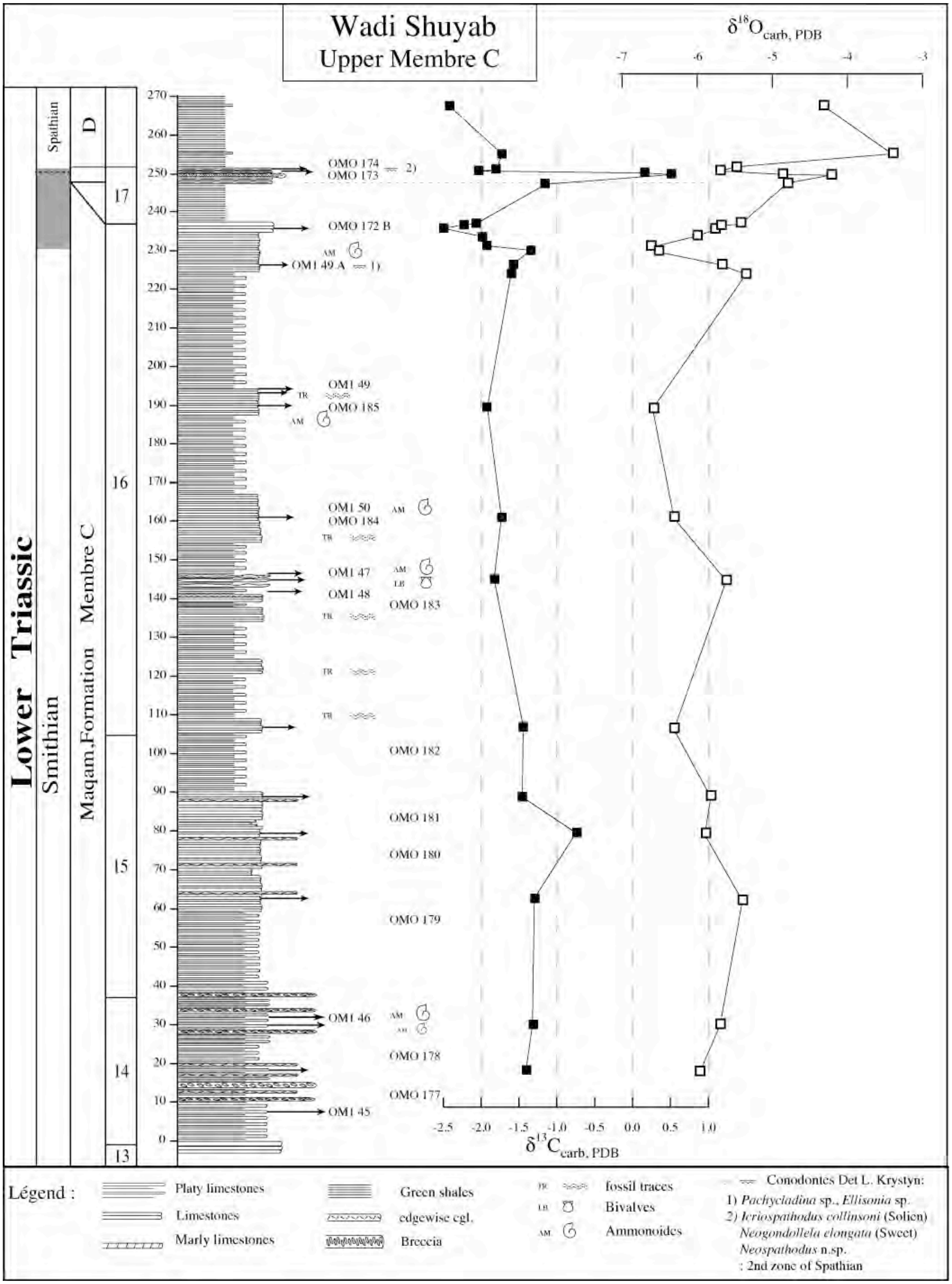



Figure M17: Lithology and stratigraphy of the upper part of Member C in Wadi Shu'yab with the Carbon and Oxygen isotope curve. The 0 meter is corresponding to the 700 meter of fig. M12.

Detail of the Carbon isotope stratigraphy *(S. Richoz)*

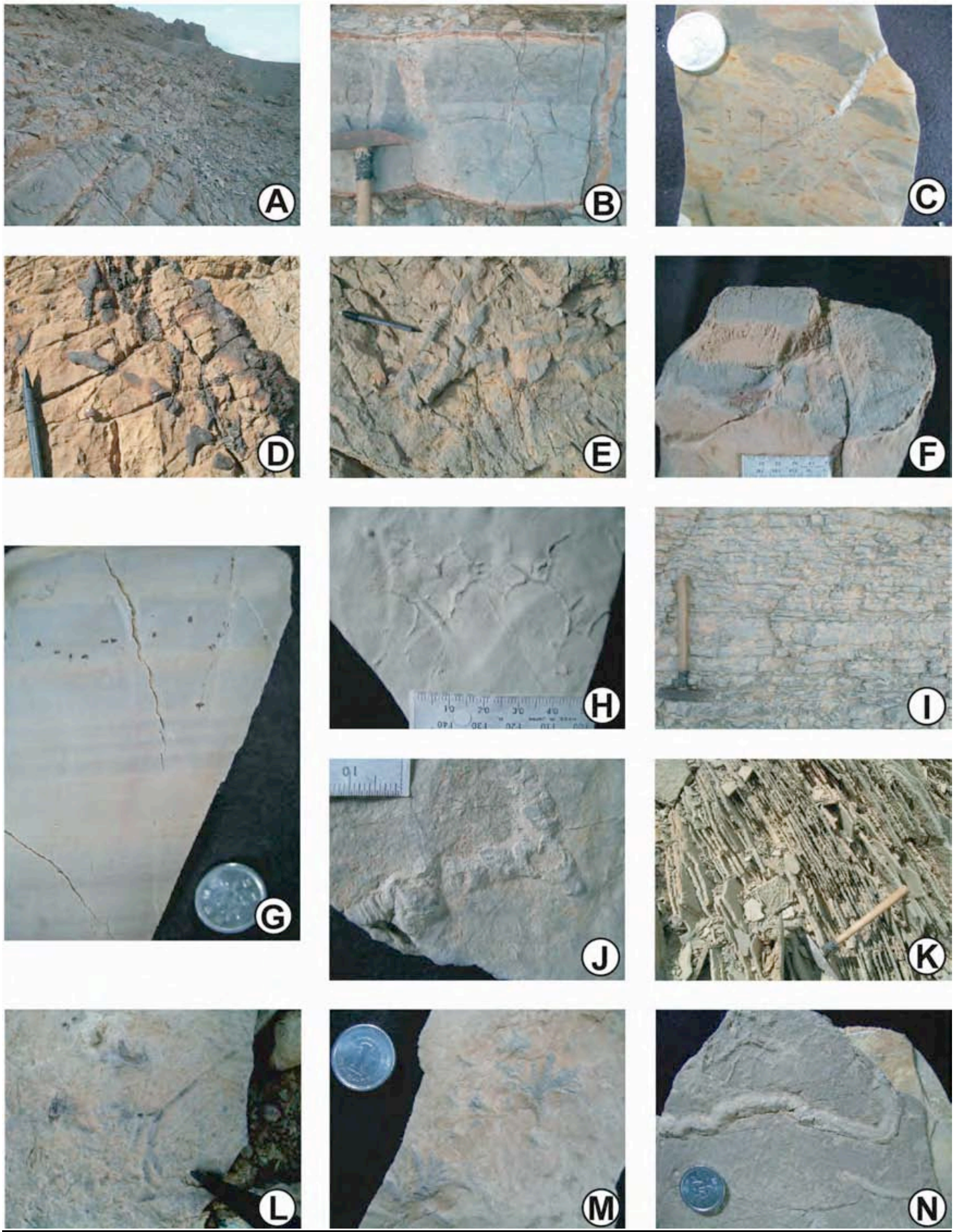



Figure M18: Selected trace fossils and ichnofabrics of the Maqam Formation. A: Thick bedded, well bioturbated limestones of Member A; B: Well bioturbated (ii 5) limestone bed of Member A; C: Well bioturbated (ii5) ichnofabric of uppermost Member B, less than 1 m below P/Tr boundary. Coin = 20mm diameter; D: Thalassinoides, uppermost Member B, Wadi Maqam; E: Rhizocorallium, uppermost Member B; F: large Rhizocorallium, uppermost

Member B; G: Laminated sediment (ii1), basal Member C, less than 1 m above P/Tr boundary. Coin = 20mm in diameter; H: cf. Protopaleodictyon, lower Member C, Wadi Maqam; I: Rare bioturbated interval (ii3), lower Member C, Wadi Maqam; J: ?Planolites with annular backfill, upper Member C, Wadi Shuyab; K: Typical, slightly bioturbated interval (ii2), upper Member C, Wadi Shuyab; L: subhorizontal Chondrites, upper Member C, Wadi Shuyab (note: straight proximal branch and few, mostly straight, shorter distal branches); M: Phycodes, uppermost Member C, Wadi Shuyab (note, bundle of strongly recurved, unbranched, distal branches). Coin = 20mm diameter; N: cf. "Scolicia", uppermost Member C, Wadi Shuyab. Coin = 20mm diameter.


Figure M19: Upper part of the Maqam Formation (members D to F). C16 Platty limestone(Smithian), C17: yellow dolomitic limestone with calcirudites., stop 4.3

**Stop 4.4 - The Ladinian radiolarites** (fig. 28) belong to the Member E**,** approximatively 60m thick and comprises mainly radiolarian chert, calcarenite and calcirudite. A metric channelling bed of calcirudite with a calcarenitic matrix crops out at the base, containing elongated clasts 5-30cm in diameter of grey micritic limestone. Above, a 20 m thick succession consists essentially of grey-brown radiolarian chert in regular cm beds with interbeds of clayey shale and in places,fine-grained calcarenite with horizons of accumulations of pelagic bivalve shells of the genus *Daonella sp*.. The top 2 m of this siliceous succession are made up of red radiolarian chert which is overlain by a carbonate succession approximately 35 m thick with abundant brown patina cherts. Above, an irregular interval, 3-6 m thick, is made up of poorly defined metre-thick beds of matrix-supported calcirudite and coarse-grained calcarenite with sub-angular and tabular clasts of grey micritic limestone ranging from 5 to 40 cm in diameter. This interval is overlain by a 20 m-thick succession made up of light grey micritic limestone with horizons of accumulations of pelagic bivalve shells, and of fine-grained, dark grey calcarenite in beds 20-60 cm thick at the base and 1-15 cm thick elsewhere. In places, the intraformational calcirudite contains slump-structures.

**Stop 4.5** - **The upper Triassic deposits** At the top of the member E is a channeling interval 1-8 m thick of calcirudite with a reduced or absent matrix, containing reworked sub-angular clasts of micritic limestone, calcarenite, and reef limestone The calcarenite of the upper carbonate succession, in addition to the reworked lithoclasts of limestone and in places chert, lava and rare quartz, also contains a biota of Late Triassic age including debris of algae, crinoids, pelagic bivalve shells and benthic foraminifera: *Trochammina* sp., *Endothyra* sp. or *Endothyranella* sp., duostominids, lituolids (Béchennec et al., 1993b). It should be noted that the discovery in this upper carbonate succession of an *Aulacoceras sp*. and an *Heterastidium sp*. few meters higher by one of us (JM) allowed the correlations with the Lower and Middle Norian of the Aqil blocs 3-4 described by L. Krystyn in Baud et al. (2001b).

## January 17: The Permian-Triassic shallow carbonate platform in Wadi Sahtan (Jabal Akhdar)

The presented sections are located in the Wadi Sahtan valley, about 4 km North of Fashah village near the road linking Fabaqah to Fashah villages in the Sahtan Bowl. In this area the Permian to Cretaceous strata of the "autochtonous" form a normal monoclinal structure dipping to the North. The Wadi Sahtan valley cuts more or less transversally the strata and the succession is very well exposed on both sides of the valley (Fig. S1).

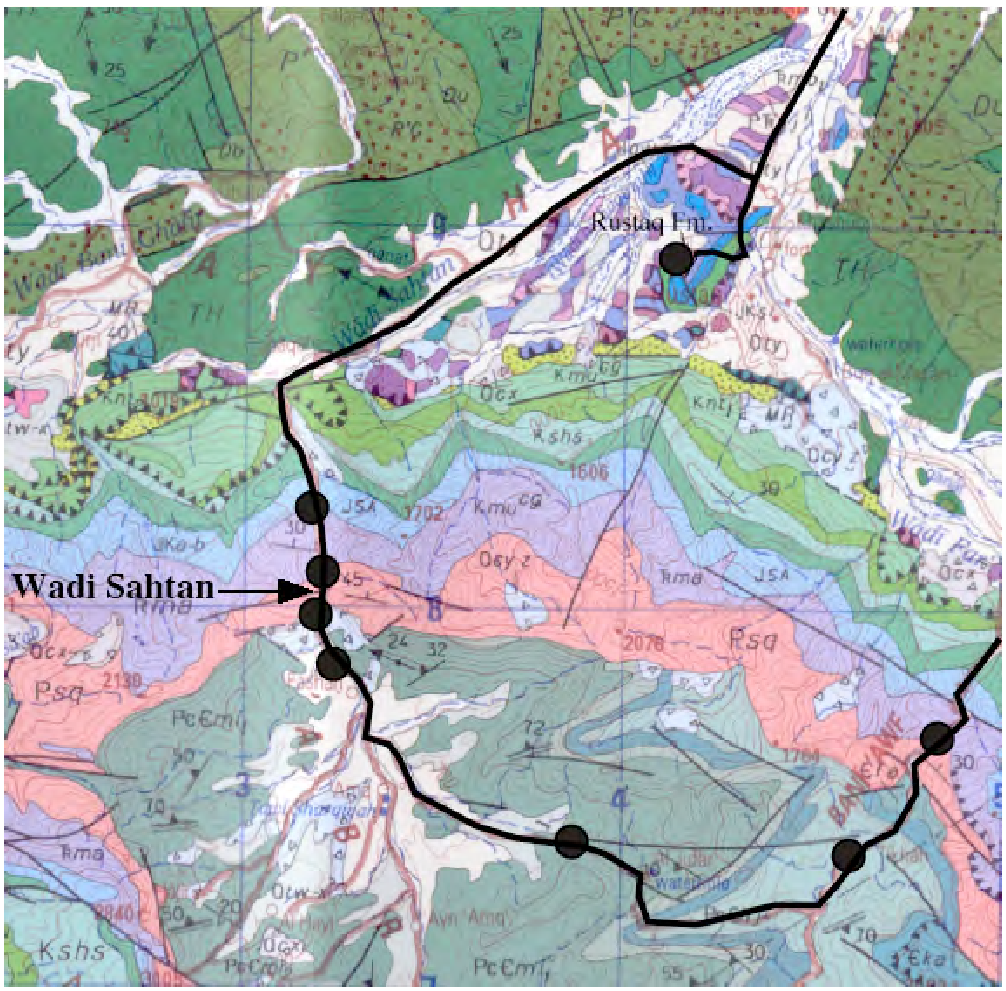



**Figure S1**: Geological map of Wadi Sahtan area (NW part of Jabal Akhdar), Grid: 10km (map Seeb, (Béchennec et al., 1992)), with the itinerary and the main stops (black dots). Saiq in rosa color and Mahil in violet.

## Introduction

The Permian-Triassic sequence deposited on the Arabian Platform, inner part of the Oman margin, is exceptionally well exposed in the Jabal Akhdar (Central Oman Mountains). The Permian and Triassic (Wordian to Rhaetian) shallow-marine carbonate occurring in this area were included into the Akhdar Group (Glennie et al., 1974), with two main formations: Saiq and Mahil representing a succession of transgression-regression (T-R) cycles noted A, B, C, etc. (Fig. S2) and ending with an emersion.

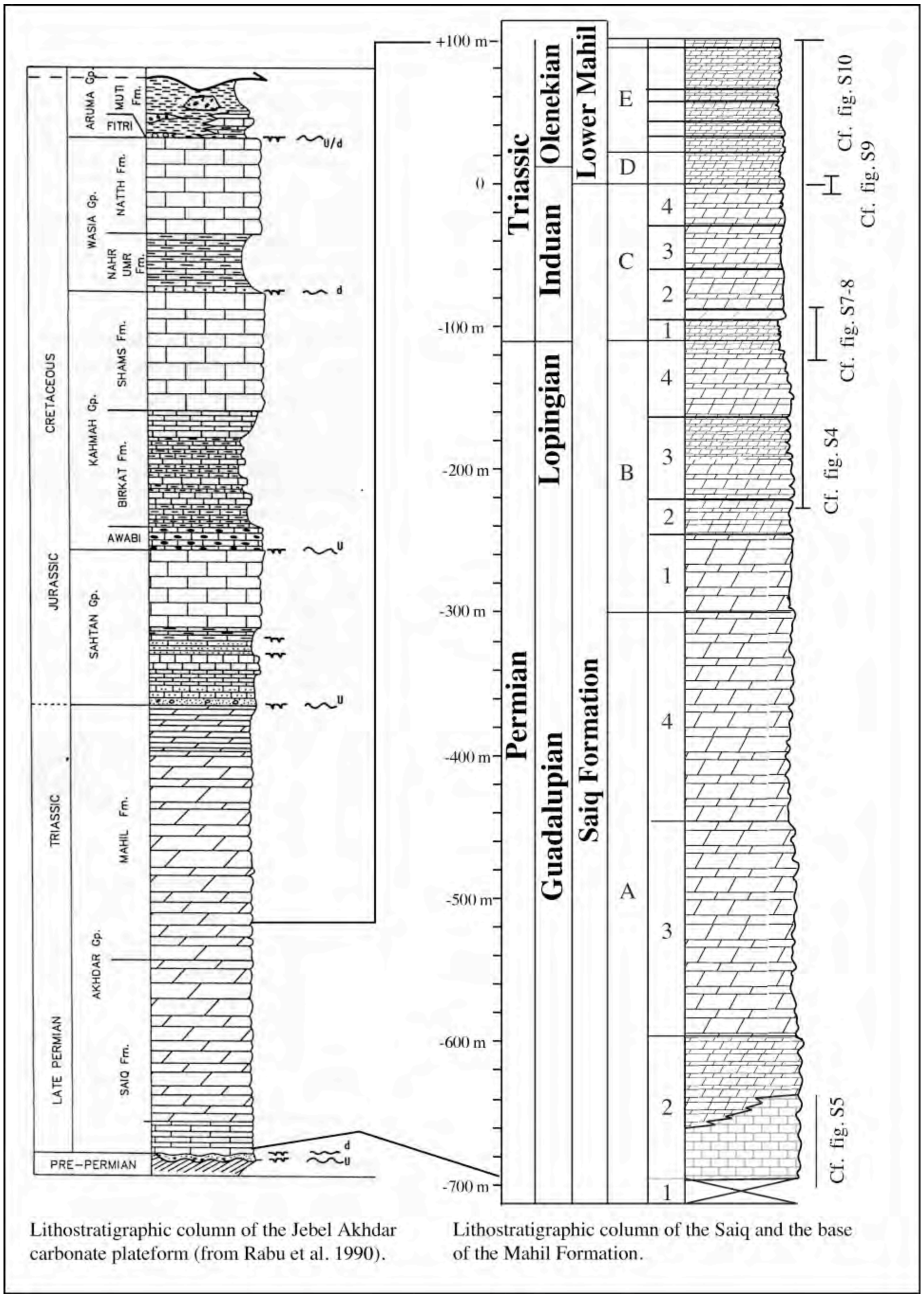



**Figure S2**: Composite stratigraphic sections in Wadi Sahtan (Jebel Akhdar).

**Stratigraphy.**
The Saiq Formation, described by Baud et al., (2001) Glennie et al., (1974) Montenat et al., (1976) and Rabu, (1988), among others, overlies unconformably Precambrian strata (Fig. **S3**), documenting the Middle Permian marine transgression. Weldlich and Bernecker (2003) described it in the metamorphic Saih Hatat.

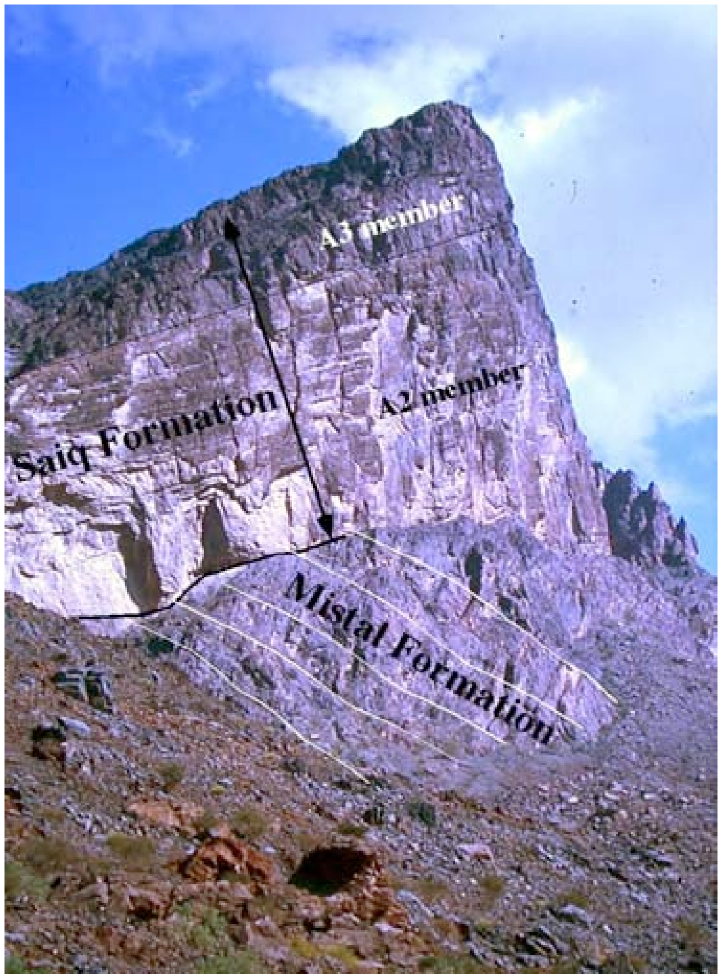



Figure S3: Transgression (black line) of the Saiq Formation (middle Permian) with angular unconformity, on the infra-Cambrian - Cambrian Mistal Formation.

In the Jabal Akhdar Mountains the basal member of the Saiq Formation, made up of terrigenous detritus occur only locally and may reach up to 20 m thickness (Rabu et al., 1990). According to these authors the remainder of the Saiq Formation is made up of an extensive carbonate unit, 450m thick (Fig. S2). The main part of the Saiq Formation is affected by pervasive dolomitization overprinting the primary sedimentary structures, therefore most of the age diagnostic fossil have been recovered from the lower part of the formation. The base of the carbonate sequence of the Saiq Formation was dated by (Montenat et al., 1976) as Neoschwagerina schuberti zone of Middle Murgabian age (Wordian). For the upper part of the Saiq Formation, a Dzhulfian age is indicated by *Staffella* cf. *sisonghensis* (Rabu et al., 1990)), and a possible Changhsingian age is based on the discovery of *Paradagmarita monodi* (Lys, 1988). New chemiostratigraphic correlations (Richoz, 2004) and see below) shallowing upwards trend towards the top of the Saiq Formation (Rabu, 1988)).

There is less information available for the overlying **Mahil Formation**. It consists of massive to thin bedded gray and whitish dolomites of Triassic age (undifferentiated) formed in intra to supratidal environments (Béchennec et al., 1992; Glennie et al., 1974; Rabu et al., 1990). The Triassic age of the Mahil Formation was attributed on the basis of foraminifera some levels of oolitic beds, occasionally occurring higher in the Formation. A Norian-Rhaetian age was suggested for the upper part of the Mahil Formation, an age indicated by the presence of Aulotortus sinuosus (Rabu et al., 1990). The top of the Mahil Formation is marked by an exposure surface, overlain by Middle Jurassic marine carbonates. The total thickness of the Mahil Formation is up to 800 meters.

In the Wadi Sathan, the Permian-Triassic section shows a 1500m thick pile of shallowing upward cycles (Fig. S2). The **Saiq Formation** is about 700m thick and consists of three main Transgressive-Regressive cycles (T-R 2$^{nd}$ order cycle). These three cycles (A, B and C) are more or less corresponding to the Weidlich (2003) supersequences (2$^{nd}$ order cycle) P2 to P4.
The lower part of the Saiq Formation with the T-R cycle A (corresponding to P2 in (Weldlich and Bernecker, 2003), 400m thick, has been subdivided in 4 units from base up:

- The A1 unit, partly terrigenous (the lower Saiq of Rabu, (1988) is not outcropping in this section.
- The A2 unit, main carbonate shallowing upward transgressive seqence is about 100m thick (fig 32). Voids at the top indicate a probable emersion. This sequence have a Wordian age by Hindeodus excavatus (Behnken, 1975 sensu Wardlaw et Collinson, 1984) (det. A. Nicora in Baud et al., 2001).
- The A3 unit, 150 m thick consits of thin-bedded, largely recristalised brown dolomites without apparent fossils.
- The A4 unit, 150 m thick, made of grey dolomite is not well outcropping and is characterized by thick levels of collapse breccia indicating a very restricted environment.

The upper part of the Saiq Formation (300 m) consist of two T-R cycles noted B and C (Figs S2, S3). Both cycles are mainly made up of dolomitized high energy calcareous sands:

- The T-R cycle B is about 190m thick. Its lower part (B1 to B2) is characterizedby thick high energy dolowakstone to dolopackstone. The upper part (B3 to B4) is made of well bedded dolomite. On the base of chemiostratigraphic correlations, (Richoz, 2004) hypothesis the Permian Triassic boundary in the last 5 meters of this cycle (see below).
- The T-R cycle C is only 90m thick with no age diagnostic. By isotopic correlation the cycle is supposed Griesbachian in age.

The top of Saiq Formation is marked by an irregular surface of hardground type, indicating an interruption in sedimentation, possibly with subaerial exposure.

The lower part of the **Mahil Formation**, examined herein, is divided in two main lithologic units, D and E, respectively 22m and 75m thick, further separated in subunits. Very small foraminifera and bivalves (Claraia) are present in the unit D of the Mahil Formation. *Cyclogira* sp. and *Earlandia* sp. were identified in three samples from unit D2 indicating an Early Triassic, Induan age.

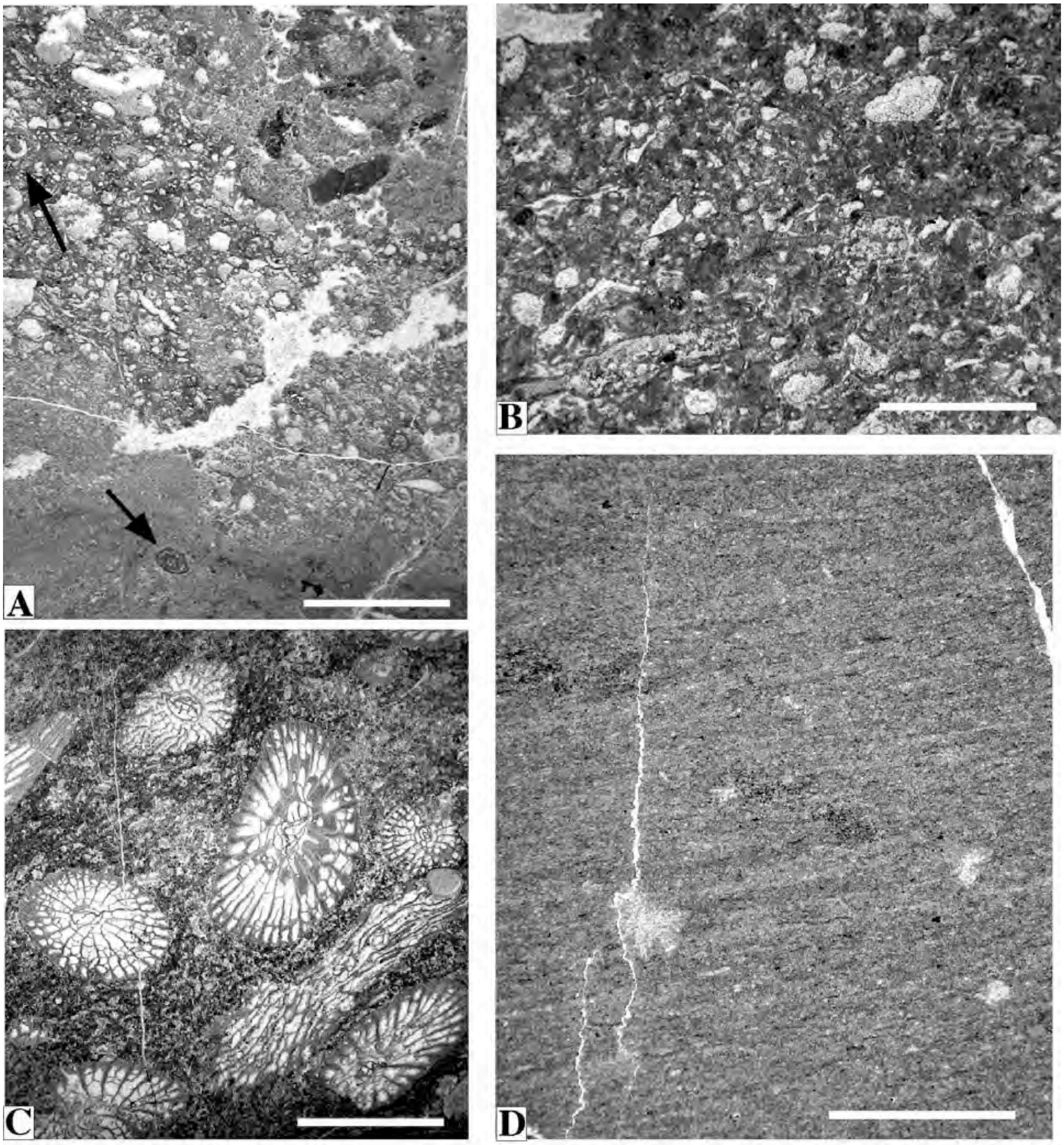



**Plate I**: Microfacies of Member B (Saiq) and D (Mahil). White bar scale is 0.5mm

A- Dolo-mudstone with *Stafella* sp. on the left down corner (arrow) overlain by dolo- bioclastic packstone with geopetal filled vugs. B3 unit of the Saiq Formation (Lopingian, late Permian).

B- Dense bioclastic packstone (tempestite) from the B4 unit of the Saiq Formation (Lopingian, late Permian).

C- Dolo-packstone with Rugosa corals of *Wentzelella*-type, uppermost B4 unit of the Saiq Formation (Lopingian, late Permian).

D- Microbial laminated dolo-mudstone of the base of the D Member of the Mahil Formation (Dienerian, early Triassic).

**Isotope stratigraphy** ( S. Richoz, figs. S4, S7 and S9)

The Saiq and Mahil Formations are composed mainly of dolomites. As shown by (Atudorei, 1999) in the Wadi Sathan, within the basal Unit A2 of the Saiq Formation where a front of dolomitisation occurs, the dolomitization processes do not affect significantly the carbon isotopic composition of the primary carbonate sediments and the dolomite have a generally a typical marine carbon isotope signature. After (Atudorei, 1999), the average d13C value for the limestone is +5.1‰ and +5.5‰ for dolomites in the same bed of the Unit A2 of the Saiq Formation (Wordian). But concerning the $\delta^{8}O$ values of limestones, they are significantly affected and about 3‰ higher than their counterparts from dolomites.

As in other part of the Neot-Tethyan Middle – Upper Permian, high positive $\delta^{13}C$ values up to 4.6‰ are recorded here up to the top of the unit B3 (upper Saiq Formation). The first negative shift occurs between Units B3 and B4 with a drop from 4.6‰ to 3.4‰ (Fig. S4). A rapid negative shift of 2.8‰ appears within an 8 m. thick interval of the transition between B and C Members . This shift is made of several steps, which do not correspond to lithological changes. Within the last 3m of high-energy bioclastic deposits with Permian fauna near the top of the B4 Unit, the $\delta^{13}C$ values drop of 1.6‰. A little positive shift of 0.9‰ occurs just after a lithological change. A second little positive shift appears above in the dolo-mudstone succession just before a second negative shift of 1.9‰ ending just above the maximum regressive level represented by a clay level (Fig. S7). In other well-dated tethyan sections, *H. parvus* occurs just before a small positive shift and the second part of the large negative shift (Holser et al., 1991; Krull et al., 2004; Richoz, 2004). A main difference with other Tethyan sections is that here the negative shift is ending before the maximum regressive level. Elsewhere, this level occurs before the second part of the negative shift. With this well known and adopted criteria of the C isotope shift, we assume to set the Permian Triassic Boundary (PTB) in the topmost B4 unit, between the black dolomite bed and the clay horizon.

The Member C is characterized by low positive values (Fig. S4), progressively higher in the upper part (from +0.8‰ to +2.3‰) to reach the maximum 90cm before the Saiq and Mahil transition. Taking account of our hypothesis on the emplacement of the PTB and the presence of Induan foraminifers at the base of the Mahil Formation, this pattern should represent Griesbachian evolution. This curve corresponds effectively to better-dated Griesbachian sections in Oman (Wasit block, (Krystyn et al., 2003; Richoz, 2004); Wadi Maqam, (Richoz, 2004) and this guide book) and elsewhere (Atudorei, 1999; Baud et al., 1996; Krull et al., 2004; Richoz, 2004)). A short negative shift to 1.2‰ appears in the first Mahil's bed before a positive shift to 2.8‰ in the first meters of brown dolo-mudstone. We observe then a strong negative shift reaching is minimum (0.6‰) just above sedimentary structure interpreted as seismite (Fig. S9). The successive 25m record a double positive peak with maximum at 4.3‰. This double shift is a distinctive pattern of the Early Smithian in Oman (Wadi Maqam and Wadi Wasit south) and other tethyan sections (Atudorei, 1999; Baud et al., 1996; Horacek et al., 2000; Richoz, 2004; Tong et al., 2002). If this hypothesis is correct, its means that the Dienerian sediments are comparatively condensed here with a maximum thickness of 10m.

The main part of the Member E (50m) has homogenous values around low positive values (0.5‰). This interval is ending with a short positive shift just under the orange dolomite (Fig. S4). This pattern is similar to the one in the well-dated Wadi Maqam section where the long homogenous low values interval is dated from Middle to Upper Smithian and the positive peak in the Smithian-Spathian boundary interval.

It is clear that without any reliable biostratigraphic control, our age correlations by isotopic stratigraphy are based on analogy. Nevertheless, the isotopic pattern is typical enough to make confident correlation with well-dated Oman sections. Taking account of these correlations, we can summary the Wadi Sahtan section as follow:
B3 and B4 units represent an Upper Permian succession, The Permian-Triassic boundary is placed in the last meter of unit B4 (Fig. S7). The Member C is composed of a transgressive depositional system of sabbkah-type sediments with a lack of fossils, assumed Griesbachian in age. The Saiq-Mahil boundary is probably Upper Griesbachian. There is some uncertainty concerning the extension of Dienerian sediments. They are probably condensed and consist of stromatolites and brown dolomudstone. Algo-bacterial sediments (stromatolites and oncolites) characterize the Lower Smithian. The Middle and Upper Smithian contains marly dolomudstone with supratidal structures and is ending with 2m of orange dolomite. Spathian is marked by thick black doloarenite.

## AKNOWLEDGMENTS

Chairman of the Organising Committee
We are particulary gratefull to Dr. Hilal bin Mohammed Al-Azri, Director General of Minerals, for his kindness, his interest and encouragements to our field works and researches. Our team is very gratefull to Dr. Jean-Paul Breton, Head of the Oman Branch of the BRGM and Françoise his wife, for their generous hospitality and their valuable help to resolve many logistic problems, to prepare the field work and organize the sample shipment. During field studies, our team has been helped by many colleagues, among them Cécile Robin and François Guillocheau.
Researches in Oman for A. Baud and S, Richoz have been supported financially by the Swiss National Foundation through grants 20-53787. 98 and 20 - 33'448.92, 2000, 045455.95 (AB), and by the Geological Museum in Lausanne. S. Richoz appreciate the hospitality of the Institute of Mineralogy and Petrography and the Institute of Geology and Paleontology, University of Lausanne for his Laboratory works on stable isotopes. L. Krystyn has been funded by Austrian National Committee for IGCP within IGCP project 467.

## REFERENCES

Angiolini, L., Baud, A., Broutin, J., Bucher, H., Hasmi, H. A., Marcoux, J., Platel, J. P., Pillevuit, A., and Roger, J., 1995, Sakmarian brachiopods from southern Oman: Permophiles, v. 27, p. 17-18.

Angiolini, L., Bucher, H., Pillevuit, A., Platel, J. P., Roger, J., Broutin, J., Baud, A., Marcoux, J., and Hashmi, H. A., 1997, Early Permian (Sakmarian) brachiopods from southeastern Oman: Geobios, v. 30, p. 378-405.

Angiolini, L., Nicora, A., Bucher, H., Vachard, D., Pillevuit, A., Platel, J. P., Roger, J., Baud, A., Broutin, J., Hashmi, H. A., and Marcoux, J., 1998, Evidence of a Guadalupian age for the Khuff Formation of southeastern Oman: preliminary report: Rivista italiana di Paleontologia e Stratigrafia, v. 104, p. 329-340.

Atudorei, N.-V., 1998, Constraints on the upper Permian to upper Triassic marine carbon isotope curve. Case studies from the Tethys, PhD Thesis: Lausanne University, 155 p.

Baud, A., Atudorei, V., and Sharp, Z. D., 1996, Late Permian and Early Triassic evolution of the Northern Indian margin: carbon isotope and sequence stratigraphy: Geodinamica Acta, v. 9, p. 57-77.

Baud, A., Atudorei, V. N., and Marcoux, J., 1999, The Permian-Triassic boundary interval (PTBI) in Oman : Carbon isotope and facies changes, in Yin, H., and Ton, J., editors, International Conference on Pangea and the Paleozoic-Mesozoic Transition: Wuhan (China), China University of Geosciences Press, p. 88-89.

Baud, A., Cirilli, S. & Marcoux, J., 1996, Biotic response to mass extinction: the lowermost Triassic microbialites. In J. Reitner, F. Neuweiler and C. Monty eds, Biosedimentology of Microbial Buildups -IGCP Project No. 380, Facies 36, p. 238-242,

Baud, A., Cordey, F., Krystyn, L., Marcoux, J., and Richoz, S., 2001, The Permian-Triassic boundary in Oman, a review., Geology of Oman, Pangea Symposium: Muscat, Oman.

Baud, A., Holser, W. T., and Magaritz, M., 1989, Permian-Triassic of the Tethys: Carbon isotope sudies: Geol. Rundschau, v. 78, p. 1-25.

Baud, A., Marcoux, J., Guiraud, R., Ricou, L. E., and Gaetani, M., 1993a, Late Murgabian Palaeoenvironments (266-264 Ma): Reuil-Malmaison, BECIP-FRANLAB.

Baud, A., Marcoux, J., Guiraud, R., Ricou, L. E., and Gaetani, M., 1993b, Late Murgabian (266-264 Ma), in Dercourt, J., Ricou, L. E., and Vrielynck, B., editors, Atlas Tethys,Palaeenvironmental maps, explanatory notes: Paris, Gauthier-Villars, p. 9-21.

Beauchamp, B., and Baud, A., 2001, Demise of Permian biogenic chert along the margins of NW Pangea, Western Tethys and Gondwana: evidence for paleoceanographic disruption and global warming, Geology of Oman, Pangea Symposium: Muscat, Oman.

Béchennec, F., 1988, Géologie des nappes d'Hawasina dans les parties orientales et centrales des montagnes d'Oman: Documents du B.R.G.M., v. 127: Orléans, France, Bureau de Recherches Géologiques et Minières, 474 p.

Béchennec F., Le Métour J., Rabu D., Beurrier M., and Villey M., 1988, The Hawasina Basin: a fragment of a starved passive continental margin thrust over the Arabian Platform during obduction of the Samail Nappe.- Tectonophysics, n° 151, pp 323-343.

Béchennec, F., Le Métour, J., Rabu, D., Beurrier, M., Bourdillon-Jeudy-De-Grissac, C., De Wever, P., Beurier, M., and Villey, M., 1990, The geology and tectonics of the Oman mountains., in Robertson, A. H. F., Searle, M. P., and Ries, A. C., editors, Special Publications of the Geological Society of London, p. 213-224.

Béchennec, F., Tegyey, M., Le Métour, J., Lemiere, B., Lescuyer, J.L., Rabu, D., Milesi, J.P.,1991, Igneous rocks in the Hawasina Nappes and the Hajar Supergroup, Oman Moutains : Their significance in the Birth and evolution of the composite extensional margin of Eastern Tethys. Tj., Peters *et al.*(Eds.)Ophiolite Genesis and Evolution of the Oceanic Listhosphere, Kluwer Academic publishers pp. 597-615.

Béchennec, F., Roger, J., Chevrel, S., and Le Métour, J., 1992a, Explanatory notes to the Geological map of Al Ashkharah, Sheet NF40-12, scale 1:250,000, Directorate General of Minerals, Oman Ministry of Petroleum and Minerals, 44 p.

Béchennec, F., Roger, J., Le Métour, J., and Wyns, R., 1992b, Explanatory notes to the Geological map of Seeb, Sheet NF40-03, Directorate General of Minerals, Oman Ministry of Petroleum and Minerals, 104 p.

Béchennec, F., Roger, J., Le Métour, J., and Wyns, R., and Chevrel, S., 1992c, Explanatory notes to the Geological map of Ibri, Sheet NF40-02, Directorate General of Minerals, Oman Ministry of Petroleum and Minerals, 94 p.

Béchennec, F., Wyns, R., Roger, J., Le Métour, J., and Chevrel, S., 1992d, Explanatory notes to the Geological map of Nazwa, Sheet NF40-07, Directorate General of Minerals, Oman Ministry of Petroleum and Minerals, 91 p.

Béchennec, F., Le Métour, J., Platel, J.P., Roger, J., 1993a, Explanatory notes to the Geological map of the Sultanate of Oman, Scale 1:1,000,000. Directorate General of Minerals, Oman Ministry of Petroleum and Minerals, 93 p.

Béchennec, F., Roger, J., Le Métour, J., and Janjou, D., 1993b, Geological map of Al Sumayni with Explanatory Notes, Sheet NG 40-14A4, scale 1:50,000, Directorate General of Minerals, Oman Ministry of Petroleum and Minerals, 50 p.

Becq-Giraudon, J.-F., and Pillevuit, A., 1995, Trilobites du Permien supérieur(Murgabien/Midien) du Nord de l'Oman: Eclogae geologicae Helvetiae, v. 88, p. 761-775.

Bernecker, M., 1996a, Upper Triassic coral communities from the Oman Mountains; occurrence and distribution pattern: Special Publication The Paleontological Society, p. 8; Pages 31.

Bernecker, M., 1996b, Upper Triassicl reefs of the Oman Mountains -data from the South Tethyan margin: Facies, v. 34, p. 41-76.

Bernoulli, D., and Weissert, H., 1987, The Upper Hawasina Nappes in the Central Oman Mountains: Stratigraphy, palinspastics and sequence of nappes emplacements: Geodynamica Acta (Paris), v. 1 / 1, p. 47-58.

Bernoulli, D., Weissert, H., and Blome, C. D., 1990, Evolution of the Triassic Hawasina basin, in Robertson, A. H. F., Searle, M. P., and Ries, A. C., editors, The Geology and Tectonics of the Oman Region: London, Special Publications of the Geological Society of London, p. 189202.

Beurrier, M., Béchennec, F., Rabu, D., and Hutin, G., 1986, Geological map of Rustaq. Sheet NF 40-3A. Scale 1/100 000: Orleans, France, Sultanate of Oman, Ministry of Petroleum and Minerals, Directorate General of Minerals.

Blendinger, W., 1988, Permian to Jurassic deep water sediments of the Eastern Oman Mountains: Their significance for the evolution of the Arabia margin of South Tethys: Facies, v. 19, p. 1 32.

Blendinger, W., 1991a, Al Aridh formation, Oman: stratigraphy and paleogeographicsignificance, in Peters, T., and al, editors, Ophiolite genesis and evolution of the oceanic lithosphere: Muscat, Ministry of Petroleum and Minerals, Sultanate of Oman, p. 575-592.

Blendinger, W., 1991b, Upper Triassic (Norian) cephalopod limestones of the Hallstatt-type, Oman: Sedimentology, v. 38, p. 223-242.

Blendinger, W., 1995, Lower Triassic to Lower Jurassic cephalopod limestones of the Oman Mountains: N. Jb. Geol. Paläont. Mh., v. 10, p. 577-593.

Blendinger, W., Furnish, W. M., and Glenister, B. F., 1992, Permian cephalopod limestones, Oman Mountains: evidence for a Permian seaway along the northern margin of Gondwana: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 93, p. 13-20.

Böhm,F.,1992: Mikrofazies und Ablagerungsmilieu des Lias und Dogger der Nordlstlichen Kalkalpen: Erlanger Geol. Abh., v. 121, 57-217.

Bougault H., Joron J.L., Treuil M., Maury R.C, 1985, IPOD leg 82 : local versus regional mantle heterogeneities : Evidence from hygromagmaphile elements. Initial Reports D.S.D.P., 82 : 459-482.

Broutin, J., Roger, J., Platel, J. P., Angiolini, L., Baud, A., Bucher, H., Marcoux, J., and Hasmi, H. A., 1995, The Permian Pangea. Phytogeographic implications of new discoveries in Oman

(Arabian Peninsula): Comptes Rendus de l'Académie des Sciences de Paris, Série II a, v. 321, p. 1069-1086.
Cordey, F., Baud, A., Béchennec, F., Gorican, S., Krystyn, L., Marcoux, J., Robin, C., and Richoz, S., 2001, Permian-Triassic deep water sediments of the Wadi Wasit revisited, Geology of Oman, Pangea Symposium: Muscat, Oman.
Cordey, F., Marcoux, J., Bucher, H., Girard, C., Lécuyer, C., Crasquin-Soleau, S., Baud, A., and Orchard, M., 1999, Record of the Permo-Triassic Crisis in Oceanic Environments: New Targets in Oman, Nevada, and British Columbia, EUG 99: Terra Abstract: Strasbourg, p. 275.
Cotten J., Le Dez A., Bau M., Caroff M., Maury R. C., Dulski P., Fourcade S., Bohn M. Brousse R, 1995, Origin of anomalous rare-earth element and yttrium enrichments in subaerially exposed basalts: Evidence from French Polynesia. Chemical Geology. 119 : 115-138.
De Wever, P., Bourdillon-De-Grissac, C., and Béchennec, F., 1988, Découverte de radiolaires permiennes au bord Sud de la Tethys (nappes d'Hawasina, Sultanat d'Oman): C. Acad. Sci. Paris, v. 307, serie II, p. 1383-1388.
Dubreuilh, J., Platel, J.P., Le Métour J., Roger, J., Wyns, R., Béchennec, F., and Berthiaux, A., 1992, Explanatory notes to the Geological map of Khaluf, Sheet NF 40-15, Scale 1:250,000. Directorate General of Minerals, Oman Ministry of Petroleum and Minerals, 92 p.
Fitton J. G., Saunders A. D., Larsen L. M., Hardarson B. S., Norry M. J, 1998, Volcanic rocks from the Southeast Greenland margin at 63°N: composition, petrogenesis, and mantle sources. Proceed. Ocean Drilling Program, Scientific Results, 152, 331-350.
Fitton J. G., Saunders A. D., Norry M. J., Hardarson B. S., Taylor R. N, 1997, Thermal and chemical structure of the Iceland plume. Earth Planet. Sci. Lett., 153, 197-208.
Fluegel, E., and Senowbari Daryan, B., 1996, Evolution of Triassic reef biota; state of the art: Goettinger Arbeiten zur Geologie und Palaeontologie, v. Sonderband, p. 285-294.
Gallet, Y., Besse, J., Krystyn, L., Marcoux, J., Guex, J., and Hervé, T., 2000: Magnetostratigraphy of the Kavaaalani section (southwestern Turkey): Consequence for the origin of the Antalya Calcareous Nappes and for the Norian (Late Triassic) magnetic polarity timescale: Geophys. Rs. Letters, 2033-2036.
Gibson S. A., Thompson R. N., Dickin A. P., Leonardos O. H, 1995, High-Ti and low-Ti mafic potassic magmas: key to plume-lithosphere interactions and continental flood-basalt genesis. Earth Planet. Sci. Lett., 136, 149-165
Glennie, K. W., Boeuf, M. G. A., Hughes Clarke, M. W., Moody-Stuart, M., Pilaart, W. F. H., and Reinhart, B. M., 1974, Geology of the Oman mountains, v. 1, The Verhandelingen van het Koninklink Nederlandsgeologisth Mijnbouwkundig Genootchachp.
Gradstein, F. M., Agterberg, F. F., Ogg, J. G., Hardenbol, J., van Veen, P., Thierry, J., and Huang, Z., 1994: A Mesozoic timescale: Journ. Geophys.Res., v. 24, 51-74.
Haq, B.U., Hardenbol, J., and Vail, P.R., 1987, The chronology of fluctuating sea levels since the Triassic, Science, v. 235, p. 1156-1167.
Haq, B. U., Hardenbol, J. and Vail, !988: Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change, in Sea-level changes, an integrated approach: Soc. Econ. Paleont. and Mineralogists, Spec. Publ. v. 42, 71-108.
Hutin, G., Bechenec, F., Beurrier, M., and Rabu, D., 1986: Geological map of Birkat al Mawz. Sheet NF 407B Scale 1:100.000, Explainatory notes: Directorate General of Minerals Oman Ministry of Petroleum and Minerals, 61 p.
Hudson, R.G.S. and Jefferies, R.P.S., 1961: Upper Triassic brachiopods and lamellibranchs from the Oman peninsula, Arabia: Palaeontology, v. 4, p. 1, 1-41.

Hudson, R. G. S., and Sudbury, M., 1959, Permian Brachiopoda from South-East Arabia: Notes et Mémoires sur le Moyen-Orient, v. VII, p. 19-55.
Immenhauser, A., Schreurs, G., Peters, T., Matter, A., Hauser, M., and Dumitrica, P., 1998, Stratigraphy, sedimentology and depositional environments of the Permian to uppermost Cretaceous Batain Group, eastern-Oman: Eclogae Geologicae Helvetiae, v. 91, p. 217-235.
Jenny-Deshusses, C. and Baud, A., 1989. Colaniella, foraminifère index du Permien tardif téthysien: propositions pour une taxonomie simplifiée, répartition géographique et environnements. Eclogae geologicae Helvetiae, 82(3): 869-901.
Krystyn, L., Richoz, S., and Baud, A., 2001, A Unique Permian-Triassic Boundary section from Oman, Geology of Oman, Pangea Symposium: Muscat, Oman.
Le Métour, J., 1988, Géologie de l'Autochtone des Montagnes d'Oman : la fenêtre du Saih Hatat: Documents du Bureau de Recherches Géologiques et Minières Orléans, v. 129, p. 1-430.
Le Métour, J., Béchennec, F., Chevremont, P., Roger, J., and Wyns, R., 1992a, Explanatory notes to the Geological map of Buraymi, Sheet NF40-14, scale 1:250,000, Directorate General of Minerals, Oman Ministry of Petroleum and Minerals, 89 p.
Le Métour, J., Béchennec, F., Roger, J., and Wyns, R., 1992b, Explanatory notes to the Geological map of Musandam and Mudha, Sheet NF40-14, scale 1:250,000, Directorate General of Minerals, Oman Ministry of Petroleum and Minerals, 54 p.
Le Métour, J., Béchennec, F., Roger, J., and Wyns, R., 1992c, Geological map of Muscat with Explanatory notes, Sheet NF40-04, scale 1:250,000, Directorate General of Minerals, Oman Ministry of Petroleum and Minerals, 76 p.
Le Métour, J., Platel, J.P., Béchennec, F., Berthiaux, A., Chevrel, S., Dubreuilh, J., Roger, J., Wyns, R., 1993a, Geological map of Oman, scale 1:1,000,000. Directorate General of Minerals, Oman Ministry of Petroleum and Minerals.
Le Métour, J., Béchennec, F., Chèvremont, P., Roger, J., and Wyns, R.,1993b, Geological map of Jabal Ar'rawdah with Explanatory Notes, Sheet NG 40-14A2/B1, scale 1:50,000, Directorate General of Minerals, Oman Ministry of Petroleum and Minerals, 55 p.
Le Métour J., Michel, J., Béchennec, F., Platel,. J.P., and Roger, J., 1995, Geology and Mineral Wealth of the Sultanate of Oman, Directorate General of Minerals, Oman Ministry of Petroleum and Minerals, 285 p.
Lys, M., 1988. Biostratigraphie du Carbonifere et du Permien en Mésogée. Documents du Bureau de Recherches Géologiques et Minières Orléans, 147, 315 p
Marcoux, J., Baud, A., and al., e., 1993, Late Anisien Palaeoenvironments (237-234 Ma): Reuil-Malmaison, BECIP-FRANLAB.
Marcoux, J., Baud, A., Ricou, L. E., Gaetani, M., Krystyn, L., Bellion, Y., Guiraud, R., Besse, J., Gallet, Y., Jaillard, E., Moreau, C., and Theveniaul, H., 1993a, Late Norian (212-234 Ma), in Dercourt, J., Ricou, L. E., and Vrielynck, B., editors, Atlas Tethys, Palaeenvironmental maps, explanatory notes: Paris, Gaultier-Villards, p. 21-34.
Marcoux, J., Baud, A., Ricou, L. E., Gaetani, M., Krystyn, L., Bellion, Y., Guiraud, R., Besse, J., Gallet, Y., Jaillard, E., Moreau, C., and Theveniaul, H., 1993b, Late Norian Palaeoenvironments (212-214 Ma): Reuil Malmaison, BECIP-FRANLAB.
Marcoux, J., Baud, A., Ricou, L. E., Gaetani, M., Krystyn, L., Bellion, Y., Guiraud, R., Moreau, C., Besse, J., Gallet, Y., Jaillard, E., and Theveniaul, H., 1993c, Late Anisien (237-234 Ma), in Dercourt, J., Ricou, L. E., and Vrielynck, B., editors, Atlas Tethys, Palaeoenvironmental maps, explanatory notes: Paris, Gauthier-Villars, p. 21-34.
Masson, H., 1972, Sur l'origine de la cornieule par fracturation hydraulique: Eclogae geologicae

Helvetiae, v. 65, p. 27-41.
Maury, R. C., Cotten, J., Béchennec, F., Caroff, M., and Marcoux, J., 2001, Magmatic Evolution of the Tethyan Permo-Triassic Oman margin, Geology of Oman, Pangea Symposium: Muscat, Oman.
Miller, A.K., and Furnish, W.N., 1957, Permian ammonoids from southern Arabia. Journal of Paleontology, v. 31, p. 1043-1051
Montenat, C., Lapparent, A. F., Lys, M., Termier, H., Termier, G., and Vachard, D., 1976, La transgression permienne et son substratum dans le jebel Akhdar (Montagnes d'Oman, Peninsule Arabique): Annales de la Société géologique du Nord, v. XCVI, p. 239-258.
Oekentorp, K., Montenat, C., and Fontaine, H., 1978, Eine kleine Korallenfauna aus dem unteren Oberperm von Saiq, Oman (Arabische Halbinsel): Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, v. 155, p. 374-397.
Orchard, M., 1994, Conodont biochronology around the early-middle Triassic boundary: new data from North America, Oman and Timor, in Guex, J., and Baud, A., editors, Recent Developments on Triassic Stratigraphy: Mémoires de Géologie (Lausanne), p. 105-114.
Orchard, M. J., 1995, Taxonomy and correlation of Lower Triassic (Spathian) segminate conodonts from Oman and revision of some species of Neospathodus: Journal of Paleontology, v. 69, p. 110-122.
Pik R., Deniel C., Coulon C., Yirgu G., Hofman C., Ayalew D, 1998, The northwestern Ethiopian Plateau flood basalts: classification and spatial distribution of magma types. Journ. Volc. Geotherm. Res., 81, 91-111.
Pik R., Deniel C., Coulon C., Yirgu G., Marty B, 1999, Isotopic and trace element signature of Ethiopian Flood Basalts: evidence for plume-lithosphere interactions. Geochem. Cosmochem. Acta, 63, 2263-2279.
Pillevuit, A., 1993, Les Blocs Exotiques du Sultanat d'Oman: Evolution paléogéographique d'une marge passive flexurale: Mémoires de Géologie, v. 17: Lausanne, Université de Lausanne, Institut de Géologie et Paléontologie, 249 p.
Pillevuit, A., Marcoux, J., Stampfli, G., and Baud, A., 1997, The Oman Exotics: a key to the understanding of the Neotethyan geodynamic evolution: Geodinamica Acta, v. 10, p. 209238.
Rabu, D., 1988, Géologie de l'autochtone des montagnes d'Oman : La fenêtre du jabal Akdar. La semelle métamorphique de la Nappe ophiolitique de Semail dans les parties orientales et centrale des Montagnes d'Oman : une revue: Documents du Bureau de Recherches Géologiques et Minières, Orléans, v. 130, p. 1-582.
Rabu, D., Béchennec, F., Beurrier, M., and Hutin, G., 1986, Geological map of Nakhl, sheet NF 40-3E, scale 1/100 000: Orléans, France, Sultanate of Oman, Ministry of Petroleum and Minerals, Directorate of Minerals.
Rabu, D., Le Métour, J., Béchennec, F., Beurrier, F., Villey, M., and Bourdillon-de-Grissac, C., 1990, Sedimentary aspects of the Eo-Alpine cycle on the northeast edge of the Arabian Platform (Oman Mountains), in Robertson, A. H. F., Searle, M. P., and Ries, A. C., editors, The Geology and tectonics of the Oman Region, Geological Society of London, Special publication 49, p. 49-68.
Richoz, S., Atudorei, V., Baud, A., and Marcoux, J., 2001a, Lower Triassic isotope stratigraphy of the Sumeini slope deposits (Maqam C, NW Oman), Geology of Oman, Pangea Symposium: Muscat, Oman.
Richoz, S., Atudorei, V., Baud, A., and Marcoux, J., 2001b, Upper Permian to lower Triassic carbon isotope record : review and new data in the Oman Mountains, from the shallow

platform to the basin., Geology of Oman, Pangea Symposium: Muscat, Oman.
Shackleton, R.M., Ries, A.C., Bird, P.R., Filbrant, J.B., Lee, C.W., and Cunningham, G.L., 1990, The Batain melange of NE Oman: in Robertson, A. H. F., Searle, M. P., and Ries, A. C., (eds) The Geology and Tectonics of the Oman Region, Geological Society of London, Special publication 49, p. 673-696
Scotese, C.R., and McKerrow, W.S., 1990, Revised World Maps and Introduction: *in* McKerrow,W.S., and Scotese, C.R., (eds), Palaeozoic Palaeogeography and Biogeography. Geological Soc. oF London, Memoir n°12, p. 1-21
Searle, M. P., Lippard, S. J., Smewing, J. D., and Rex, D. C., 1980: Volcanic rocks beneath the Semail ophiolite of Oman and their significance in the Mesozoic evolution of Tethys: J. geol. Soc. London, v. 137, 589-604.
Searle, M. P., Cooper, J. W., and Watts, K. F., 1990, Structure of the Jabal Sumeini -Jabal Ghawil area, Northern Oman, in Robertson, A. M., and A., R., editors, The Geology and Tectonics of the Oman region, Special Publications of the Geological Society of London, p. 361-374.
Stampfli, G., Marcoux, J., and Baud, A., 1991, Tethyan margins in space and time.: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 87, p. 373-409.
Tozer, E. T., and Calon, T. J., 1990, Triassic ammonoids from Jabal Safra and Wadi Alwa, Oman, and their significance, in Robertson, A. H. F., Searle, M. P., and Ries, A. C., editors, The Geology and tectonics of the Oman Region: Geological Society Special Publication: London, The Geological Society, p. 203-211.
Veevers, J. J., and Tewari, R. C., 1995, Permian-Carboniferous and Permian-Triassic magmatism in the rift zone bordering the Tethyan margin of southern Pangea: Geology (Boulder), v. 23, p. 467-470.
Watts, K. F., 1985, Evolution of a carbonate slope facies along a South Tethyan continental margin : the Mesozoic Sumeini group and the Qumayrah facies of the Muti formation, Oman., University of California, Santa Cruz.
Watts, K. F., 1988, Triassic carbonate submarine fans bounding the Arabian carbonate margin, Sumeini Group, Oman: Sedimentology, v. 34, p. 43-71.
Watts, K. F., 1990, Mesozoic carbonate slope facies marking the Arabian platform margin in Oman: depositional history, morphology and peleogeography, in Robertson, A., Searle, M., and Ries, A., editors, The Geology and Tectonics of the Oman Region, Special Publications of the Geological Society of London, p. 139-159.
Watts, K. F., and Blome, C. D., 1990, Evolution of the Arabian carbonate plateform margin slope and its response to orogenic closing of a Cretaceous basin, Oman, in Tucker, E., Lee Wilson, J., Crevello, P. D., Sarg, J. R., and Read, J. F., editors, Carbonate platforms: facies, sequences and evolution: Special Publication Number 9 of the international association of sedimentologists, Blackwell scientific publications.
Watts, K. F., and Garrison, R. E., 1986, Sumeini group, Oman. Evolution of a Mesozoic carbonate slope on a South Tethyan continental margin.: Sedimentary geology, v. 48, p. 107-168.
Weidlich, O., 1996a, Bioerosion in Late Permian Rugosa from Reefal Blocks (Hawasina Complex, Oman Mountains) - implications for reef degradation: Facies, v. 35, p. 133-142.
Weidlich, O., 1996b, Comparative analysis of Late Permian reefal limestones from the Capitan Reef (New Mexico, USA) and the Oman Mountains: Goettinger Arbeiten zur Geologie und Palaeontologie, v. Sonderband, p. 329-332.

Weidlich, O., 1999, Taxonomy and reefbuilding potential of Middle/Late Permian Rugosa andTabulata in platform and reef environments of the Oman Mountains: Neues Jahrbuch fur Geologie und Palaontologie-Abhandlungen, v. 211, p. 113-131.
Weidlich, O., Bernecker, M., and Flugel, E., 1993, Framework reconstruction of Upper Permian and Triassic reefal carbonates at the southern Tethyan margin (Sultanate Oman); a cornerstone for comparison, in Beauchamp, B., Embry, A., and Glass, D., editors, Carboniferous to Jurassic Pangea: Calgary, p. 331.
Weidlich, O., Bernecker, M., and Flügel., E., 1993, Combined quantitative analysis and microfacies studies of ancients reefs: An integrated approach to upper Permian and upper Triassic reef carbonates (Sultanate of Oman): Facies, v. 28, p. 115-144.
Weidlich, O., and Flugel, H. W., 1995, Upper Permian (Murghabian) Rugose Corals from Oman (Baid Area, Saih Hatat) -community structure and contributions to reefbuilding processes: Facies, v. 33, p. 229-263.
Weidlich, O., and Senowbari, D. B., 1996, Late Permian "sphinctozoans" from reefal blocks of the Ba'id area, Oman Mountains: Journal of Paleontology, v. 70, p. 27-46.
Wyns, R., Béchennec, F., Le Métour, J., Roger, J., and Chevrel, S., 1992, Geological map of Sur, Sheet NF 40-08, scale 1:250,000. Directorate General of Minerals, Oman Ministry of Petroleum and Minerals, 103 p.
Yanagida, J., and Pillevuit, A., 1994, Permian Brachiopods from Oman: Memoirs of the Faculty of Science, Kyushu University, Series D, Earth and Planetary Sciences, v. XXVIII, p. 61-69.

## REFERENCES

Angiolini, L., Balini, M., Garzanti, E., Nicora, A. & Tintori, A., 2003a. Gondwanan deglaciation and opening of Neotethys: the Al Khlata and Saiwan Formations of Interior Oman. Palaeogeography Palaeoclimatology Palaeoecology, V.196(1-2), p. 99-123.
Angiolini, L., Balini, M., Garzanti, E., Nicora, A., Tintori, A., Crasquin, S. & Muttoni, G., 2003b. Permian climatic and paleogeographic changes in Northern Gondwana: the Khuff Formation of Interior Oman. Palaeogeography Palaeoclimatology Palaeoecology, V.191(3-4), p. 269-300.
Baud, A., Béchennec, F., Cordey, F., Krystyn, L., Le Métour, J., Marcoux, J., Maury, R.et Richoz, S., 2001a. Permo-Triassic Deposits: from the Platform to the Basin and Seamounts. Conference on the Geology of Oman, Field guidebook, Excursion A01, Muscat, Oman.
Baud, A., Béchennec, F., Cordey, F., Le Métour, J., Marcoux, J., Maury, R.et Richoz, S., 2001b. Permo-Triassic Deposits: from Shallow Water to Base of Slope, a guidebook. Excursion B01, International Conference - Geology of Oman, Muscat.
Baud, A., Marcoux, J., Guiraud, R., Ricou, L. E. & Gaetani, M., 1993. Late Murgabian (266-264 Ma). *In :* Dercourt, J., Ricou, L. E., & Vrielynck, B., (eds.), Atlas Tethys, Palaeenvironmental maps, explanatory notes: Paris, Gauthier-Villars, p. 9-21.
Besse, J., Torcq, F., Gallet, Y., Ricou, L.E., Krystyn, L. & Saidi, A., 1998. Late Permian to Late Triassic palaeomagnetic data from Iran: constraints on the migration of the Iranian block through the Tethyan Ocean and initial destruction of Pangaea. Geophysical Journal International, V. 135(1), p. 77-92.
Immenhauser, A., Schreurs, G., Peters, T., Matter, A., Hauser, M. & Dumitrica, P., 1998. Stratigraphy, sedimentology and depositional environments of the Permian to

uppermost Cretaceous Batain Group, eastern-Oman. Eclogae Geologicae Helvetiae, V. 91, p. 217-235.
Krystyn, L., Richoz, S., Baud, A. & Twitchett, R.J. (2003). A unique Permian-Triassic boundary section from Oman. Paleogeography, Paleoclimatology, Paleoecology, V.191, p. 329-344.
Maury, R.C., Bechennec, F., Cotten, J., Caroff, M., Cordey, F. & Marcoux, J., 2003. Middle Permian plume-related magmatism of the Hawasina Nappes and the Arabian Platform: Implications on the evolution of the Neotethyan margin in Oman. Tectonics, V.22(6), art n° 1073.
Richoz, S. (2004) : Stratigraphie and variation isotopique du carbone dans lePermien supérieur et le Trias inférieur de quelques localités de la Néotéthys (Turkie, Oman, Iran). PhD thesis, Lausanne, 248pp.
Ricou, L.-E., 1994. Tethys reconstructed - plates, continental fragments and their boundaries since 260 ma from central America to south-eastern Asia. Geodinamica Acta, 7(4): 169-218.
Saidi, A., Brunet, M.F. & Ricou, L.E., 1997. Continental accretion of the Iran block to Eurasia as seen from late Paleozoic to early Cretaceous subsidence curves. Geodinamica Acta, V.10(5), p.189-208.
Twitchett, R.J., Krystyn, L., Baud, A., Wheeley, J.R. & Richoz, S., 2004. Rapid marine recovery after the end-Permian extinction event. Geology, V.32(9), p. 805-808.