المؤتمر الدولي لجيولوجية عمان

INTERNATIONAL CONFERENCE GEOLOGY OF OMAN

Excursion B01

Permo-Triassic Deposits: from Shallow Water to Base of Slope

Leaders: A. Baud, F. Bechennec, F. Cordey, 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

Permo-Triassic Deposits: from Shallow Water to Base of Slope

Post-Conference Excursion No. B01 in the Oman Mountains
January 17 - 20, 2001

Leaders

**Aymon BAUD, François BÉCHENNEC, Fabrice CORDEY ,
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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.

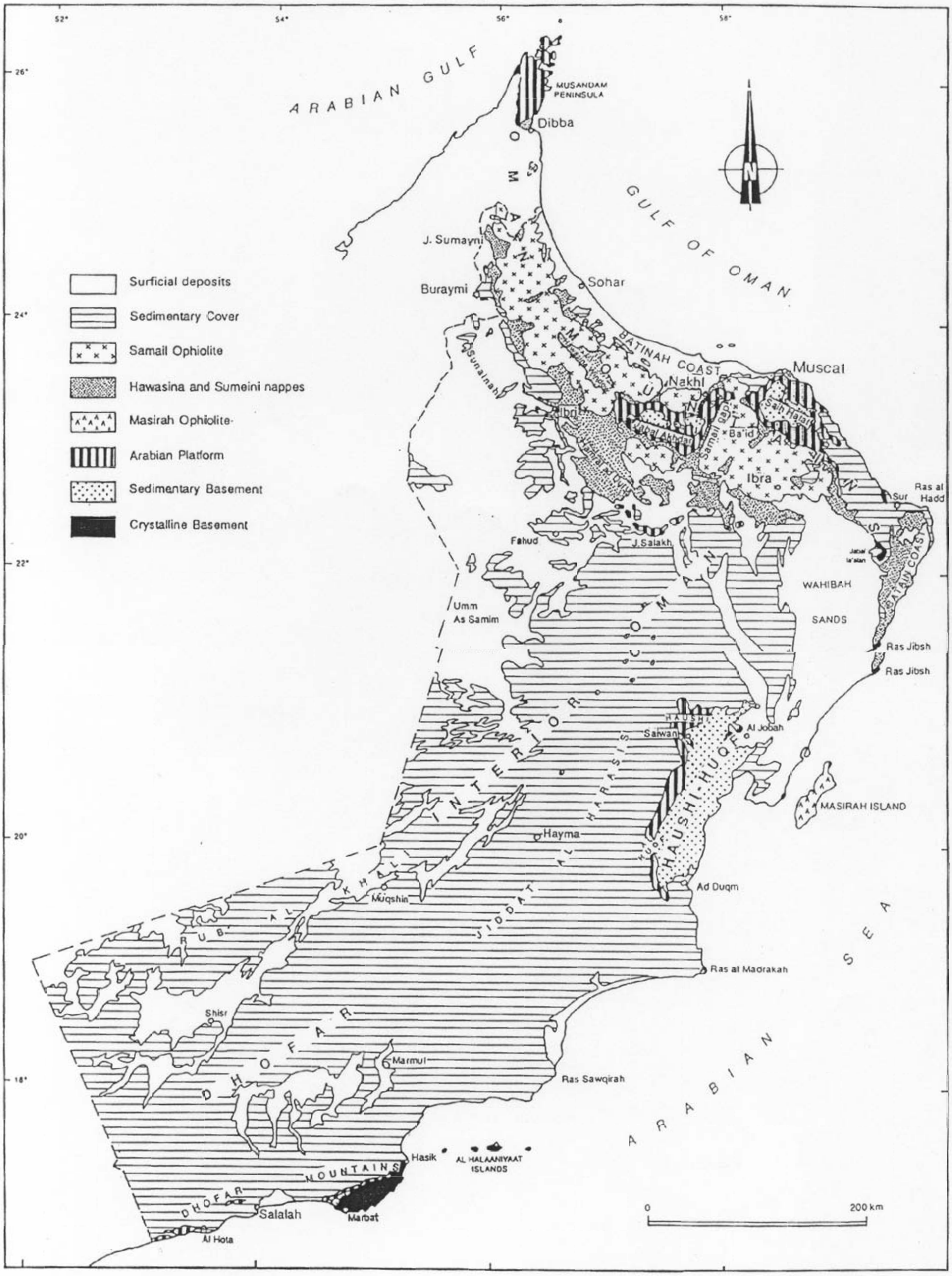


Fig. 1- Geological sketch map of the Sultanate of Oman (from Le Metour et al., 1995).

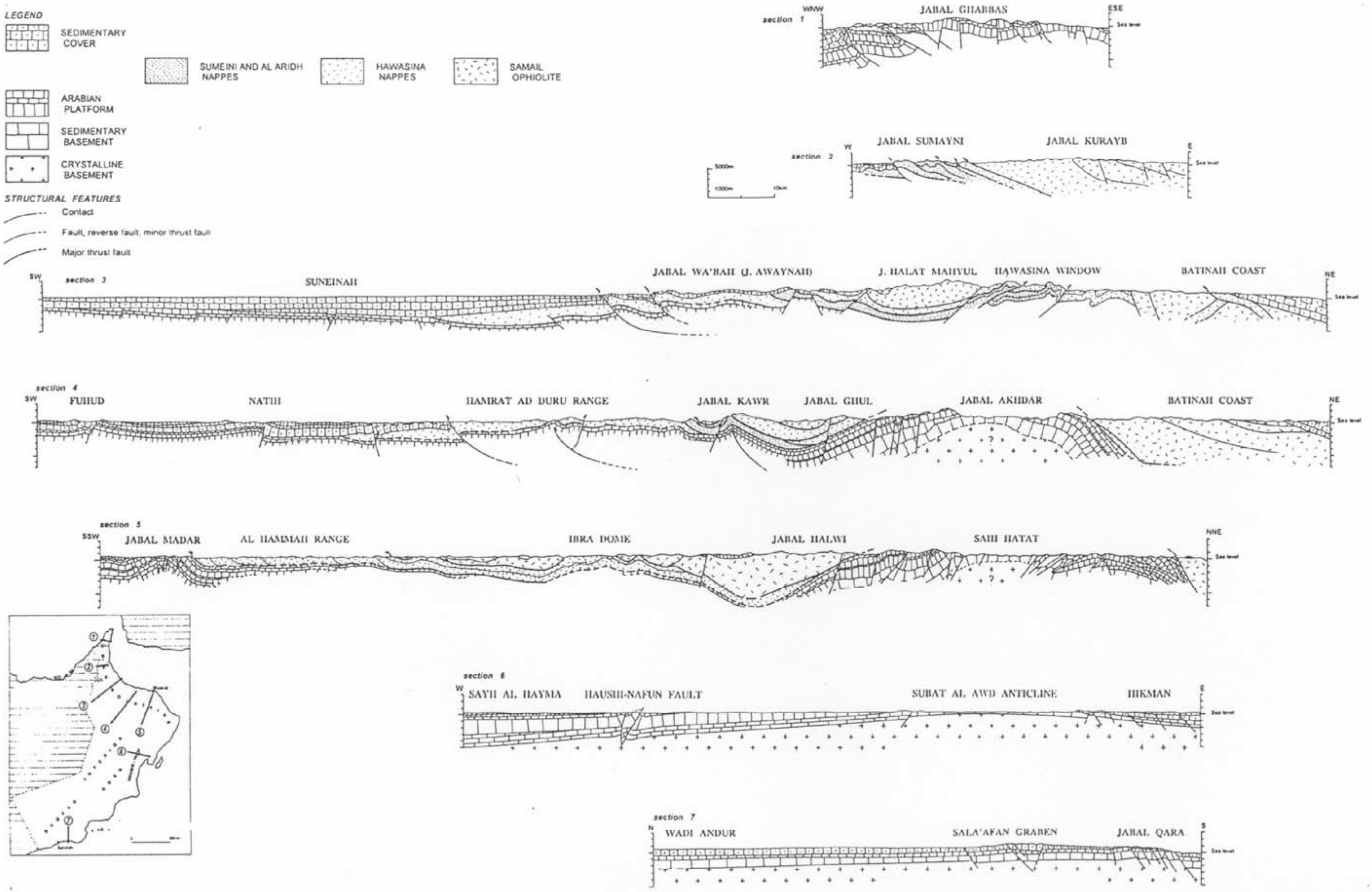


Fig. 2- Structural cross-sections from the N to the S of Oman (from Le Métour et al., 1995)

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 .

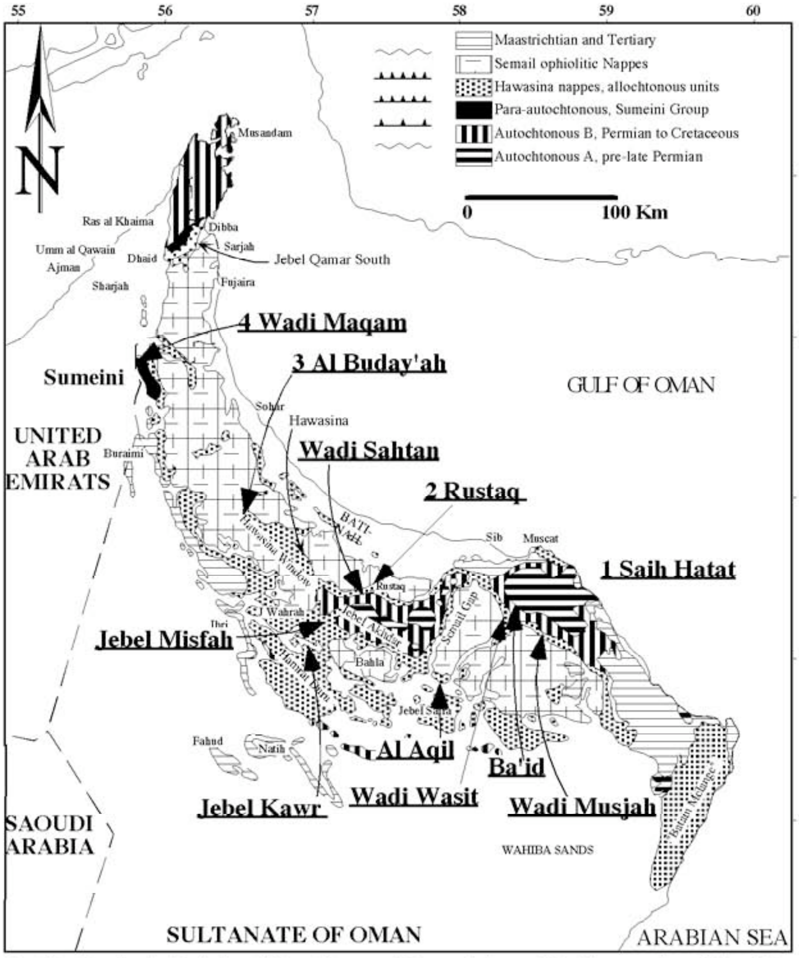


Fig. 3: Geological sketch of the Oman Mountains with the main visited localities (Excursions A01 and B01 = 1 - 4). Modified, from Pillevuit et al., (1997)

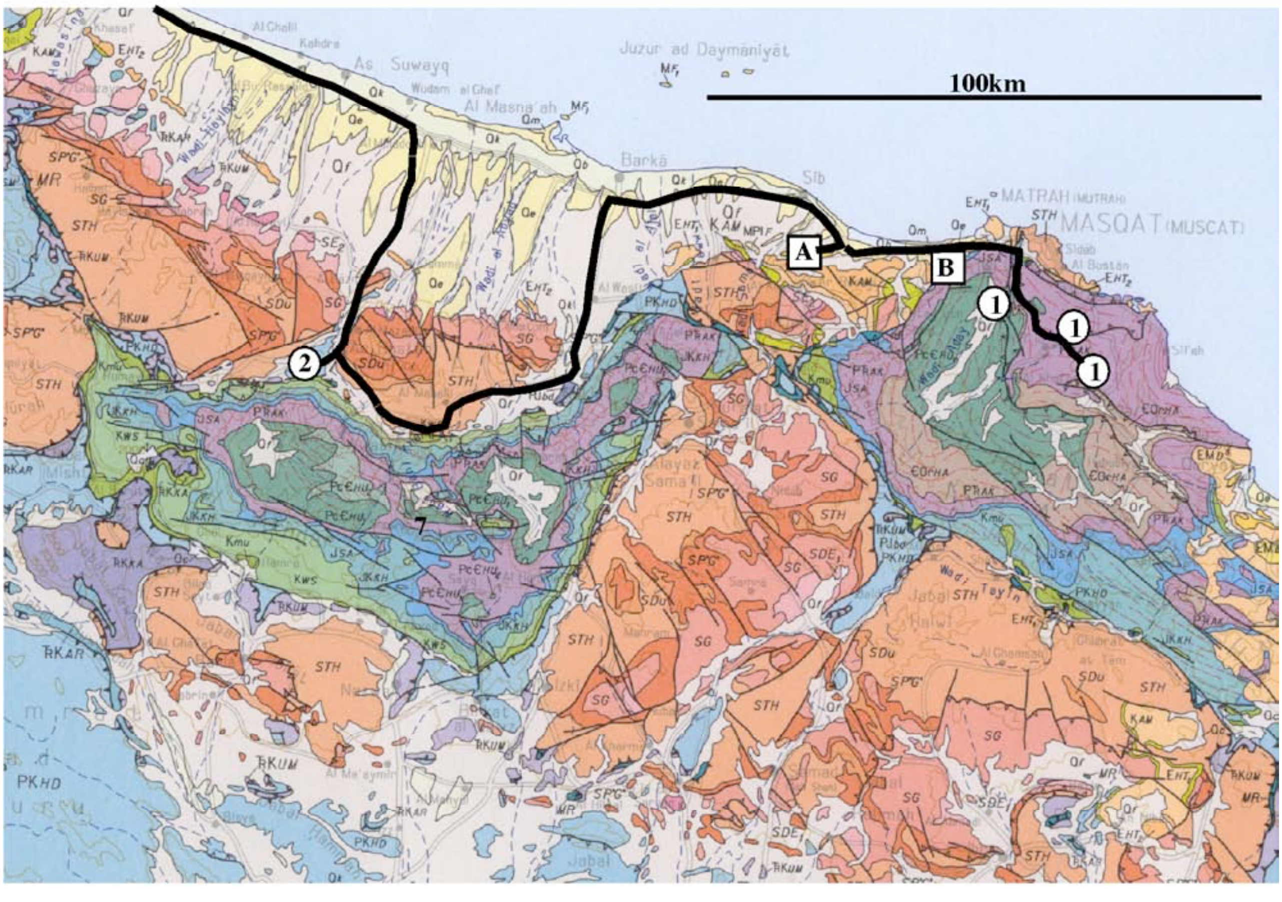


Fig. 4: Geological Map of the Field excursion B01, with the main stops (1-2) and places of overnight (A, B). Map from Le Métour et al., (1993a)

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		*postherneteini* *mosheri*	205Ma
		NORIAN		*bidentata* *steinbergensis* *serrulata* *postera* *elongata* *spiculata* *multidentata* *triangularis* *quadrata* *navicula* *primitius*	
		CARNIAN		*communisti* *nodosus* *polygnathiformis*	
	MIDDLE	LADINIAN		*mungoensis* *hungaricus* *trumpyi*	241Ma
		ANISIAN		*excelsa* *constricta* *bulgarica* *shoshonensis* *germanica* *regale* *timorensis*	
	EARLY	OLENEKIAN		*triangularis* *aff. timorensis* *sweeti* *homeri* *milleri* *waageni* *meeki* *pakistanensis*	
		INDUAN		*cristagalli* *dieneri* *kummeli* *carinata* *parvus*	253Ma
PERMIAN	LATE	CHANGHSINGIAN	DORASHAMIAN	*changxinensis* *subcarinata*	
		WUCHIAPINGIAN	DZHULFIAN	*wangi* *orientalis* *transcaucasica* *quangyuanensis* *leveni* *asymmetrica* *dukouensis*	
	MIDDLE	CAPITANIAN	MIDIAN	*altudaensis* *postserrata*	264Ma
		WORDIAN	MURGABIAN	*aserrata*	
		ROADIAN	KUBERGANDIAN	*nankingensis*	
	EARLY	KUNGURIAN	BOLORIAN	*sulcoplicatus* *prayi* *"exsculptus"*	
		ARTINSKIAN		*pequopensis* *pnevi* *postwhitei* *florensis* *whitei*	
		SAKMARIAN		*trimilus* *barskovi*	
		ASSELIAN		*fusus* *nevaensis* *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.

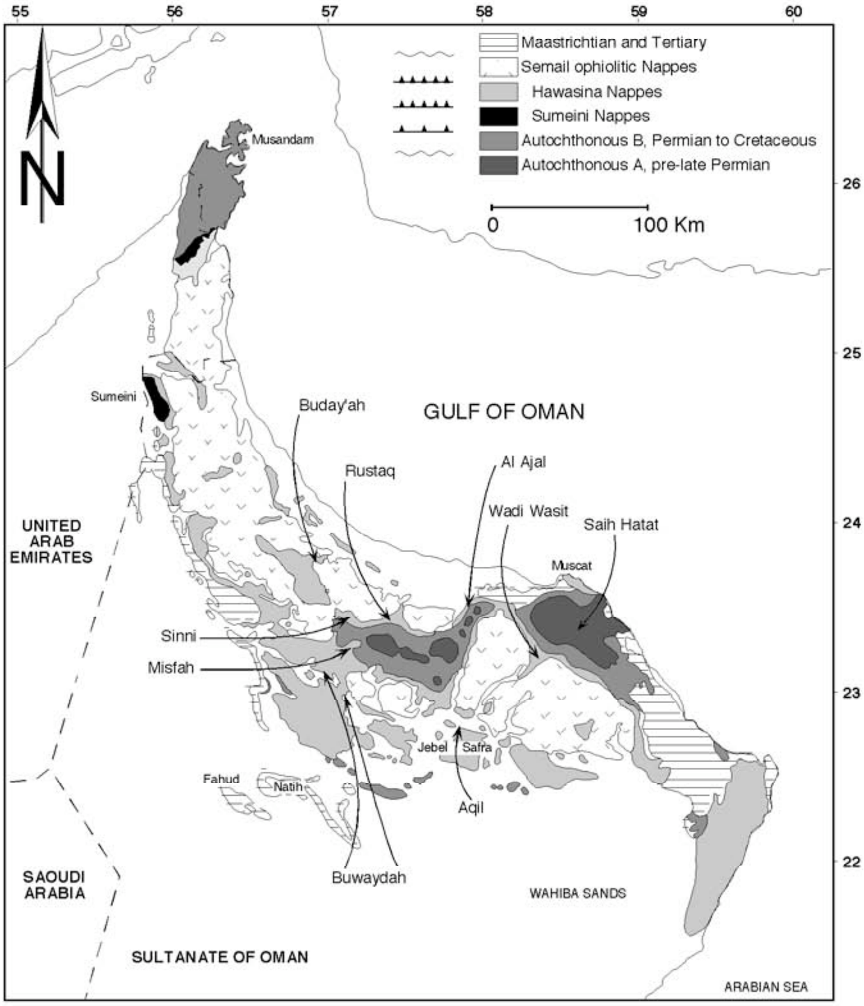


Fig. 5 -Geological sketch map of the Oman Mountains (after Glennie et al. 1974) with localities of Permian-Triassic volcanism cited in the text.

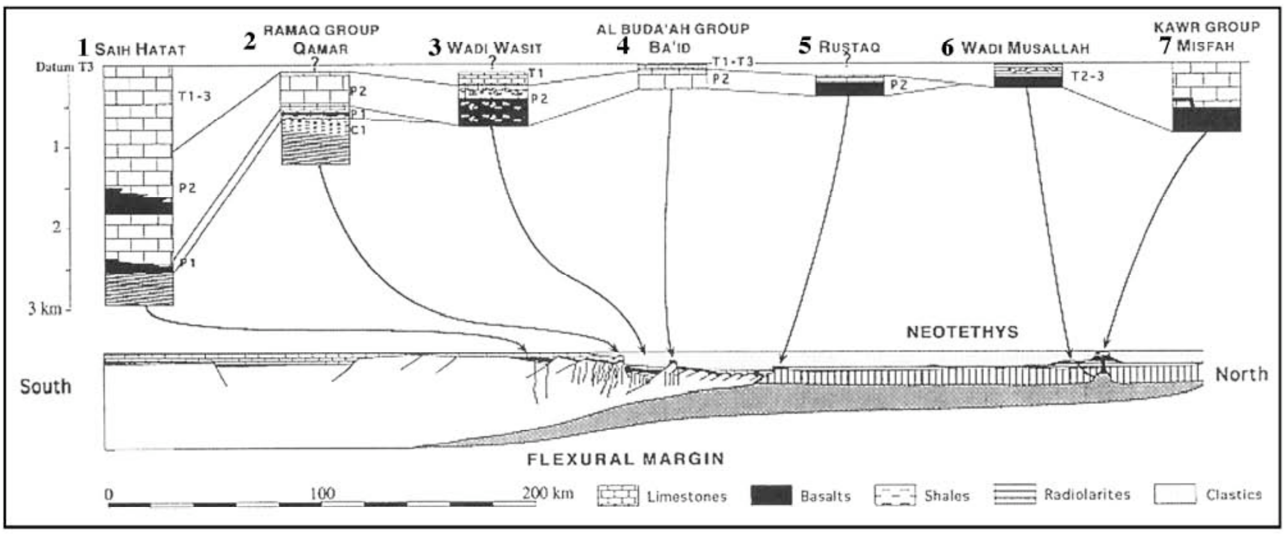


Fig. 6 -Oman margin in the late Triassic, from proximal (1) to distal (7) (after Pillevuit et al., 1997).

1.3 Carbon isotope stratigraphy *(S. Richoz)*
$\delta^{13}C$ and $\delta^{18}O$ isotope stratigraphy has been studied in 6 different sections of various environment from shallow to deep water facies zones of the Upper Permian-Lower Triassic carbonate sequences (bulk rock, new data and data from Atudorei, 1999).

Wordian carbonates have in all sections high $\delta^{13}C$ values between +3‰ and +6.6‰. These high values are still present in Capitanian to Wuchiapingian carbonates.
According to Baud et al. (2001) dated Changhsingian carbonates are present 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.

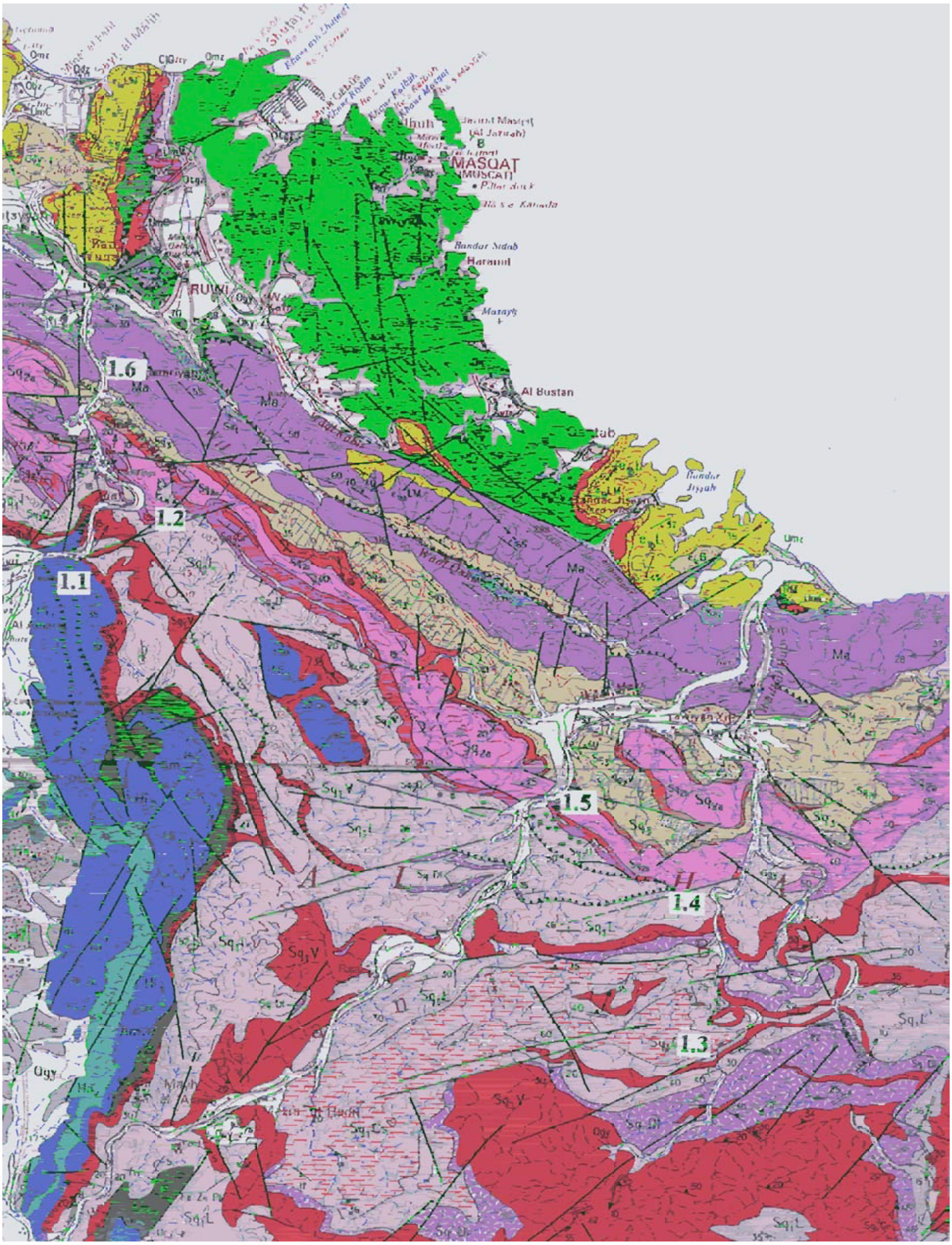


Figure 7– Geological map of the Wadi Aday – Wadi Mayh – Wadi al Hulw area, Saih Hatat region (Scale 1:100 000 ; Le Métour et al. 1986 a&b)

2. Description of the visited outcrops (fig. 3, 4).

January 17 Saih Hatat: Late Permian transgression and shallow marine carbonates of the Permian Saiq and Triassic Mahil Formations

By J. Le Métour

Routing
The outcrops and sections referred to are in the north-eastern part of Saih Hatat (fig. 7) covered by the 1:100 000 scale geological maps of Masqat and Quryat (Le Métour et al., 1986 a and b) and the 1:250 000 scale geological map of Masqat (Le Métour et al., 1992).

Introduction:
Today we visit the Saih Hatat window, begining the study of the parautochthonous unit of the Oman Mountains that we will complete at Sumeini (Jan. 19-20). We shall look at two particular aspects of the geology of Saih Hatat:
- Late Permian extension and intracontinental rifting on the Northeast edge of the Arabian platform;
- Early Triassic post – rift platform carbonate deposition on the Northeast edge of the Arabian platform.

Today's traverse enables us first of all to observe the major unconformity at the contact of the Late Permian to Turonian-Coniacian volcanosedimentary and carbonate cover with the Late Proterozoic to Middle Ordovician sedimentary basement. The following stops show the thickness and extent of the syn-rift deposits recently attributed to the Late Permian – conglomerates, rhyodacitic volcaniclastic deposits, open marine slope and base of slope carbonates. These deposits underline the tectonic and volcanic activity (intraplate extensional magmatism) of the north-east border of the Oman platform during the marine transgression of the "Fusulinid Sea".

In the north-eastern part of Saih Hatat these rocks mark the opening of the Hulw marine half-graben bordered to the west by the inner shelf of Jabal Akhdar and towards the north-east by the Hamrat Duru basin. The last stops are to see the post-rift sediments deposited in a stable internal carbonate platform environment – latest Permian bioclastic limestone and early Triassic sub-evaporitic shaly limestone and and dolomite.

We shall also be able, along today's traverse, to appreciate the effects of the Eo-Alpine deformation, that took place here in the glaucophane/crossite-epidote blueschist zone of HP/LT metamorphism (Lippard, 1983; Le Métour et al., 1986c; Le Métour, 1987; El Shazly and Coleman, 1990 ; Michard et al., 1991,). The folding, schistosity and thrust faulting that we can see are attributed to north-verging shear deformation consistent with partial subduction of the north-eastern corner of the Arabian Platform beneath the Neo-Tethyan oceanic crust (Le Métour et al, 1986 c; Le Métour, 1987; Rabu, 1987). This early Eo-Alpine tectonometamorphic phase preceded the NNE-SSW overthrusting of the Hawasina and Samail Ophiolite nappes during the Campanian. As in Jabal Akhdar, this second Eo-Alpine tectonic phase is poorly marked here, with mylonitic schistosity at the base of the overthrust sheet and minor south-verging thrust faults associated with ramp development in the parautochthonous platform unit.

Stops

Stop 1.1: **Right bank of Wadi Aday** (fig. 8) – The Permian unconformity.
The Saiq Formation, unconformably overlies the Sedimentary Basement in the Oman Mountains. Immediately overlying the unconformity are 0-20 m of conglomerate and fluvial pebbly sandstone, probably correlative with the Gharif Formation in Interior Oman. In Jabal Akhdar and western Saih Hatat, the earliest transgressive marine deposits are siltstone and bioclastic dolomitic limestone (0-30 m), with a foraminiferal assemblage dated to late Murghabian to Midian times.

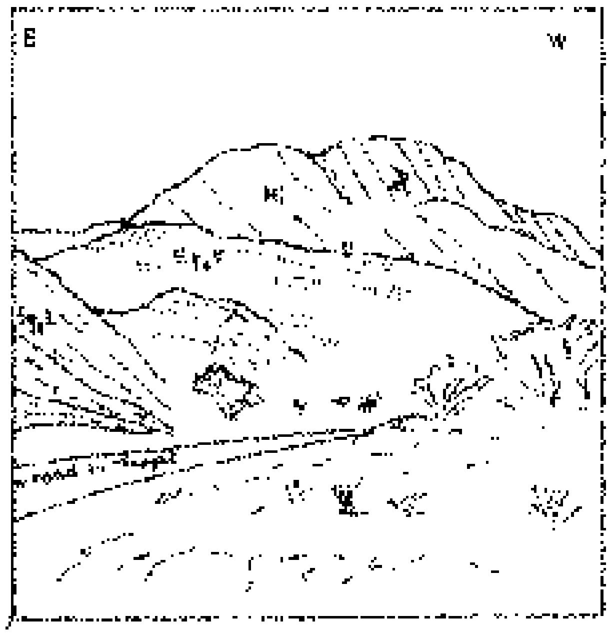


Figure 8 – Inverted, discordant sedimentary contact between the Hiyam Formation dolomite (Hi: upper part) and the Saiq Formation conglomerate (Sq_1V: lower part), south bank of Wadi Aday)

We are here on the overturned limb of a NE-verging recumbent fold that deforms the stratification and schistosity (S1) in both the Late Proterozoic and the Late Permian formations.
The inverted, discordant sedimentary contact between the dolomitic marble of the Late Proterozoic Hiyam Formation and the structurally underlying but stratigraphically higher metaconglomerate and mica schist of the Late Permian Saiq Formation. The unconformity, with an angular discordance of some 30-40°, is underlined by scouring at the base of the metaconglomerate. The basal member of the Saiq Formation (Sq1) comprises, from base to top:

• ± 20 m, poorly bedded metaconglomerate comprising flattened and stretched worn pebbles of quartz, quartzite, mica schist and dolomite in a rather scanty quartz-mica-carbonate-matrix.
• 40-50 m, discontinuous beds of metaconglomerate alternating with whitish-grey mica schist derived from marine volcanoclastic deposits of rhyodacitic composition and rare soda-dacitic lava flows.
• Interbedded mica schist and rusty-brown, then grey, calcareous and dolomitic, bioclast-bearing marbles with wavy bedding, nodular structures and chert nodules.

The marbles contain coral and crinoid debris, bryozoans and fusulinids, and are derived from open shelf carbonates. They are lateral facies equivalents of the inner shelf late Murghabian dolomitic limestone of the Sib and Fanjah 1/100 000 map areas.
The rocks in the basal unit are slope and open marine deposits laid down in the fault-bounded Hulw half-graben (fig. 1.3) that characterises the Late Permian extension and rifting of the Arabia-Iran continental landmass.

Stop 1.2: **Right bank of Wadi Aday** (fig. 7) – The Permian bimodal volcanism and platform carbonates.
In northeastern Saih Hatat, a significant volcaniclastic and volcanic sequence is present in the lower part of the Saiq Formation, between a basal layer of polymict conglomerate representing debris flow deposits, and overlying outer-shelf carbonates enclosing olistoliths (fig. 9).
The volcanic sequence consists mainly of tuffite and tuff with subordinate pillowed basaltic and andesitic to rhyodacitic lava and a microgranite intrusion, and thickens greatly from southwest to northeast (from 60 m to about 1000 m). The sedimentary rocks are syn-rift deposits laid down in a broad subsiding graben near the continental slope (Al Aridh Group deposits). The sediments were overlain, from the late Murghabian-Midian, by shallow-marine limestone corresponding to that in the upper part of the Saiq Formation in Jabal Akhdar.
The available analyses of Sq2v volcanic rocks (data from D. Maury) are strongly enriched in the most incompatible elements (group 4: strongly enriched patterns typical of intraplate alkali basalts). They are typical of high-Ti basaltic series identical to plume-related alkali basalt series

from intraplate continental or oceanic settings. They include several alkali basalts and one intermediate lava (mugearite).

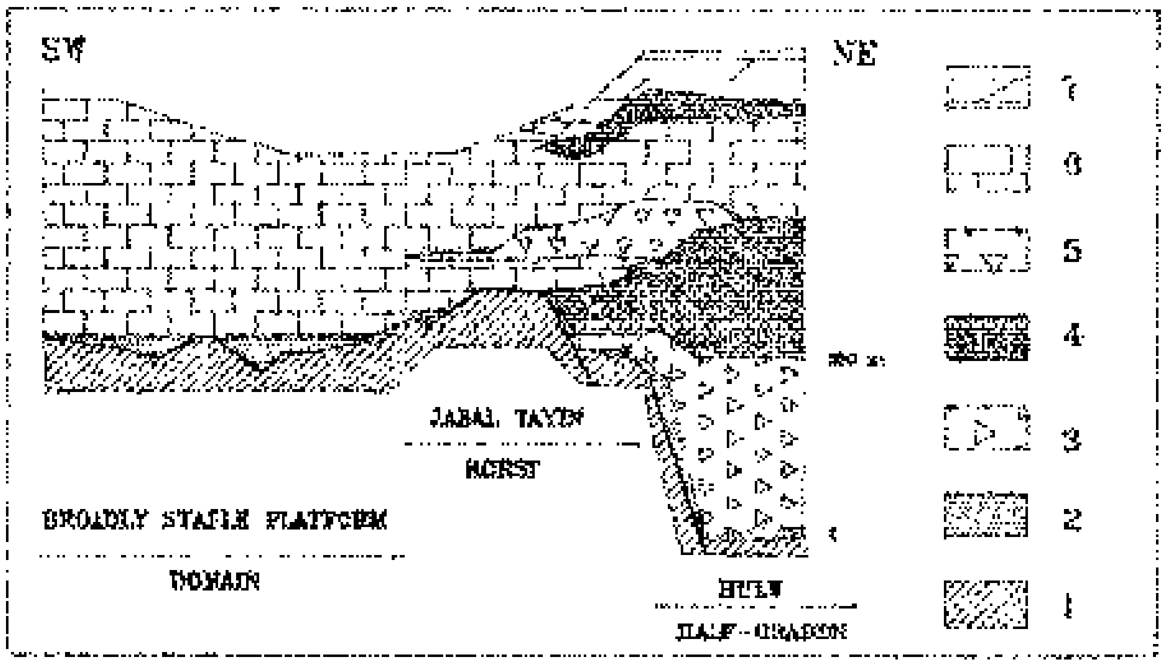


Figure 9 – Paleogeographical diagram showing the distribution of various lithologic facies on the Permian platform.1: Pre-Permian series; 2: conglomerate, sandstone and siltstone; 3: rhyodacitic tuffite; 4: external platform carbonate; 5: trachy-andesitic and basaltic lava; 6: internal platform carbonate, 7; evaporite and carbonate. Total length of the profile, 150 km.

Stop 1.3 - Hillo track, 4 km southwest of Hulw village

The sedimentary passage from the Sq1V mica schists to the Sq1L carbonates can be followed in a 500 m section along Wadi al Hulw. The sequence, from south to north, is:

• Schistose, highly recrystallised amphibolite (crossite/glaucophane-actinolite-albite-epidote-chlorite), a metadoleritic dyke (SqD1) intrusive into the Saiq Formation.

• Interbedded greyish white mica schist and rusty brown, then grey dolomitic limestone, deformed by asymmetrical medium to large scale folds overturned towards the south, on the inverted limb of a large recumbent F2 fold.

-greyish-white mica schist,

-faulted, light yellow massive to bedded dolomitic marble,

-silvery-grey nodular calcareous mica schist.

Stop 1.4 – Hillo track, 3 km west of Hulw village

On the left bank of Wadi al Hulw, the highly recrystallized calcareous marble of the basal member (Sq1L) of the Saiq Formation contains abundant bioclasts of corals, gastropods, lamellibranchs and crinoids. These well-bedded, bioclastic metalimestones were previously attributed to the Late Proterozoic Hijam Dolomite Formation (Glennie et al., 1974).

Here, a typical facies of the carbonate deposits of the basal member of the Saiq Formation can be observed. It consists of thin-bedded, grey metalimestone, which may contain chert nodules, enclosing olistoliths several metres in size of massive white or grey-white dolomitic marble and grey-black, bedded, nodular metalimestone. This facies is common in northeastern Saih Hatat, at this level in the Saiq Formation. It represents base-of-slope deposits in an external shelf domain during the filling of the Permian Hulw half-graben.

Stop 1.5 – Hillo track, 5 km south-south-west of Tawiyan Yiti village

At about 5 km to the southwest of the village of Tawiyan Yiti, Wadi Mayh cuts the middle members (Sq2 and Sq3) of the Saiq Formation. The basal Sq1L member here consists of whitish massive marble which derive from reefal limestone.

The recrystallised black limestone (Sq2a), in even, 15-50 cm beds, includes bioclast-rich horizons with corals, crinoids and large benthic foraminifera including fusulinids. These are inner shelf, foetid limestones that, immediately to the west, have been dated as Murghabian to Djulfian (Late Permian). They rest on about 50 m of metamorphic volcanic rocks (alkali basalt and trachyandesite) recrystallised in the blueschist facies.

Stop 1.6 – Right bank of Wadi Aday

The syn-rift sediments of the basal members of the Saiq Formation were overlain, from the late Murghabian-Midian, by shallow-marine limestone corresponding to that in the upper part of the Saiq Formation in Jabal Akhdar.

Here, the top of the Saiq Formation is composed of highly sheared beige-orange calcschists, and thin-bedded black metamorphic limestone. The association of these two facies is characteristic of the top of the Saiq Formation in the Saih Hata area.

The Mahil Formation (500-900 m), disconformably overlying the Saiq Formation in both the Jabal Akhdar and Saih Hatat areas, as well as farther south in Jabal Madar, constitutes the upper Akhdar Group. It consists of well-bedded, grey-white to beige dolomite containing algal laminations, fenestrae, teepee structures and mudcracks, and represents deposition in an intertidal to supratidal sabkha-type environment throughout the Triassic. However, dolomite with *Aulotortus sinuosus* (late Norian to Rhaetian) in the top of this formation and known only in this northern part of Saih Hatat includes quartzose sandstone intervals. The top of the Mahil Formation is commonly karstified and capped by a few metres of continental weathered rocks, more or less reworked, testifying to subaerial weathering and erosion in Jabal Akhdar and Saih Hatat between the latest Triassic and late Early Jurassic (Pliensbachian to Toarcian), when marine deposition recommenced.

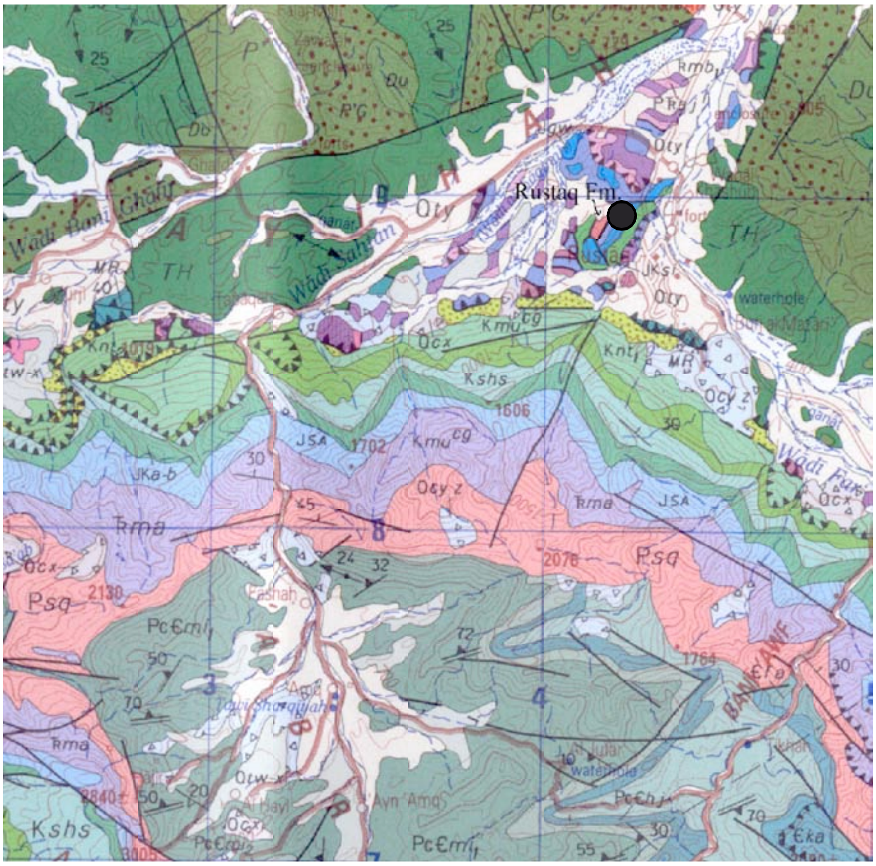


Fig. 10- Geological map of Rustaq area (NW of Jabal Akhdar), Grid: 10km. (Map Seeb, Béchennec et al., 1992b),

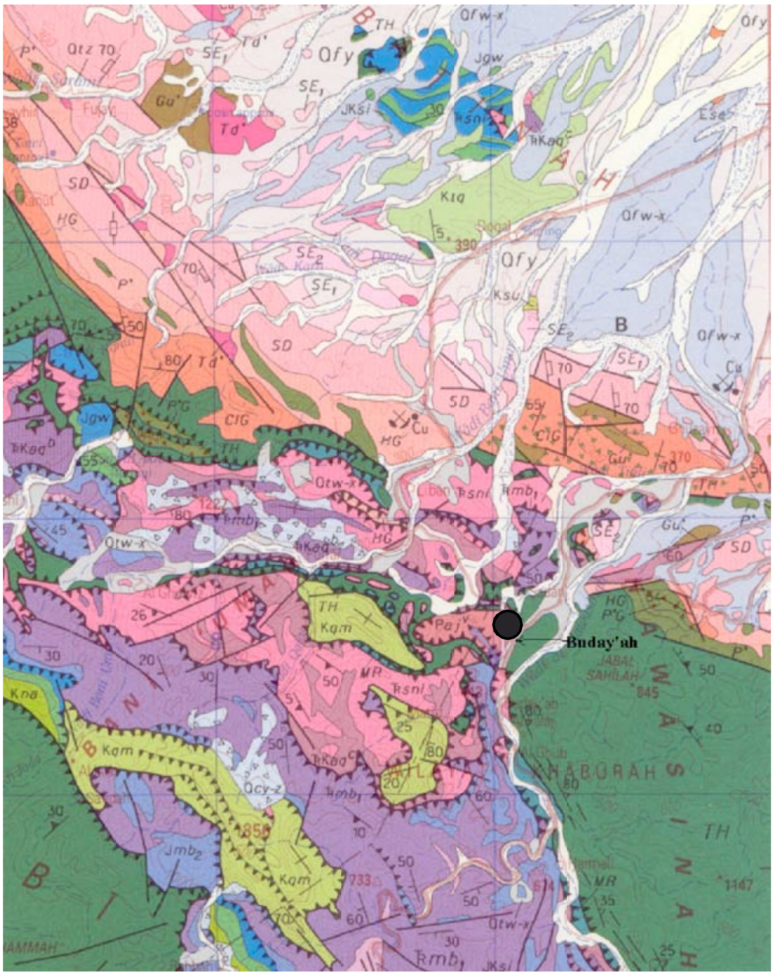


Fig. 11- Geological map of Buday'ah area (Map Ibri, Béchennec et al., 1992c)

January 18 Morning: Rustaq section1, middle Permian cephalopod limestone on pillow lavas (Hawasina Nappes)

Routing (fig. 4)
From Seebt area we take for about 80km the highway Nr 01 to the West along the Badinah coast, then turn left Southward in direction of the village of Nakhln and again Westward to the village of Rustaq.The geological map is presented at the fig.10 and the outcrop map at fig. 12.

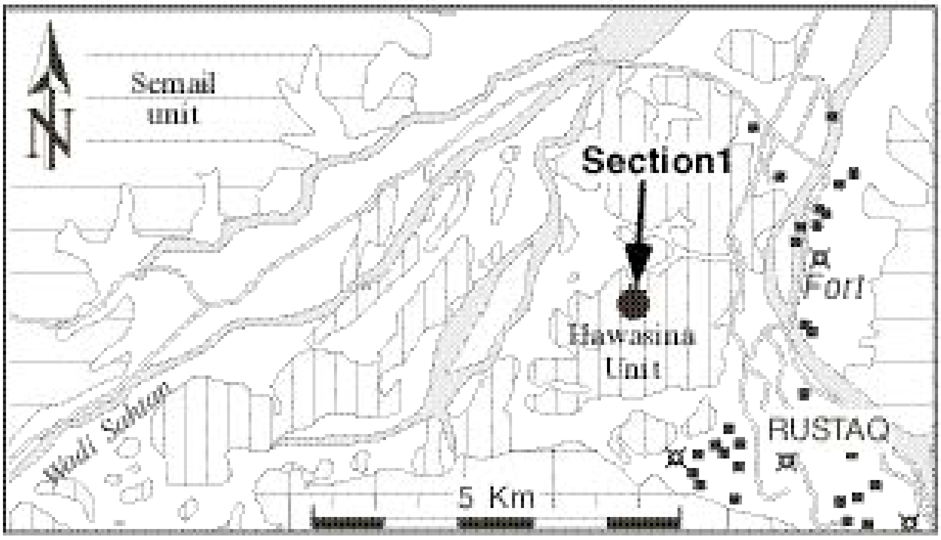


Figure 12- Map of the Rustaq area (see figure 10 for location). (Modified after Pillevuit et al., 1997, fig.15)

Introduction
The cephalopod limestones of Rustaq were recognised by Béchennec (1988) and described in detail by Pillevuit (1993). He named the Rustaq Formation this lithological succession tectonically overlain by the Matbat Formation. Shortly later on Pillevuit' study of the outcrop in 1990, Blendinger came, collected samples and ammonoids and sent it to Glenister. They published their results in 1992.
The Rustaq Formation occurs as tectonically isolated slabs in the hills west of the Rustaq village (Figs. 10, 12).The base of the Formation consists of about 50m of mafic pillow basalts and green tuffites. Two basalts have been analyzed by one of us (R.M.), and their trace elements patterns are quite similar to those of Pillevuit's (1993) samples that he has also reanalyzed. They are slightly enriched in incompatible elements and classify among enriched MORB. Such patterns are found in low-Ti basalts from rifts and plateaus as well as from seaward-dipping reflector sequences in passive ocean margins. They are also found in basalts from truly oceanic settings, but located near hot spots (e.g. close to Iceland or the Azores in the North Atlantic).

Stops

Stop 2.1 - Panorama of the Rustak Formation outcrops (fig. 13)

Stop 2.2 - Stratigraphy of the Rustak Formation (fig. 14)
Near the top of the pillow lava succession, inter-pillow cavities are filled up with red lime mudstone providing conodonts (*Gondolella siciliensis*, dét. L. Krystyn). The red cephalopod argillaceous limestones filled the irregular upper surface of the pillows and contain crinoid ossicles and ammonoids. The following dm thick beds, ammonoids rich, are typical condensed cephalopod limestones known in the Triassic of Eastern Alps as the Hallstatt limestone. Thin coatings of black Manganese oxide minerals are lining the shells (fig.16). The red lime wackestone to packstone contain crinoids, foraminifera, bryozoans, conodonts, and ostracods.

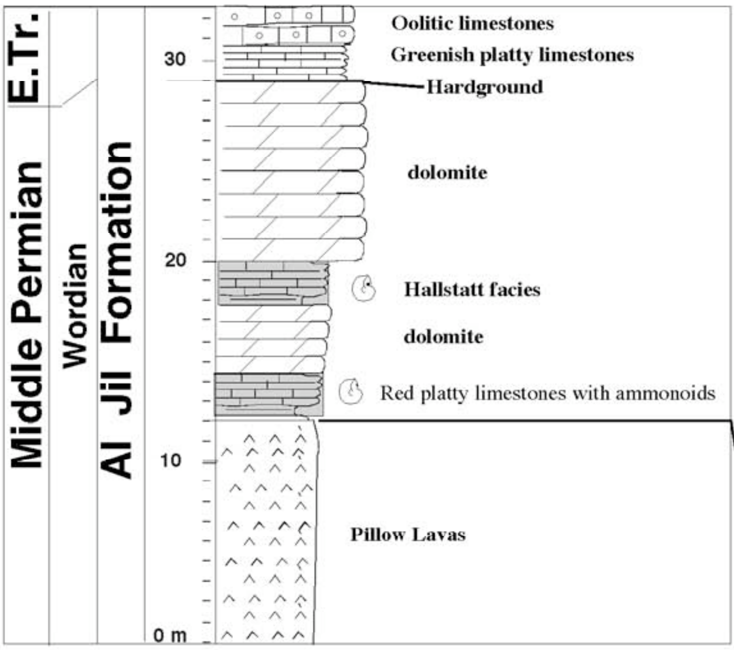


Figure 13- Stratigraphic sketch (section 1 of Rustaq) description in the text. (Modified after Pillevuit 1993, fig. 68).

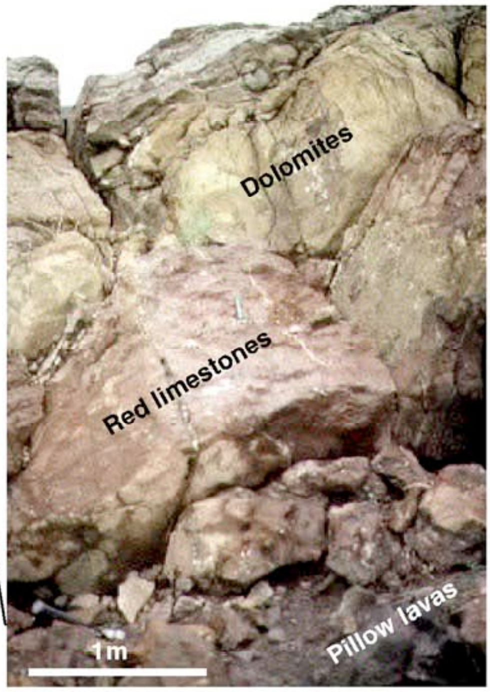


Figure 15- The Rustaq section 1 outcrop.. Details of the sedimentary cover above the pillow lavas.

Figure 14- The Rustaq section 1 outcrop. View of the contact between the pillow lavas and the sedimentary cover.

Figure 16- Wordian ammonoids from the red limestones on the top of the pillow lavas with a Mn coating.

A dolomitisation front occurs about 1.5m above the pillows (fig. 15) and higher up (10m) there are only pluri-dm patches of undolomitized red limestones. According to Pillevuit (1993) the ammonoids are, in ascending order (Determinations of W.W. Nassichuk):

733- *nautilicone, Aricoceras sp., Neocrimites sp., Hyaitoceras sp., Agathiceras sp., A. suessi, Stacheoceras sp., bactritid, Waagenoceras sp., W. nikilini, Altudoceras sp., A. n. sp., Parapronorites sp., P. beyrichi, Tavroceras sp., Eumedlicottia verneuili, Virgaloceras noduliferum, Sosiocrimites n. sp., Tauroceras sp., Daraelites sp., Neoaricoceras ? sp., Hyattoceras sp., Martoceras dame, Thomceras ? sp., Neogeoceras canavarii,, Bitaunioceras sp., cycloceratid (?Brachycycloceras).*

734- *Epadrianites involutus.*

735- *Altudoceras? sp., Conchidium?, Propinacoceras sp., Platyceras? sp., Epadrianites? sp., Tauroceras sp., Stacheoceras sp.*

736- *Medlicottia? sp.,*

737- *Stacheoceras sp.*

The following other molusks have been described by Niko et al. (1996): orthocerids - *Brachycycloceras rustaqense sp*. nov. and *Sitaunioceras* cf. *zonatum* (Gemmellaro), nautilid - *Liroceras sp*. and bactritid -*Bactrites?* sp..

In "en vrac" sampling of Blendinger, Furnish and Glenister determined in addition to the above list the ammonoids *Sicanites schopeni, Agathiceras suessi, Sosiocrimites insignis, Altudoceras sosiense* and *Paraceltites hoeferi*, and Kozur the conodonts *Mesogondolella sosiensis* and *Stepanovites* sp. (Blendinger et al., 1992). The trilobite *Timoraspis breviceps* (Becq-Giraudon & Pillevuit, 1995) and the conodont *Gondolella siciliensis* (dét. L. Krystyn) occur in the samples 734 and 735 of Pillevuit,
According to the different authors, the age of this unit is Wordian and is correlated with the equivalent Sosio fauna in Sicily.

The dolomitised cephalopod limestone (fig.16) are overlain by a 8 m thick series showing: (1) at the base, a sequence of grey/violet shale with subordinated beds, 30 cm thick, of fawn fine-grained calcarenite, (2) at the top a sequence of oolitic calciturbidite in beds 60cm thick interbedded with shale.

January 18 Afternoon: Buday'ah: a Late Permian Hawasina basinal unit, MORB pillow basalt and radiolarian units

Routing (geological map at the fig. 11).
Between Buday'ah and Al Kuryah along wadi Hawasina. 250 m before sign « Al Kuryah 4 km », turn left and follow wadi along 500 m.

Introduction (*F. Béchennec, F. Cordey and R. Maury*)
Located in the northeast part of the Hawasina Window (fig. 11, Ibri map, Béchennec et al., 1992c), this locality is among the only places where the lower member of the **AI Jil Formation** is exposed (figs. 17, 18). Originally defined at the foot of Jabal Misht and around Taw in the central West Oman Mountains (Seeb map area, Béchennec, 1987), this formation was partIy redefined in the same area during 1:250,000-scale mapping (Béchennec *et al.*, 1992a).
The **lower member** is composed of volcanic rocks, overlain by a generally rather thin sequence of shale and radiolarian chert of middle and late Permian age, and an **upper member** which is composed mainly of either calcirudite containing blocks of reworked shallow-marine carbonate, or alternatively calcilutite and fine-grained flaggy calcarenite associated with shale and locally with quartzose sandstone. The base of the AI Jil Formation is unknown since the lowermost part of the lower member is everywhere tectonically truncated. The formation is conformably overlain by middle and late Triassic radiolarian chert of the Matbat Formation (fig. 20, stop 3.2).

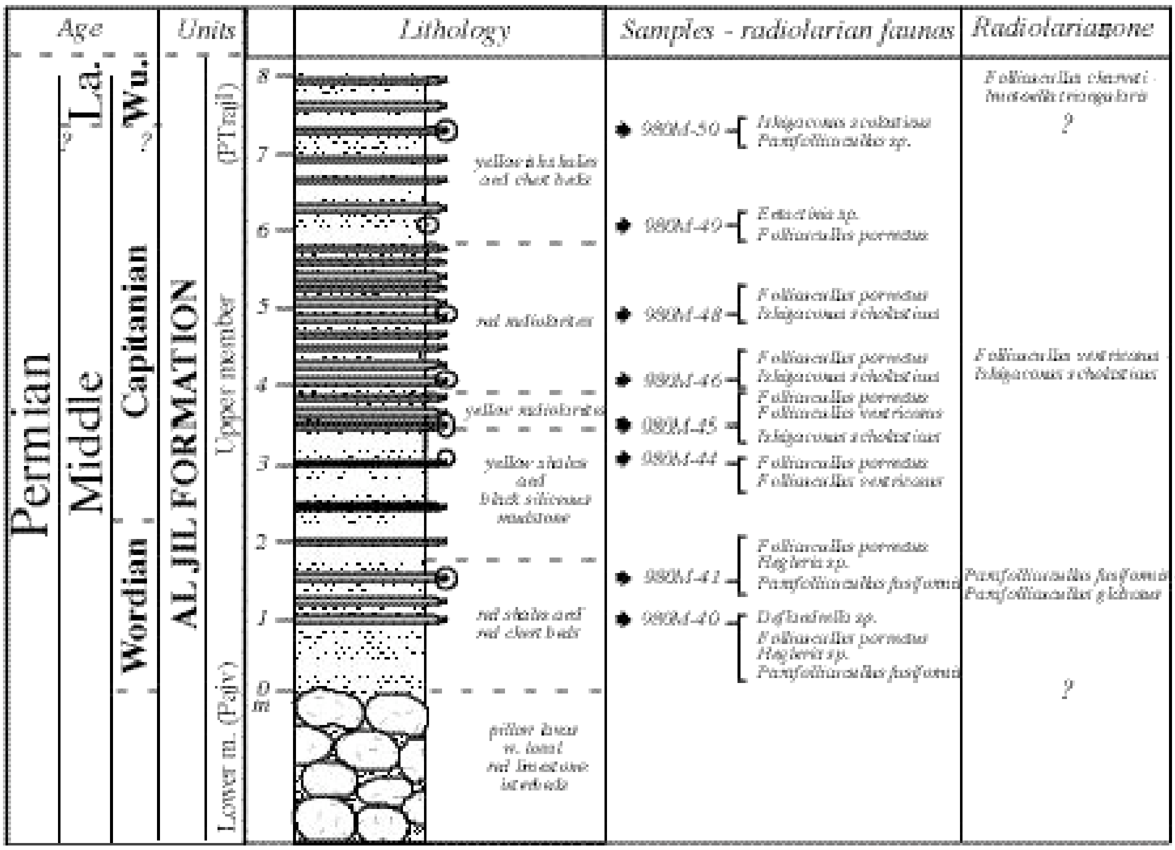


Figure 17- Stratigraphy of lower member and basal upper member of the Al Jil Formation at stops 3.1 and 3.2. (F. Cordey)

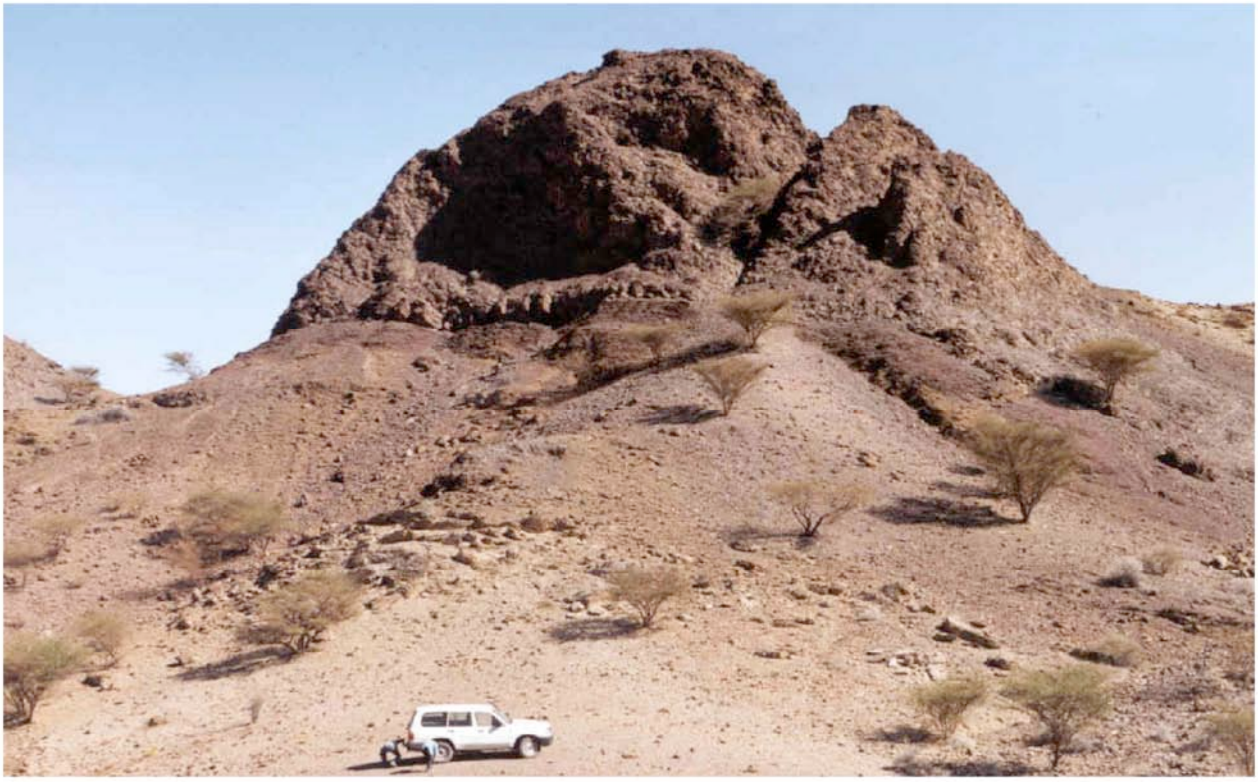


Figure 18- View of locality. Overturned succession of MORB-type lavas (Al Jil, lower member Pajv) and Late Permian radiolarian chert and shales (base of the upper member PTrajl).

Figure 19 - Close-up of overturned contact between pillow-lavas and siliceous shales w. chert beds. Jean Marcoux for scale.

Figure 20 -View of Middle and Late Triassic radiolarian chert outcrop of the Matbat Formation (hammer for scale).

Stops

Stop 3.1 - **The lower member** (basaltic pillow lavas -Pa*jv*, presented by R. Maury.*)* of the Al Jil Formation (fig 17) forms two hills, one roughly 1 km across and the other several kilometres across. The basal volcanic sequence is composed of dark-green to brown, slightly amygdaloidal, pillow basalt in which the pillows range in diameter from 20 cm to 1 m and have aphyric cores and rims which locally contain plagioclase phenocrysts. Locally, interpillows are filled with red, fine-grained carbonates with unidentified ammonites. The basalt has microlitic texture, is generally spherulitic and locally porphyritic; it is composed of plagioclase mainly as sheafs of skeletal microlites but also in spherulites and in places as phenocrysts, rare clinopyroxene as fine prisms and phenocrysts replaced by carbonate and oxides, Fe- Ti oxides occuring interstitially and as elongate skeletal crystals, and carbonate in small amygdales. Data on rare earth elements (REE), Th and high field strength elements on two basalt samples at Buday'ah show transitional and enriched MORB signatures (Maury et al., 2001); such association is found in rift and plateaus as well as fin seaward-dipping reflector sequences in passive ocean margins. They are also found for basalts from truly oceanic settings, but located near hot spots (e.g. close to Iceland or theAzores in the North Atlantic).
The upper member (radiolarian chert, beige flaggy limestone and shale, quartz sandstone, PTr *ajl,* presented by F. Cordey*)* is shown at the fig. 17 and illustrated at the figs. 18-19. The base of the upper member of the AI Jil Formation, near Buday'ah in the northeastern part of the Hawasina Window, consists of a succession of siliceous shale and radiolarian chert resting conformably on the basalt of the lower member, and dated as Wordian on the basis of radiolarians (Béchennec, 1987; De Wever *et al*, 1988). More recent studies point out the succession of the following basal units (figure 17): red shales and red chert beds (2 m), yellow shales and black siliceous mudstone (2 m), yellow radiolarites (0.5 m), red radiolarites (2 m), yellowish shales and chert beds (2 m). Radiolarians range in age from Wordian to Capitanian on the basis of 9 associations (fig. 17) correlated with *Parafollicucullus fusiformis* - *Parafollicucullus globosus* and *Follicucullus ventricosus* - *Ishigaconus scholasticus* assemblage zones of Kozur (1989).

The occurrence of Late Permian (Wuchapingian) strata is not yet established at this locality but is probable: the basal cherts/shales are overlain, on the side of the hill, by a succession of beige shale, thin-bedded and flaggy calcilutite and beige fine-grained calcarenite where no diagnostic fauna have been recovered but which may be Early Triassic in age.

Stop 3.2 Middle and Late Triassic radiolarian chert (fig. 20) of the lower member of basal unit (Mb1c), Matbat Formation, Hamrat Duru Group, presented by F. Cordey. From the previous stop, drive on main road for 9.4 km (direction Al Khaburah). The section of subvertically dipping coloured ribbon chert succession is on left hand side of road.

The Matbat Formation, originally defined at the foot of Jabal Misht, in the Seeb map area to the east (Béchennec, 1987), has been partly redefined in the same area (Béchennec et al., 1992a) to include radiolarian chert previously attributed to the upper member of the Al Jil Formation. The Matbat Formation, overlying the Al Jil Formation and itself overlain by the Guwayza Formation, includes two members, a lower chert and limestone member, and an upper sandstone/shale member. The most extensive exposure of the lower member occurs within the Hawasina Window (Ibri map area, Béchennec et al., 1992c), where its stratigraphy is very similar to that in both the type-section and the Wadi al Ayn area. Stop 3.2 displays the radiolarian chert unit of the lower member. Over a thickness of about 13 m, it displays a succession of well-bedded red and green radiolarian chert in beds 1-10 cm thick with shale interbeds.At this locality, radiolarian chert collected at regular intervals from bottom to top released radiolarian associations ranging in age from late Ladinian to early or middle Norian, based on the following associations: *Muellertortis cochleata minoensis* (Muellertortis cochleata zone, Longobardian), *Pseudostylosphaera goestlingensis* and *Tritortis kretaensis* (Tritortis kretaensis zone, late Longobardian or Cordevolian), *Capnodoce anapetes* and *Capnuchosphaera deweveri* (Capnodoce zone ; Xipha striata or Latium paucum subzones, early or middle Norian) (Cordey, unpublished data).

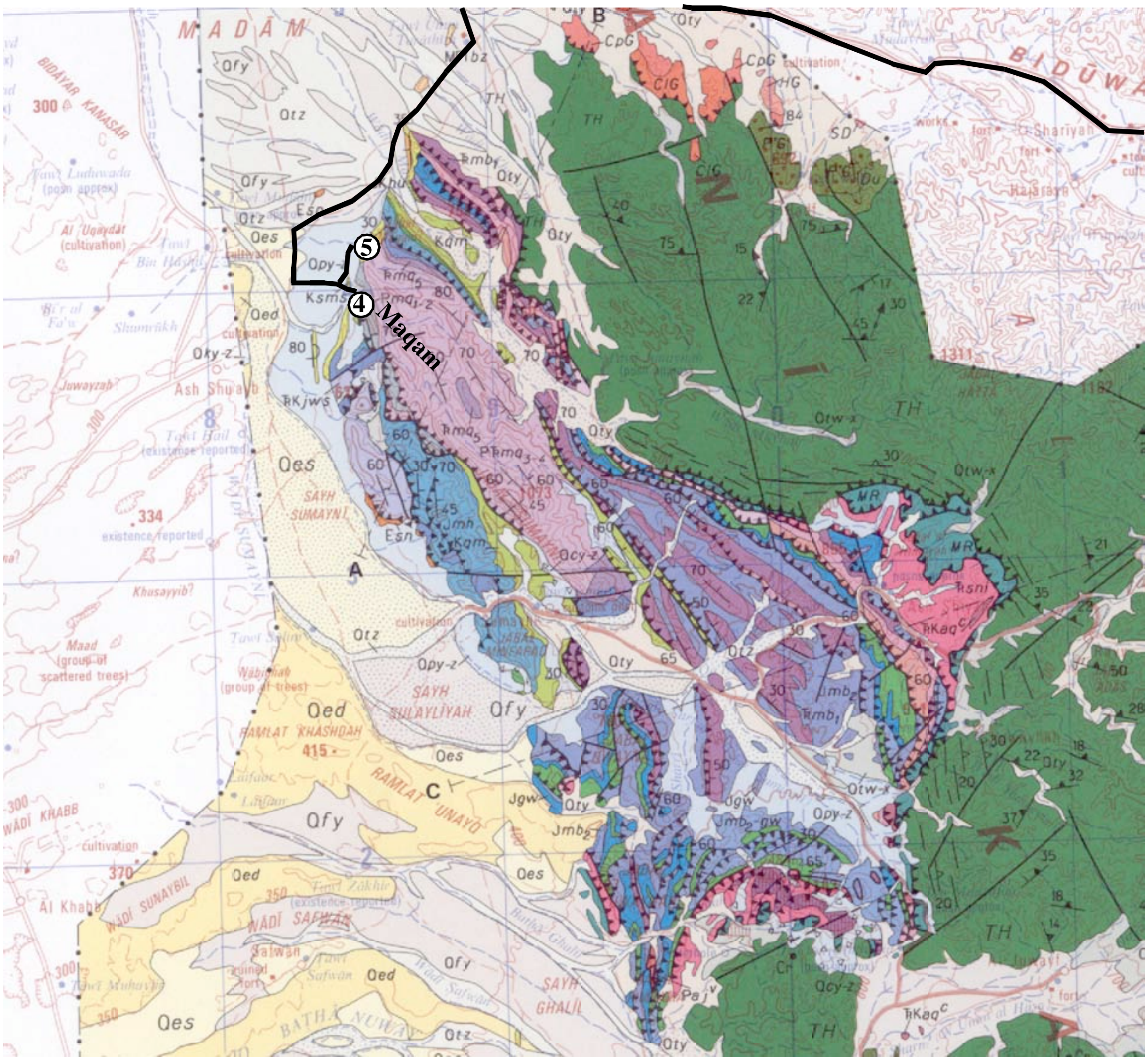


Figure 21- Geological map of the Sumeini area (Map Buraymi, Le Metour et al., 1992).

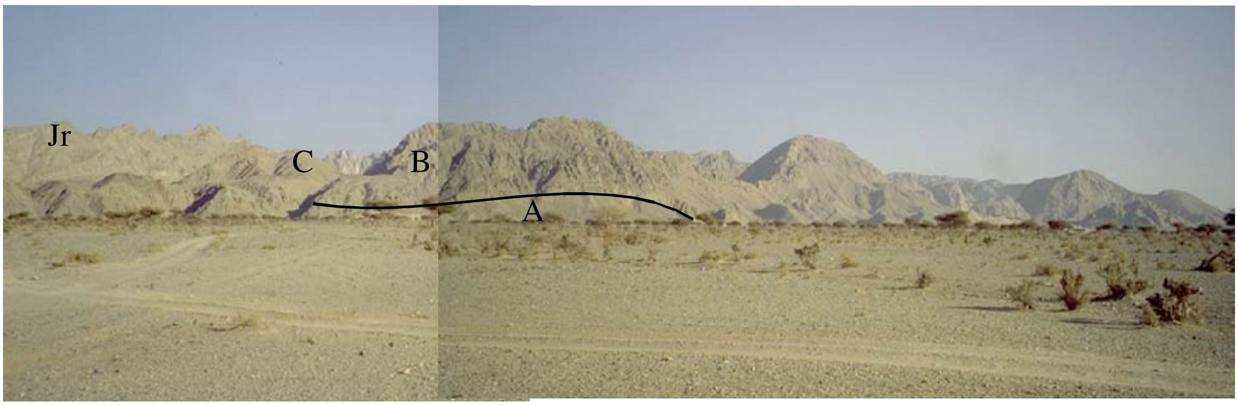


Figure 22- Panorama of Sumeini Range in the Wadi Maqam area; A, B, C, middle Permian to lower Triassic members of the Maqam Formation; Jr, crest forming Jurassic carbonates in the ground.

January 19: The Sumeini Group in the Wadi Maqam: from late Permian to middle Triassic carbonate slope deposits.

Routing (fig. 21)
The section choosen for the fieldtrip is located East of Shuayb village and corresponds to the section MS-6 of Watts and Garrison (1986). The lower part (Member A) is located along a small hills about 500m South of the entrance of the Wadi Maqam gorge (fig. 22). A good profile of the Member B can be see in the gorge and the boudary with Member C that correspond to the Permian-Triassic boundary crops out on a high, on the right flanc, near the end of the Gorge (Richoz et al. 2001b).

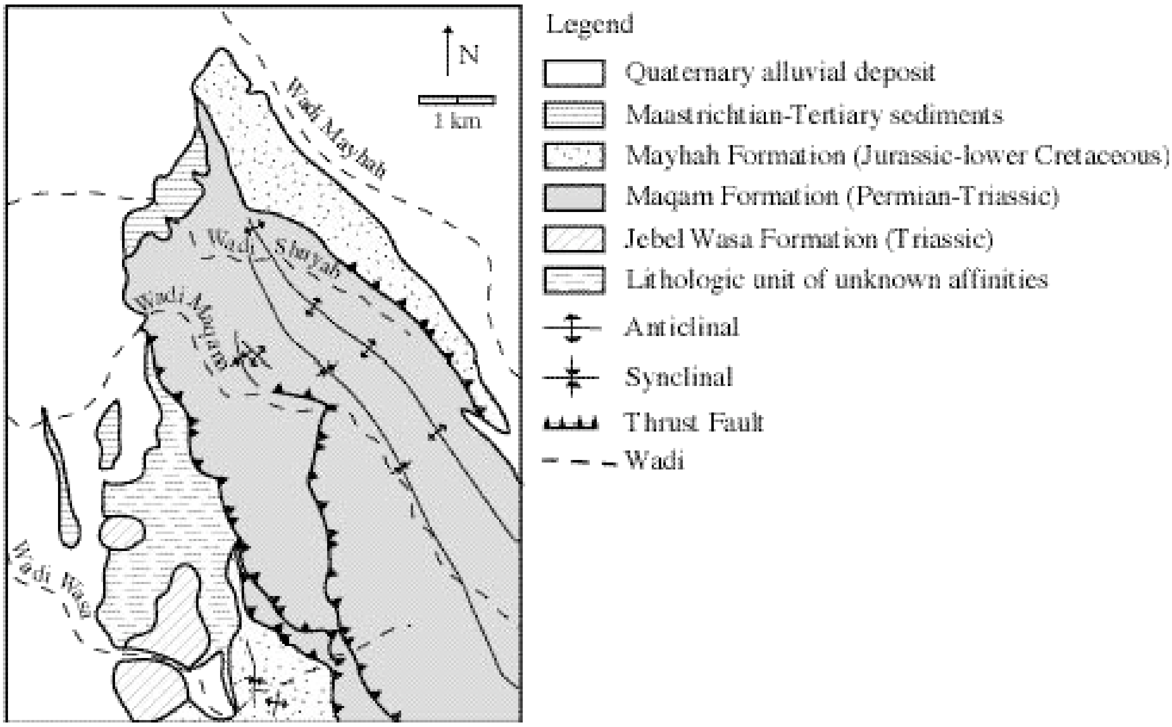
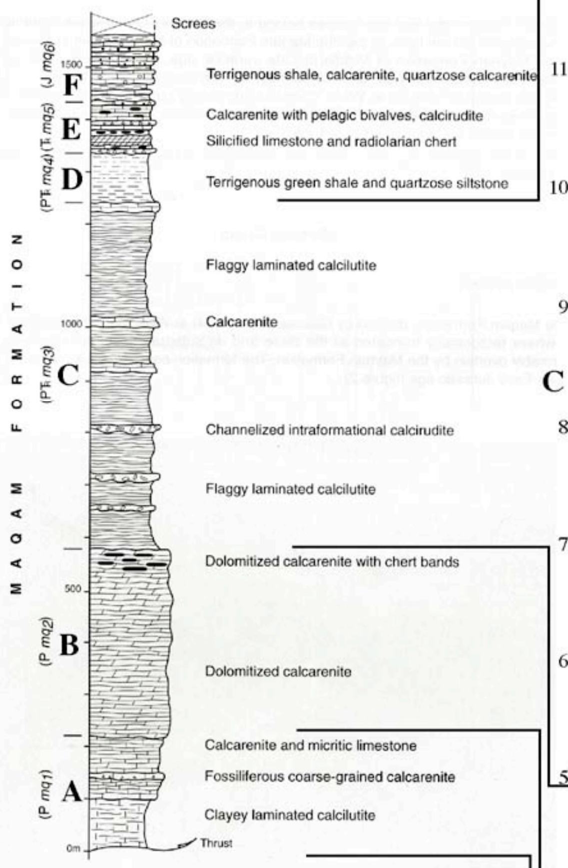


Figure- 23 Simplified geological map of Sumeini Area. (After Watts & Garrison, 1986).

Introduction
The Sumeini Group, as defined by Glennie et al. (1974) is represented by a thick sequence (about 2500 m) of Permian to Cretaceous slope carbonate deposits and crops out (Searle et al., 1990; Le Métour et al., 1992) near the border between Oman and the United Arab Emirates (fig. 23). A comprehensive sedimentological study of the Sumeini Group has been carried out by Watts (1985, 1988, 1990) and by Watts and Garrison (1986). Detailed maping and stratigraphical studies were done by Le Métour et al, (1991) and Béchennec et al., (1993). The lower part of the Sumeini Group (about 1700 m thick) is included in the Maqam Formation (Upper Permian to lower Jurassic), further subdivided into 6 members (A, B, C, D, E and F, fig. 24).



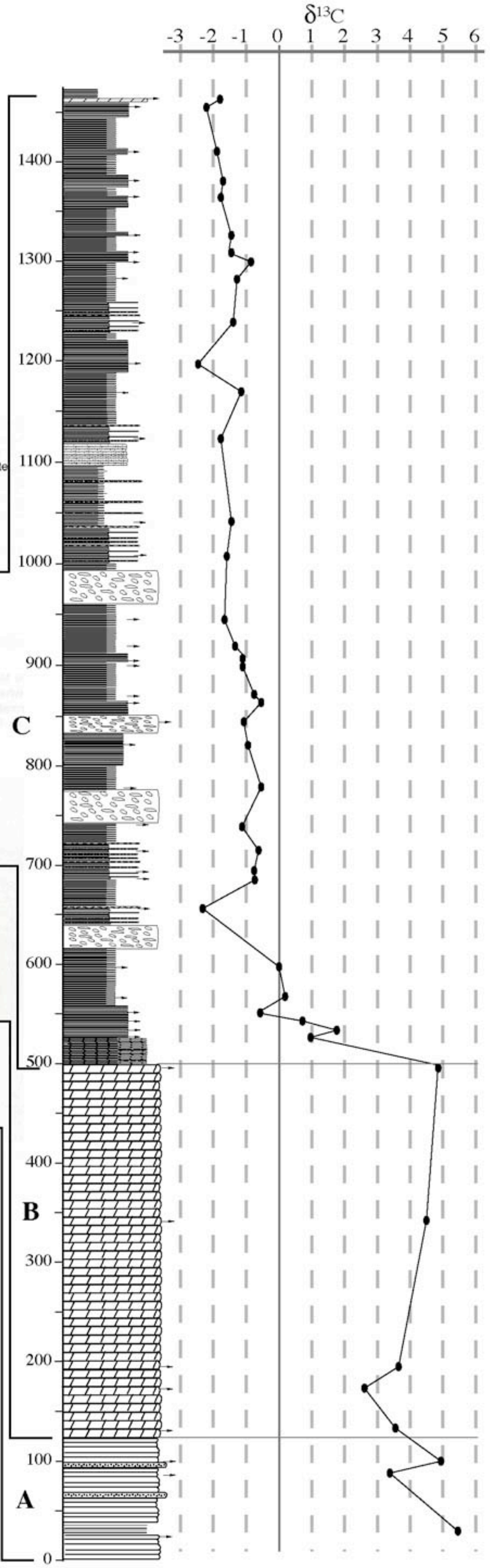


Figure 24- Stratigraphic section of the Maqam Formation from Le Métour et al., (1992a). Members A-F according to Watts, (1985)

Figure 25- Carbon isotope profile of the Maqam Formation, member A, B, C. (Data from Atudorei, 1999, for the members A and B and from Richoz et al., 2001b, for the member C)

Isotope stratigraphy (*S. Richoz*)
The present $\delta^{13}C_{tot}$ isotopic curve (fig. 25) is a compilation of data from Richoz et al. (2001b) and Atudorei (1998).
The highest $\delta^{13}C_{tot}$ values (+5.5‰) are recorded in members A and B and correspond to the high Middle - Late Permian values recorded in the Tethys (Baud et al., 1989). At the boundary between members B and C, $\delta^{13}C_{tot}$ values drop from +4.9‰ at the top of the member B to near 1‰ at the bottom of member C and then decrease down to -2.3‰ higher up. This drop of around 7‰ in the $\delta^{13}C_{tot}$ values is one of the largest known in the Phanerozoic and at least the largest within the PTBI in the Tethys.
In numerous sections along the Tethys (e.g. Baud et al., 1989, 1996, Atudorei 1999), it is observed that following this PTB drop, a positive shift to values between +1 and +2‰ occurs in the upper Griebachian and in the upper Smithian. But throughout the lower Triassic member C of the Maqam Formation, $\delta^{13}C_{tot}$ values remain at low values between -0.5‰ and -2.2‰.
If diagenetic effects lowering values can not be excluded, we assume that this negative trend represent original variations.
$\delta^{18}O$ curves have values from -3.2‰ to -4.0‰ for member A and B, shifting at the beginning of member C down to -5.2‰ and then staying stable between -5.4‰ / -6.9‰. If this shift corresponds to the Permian-Triassic limit, it corresponds also to the dolomitisation front and certainly is affected by it. But we have no reason to believe that $\delta^{13}C_{tot}$ is also affected.
Corresponding to each thick turbiditic event occuring in the platy limestones, a 0.5‰ negative shift in the isotopic curve is recorded. We can suppose that this change is due to the massive input of the platform carbonate in the slope system.

Stops

Stop 4.1 - The panorama at the entrance of the Wadi Maqam is presented at the fig. 22.

Stop 4.2 - Member A of the Maqam Formation (figs. 24-25), here about 80 m thick, (but laterally up to 250m) is tectonically truncated at the base and its substratum remains unknown. The lithology consists of gray and black thinly bedded limestones alternating with marls and locally with sandstones. Upward, this succession also includes sparse fine-grained calcirudite and coarse-grained calcarenite in channeling beds 80-150cm thick. The uppermost part is partly dolomitised. Fossils were recovered from the lower half of the unit. A Wordian age was proposed by Pillevuit (1993) on the basis of the ammonoids *Stacheoceras sp., Adrianites* ? of *A. isoniorphus, Aghathiceras sp*. (Determination from W.W. Nassichuck), of the trilobites *Néoproetus indicus,* Tesch, n. subsp. *Ditomopyginae* (Becq-Giraudon and Pillevuit, 1995) and of the ostracods *Bairdia sp., Aurigerites sp., Healdianella sp., Acratia sp.* (Determinations S. Crasquin Soleau). Rugose and favositid corals, bryozoa, crinoids and Productid brachiopods also occur, some of them reworked**.**

Stop 4.3 - The lower part of member B consists of a 365 m thick sequence of predominantly thin-bedded to massive dolomites with numerous dolorudite intervals and locally abundant breccia in the lower part (Watts and Garrison, 1986). According to these authors, the contact with the underlying A Member is irregular. Corals recovered from the lower part indicate a Capitanian age.

Stop 4.4 - The upper part of member B consists 50m of dm sized bed of cherty dolomites rich in sponge spicules. It must be emphasized that a silica rich interval is widesprad on NW Pangea margin and also known in the Lopingian carbonate of the Tethys. Biogenic silica factories collapsed near the end of the Permian period throughout the world (Beauchamp & Baud, 2001)

Stop 4.5 - **The Permian-Triassic transition** has been studied in 1998 by three of us (A.B., F.C. and J.M.) and in 2000 by A.B. and S.R. and some recent results will be presented at this stop. The cherty dolomites are abruptly replaced by microbial platy limestones. This fine laminated stromatolitic facies is is typical of the basal Triassic carbonate transgression in the Tethys (Baud et al. 1996). A very important negative shift of carbone isotope takes place at the top of the member B and continues into the basal part of the member C (Richoz et al., 2001b, fig. 25). As a result, the Permian-Triassic transition can be constrained within few meters, at the very base of the member C (Baud et a., 2001).

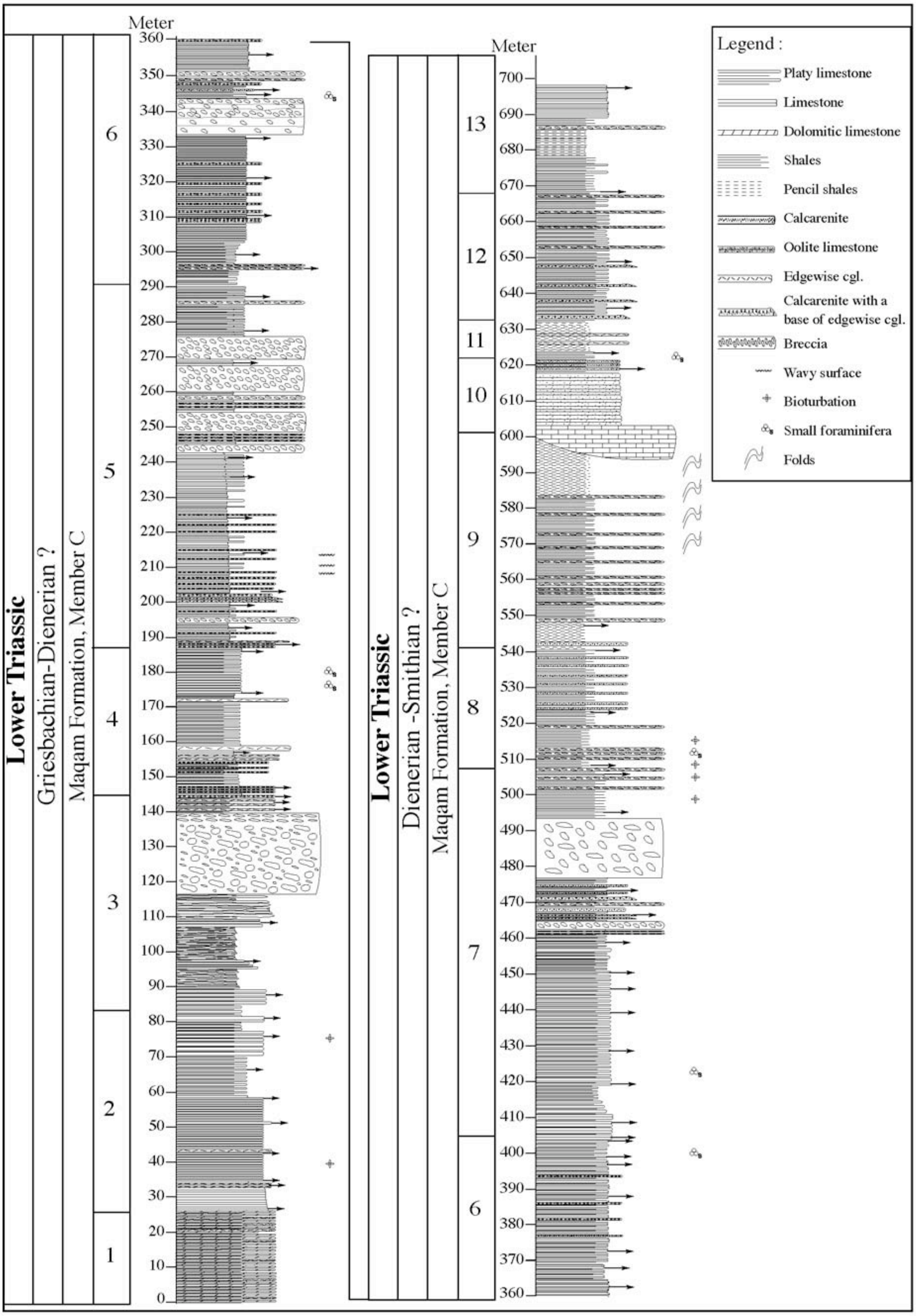


Figure 26- Measured section from the member C of the Maqam Formation (Wadi Maqam).

The Member C (figs. 24-26) is a very thick unit (900m) essentially of platy limestones, calcarenites and calcirudites. It comprises mainly grey-beige calcilutite, laminated and flaggy, interbedded with sparse beds of fine-grained calcarenite in cm beds. Channelizing beds of intraformational calcirudite are also part in this succession which constitutes the great part of the outcrops of the Sumeini Group A detailed sedimentological survey and depositional model of carbonate submarine fans have been presented and discussed by Watts (1988).

Stop 4.6 - The lower part of member C (fig. 26). The calcirudites, commonly clast-supported (edge-wise conglomerates), are characterized by tabular clasts representing the sub-in situ reworking of the laminated, platy calcilutite. In places, the calcarenite becomes predominant and interbedded with calcirudite in metric beds. Some levels of the calcarenite contains reworked tangential ooliths, limestone clasts and a sparse biota of silicisponge spicules, mollusc debris and benthic foraminifera *Trochammina* sp. An Induan age (early Triassic) of the lower part is given by *Cyclogira* and *Earlandia* type foraminifera found about 160m above the base. Fossils tracks and other bioturbation begin very early (after 70m) in the section but there are rare and poorly represented. They become more present in the third part of the section and are very common and various in the last 100m.

Stop 4.7 and 4.8 - We will look at the middle part of the member C (fis. 25-26)**.**

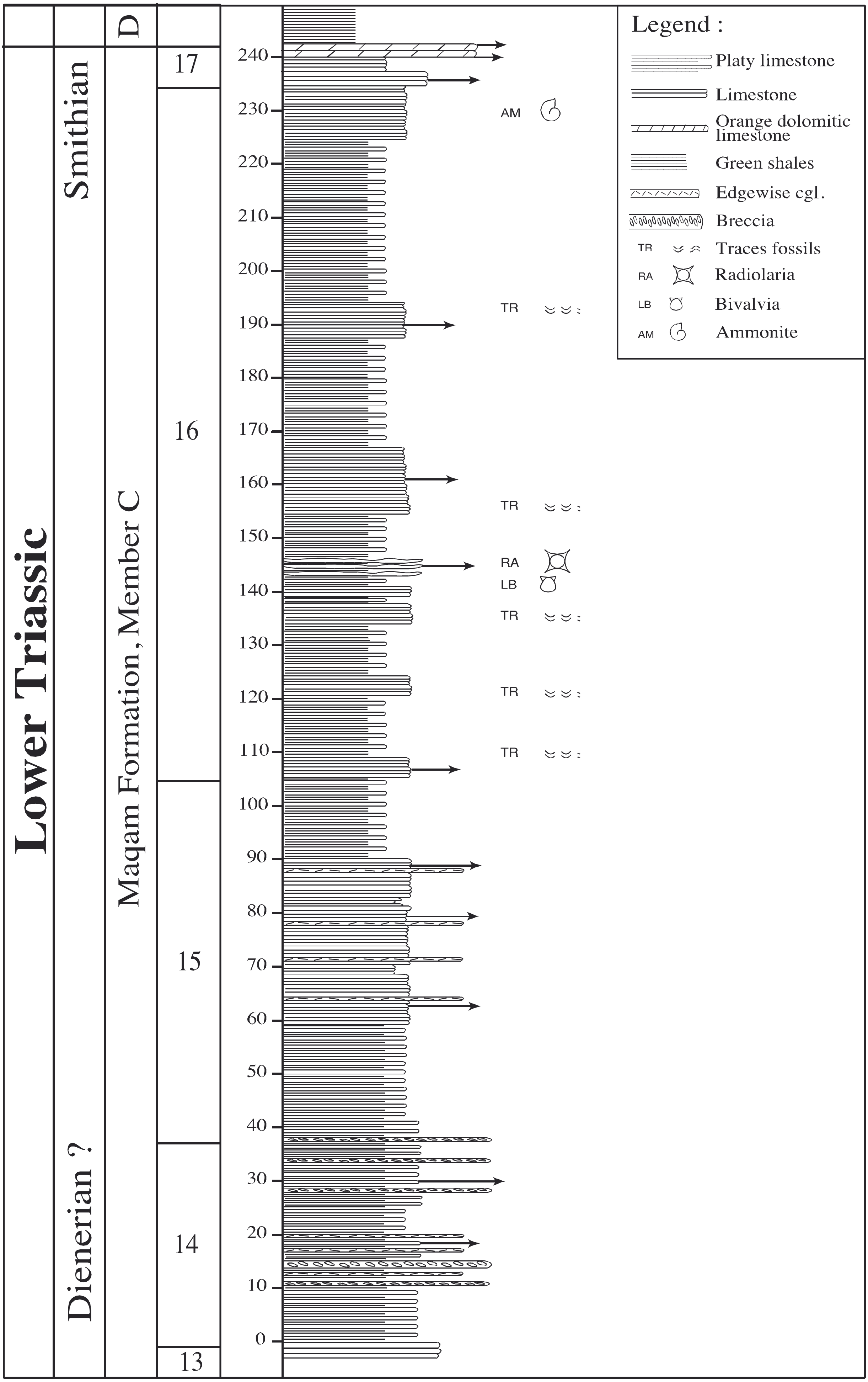


Figure 27- Measured section from the top of member C of the Maqam Formation (Wadi Shuyab).

January 20 Morning: The Sumeini Group in the Wadi Shuayab: from Lower to Late Triassic slope deposits

Routing

The Wadi Shuayab is N of the Wadi Maqam (see sketch map, fig 23).

Introduction

We will look at the **member D** and **E** (figs 24 and 28) of the Maqam Formation (Middle to Upper Triassic) described by Watts and Garrison (1986), Le Métour et al, (1991), Béchennec et al., (1993). The **member D** crops out in the Wadi Shuayb and consits of green terrigenous shale and quartzose siltstone, about 100m thick. No fossils have been found in this member whose age remains uncertain, lying between the Olenekian (Smithian) and the Ladinian. The **member E** is approximatively 60m thick and comprises mainly radiolarian chert, calcarenite and calcirudite. The age is Ladinian to Norian. The **member F** of the Maqam Formation is approximately 150 m thick and consits of shale, quartz sandstone, quartzose calcarenite and calcarenite, Liassic in age.

Stops

Stop 5.1 - panorama of the Triassic deposit in the Wadi Shuayab (fig. 28)

Stop 5.2 - the upper part of the lower Triassic platty limestone (fig. 27)

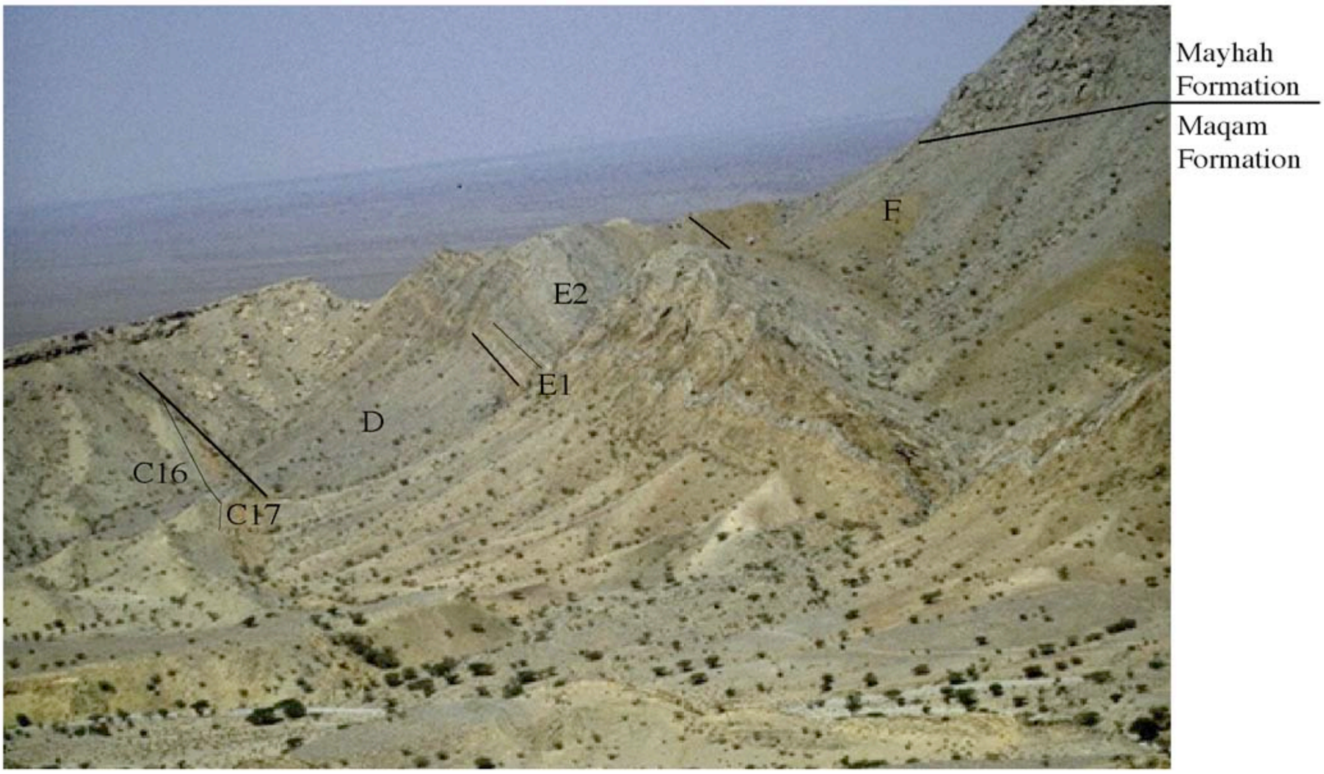


Figure 28- Upper part of the Maqam Formation (members D to F, Middle - Late Triassic).

C16 Platty limestone (Smithian)
C17 Orange coloured dolomite
D Green terrigenous shale
E1 Radiolarian chert ⎤ **(Ladinian to Norian)**
E2 Calcarenite with pelagic bivalves ⎦
F Terrigenous shales, quartz sandstone, calcarenite (Lias)

Stop 5.3 - The Ladinian radiolarites (fig. 28) belong to the Member E**,** approximatively 60m thick and comprises mainly radiolarian chert, calcarenite and calcirudite. A metric channelling bed of calcirudite with a calcarenitic matrix crops out at the base, containing elongated clasts 5-30cm in diameter of grey micritic limestone. Above, a 20 m thick succession consists essentially of grey-brown radiolarian chert in regular cm beds with interbeds of clayey shale and in places,fine-grained calcarenite with horizons of accumulations of pelagic bivalve shells of the genus *Daonella sp.*. The top 2 m of this siliceous succession are made up of red radiolarian chert which is overlain by a carbonate succession approximately 35 m thick with abundant brown patina cherts. Above, an irregular interval, 3-6 m thick, is made up of poorly defined metre-thick beds of matrix-supported calcirudite and coarse-grained calcarenite with sub-angular and tabular clasts of grey micritic limestone ranging from 5 to 40 cm in diameter. This interval is overlain by a 20 m-thick succession made up of light grey micritic limestone with horizons of accumulations of pelagic bivalve shells, and of fine-grained, dark grey calcarenite in beds 20-60 cm thick at the base and 1-15 cm thick elsewhere. In places, the intraformational calcirudite contains slump-structures.

Stop 5.4 - **The upper Triassic deposits** At the top of the member E is a channeling interval 1-8 m thick of calcirudite with a reduced or absent matrix, containing reworked sub-angular clasts of micritic limestone, calcarenite, and reef limestone The calcarenite of the upper carbonate succession, in addition to the reworked lithoclasts of limestone and in places chert, lava and rare quartz, also contains a biota of Late Triassic age including debris of algae, crinoids, pelagic bivalve shells and benthic foraminifera: *Trochammina* sp., *Endothyra* sp. or *Endothyranella* sp., duostominids, lituolids (Béchennec et al., 1993b). It should be noted that the discovery in this upper carbonate succession of an *Aulacoceras sp*. and an *Heterastidium sp*. few meters higher by one of us (JM) allowed the correlations with the Lower and Middle Norian of the Aqil blocs 3-4 described by L. Krystyn in Baud et al. (2001b).

January 20 Afternoon: Way back to Muscat

AKNOWLEDGMENTS

Our thanks are to His Excellency Ali Masoud Al-Sunaidy, Under Secretary of Commerce & Industry, Ministry of Commerce and Industry, chairman of the Organising Committee of the International Conference on the Geology of Oman.
We are particulary gratefull to Dr. Hilal bin Mohammed Al-Azri, Director General of Minerals, Vice Chairman of the Organising Committee, for his kindness, his interest and encouragements to our field works and researches and his support to publish this Guide Book.
Our team is very gratefull to Dr. Jean-Paul Breton, Head of the Oman Branch of the BRGM and Françoise his wife, for their generous hospitality and their valuable help to resolve many logistic problems, to prepare the field work and organize the sample shipment. During field studies, our team has been helped by many colleagues, among them Cécile Robin, Spela Gorican and François Guillocheau. We appreciate the analysis of preliminary conodont collections by Catherine Girard (Université Claude Bernard Lyon 1) and Mike Orchard (Geological Survey of Canada).
Researches in Oman for A. Baud and S, Richoz have been supported financially by the Swiss National Foundation through grants 20-53787. 98 and 20 - 33'448.92, 2000, 045455.95 (AB), and by the Geological Museum in Lausanne.
F. Béchennec, F. Cordey, J. Marcoux and R. Maury fieldworks have been sponsored in 1999 and 2000 by the French CNRS INSU, Programme I.T., and F. Cordey also by the French CNRS-Crisévole Project (Programme Environnements, Vie et Société) and the laboratory FRE2158.
For Previous fieldworks, A. Baud and J. Marcoux recieved funding from the International Tethys Programm.
Alain Pillevuit (1995), Hugo Bucher (1996) and Viorel. Atudorei (1997) accompanied A. Baud and occasionnaly J. Marcoux in the field. Thanks for their valuable help and for intense scientific discussions. In this guide book we are using some of our jointly works.
S. Richoz appreciate the hospitality of the the Institute of Mineralogy and Petrography and the Institute of Geology and Paleontology, University of Lausanne for his Laboratory works on stable isotopes and he thanks Andreas Mulch for helping him with the english translation.

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