المؤتمر الدولي لجيولوجية عمان

# INTERNATIONAL CONFERENCE GEOLOGY OF OMAN


**Excursion A01**

## Permo-Triassic Deposits: from the Platform to the Basin and Seamounts

**Leaders: A. Baud, F. Bechennec, F. Cordey, L. Krystyn, J. Le Metour, J. Marcoux, R.Maury and S. Richoz**

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INTERNATIONAL CONFERENCE ON THE GEOLOGY OF OMAN,
PANGEA SYMPOSIUM AND FIELD MEETING

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## Pre-Conference Excursion No. A01 in the Oman Mountains,
## January 8 - 11, 2001

**Leaders**

**Aymon BAUD, François BÉCHENNEC, Fabrice CORDEY , Léopold KRYSTYN,
Joël LE MÉTOUR, Jean MARCOUX, René MAURY and Sylvain RICHOZ**

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## Content

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

By F. Béchennec

**1.- Structure of the Oman Mountains**

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.

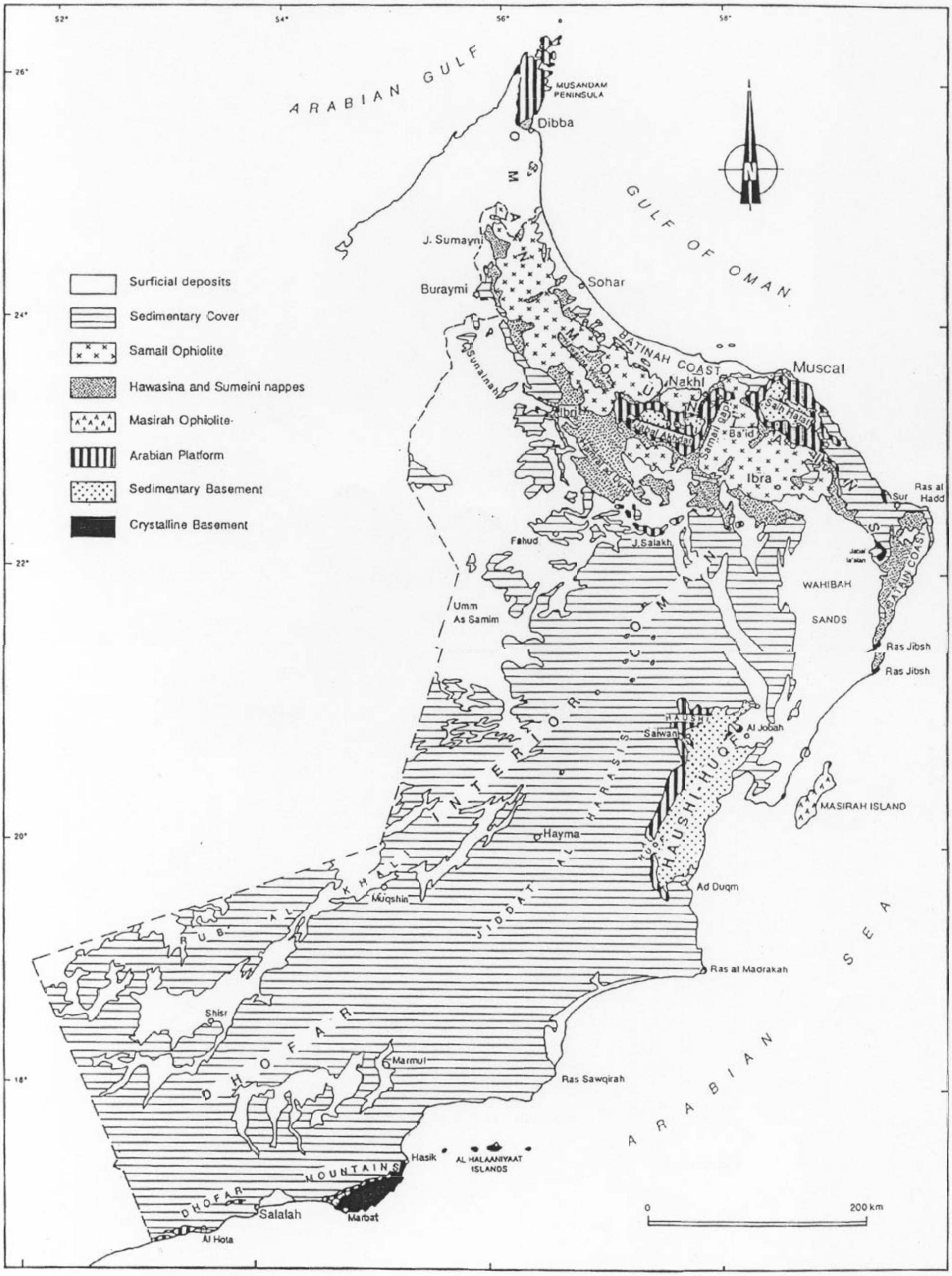



**Fig. 1- Geological sketch map of the Sultanate of Oman (from Le Metour et al., 1995).**

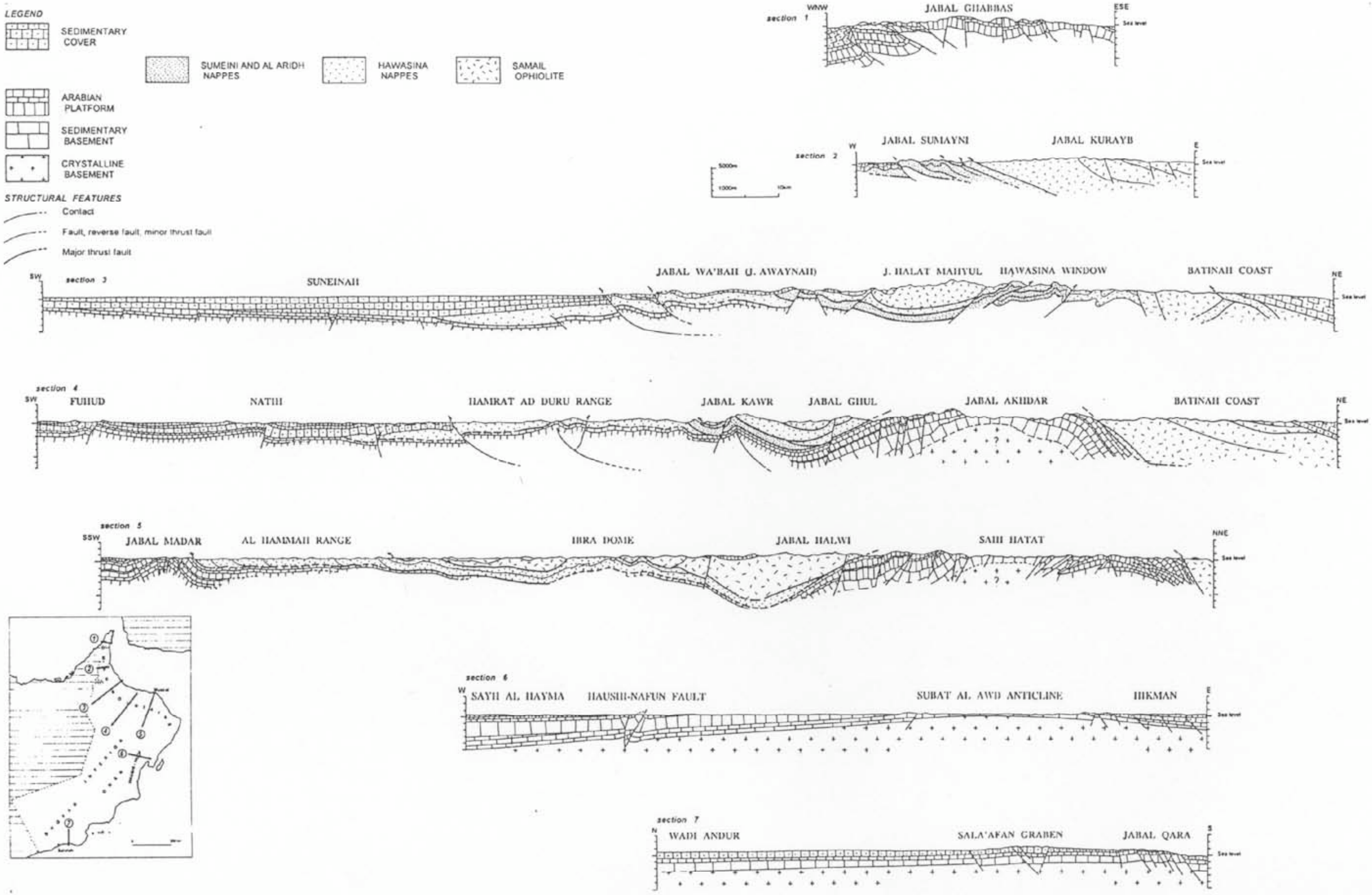



Fig. 2- Structural cross-sections from the N to the S of Oman (from Le Métour et al., 1995)

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. Finally this compressive tectonism leads in Campanian times to the obduction of the Samail Ophiolite and the destruction of the Oman continental margin with the overthrusting of the Hawasina and Sumeini nappes.
Then, an uplift episode affected the Oman Margin of the Arabian Platform and led to the formation of an Eoalpine Oman Mountain chain.
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.

## 2- Permian birth and evolution of the Arabian passive margin

At the end of the Palaeozoic the continents were gathered together to form the Pangea supercontinent and in his southern half, Oman and the Arabian Peninsula formed part of the Gondwana continent as well as Africa, Iran, India, etc….(Scotese and McKerrow, 1990). During the Late Carboniferous-Earliest Permian period, the Gondwana continent was subjected to glaciation (Al Khlata tillite in Oman).

### 2.1 The precursors of Neo-Tethyan tectonism

The end of the glacial period in the Early Permian resulted in a global rise in sea level, which subsequently submerged part 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) shallow-marine carbonate are also identified in Hawasina units of the Batain plain (Pillevuit, 1993, Pillevuit et al., 1997 ) documenting the northeasternward extension of a rim basin.
However, such marine deposits are unknown in the central and southeastern 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 precursor of the Neo-Tethyan tectonism, initiating a shoulder and concomitant rim basins where the marine deposits laid down.

### 2.2 The first stage of the Neo-Tethyan extension

The first stage of the Neo-Tethyan extension begins in the Late-Early/Early-Middle Permian and is 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 clearly 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 deposits of the lower part of the Saiq Fm.;

Global sea level rose to a maximum during the Late-Early Permian (Kubergandian)( Haq et al., 1987); however, only rare shallow-marine carbonate of this age is found in Oman, as reworked blocks in proximal turbiditic facies of the Hawasina units on the Batain Coast (Béchennec et al., 1992a) where probably the former "rim basin" persisted : then most of Oman remained emergent.

Subsequently the terrigenous siliciclastics deposits of the Gharif Fm. (Kubergandian-Murghabian, Broutin et al., 1995) and of the base of the Qamar and Saiq Fms., resulted of rapid erosion of the shoulder initiated in Early Permian and were laid down in a continental environment.

**2.3 The climax of the Neo-Tethyan extension in Middle Permian (Murgabian )**

***2.3.1 The flexing of the northeastern margin of the Arabian Peninsula***

In the Middle Permian (Murgabian), in spite of the global sea level fall, and in opposite of the Kubergandian time, 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 platform carbonate, the Arabian Platform; in Jabal Akhdar, a 400m-m-thick succession of shallow-marine carbonate, the Saiq Fm., is dated Middle Permian (Murgabian) and Late Permian (Djulfian) in the uppermost part (Montenat et al., 1976; Rabu, 1988); a similar succession occurs 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)). Clearly this transgression was the result of flexure of the Arabian Peninsula, related to thermal subsidence associated with the Neo-Tethyan tectonism (Le Métour et al., 1995).

***2.3.2 The horst and graben tectonics on the margin of the Arabian peninsula***

When the Jabal Akhdar became a stable platform in Murgabian time, the horst and graben tectonics initiated in Late-Early/Early-Middle Permian developed a climax in the Saih Hatat. This gave rise to considerable thickness variations between the relatively condensed carbonate successions on the horsts and very thick successions in the grabens where the deposits in places, are made of conglomerates and olistoliths of shallow-marine carbonate. Furthermore, two intervals of volcanic and volcaniclastic rocks are related to this tectonism (Le Métour, 1988). This is particularly well developped in the Hulw graben (Saih Hatat) where the earliest interval located at the base of the carbonate succession is about 500m thick and is mainly made of tuffite and tuff with accessory andesite-rhyodacite. The later interval, 20 to 150m thick, is located in the middle part of the Saiq carbonate succession; it essentially comprises basalt, trachyandesite and rhyodacite with accessory tuff and dolerite and rhyodacite plugs. The intermediate to acid rocks of the earlier episode correspond to sub-alkaline rhyodacite, whilst those of the later one are transitionnal in caracter, probably corresponding to a magmatic suite that was differentiated from an alkaline to transitionnal magma (Le Métour, 1988; Béchennec et al., 1991; Pillevuit, 1993; Pillevuit et al., 1997).

***2.3.3 The breakdown of the Gonwana: formation of the Arabian passive margin***

In Middle Permian (Murgabian), breakdown of the Gondwana land became established with northward drifting of the Iran/Mega Lhasa microcontinent (Baud et al., 1993); subsequently the most striking effect of the climax of the Neo-tethyan extension was the formation of a continental slope (Sumeini) and a basin (Hawasina) that constituted with the adjacent Arabian Platform, the southern continental passive margin of the Neo-Tethys. Furthermore early-rifted blocks detached from the edge Arabian shield formed isolated proximal platform along the continental slope (later they were incorporated in the Hawasina Nappes).

- Continental slope deposits are clearly identified (with slumps and intraformationnal breccia) in the northwestern part of the Oman Mountains (Jabal Sumayni), where they form the basal part of the Maqam Fm. dated as Middle Permian (Murgabian -Midian) (Pillevuit, 1993; Pillevuit et al., 1997 ). Such deposits type are also identified in the Hawasina units of the Batain Plain (southeastern part of the Oman Mountains) , the "Qarari Limestone" (Shackleton et al., 1990; Béchennec et al., 1992a; Wyns et al., 1992) dated as Middle Permian (Wordian) (Immenhauser et al., 1998).
- The proximal isolated platform identified 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 shallow-marine carbonates. The Jabal Qamar unit includes a fragment of the pre-Middle Permian Basement (Rann, Ayim and Asfar Fms. (Pillevuit, 1993) overlain in unconformity by the Late Early-Early Middle Permian shallow-marine carbonate Qamar Fm. with his quartz-sandstone basal member. The Baid unit is truncated at the base and is made of about 100 m of the Middle-Late Permian (Murgabian -Djulfian) shallow-marine carbonate (Baid Fm., Béchennec, 1988; Pillevuit, 1993, Pillevuit et al., 1997).The proximal (in regard with the Arabian Platform) paleogeographic position of these Permian tilted blocks is documented by: (1) the similarity of these successions in age and facies with those of the

others parts the Oman Mountains (Jabal Akhdar, Saih Hatat, Musandam); (2) the presence of reworked boulders originating in these blocks, in the calcirudites of the proximal units of the Hawasina Nappes.

- Basin facies of the Middle Permian are present in the Hawasina Nappes at the base of numerous tectonics units, made up of formations from the Hamrat Duru Gp.. These successions generally commence with thick volcanic sequences (Al Jil Fm); they are particularly well exposed to the north of the Hawasina Window (Buday'ah area) and of Jabal Akhdar (Al Ajal region) and in the southern flank of the Saih Hatat (Baid, 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). These volcanic rocks are either of MORB type or alkali basalt-related; however N-MORB (depleted) have not been found, most of the sample studied ranging from transitional MORB to enriched MORB (Maury et al., 2001).

  The volcanic succession is generally overlain by red radiolarian chert and shale, dated as Middle Permian (Murgabian ) in Buday'ah and Al Ashkharah areas (Béchennec, 1988; De Wever et al., 1988; Béchennec et al., 1992a-c). In the Baid region the volcanic series is capped by red cephalopods-bearing carbonate, dated Middle Permian (Wordian) (Blendinger et al.,1992), shale 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, 1993; Pillevuit et al., 1997 ).

## 3- The end-Permian -Triassic evolution of the Arabian passive margin

### 3.1 Doming of the Arabian Platform

After the peak of extensional tectonic regime in the Murgabian, a stable carbonate platform became established on the Arabian Peninsula; the Saiq, Khuff and Hagil Fms., show a strong regressive tendency, up to the Djulfian, with restricted environment facies and a reduced biophase, mainly associated with a global fall in sea level, at this time (Haq et al., 1987). However, no sign of emergence has been found. In the Early Triassic, the global sea level rose strongly to reach a maximum in the Carnian-Norian, only to fall again in the Rhaetian (Late Triassic). The Early Triassic sea level rise is recorded with terrigenous deposits at the base of the Mahil and the Sudair Fms., respectively in the Saih Hatat/Jabal Akhdar and Interior Oman. Then, the huge triassic carbonate successions (350m for the Sudair Fm.; 500-800m for the Mahil Fm.; 850m for the Ghail, Milaha and basal Ghalilah Fms., in Musandam) indicate a continual tendency toward sub-aerial exposure; this pervasive tendency, whilst globally the sea level was rising, implies doming of the Arabian Platform; this led to emergence, (1) as early as the end of Permian, of the positive Huqf axis area, where continental sediments were deposited (Minjur Fm.), (2) later at the end of Triassic, of the greater part of the Arabian Platform with the exception of the Musandam (Le Métour et al., 1992b; Le Métour et al., 1995)

### 3.2 Renewed Triassic extension on the Continental Slope and in the Hawasina Basin

#### *3.2.1Foundering of the Permian tilted block of Baid*

An extensional tectonic regime in the slope/ basin is documented on the tilted Baid block (integrated in the Hawasina thrust sheets) by Hallstat type limestone deposits (Alwa Fm., Pillevuit, 1993; Pillevuit et al., 1997 ); this series 30-40m thick, caps the Late Permian shallow-marine carbonate (Baid Fm.) and are mainly made of cephalopod-rich red pelagic limestones, dated from base up, Dienerian, Smithian, Anisian, Ladinian, Carnian, Norian. The tectonic instability is also documented by angular unconformities and by clast-supported breccia with Late Permian remains, in the Hallstat type succession ( Tozer and Calon, 1990; Pillevuit, 1993; Pillevuit et al., 1997 ).

#### *3.2.2 The Triassic extension on the Continental Slope*

The extensional tectonic regime on the Continental Slope, is marked:

1. In the northwestern part, by active subsidence an instability recorded by the huge thickness, about 700m, as well as by the numerous breccia of the Early Triassic Sumeini deposits (Mq 3 Member of the Maqam Fm., Watts and Garisson, 1986; Béchennec et al., 1993b; Le Métour et al., 1993b). This instability is pervasive throughout the Triassic as documented by the coarse calcirudites interbedded in the chert and calcarenite succession of the Ladinian-Norian Mq 5 Member of the Maqam Fm..
2. In the southeastern part, by Carnian magmatism of alkaline affinities, locally well developped at the base of the Al Aridh Gp. (Béchennec et al., 1992c-d ) and capped by olistostrome with reworked blocks and megablocks of Triassic shallow-marine carbonate. However the paleogeographic position of the Al Aridh slope unit is not definitively cleared: according to Bernouilli and Weissert (1987); Béchennec (1988); Béchennec et al. (1988); Pillevuit (1993); Pillevuit et al. (1997) this unit could be in a distal position in the Hawasina Basin; according to Blendinger (1991) and Béchennec et al. (1992b-d) it could constitute the southeastern Arabian continental slope.

***3.2.3 The Late Triassic peak of Neo-Tethyan extension in the distal Hawasina Basin***

In the proximal Hawasina Basin, where the series of the Hamrat Duru Gp. was deposited the Triassic tectonism was sligh and only the units close to the continental slope comprise any beds of coarse calcirudite and calcarenite recording tectonic instability; however, locally (in the Diba zone and in the Central Oman Mountains) volcanic rocks are interbedded in the Ladinian-Norian basal cherty member of the Matbat Fm. (Béchennec et al., 1992c; Le Métour et al., 1992b), giving clear evidence of the extensional regime.

The Late Triassic peak of Neo-Tethyan extension affected the distal part of the Hawasina Basin as documented by:

- The evolution of the basin paleogeography with the creation of the Misfah distal Platform and of the Umar Basin;
- The significant volcanic activity developed in these settings;
- The strong subsidence reflected by the huge thickness of the Late Triassic shallow-marine carbonate deposited on the distal platform;

The Kawr and Umar Groups which crop out as several tectonic units at the summit of the stacked Hawasina Nappes, comprise a thick basal volcanic member or formation (respectively, Misfah basal Member and Sinni Formation, Béchennec, 1988) Late Triassic in age. These volcanic rocks display 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).

In the Kawr setting this volcanic unit is overlain by a particularly thick (800m) shallow-marine carbonate member (upper Misfah Member, Béchennec, 1988), Late Triassic in age. However the presence of hardgrounds and, in places, microkarsts reflect a end-Triassic emergence of this distal platform.

In the adjacent Umar Basin, the Late Triassic sedimentary succession is made of pelagic limestone and radiolarian chert without any terrigenous influx; the only clastic sediments are calcirudite and megabreccia made of reworked boulders of shallow-marine carbonate originating from the Misfah Platform.

Like this, after the two peaks of extensional tectonism that succeeded one another in the Middle Permian and in the Late Triassic, the main features of the Arabian passive margin were formed .

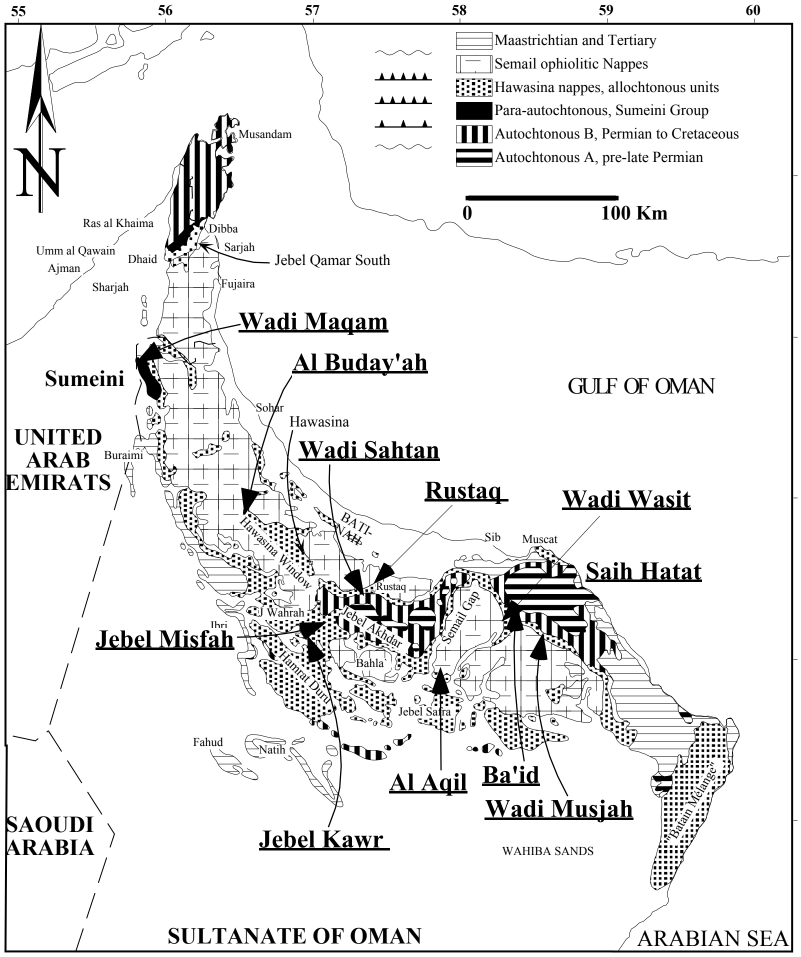



**Fig. 3: Geological sketch of the Oman Mountains with the main visited localities (Excursions A01 and B01) modified, from Pillevuit et al., (19910**

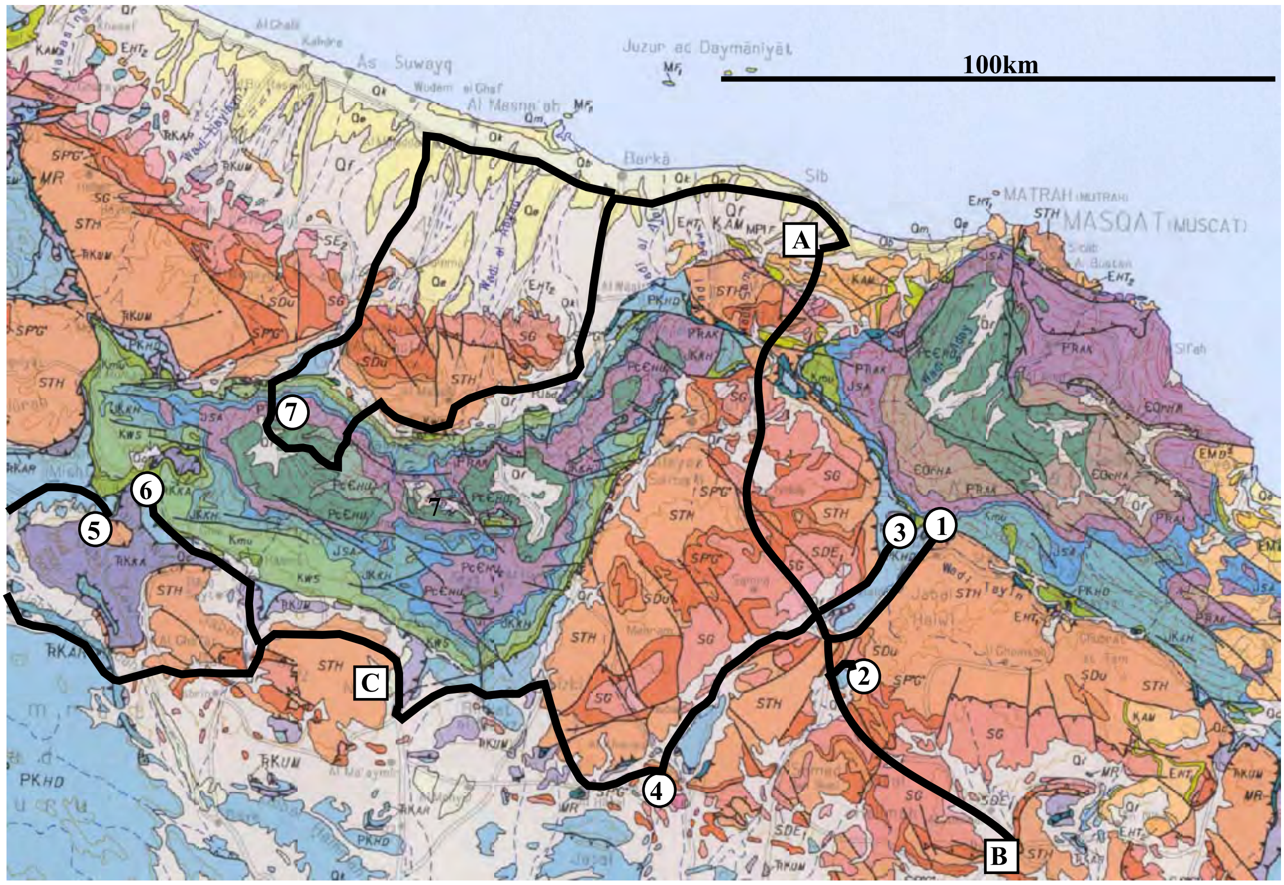



**Fig. 4: Geological Map of the Field excursion A01, with the main stops (1-7) and places of overnight (A, B, C). Map from Le Métour et al., (1993a)**

**PART II**
**INTRODUCTION AND DESCRIPTION OF THE VISITED OUTCROPS**

## 1-. Introduction

## 1.1 Permian - Triassic stratigraphic nomenclature

| | | Stand. Stages | Tethyan Stages | Conodont zones | |
|---|---|---|---|---|---|
| TRIASSIC | LATE | RHAETIAN | | *posthernsteini*<br>*mosheri* | 205Ma |
| | | NORIAN | | *bidentata* *steinbergensis*<br>*serrulata*<br>*postera*<br>*elongata*<br>*spiculata*<br>*multidentata*<br>*triangularis*<br>*quadrata* *navicula*<br>*primitius* | |
| | | CARNIAN | | *communisti*<br>*nodosus*<br>*polygnathiformis* | |
| | MIDDLE | LADINIAN | | *mungoensis*<br>*hungaricus*<br>*trumpyi* | 241Ma |
| | | ANISIAN | | *excelsa* *constricta*<br>*bulgarica*<br>*shoshonensis*<br>*germanica* *regale*<br>*timorensis* | |
| | EARLY | OLENEKIAN | | *triangularis* *aff. timorensis*<br>*sweeti* *homeri*<br>*milleri* *waageni*<br>*meeki*<br>*pakistanensis* | |
| | | INDUAN | | *cristagalli*<br>*dieneri* *kummeli*<br>*carinata*<br>*parvus* | 253Ma |
| PERMIAN | LATE | CHANGHSINGIAN | DORASHAMIAN | *changxinensis*<br>*subcarinata* | |
| | | WUCHIAPINGIAN | DZHULFIAN | *wangi*<br>*orientalis*<br>*transcaucasica*<br>*guangyuanensis*<br>*leveni*<br>*asymmetrica*<br>*dukouensis* | |
| | MIDDLE | CAPITANIAN | MIDIAN | *altudaensis*<br>*postserrata* | 264Ma |
| | | WORDIAN | MURGABIAN | *aserrata* | |
| | | ROADIAN | KUBERGANDIAN | *nankingensis* | |
| | 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* | |

**Table 1- Permian-Triassic Time table with standard and Tethyan stages name.**
**Conodont biochronology based on Permophiles 36 and Orchard & Tozer (1997).**

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 the most recent time table as adopted by the IUGS and distributed at the 31th IGC in Rio de Janeiro (2000). The conodont biochronological scale has been published in Permophiles 36, p. 2 (2000) and the Triassic one by Orchard and Tozer (1997). The Tethyan stage names used in some part of this guide book are shown according to their correlative standard stages.

## 1.2 Magmatic evolution of the Permo-Triassic Tethyan margin in Oman *(R. 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.

## 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 only as resedimented pebbles or clasts in basinal Triassic to Cretaceous sediments of the Oman margin. In stratigraphic successions, they are supposed to be in the shelf sediments (Parautochtonous : Saih Hatat, Jabal Akhdar -Wadi Sathan section, Jabal Sumeini -Wadi Maqam section) but without biostratigraphic constraints.
$\delta^{13}C_{tot}$ 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 $\delta^{13}C$ 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, $\delta^{13}C$ 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 $\delta^{13}C$ 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 $\delta^{13}C$ values vary between -0.5‰ and -2.5‰.

Thus, Lower Triassic carbonates show a great variability in $\delta^{13}C_{tot}$, 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 $\delta^{13}C_{tot}$ 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 $\delta^{13}C$ values of the seawater related to particular paleoceanographic settings.

Despite the variability within paleogeographic domains and the poor correlation control, present data allows to asume that Upper Permian carbonates are relatively constant with high $\delta^{13}C$ positive values and are followed by a worldwide large negative shift of the $\delta^{13}C$ at the Permian-Triassic boundary. During the Lower Triassic $\delta^{13}C$ 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.

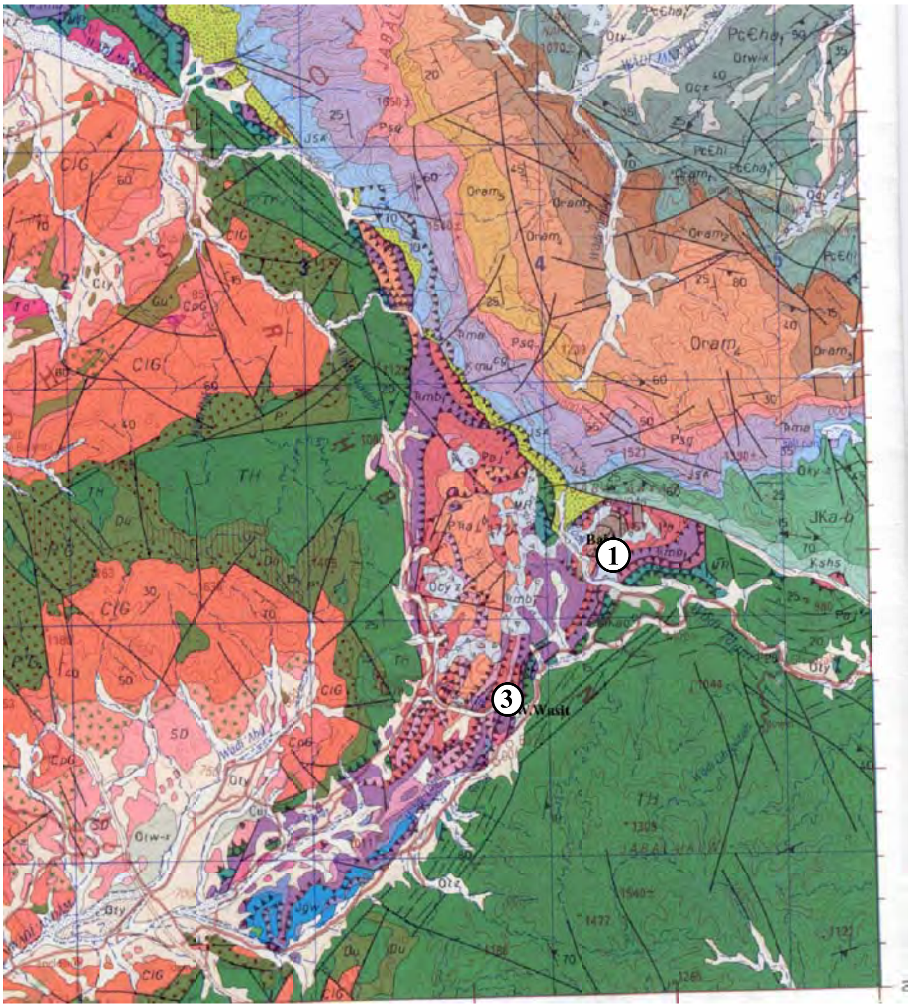



**Figure 5- Geological map of Ba'id area (from Béchennec et al., 1992b)**
**Stops 1.1 to 1.3, Wadi Alwa Megabloc; stop 3.1, 3.2, Wadi Wasit.**

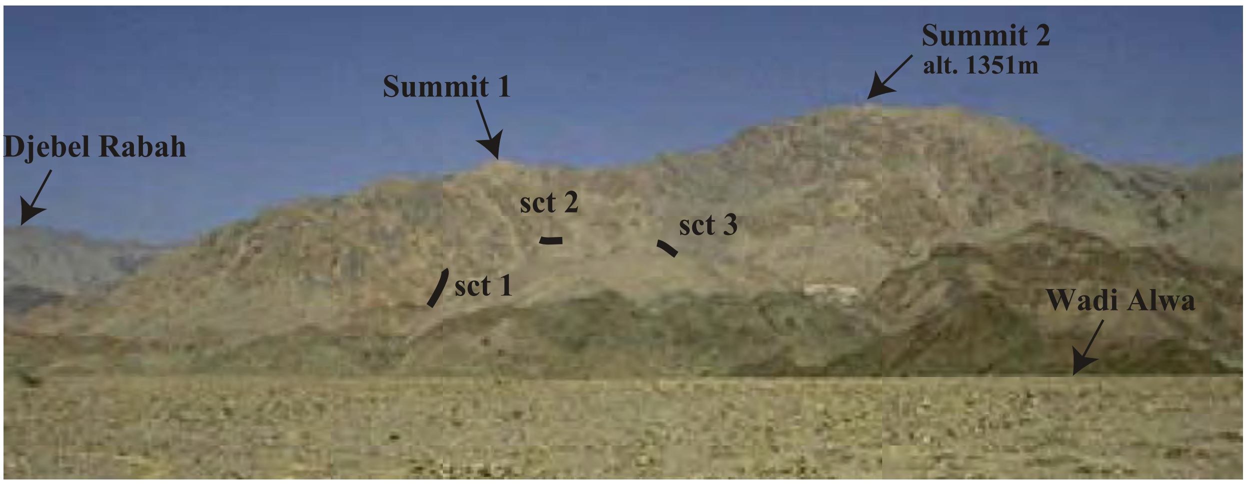



**Figure 6- Panorama of Wadi Alwa Mega-block.**

**sct 1: Permian-Triassic in Eastern flank of Wadi Alwa Mega-block (section 4 in Pillevuit, 1993).**
**sct 2: Upper Triassic-Lower Jurassic red limestones. (section 5 in Pillevuit, 1993).**
**sct 3: Contact between Upper Permian carbonate plateform and Lower Triassic Hallstatt-type limestone.**
**We will see section 2 and 3 during the field trip.**

## 2-. Description of the visited outcrops

### January 8 Morning: The Wadi Alwa mega-block

### Upper Permian carbonate, Lower Triassic pelagic limestone, Upper Triassic to Lower Jurassic ammonitico red limestones.

**Routing** (fig. 4 and 5)
The Ba'id window is reached via the Muscat-Nizwa highway to Bidbid and then following the Sur road through the ophiolite of Wadi Uqq. The new Wadi Tayin road follows the eastern rim of the Ba'id window. Stop 1 is located after crossing the Ba'id village, along the right flanc of the Wadi Alwa (fig. 5).

**Introduction**
Located about 50 kilometres South of Muscat (Fig. 4) the Wadi Alwa mega-block (Figs.7,8) is part of a complex tectonostratigraphic assemblage (Fig. 7) that rests on the lower Hawasina Nappes. Three formations ranging from the Upper Permian to the Jurassic, with a sequence characteristic of a drowning platform (fig. 9), form the Al Buda'ah group (Pillevuit, 1993).

**The Baid exotic block is a worldwide unique exposure because it witnesses an Early Mesozoic stable pelagic environment which persisted with just minor changes for more than 100 million years. It represents a tiny piece of a paleogeographic realm where more stable conditions should have provided better survival chances across the T-J crisis interval than the environmentally stressed shallow shelf regions of the oceans. This realm must have been widespread in the tropical belt of the Neotethys ocean but has been lost nearly completely by later subduction and collision.**

**Stratigraphy.**
According to Pillevuit et al. (1997), the Middle-Upper Permian **Ba'id Formation** is represented by thinning upward sequences of black limestones. It consists of grainstone-packstone-wackestone, 1 to 5 m thick beds (Fig. 10, 11), that are generally overlained by thin red beds with vadose diagenetic cements suggesting an emersive trend. Locally some coral-boundstone layers are intercalated with these facies. The thickness of this formation never seems to exceed 100 m. The foraminifera represented by *Baisalina* sp., *Bradyina* sp., *Dagmarita* sp., *Eotuberitina* sp., *Geitzina* sp., *Globivalvulina* sp_ *Hemigordius* sp., *Langella* sp., *Lasiodiscus* sp., *Nankinella* sp., *Nodosaria* sp., *Paraglobivalvulina* sp., *Pseudotrisfix* sp., *Rectostipulina quadrata* (Jenny-Deshusses), *Reichelina* sp. and *Vermiporella* sp.,suggest a Wordian to Capitanian age for the lower part of the section (Fig. 9) and Lopingian age for the topmost levels (Fig. 10).

The original substratum of the Ba'id Formation is unknown. The different facies are well developed along the northern flank. The south-western part of the exotic is intensely dolomitised and brecciated (Fig.7); the breccia is interpreted as a hydraulic breccia (Masson, 1972).
The Wadi Alwa mega-block is well know for its Triassic ammonoid-rich limestones, a particular interest presenting the Hallstatt-type limestones (Tozer and Calon, 1990; Blendinger, 1991; 1995; Orchard, 1995). It has been named the **Alwa Formation** by Pillevuit (1993) and a complete survey based on conodonts has been conducted by L. Krystyn (unpublished).
This Formation was previously observed by Béchennec (1988) who described it as "a 1ight grey ammonoid-bearing limestone". Blendinger (1988), Tozer & Calon (1990) and Blendinger (1995) described the formation as composed of "cephalopod rich limestone blocks" and "Hallstatt limestone blocks" respectively.

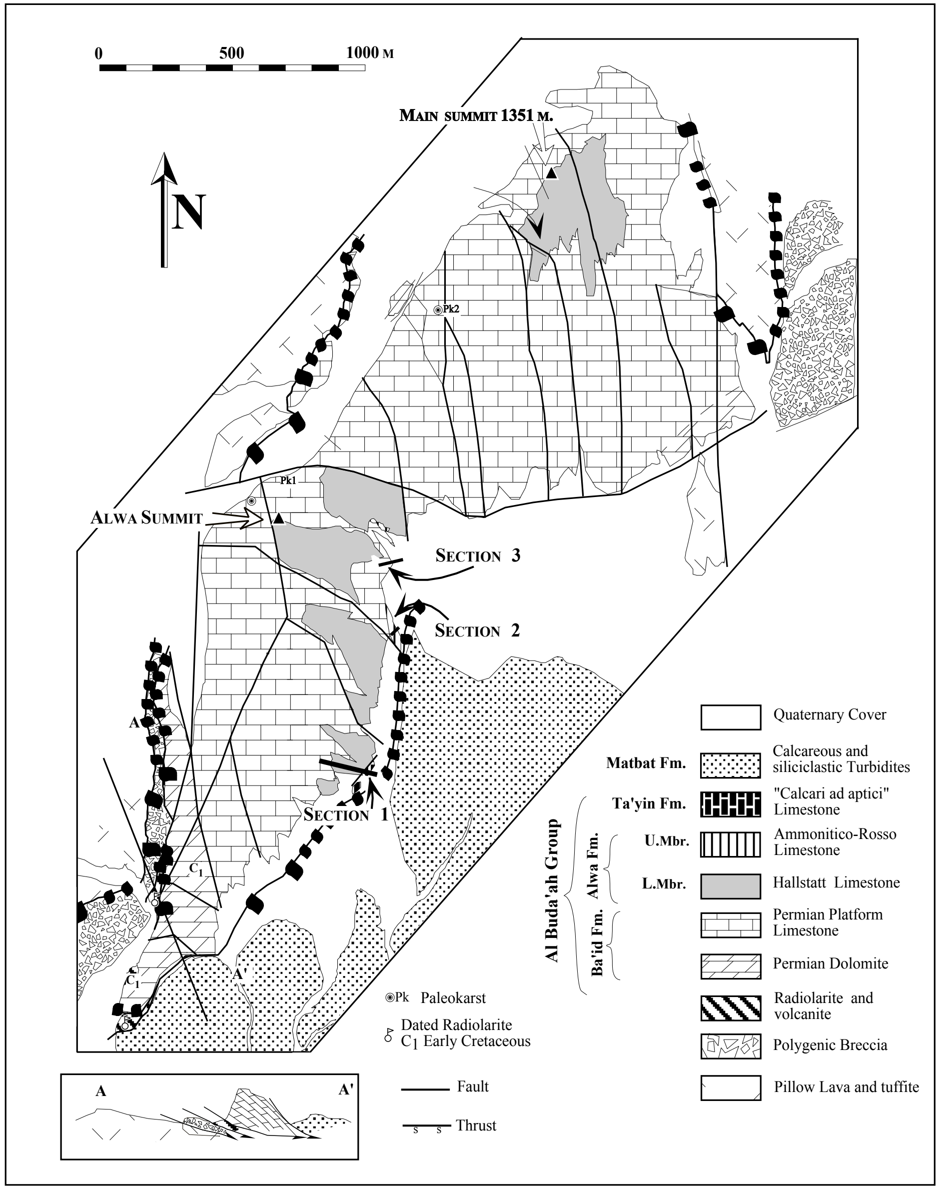



**Figure 7:** Geological sketch of the Wadi Alwa Mega-block (modified, from Pillevuit et al. 1997)

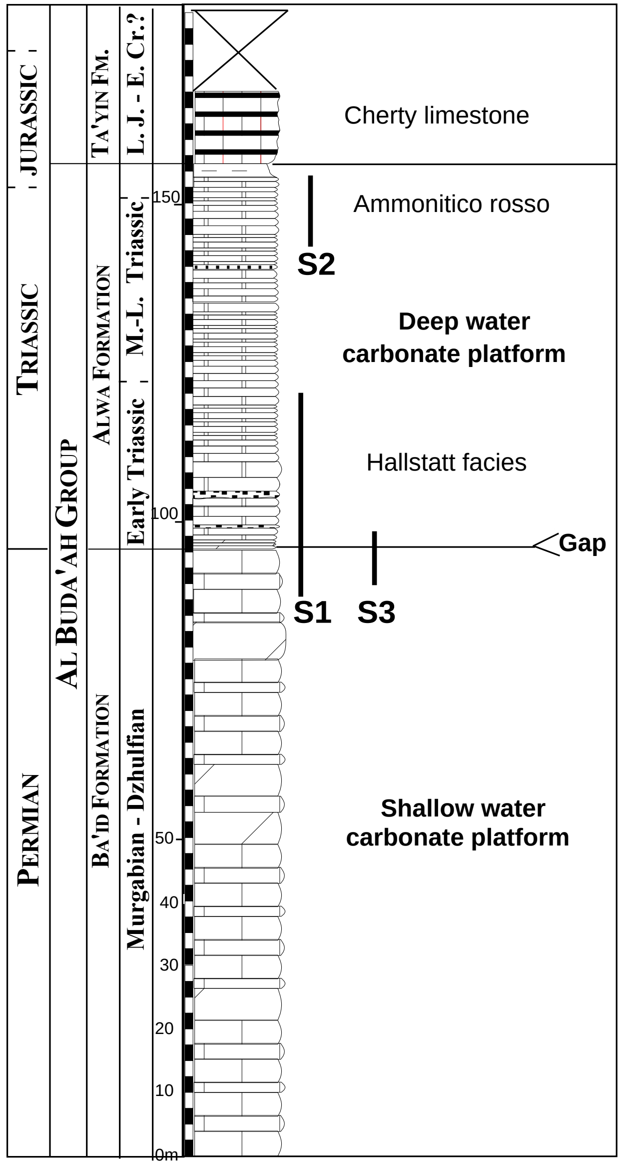



**Figure 8:** General lithological profile of the Wadi Alwa Mega-block. S1, S2, S3: sections described in the text and illustrated in fig, 9, 13, 14

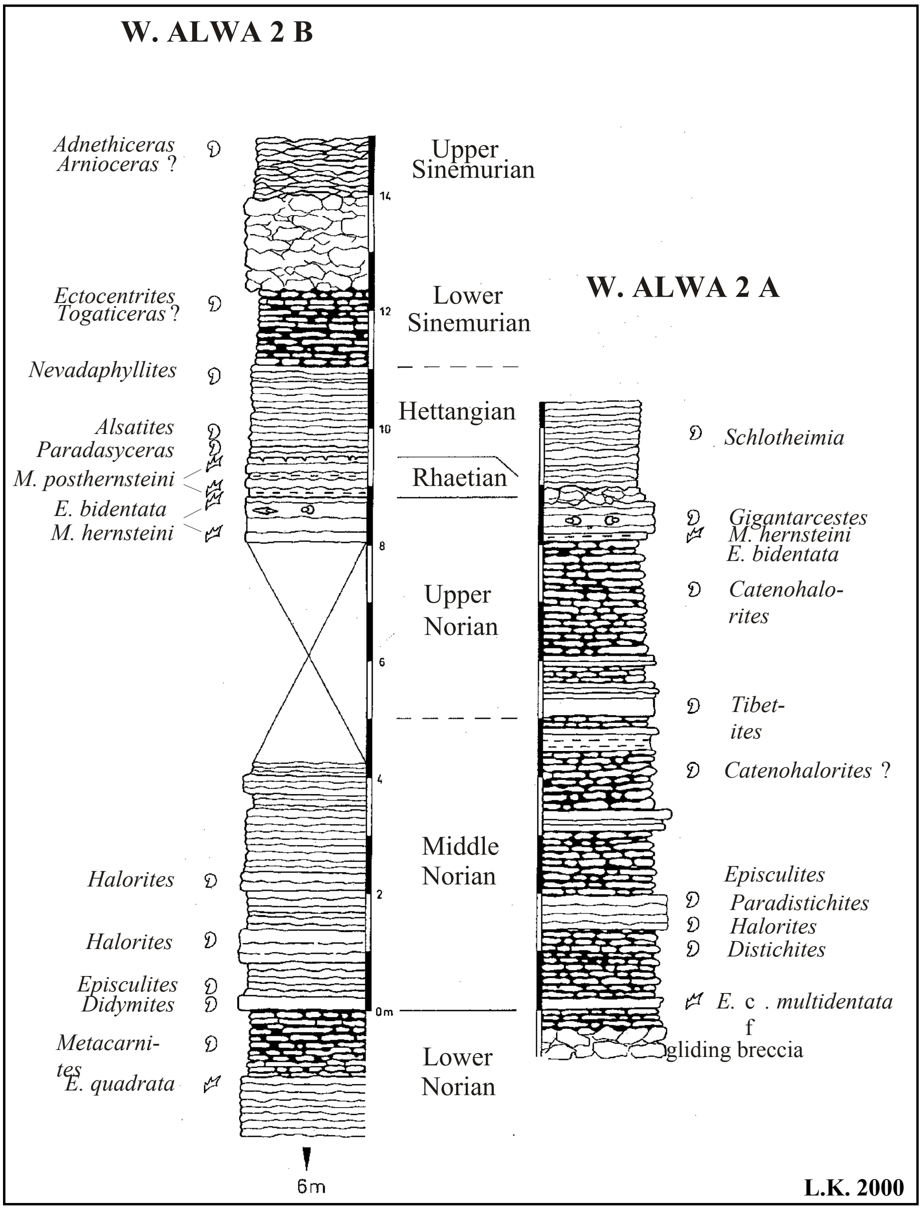



**Figure 9- Wadi Alwa Mega-Block, section 2. Red "ammonitico rosso" at the Triassic-Jurassic Transition**

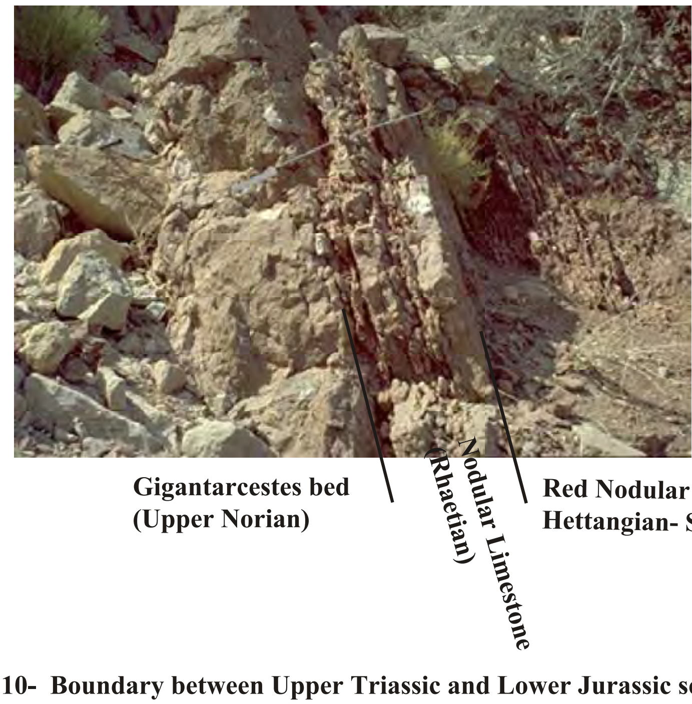



**Figure 10- Boundary between Upper Triassic and Lower Jurassic sediments**

**The lower member of the Alwa Formation** contains a 25 m thick series of cephalopod -rich red limestones, of typical Hallstatt type. It has been studied by Atudorei and Baud on the S flank of the Mountain (figs. 6, 7 and 11) and also by Pillevuit (1993, fig. 34, page 63 -the section corresponds to section 4 therein- and Plate 2. Fig. 1). This section is described also by Blendinger (1995, section Wadi Alwa II in fig. 7, page 585) and by Pillevuit et al. (1997, fig. 10, page 218). This section consist of a 25-30m thick sequence of red, pelagic limestones of Hallstatt-type that overlies disconformably the Ba'id Formation (fig. 11). The first 6 m are represented by pinkish microgranular dolomites, probably dolomitized Hallstatt-type limestones. The succession is often disrupted by low angle faults. Blendinger (1995) proposed that even the contact with the Ba'id Formation is a fault plane. However, a careful examination of sedimentary structures allows a reliable recognition of the stratigraphic relationships. The limestones are rich in ammonoids and the microfacies are characterized by lime wackestones to packstones with thin bivalve filaments, baby-ammonoids and occasionally ostracodes and crinoid elements. They exhibit some particular features comparing to the typical Hallstatt-type limestones. The fossils do not have Fe-Mn oxydes coatings (Tozer and Callon, 1990) and they are filled almost exclusively with white spar (Blendinger, 1995). Hardground surfaces are not common. A prominent characteristic is given by the abundant evidence of microbial activity, which appears to have played an important role in the carbonate accumulation. Decimetric layers (probably lenticular) of gray-white thrombolites with radiating crystal occur over the section (we identified at least three). Stromatactis-type structures are present at both macro and microscopic scale (Blendinger, 1995, cites even "zebra-rock" structures from the "summit block"). In thin sections, mainly in samples from the upper part of the section, microbial-type structures are abundant (mainly beneath the stromatactis-type voids), as zones with clotted fabric and even well preserved cyanobacterial filament moulds. In the thrombolitic levels, organic remnants of microbial mats are preserved. Another distinctive feature of the red limestones occurring in the studied section is the presence of two interstratified meter thick levels of resedimented limestones including clasts of latest Permian carbonates (with Colaniella gr ex parva, Jenny-Deshusses and Baud, 1989) and clasts of Hallstatt-type limestones. We interpreted these levels as the result of reworking of unlithified Permian sediments (soft-sediments) but they could present late hydraulic breccia injections.
The reference section of the lower Alwa Formation crop out on the top of the Wadi Alwa summit and bas been studied by Blendinger (1995) and more recently by Krystyn (unpublished results). The lower member of the Alwa Formation has been dated as Dienerian to Early Carnian (Tozer & Calon, 1990; Pillevuit, 1993; Blendinger, 1995) and the lower part contains small specimens of *Gyronites* sp. indicating Dienerian or Lower Smithian age. The first Early Smithian ammonoids, *Flemingites* sp. and *Pseudoflemingites rotelliformis* have been found in a bed that, according Blendinger (1995) also contains the conodonts *Neospathodus waageni, Ellisonia* ex gr. *nevadensis*, *Neohindeodella triassica*. The Late Smithian is proven by *Anasibirites* cf. *typus*, *Wyomingites dieneri*, *Paranannites* sp., *Inyoites uiveni* (Tozer & Calon, 1990). Spathian rocks are documented by *Procarnites* and *Subcolumbites* (Blendinger 1991). The Lower Triassic part is more than 60 m thick and has been deposited relatively fast and continuously compared to the overlying Middle and basal Upper Triassic strata. The latter are very thin (just 10 m) and represent typical Hallstatt facies with common hardgroud formation and ironmanganes coated fossils (fig 8).

**The upper member, of the Alwa Formation** is approximately 20 m thick and will be presented at the stop 2 (fig.9, 10) by L. Krystyn. It is located on the footwall of the mountain (fig. 11 in Pillevuit et al 1997) in head of a small ravine and consists of two isolated sections which dip similarily steep but strike perpenticular to each other along the two sides of the gully. They form the type locality of this upper member which consists of predominantely nodular thin bedded red ammonoid bearing limestones comparable to the ammonitico rosso facies of the Southern Alps (Clari et al., 1984) and the Adnet limestone of the Austrian Calcareous Alps (Böhm 1992). The eastern section, located on the left side of the gully (photo in Pillvuit et al. 1997, fig. 11) is more marly and stratigraphically less complete than the one on the right flank. Due to these differences the sections are documented independently as Wadi Alwa 2 A and Wadi Alwa 2 B (fig. 9) (IV A and IV B in Blendinger, 1995). Most probably they formed originally the normal stratigraphic hanging wall of the summit exposure of the Baid exotic. Now they build isolated blocks in the very top of the megabreccia with hydraulic breccia contacts to the surrounding rocks. About 500 m to the south another block in the top of the breccia could have formed the primary stratigraphic continuation. It includes finegrained grey and red cherty limestones named as Tayin formation by Pillevuit 1993 of Upper Jurassic or earliest Cretaceous age. This block must predate the tectonic event leading to the destruction of the former Baid exotic plateau and provides the only clear hint to date its redeposition into the Wadi Alwa megabreccia of the distal Hawasina basin.

**Paleotectonic**

The lower member in a section near Summit 1 displays angular unconformities and matrix-free breccia channels with Upper Permian limestone blocks (Capitanian-Lopingian) indicating a tectonic instability of these beds during the Early Triassic. The above mentioned Upper Jurassic block must predate the tectonic event leading to the destruction of the former Baid exotic plateau. It provides the only clear hint to date its redeposition into the Wadi Alwa megabreccia of the distal Hawasina basin. In 1995, Blendiger described the limestones of the upper Alwa formation as matrix of a Permo-Triassic breccia and concluded a Lower Jurassic tectonic instability.

**Paleogeography**

Mapping by Villey et al. (1986c), Béchennec et al. (1992b) and Pillevuit (1993) shows that the Wadi Alwa mega-block occurs in a lower tectonic position in the Hawasina Nappes suggesting that the palaeogeographical position of this exotic must have been situated close to the Oman margin.
The stratigraphic succession of the Al Buda'ah Group does not fit with the sequence observed in the Saih Hatat (Le Métour, 1988; Rabu, 1988) nor with the Ramaq Group (Pillevuit, 1993), mainly because of the Triassic and Jurassic pelagic depositional environment observed in the Wadi Alwa mega-block which indicate a more distal position on the margin. Béchennec et al., 1992b, Le Métour et al., 1994 and Pillevuit et al. (1997) have interpreted this sequence as being derived from a tilted block of the Oman margin (Béchennec et al., 1992b; Le Métour et al., 1994). This conclusion is also supported by the Permian platform and Triassic Hallstatt limestones blocks deposited in the proximal turbitite of the Hawasina Basin. Earlier models of the Oman margin were presented by Bernoulli and Weissert (1987) and by Stampfli et al. (1991), but in fig. 12 we are giving the Pillevuit et al. (1997) sketch with the Triassic position of some of the visited sections. Pillevuit (1993) published sketches of the Permo-Mesozoic evolution of the Oman margin. Middle Permian paleogeography of the Tethys and its southern margin has been presented by Baud et al., (1993a and b), Anisien and Norien by Marcoux et al., (1993a-d).

**Isotope stratigraphy** (fig, 14)

The Wadi Alwa section 1 is interesting for isotopic stratigraphy because it is one of the rare occurrences of Hallstatt-type limestones in the Lower Triassic. Pelagic facies is considered as a very good recorder of surface water carbon isotopic composition. The reason is that these sediments escape continental inputs and have a high Carbonate/organic carbon ratio which makes diagenetic overprint difficult.
$\delta^{13}C$ isotopic stratigraphy on bulk rock has been established by A. Viorel (1999) on section 1 (fig 4; 7) with the highest values (from +2.5‰ to +4.5‰) in the Middle-Upper Permian Ba'id Formation. Though the curve is relatively stable with high values for the Permian, it shows a high variability in the Triassic Alwa Formation. The negative shift between the Permian and the Triassic is not so marked (only 2‰). due to the gap of the lowermost Triassic. The pink dolomite at the base of the Alwa Formation (Dienerian? -Lower Smithian) shows relatively high values (between +1.7‰ to +3.6‰). Values decrease again in the ammonoids rich Hallstatt-type limestones to values around +0.5‰ and increase in the overlying strata up to +2.2‰. Another negative shift down to 0‰ was found in the first level of resediments. $\delta^{13}C$ values stabilize higher up around +1‰ with a minor excursion to 0.3‰.

Even though a diagenetic effect for this high variability in the Lower Triassic can not be totally excluded, avaiable data seem to reflect short term primary variations in the productivity of surface seawater.

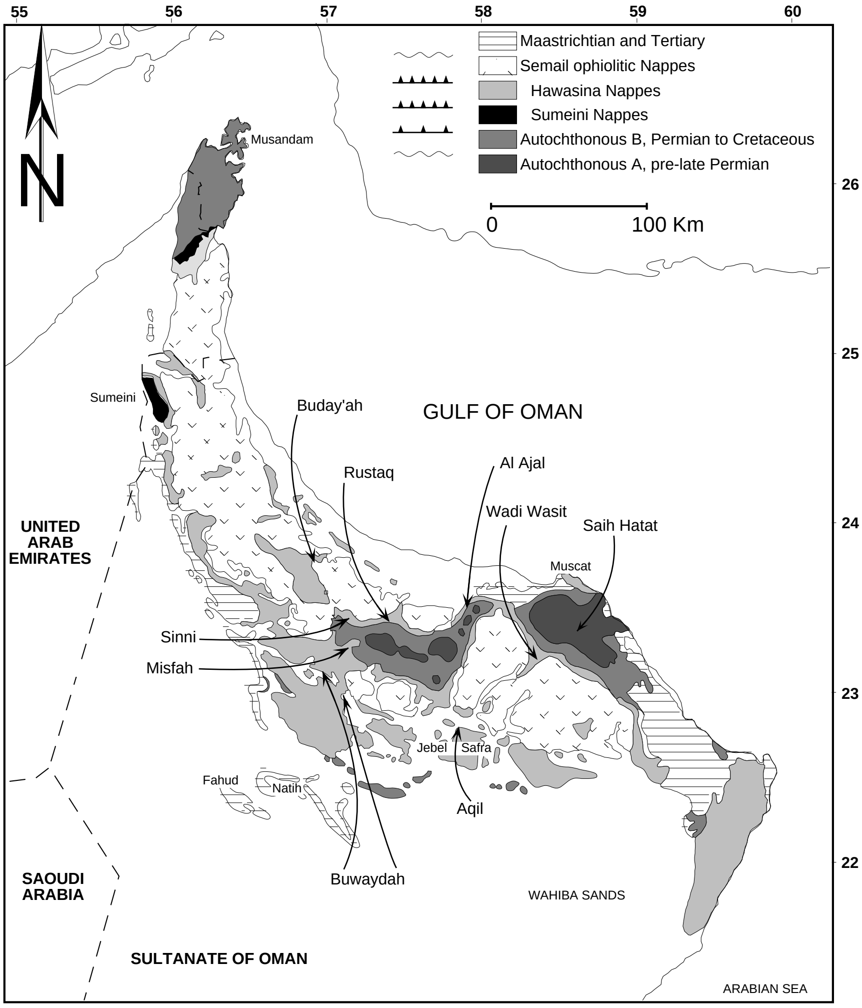



Fig. 11 -Geological sketch map of the Oman Mountains (after Glennie et al. 1974) with Permian-Triassic volcanism localities cited in the text.

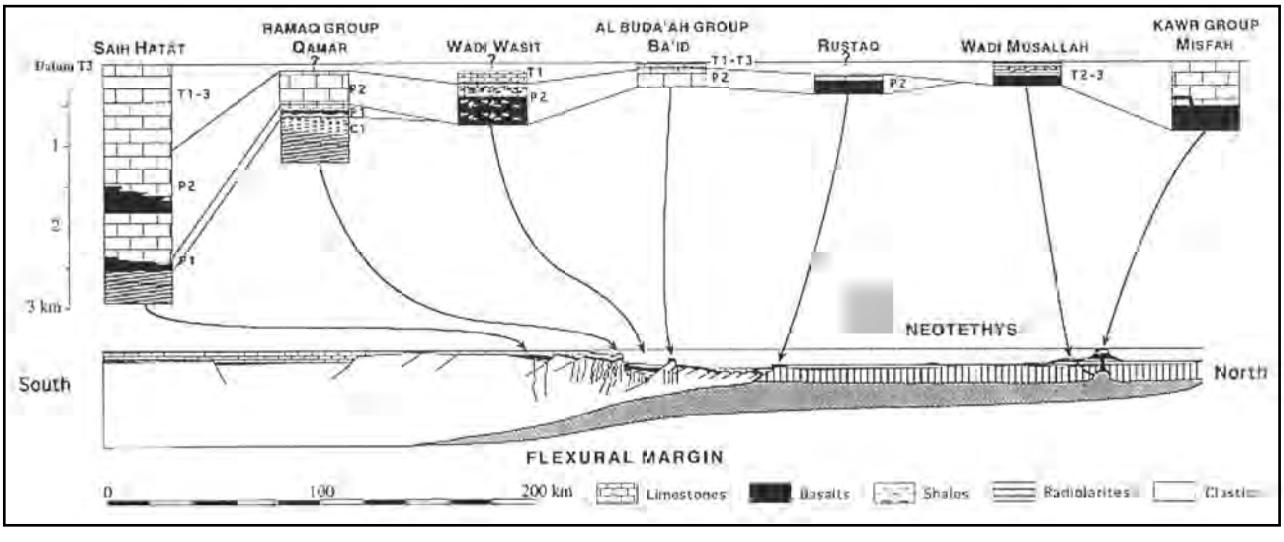



Fig. 12 -The Oman margin in the late Triassic (from Pillevuit et al., 1997)

## Stops

**Stop 1.1:** Panorama of the Wadi Alwa mega-block seen from the south (fig.6 ).
From this stop, a general geological outline of the area will be given (see figs. 6,7 and 8 and the introduction above). Then one hour trek on the S flanc of the Alwa Mountain will bring us to the next stop.

**Stop 1.2**: The upper member of the Alwa Formation (L. Krystyn, figs 8, 9).
We will visit the outcrop named as Wadi Alwa IV by Tozer et Calon and described later in detail by Blendinger. It is located on the footwall of the mountain (our fig 10 and fig. 11 in Pillevuit et al., 1997) in head of a small ravine and consists of two isolated sections which dip similarily steep but strike perpenticular to each other along the two sides of the gully.
The two sections are very similar in thickness and microfacies. Bioclastic wackestones with varying amount of in part ironoxid coated ammonoid shell debris and crinoids (pl. 1, figs.. 1-2) are characteristic in the Triassic part. Within the Rhaetian a gradual decrease of the biogenic content is observable which leads to comparably monotonous wackestones rich only in sponge spicules in the Jurassic. The more clay-rich matrix shows intensive bioturbation and common microstylolithic brecciation (pl. 1. Figs. 3-4) typical for the Jurassic ammonitico rosso. The Triassic-Jurassic boundary is well and undisturbed developed and exposed in Wadi Alwa IV B but tectonically overprinted and post-depositionally brecciated in Wadi Alwa IV A. An Iron-oxide coated hardground marks the top of the Triassic and is the only indicator for the missing of the basal Jurassic Planorbis zone. In both sections the rocks are slightly marlier above the boundary and therefore not so resistent as directly below, making the boundary well accentuated in outcrop. The Middle Norian nodular limestones of Wadi Alwa IV A are otherwise very similar to the Jurassic ones of both sections.
The sections have been combined dated by ammonoids and within the Triassic parts also by conodonts (fig. 9). Wadi Alwa IV B is stratigraphically more complete and includes the whole Norian (about 20 m) followed by a thin Rhaetian ($\leq$ 1m) to Hettangian ($\leq$ 2m) interval, and a synsedimentary (Pl. 1, figs. 5-6) disturbed Sinemurian (at least 4m). Precise datings rely on conodonts in the Triassic part as ammonites are not so common and normally preserved as internal molds allowing in many cases only a generic determination. The Jurassic ammonite fauna is dominated by phylloceratids and lytoceratids and allows no exact biochronologic subdivision.

**Stop 1.3**: section 3, Permian-Triassic contact (fig. 13).
200m Nord-East of the previous stop (map, fig. 7), we will look at the contact between the Upper Permian shallow water carbonates of the Ba'id Formation with the Smithian (?) deep water carbonates partially dolomitized of the the Alwa Formation ( Hallstatt-type limestones)

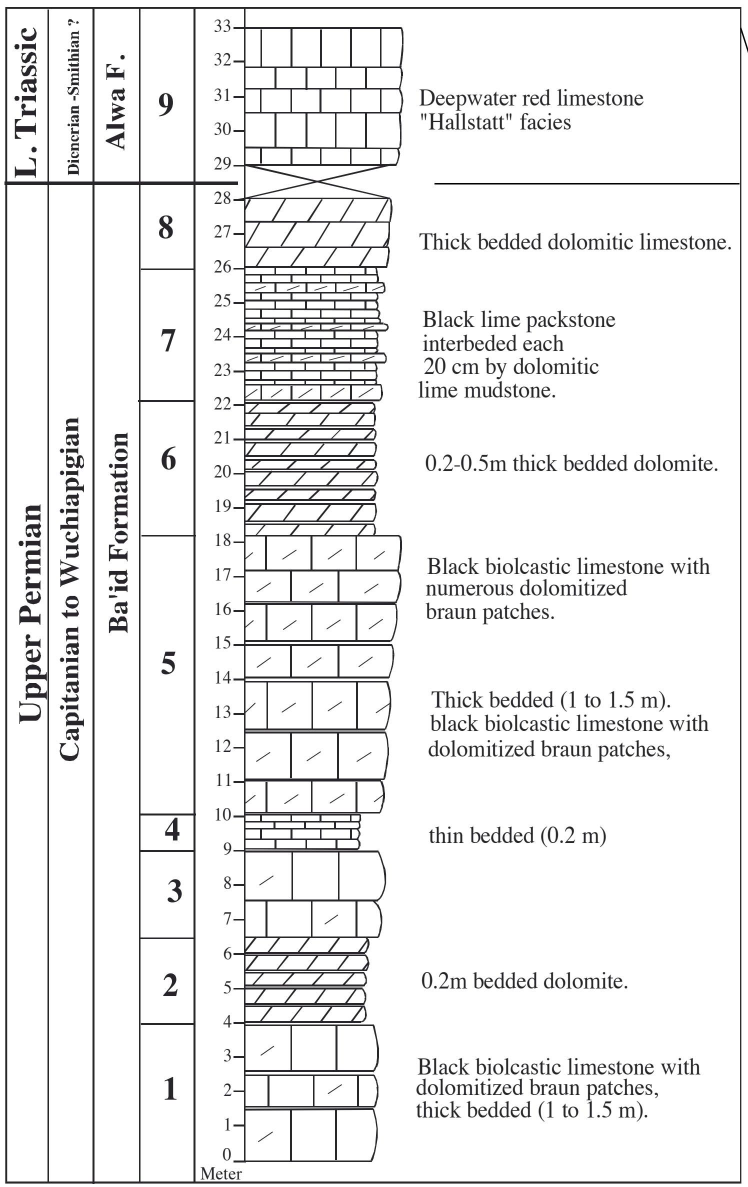



**Figure 13 :** Wadi Alwa Mega-Block, section 3

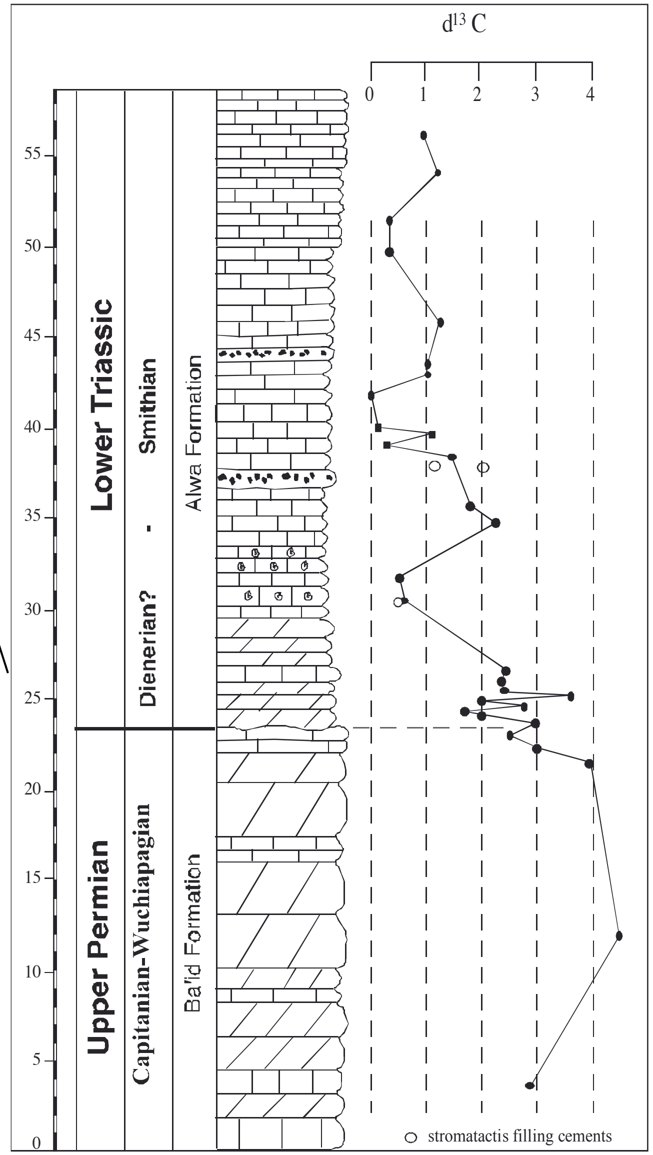



**Figure 14 :** Wadi Alwa Mega-Block, section, Lithology and C isotope curve.

## January 8 Late afternoon: Wadi Musjah

By A. Baud and S. Richoz

**Routing** (2 in fig 4).
The Wadi Musjah outcrops (fig. 15) are located near the main road linking Bidbid to Ibra, S of the Wadi Tayin road and NE of the Rawda village.

**Introduction**
The section we will visited (fig. 17) corresponds to "Wadi Musjah nord-est" or section 4 of Pillevuit, 1993 and is illustrated in fig 29 of Atudorei (1999).

**Isotope stratigraphy** (fig 16)
$\delta^{13}C$ isotopic stratigraphy on bulk rock has been established by A. Viorel (1999) with the highest values (around +4. ‰) in the gray Middle Permian limestone. The Lower Triassic (Dienerian) thin bedded limestones show unusual high values (+3‰) with very few variations. These very high Lower Dienerian $\delta^{13}C_{tot}$ values must be compared with other sections. A negative shift to values around +1.8‰ occurs in the topmost beds (Upper Dienerian?).

## Stop

**Stop 2.1:** The Permian-Triassic Wadi Musjah exotic (figs 16 and 17).
The base of the sequence occurs on the western flank of a small hillock and consists of gray bioclastic limestones (unit 1 in fig. 12). They provided foraminifera which indicating a Late Permian age. They are overlain by a massive dolomitized breccia (unit 2, fig. 12), 10m thick. The following 15m thick sequence (units 3 and 4, fig. 12) consists of platy limestones, thick bedded resedimented limestones and dark gray limestones with siliceous nodules. Overlying it follows. The contact between the dolomitized breccia and the platy limestones (units 2 and 3) is sharp and irregular. The base of unit 3 shows two layers (about 0.2 m each) of pinkish, micritic limestones similar to the Hallstatt-type limestone, followed by gray platy limestones. Conodonts recovered from these beds indicate a Lower Dienerian age (Krystyn, personal communication). The beds of resedimented limestones have often irregular bedding surface due to submarine erosional processes.

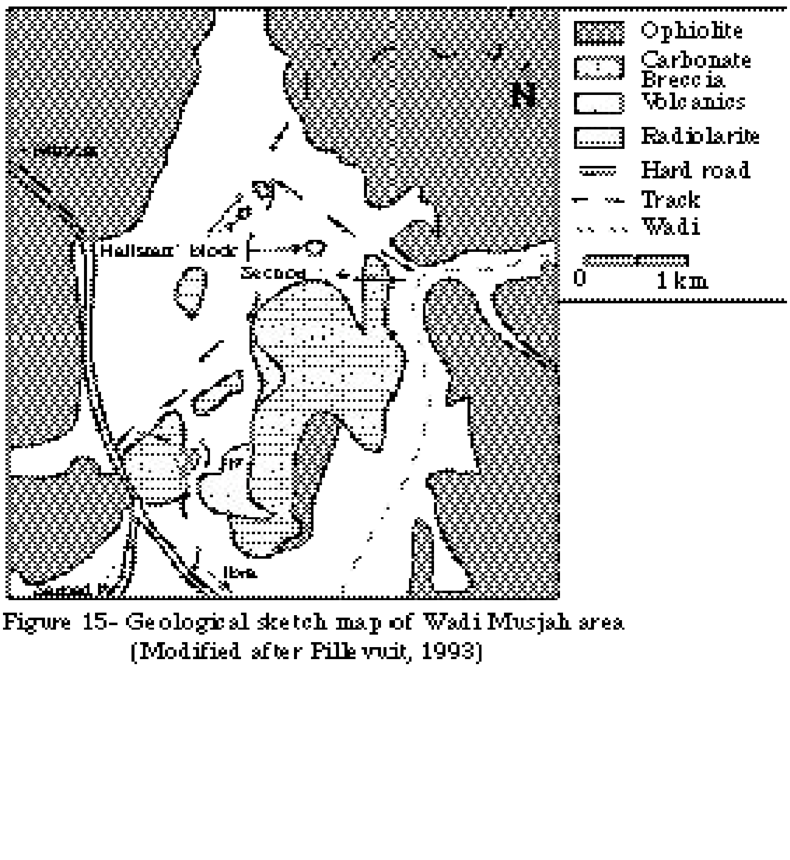



Figure 15- Geological sketch map of Wadi Musjah area
(Modified after Pillevuit, 1993)

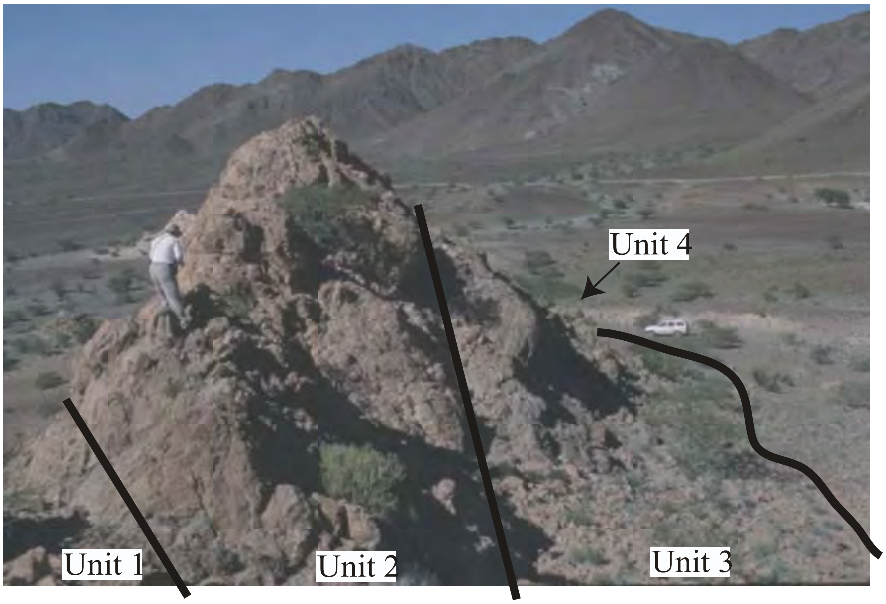



**Figure 16- Wadi Musjah, North East section.**
**Details and isotopic curve in section, figure 17**

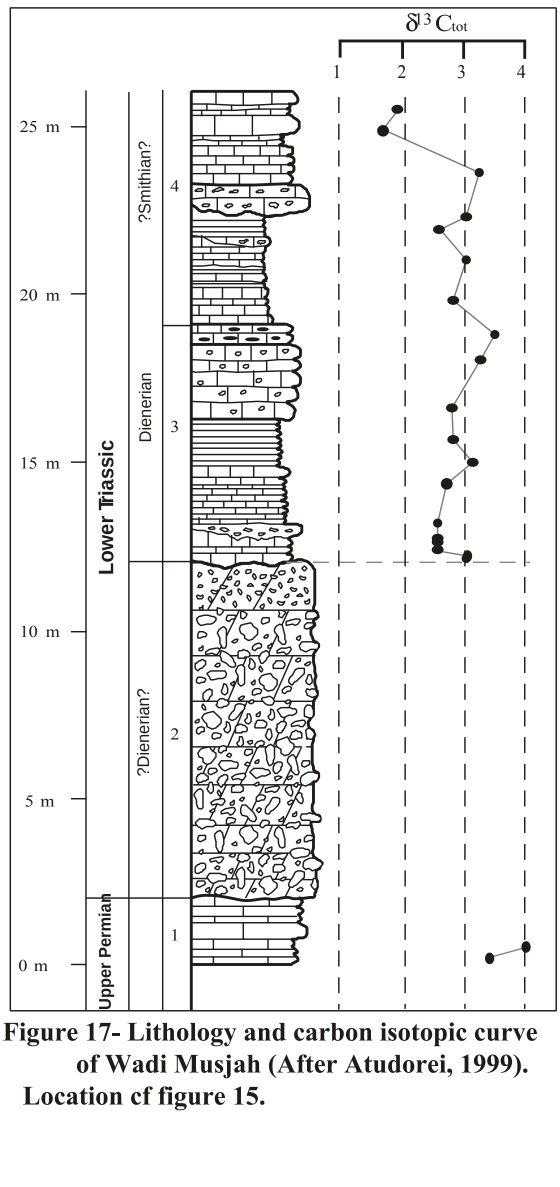



**Figure 17- Lithology and carbon isotopic curve**
**of Wadi Musjah (After Atudorei, 1999).**
**Location cf figure 15.**

**January 9 Morning: The Wadi Wasit Permian and Triassic deep water sediments of the Hawasina units**

**Routing**(fig 11 and 18).
The Wadi Wasit area is situated about 4km to the SW of the Wadi Alwa visited the previous day and the section is located near the road linking Wadi Ta'yin to Wadi Rahbah .

**Introduction:**
Located Southwest of the Alwa mega-block the Wadi Wasit area provides one of the best and the most extensive exposures of Permian and Triassic deep water sediments in the Hawasina allochthon. This area belong to the Baid tectonic window that forms an anticline with a roughly N-S trending axis and exposes southward emplaced imbricates units of Hawasina sedimentary and volcanic rocks below the Samail ophiolite. The Arabian Platform autochthon rocks of the southern part of the Saih Hatat close the window to the north.

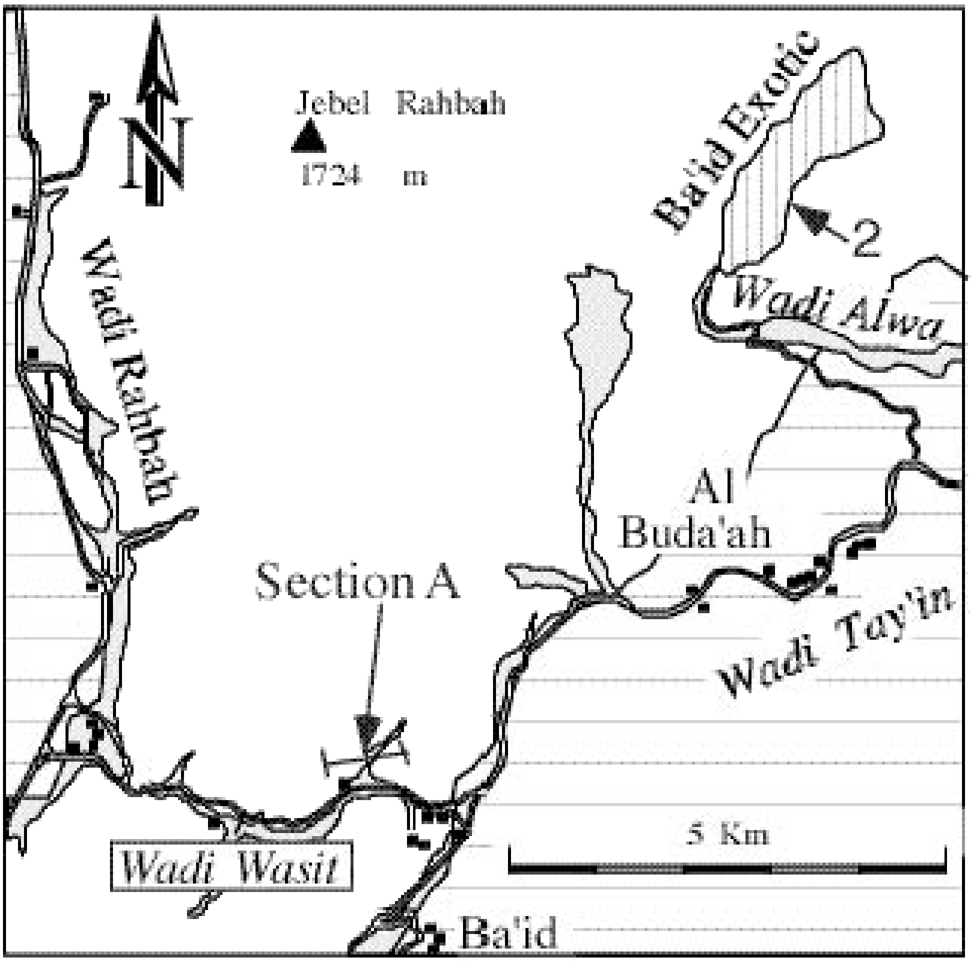



**Fig. 18- Sketch map of the Wadi Wasit area (modified from Pillevuit et al., 1997)**

**Stratigraphy.**
The most complete Wadi Wasit section (fig.19) includes the Permian lower part of the Al Jil Formation (Béchennec, 1988, Béchennec et al., 1992b). It consists of about 250m of pillow lava with 4 main intercallations, 10 to 30m thick, of cherts, of volcanic breccia, of calcareous gravity flow deposits with Lower and Middle Permian shallow shelf or reef boulders and of cephalopod red lime wackestones (Pillevuit et al., 1997).
Overlying the upper pillow lava intervall (1) (see short description of volcanic rocks below) there are 4 main lithological units. The cephalopod red limestones (2) are directly in contact with the pillow lava. Furnish and Glenister in Blendinger et al. (1992) determined the ammonoids of the Wadi Wasit and gave the following list, named "sicilian species": *Parapronorites konincki*, *Propinacoceras beyrichi*, *Eumedlicottia bifrons, Neogeoceras marcoui*, *Adrianites elegans*,

*Aricoceras ensifer*, *Tauroceras scrobiculatum, Stacheoceras sp.* and *Waagenoceras sp.*. *Epadrianites beyrichi* is known from Timor and *Mongoloceras omanicum* is a new species. This fauna and the conodont *Mesogondolella siciliensis* (det. H. Kozur) are Wordian in age. Overlying are nodular, cherty and turbiditic (allodapic) limestones (3). Sedimentological studies have been published by Blendinger (1988, 1990). The following unit (4) is massive, completely dolomitized and consists of a gravity flow deposit partly composed of reef boulders. In an other tectonic slice, a lateraly equivalent unit contain a large boulder with a Middle to Upper Griesbachian bivalve Coquina limestone resting on Wordian reef boundstone (L. Krystyn et al., 2001), the age of the overlying deep-water platty limestones (5) is Dienerian. Its means that the breccia deposition occurs at the beginning of the Dienerian. The reef biota of the Permian reef boulders deposited in these deep water sediments have been intensively studied by a team from the Erlangen Paleontological Institution and also compared with the El Capitan reference section of W Texas (Fluegel in Blendinger and Flügel, 1990, Senowbari et al., 1992; Weidlich, 1996a; Weidlich, 1996b; Weidlich et al., 1993; Weidlich and Flugel, 1995; Weidlich and Senowbari, 1996)

**Permian Volcanic rocks**

According to Béchennec 1988, Béchennec et al., 1991, Pillevuit, 1993, Pillevuit et al., 1997, the pillow basalts of the Wadi Wasit have an within-plate signature. This interpretation have been confirmed by Maury et al., (2001) which note that these volcanic rocks are strongly enriched in the most incompatible elements and are typical of high-Ti basalts identical to plum-related alkalibasalts from intraplate continental or oceanic settings.

**Isotope stratigraphy** (after Atudorei, 1999).

Units 2 and 3 have high $\delta^{13}C_{tot}$ values between +4‰ and +5‰ consistent with Late Permian usual values. In two parallel sections, the $\delta^{13}C$ isotopic curve in the unit 4 show two different responses (fig. 19). Both begin in the lowermost part of the platy limestones with quite high values up to +2.8‰ and then decrease around 0‰. Then, one section stay stable around 0‰ but the other shift up to 2‰.

## Stops

**Stop 3.1**: panorama of the Hawasina units in the Wadi Wasit

**Stop 3.2**: stratigraphy of the Al Jil Formation on the left side of the Wadi Wasit (fig. 19 .).

The section A, we will see during the excursion is located on the left and NE side of the Wadi Wasit. It is the upper part of the complete section and consists of 5 main lithologic units (Al Jil Fm.) from base up:

- Unit 1 (only its uppermost part is represented in fig. 19) is a thick volcano-sedimentary sequence made up of alkali pillow basalts WPB-type (Béchennec 1988, Béchennec et al., 1991, Pillevuit, 1993, Maury et al., 2001) and of tuffites with interbeds of radiolarites.
- Unit 2, 19m thick, consists essentially of medium bedded red limestones with some levels of fine-grained resedimented limestones and red shales interbeds.
- Unit 3 (21m thick) consists of depositional sequences mainly of turbiditic lime packstones and red shales, the latter being more abundant in the upper part. The allodapic limestones are represented either by calcarenites or calcirudites and they include occasionally reddish-whitish chert nodules.
- Unit 4, about 20-30 m thick is represented by a massive dolomitized breccia with blocks of reefal limestones (Weidlich et al., 1993).
- Unit 5 starts with gray platy limestones and thin shales or marlstones interbeds, over a 6 m thickness. The contact with massive dolomitized breccia is irregular and marked in some depressions by a thin layer of marly shales. Elsewere the platy limestones unit is overlain by a green shale/fine-grained quartz-sandstone sequence 12 m thick and then by a green/red radiolarian chert series, base of the Matbat Fm.

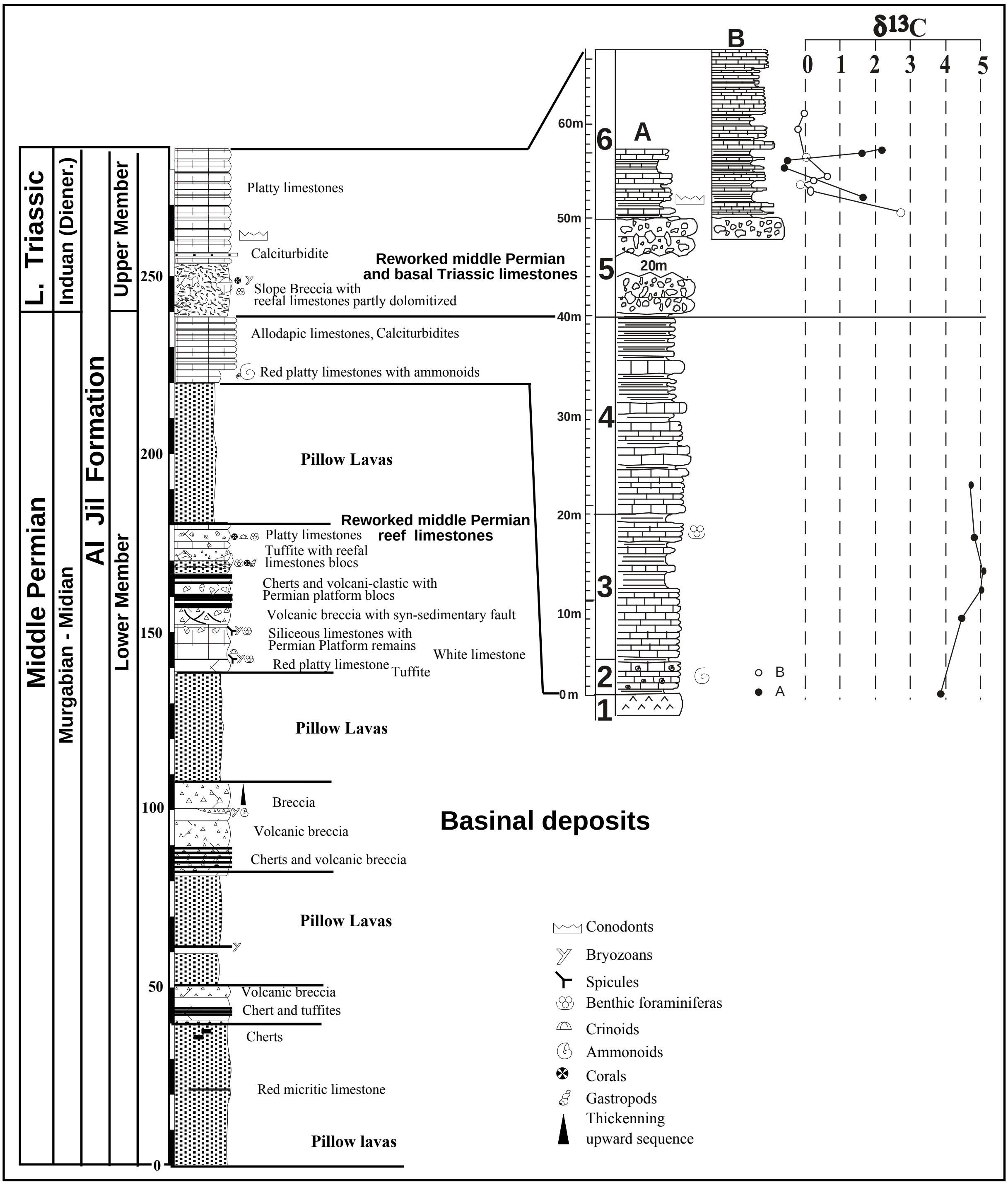



**Figure 19- Wadi Wasit composite section (modified from Pillevuit et al. 1997); section A and B modified from Atudorei (1999); Carbon isotope curve from Atudorei, (1999).**

**January 9 Afternoon: the Upper Triassic to Lower Jurassic exotic blocks of the Aqil Breccia**
By L. Krystyn

**Routing** (figs. 20, 21)
The village Al Aqil (also known as Aquil) is situated along the main road (33) from Izki to Sinaw about 20km southeast of Izki. From Wadi Tayin the locality can be reached along a gravel road through Wadi Endam (fig. 1) running into road 33,5km to the east of Aqil. The outcrop to be visited is just south of the tarmac road on top of the single prominent hill located some 100m to the northeast of the village.

**Introduction:** The above mentioned hill is the erosional product of a resistent subvertically dipping limestone breccia bed called here informally as Aqil breccia. The later crops out as elongated southwest to northeast striking body of about 500m length (fig. 20). Is has a lense-shaped form with the greatest thickness (30m) on the top of the hill and pinches out in both directions towards the hill base, in the southwest right at the village entrance (Pillevuit 1993, fig. 108). This is the only place to study the stratal relationships between dm-bedded calciturbidites and the Aqil breccia resting as debris flow with erosional contact on the lower fan sediments underlain by darkbrown radiolarites . The megascopic blocks of the Aqil Breccia are angular to subangular and may reach up to bungalow-size but are usually smaller than one cubicmeter. Several main lithotypes occur as clasts within the breccia. They are either of shallow water (see Senowbari-Daryan et al., 1999), pelagic (Blendinger, 1991) or less common of volcanic (Pillevuit, 1993) origin. Blendinger (1991) described blocks with three different lithozones – a basal forereef breccia (= Reef limestone unit), a crinoidal-brachiopod packstone (=Crinoidal limestone unit) and finally a cephalopod Hallstatt-type limestone unit. The breccia contains additional smaller, decimeter-sized clasts of basaltic lava which is interpreted as the original substratum of the (Carnian) reef limestone described by Blendinger (1991). Other large components are built by Norian forereef limestones similar to the Dachstein reef-limestone of the Austrian Limestone Alps. Breccia matrix is rare and is only found in sediment-filled pockets between bigger clasts where it consists of reddish pigmented sand-sized calcareous fragments of identic lithotype

The reconstructed stratigraphic sequence (fig. 22) with basal pillow basalts followed mainly by pelagic sediments is in parts (with exception of the reefal limestones) similar to the sedimentary column of the Haliw formation (Glennie, 1974; Baumgartner et Weissert, 1987) into which the Aqil breccia has been embedded by gravity flow processes (Blendinger, 1991). The emplacement age is not well constrained; it is definitely post-Early Liassic but could be of much younger (eventually Early Cretaceous) age according to sparse radiolarian data from surrounding rocks (Pillevuit, 1993). An exact dating is difficult due to the disconformal erosional contact with the underlying Haliw formation. Depending on its shallow water blocks the Aqil breccia has been erroneously identified as Misfah formation by Hutin et al. (1986). This is unjustified because of the highly differing lithologies and the completely different sequences (see description of Jebel Kawr). Neverless, the reefal limestones within the Aqil breccia could indicate a close paleogeographic relationship with the Misfah carbonate platform. A primary position of the Aqil exotics at the former partly drowned rim of the Misfah platform facing closely the Haliw segment of the Hawasina basin is therefore plausible (cf. fig . 12)

## Stops

**Stop 4.1**: Panoramic view from the Aqil hill (small map, fig. 21).
Our excursion site is on top of the hill from where the view towards the north shows in the foreground dispersed outcrops of Aqil breccia (wide, blocky) and of the Haliw formation (dark red, smooth surface). Behind and tectonically above follows the main mass of the brownish weathering Semail Ophiolite building the highest tectonic stack in the Allochtonous of the Oman mountains. South of Aqil the wide wadi peneplain is terminated by the Jebel Safra, a mountain range composed of Jurassic and Cretaceous deep water rocks (Hutin et al., 1986). The later contain also exotic pelagic (Hallstatt type)

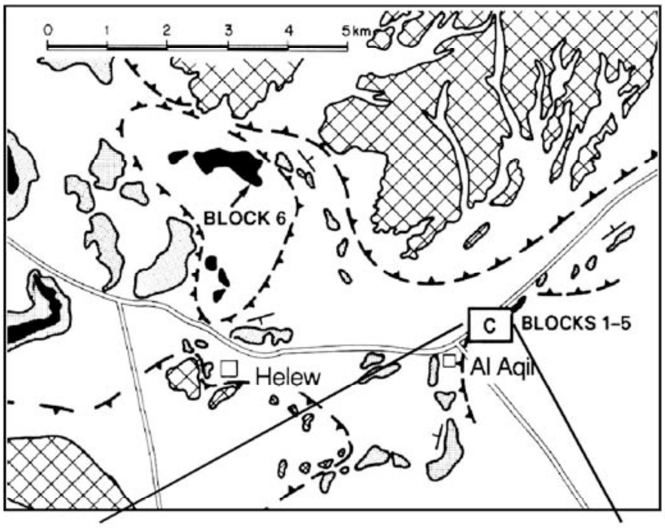



**Figure 20- Geological sketch of the Al Aqil area (modified from Blendinger, 1991)**

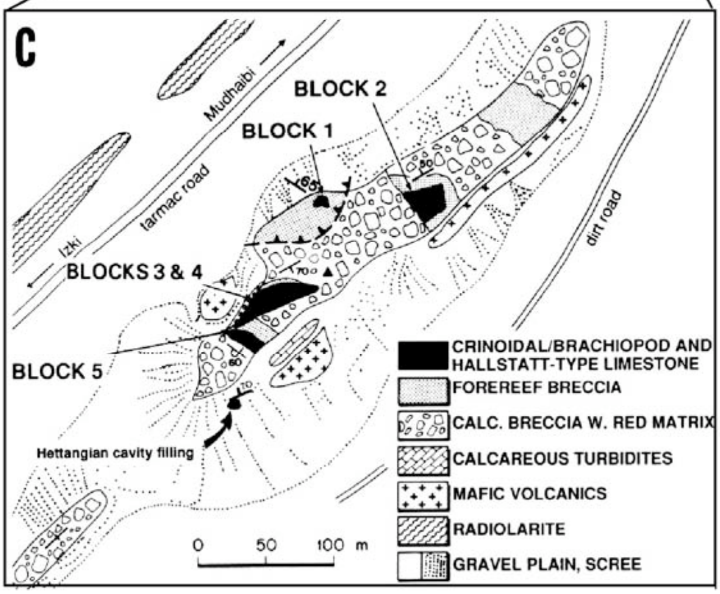



**Figure 21- Geological sketch of the hillock with blocks 1 to 5 described in the text and in the figures 23 and 24 (modified from Blendinger, 1991)**

| | | BLOCKS 1-5 | OTHER CLASTS |
|---|---|---|---|
| LIASSIC | Hett./Sin. | Cephalopod Limestone (Hallstatt type) | Cephalopod Limestone |
| UPPER TRIASSIC | Norian - Rhaet. | | Reef Limestone (Dachstein type) |
| | Carnian | Crinoidal Limestone | ? |
| | | Reef Limestone (Wetterstein type) | |
| | | | Pillow basalts (Haybi Volcanics) |

**Figure 22- Composite stratigraphy of Aqil Breccia clasts.**

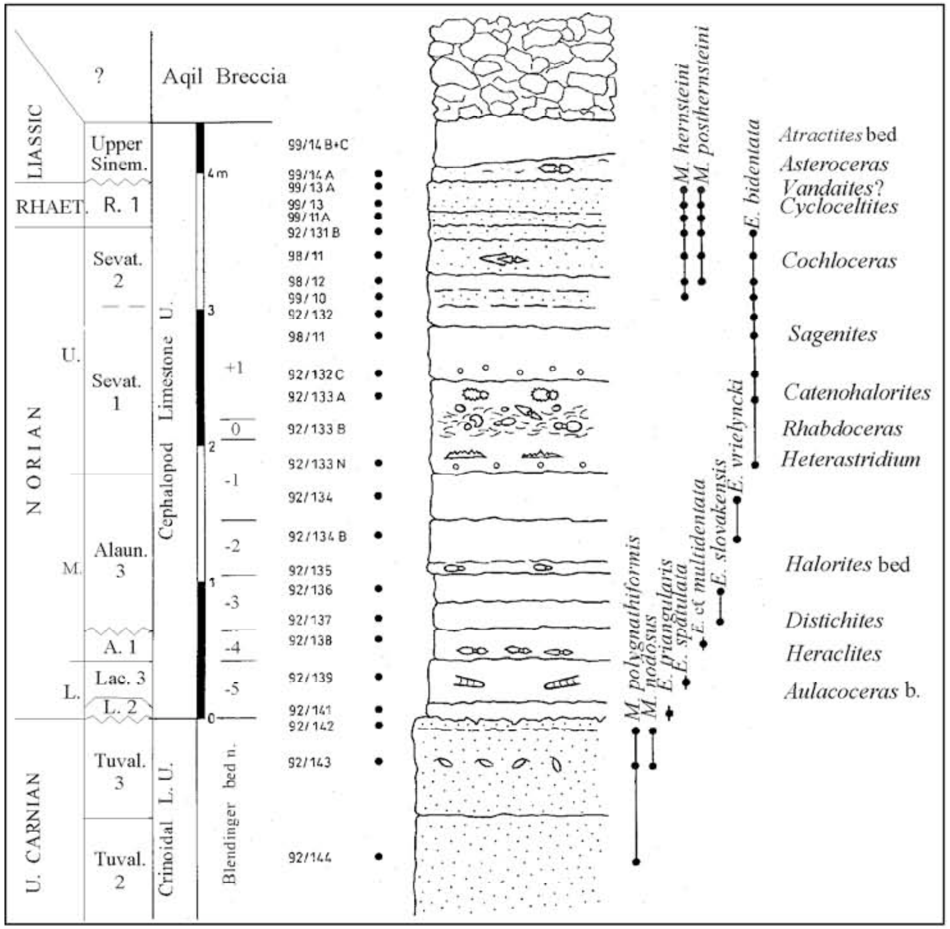



**Fig. 23- Aqil: Detailed stratigraphy of basal part of block 3-4.**

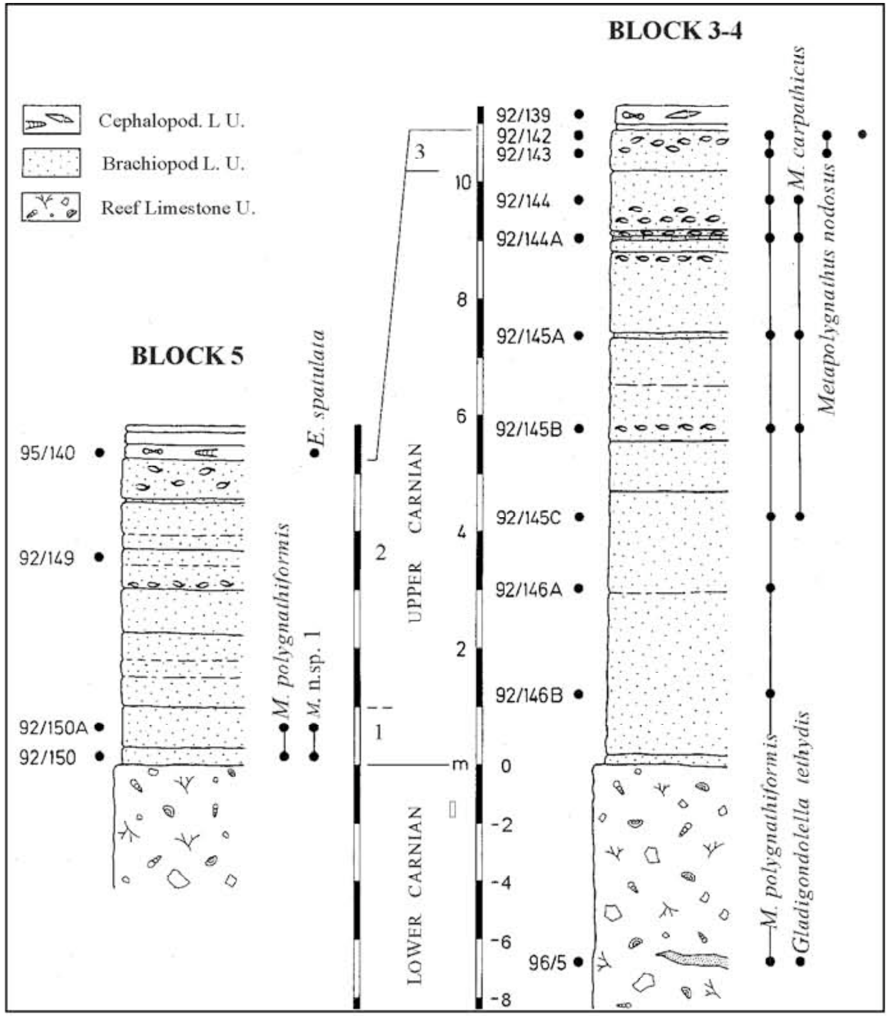



**Fig. 24-Aqil: Detailed stratigraphy of upper part of block 3-4.**

blocks (Tozer et Calon, 1990; Blendinger, 1995) which differ considerably from the Aqil ones. The Jebel Safra blocks are of Lower Triassic age, accompanied by Permian reefal limestone blocks and are embedded into the Guwayza formation.

**Stop 4.2**: Aqil exotic block 3-4 (Upper Triassic to Lower Jurassic sequence)
The below described Aqil exotics are located within the center of the breccia on the hilltop (fig. 21) and build there several large sized (max. 20x10x5 m) isolated but coherent blocks numbered as 1-5 by Blendinger (1991). Lithology and sedimentology of these fossil-rich blocks have been described by Blendinger (1991). Due to insufficient biostratigraphic data Blendinger included all 3 units into the Norian in accordance with the stratigraphically well constrained cephalopod limestone at the top. Subsequent detailed micro- and megafossil investigations have changed considerably the previous age assignment to an interval ranging from the Lower Carnian to the Upper Sinemurian (fig. 22). Block 3-4 (fig. 23, 24) is the thickest and stratigraphically most complete one and is examined in detail. The block consists of a basal reef limestone unit (up to 12m thick), a disconformably and partly also discordantly overlying crinoidal limestone unit (8 – 11m) and a capping cephalopode limestone unit (4m).

**Together with the other coeval exotic blocks it represents within a thickness of just 20m an incredible large time slice of about 30 Ma from the base of the Upper Triassic close to the top of the Lower Liassic (see figs. 23, 24). The thin sequence actually is a result of very reduced sediment accumulation and of submarine hiatuses which are responsible for the missing of about one third of the time span mentioned above.**

Three paraconformities have been detected in the sequence each spanning time intervals of more than one Ma.
-The first one marks the Carnian-Norian boundary with a gap of about 3 Ma.
-The second leads to the missing of part of the Middle Norian (Alaunian 2 zone), a phenomenon common in Hallstatt type pelagic limestone sequences of the Tethys where it causes major problems in establishing a complete magnetostratigraphy of this time interval (Gallet et al., 2000).
-The largest gap is centered around the Triassic-Jurassic boundary with the top-Rhaetian, the whole Hettangian and a part of the Sinemurian missing. According to Gradstein et al. (1994) this means a time interval of nearly 8 Ma.

Blendinger (1991) interpreted the pelagic cover of the reef limestone as deposited on the slope of an active carbonate platform. This interpretation is no longer compatible with the new age constraints of the rocks. In fact the blocks record a typical drowning succession (Schlager, 1997) similarly to the Early Jurassic onset of the ammonitico rosso in the western Tethys (Böhm, 1992; Zempolich, 1993). In such a succession sediment is accumulated during relative sealevel rise whereas sealevel falls are responsible for breaks and hardground formation. In terms of sequence stratigraphy the breaks can be interpreted as lowstands indicative of sequence boundaries (Haq, 1991). Two of them are recorded in the Carnian, one in the Norian and one at the Triassic-Jurassic boundary of block 3-4 (see above).

Reef limestone unit, built by massif, coarse-grained grey lithoclastic rud- and grainstone rich in echinoderms (echinid spines, crinoid ossicles) and scattered reefoidal bioclasts (cereoid and dendroid corals, various calcareous sponges, *Tubiphytes* and algae (Senowbari-Daryan et al., 1991).
A single pocket of filament bearing limestone in the lower part of the unit delivered conodonts (*Metapolygnatus polygnathiformis*, *Gladigondolella tethydis*) of Lower Carnian age.

Crinoidal limestone unit, decimeter to meter bedded grey and light red crinoidal pack- and grainstones with various amount of brachiopod shells of *Oxycolpella omanica* (see Senowbari-Daryan et al., 1999) bounded by fibrous cement. Disarticulated crinoid ossicles dominate throughout whereas brachiopods are more frequent in the upper part of the unit which contains a more finegrained lime mud matrix and filaments ( pl.2,fig. 1). This suggests a continuous deepening of the environment from well above the storm weather base partly to below it at the top of the unit. The crinoidal limestone shows remarkable thichkness changes over short distances. Blendinger has

explained this by syndepositional faulting but an onlap geometry above the drowning unconformity surface of the reef limestone may produce a similar effect in such a small-scaled outcrop.
The crinoidal limestone is dated as Upper Carnian (Tuvalian) by conodonts (*M. polygnathtiformis*, *M. nodosus*).

Cephalopod limestone unit, consists of centimeter to decimeter bedded brownish-red wackestones megascopicly rich in cephalopod shell debris and in certain layers (around 92 / 133) in Heterastridium (pl. 2, fig. 3). The microfacies changes from filament bearing beds (pl. 2, fig. 3) in the Lower and Middle Norian to crinoid and shell debris rich wackestone (pl. 2, fig. 4-5) in the Upper Norian to Lower Jurassic interval. A single bioclastic ammonoid grainstone (92 / 133 B) maybe interpreted as storm induced event bed formed around the deep storm wave base. This would exclude a deposition depth below 200 m (Zempolich, 1993). A drastic change towards continous deposition without episodic currents is indicated only in the topmost bed (99/14 C) by a radiolarians bearing mudstone microfacies (pl. 2, fig. 6). Bedding plains are usually developed as hardgrounds occassionaly with thin Fe-oxide crusts. Ammonoids are fairly common and due to their calcitic shell with oxidic coating often easily extractable. They show a characteristic preservation with the lower half complete and excellently preserved whereas the upper side is often corroded or eroded.

The cephalopod limestone is dated by ammonoids and conodonts as Norian to Lower Rhaetian. Age-diagnostic genera are *Heraclites*, *Halorites*, *Rhabdoceras*, *Catenohalorites*, *Cochloceras*, *Cycloceltites* and *Vandaites* (questionable in thin section). The conodont fauna is dominated by species of *Epigondolella* and in the topmost Triassic by *Misikella.* From the basal Jurassic bed 99/14 A rare large specimens of *Asteroceras stellare* and a mass occurence of *Atractites* record an Early Upper Sinemurian age.

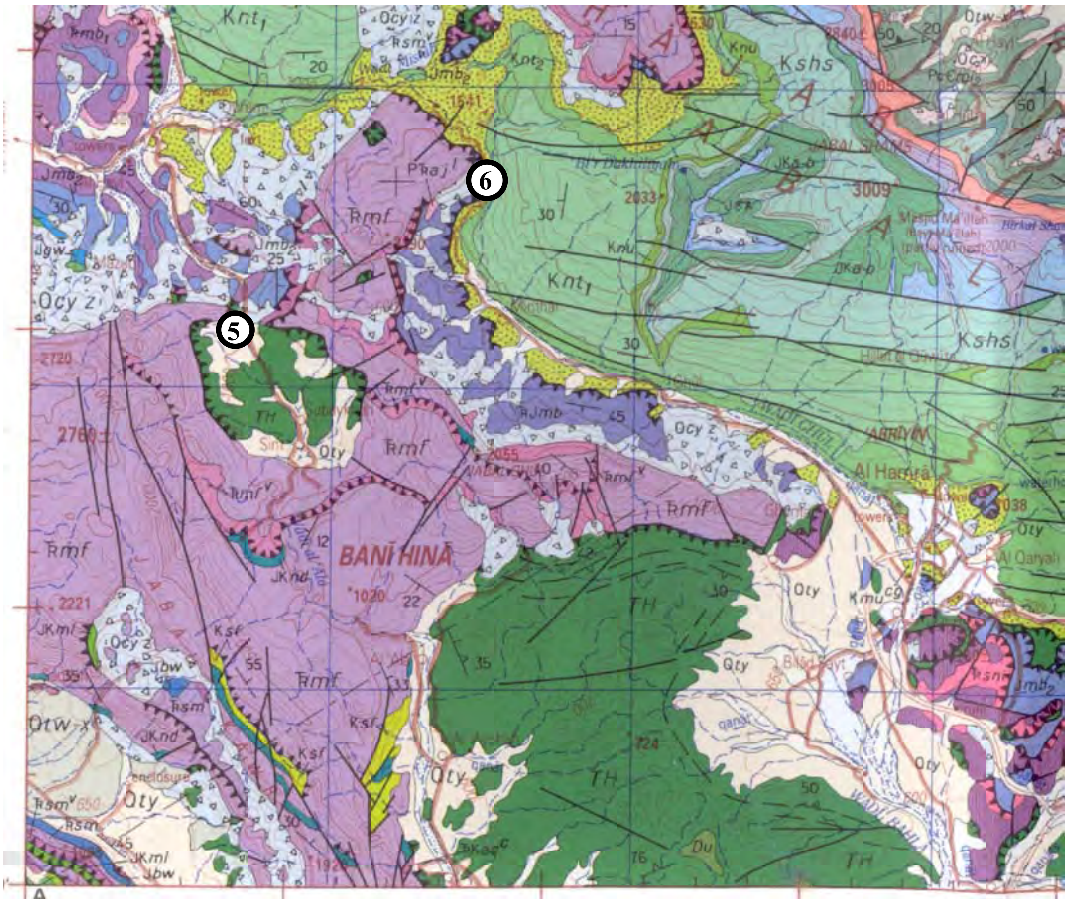



**Fig. 25- Geological map of Jebel Kawr-Misfah area (from Béchennec et al., 1992)**
**Stop 5, Sint section; stop 6, Misfah section**

**Fig. 26- View of the Jabal Kawr from the South, a Norian-Rhaetian carbonate platfor**

**January 10, Morning: Middle-Upper Triassic carbonate platform of the Sint section, Jabal Kawr**

by L. Krystyn

**Routing** (Fig, 25).

The outcrop is located in the northeastern-most corner of the Jabal Kawr massif (fig. 26), just west of the place where the road after a steep ascent from Barut reaches its highest point to descent afterwards slowly into the Sint depression The later is filled by a thin pile of Semail ophiolite building the tectonic cover of the Kawr group.

**Introduction:** The Kawr Group was originally described by Béchennec (1988) and redefined in Pillevuit (1993). This group crops out mainly along the southern flank of the Jabal Akhdar, in Jabal Kawr, Misfah, Misht and Ghul (Béchennec et al., 1992b-c; Beurrier et al., 1986b; Minoux & Janjou, 1986) and in the Dank area in the Jabal Hamrat al Hasan (Le Métour et al., 1991). This group is thrusted onto the Al Aridh Group as exposed in the Nadan Window or onto the Hamrat Duru Group as seen in Jabal Misfah. It is generally overthrusted by the harzburgites of the Samail Ophiolite as observed on the top of the Jabals Kawr and Misfah (Béchennec, 1988 Béchennec et al., 1992b-c), and locally by the Umar Group.

The steeply to subvertically dipping so-called Sint section runs east-west along a small crest about 100m in altitude uphill of the road. The outcrop is the only place within the region where part of the reefal platform margin of the usually lagoonal Misfah formation is exposed.

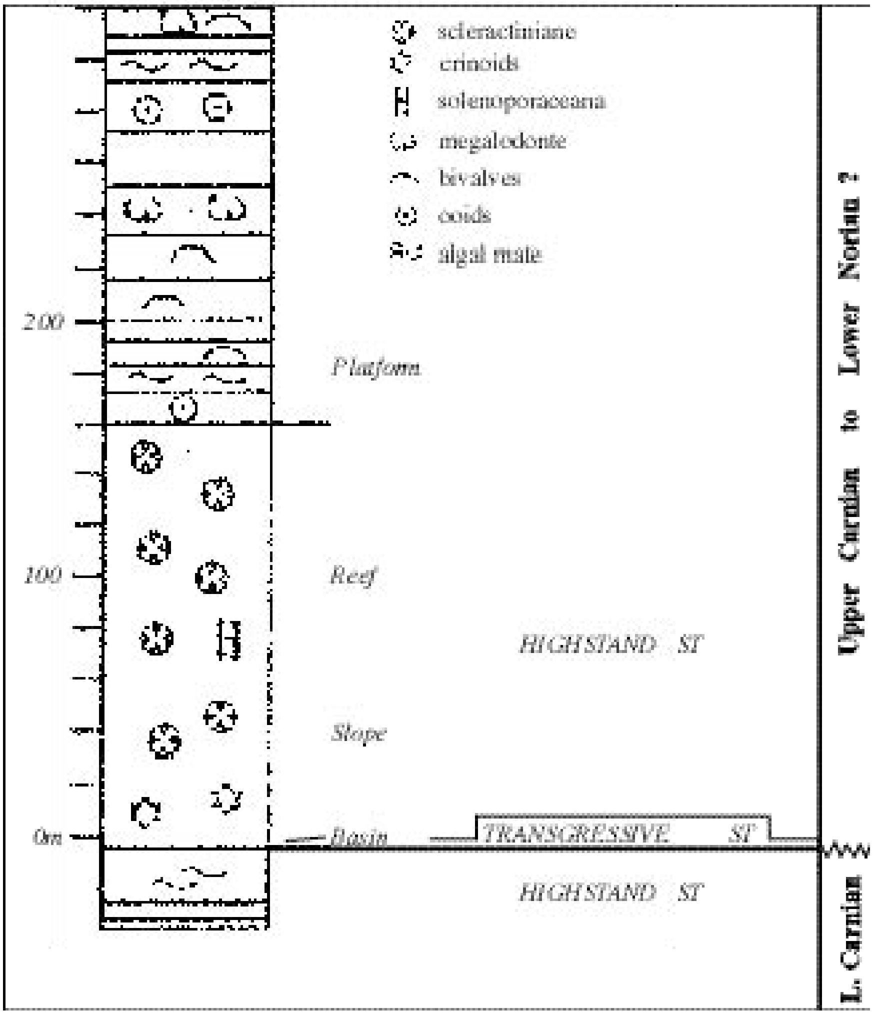



**Figure 27- Stratigraphic sketch of the Kawr section**

## Stop

Stop 5.1- Upper Triassic reefal platform margin of the Kawr Group (fig. 27).
The sequence is underlain by a thin and only locally exposed level of black basaltic lava forming elsewhere the stratigraphic base of the Kawr group (the volcanic formation of Pillevuit, 1993; Béchenec, 1988).
The volcanic formation is dated as Ladinian to Carnian by Pillevuit (1993). It is similar to the Haybi volcanics of Searle et al., (1980) and is in my opinion a stratigraphic counterpart of the Lower Carnian volcanic basement of the Haliw formation and the Aqil exotic blocks (see January 9, afternoon stop). Above the lavas follow 25m of thick-bedded fine-grained light coloured shallow water limestones with some reddish bioclastic beds at the base and rare oncoidal and lamellitic layers in the top (Bernecker, 1996). This package is interpreted as a time-correlative lagoonal representative of the Aqil reefal limestone unit of Lower Carnian age. It is followed disconformably by a new sedimentary cycle attributed to the Misfah Formation s. str. The sharp and erosional contact is indicative of a pronounced sequence boundary (fig. 27) corresponding to the Upper Carnian drowning event of the Aqil blocks.
A careful survey of the base of the Misfah formation has led to the vertical discrimination of 1) a thin basinal interval (about 5m) overlain by 2) allodapic lower slope deposits (50m) changing into 3) reefal limestones (appr. 100m) which are finally topped by 4) cyclic bedded lagoonal megalodont-bearing limestones of several 100m in thickness (fig. 27). By a rich conodont fauna in member 1, composed of *Metapolygnathus polygnathiformis* and *M. nodosus*, the base of the Misfah formation as well as its reefal fauna could be dated as top-Carnian (Tuvalian 3). In sequence stratigraphic terms, member 1 is interpreted as the maximum flooding surface of a late transgressive system tract, members 2 + 3 as early highstand system tracts and member 4 probably as late HST of a pronounced and widespread developed Tethyan Upper Carnian sequence corresponding to the UAA 3.2 third-order cycle of Vail et al. 1991.

**Member 1** is dark grey coloured and characterised by a rich representation of crinoid ossicles and bedding parallel orientated disarticulated shells of large brachiopods. Packstones with rare filaments change to grainstones with unsorted mm-sized reefal bioclasts towards the top.
The allodapic **member 2** is rich in litho- and bioclasts of reefal origin and echinoid remains (club shaped "*Cidaris*" spines of cm-size).
**Member 3** is developed as massive light coloured limestone with a variety of reefal environments described in detail by Weidlich et al. (1993). The lower half is still rich in echinid spines and shows local shell concentrations of bivalves, brachiopods and rare ammonites (*Arcestes, Megaphyllites*). Debris of reef organisms is most common but in-situ patches seem to be rare. Section-up larger skeletal frame works of cereoid and dendroid corals with subordinate calcisponges, solenoporaceans and chaetetids are bounded by frequent spongiostromata crusts (Weidlich et al., 1993). The uppermost part of member 3 shows a gradual reduction of reefal organisms and at the end changes to a megascopicly fossil-poor massive lithoclastic grainstone.
The boundary to the lagoonal **member 4** is sharp and represents a diastem. Well differentiated decimeter to meter thick pack-and grainstone beds with incomplete Lofer cycles (supratidal member missing) are rich in disarticulated and reworked as well as in-situ megalodont shells. This typical lagoonal platform facies is well comparable to the Norian Dachstein limestone of the Northern Calcareous Alps in Austria. The thickness of this monotonous main mass of the Misfah formation exceeds 700m (Pillevuit, 1993) and forms the prominent steep walls of the surrounding mountains (Jabal Misfah, Jabal Misht).

## January 10, Afternoon: Jabal Misfah

By F. Béchennec, J. Marcoux and R. Maury

**Routing** (fig  25).
Jabal Misfah is very close in distance to the Djebel Kawr profile examined in the morning, but as it is no practicable road we have to go back and turn all around the Jabal Kawr and take a small road going to the village of Misfah

**Stratigraphy** (fig. 28)
**The volcanic formation**, tectonically truncated at the base, is well developed in Jabal Kawr, Jabal Ghul and Jabal Misfah, particularly on the eastern flank of this mountain. It is composed of a series, up to 100m thick, of massive basalts and less commonly pillows, trachyandesite, hyaloclastites and tuffites. Locally, cutting the base of the shallow-marine carbonate series, is a breccia-pipe including carbonate fragments, basalt , gabbro and rare peridotite blocks associated with a lava lake; furthermore, sills of sodic trachyte are interbedded with the limestones (Béchennec, 1988).

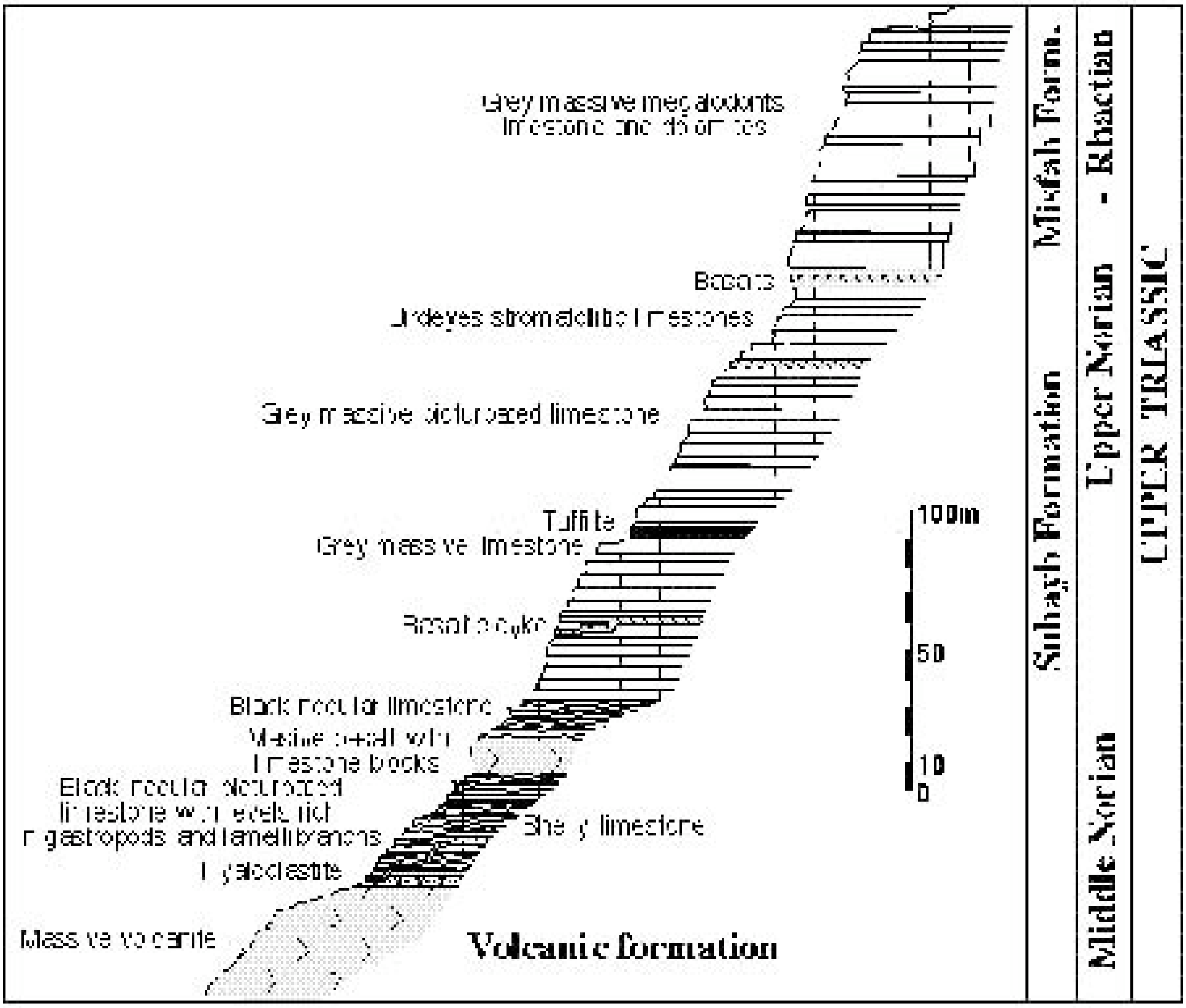



**Fig. 28- Stratigraphic sketch of the Misfah section (modified after Pillevuit et al., 1997). The Norian-Rhaetian age is based on the new data of L. Krystyn (in the text).**

**The Subayb Formation** (Pillevuit, 1993) is characterised by 80 to 100 meters (150 meters in Jabal Sawda) of thinly bedded black to yellow marly nodular limestones (Fig. 21). In the Jabal Misfah this sedimentary sequence is cut across by numerous massive basaltic dikes and sills, and in some places, conglomeratic tuffites including limestones and basaltic boulders are intercalated. A Ladinian-Carnian age was based on the occurence of the following benthic foraminifera: *Aulotortus praegashei* (Koehn-Zaninetti, 1968), *Trocholina* sp., *Nubecularia* sp., *Gsollhergella* spiroloculiffirmis (Oravezne-Scheffer), *Aulotortus planidiseoides* (Oberhauser, 1964), *Lamelliconus multispirus* (Oberhauser, 1957) and *Lamelliconus procera*? (identifications by L. Zaninetti & R. Martini). There are also centimetre sized megalodonts, giant (up to 30cm long) helicoidal gastropods and plants remains in the lower parts of the formation.

Recently, the age of the Subayb Formation has been revised and attributed to the Middle-Late Norian on the base of a brachiopod fauna collected by L. Krystyn and determined by M Siblik. The Subayb formation is a lithologic and most probably also stratigraphic counterpart of the " dark grey limestones with recristallized corals" intercatated as individual member into the thick pile of stromatolitic and Megalodon-bearing limestones of Jabal Kawr (Bernecker, 1996).

**The Misfah Formation** is the most conspicuous formation of the Kawr Group. It measures 500 to 600m in thickness and consist of thick massive grey meter-bedded grey platform limestones, grey Megalodon-bearing and stromatolitic limestones. In the Jabal Misfah, this sedimentary sequence is locally interrupted by two levels of red paleosoils, and locally by basaltic sills and dykes. The top of the sequence is mainly composed of loferitic or locally oncoid-rich limestones. The base of this formation was dated as Ladinian-Carnian by benthic foraminifera (*Aulotortus praegashei*, Koehn-Zaninetti, 1968 and *Diplominidae* sp., identifications by L. Zaninetti & R. Martini) but recently revised as topmost Norian-Rhaetian by L. Krystyn. The top of the formation has been dated Norian-Rhaetian by Béchennec (1988) and Glennie et al. (1974) who also mentioned fauna that could indicate an Early Liassic age.

**The Fatah Formation** overlies the Misfah Formation but is preserved in only a few places, like in Jabal Kawr (Minoux & Janjou, 1986; Béchennec et al., 1992b) and Jabal Hamrat al Hasan (Le Métour et al., 1991). The facies of this formation is represented by Rosso Ammonitico-type limestones, generally not thicker than 1 meter, but up to 6m in places (Figs. 23-24). The limestones are grey and red nodular and condensed with corroded ammonoids. A manganiferous hard-ground rich in ammonoids and belemnites, which locally comprises an organic rich detrital unit composed with fish bones and teeth, is generally observed at the base of this formation. The age of this formation ranges at least from the Late Toarcian in Jabal Kawr (Béchennec et al., 1992b; 1992c) to the Late Early Bajocian (*Emileia* sp. with thin costa indicating the upper Laeviuscula Zone; identification by R. Enay) for the top of the formation based on an ammonite found at Jabal Hamrat al Hasan.

## Stop

**Stop 6.1:** Panorama and outcrops of the Triassic units of the Jabal Misfah (fig. 28)
The volcanic rocks developed in Jabal Misfah shows alkali basalt compositions (Béchennec, 1988; Béchennec et al., 1991; Pillevuit 1993; Maury et al., 2001). The pillows from the lowermost part of the pile and the lower sill interbedded in the limestone series, are moderately to consistenly enriched in the most incompatible elements, and classify among the high-Ti basalts of intra-plate tholeiitic type, commonly found in trapps, plateaus, seaward-dipping reflector sequence and ocean island. The rocks from the upper part of the volcanic pile, i.e the middle and upper sills and the summital lava lake are typical alkali basalts. The temporal evolution from plume-related tholeiites toward alkali basalts is often documented in ocean islands, where they change usually results from a decrease of partial melting of their mantle source.

A Ladinian-Carnian age was assigned to this formation (Béchennec, 1988; Pillevuit 1993) based on benthic foraminifera found in a few intercalated layers of black nodular limestone in the upper part of the formation: i.e. *Turriglomina mesotriasica*?, *Involutina* sp., *Involutina eomesozoica* (Oberhauser), *Triadodiscus eomesozoicus* (Oberhauser, 1957) and *Aulotortus praegashei* (KoehnZaninetti, 1968), (identifications by L. Zaninetti & R. Martini). The presence of *Turriglomina* indicates an open marine environment (L. Zaninetti, pers. com.). .). But according to L. Krystyn, the age is preferably Middle-Late Norian due to the presence of a small shelly fauna including the brachiopod *Spiriferina griesbachi* Bittner (det. by M.Siblik). This form is widespread in top-Middle Norian to Upper Norian strata of the Himalayas and has also been described from Norian strata of the Musandam peninsula (Hudson & Jeffferies, 1961).

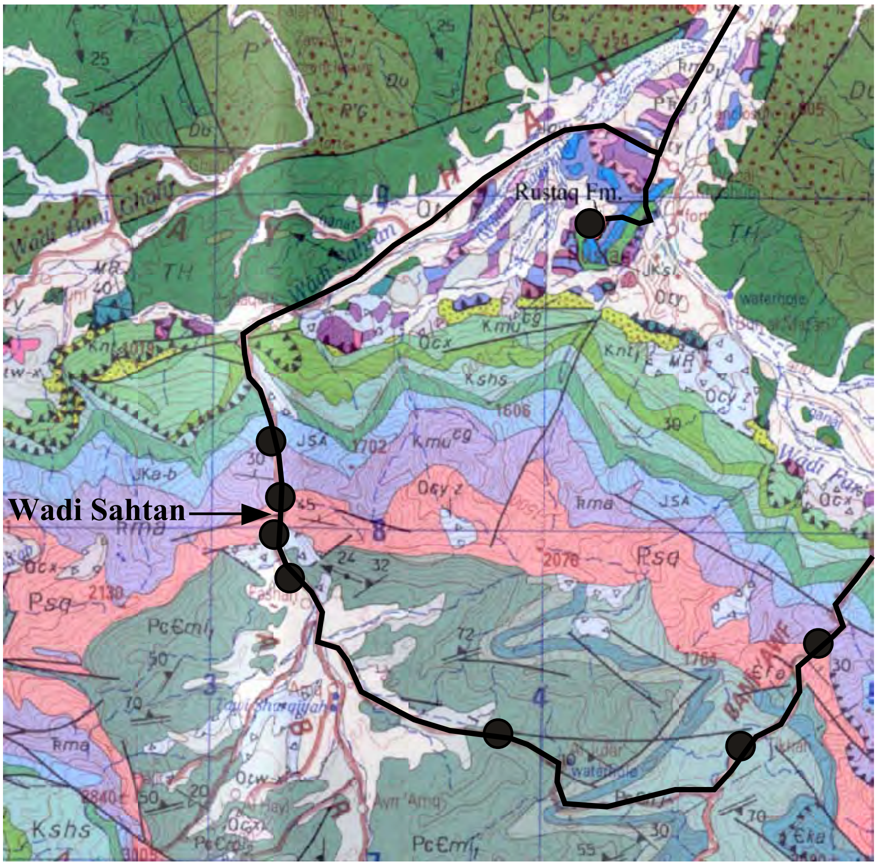



**Fig. 29- Geological map of Wadi Sahtan area (NW part of Jabal Akhdar), Grid: 10km. (map Seeb, Béchennec et al., 1992b), with the itinerary and the main stops (black dots).**

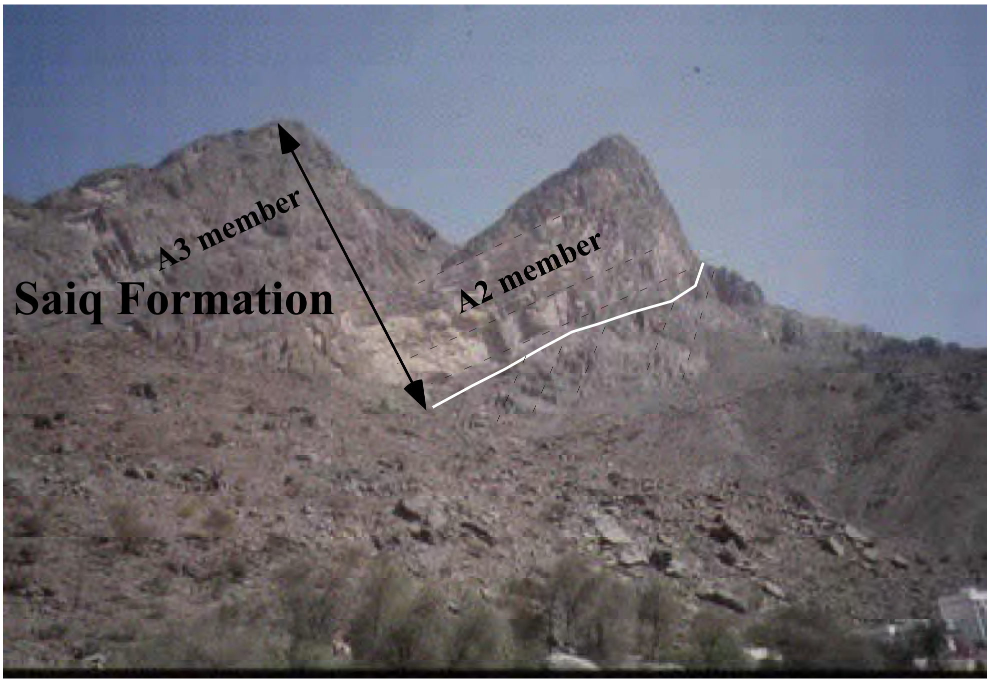



**Fig. 30- Transgression (white line) of the Saiq Formation with angular unconformity, on the infra-Cambrian - Cambrian Mistal Formati**

## January 11: The Permian-Triassic shallow carbonate platform in Wadi Sahtan (Jabal Akhdar)

By A. Baud and S.Richoz.

Routing **(fig 29)**

**The examined sections for the present study are located in the Wadi Sahtan valley, about 4 km North of Fashah village near the road linking Fabaqah to Fashah villages. 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.**

### 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 shallow-marine carbonate occurring in this area were included into the Akhdar Group (Glennie et al., 1974), with two main formations: Saiq and Mahil (fig 31).

### Stratigraphy.

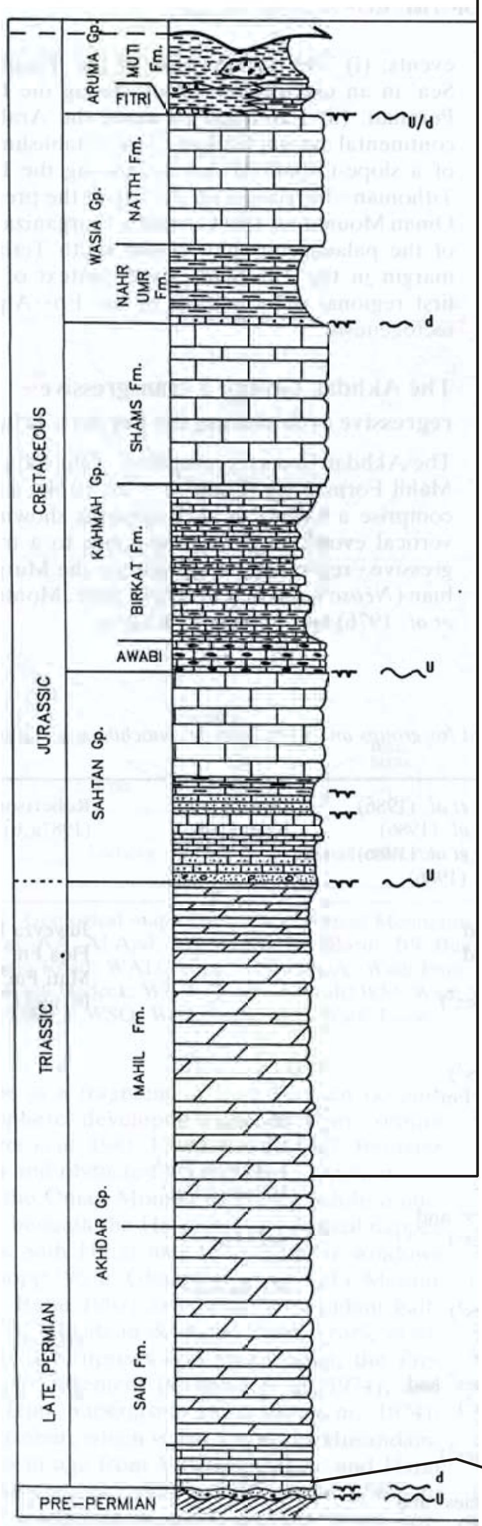
The Saiq Formation, described by Glennie et al. (1974), Montenat et al. (1976) and Rabu (1988), among others, overlies unconformably Precambrian strata (fig. 30), documenting the Late Permian marine transgression. In the Jabal Akhdar Mountains the basal member of the Saiq Formation, made up of terrigenous detritus occur only locally and may reach up to 20 m thick (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 31). The main part of the Saiq Formation is affected by pervasive dolomitization which overprinted 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). There is a 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 (Glennie et al., 1974; Rabu et al., 1990; Béchennec et al., 1992). The Triassic age of the Mahil Formation was attributed on the basis of foraminifera from some levels of oolitic beds, occasionally occurring ihigh 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.

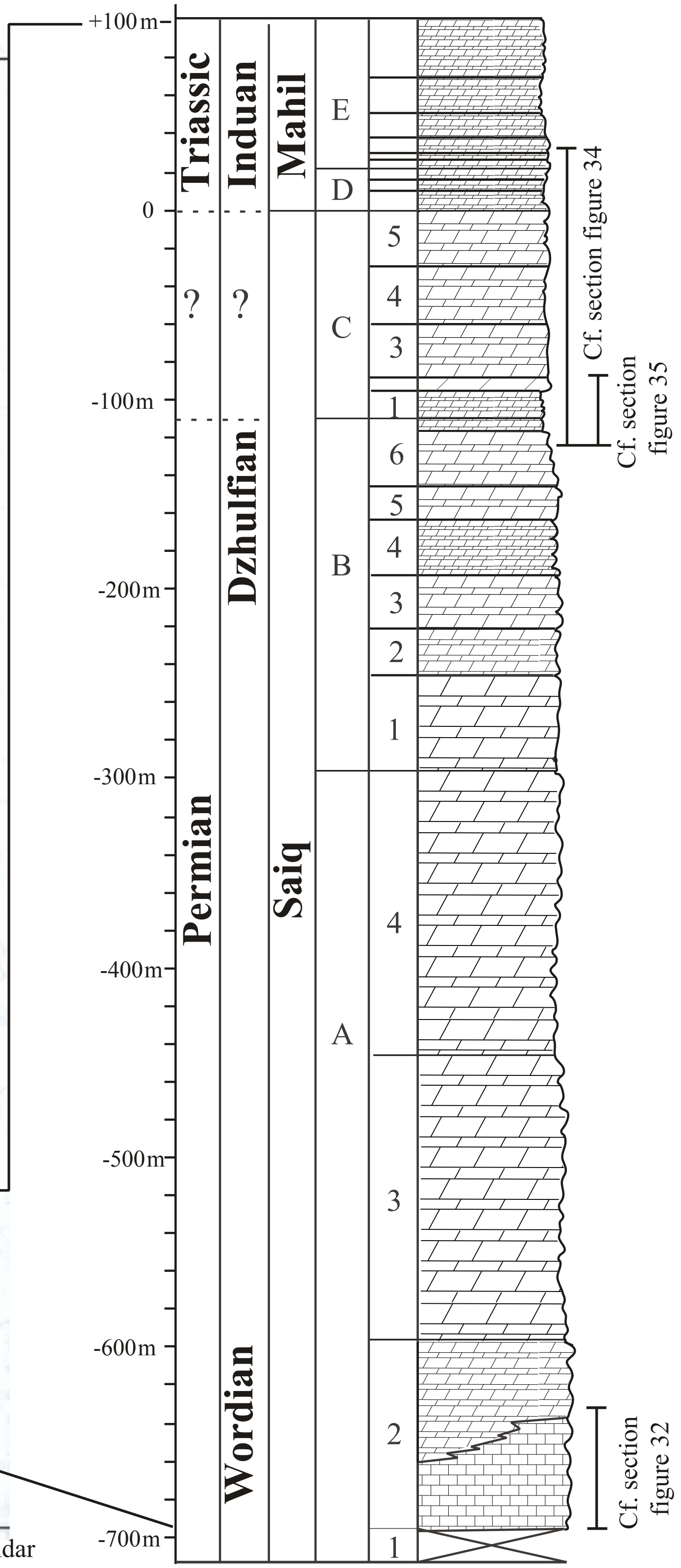
The Permian-Triassic section shows a 1500m thick pile of shallowing upward cycles (fig 31). The Saiq Formation is about 700m thick and consists of three main T-R cycles (2$^{nd}$ order cycle).

The lower part of the Saiq Formation with the T-R cycle A, 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).
- 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.




Lithostratigraphic column of the Jebel Akhdar carbonate plateform. (From Rabu et al. 1990)




Lithostratigraphic column of the Saiq and base of the Mahil Formation

**Figure 31- Composite stratigraphic sections in Wadi Sahtan (Jebel Akhdar)**

The upper part of the Saiq Formation (300 m) consist of two T-R cycles noted B and C (figs 31, 34, 35). Both cycles are mainly made up of dolomitized high energy calcareous sands:

- The T-R cycle B is about 190m thick.
- The T-R cycle C is only 90m thick with no age diagnostic.
- 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 are present in the unit D of the Mahil Formation. *Cyclogira* and *Earlandia* were identified in three samples from unit D2 indicating an Early Triassic, Induan age.

**Isotope stratigraphy** (fig 34)**:**
$\delta^{13}C_{tot}$ and $\delta^{18}O$ isotopic profiles in Wadi Sahtan have been obtained by Atudorei (1999) and completed only recently. We can clearly see a negative shift at the top of the unit B of the Saiq Formation from +3.5‰ to +1.5‰. Then values stay quite constant between +0.9‰ and +1.9‰ in the unit C. In the Unit D (base of the Mahil Formation) values show a great variability but an increasing trend up to +4.0‰. can be clearly distingished
All biostratigraphically well-constrained isotopic profiles in the Tethys, show a strong negative shift just before or at the Permian-Triassic boundary and an increasing trend during the Late Griebachian-Early Dienerian. With respect to that evolution, we assume the Permian-Triassic boundary to be located at the contact between unit B and C of Saiq Formation. Furthermore a Late Griebachian-Early Dienerian age for the unit D of Mahil Formation corresponding to the Induan age given by foraminifera is proposed.

## Stops

The Wadi Sahtan section shows a 1500m thick pile of shallowing upward cycles. The Saiq Formation is about 700m thick and consists of three main T-R cycles (2nd order cycle).

**Stop 7.1**: Panorama of the transgression of the Saiq Formation with angular unconformity (fig 30).
The Wordian part of Saiq Formation is lying on Mistal Formation, probably Cambrian in age.

**Stop 7.2**: Stratigraphy of the lower part of the Saiq Formation at the entrance of the Wadi Sahtan Gorge This section will be presented by L. Angiolini (fig 32).
The A2 unit is calcareous in the lower part and dolomitic in the upper part with oblique front of dolomitisation. The lower part is very fossiliferous and have been studied and sampled by L. Angiolini, M. Balini and A. Nicora.. A. Nicora determined the conodonts.
Different fossil groups have been described in detail by Montenat et al. (1976). As mentionned above, according to these authors and to Lys (1988) the age is Middle Murgabian (Wordian). Thin bedded dolomites with vugs indicate emersive conditions at the top.

We can see a clear irregular front of dolomitisation (fig 33). V. Atudorei sampled the irregular front of dolomitisation for isotope studies (Atudorei, 1999). A. Baud and S. Richoz studied the upper part of the T-R cycle A.

**Stop 7.3:** Stratigraphy of the middle part of the Saiq Formation.
The T-R cycle B, about 190m thick, is characterized by thick bedded high energy dolomitic packstone to grainstone in the lower part (units B1 to B3) (fig 37) and by thin bedded shallowing upward sequences in the upper part (units B4 to B6) (fig 38). Fusulinids, small forams, bryozoans, crinoids, bivalves are the main fossils. There is at least 3 levels with fascicultate corals in the upper unit B6. The top of this unit that is the regressive part of cycle B is made up of dark thin bedded dolomitic mudstone, clay horizon and supratidal breccia. According to the presence of the foraminifera *Hemigordiopsis sp*. and the calcareous algae *Permocalculus sp*. (determination C. Jenny) the age of the upper part of the Cycle B is Lopingian, probably Dzhulfian (Wuchiapingian) (figs 35, 36).

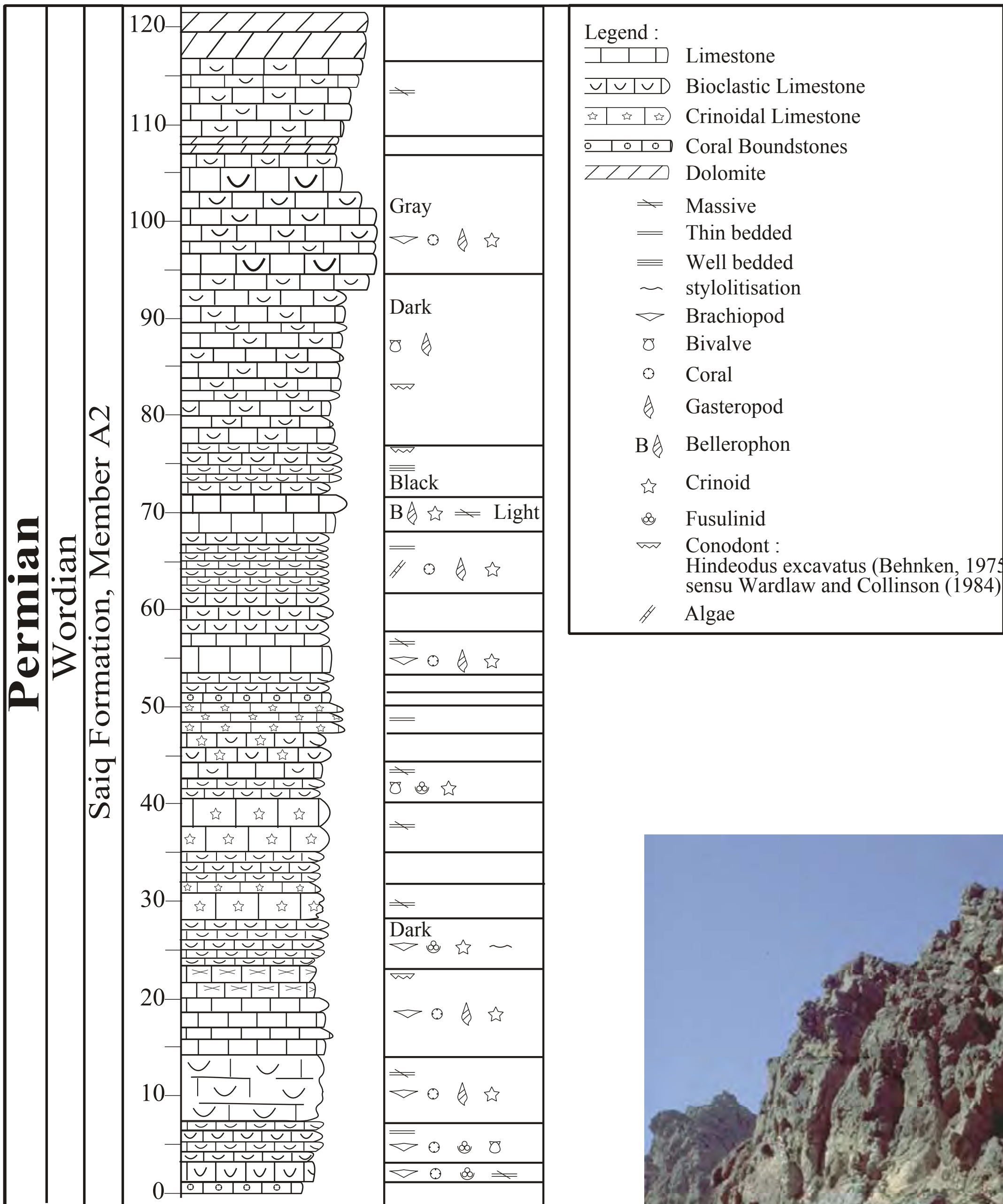



**Figure 32- Lithological sktech of the lower part of the Saiq Formation (unit A2). (Field work of L. Angiolini, M.Balini. and A. Nicora. Conodonts determination by A. Nicora).**


**Figure 33- The oblique front of dolomitisation in unit A2 of the Saiq Formation.**

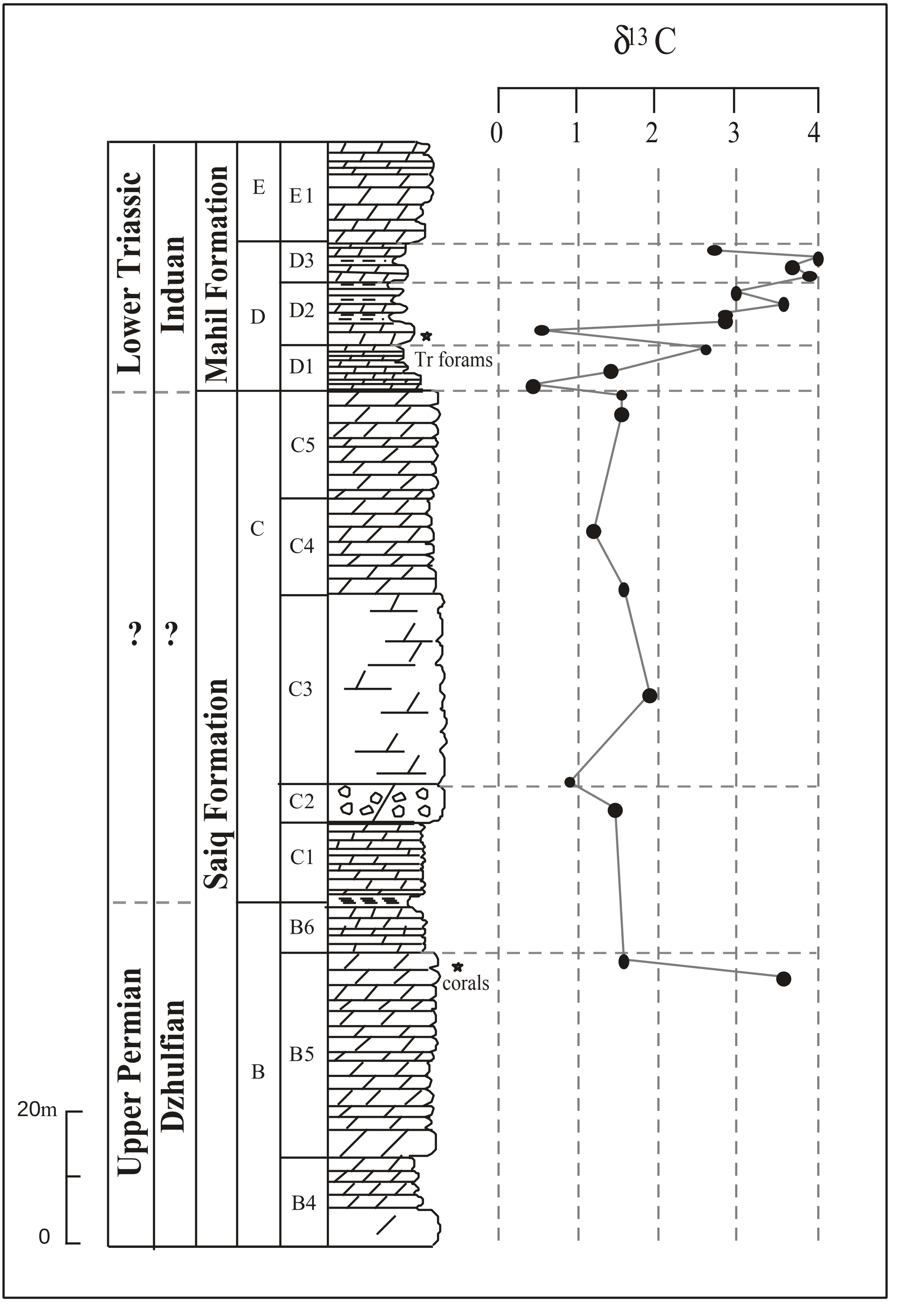



**Figure 34- Lithology and Carbon istope profile of Wadi Sahtan section. (modified after Atudorei, 1999)**

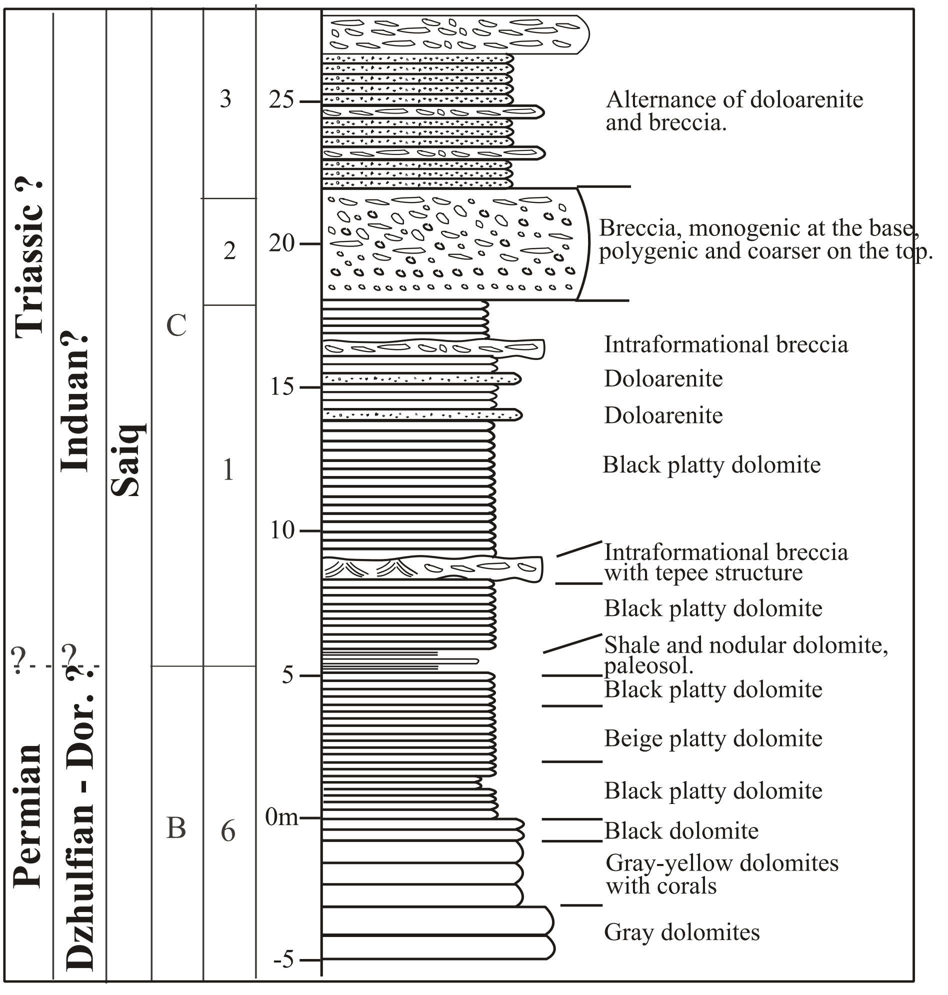



**Figure 35- Lithostratigraphic section of the transition between cycle B and C. (Saiq Formation). A presumed Permian-Triassic Boundary.**

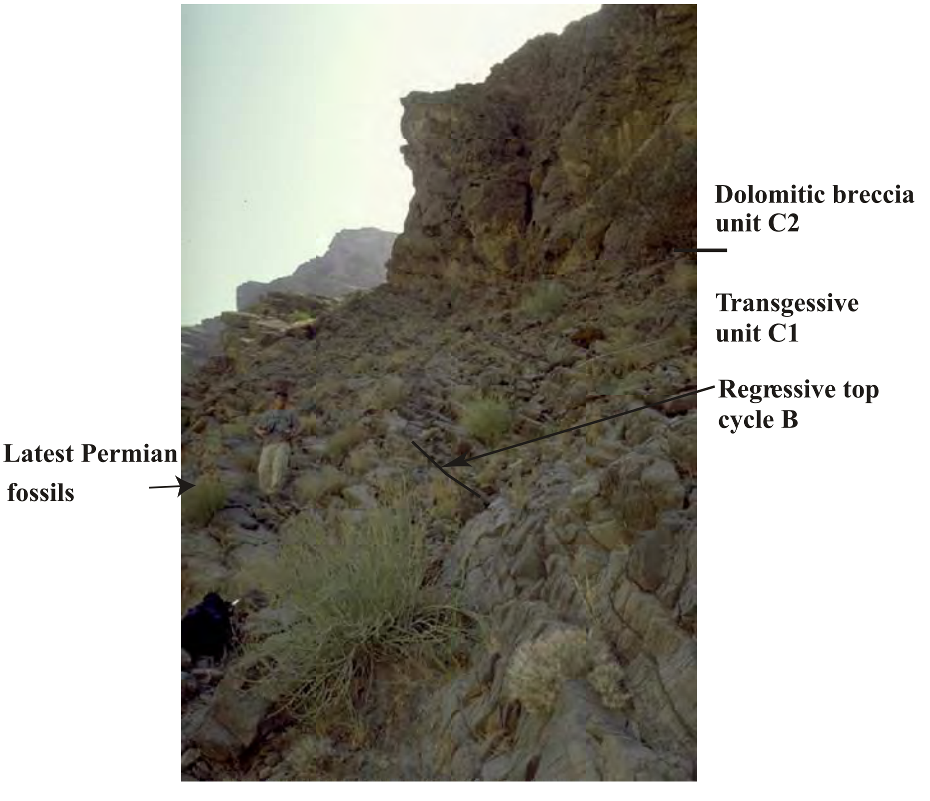



**Figure 36- Transition between cycle B and C, Saiq Formation. A presumed Permian-Triassic Boundary.**

**Figure 37- Cycle B of Saiq Formation (Upper Permian)**

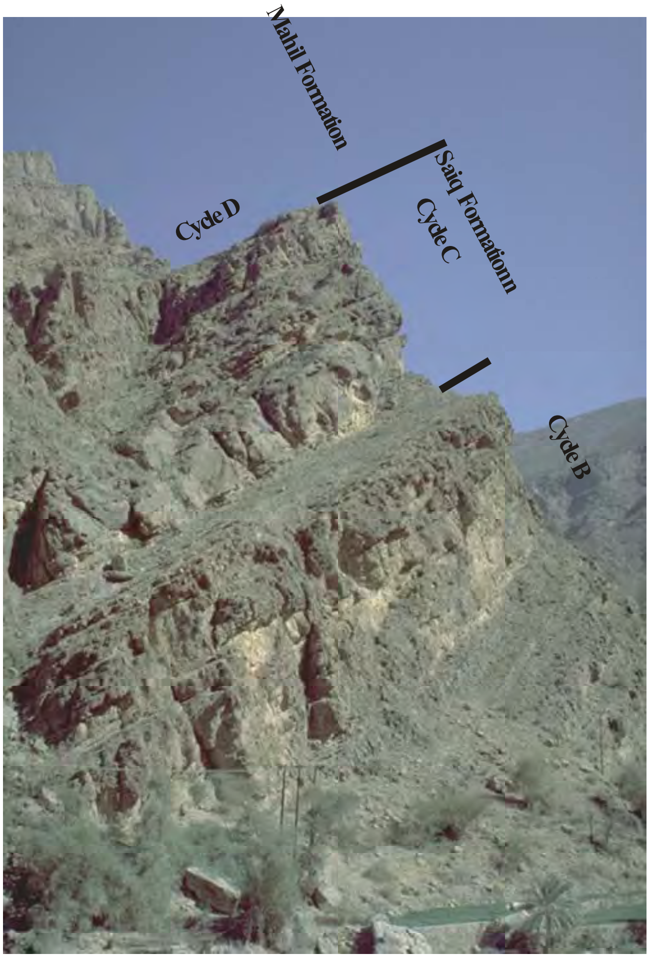



**Figure 38 Transition between cycle B and C of Saiq Formation (Permian-Triassic boundary ?), cycle C (about 90m thick) and the lowermost part (cycle D) of Mahil Formation.**

**Stop 7.4:** The upper part of the Saiq Formation (Lopingian).
The T-R cycle C is beginning with a 5m thick dolomitic breccia overlying thin bedded supratidal dolomite (fig 35, 36). The main part of this cycle, about 70m thick (fig 34, 38) is made up of recristalized dolomitic intraclastic grainstone with unrecognisable bioclasts (algae?, forams?). There is no age diagnostic fossils for this cycle.

**Stop 7.5:** Transition to the Mahil Formation and lower part (Induan) of Mahil Formation (fig 38).
We will examine the top of Saiq Formation that is marked by an irregular surface of hardground type, indicating an interruption in sedimentation, possibly with subaerial exposure.
Overall, both D and E units of the Mahil Formation consist of gray and yellowish peritidal dolomites and dolomitic limestones and are characterized by terrigenous input with horizons of fine silt or purple clay.
Unit D starts with a bed of dolomitic conglomerates up to 0.6m thick reworking underlying unit, overlaid by a 0.3m thick bed of black dolomites with columnar stromatolites. These two beds are distinctive for the base of the Mahil Formation. The sequence grades upward to thinly bedded dolomites with ripple marks structures, yellowish dolomitic marls and several levels of dolomitic paleosoils and purple clays. Algal-bacterial structures as laminites and stromatolites are common features of the Mahil Formation. Very small foraminifera and bivalves are present in the unit D of the Mahil Formation. *Cyclogira* and *Earlandia* were identified in three samples from unit D2 indicating an Early Triassic, Induan age.
Unit E exhibit similar sedimentary structures, however it is more massive and marly interbeds are rare.

**Stop 7.6:** The boundary between the Akhdar Group (Permo-Triassic) and the the Sahtan Group (Jurassic).

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**Plate 1**

Thin-sections of the upper Alwa formation (Fig. 1 from section 2 B, others from 2 a). Magnification 4x.

Fig. 1: Cross-section through part of a calcitic *Pinacoceras* shell filled of wackestone rich in juvenile ammonites, echinoderms and small fragmented cephalopod shell debris. Sample 0/02 (Upper Norian).

Fig. 2: Bioclastic wackestone with variostomid foraminifera and echinoderms and a geopetally filled burrowing. Sample 92/123 A (Upper Norian).

Fig. 3: Sponge spicules bearing wackestone with less densely packed bioclasts. Sample 96/23 (Lower Rhaetian).

Fig. 4: Finegrained sponge spicules bearing wackestone with comparably rare bioclasts, Sample 95/31 (top-Rhaetian).

Fig. 5: Inhomogeneously burrowed, sponge spicules-rich wackestone with rare bioclasts (mollusc shell debris, crinoids, microgastropods). Sample 95/32 (Lower Sinemurian).

Fig.6: Flaser-nodular and microstylolitic brecciated sponge spicules-rich wackestone with local concentrtations of juvenile cephalopod shells. Sample 96/29 (Upper Sinemurian).

**Plate 2**

Thin-sections of the topmost Crinoidal Limestone unit (1) and the Cephalopod Limestone unit (2-6) of Al Aqil exotic block 3-4. Magnification 4x.

Fig. 1: Bioclastic wackestone rich in filaments (juvenile *Halobia* shells) and microcrinoids (roveacrinids) with disarticulated brachiopods and crinoids. Sample 92/142 (uppermost Carnian),

Fig. 2: Boclastic wackestone rich in microfilaments and ironoxide impregnated foraminifera and cephalopod shell debris, with geopetally filled ammonites (*Placites, Arcestes*). Sample 92/136 B (Middle Norian).

Fig. 3: Shell debris-rich wackestone with pelagic hydrozoans (*Heterastridium*) and arcestid ammonite. Sample 92/133 C (Upper Norian).

Fig. 4: Bioclastic wackestone ironoxide imprepnated crinoids, foraminifera and cephalopod shell fragments. Sample 99/10 (Upper Norian).

Fig. 5: Densely packed bioclastic wachestone with common ironoxidic coatings. Sample 99/14 A (Upper Sinemurian).

Fig. 6: Radiolarian.rich mudstone. Sample 99/14 C (Sinemurian ?).

# Plate 1

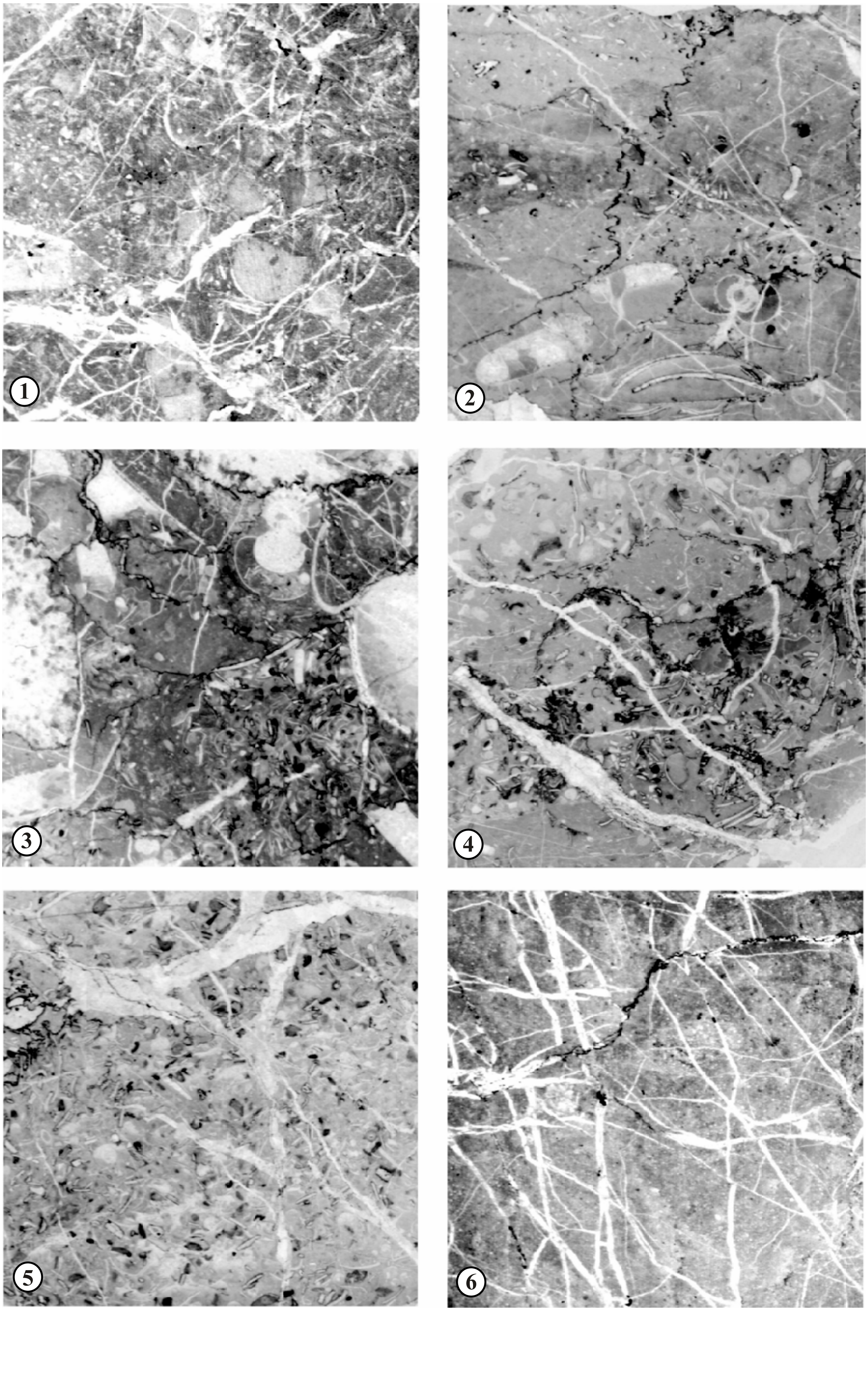

**Plate 2**