IAS 2005 Muscat, OMAN

MESOZOIC EVOLUTION OF THE TETHYAN MARGIN OF OMAN

(BF4)

Arabian platform, inverted deep-sea plain deposits (Hawasina), Samail ophiolites

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DAY 1 (Thursday 06 January):

- Departure from parking of the Seeb Golden Tulip Hotel 08:00 hrs
- The Permian-Triassic shallow carbonate platform in Wadi Sahtan
- Field lunch

Overnight Al Suwaidi Beach Resort Barka

DAY 2 (Friday 7-January):

- Scenic drive across the Oman Mountains; overview of the tectonostratigraphic history.
- Field lunch
- Triassic to Middle Jurassic proximal Debris-flow of the Al Aridh allochtonous unit in Jebel Buweidah

Overnight: Falaj Daris Hotel, Nizwa

DAY 3 (Saturday 8 January):

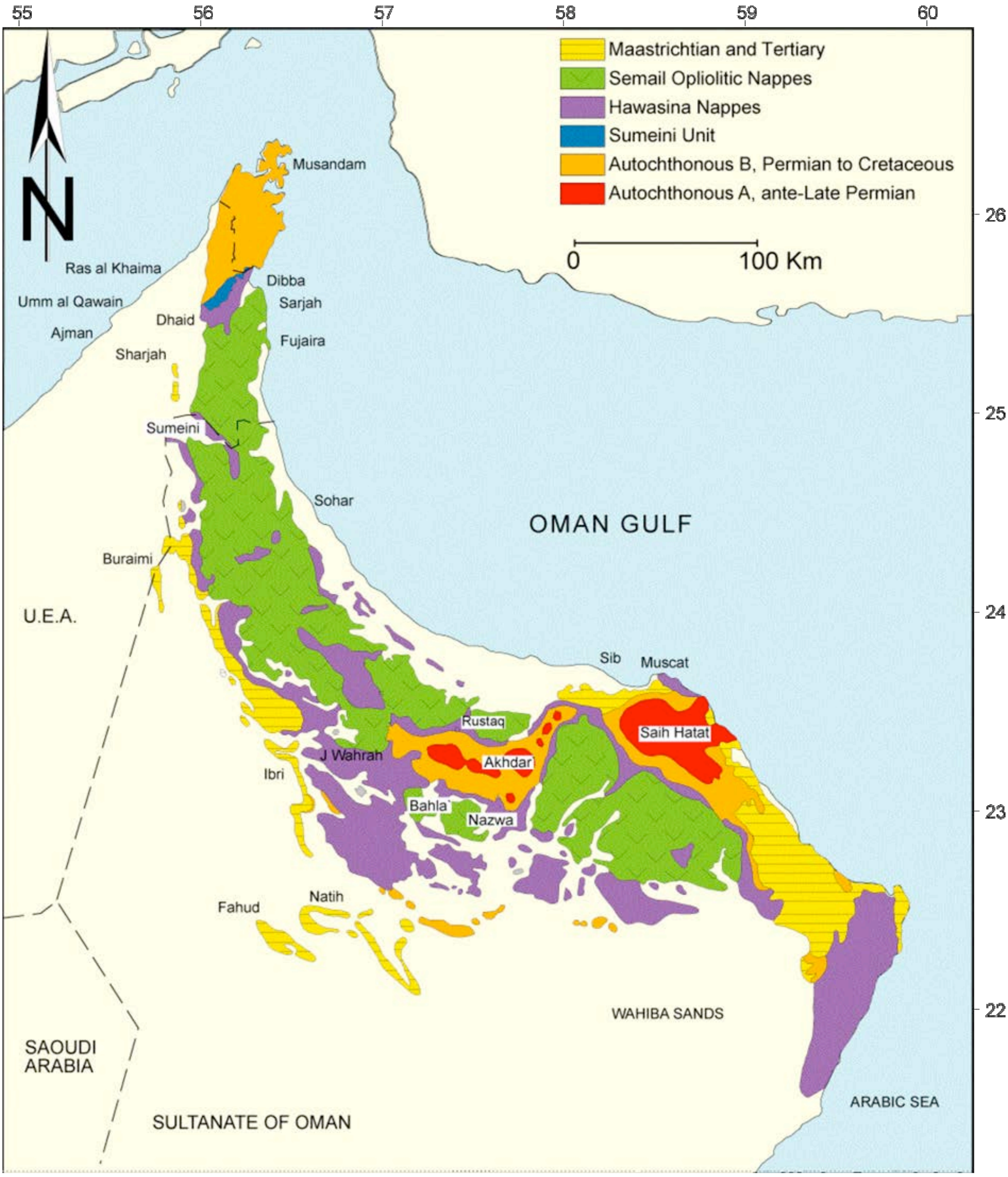
- Authochtonous Jurassic and Cretaceous plaform carbonates in the Wadi Mu'aidin
- Field lunch
- Correlative Jurassic and Cretaceous proximal turbidites in the Hawasina allochton

Overnight: Falaj Daris Hotel, Nizwa

DAY 4 (Sunday 9 January):

- Triassic to Cretaceous distal turbidites in Jebel Safra (route Izki – Sanaw)
- Field lunch
- Drive back to Muscat, check in-registration at SQU

Night: Hotel in Muscat (not part of this trip)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Maastrichtian and Tertiary
Semail Opliolitic Nappes
Hawasina Nappes
Sumeini Unit
Autochthonous B, Permian to Cretaceous
Autochthonous A, ante-Late Permian
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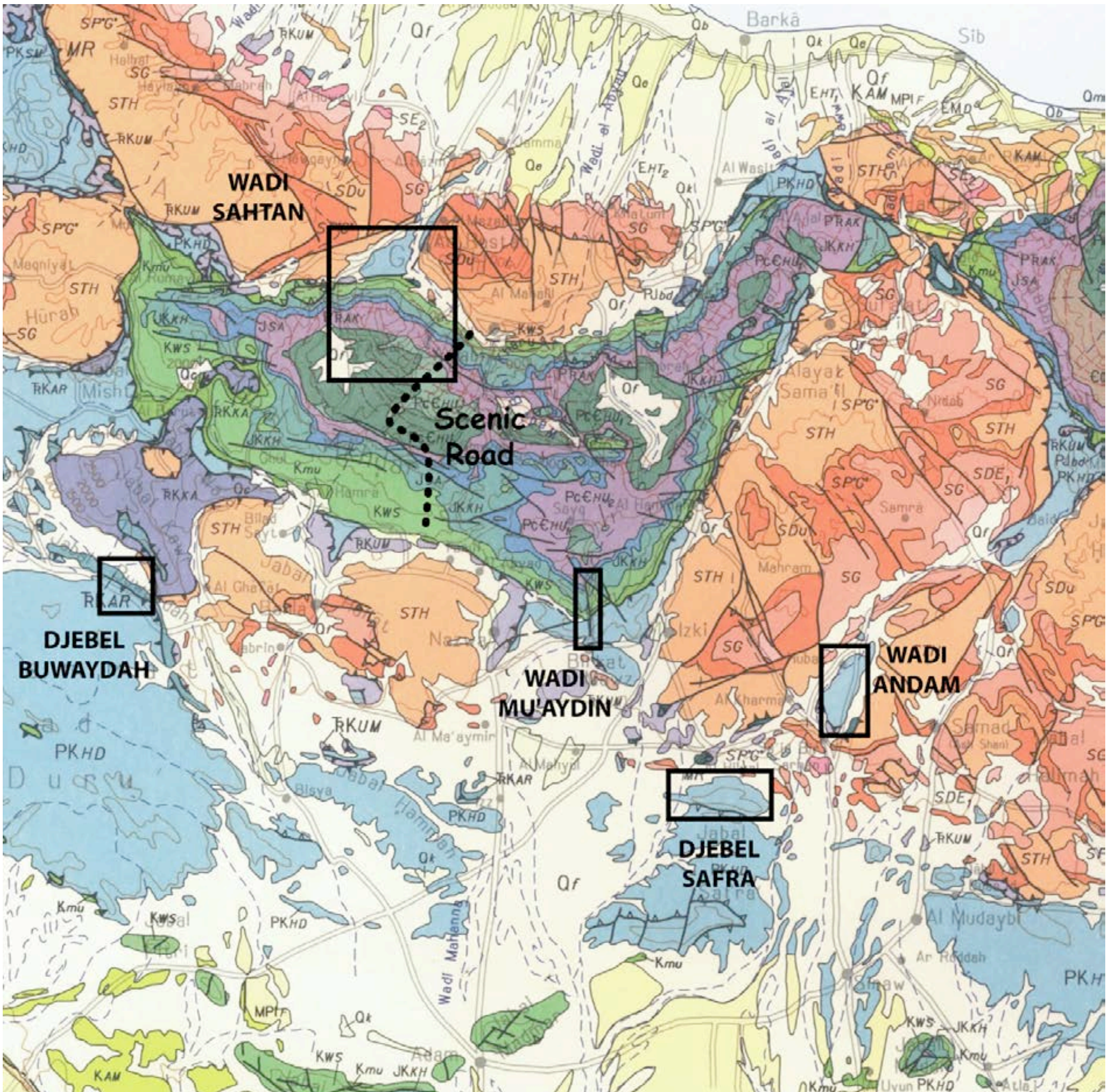


WADI SAHTAN
Scenic Road
DJEBEL BUWAYDAH
WADI MU'AYDIN
WADI ANDAM
DJEBEL SAFRA

THE PERMIAN-TRIASSIC SHALLOW CARBONATE PLATFORM IN WADI SAHTAN (JABAL AKHDAR)

Field trip writers:

Aymon BAUD
Sylvain RICHOZ

January 6 : The Permian-Triassic shallow carbonate platform in Wadi Sahtan (Jabal Akhdar)

By A. Baud and S. Richoz

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 the Sahtan Bowl. In this area the Permian to Cretaceous strata of the "autochtonous" form a normal monoclinal structure dipping to the North. The Wadi Sahtan valley cuts more or less transversally the strata and the succession is very well exposed on both sides of the valley (Fig. S1).

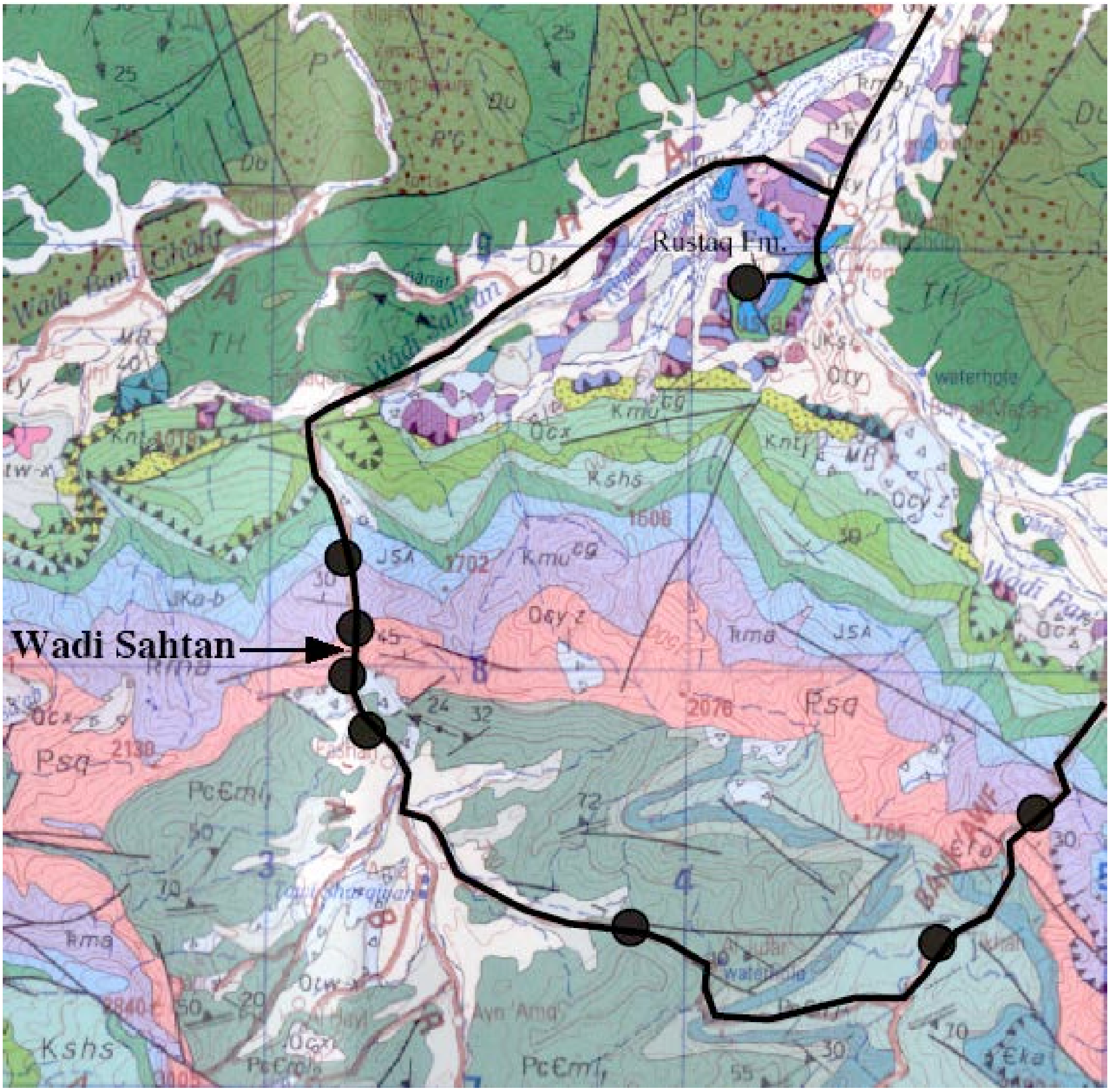
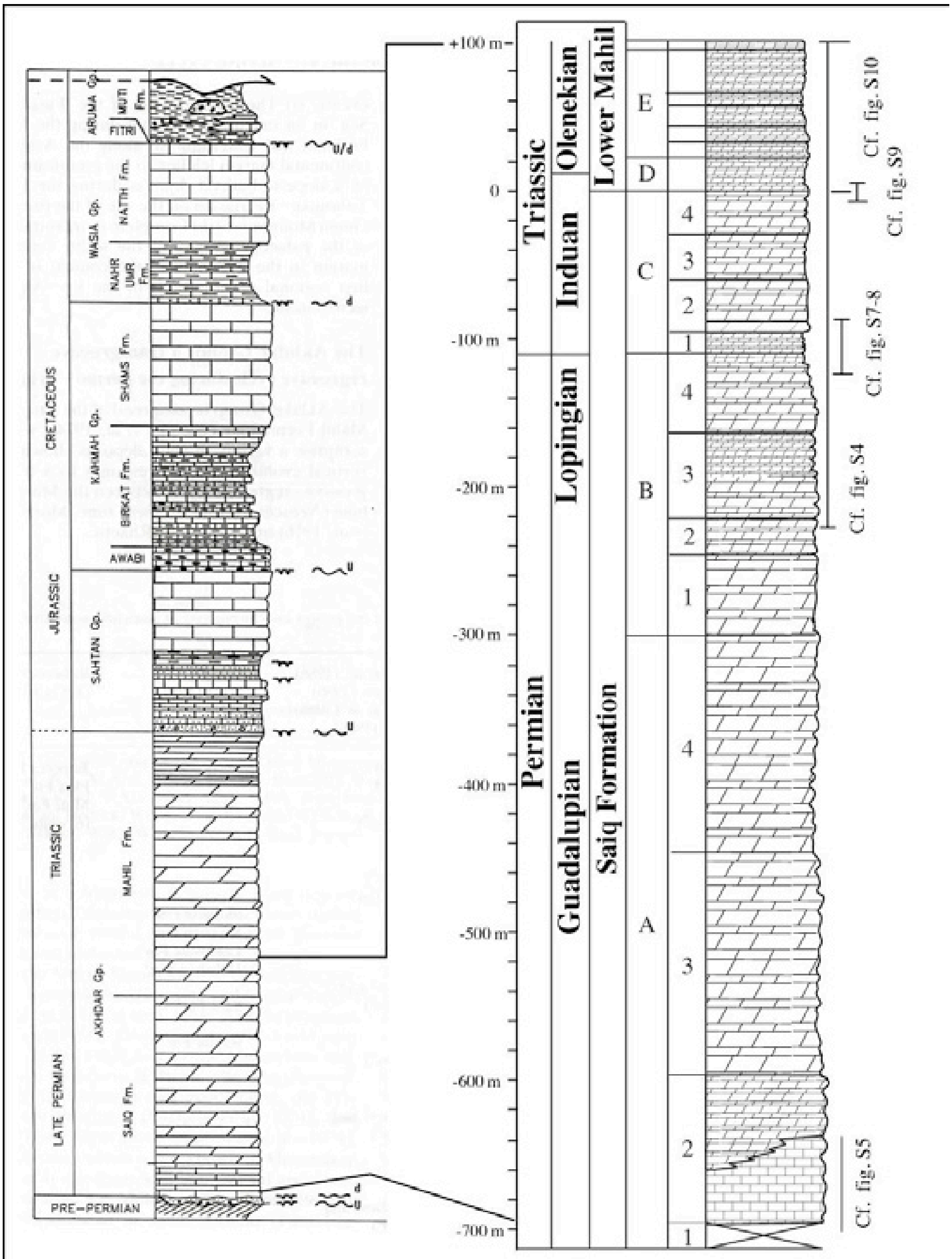


Figure S1: Geological map of Wadi Sahtan area (NW part of Jabal Akhdar), Grid: 10km (map Seeb, (Béchennec et al., 1992)), with the itinerary and the main stops (black dots). Saiq in rosa color and Mahil in violet.

Introduction

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



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

Lithostratigraphic column of the Saiq and the base of the Mahil Formation.

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

Stratigraphy.

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

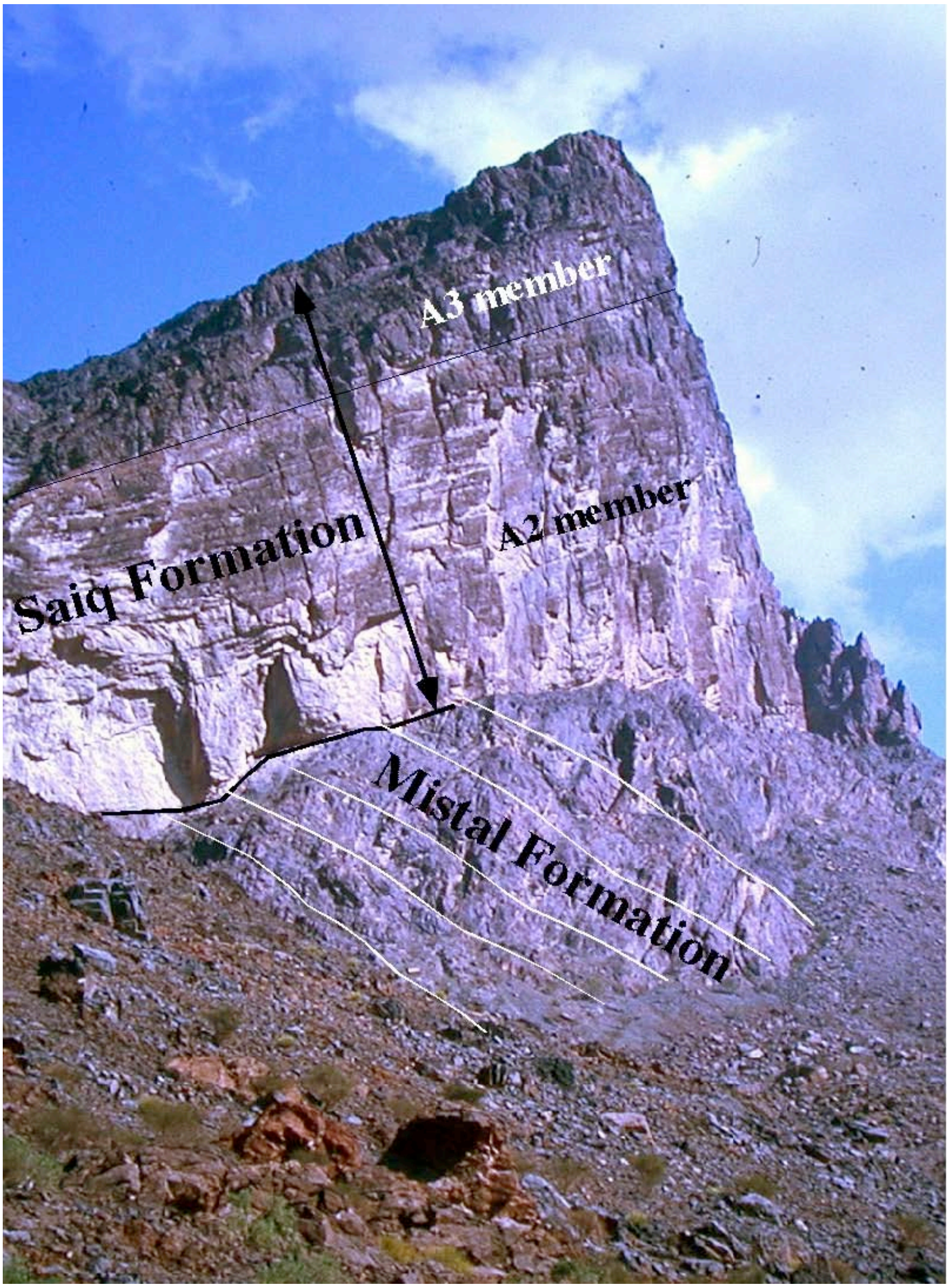


Figure S3: Transgression (black line) of the Saiq Formation (middle Permian) with angular unconformity, on the infra-Cambrian - Cambrian Mistal Formation.

In the Jabal Akhdar Mountains the basal member of the Saiq Formation, made up of terrigenous detritus occur only locally and may reach up to 20 m 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. S2). 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). New chemiostratigraphic correlations (Richoz, 2004) and see below) shallowing upwards trend towards the top of the Saiq Formation (Rabu, 1988)).

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

In the Wadi Sathan, the Permian-Triassic section shows a 1500m thick pile of shallowing upward cycles (Fig. S2). The **Saiq Formation** is about 700m thick and consists of three main Transgressive-Regressive cycles (T-R 2nd order cycle). These three cycles (A, B and C) are more or less corresponding to the Weidlich (2003) supersequences (2nd order cycle) P2 to P4. The lower part of the Saiq Formation with the T-R cycle A (corresponding to P2 in (Weldlich and Bernecker, 2003), 400m thick, has been subdivided in 4 units from base up:
- The A1 unit, partly terrigenous (the lower Saiq of Rabu, (1988) is not outcropping in this section.
- The A2 unit, main carbonate shallowing upward transgressive seqence is about 100m thick (fig 32). Voids at the top indicate a probable emersion. This sequence have a Wordian age by Hindeodus excavatus (Behnken, 1975 sensu Wardlaw et Collinson, 1984) (det. A. Nicora in Baud et al., 2001).
- The A3 unit, 150 m thick consits of thin-bedded, largely recristalised brown dolomites without apparent fossils.
- The A4 unit, 150 m thick, made of grey dolomite is not well outcropping and is characterized by thick levels of collapse breccia indicating a very restricted environment.

The upper part of the Saiq Formation (300 m) consist of two T-R cycles noted B and C (Figs S2, S3). Both cycles are mainly made up of dolomitized high energy calcareous sands:
- The T-R cycle B is about 190m thick. Its lower part (B1 to B2) is characterizedby thick high energy dolowakstone to dolopackstone. The upper part (B3 to B4) is made of well bedded dolomite. On the base of chemiostratigraphic correlations, (Richoz, 2004) hypothesis the Permian Triassic boundary in the last 5 meters of this cycle (see below).
- The T-R cycle C is only 90m thick with no age diagnostic. By isotopic correlation the cycle is supposed Griesbachian in age.

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

The lower part of the **Mahil Formation**, examined herein, is divided in two main lithologic units, D and E, respectively 22m and 75m thick, further separated in subunits. Very small foraminifera and bivalves (Claraia) are present in the unit D of the Mahil Formation.

Cyclogira sp. and *Earlandia* sp. were identified in three samples from unit D2 indicating an Early Triassic, Induan age.

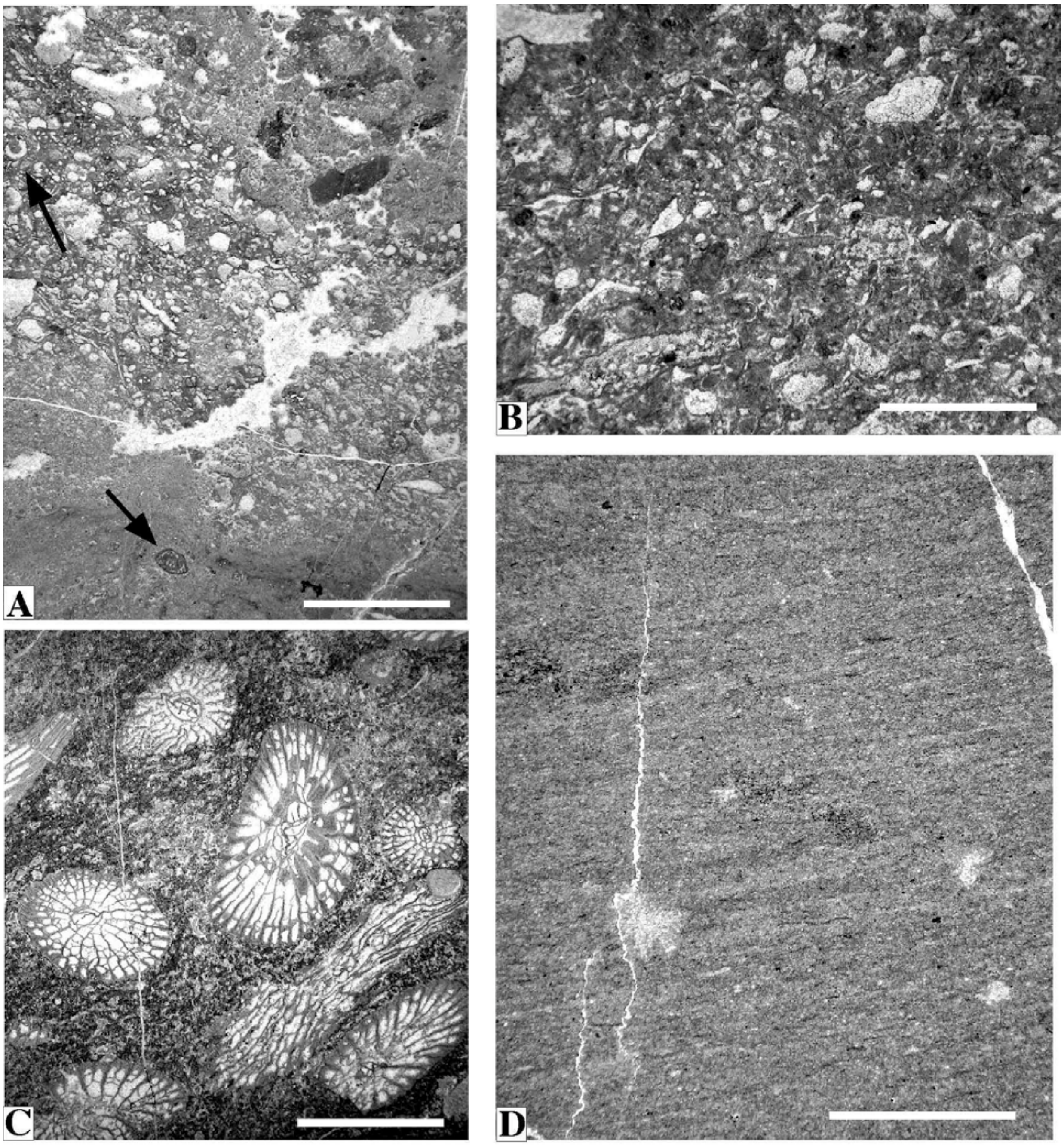


Plate I: Microfacies of Member B (Saiq) and D (Mahil). White bar scale is 0.5mm

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

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

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

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

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

The Saiq and Mahil Formations are composed mainly of dolomites. As shown by (Atudorei, 1999) in the Wadi Sathan, within the basal Unit A2 of the Saiq Formation where a front of dolomitisation occurs, the dolomitization processes do not affect significantly the carbon isotopic composition of the primary carbonate sediments and the dolomite have a generally a typical marine carbon isotope signature. After (Atudorei, 1999), the average d13C value for the limestone is +5.1‰ and +5.5‰ for dolomites in the same bed of the Unit A2 of the Saiq Formation (Wordian). But concerning the $\delta^{18}O$ values of limestones, they are significantly affected and about 3‰ higher than their counterparts from dolomites.

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

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

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

It is clear that without any reliable biostratigraphic control, our age correlations by isotopic stratigraphy are based on analogy. Nevertheless, the isotopic pattern is typical enough to make

confident correlation with well-dated Oman sections. Taking account of these correlations, we can summary the Wadi Sahtan section as follow:
B3 and B4 units represent an Upper Permian succession, The Permian-Triassic boundary is placed in the last meter of unit B4 (Fig. S7). The Member C is composed of a transgressive depositional system of sabbkah-type sediments with a lack of fossils, assumed Griesbachian in age. The Saiq-Mahil boundary is probably Upper Griesbachian. There is some uncertainty concerning the extension of Dienerian sediments. They are probably condensed and consist of stromatolites and brown dolomudstone. Algo-bacterial sediments (stromatolites and oncolites) characterize the Lower Smithian. The Middle and Upper Smithian contains marly dolomudstone with supratidal structures and is ending with 2m of orange dolomite. Spathian is marked by thick black doloarenite.

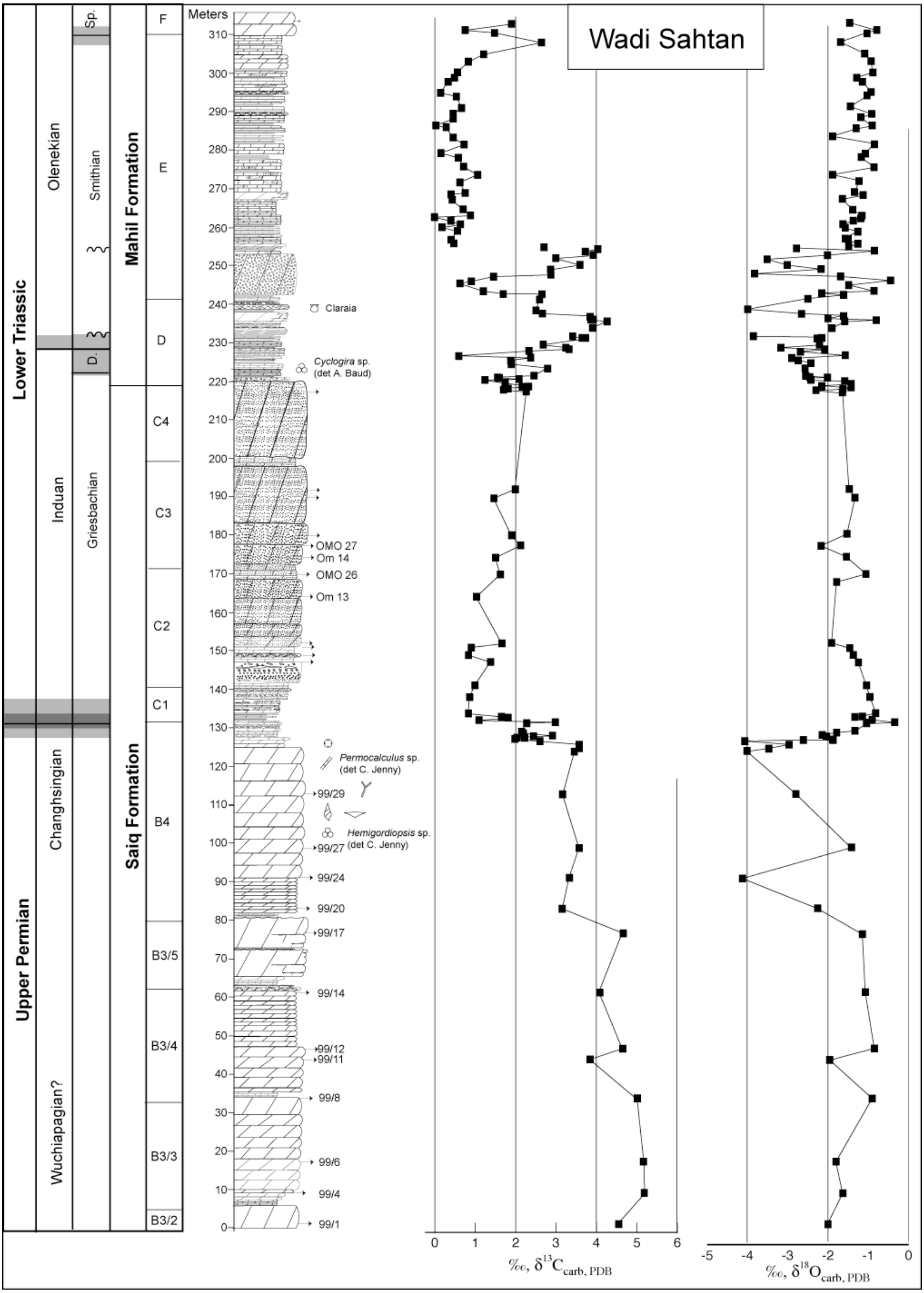


Figure S4: Lithology and Carbon istope profile of Wadi Sahtan section. (Richoz, 2004)

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 1: Panorama of the transgression of the Saiq Formation with angular unconformity (Fig. S3).
The Wordian part of Saiq Formation is lying on Mistal Formation, probably Cambrian in age

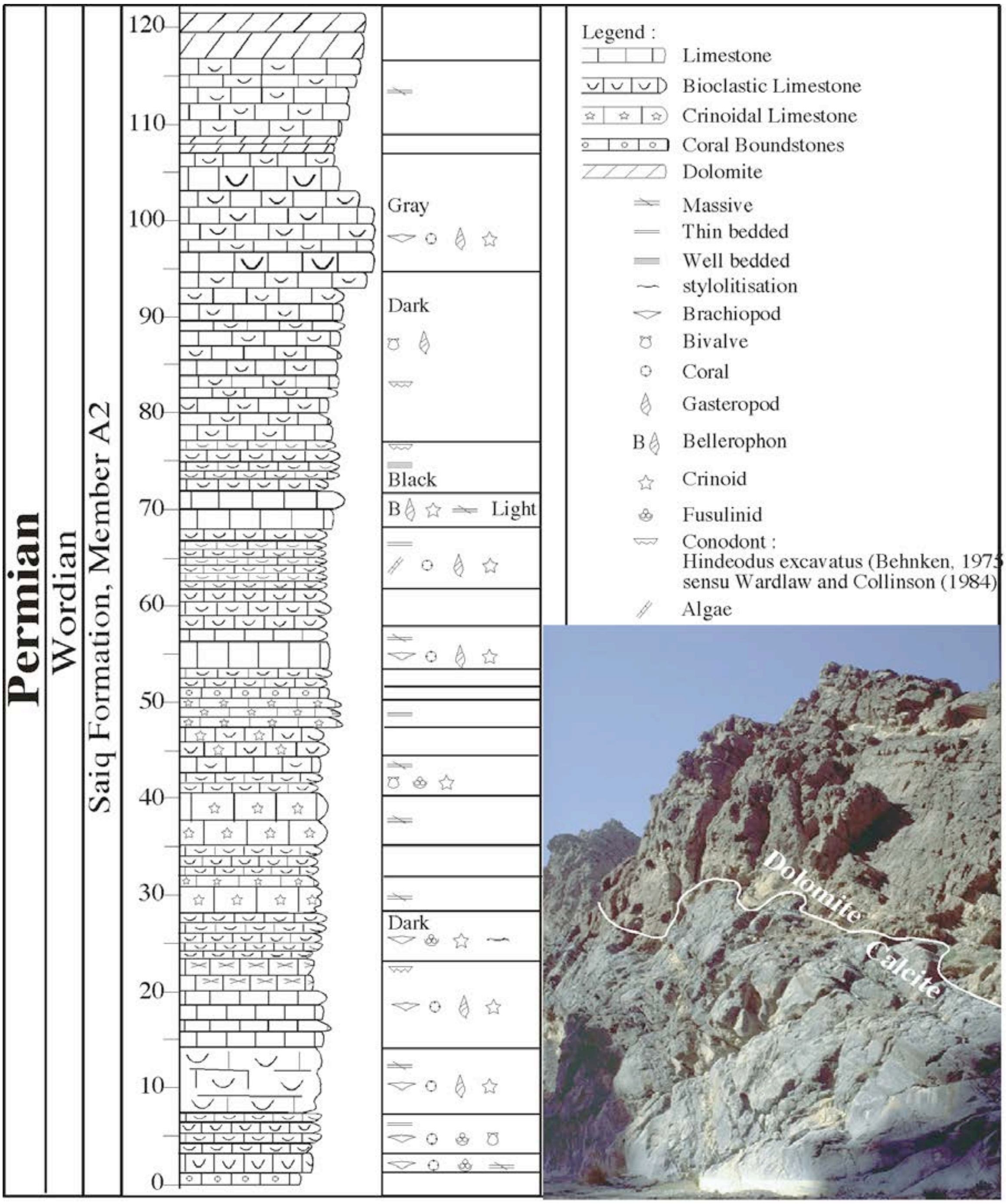


Figure S5: Lithological sktech of the lower part of the Saiq Formation (unit A2). (Field work of L. Angiolini, M.Balini. and A. Nicora. Conodonts determination by A. Nicora).
On the right down, the oblique front of dolomitisation in unit A2 of the Saiq Formation.

Stop 2: Stratigraphy of the lower part of the Saiq Formation at the entrance of the Wadi Sahtan Gorge (Fig. S5).
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 Wordian conodont *Hindeodus exacavatus* (Behnken).
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 that is corresponding to upper Wordian – lower Capitanian in the standard time scale. Thin bedded dolomites with vugs indicate emersive conditions at the top.
We can see a clear oblique front of dolomitisation (Fig. S5). 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.

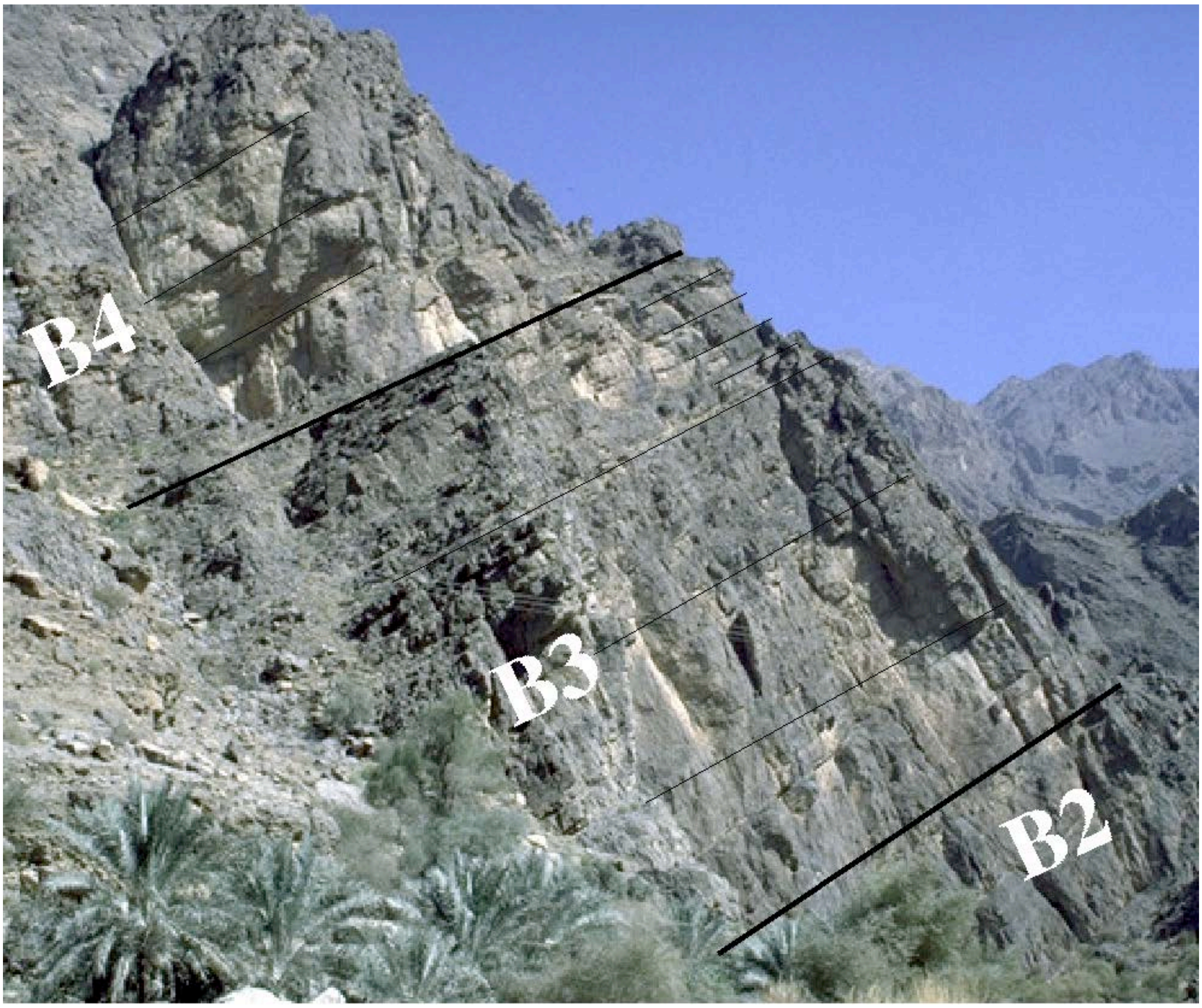


Figure S6- Cycle B of the Saiq Formation (late Permian)

Stop 3: Stratigraphy of the middle part of the Saiq Formation Cycle B and transition to Cycle C.
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 B2) and by thin bedded shallowing upward sequences in the upper part (units B3 to B4, Fig. S6 and Pl. 1A, 1B and 1C) Fusulinids, small foraminifers, calcareous algae, bryozoans, crinoids, brachiopods,

gasteropods are the main fossils. 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 (Figs S6-7). The top of B4 is the regressive part of cycle B. After metric gray bioclastic dolomite, there are at least 3 decimetric levels with Rugosa corals of *Wentzelella*-type (Plate 1C) and crinoids concentration. By isotopic correlation, this is the last beds before the extinction event. It is to be notified than crinoids concentration were also observed in Saih Hatat and in P-T profiles of S Turkey just before the extinction event ((Richoz, 2004; Unal et al., 2003). Then follow dark thin bedded (5 to 20cm thick) dolo-mudstone with some soft pebbles, some beds of supratidal breccia. The Cycle B is ending by a 30 cm thick clay horizon comprising a 5cm thick calcareous level, which can represent a paleosol (Fig. S7).

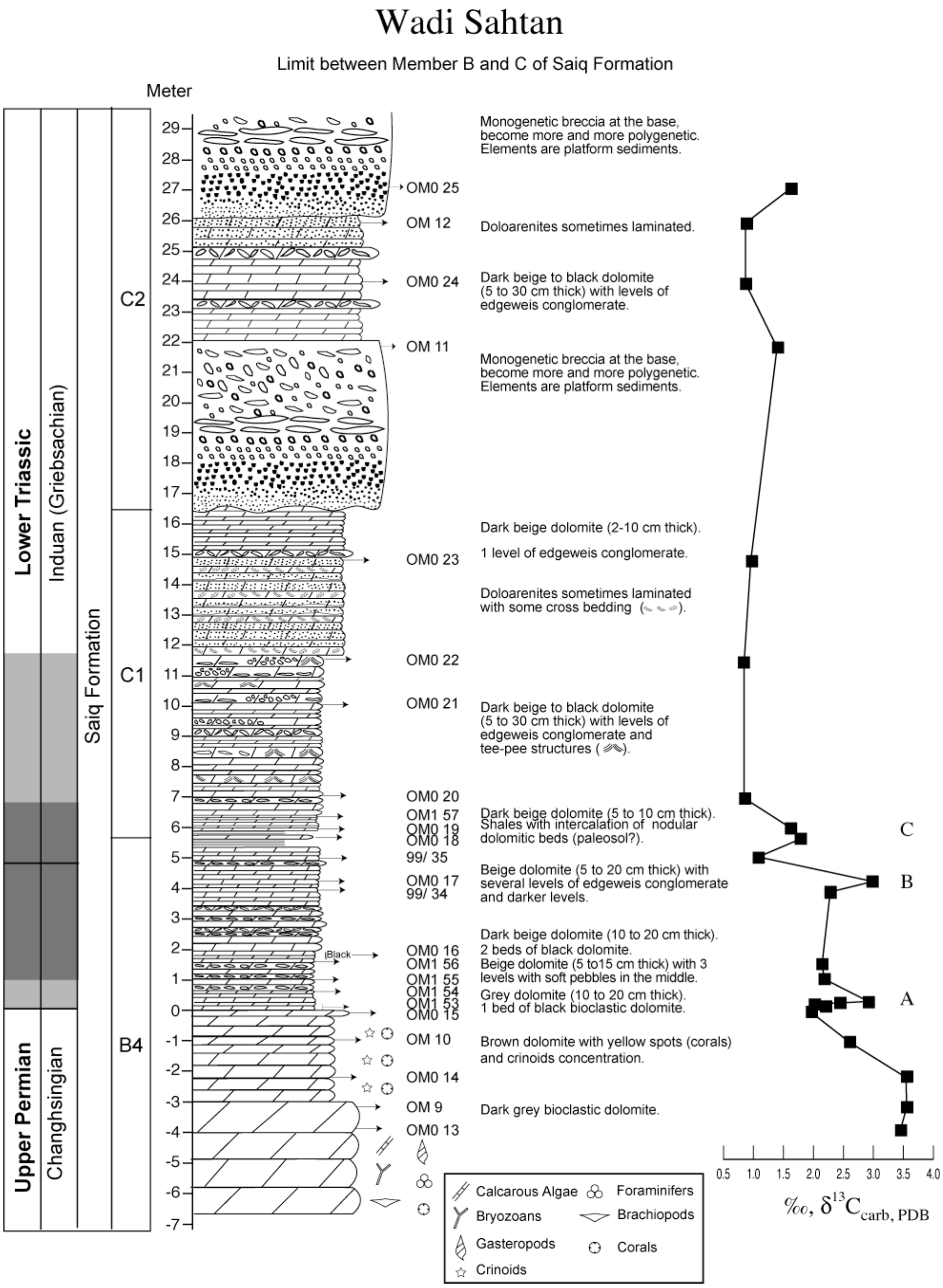


Figure S7: Litho- and isotope stratigraphy of the transition between cycle B and C (Saiq Formation). An assumed Permian-Triassic Boundary ((Richoz, 2004).

The first sequences (C1) of the Cycle C begin with 5m of beige to black thin bedded (5 to 30cm thick) dolomudstone with some soft pebbles, tee-pee structure and supratidal breccia beds. It is overlying by 3m of thin-bedded doloarenite with laminations and cross bedding, one supratidal breccia bed and 1m50 of thin-bedded dolomudstone.

Stop 4: The upper part of the Saiq Formation (Griesbachian).
The T-R cycle C, about 70m thick is beginning with a 5m thick dolomitic breccia overlying C1 with channel structure (fig S8). This breccia has monogenic elements, gradded bedded from sand to 10cm thick elements. Over we observe 3m of thin-bedded dolomudstone with some supratidal breccia. The upper part of C2, C3 and C4 are made of re crystallized dolomitic intraclastic grainstone, metric to decimetric bedded, the top of some metric beds are made of monogenic breccia with angular elements. There are no age diagnostic fossils for this cycle, carbon isotopic correlations give it a Griesbachian age.

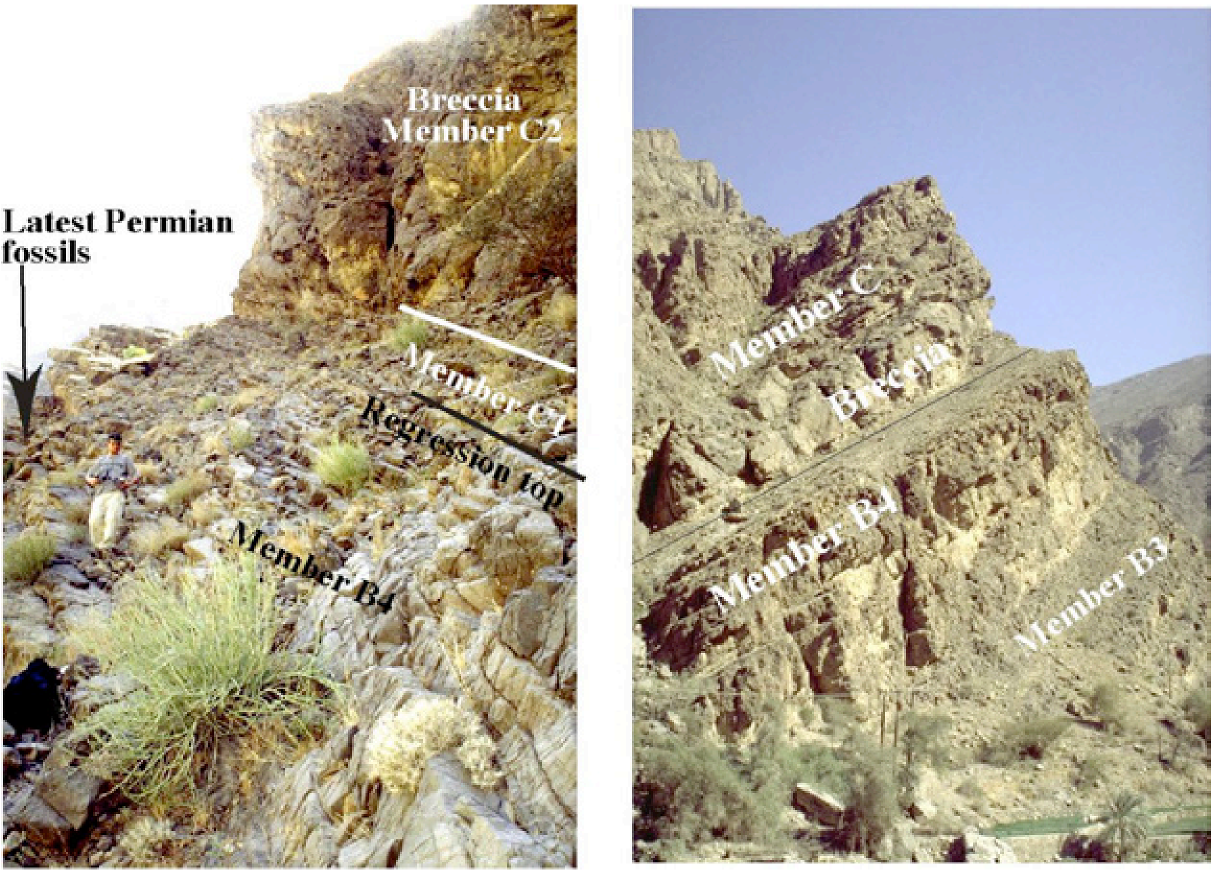


Figure S8: Transition between cycle B and C, Saiq Formation, an assumed Permian-Triassic Boundary. General overview on the right and detailed lithology on the left.

Stop 5: Transition Between Saiq and Mahil Formation and Lower part (Induan) of Mahil Formation (**fig S9**).

The last Saiq sequences (C4) is ending after the last breccia by gray fine doloarenite overlied by a first hardground, a last 30cm doloarenite bed and a second hardground, which is the mark of the top of the Saiq The irregular surface of hardground type indicate an interruption in sedimentation, possibly with subaerial exposure.
Overall, both D (22m) and E (75m) units of the Mahil Formation (Fig. S10) consist of gray and yellowish peritidal dolomites and dolomitic limestones and are characterized by

terrigenous input with horizons of fine silt or purple clay. Microbial structures as stromatolites and oncolites are common features of the Mahil Formation (Pl. 1D).

Unit D starts with a bed of dolomitic conglomerates up to 0.6m thick. The matrix is an oolitic packstone to wackstone with bivalves, elements are oolitic packstone to wackstone. A hardground and 2m of black dolomites with columnar and planar stromatolites and some arenitic lenses overlay this bed. This succession is 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. Some distinct levels are to be mentionned. At meter 6 above the base of the Formation, appear the first vertical bioturbations and some sedimentary structures, which can be interpret as seismite (Twitchett, oral communication). A 2m30-thick tempestite bed appears at 16m. It contains arenitic lenses, evaporitic crystals and it is very bioclastic (bivalves, foraminifers and spicules) at the top. At 19m there is a one-meter-thick bivalves-bearing bed.
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. Carbon isotopic correlations assume an Upper Griesbachian, Dienerian and Lower Smithian for this unit D. So it should be condensed or containing some gap.

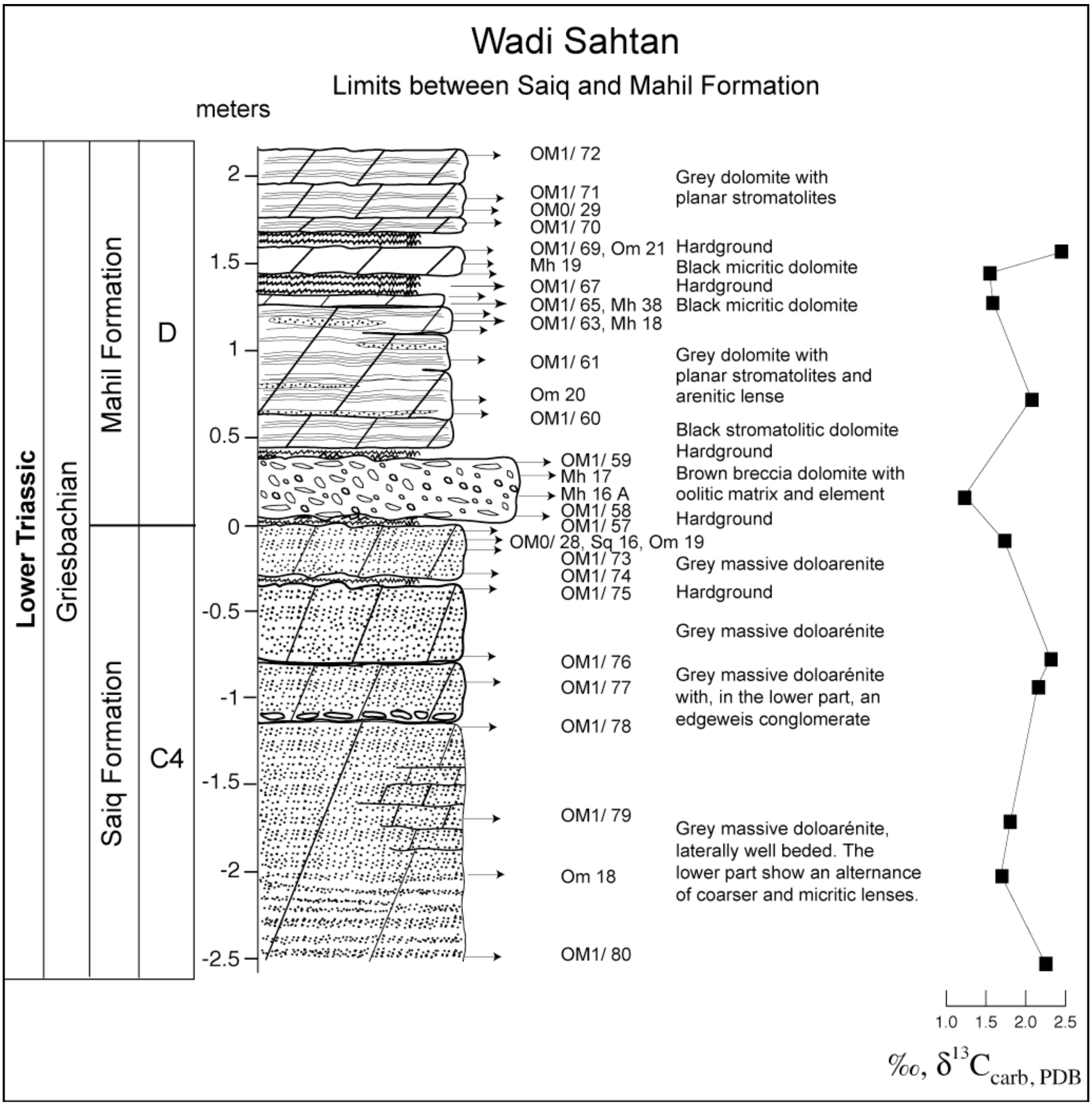


Figure S9: Transition between cycle C and D (Saiq-Mahil boundary) with C isotope curve (Richoz, 2004).

Unit E exhibit similar sedimentary structures, however it is more massive and marly interbeds are rare. Hardground are frequent. This unit starts by a 10m thick oncolite level and is ending with 1m50 level of orange dolomite very well recognizable. Carbon isotopic correlations assume a Smithian age for this unit E. The F sequences overlying, is coposed of metric black dolomite without marls. The boundary between sequences E and F is predicted to be the Smithian-Spathian boundary by isotopic correlations.

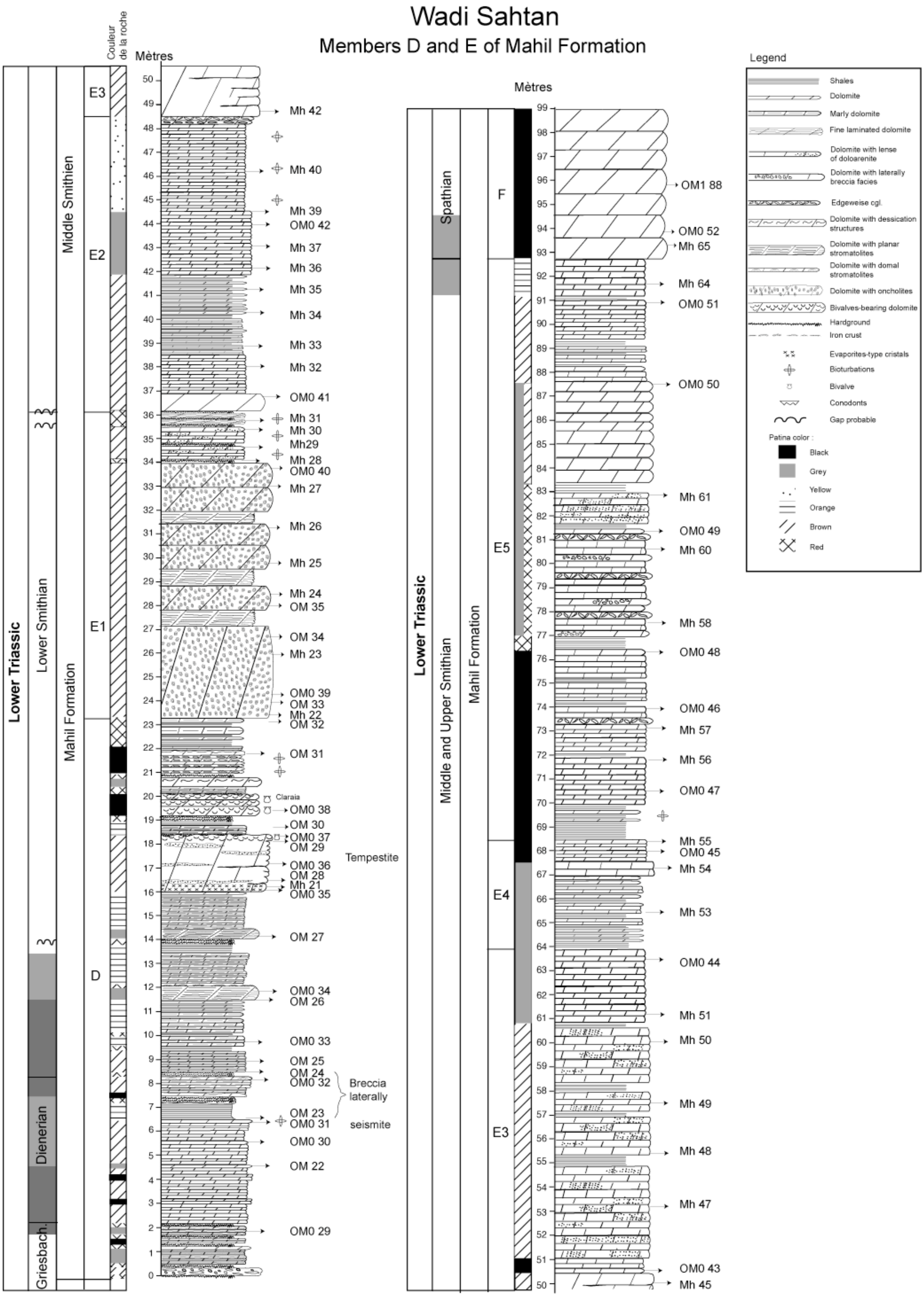


Figure S10: Lithostratigraphy of the lower part of the Mahil Formation (Richoz, 2004).

Stop 6: The boundary between the Akhdar Group (Permo-Triassic) and the the Sahtan Group (Jurassic).

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

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

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

Before the Neo-Tethyan rifting

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…(Ricou, 1993). During the Late Carboniferous-Earliest Permian period, the Gondwana continent was subjected to glaciation (Al Khlata tillite in Oman).

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 eastern part of the Oman mountains (Jabal Akhdar and Saih Hatat) indicating that, at this time, this region constituted a positive zone; this is probably in relation with a flexural doming precursor of the Neo-Tethyan rifting, initiating a shoulder and concomitant rim basins where the marine deposits laid down.

The first stage of the Neo-Tethyan rifting

The first stage of the Neo-Tethyan extension begins within the Kungurian-Roadian 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 siliclastic terrigenous deposits of the lower part of the Saiq Fm. (Saiq A1 unit).

Global sea level rose to a maximum during the Late-Early Permian (Kungurian, Haq et al., 1987); however, only rare shallow-marine carbonate of this age are 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. (Kungurian-Roadian, 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.

From rifting to break-up, the Neo-Tethyan opening

At the dawn of the Wordian (Middle Permian), within a sea level rise, the "Fusulinid Sea" transgressed over most of Oman with the exception of the Jabal Ja'alan and the Huqf-Dhofar axis; this transgression enabled the establishment of a vast carbonate platform in Jabal Akhdar, a 400-700m-thick succession of cyclic shallowmarine carbonate, the Saiq Fm (Middle-Late Permian, basal Triassic, Baud et al. 2001, Richoz, 2004); 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, 2003). Clearly, for us, this transgression was the result of the break-up of the Neo-Tethyan rift and the associated thermal subsidence.
This Neo-Tethyan break-up occurs with the northward drifting of the Iran/Mega Lhasa microcontinent (Baud et al., 1993, 2001); 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 distal platforms along the continental slope (later they were incorporated in the Hawasina Nappes).

The 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 (Wordian, Pillevuit, 1993; Pillevuit et al., 1997; or Roadian, Krystyn, oral communication). Different type of deep water black limestones are also identified in the basinal 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) with a base dated as Roadian (Middle Permian, Immenhauser et al., 1998) and the top Wuchiapingian (Kozur, unpublished results).

The distal isolated platform identified as nappes in Baid and Jabal Qamar areas by Béchennec, 1988; Béchennec et al., 1992b; Pillevuit, 1993, Pillevuit et al., 1997, are mainly made of Middle-Late Permian open shelf carbonates. The Jabal Qamar unit includes a fragment of the pre-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 (Capitanian-Wuchiapingian) shallow-marine carbonate (Baid Fm., Béchennec, 1988; Pillevuit, 1993, Pillevuit et al., 1997). The distal paleogeographic position of these Permian tilted blocks in regard with the Arabian Platform is documented by:
(1) The differences in terms of facies (open marine with ammonoids) with those restricted of the others parts the Oman Mountains (Jabal Akhdar, Saih Hatat, Musandam);
(2) The presence of reworked boulders originating from these isolated platforms in the calcirudites of the proximal units of the basinal Hawasina Nappes.

Basinal 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 Group. These successions starts generally with thick volcanic sequences (Al Jil Fm); they are particularly well exposed to the north of the Hawasina Window (Buday'ah area) and of the Jabal Akhdar (Al Ajal region) and in the southern flank of the Saih Hatat (Wadi Wasit area); they have been also identified locally, near Nahkl and Rustaq and in the Batain plain near Al Ashkharah. Predominantly these volcanic rocks comprise tubular pillow basalt and subordinated andesitic and trachytic lava, hyaloclastite and tuff (Béchennec, 1988; Béchennec et al., 1991; Béchennec et al., 1992a-b-c, Pillevuit, 1993, Pillevuit et al., 1997). These volcanic rocks are either of MORB type or alkali basalt-related; however N-MORB (depleted) have not been found as most of the studied samples range from transitional MORB to enriched MORB (Maury et al., 2003). The volcanic succession is generally overlain by red radiolarian chert and shale, dated as Middle Permian (Wordian) in Buday'ah and Al Ashkharah areas (De Wever et al., 1988; Béchennec et al., 1992a-c, Cordey in Baud et al. 2001b). In the Wadi Wasit area, the volcanic series is capped by red cephalopods-bearing carbonate, dated Middle Permian (Wordian, Blendinger et al., 1992; Pillevuit et al. 1997, Baud et al. 2001b), by shales and breccia with reworked blocks of Middle Permian platform carbonate (Béchennec et al., 1992b; Pillevuit 1993). Near Nahkl the volcanic series includes blocks of Middle Permian shallow-marine carbonate and is overlain by pelagic limestone. In the Rustaq area the volcanic succession is also capped by a condensed carbonate sequence (Hallstatt facies type) dated as Middle Permian (Wordian, Blendinger et al., 1992, Pillevuit et al. 1997, Baud et al. 2001b).
Following the peak of the thermal subsidence in the Wordian-Capitanian, a stable carbonate platform became established on the Arabian Peninsula. The Saiq, Khuff and Hagil Fms, show a strong regressive tendency at the end of the Guadalupian, with restricted environment facies and a reduced biophase, mainly associated with a global fall in sea level, at this time (Haq et al., 1987).
During the Lopingian, the subsidence as recorded in the Saiq mega-cycle B (up to 300m of shallowing upward cycles) is still well active.

The Permian-Triassic transition and the lower Triassic deposits on the Arabian passive margin.
At the end of the Permian, regressive conditions up locally to emersion are recorded as well on the Arabian carbonate platform (Jabal Akhdar, Saih Hatat, Musandam) as on the continental slope (shallowing in the Sumeini unit).

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

On the slope of the continental margin, a continuous carbonate deposition and shale has been recently precisely dated from Changsingian to Spathian. Overlying the Wuchiapingian? deep-water chert and dolomite (upper Mq 2 Member of the Maqam Fm), we note the deposition of Changsingian shallowing siliceous strongly bioturbated lime mudstones. A huge facies change occurs with the Griesbachian papery, laminated calcimicrobial mudstone overlying the boundary clay (base of Mq 3 Member of the Maqam Fm). The calcarenite, calcirudite turbidites and avalanches with shallow water upper Permian lime clasts start in the Dienerian (instability period). The incredible thickness of the Smithian deposits (platy limestones, shales and megabreccia up to 900m deposition; middle and upper Mq 3 Member of the Maqam Fm) indicate an high carbonate productivity on the platform and a very active subsidence at the base of slope (Watts, 1985; Baud et al. 2001; Richoz 2004)).

On the Baid tilted block, after karstification of the Permian carbonate platform and a Dienerian tectonic activity, the Dienerian-Smithian deep-water red ammonoïd limestone is filling fissures and cavities (Hallstatt breccia) and is deposited over the Permian limestones (Tozer and Calon, 1990; Pillevuit, 1993; Pillevuit et al., 1997, Baud et al. 2001, Richoz 2004).

In the proximal basin (Wadi Wasit units) the Lopingian allodapic limestones are partly eroded by a submarine avalanche breccia containing Permian to basal Triassic mega-blocks. One of these blocks with a unique Permian-basal Triassic record has been analyzed in Krystyn et al. (2003) and Twittchett et al. (2004). Upper Dienerian to Anisian deep-water platy limestones overlain the lower Dienerian mega-block breccia.

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

The Olenekian to Rhaetian evolution of the margin

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

On the slope of the continental margin, the thick Smithian deposits are overlain by Spathian-Anisian shales and Ladinian radiolarites in stable condition. During the Carnian-Norian, a pervasive instability is documented by the coarse calcirudites interbedded in the chert and calcarenite succession of Mq 5 Member of the Maqam Fm..

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

In some area of the distal basin (Diba zone and 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 a renewed extensional regime. The Late Triassic evolution of the distal part of the Hawasina Basin is documented by the creation of the Misfah distal Platform and by the Umar Basin. A strong subsidence is 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 unit that 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, 2003). In the Misfah setting this volcanic unit is overlain by a Norian marly nodular limestone (Subayb Formation,) and by a thick (600m) shallow-marine carbonate Formation (Misfah, Pillevuit, 1993), Norian-Rhaetian in age (Krystyn in Baud et al. 2001b). The presence of hardgrounds and, in places, microkarsts reflect the end-Triassic sea level fall. In the adjacent Umar Basin, the Late Triassic sedimentary succession consists of pelagic limestone and radiolarian chert without any terrigenous influx; the only clastic sediments are calcirudite and megabreccia made of reworked boulders of shallow-marine carbonate originating from the Misfah Platform.

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THE JURASSIC AND CRETACEOUS CARBONATE PLATFORM OF THE DJEBEL AHKDAR

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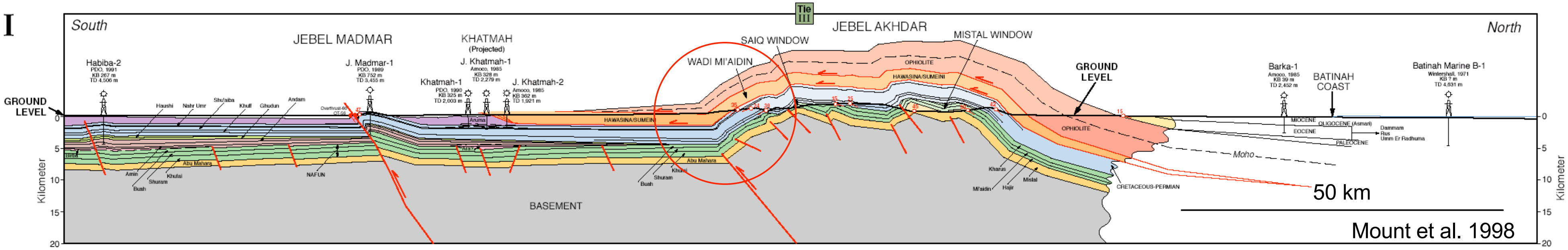
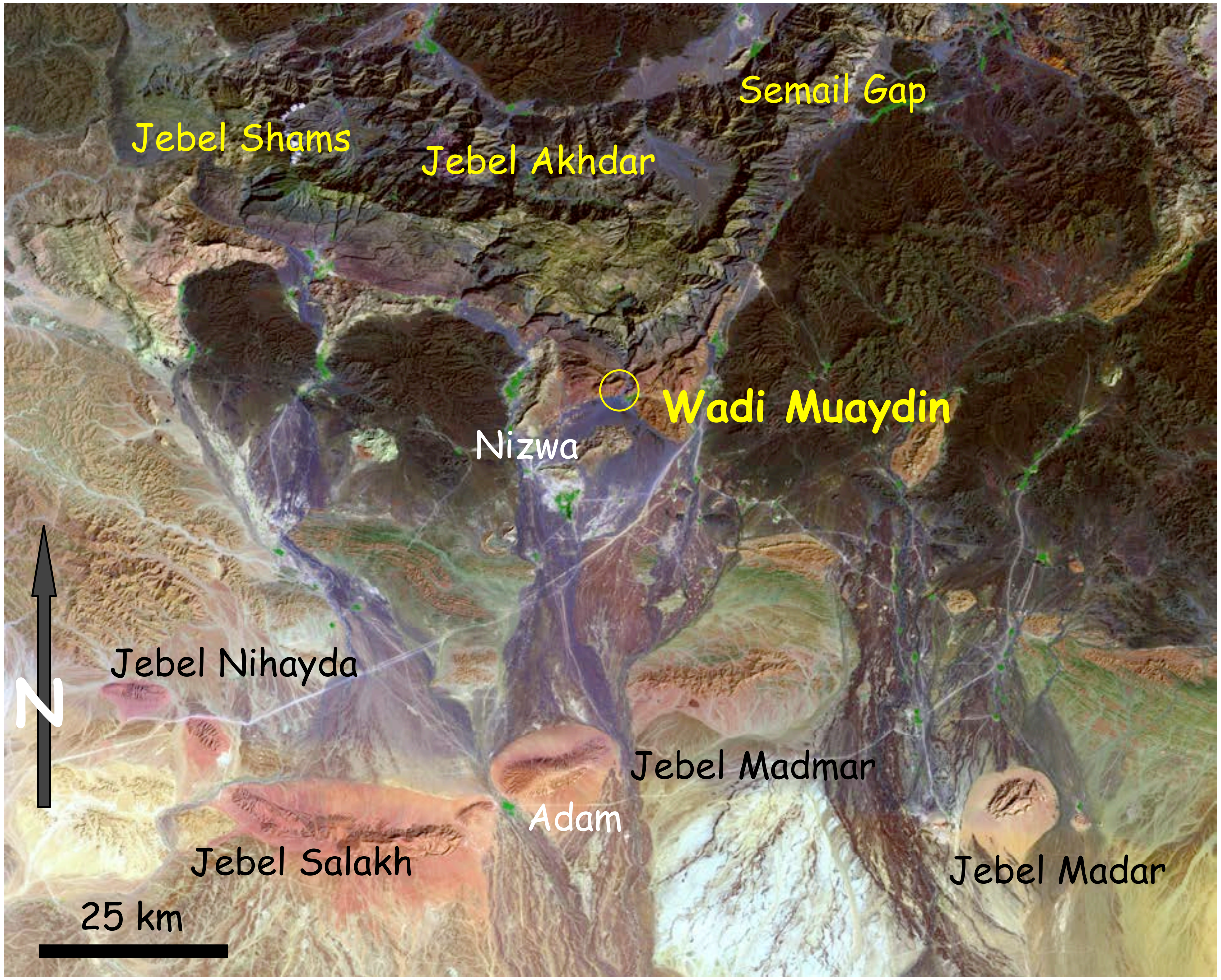
Henk DROSTE

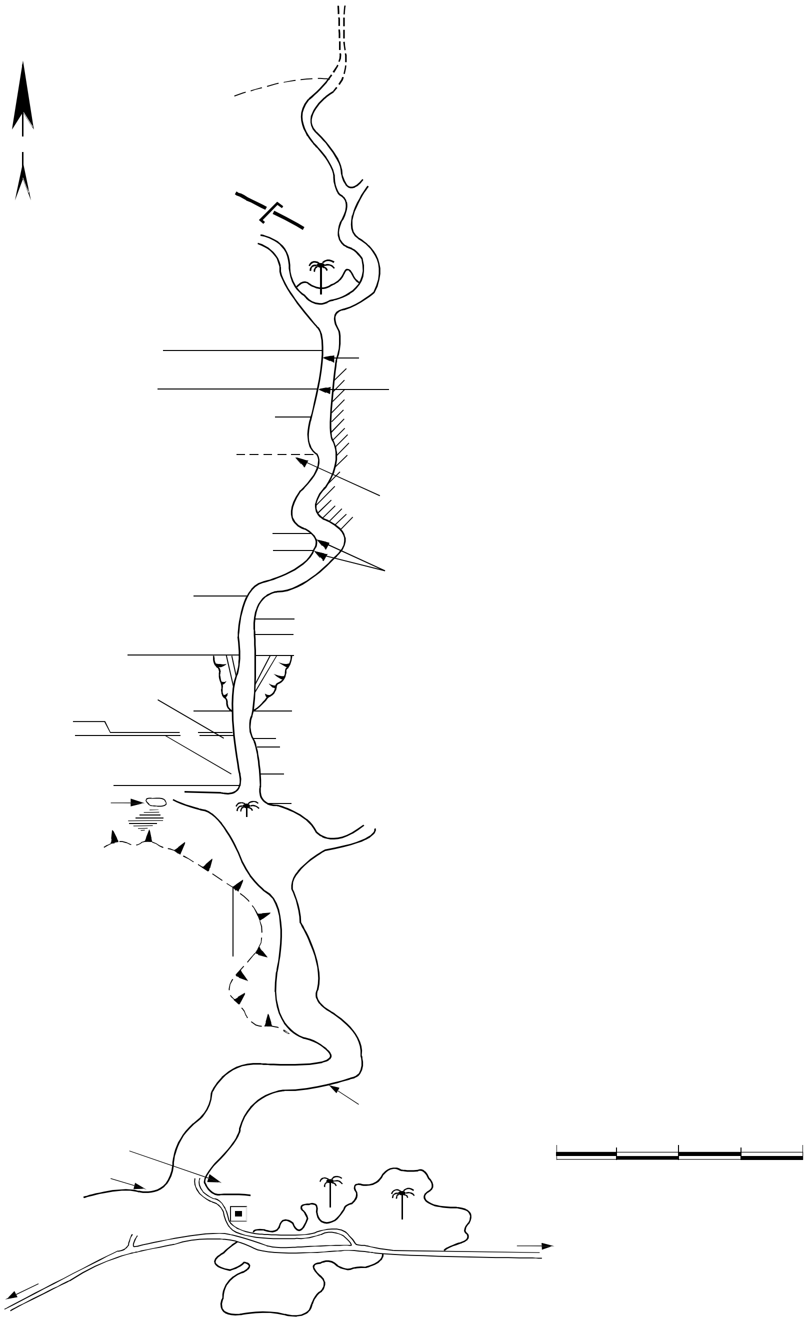


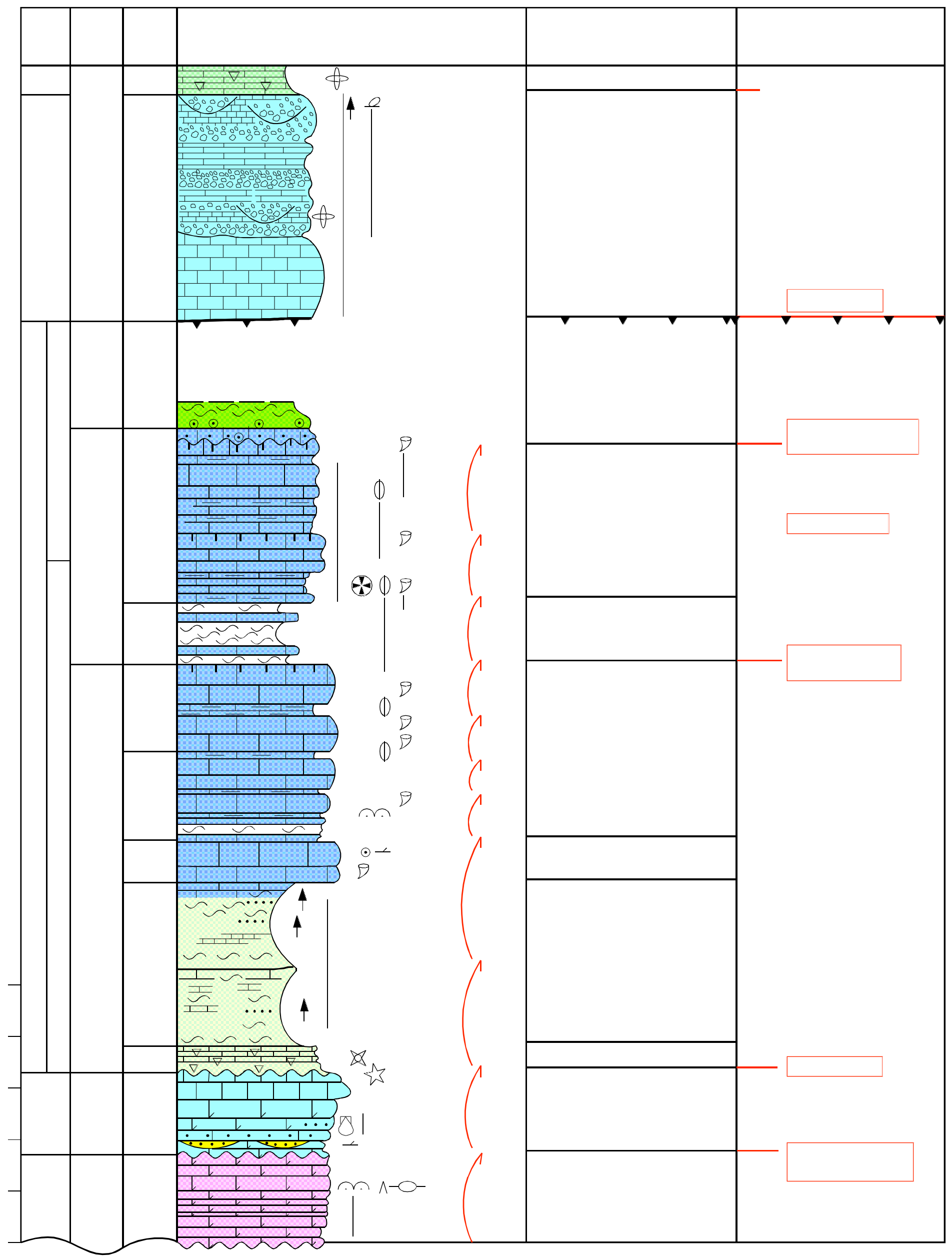
Wadi Mi'aidin is located on the southern flank of the Jebel Akhdar some 20 km from Muscat. It one of the numerous wadis draining the Jebel Akhdar forming vast alluvial plains into the flat land to the south. In the water-rich area of the foothills settlements established in several oasis and towns. Birkat al Mawz (banana lake), an old village with a fort and rich plantations, taps its water through an ancient drainage system (falaj) directly from the Wadi gravel at the lower end of the Wadi Mi'aidin.

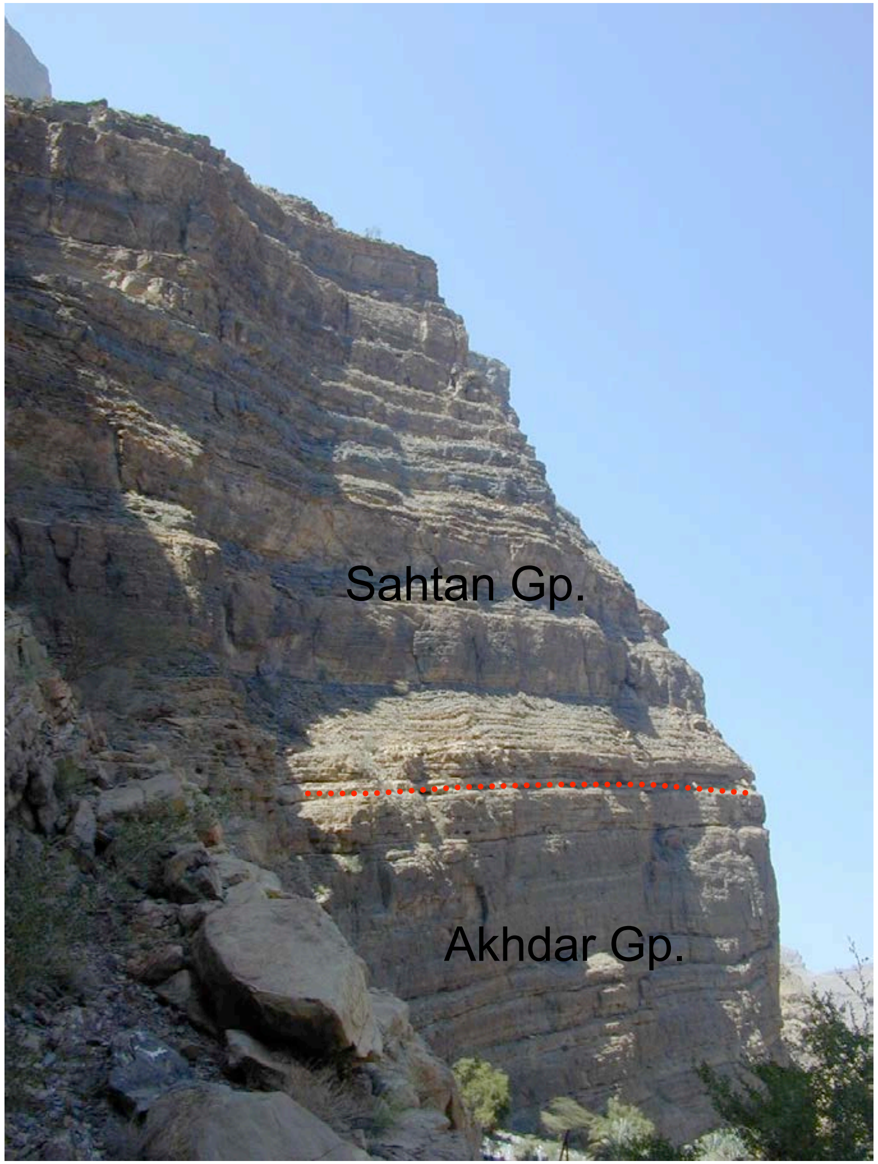
The wadi cuts through the southern flank of the autochtonous series of the Jebel Akhdar anticline. The Mesozoic formations from the Triassic Mahil to the Upper Cretaceous Muti Fromation are easily accessible along the wadi floor. The terrain at the lower end of the wadi in the area of Birkat al Mawz is occupied by overthrust Mesozoic sediments of the Hawasina nappes.

Some 400 m NW of the fort at Birkat al Mawz the road enters the lower end of the wadi which is flanked here by carbonates of the allochtonous Hamrat Duru Group. After 4 km the wadi widens in the contact zone from the truncated autochtonous Muti Formation to the overthrust Guwayza Limestone of the Hamrat Duru Group. The road towards the NE leads to the Saiq Plateau. The wadi continuous to the North into a narrow gorge cut into the carbonates of the Wasia, Kahmah and the Sahtan Groups. After some 5 km one reaches the palmgardens of the village Mi'aidin on Triassic Mahil dolomites. This location is a convenient starting point for a detailed study of the entire cross section.







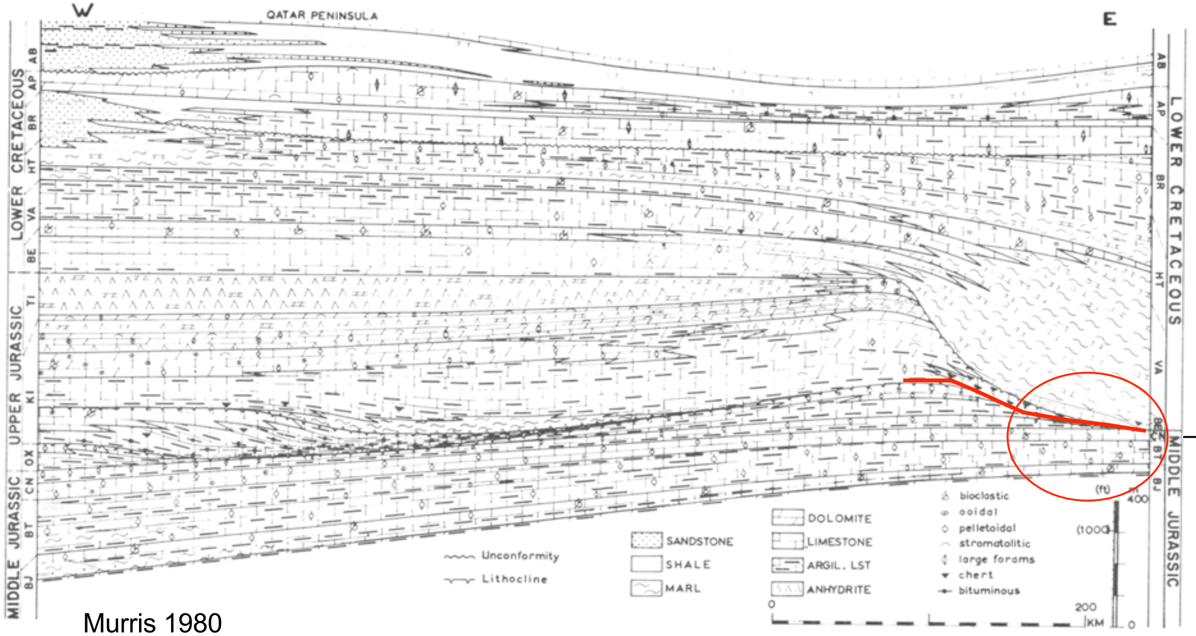


Wadi Mi'Aidin, UTM 40 568500/2542250

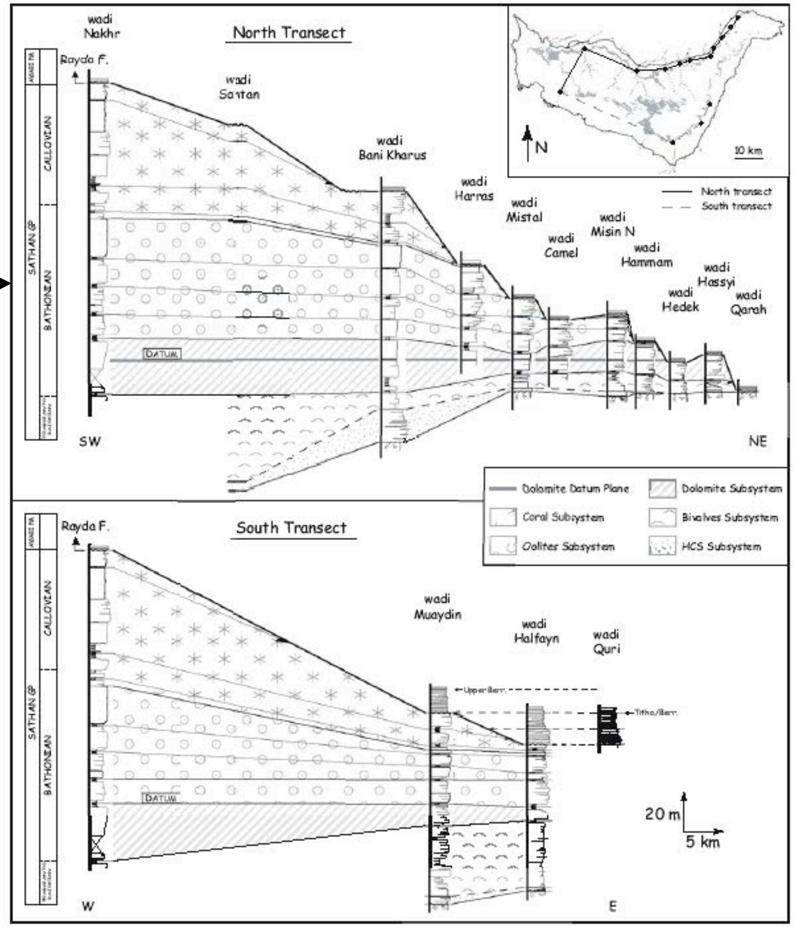
Jurassic Sahtan Group

The Sahtan Group consists of a basal interval of mixed siliclastics and carbonates which progressively change upwards into a limestone sequence. The lower part contains beds of variably sandy, bioclastic, ooidal and pelletoidal lime wacke to packstones (bluish grey), dolomitic mudstones, dolomites (yellow-brown), siltstones to coarse-grained sandstones and ferruginous oolites (rusty brown). Lithiotis bivalves accumulations occur at scattered horizons. At the basal unconformity a conglomerate with large reworked blocks probably from the Triassic may is present. Wave ripples and cross bedding, in places possibly herring-bone can be seen in the silts- and sandstones. Bioturbation occurs both in the carbonates and siliciclastics.
The upper part consists of bluish-grey fossiliferous bioclastic oolitic pelletoidal lime wack- to packstones, some lime mudstones and rare grainstones and is in places dolomitic (yellowish).
Looking from a distance at the cliff face a clear cyclic development of the Sahtan can be seen. The cycles are expressed by a receding lower part and a thicker to massive bedded cliff forming top. They are formed by shallowing upward packages with mudstones grading into grainstone at the top, relatively abruptly overlain by mudstone of the next cycle (Glennie et al 1974). In the sandy lower part of the section two thick cycles are developed, the second one capped by a cross bedded sandstone. Above this the cycles are much thinner and initially more argillaceous but show a systematic thickening and cleaning upward trend. In other more complete sections in the Jebel Akhdar intertidal stromatolites start to develop at the top of the Sahtan.
The exposed of the Sahtan Group forms a major transgressive regressive cycle initially flooding the subaerially exposed and eroded Triassic in a coastal depositional setting, showing a progressive decrease of siliciclastic influx upwards and establishment of a shallow water carbonate platform, which in turn shows an overall shallowing upward with an increase of intertidal facies. The transgressive maximum is located in the interval with the thin muddy deeper water cycles in the middle of the section while the overlying thickening upward stacking pattern is thought to represent the overall prograding carbonate ramp.

Jurassic Sahtan Group



Murris 1980



Rousseau et al. in prep.

The Sahtan Group comprises the Jurassic sequence (Pliensbachian to probably Oxfordian, Glennie et al 1974) which rests with a slightly angular unconformity on the Triassic Mahil Formation. The Sahtan has a variable thickness in the Oman mountains (and subsurface) as a result of truncation below a major mid-Jurassic unconformity related to the break-away of India in the east. The basal Sahtan of the Oman mountains correlates well with the Mafraq Formation known from the wells in the interior of Oman. The upper part of the Sahtan Group most likely represents the Dhruma Formation.

A more complete Jurassic sequence is present in the subsurface where the Tuwaiq Fm is still preserved below the unconformity.

Jurassic Sahtan Group

In the Late Jurassic the Arabian Plate margin collapsed and drowned as the Indian plate moved away. The Late Jurassic platform margin developed in the central parts of the Arabian Plate running more or less N-S in the UAE. The Upper Jurassic in Oman is developed in a deep water facies Therefore the prolific shallow water carbonate sands alternating with evaporites (Arab Fm.) and thick anhydrite seal (Hith Fm.) of the Rub al Khali basin are not present.

HYDROCARBON HABITAT AND STRATIGRAPHY

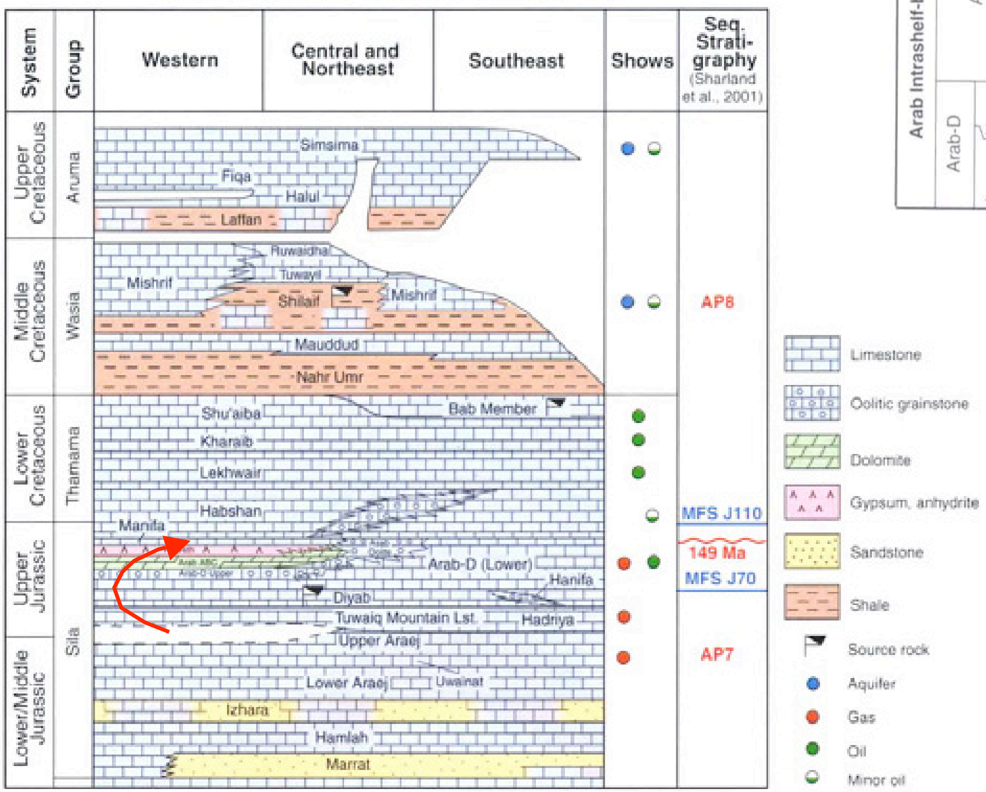
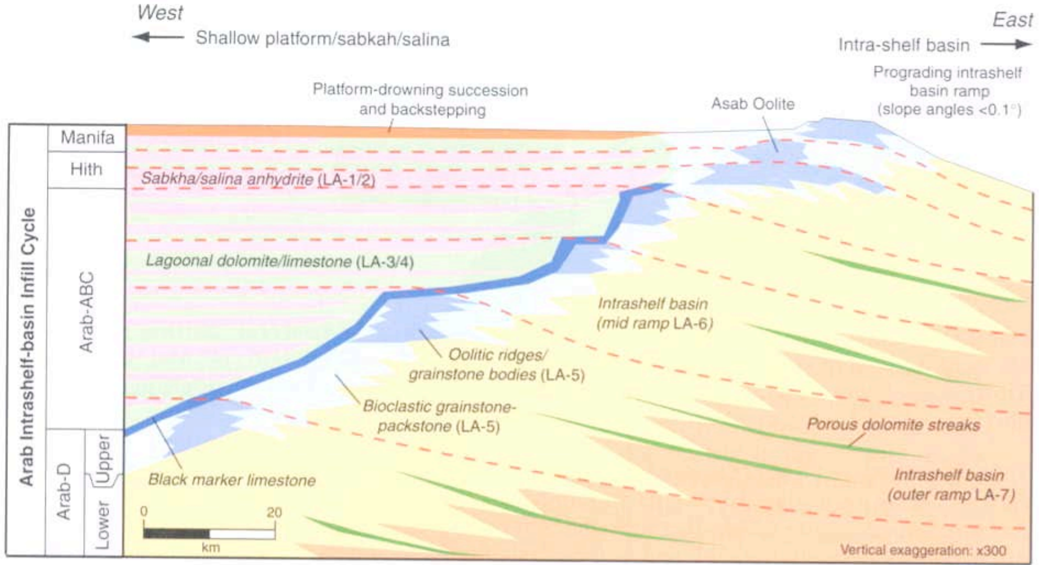


Figure 3: The Arab Formation in the context of the hydrocarbon habitat of the Central Abu Dhabi Ridge, showing stacked Jurassic and Cretaceous intrashelf basins.

DEPOSITIONAL FACIES DISTRIBUTION



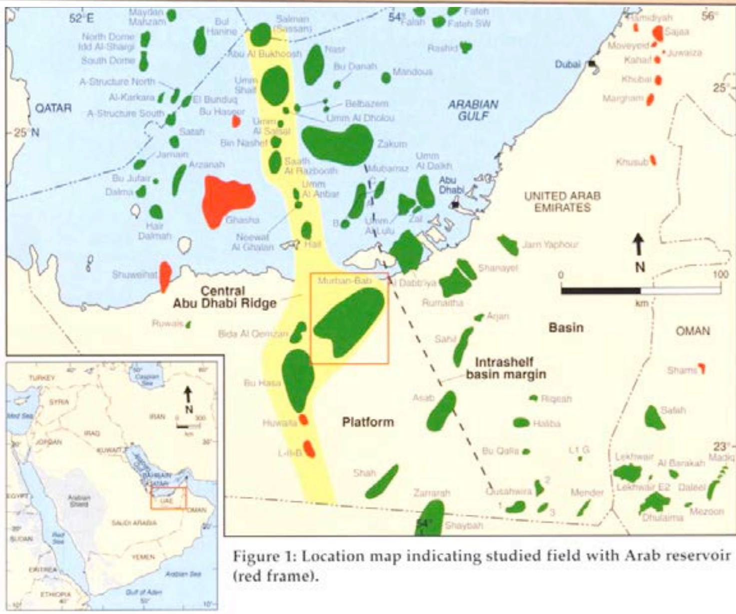
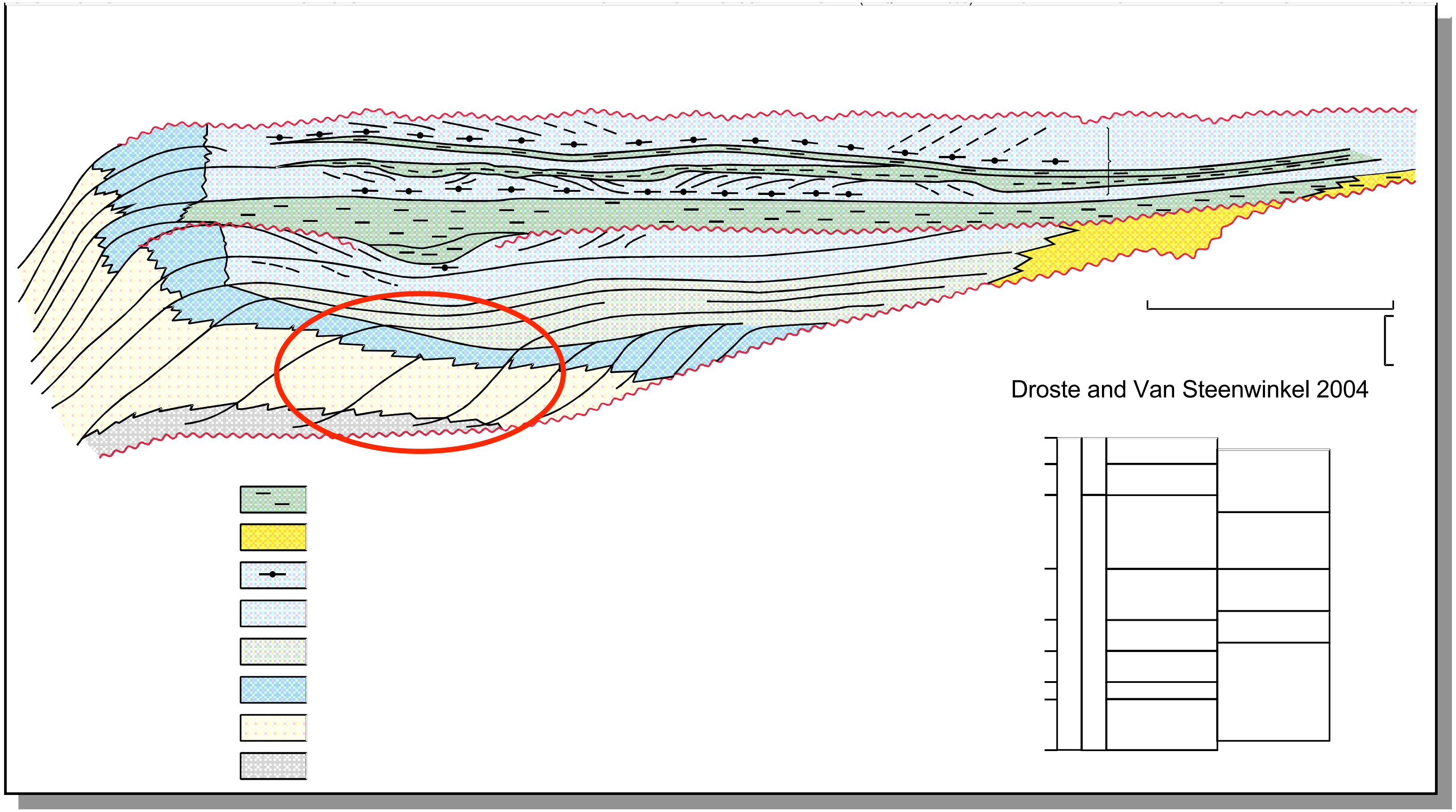


Figure 1: Location map indicating studied field with Arab reservoir (red frame).

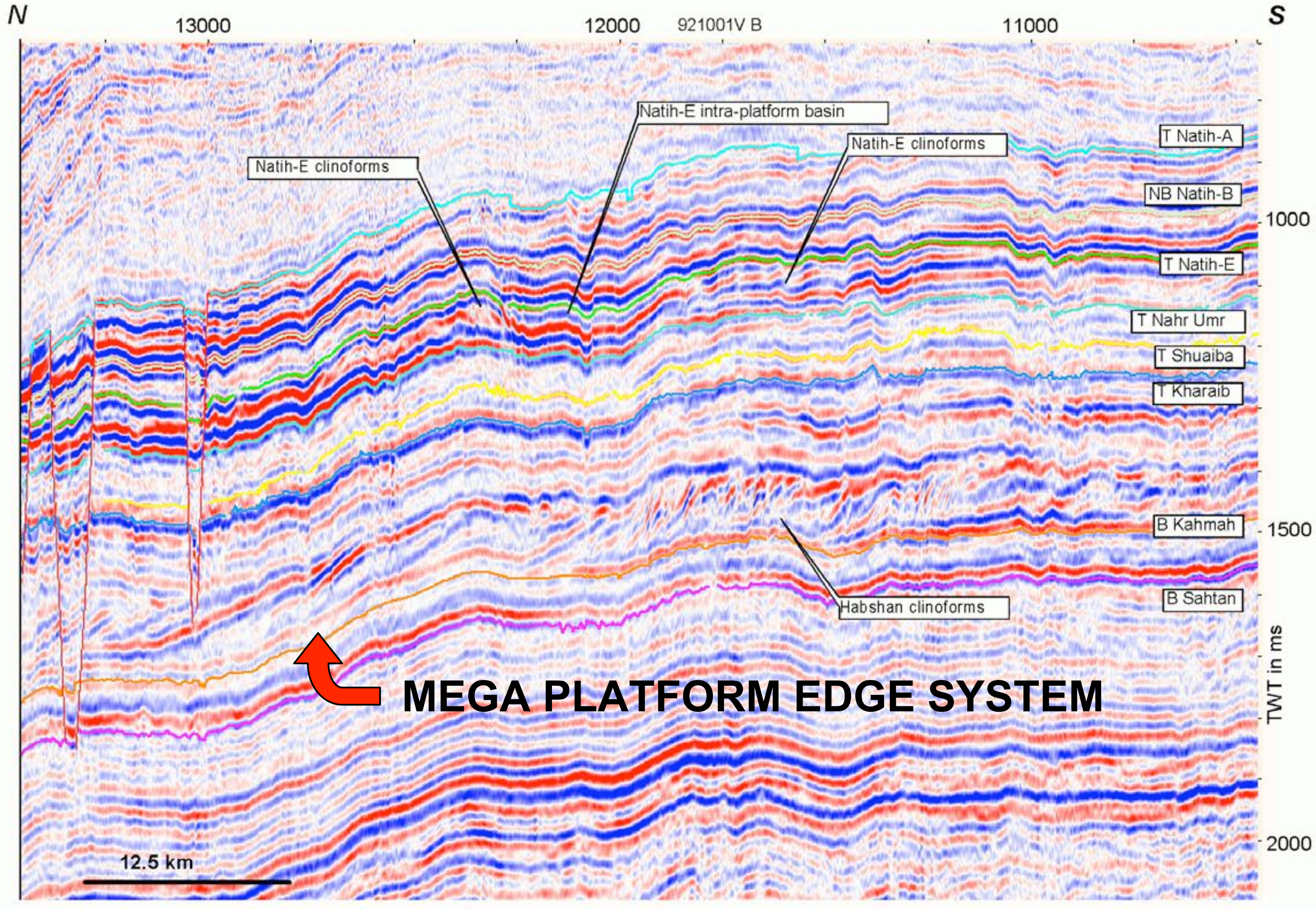
Grötsch et al. 2003

Cretaceous carbonate platform



The Cretaceous platform started to grow in central Oman after a major transgression over a collapsed Jurassic carbonate platform. From here, the edge of the platform prograded some 250 km to the north in approximately 15 Ma (Berriasian to Late Hauterivian). This prograding carbonate belt is referred to as Habshan Formation. During this phase, the platform edge is dominated by bioclastic and oolitic sands. The water depths in front of the platform were in the order of a few hundred meters. The Salil and Rayda Formations are interpreted as the isochronous offshore slope and deep-sea equivalents of the prograding carbonate platform.
The progradational phase is followed by a mainly aggradational trend, which lasted some 35 Ma (Barremian to Early Turonian), with only minor shifts in the position of the platform margin which consisted of microbially cemented beach deposits and rudist microbial bioconstructions. The 700 m thick platform interior that developed behind it forms the historical 'layer-caked' platform, which contains several intra-platform basins. Pulses of clastic sediment flux onto this platform were derived from the exposed Arabian shield and fringing exposures of Palaeozoic sediments in the southwest.

Cretaceous carbonate platform



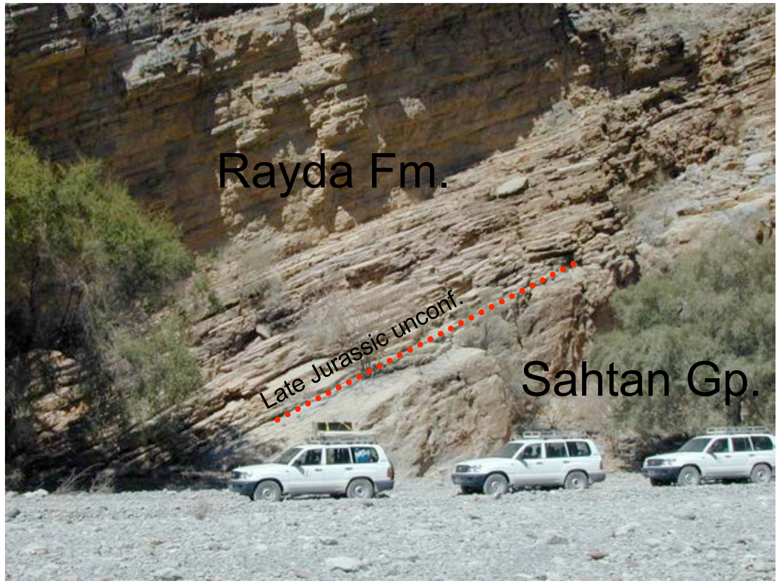
Droste and Van Steenwinkel 2004

On seismic, well-defined clinoforms (above 'B Kahmah' marker) of the 'Habshan system' document northward progradation during the initial stage of the large-scale Cretaceous platform development. Well data show that facies shallow upward within a clinorm belt from basinal (Rayda Formation) to slope (Salil Formation) into shallow-marine oolitic and bioclastic shoals (Habshan Formation).

Rayda and Salil Fm.

The Rayda Formation is about 130 m thick and consists of light-grey weathering, thin-bedded lime mudstones with brown to black chert layers and nodules. The very fine-grained limestone is rich in radiolaria, sponge spicules, pelagic crinoids and tintinnids indicating earliest Cretaceous latest Jurassic. Planktonic foraminifera, belemnites, rare ammonites and common bioturbation occur in these beds. Because of the very fine-grained nature and the light colour these limestones are often called "porcellanites" in field descriptions. A condensed horizon occurs at the basal unconformity (not observed in Mi'aidin section). This interval contains corroded limestone pebbles (undated) numerous vertrebrate teeth and bones, casts of ammonites and belemnites set in a red lime wackestone matrix (Haan et al, 1990). Towards the top of the Rayda the carbonates gradually become dark grey to black-weathering and thicker bedded (medium to thick-bedded). The transition into the overlying Salil is gradual. The Rayda Formation was deposited in a deep marine bathyal environment starved from clastic influx. The age of the Rayda is Early Berriasian in age possibly extending into the earliest Valanginian at some localitites (Simmons 1994).

The Salil Formation is about 330m thick and consists mainly black argillaceous lime mudstones, which characteristically weather olive-green to brown-grey. A cyclic develpment can be seen expressed as a series of thin-bedded, recessive units consisting of argillaceous lime mudstones separated by thicker-bedded scarps of lime wackestones. In the middle part massive dark coloured lime-mud- and wackestone form a steep cliff. Macrofossils are less common than in the Rayda Formation and bioturbation is more intense. Calpionellids occurring in the Salil Formation suggest a Berriasian to Valanginian age. In contrast to the underlying Rayda Formation the Salil is characterised by fine clastics content and turbiditic events suggesting deposition in the proximal basin and on the slope. The uppermost beds contain an increasing proportion of of bioclastic material and are transitional into the overlying Habshan Formation with a general upward increase of bed thickness which eventually becomes cliff forming at the base of the Habshan. The Salil Formation is of Berriasian to Valanginian in age, possibly Hauterivian in its upper part (Simmons, 1994)



Wadi Mi'Aidin, UTM 40 568500/2541500

Wadi Mi'Aidin, UTM 40 568500/2541250

Habshan Fm.


Cross-bedded oolitic grainstones

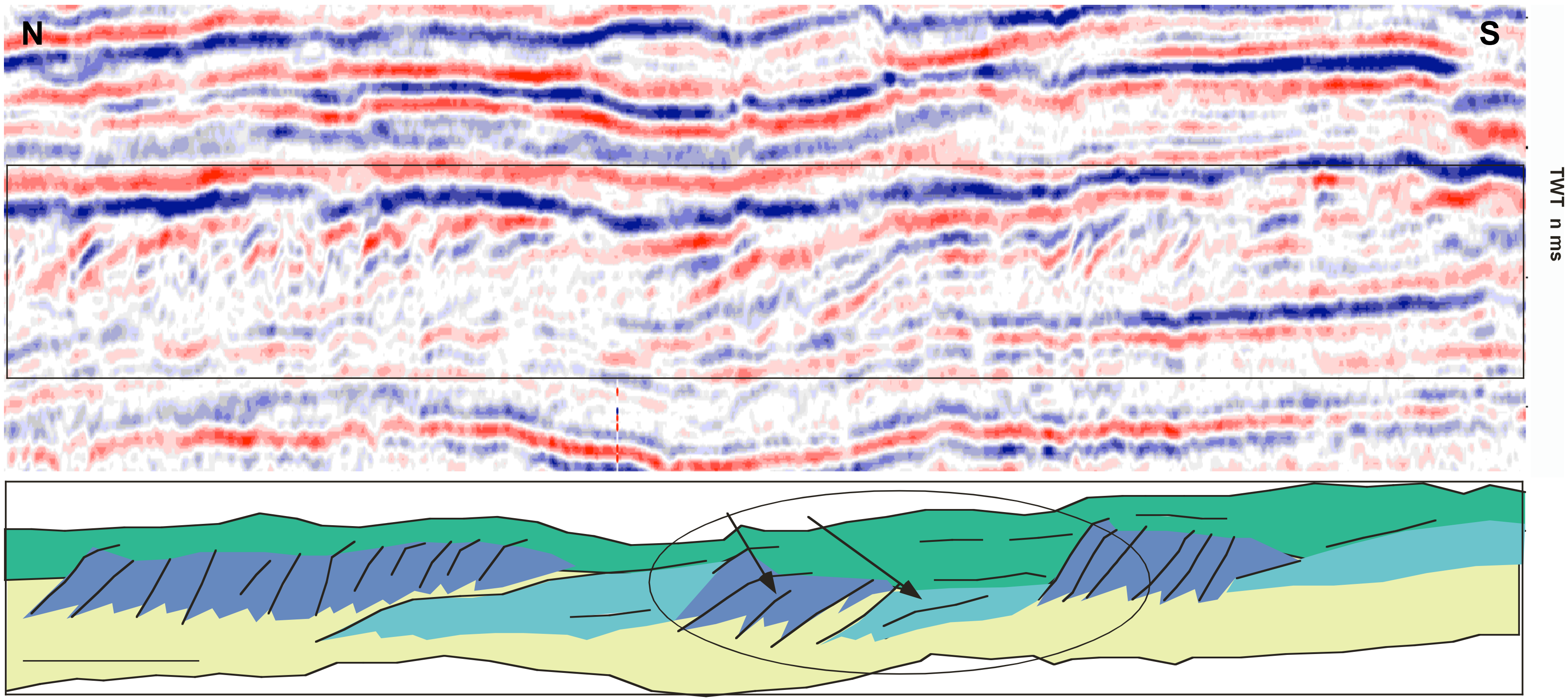
The Habshan Formation is about 44 m thick and starts with meter bedded to massive bioclastic/peloidal grainstones with Lithocodium/Bacinella, rudists and corals grading into bioclastic/oolitic grainstones with cross bedding and some coarse skeletal grainstones containing rudist, gastropod and coral fragments. The Habshan was deposited in a very shallow marine, high energy environment with carbonate shoals. The Habshan is of Hauterivian age, possibly Late Valanginian in its lower part (Simmons 1994).

The overlying Lekhwair Formation is 155 m thick and consists in the lower part of interbedded nodular mud- wackestones and decimeter bedded wackestones with gastropods and small rudists. Bioturbation is common but some intervals with stromatolites, bird's eye structures and mud cracks have been reported. The upper part consists of small cycles (3 - 12 m thick) of argillaceous nodular yellowish (dolomitic) bioturbated pack- to wackestones and well bedded (decimeter to meter) packstones with rudists, gastropods of dasyclads. The basal part of the Lekhwair was deposited in a very shallow to restricted supratidal environment, the upper part in a more open marine shallow marine platform setting. The Lekhwair Formation is Hauterivian (mainly) to Barremian in age (Simmons 1994).


Wadi Mi'Aidin, UTM 40 568500/2540250

Rudist coral rudstone

Habshan Fm.

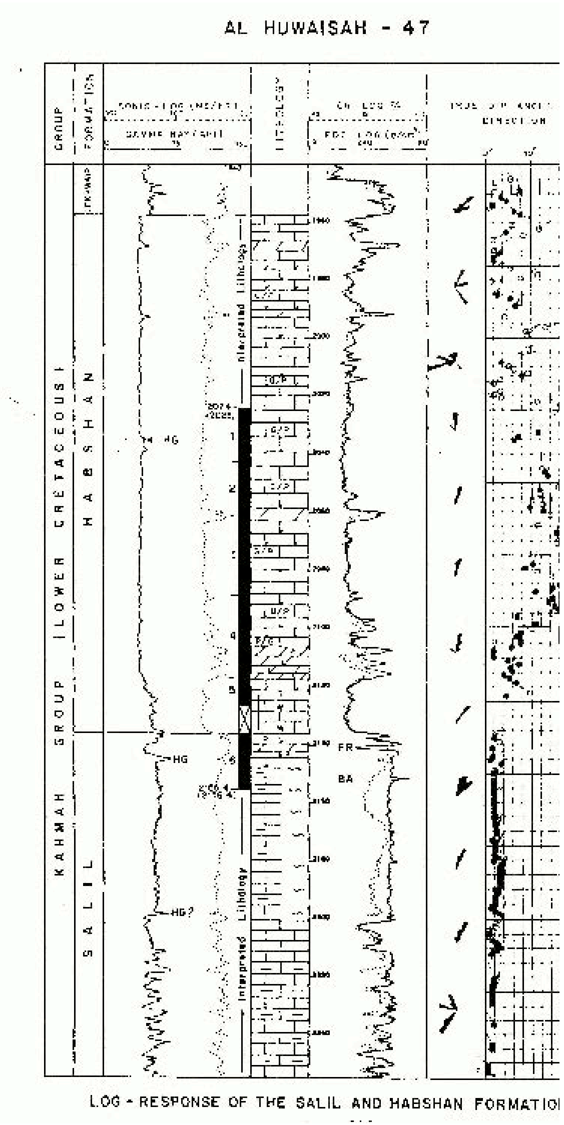


Droste and Van Steenwinkel 2004

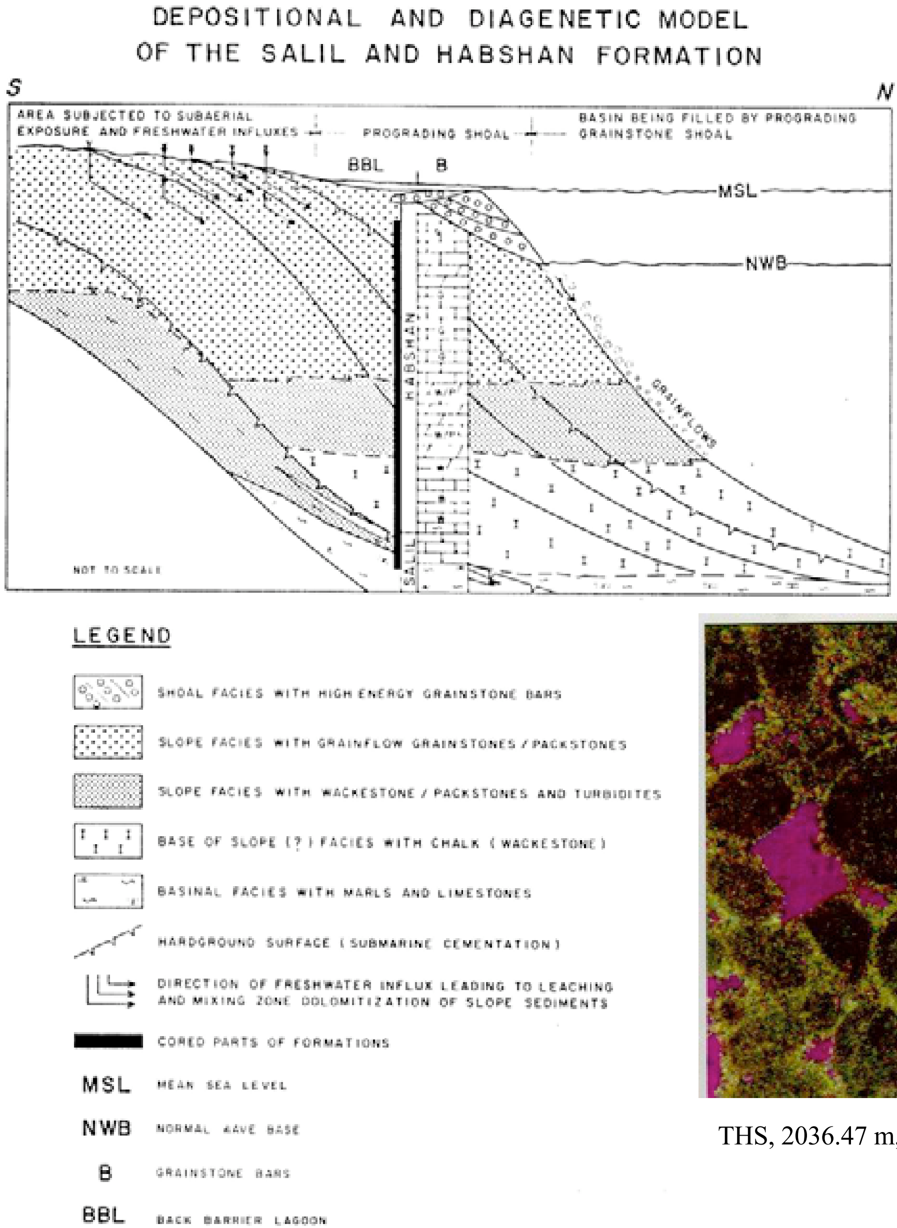
The Habshan clinoform belt is internally organised as packages of 10-20 km width . Each package shows a change from low- to high-angle dips. Dips vary from less than 1° up to 20°. Core material shows that the difference in inclination is associated with variations in sediment fabric. Intervals with high-angle clinoforms consist of thick sequences with platform-derived grain- and packstones, deposited as mass flow deposits on a submarine slope. The low-angle clinoforms are characterised by open-marine, mud-dominated lime turbidites and marls.

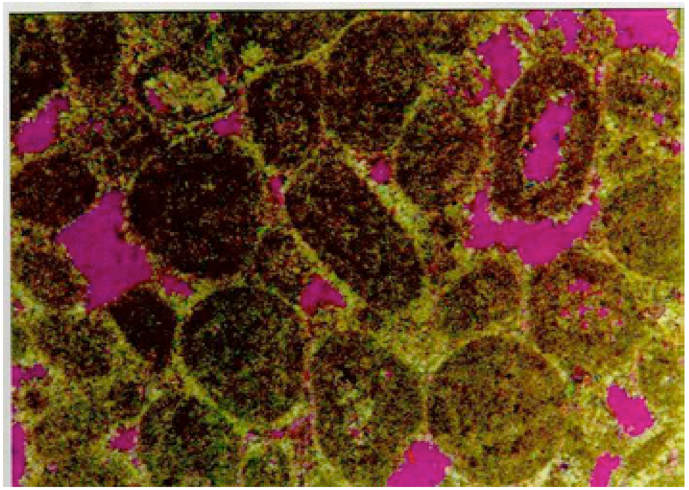
The high-angle seismic reflections are caused by the impedance contrast across dolomitised hardgrounds within the grainy slope deposits. The low-angle clinoforms in the finer-grained sediments are reflected by the impedance contrast between submarine cemented lime-packstone turbidites and the surrounding marly limestones.

Habshan Fm.



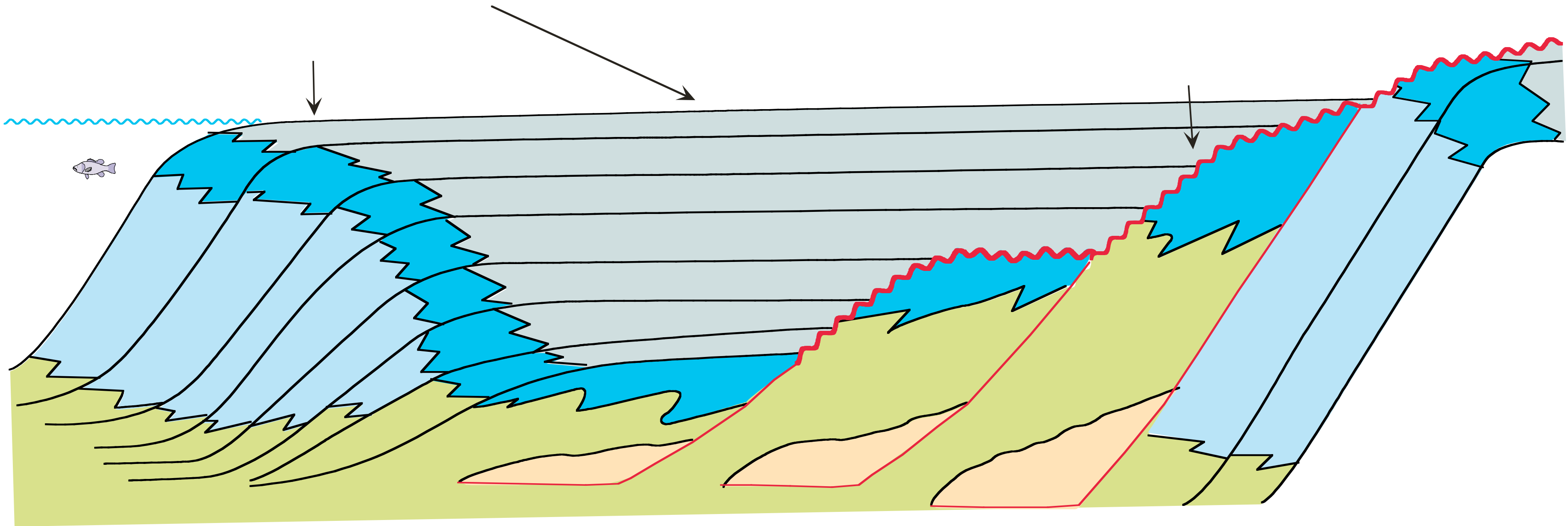
From Gökdag 1989





THS, 2036.47 m, por 27.5 % Perm 423 mD, red is porosity

Habshan Fm.

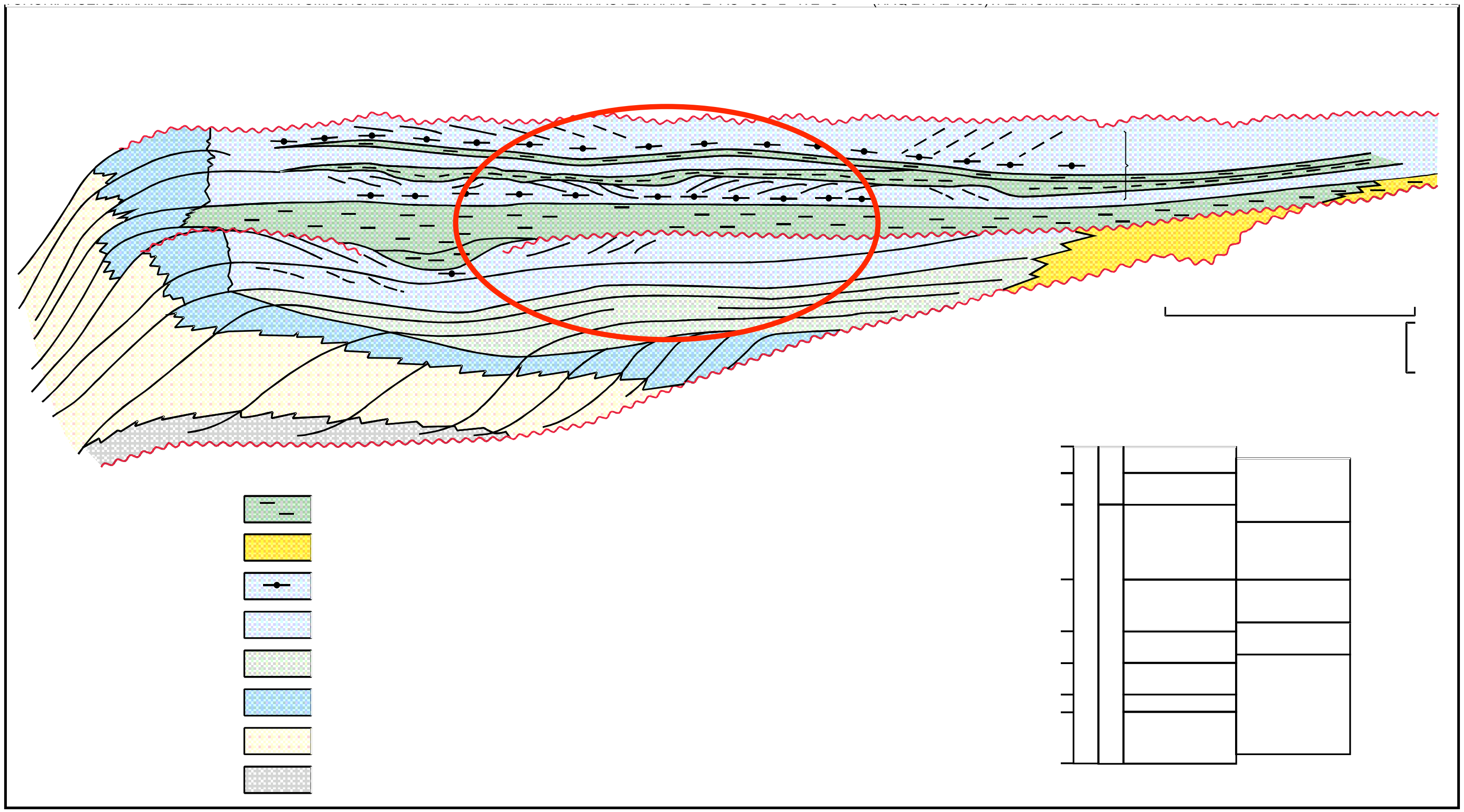


Droste and Van Steenwinkel 2004

High-angle dips are formed during aggradation of the Habshan carbonate platform during relative sea level rise; whereas low-angle dips result from forced regressions during relative sea level fall. There are at least 6 of these third order? cycles observed on the available seismic data in the study area, which only covers part of the platform. The variations in relative sea level impact stacking patterns, composition of the slope sediments and their inclination.

The overall progradation of the Habshan system in its first phase indicates that the third-order sea level rises were buffered by the overall, second-order regressive trend. Carbonate production was always faster than the increase in accommodation space. A transgressive systems tract with a landward shift of the platform edge was generally missing. The change-over from lowstand to highstand at the inflection point of a eustatic sea-level rise is represented by a relatively high aggradation/progradation ratio, leading to a steep platform edge.

Platform interior carbonates

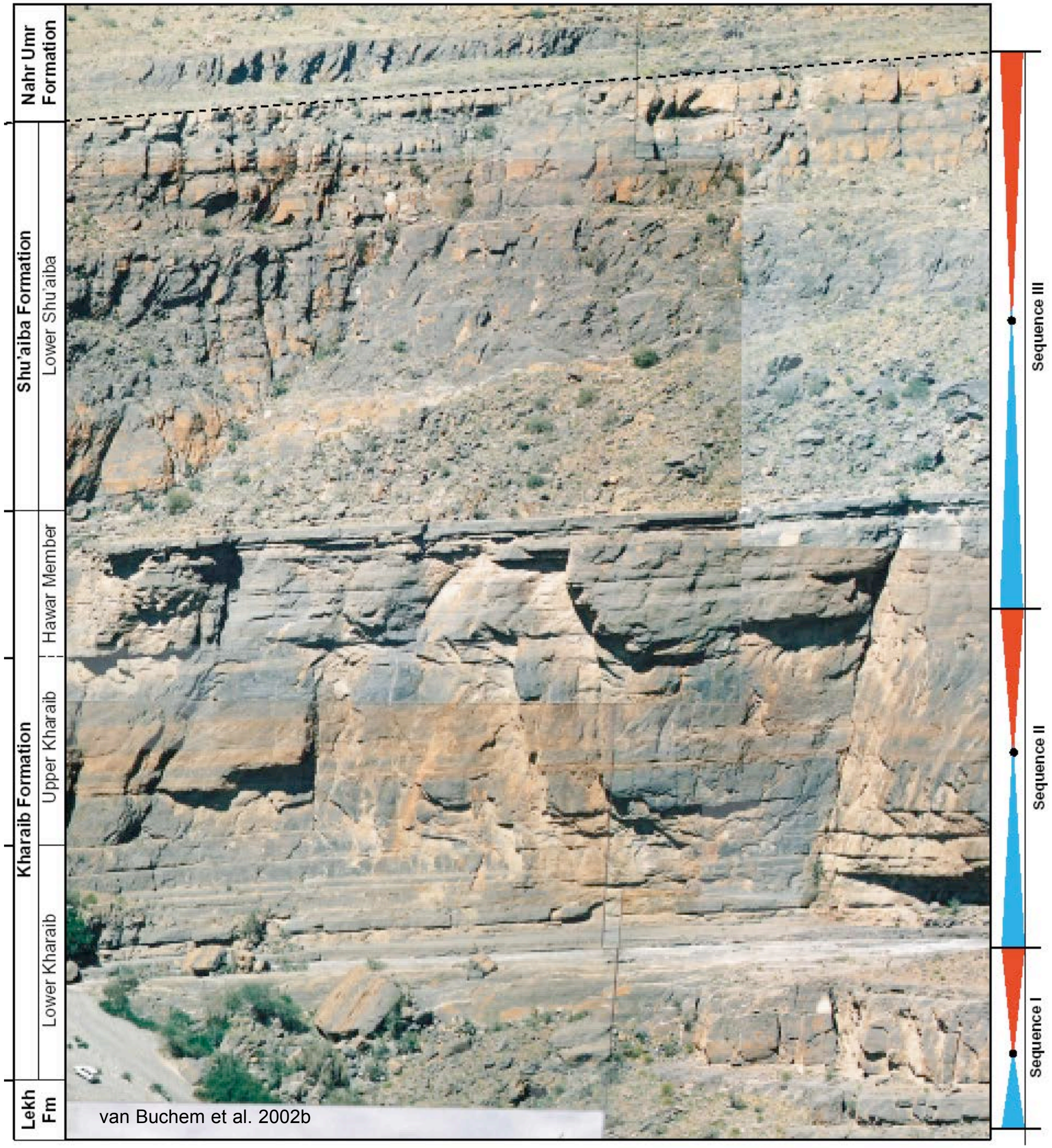


Lekhwair Formation: Cycles consisting of restricted-marine, argillaceous limestones and more open-marine, skeletal wackstones to peloidal/skeletal lime packstones and grainstones with rudist biostromes;
Kharaib and Lower-Shuaiba formations: Deepening and shallowing upward cycles of restricted-marine, argillaceous lime wacke- to packstones, microbial boundstones, open-marine packstones and grainstones with rudist biostromes (van Buchem et al., 2002b);
Upper Shuaiba Formation: Argillaceous lime mudstones interbedded with deeper-water shales and redeposited grainstones and packstones, locally coarse-grained shallow-water packstones to grainstones. This formation is only locally developed in the northwest of Oman. The Wasia Group is Albian to Early Turonian in age and consists of the Nahr Umr Formation at the base and the Natih Formation at the top.
The Nahr Umr Formation is a laterally extensive unit of shallow-marine, calcareous shales, grading into lime mudstones towards the north. This formation becomes more sandy to the south, especially where it onlaps pre-Cretaceous clastics.
The Natih Formation consists of mainly mud-supported and some grain-supported limestones with local rudist development, alternating with calcareous shales. It contains two organic-rich chalk levels with source rock potential deposited in intra-platform basins (Hughes Clarke, 1988; van Buchem et al. 1996, 2002a)
High-resolution seismic data of the Cretaceous platform interior carbonates of Oman show a complex internal architecture, with abundant inclined stratal and mounded stratal geometries rahter than a “layer-cake’ stratigraphy (see Jebel Madmar and Jebel Madar).

Shuaiba and Kharaib Fm.

The Kharaib is 142 m thick and starts with a meter bedded to massive wacke- packstones with rudists (52 m thick). These are overlain by a 20 m thick interval of nodular argillaceous wacke - packstones with large orbitolinids and well bedded bioturbated wackestones. These beds are also known as the Palorbitolina Member 1 (P1). These beds are followed by 40 m of massive bedded, bioturbated dolomitised mud- wackestones with rudist accumulations. The top of the Kharaib is formed by a second Palorbitolina bed (P2) of 30 m thick with nodular argillaceous wackestones with orbitolinids and well bedded pack- wackestones with corals and orbitolinids. This member is considered to be equivalent to the Hawar "shale" Member known from subsurface data. The Kharaib is of Late Barremian to Early Aptian age. The Kharaib consists of two shallowing upward units on the carbonate platform with high energy mounds capped by the flooding events of P1 and P2. The top of the cycles may have been exposed and the drowning was possibly enhanced by the influx of fine clastics during the transgression.

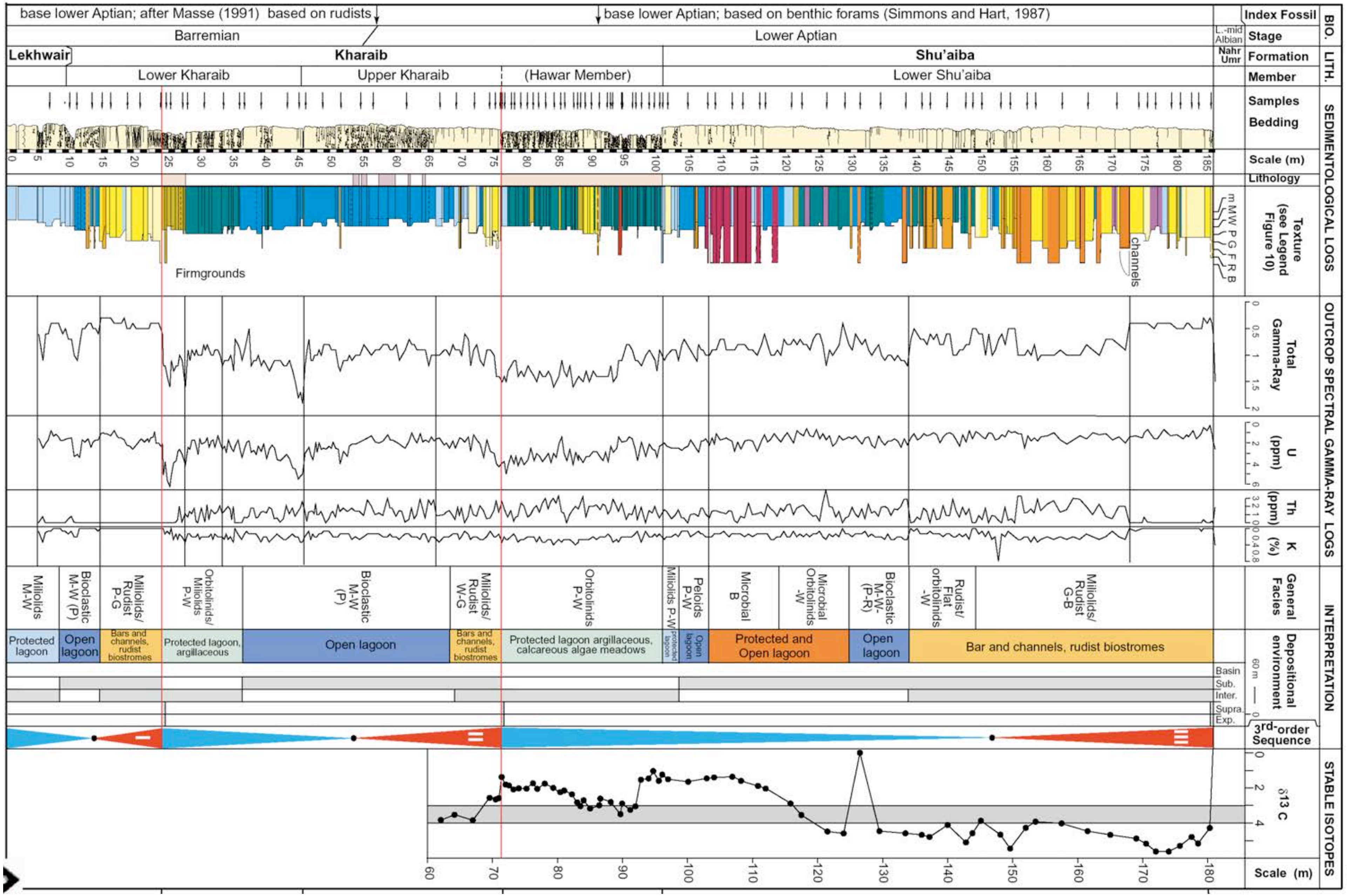
The Shuaiba Formation is 87 m thick and consists in the lower part of wackestones with scattered algal lamination or Bacinella nodules and only few rudists. The upper part consists of wacke- to packstones (occasionally grainstones) with abundant rudists. The Shuaiba in Mi'aidin is Early Aptian in age. The Shuaiba forms a transgressive regressive cycle with the lower transgressive part consisting of shallow water algal platform facies and the upper part of prograding rudistid shoals. The top of the Shuaiba is bored with ferruginous incrustations.



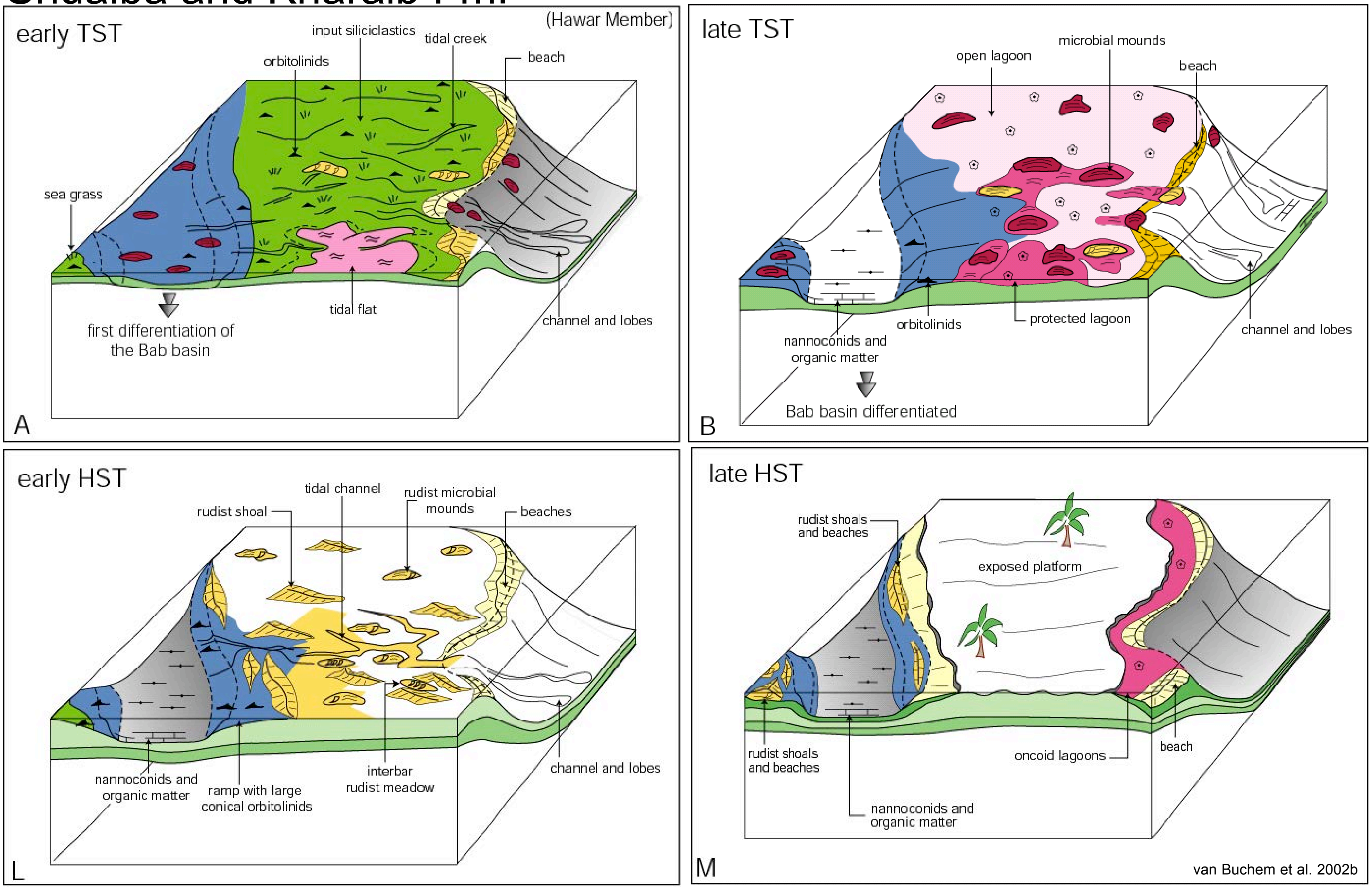
Wadi Mi'Aidin, UTM 40 568000/2539750

Shuaiba and Kharaib Fm.

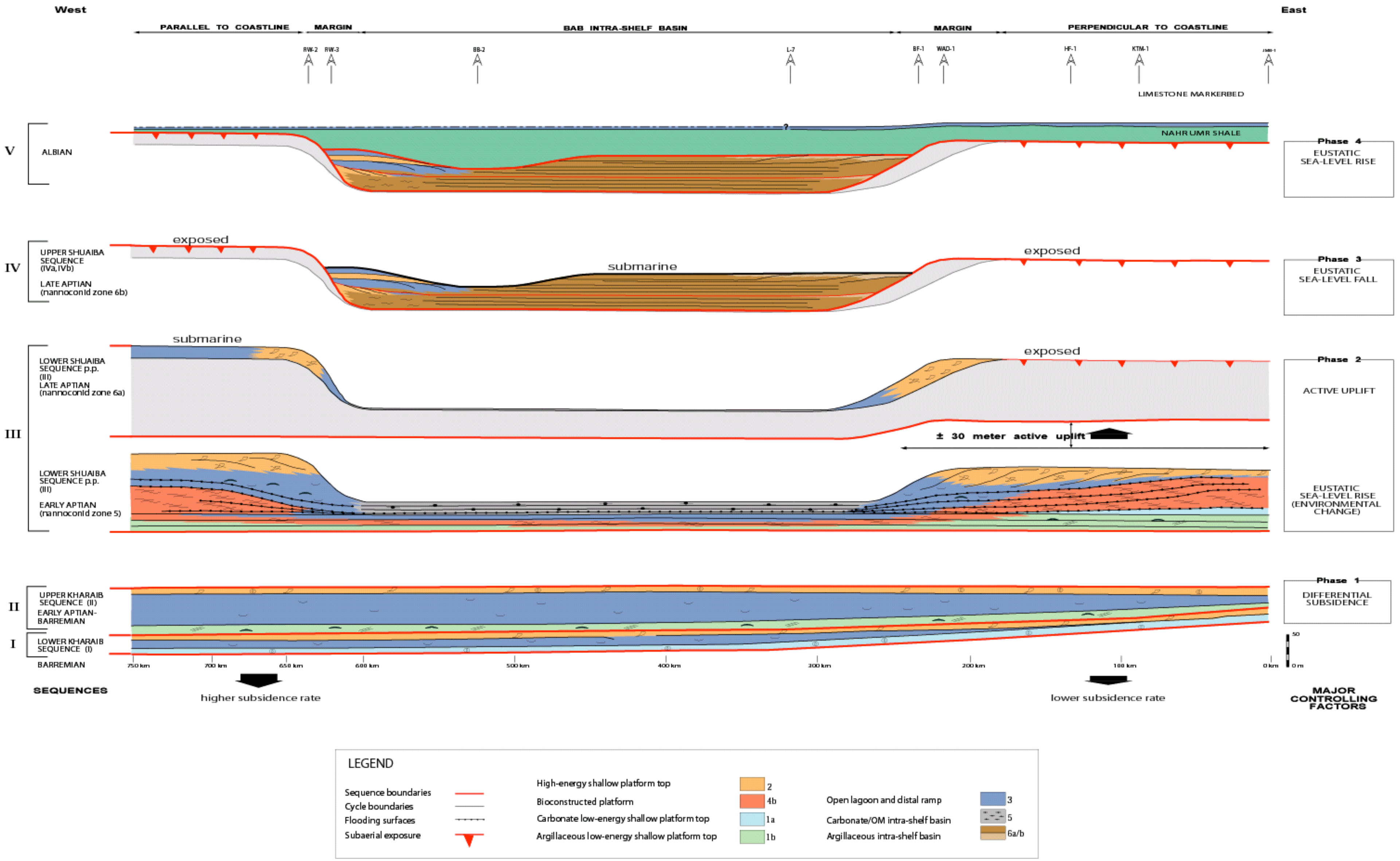
Wadi Mu'Aidin outcrop section (van Buchem et al. 2002b)



Shuaiba and Kharaib Fm.



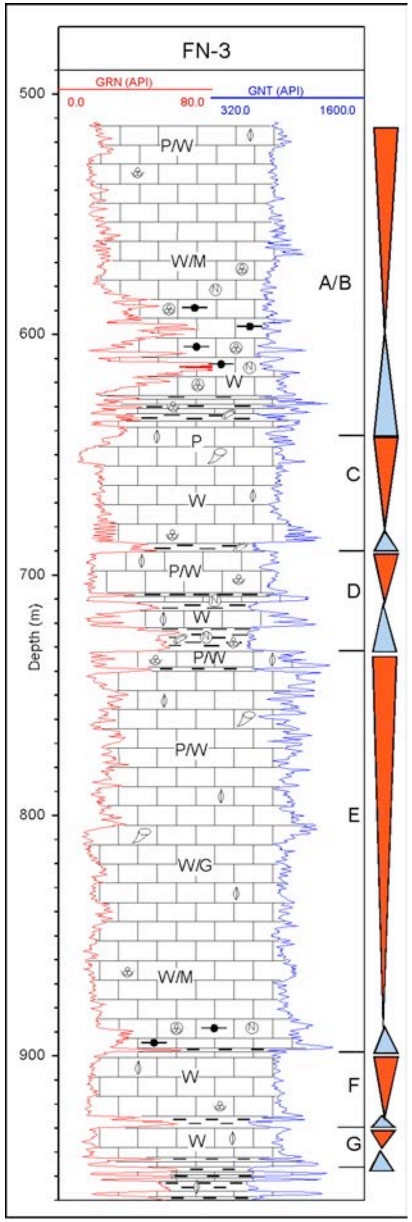
Shuaiba and Kharaib Fm.



van Buchem et al. 2002b

Natih Fm.

Wadi Mi'Aidin, UTM 40 567750/2538750

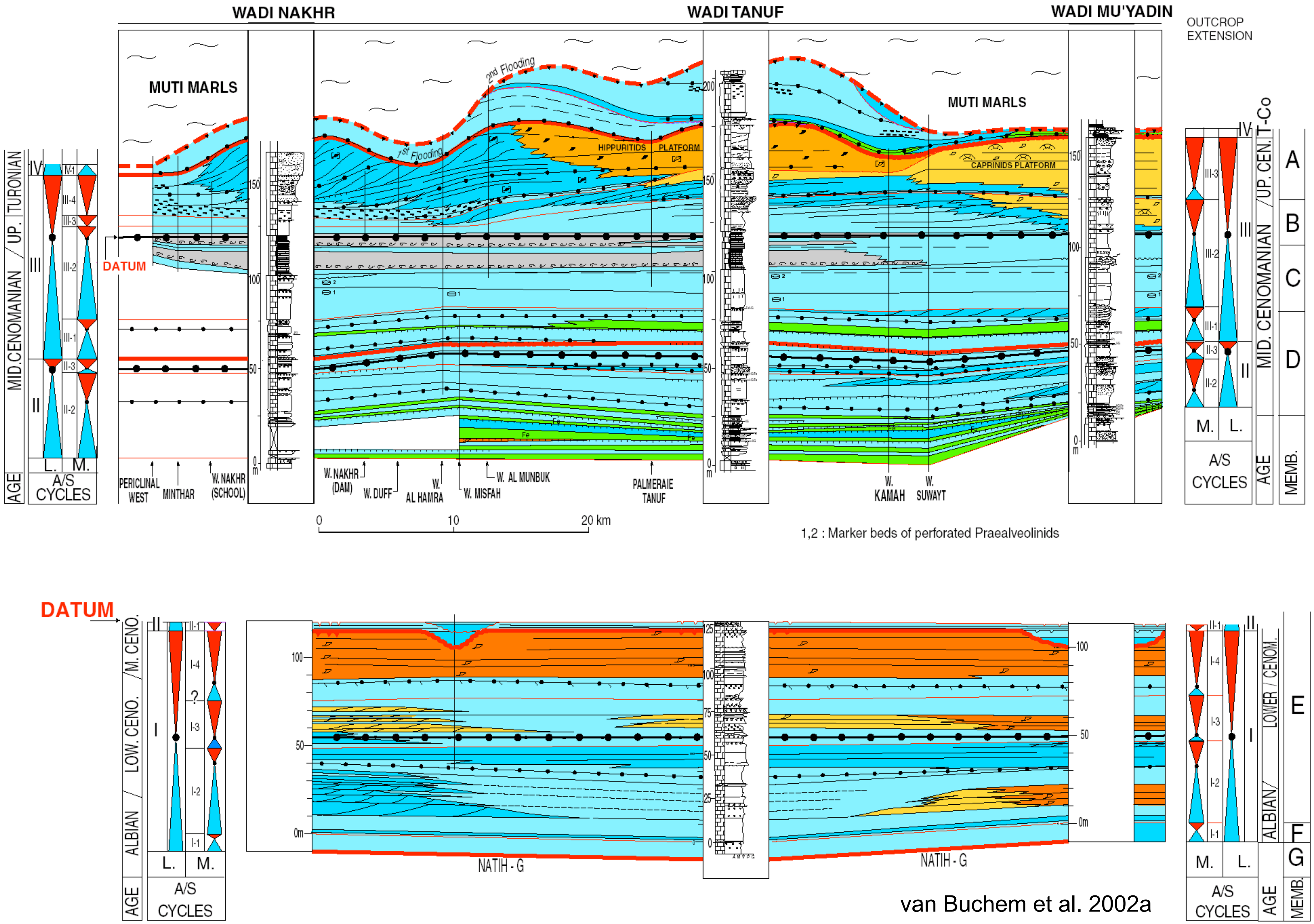


Droste and Van Steenwinkel 2004

The Natih Formation (280 m thick) consists of mainly mud supported and some grain supported limestones alternating with calcareous shales and marlstone layers. The formation is made up of a number of repetitive sedimentary cycles of ten to several ten's of meters thick, each consisting of a thick carbonate and thin mixed carbonate clastic unit. Vertical facies trends show that each sedimentary cycle consists of a deepening and shallowing upward interval. The main cycles form the basis of an informal subdivision of the formation in the subsurface into 7 members lettered "a" to "g" downwards (Hughes Clarke, 1988). These members are laterally extensive and can be easily correlated in the subsurface all over Oman. These cycles are less clearly visible in the outcrop. The two lower units may only be represented by two relatively thin beds at the base of the cliff on top of the Nahr Umr Shale. The e member forms the main part of the first cliff and is capped by an iron crust. A number of relatively thin cycles occur in the overlying d and c members. The a and b members form the second major cliff. The Natih is of Late Aptian to Early Turonian age.

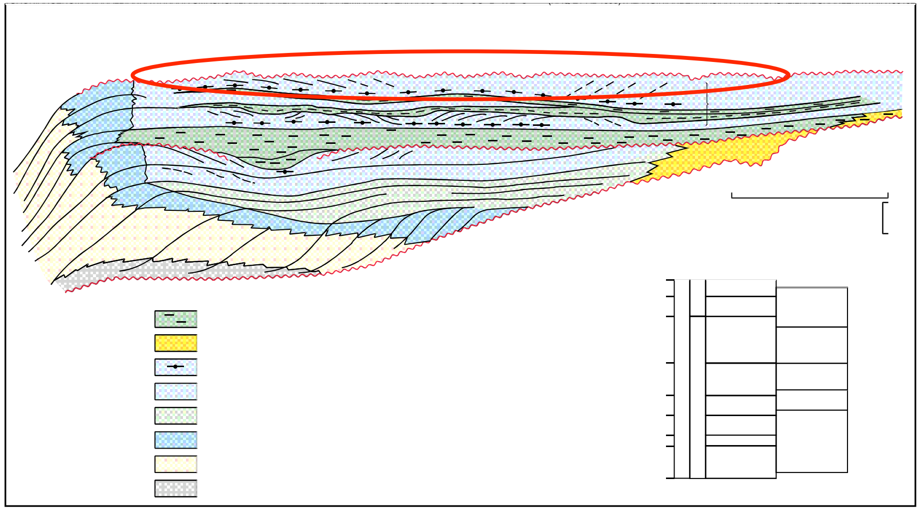
Natih Fm.

West *East*



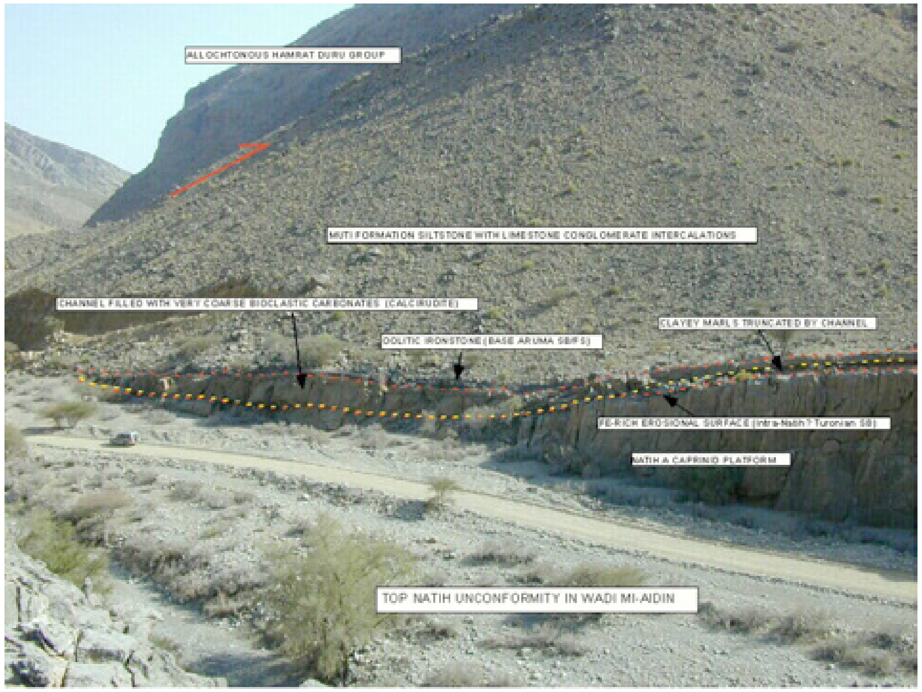
van Buchem et al. 2002a

Base Aruma unconformity



The Cretaceous carbonate platform was terminated by a regional phase of uplift and subaerial exposure in the Turonian. The uplift is thought to be related to the formation of a wide peripheral foreland bulge during the initial phases of the collision of the Arabian and Eurasian plates. As a result, the top Natih has been faulted, truncated, karstified and incised by extensive channel systems.

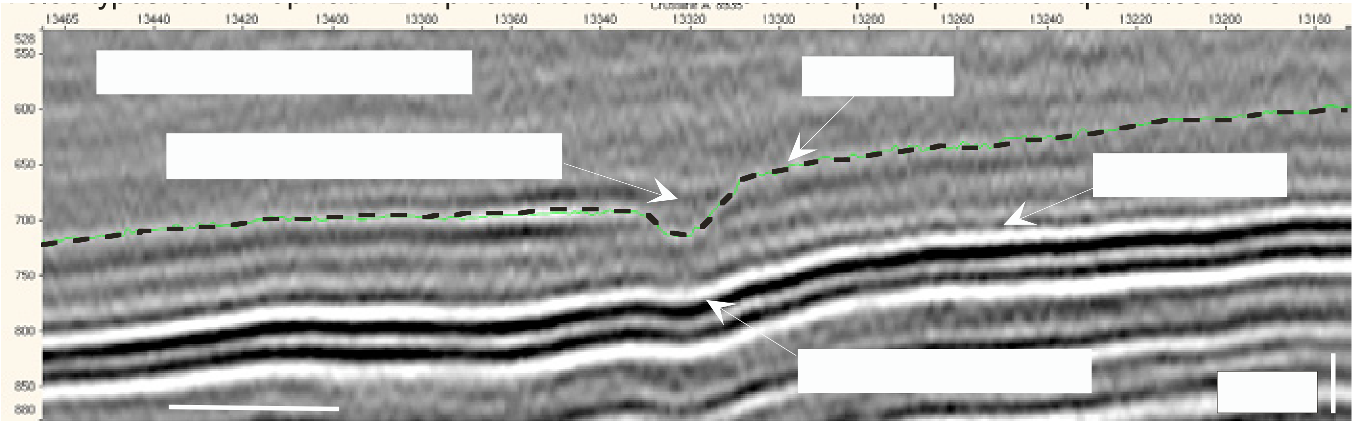
Several generations of highly sinuous channels are visible on seismic. Some incisions cut more than 150 m into the underlying carbonates and reach a width of several hundred meters. The period of emersion only lasted a few million years (Scott 1990) and was followed by a rapid deepening in the Coniacian/Santonian, as the foreland basin started to develop (e.g. Burchette, 1993). During this drowning the palaeotopography of the top Natih was covered by shales of the basal Fiqa Formation (Aruma Group). Well data show that the lower part of this shale package is lignitic and contains thin streaks of siltstone and fine sandstone, as well as traces of glauconite and marine fauna. This suggests a marginal marine (estuarine) to lagoonal setting. The top of the lagoonal shales is marked by an iron-oolitic glauconitic claystone, which is overlain by hemipelagic and pelagic mudstones.

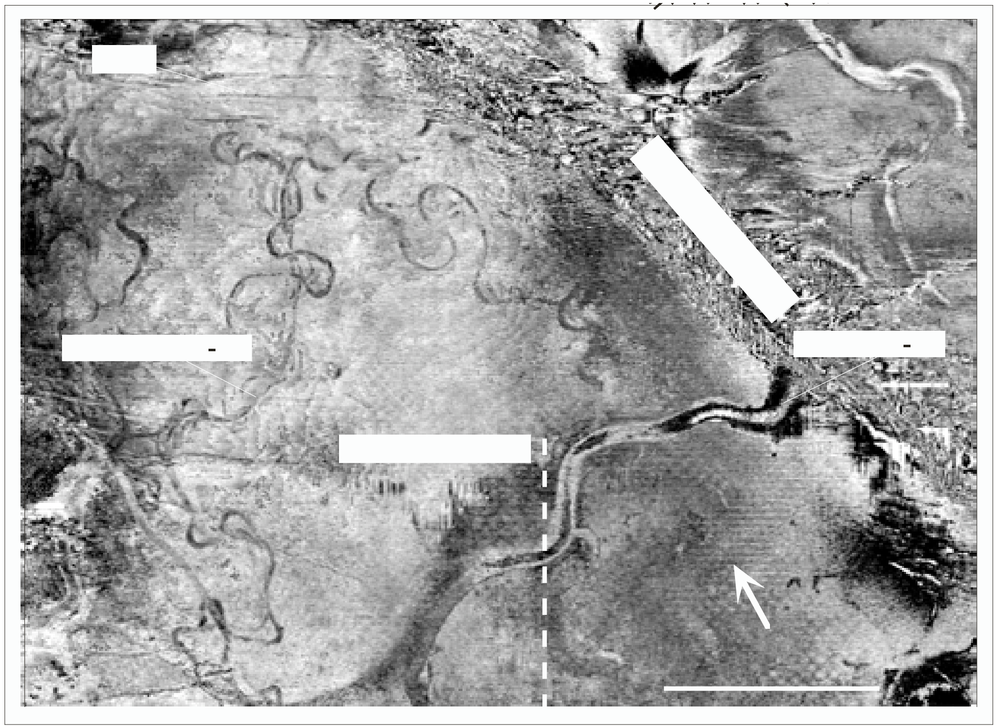


The Muti Formation (± 150 m, Late Santonian to Campanian) is the basal part of the Aruma Group and unconformably rests on the Natih Formation. The top of the Natih is marked by a hardground with an iron crust overlain by iron oolites of the Muti Formation.. The basal few meters of the Muti Fm.consists of reworked ferruginous oolites and channels of calcarenites and conglomerate. These are ovelain by poorly exposed yellowish gey silty marls. The abundant biogenic content includes planktonic foraminifera, indicating deposition in deeper open marine waters and bioclasts reworked from shallow environments. The basal part represents the flooding of the subaerially exposed Natih. The Muti Formation is overlain and tectonically truncated by the Hawasina Nappe (Hamrat Duru Group).

Wadi Mi'Aidin, UTM 40 567500/2538250

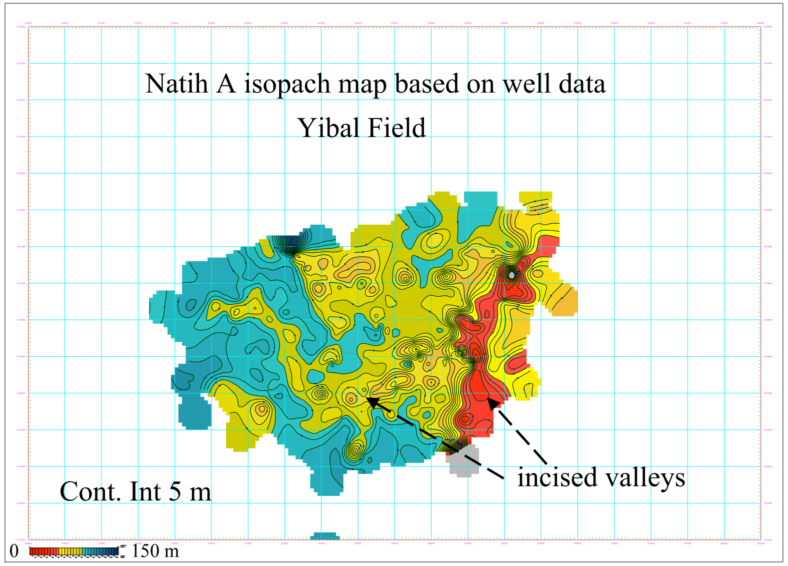
Base Aruma unconformity



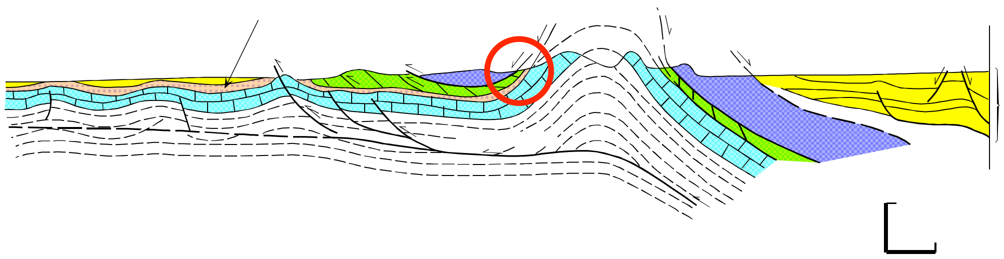


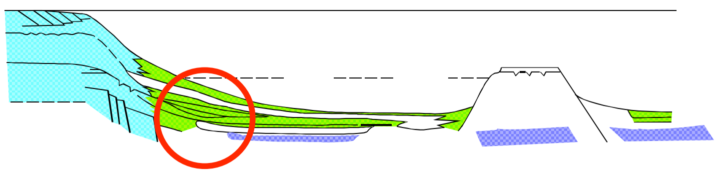
Subsurface examples of the top Natih unconformity

Droste and Van Steenwinkel 2004



Slope deposits





The Hamrat Duru Group (± 500 m) is of Late Triassic to Middle Cretaceous age and belongs to the overthrust Hawasina allochtonous unit that was deposited some hundred or more kilometers to the north. It consists of sandstones at the base and oolitic limestones and limestone breccias and conglomerates in the middle and upper part deposited as mass flows (the Guwayza Formation). These are overlain by thin bedded cherts and silicified limestones of the Late Jurassic Early Cretaceous Sid'r Formation. The Sid'r Formation contains radiolaria and tintinnids and is an age and facies equivalent of the Rayda Formation.

Wadi Mi'Aidin, UTM 40 569000/2536250

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THE DEEP-SEA
HAMRAT DURU / HAWASINA BASIN
and associated units (Sumeini, Al Aridh)

Field trip writers:

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Francois GUILLOCHEAU
Philippe RAZIN
François BECHENNEC
Spela GORICAN
Eric LASSEUR
Jean MARCOUX

The deep-sea part of the Tethyan paleomargin is exceptionally preserved in Oman. This margin has been obducted by the Samail ophiolites during Late Cretaceous, but no collision occurred later. In consequence, all the slope and base-of-slope sediments have been tectonically inverted and stacked on the Arabian platform as Hawasina nappes with low internal deformations. This paleomargin records a continuous sedimentary history from the Late Permian to the Late Cretaceous.

The aim of this field trip is to use sedimentological and sequence stratigraphic interpretations of a deep-sea gravitary record to better understand the geodynamic evolution of this paleomargin

THE HAWASINA/HAMRAT DURU BASIN

The Oman Tethyan paleomargin is now split into three different allochtonous tectonic units :

- the **Hamrat Duru** unit,
- the **Sumeini** unit,
- the **Al Aridh** unit.

The relative position of these units and the nature of the underlying crust in still debated! The Hamrat Duru unit has been classically interpreted as a basin – the Hawasina Basin - located downstream of the transition between the continental and oceanic crust. In this scheme, the Al Aridh unit was parts of seamounts, downstream located of the Hawasina Basin (Bernouilli & Weissert, 1987; Bernouilli *et al.*, 1990). For Béchennec *et al.* (1988,1991), the Al Aridh unit is in an upstream position compare to the Hawasina Basin. It is a lateral equivalent of the Sumeini unit. They are both slope to base-of-slope deposits, one overfed (Sumeini) and one underfed (Al Aridh).

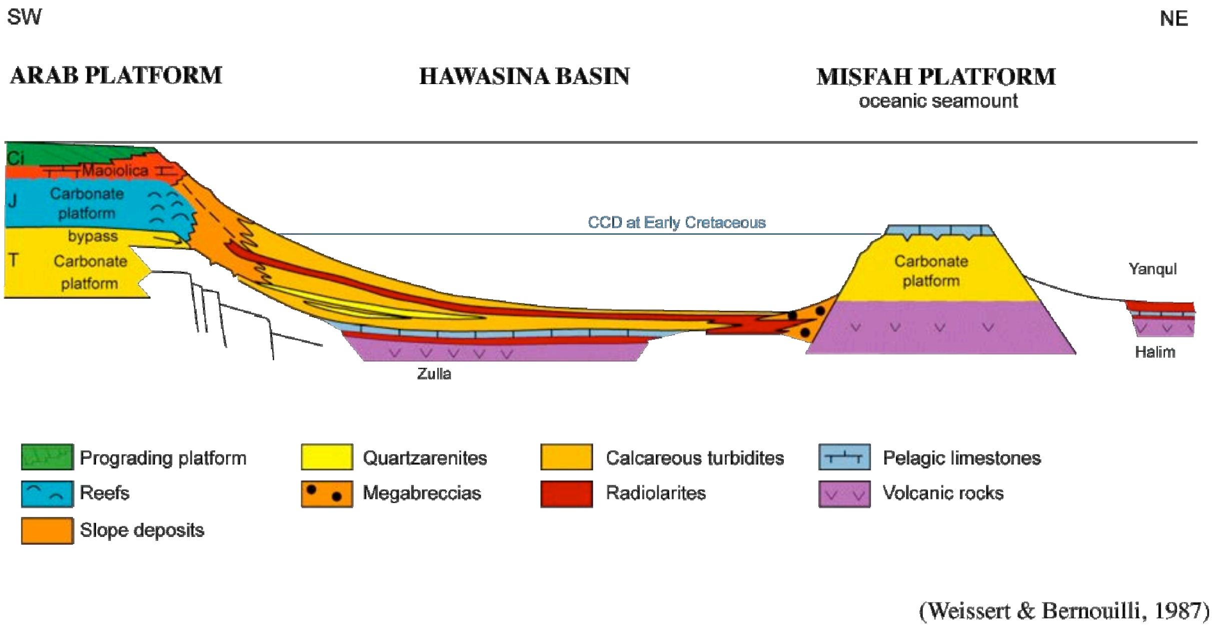


Fig. 1 Bernouilli & Weissert's interpretation of the Oman's Tethyan plaeomargin

Recent geochemical studies of the associated volcanic rocks (Maury *et al.*, 2003; Lapierre *et al.*, 2004) suggest an intermediate crust below this margin.

Our paleogeographic reconstructions indicate a proximal (base-of-slope) setting for the Sumeini unit, which passes seaward to the Hamrat Duru unit. The Al Aridh units look like the most distal deposits along the depositional profile, even they can be shallower than the Hamrat Duru unit. They are probably base-of-slope sediments of the most distal tilted block, just before the transition to the oceanic crust.

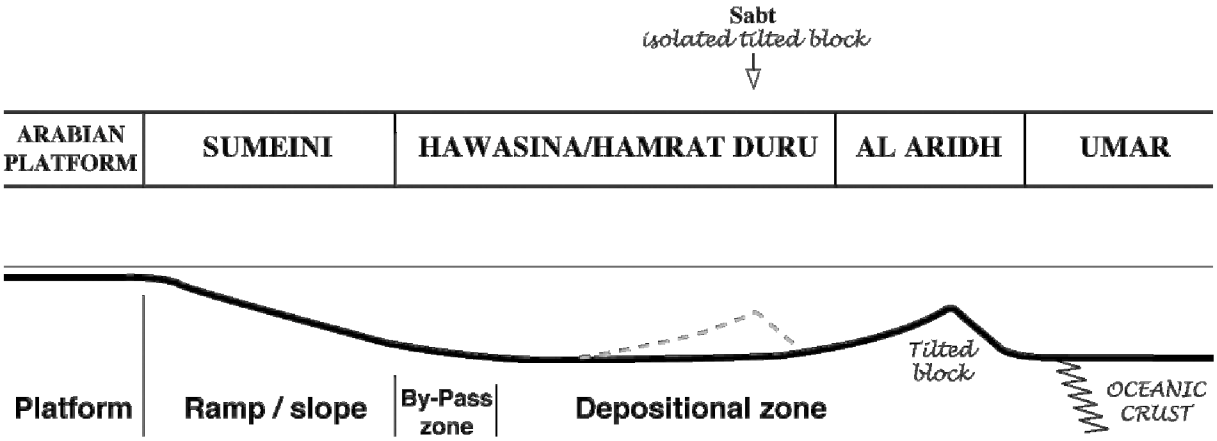


Fig. 2 Our interpretation of the Oman's Tethyan plaeomargin

Most of the sediments of the allochtonous units are carbonate deposits. siliclastic deposits are the muds of the marls and the quarzitic sands located through time in the Lower Jurassic. Some siliceous (radiolaritic) siliceous deposits occur.

All the sediments of those three units are composed of gravitary facies. Al the radiolaritic sediments (cherts) are the result of low density turbidity currents deposits. No real hemipelagic deposits exist! All these deposits can be described using the Mutti's classification of facies (Mutti, 1992) : they go from slump and conglomerates (F2, in Mutti's classification) to distal low density turbidity currents (F9). Some new facies have been defined (see the next chapter, Guwayza Fm, for discussion).

Few channel deposits, and then few real deep-sea fans, exists (Lower Jurassic siliciclastic deposits of the Matbat Fm ?). They are mainly basin-plain deposits coming from the fringing deposits of the shelf (multi-source system instead of point-source). The main difference is the amount of sediments available on the top of the slope/ramp deposits. We can distinguish underfed periods form normally to overfed periods where large by-pass zone occurred at the base of the slope/ramp. In this former case, by-pass zones supplied various types of lobe deposits.

These three units have been studied in the frame of a French Project (CNRS program IT "Earth Interior"). Measured sections have been studied going from the sub-autochtonous Arab platform to the most distal units. Datation and correlations are based and validated by biostratigraphic data mainly based on radioralians. Those studies have been made by Spella GORICAN, ZRC SAZU, Slovenia. All those lithological, biostratigraphical and sedimentological are synthetized over four logs :

- the Arabian platform (Droste & van Steenwinkel, 2004),
- the Sumeini unit, the distal ramp,
- the Hawasina unit, deep-sea plain deposits on a thinned continental crust
- the Al Aridh unit, gravitary deposits at the base of the most distal tilted block, just before the transition with the oceanic crust.

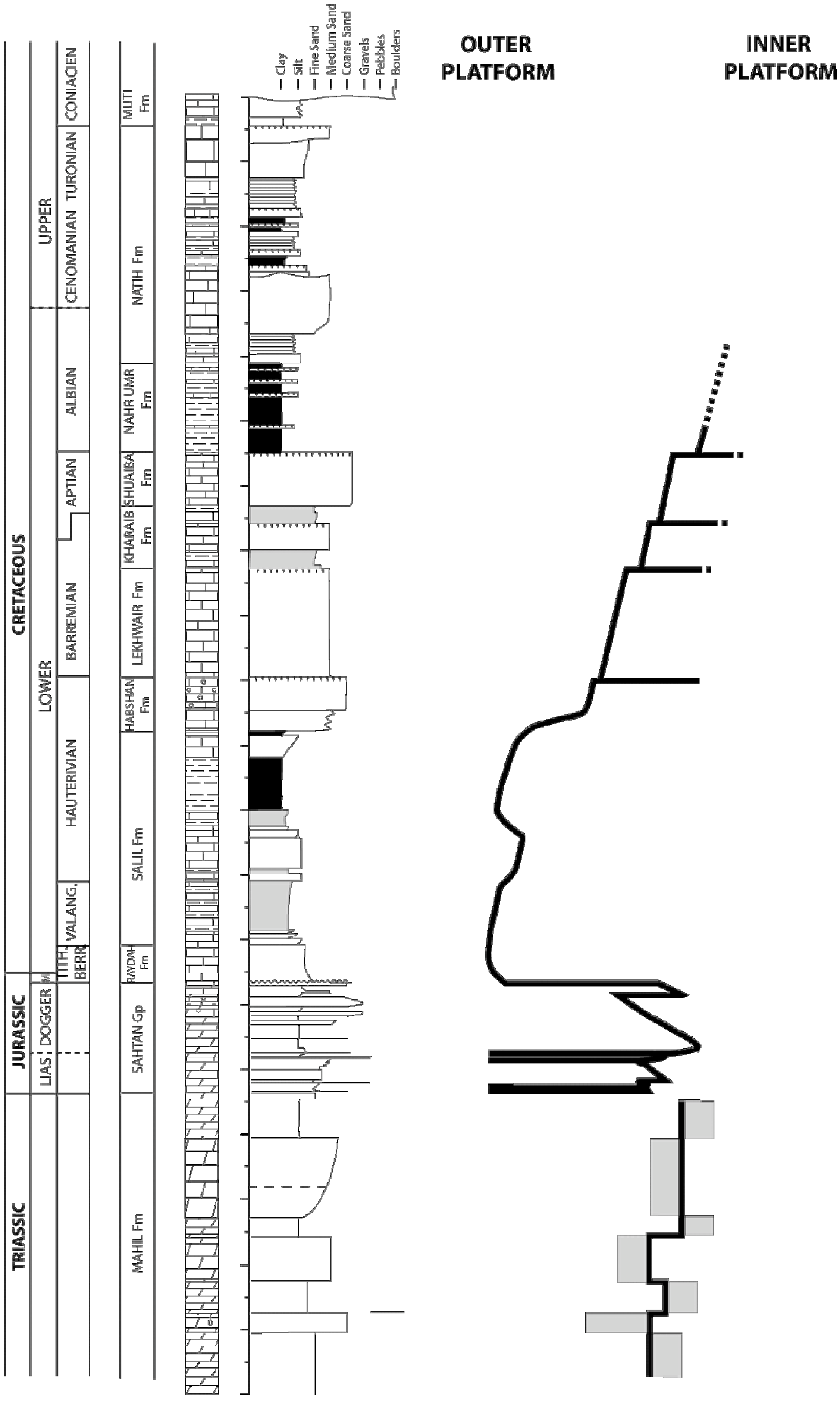

OUTER PLATFORM
INNER PLATFORM
TRIASSIC
JURASSIC
CRETACEOUS
LIAS
DOGGER
M
LOWER
UPPER
TITH. BERR
VALANG.
HAUTERIVIAN
BARREMIAN
APTIAN
ALBIAN
CENOMANIAN
TURONIAN
CONIACIEN
MAHIL Fm
SAHTAN Gp
RAYDAH Fm
SALIL Fm
HABSHAN Fm
LEKHWAIR Fm
KHARAIB Fm
SHUAIBA Fm
NAHR UMR Fm
NATIH Fm
MUTI Fm
Clay
Silt
Fine Sand
Medium Sand
Coarse Sand
Gravels
Pebbles
Boulders

Fig.3 Lithostratigraphy, chronostratigraphy and sedimentary facies evolution of the Arabian Platform (Djebel Akhdar area)

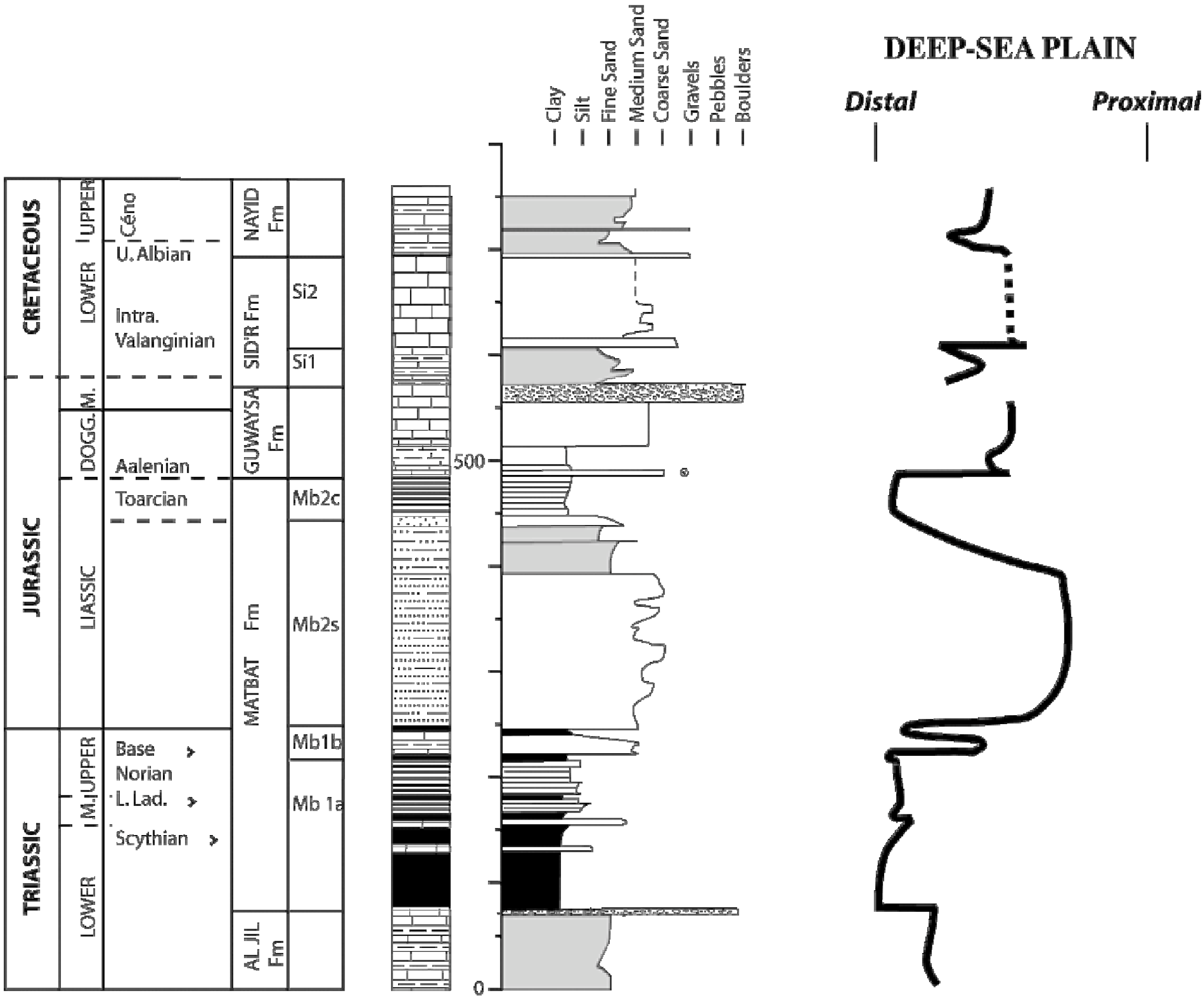


Fig.4 Lithostratigraphy, chronostratigraphy and sedimentary facies evolution of the Hamrat Duru/Hawasina deep-sea basin (distal part, Djebel Safra area)

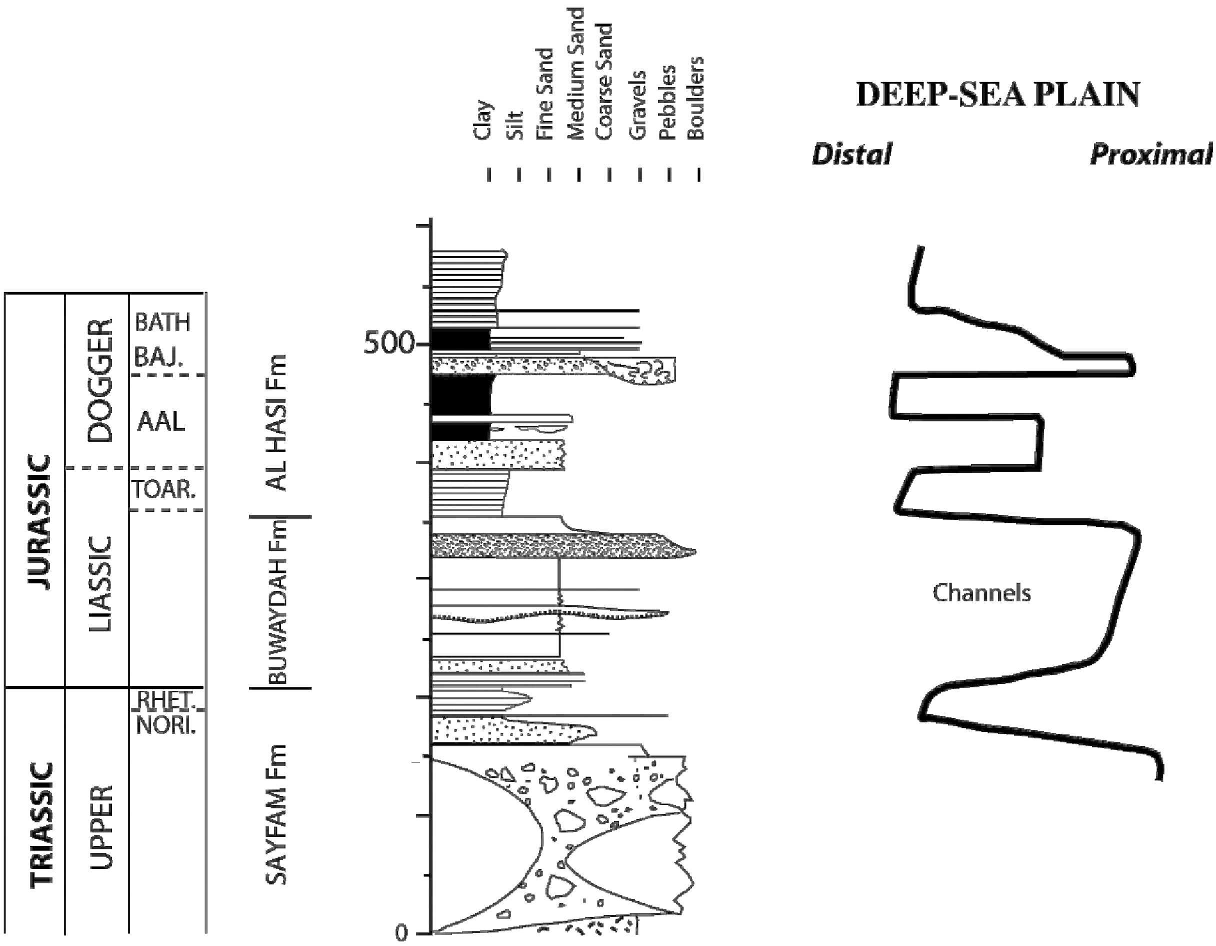


Fig.5 Lithostratigraphy, chronostratigraphy and sedimentary facies evolution of the Al Aridh unit (most seaward tilted block upstream of the oceanic crust transition)

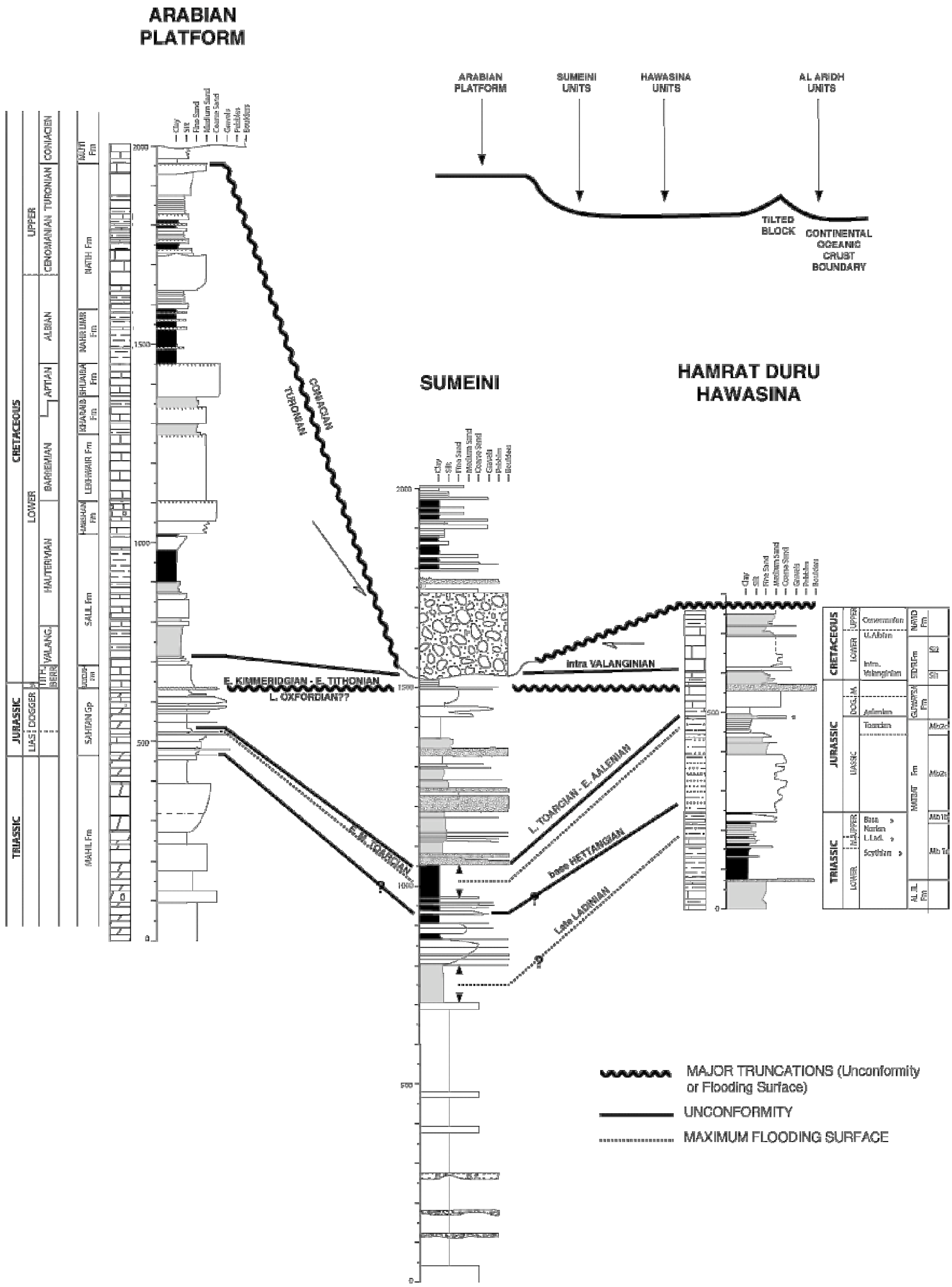


Fig.6 Correlations between the Arabian platform, the Sumeini unit (base-of-slope/ramp) and the Hawasina/Hamrat Duru unit (deep-sea plain)

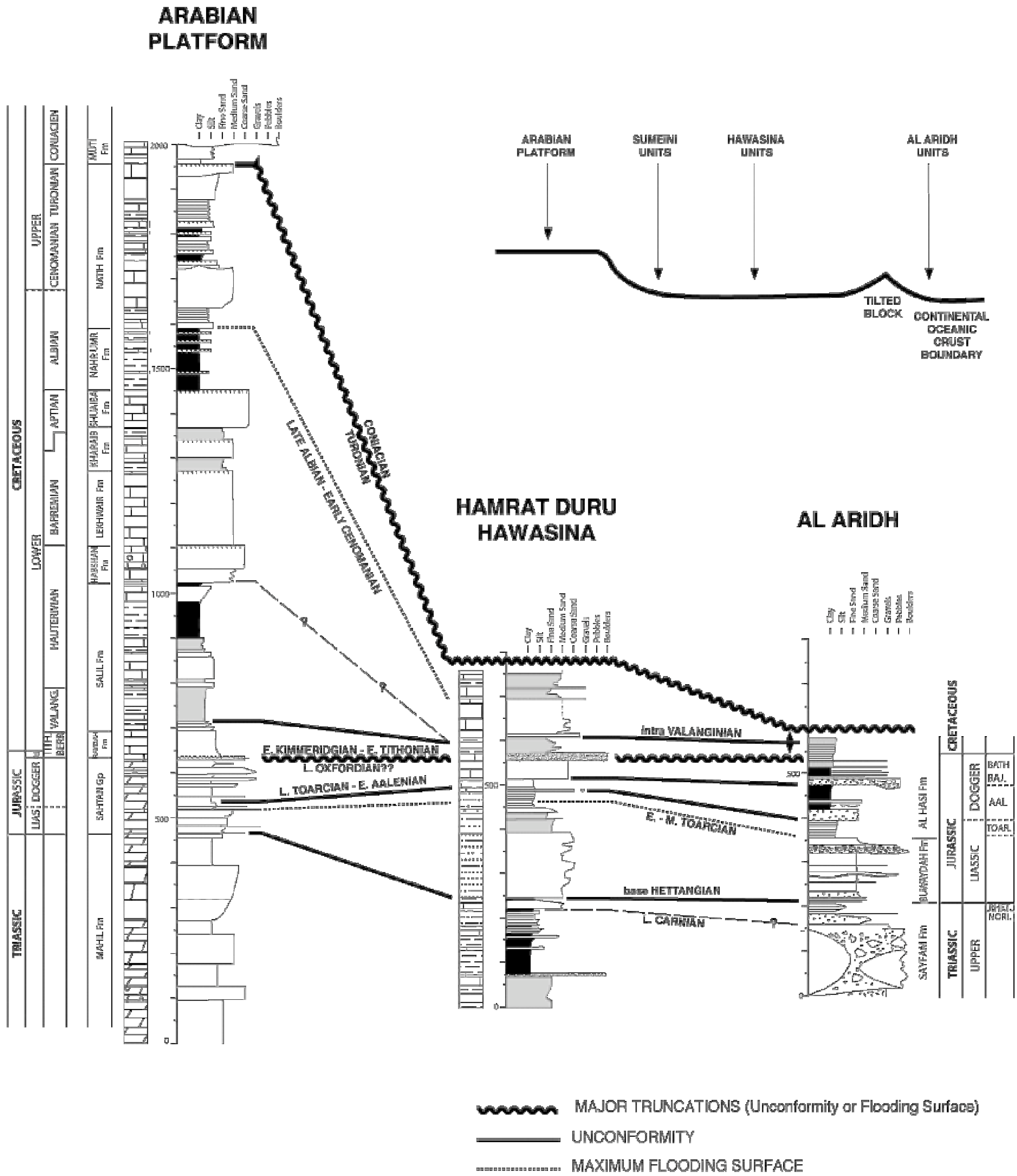
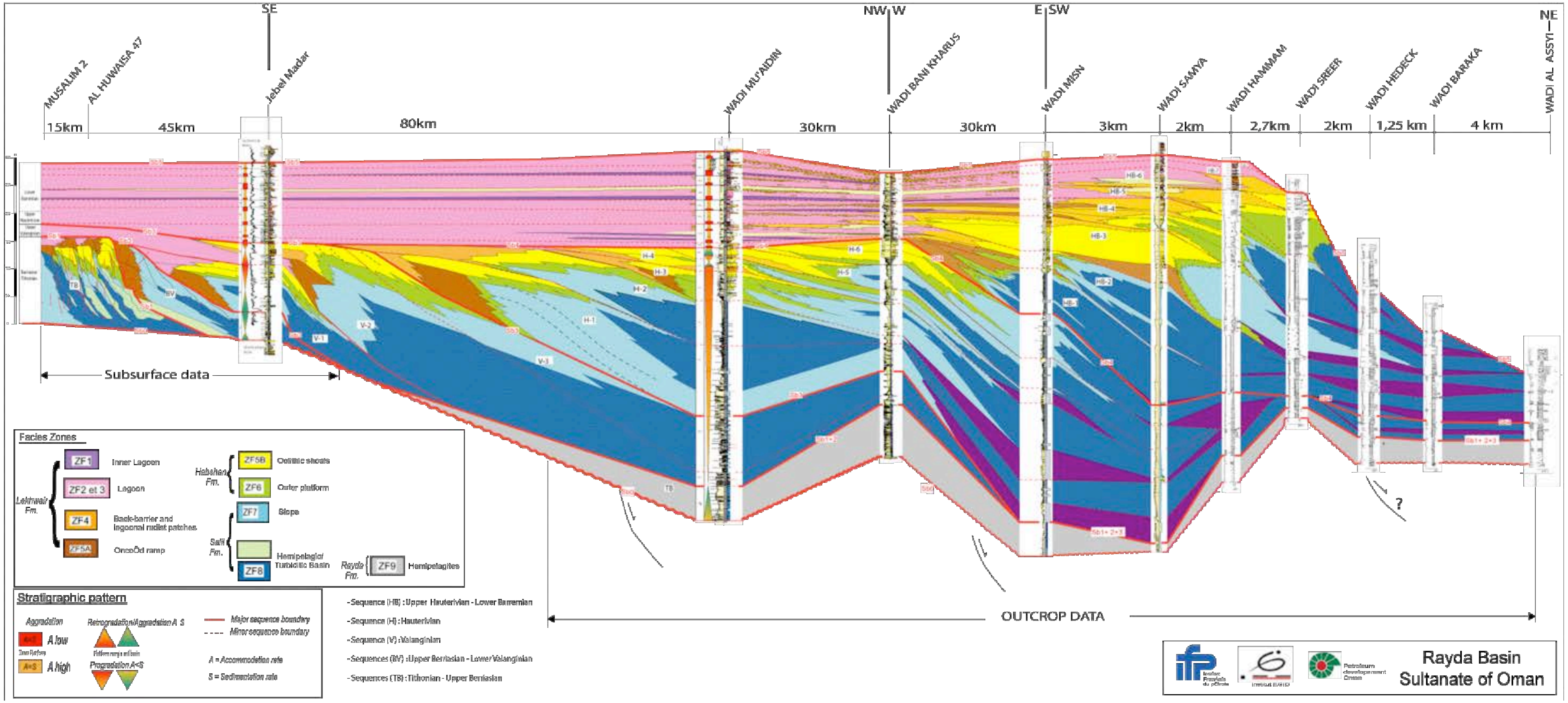


Fig.7 Correlations between the Arabian platform, the Hawasina/Hamrat Duru unit (deep-sea plain) and the Al Aridh unit (distal tilted block upstream of the oceanic crust)

Fig. 8 Geometry of the Arabian platform (Oman part) from the Tithonian to the Barremian (Le Bec thesis, 2004)


SE
NW W
E SW
NE
MUSALIM 2
AL HUWAISA 47
Jebel Madar
WADI MU'AIDIN
WADI BANI KHARUS
WADI MISN
WADI SAMYA
WADI HAMMAM
WADI SREER
WADI HEDECK
WADI BARAKA
WADI AL ASSYI
15km
45km
80km
30km
30km
3km
2km
2,7km
2km
1,25 km
4 km
Subsurface data
OUTCROP DATA
Facies Zones
Lekhwair Fm.
ZF1 Inner Lagoon
ZF2 et 3 Lagoon
ZF4 Back-barrier and lagoonal rudist patches
ZF5A Oncoïd ramp
Habshan Fm.
ZF5B Oolitic shoals
ZF6 Outer platform
Salil Fm.
ZF7 Slope
Hemipelagic Turbiditic Basin
ZF8
Rayda Fm.
ZF9 Hemipelagites
Stratigraphic pattern
Aggradation
A low
A high
Retrogradation/Aggradation A S
Progradation A<S
Major sequence boundary
Minor sequence boundary
A = Accommodation rate
S = Sedimentation rate
-Sequence (HB) : Upper Hauterivian - Lower Barremian
-Sequence (H) : Hauterivian
-Sequence (V) : Valanginian
-Sequences (BV) : Upper Berriasian - Lower Valanginian
-Sequences (TB) : Tithonian - Upper Berriasian
Rayda Basin
Sultanate of Oman

Highest resolution correlations have been carried out in the Hawasina units, based on both sequence stratigraphic and biostratigraphic correlations.

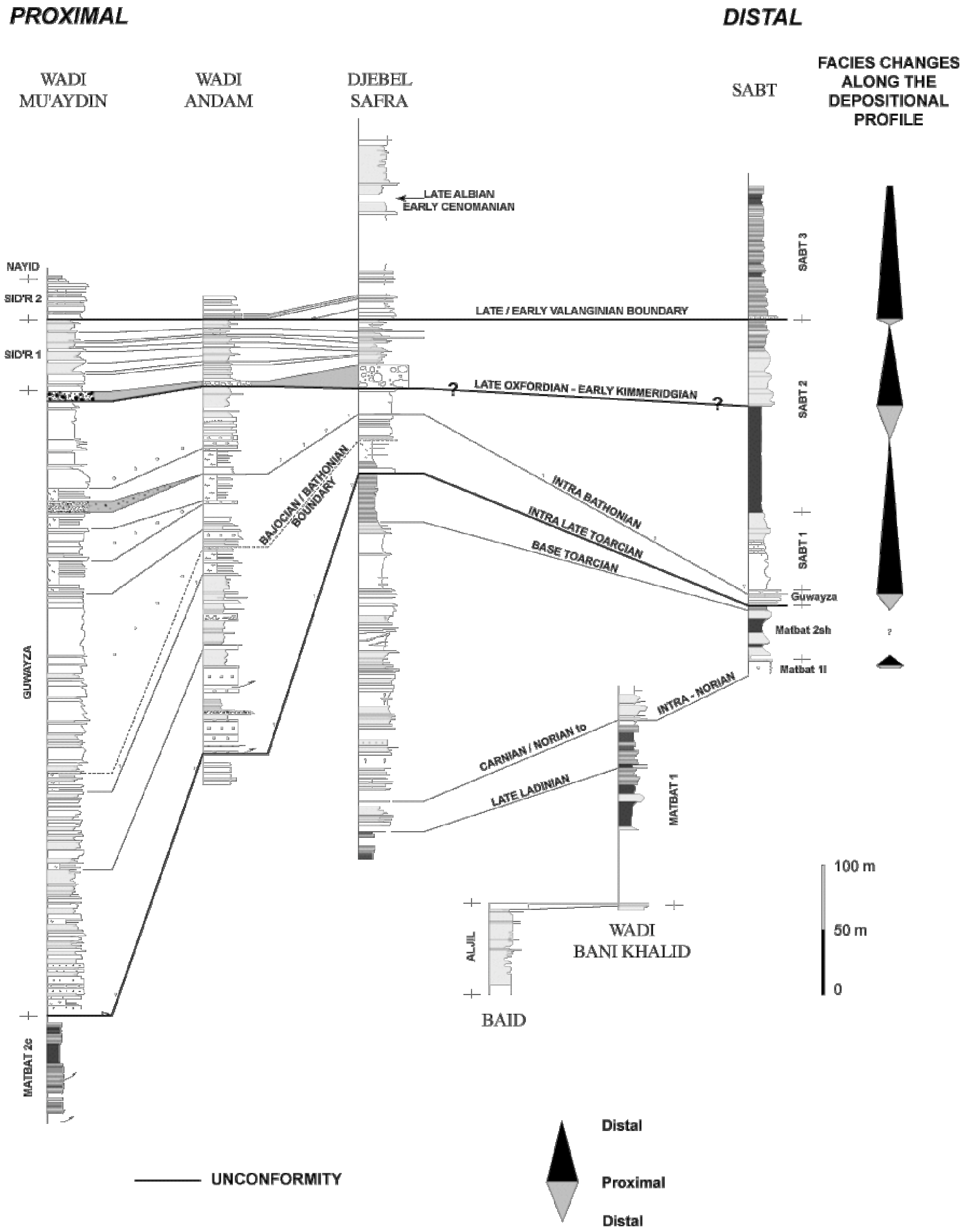


Fig.9 Correlations within the Hawasina/Hamrat Duru deep-sea basin

During **Triassic** time, high aggradation occurs on both platform and slope deposits (Sumeini unit). Excepted during the base Scythian and the Late Norian / Rhaetian, the deep Hamrat Duru system is underfed with the deposition of clays and cherts deposits (low density turbidity currents).
The most distal tilted block, just before the oceanic crust (Al Aridh unit), is still tectonically active with deposition of thick debris flows (few 100s meters large blocks).

During **Liassic** time, a few sediments are preserved on the shelf (very shallow to lagoonal flat-topped platform). Localized thick wedges of siliciclastic deposits occur in the deep-sea Hamrat Duru basin. The tectonic significance of this event is still poorly understood. It could be related to the intraplate deformations associated with the end Karoo rifting between Madagascar and East Africa.
The Al Aridh tilted block is still shallow enough for supplying a large amount of carbonate (mainly mud with few ooids) toward the deep basin.
Lower Toarcian records a break in the basin history with a global starvation of the system (mainly cherts deposits). This underfedding of the basin has to be related with the global anoxic event which occurred at the Tethys scale.

The **Late Toarcian / Aalenian** (transition Early / Middle Jurassic) records a major change in the deep sea Hamrat Duru system, less marked on the shelf that is still a very shallow to lagoonal flat-topped platform with low sedimentation rate. A thick turbiditic system (Guwayza Formation) takes place in the deep Hamrat Duru system, mainly made of ooids and carbonate muds.

A major unconformity occurs both on the shelf and in the deep-sea basin (not in the Al Aridh unit) at the **end Late Jurassic** (Intra Kimmeridgian?). This event corresponds to a 200 km retreat of the platform and to the deposition of debris flows in the deep-sea basin. The age of this event is still poorly constrain, between Late Oxfordian and Early Tithonian. This event corresponds to a major intraplate deformation at Arabia and western Africa-scale. It is coeval with the drifting of the Indian Ocean (Salman & Abdullah, 1995).

The **Cretaceous** correspond to the deposition of a thick progradational-aggradational wedge on the platform and to the starvation of the deep-sea basin (very low deposition rate of cherts in the Al Aridh unit and thin-bedded turbidites in the Hamrat Duru unit).
An unconformity occurs during the Valanginian (around the Early/Late Valanginian boundary) in the basin. It corresponds to a major downward shift of the platform with accommodation space removal (Le Bec, 2004). This event has to be related to the cooling event of the Valanginian.
Late Albian time correspond to a starvation (silicified hemipelagites) of the basin.

At **Coniacian** time, the basin becomes a foreland basin with the initiation of the Samail ophiolite obduction. The Turonian/Coniacian boundary is a major unconformity in the Sumeini units.

THE MIDDLE/UPPER JURASSIC GUWAYZA Fm

Numerous studies have been carried out on the deep-sea siliciclastic deposits, mainly on present-day deep-sea fans. Few studies relate to the deep-sea carbonate systems. They concern or "shallow" (less than few hundreds of meters) gravity deposits or present-day real deep-sea settings (mainly peri-Bahamas systems).

The aim of this contribution is to reconstruct both facies and geometries of a real past deep-sea turbiditic system along the exceptionally preserved deposits of the Tethyan passive paleomargin of Oman. This margin has been obducted by the Samail ophiolites during Late Cretaceous, but no collision occurred later. In consequence, all the slope and base-of-slope sediments have been tectonically inverted and stacked on the Arabian platform as nappes with low internal deformations.

The studied deposits correspond to the Guwaysa Formation of Late Toarcian to Oxfordian age.

Two groups of nappes units have been studied:

(1) proximal units, cropping out along a continuous cliff with few deformations between Wadi Muti and Wadi Mu'Aydin (Izki area) and ,
(2) distal units, Wadi Andam (area), Djebel Safra, Hamrat Duru Range (East of Nizwa).

Excepted for the proximal unit, where geometries have been established along photo panels and by "physical" correlations, most of the geometrical reconstructions are based on correlations of measured sections from one nappe to the other one. Correlations are based on the vertical stacking pattern of the facies, *i.e.* on the recognition of the same different order of vertical facies changes between two sections. This reveals progressive facies variations along the different measured sections. Correlations between the two nappes units are based on (1) biostratigraphy (radiolarians) and (2) global facies variations established for each unit.

FACIES

12 facies have been defined. They are all made-up of clastic carbonates with a few siliciclastic content (quartz and few clays). Carbonates are mainly ooids and fine-grained sediments called here "muds". Diagenetic transformations overprint the initial grain-size (probably silt-size) .

All the facies are gravitary deposits. Most of them (12 over 11) can be described using the Mutti's nomenclature (1992), which have been adapted for the fine-grained deposits (F9 has been splitted into 6 facies).

Gravity processes have been interpreted using two nomenclatures: the classical one synthesised by Mutti (1992) and a new one proposed by Mulder & Alexander (2000). By-pass facies are very well developed, going from classical Mutti's F6 facies (megaripples) to pebbles lags (called here F3L), or to top erosional surfaces with negative imprints of flute casts.

N°	CHARACTERISTICS	DESCRIPTION	PROCESSES
F 3	**CLAST-SUPPORTED CONGLOMERATES**	Homolithic clast-supported conglomerates Subangular to rounded pebbles Structureless, sometimes normally graded , few imbrications	High-density turbidity current *Hyperconcentrated flow*
F 3L	**PEBBLE LAYER**	Bed made of a single pebble layer, more or less clast supported Subangular to rounded pebbles	Lag deposits By-pass zone
F 4-5	**COARSE-GRAINED SANDS TO GRANULES**	Homolithic poorly-sorted coarse-grained ooidic sands with granules and small pebbles Structureless or crude planar laminations sometimes normally graded	High-density turbidity current *Hyperconcentrated flow*
F 6	**POORLY SORTED COARSE-GRAINED SANDS WITH CURRENT MEGARIPPLES**	Homolithic poorly-sorted coarse-grained ooidic sands with granules and pebbles Current megaripples laminasets with top erosional truncations	By-pass zone
F 7-8	**MEDIUM TO COARSE-GRAINED SANDS**	Homolithic to heterolithic medium to coarse-grained ooidic sands Planar laminations, sometimes normally graded Very rare water escape structures (dishes)	High to medium-density turbidity current *Concentrated flow*
F SL	**« SLATTY » MEDIUM-GRAINED SANDS**	Homolitic to heterolithic stacking of few centimeters-thick planar laminasets of medium-coarse-grained ooidic sands, made up of crude planar laminations Possible metric-scale undulations, similar to HCS-like structures	Medium-density turbidity currents ?
F 9tr	**BOUMA SEQUENCE** **Tc traction ripples**	Alternation of more or less carbonated clays with medium –grained sands Tbc Bouma sequences with traction current ripples flowing in the same direction than the underlying flute casts and parting lineations	Medium-density turbidity currents Tc unidirectional induced flow

F 9et	**BOUMA SEQUENCE** **Top erosional**	Alternation of more or less carbonated clays with medium –grained sands Tbc Bouma sequences with top erosional surfaces (3D erosional current ripples)	Medium-density turbidity currents By-pass zone
F 9cl	**BOUMA SEQUENCE** **Tc climbing ripples**	Alternation of more or less carbonated clays with medium –grained sands Tc Bouma sequences with large climbing ripples (type A) Current ripples are oriented at right angle compare to the base flute casts	Medium-density turbidity currents
F 9bp	**BOUMA SEQUENCE**	Alternation of fined-grained carbonate sands and carbonate « muds » (silt size) Few centimetric-thick sands beds (Bouma Tcd) are truncated at the top by an erosional surface filled by carbonate « muds »	By-pass zone
F 9mc	**STOW SEQUENCE** **Te marly clays**	Alternation of more or less carbonated clays with fine–grained sands Stow sequence (= Bouma Td)	Low-density turbidity currents
F 9cm	**STOW SEQUENCE** **Te carbonate mud**	Alternation of carbonated silts (« mud ») with fine–grained sands Stow sequence	Low-density turbidity currents

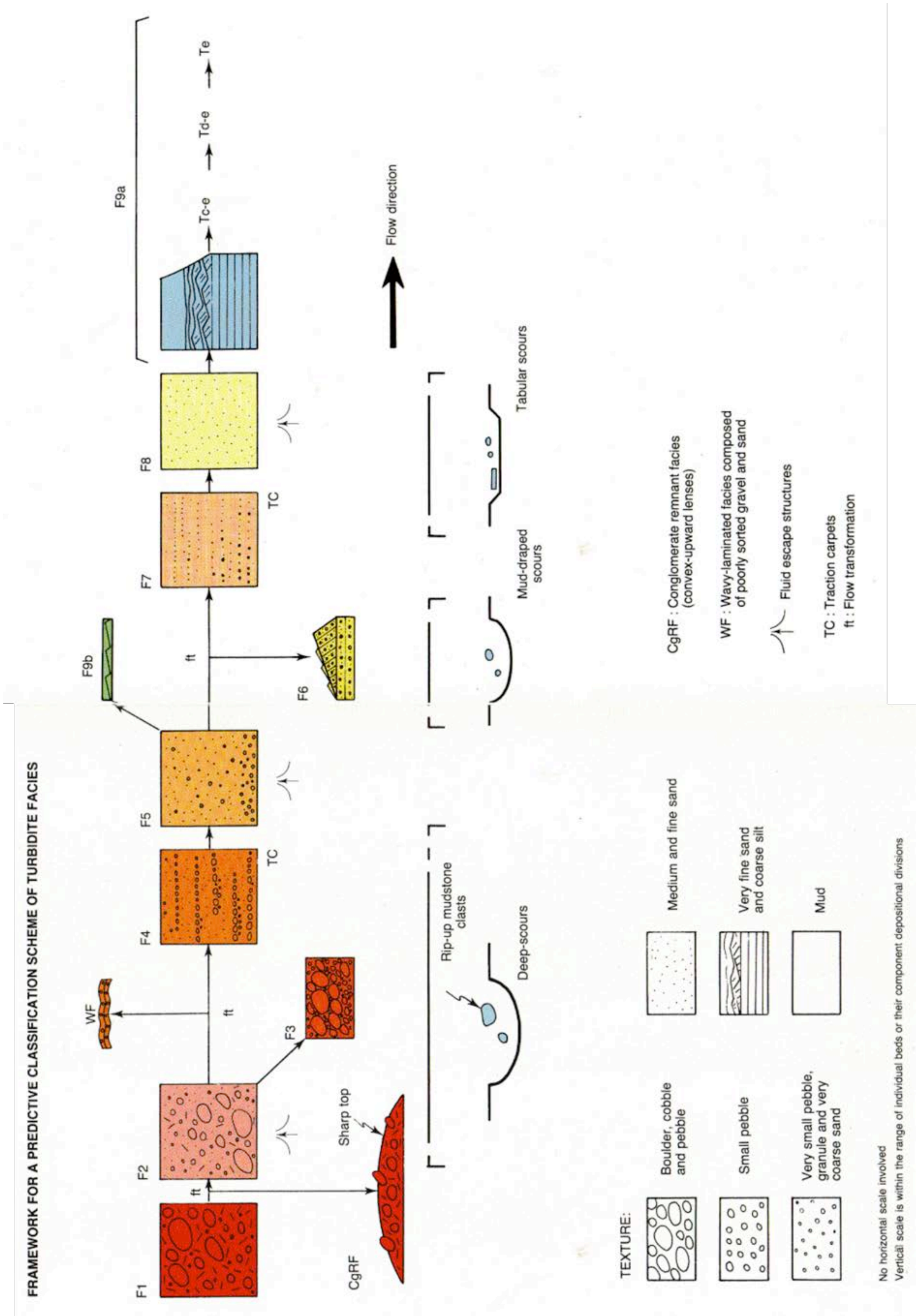


Fig.10 Turbiditic facies classification of Mutti (1992)

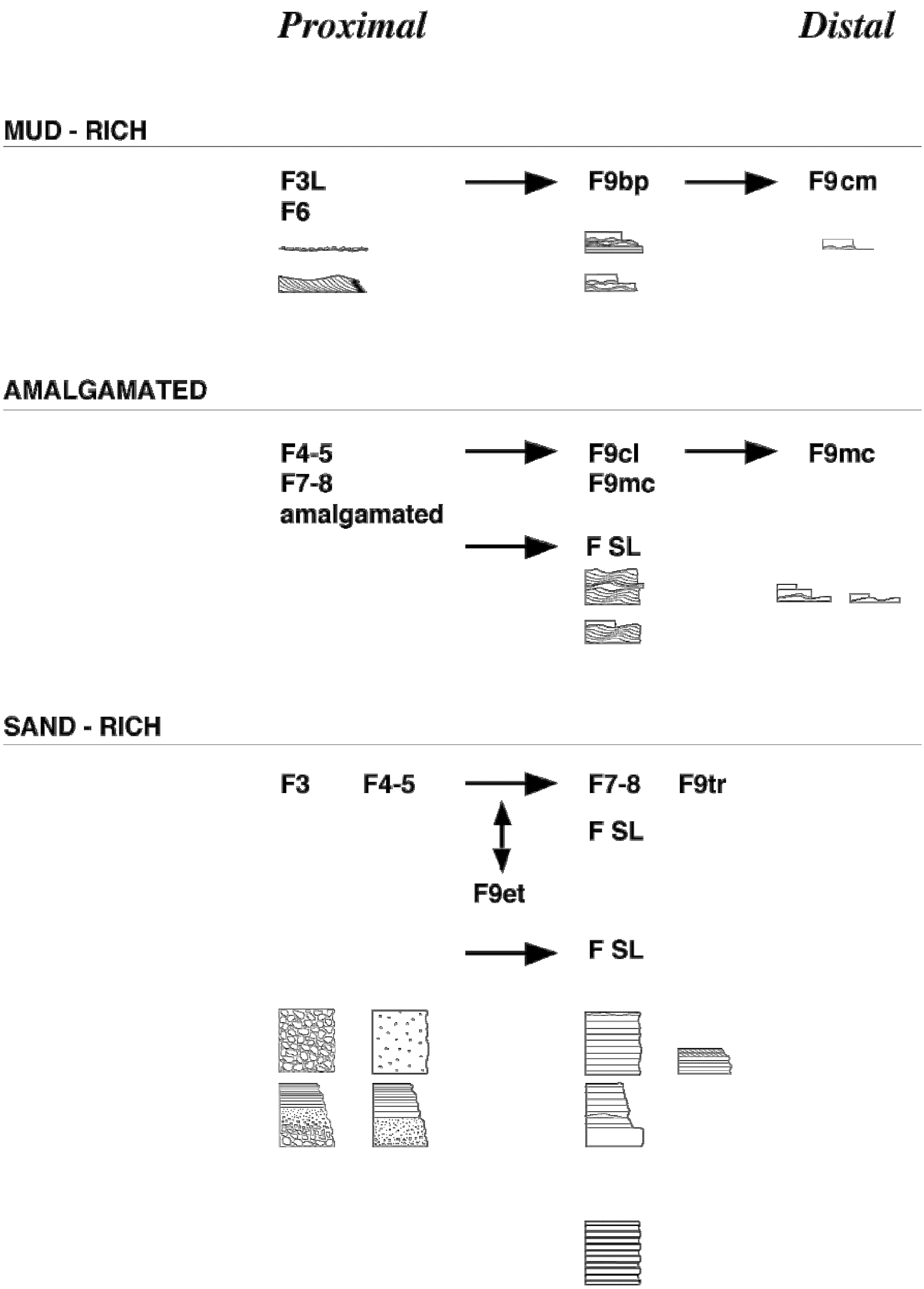


Fig.11Facies classification and facies associations of the Guwayza Fm

CYCLES DEFINITION

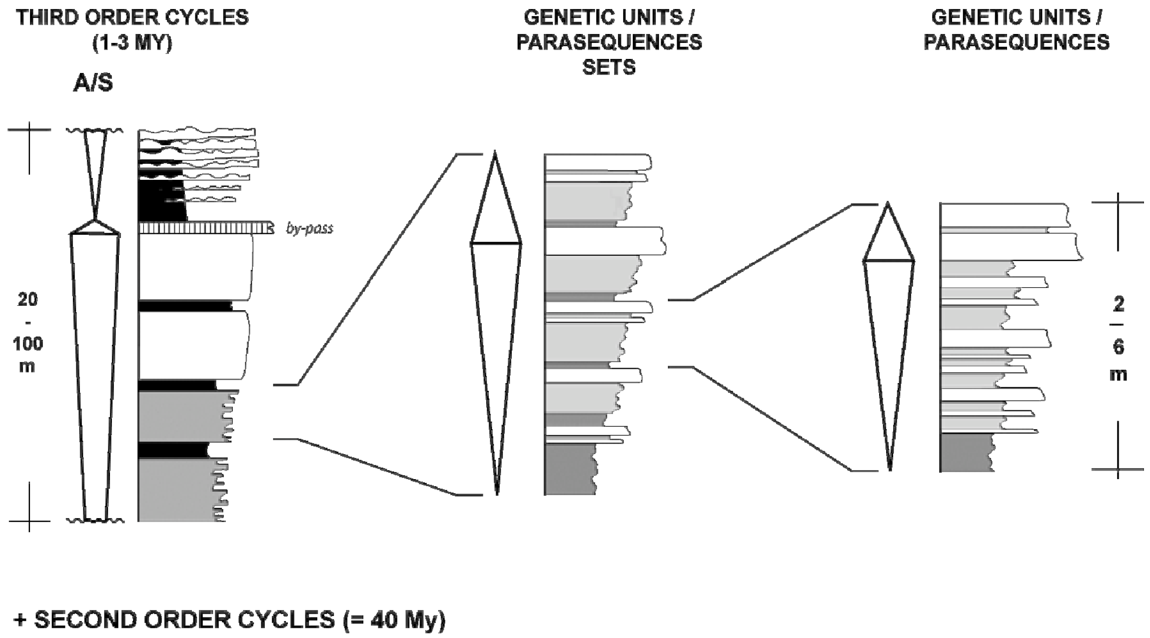


Fig.12 Sequence hierarchy of the Guwayzah Fm

In such turbiditic setting, stratigraphic sequences or cycles are defined as repetitive motifs of facies variations. Sequences/cycles are here defined between two successive distal facies, in the definition of Mutti (1992).

At least four orders of superimposed sequences/cyles can be defined:

- the elementary sequences, few meters-thick, called here genetic units (equivalent to the parasequences or to the 5th order cycles),
- the genetic units (or parasequences) sets, 10m to few 10s m-thick (4th order cycles),
- the third order cycles, 20m to 100 m-thick,
- the second order cycles, including all the Guwaysa Fm, of Middle Toarcian to Oxfordian age.

THIRD ORDER CYCLES : GEOMETRY AND CONTROL

Third order cycles result form the time succession of three terms.

- The **sand-rich** term, mainly homolithic, is mainly made-up of facies F4-5, F7-8 and FSL. It pinches out downstream with the geometrical characteristics of a progradational wedge (downlap?). The most sandy facies occur on the top of the term (sandy upward trend).
- The **amalgamated** term, few meters-thick, is upstream composed of highly amalgamated facies F4-4 and F7-8. They pass laterally to a downstream thickening wedge made up of a thinning-upward and fining-upward trend of marly clays to clayey marls (F9mc) and sand alternations (F9cl). The sands are 10 cm-thick Bouma Tbc sequences with climbing ripples (A,B) indicating currents perpendicular to the basal flute casts (possible reorientation of the turbidity currents by the oceanic currents?). The upstream amalgamated facies record a by-

pass of the gravitary flows. The total thickness of the sandy and the amalgamated terms do not show significative variations downstream.

- The **mud-rich** term, heterolithic, is made up of a thickening and coarsening-upward alternation of carbonate muds (facies F9bp and F9cm) and very coarse-grained sands with granules and pebbles with numerous evidences of by-pass (megaripples, lags, numerous erosion surfaces, facies F6). Coarse-grained sand beds are more amalgamated upward. Laterally, they pass to more muddy deposits alternating with 10cm-thick Bouma Tbc sequences with eroded top.

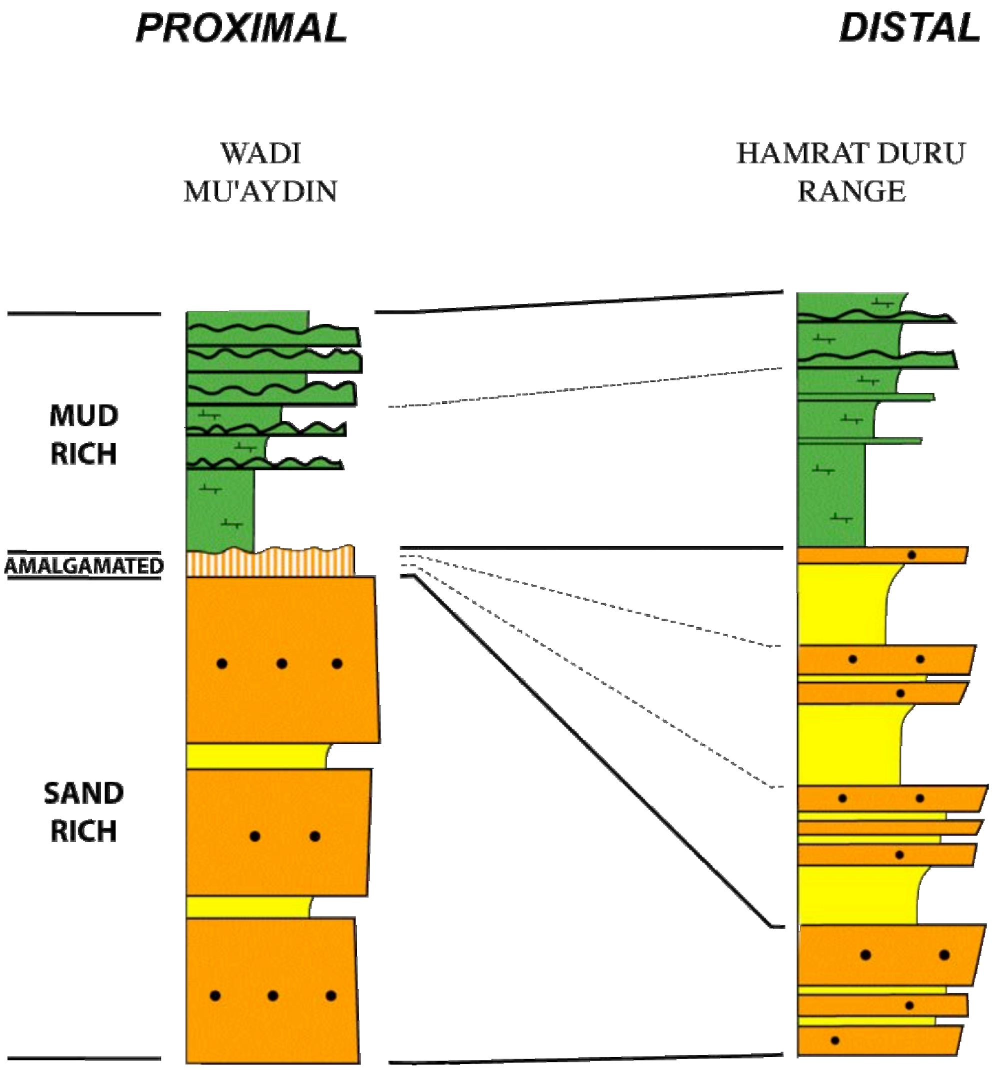


Fig.13 Third order cycles variations along the depositional profile: logs

In consequence, the Guwaysa Fm shows two types of by-pass facies, one with a downstream wedge of sediments and another one with no lateral significative thickness changes passing through finer-grained sediments. Surprisingly, the typical by-pass facies of Mutti (1992) correspond here to the second type.

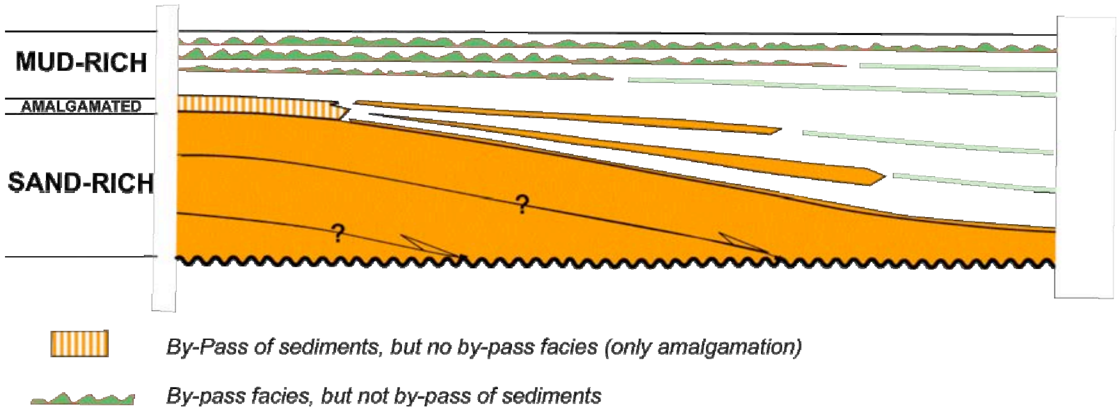


Fig.14 Third order cycles variations along the depositional profile: 2D geometry

This evolution is interpreted as a consequence of variations of the carbonate clastic supply coming from the platform, in response to relative sea-level changes.

- During **relative sea-level lowering** (mud-rich term), the carbonate production decrease strongly. Storm waves destroy the carbonate platform, partly lithified. Only pelagic production occurred, leading to the deposition of carbonate muds. The clasts coming from the erosion of the platform by storm waves are reworked in the deep-sea plain by hyperconcentrated flows containing few sands. This explains the occurrence of by-pass facies with no downstream associated wedges. The sequence boundary (unconformity) is located at the time of maximum amalgamation of very coarse-grained sands, *i.e.* at the boundary between the mud and the sand-rich terms.
- During the **early beginning of the relative sea-level rise** (sand-rich term), the depth on the shelf is high enough to product ooids to feed the sand-rich term. Increasing of the depth leads to better condition of carbonate production, explaining the sandy upward trend in the deep-sea plain.
- During the **end of the relative sea-level rise** (amalgamated term), the depth on the shelf is too high to produce a large amount of ooids. This explain the amalgamated term, less and less supplied by ooids, where pelagic muds become dominant (thinning and fining-upward trend). Gravity flows by-passed over the underlying sand-rich wedge.

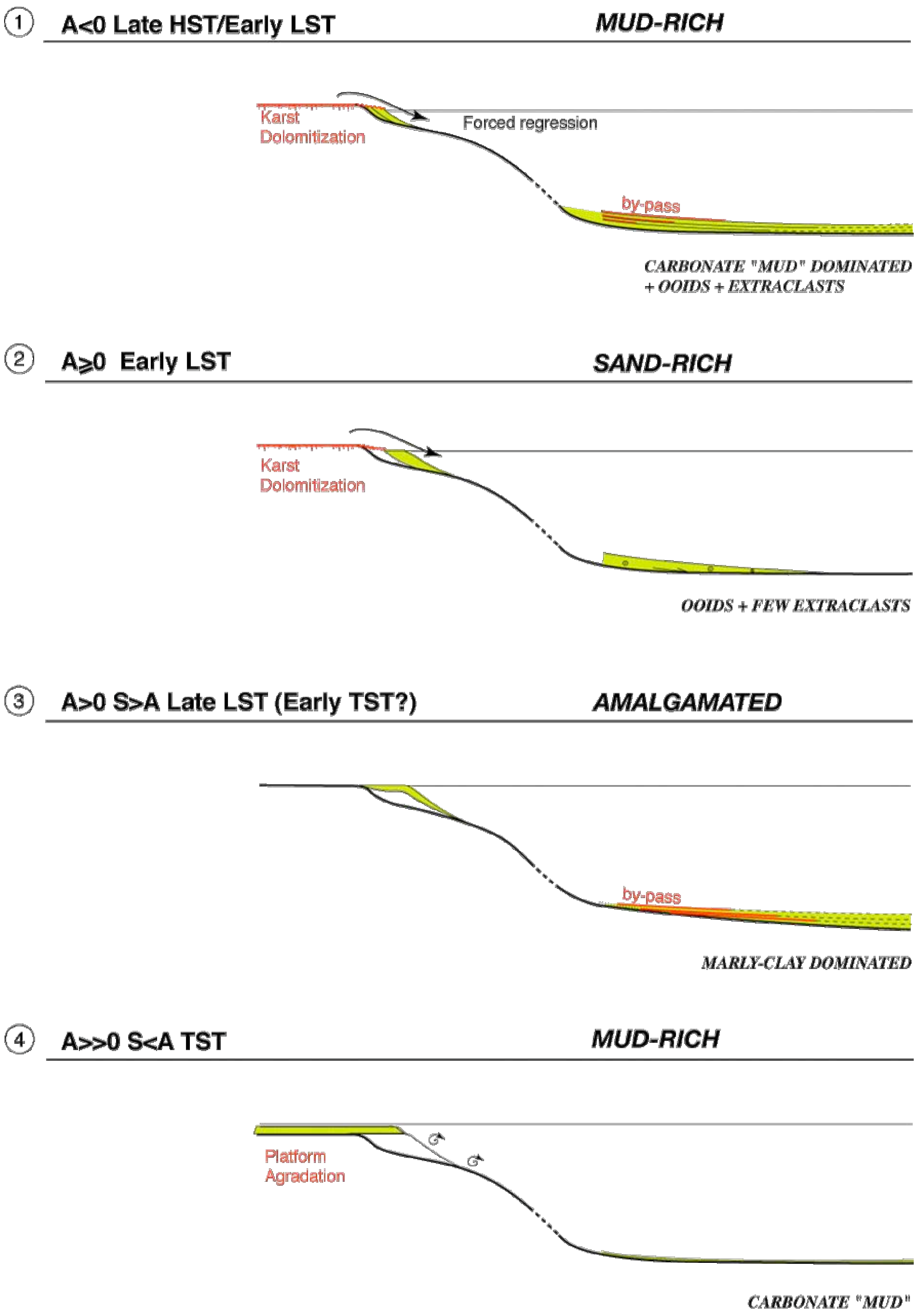


Fig.15 Relationship between the platform and the deep-sea basin during a third order relative sea-level change cycle (Guwayza Fm)

GRAVITARY SYSTEM PHYSIOGRAPHY

The Guwaysa deep-sea carbonate deposits can be defined as a multi-source "ramp" system evolving through time form sand-rich to mud-rich lobes. This turbiditic system is fed by ooidic shoals located at the platform margin wedge, excepted along a major crustal discontinuity, the Samail gap, where an extraclastic point-source occurred (erosion of older carbonates). This leads to the definition of two subsystems a carbonate-dominated one, only made of ooids with clastic deposits (quartz, Triassic pebbles and granules…) and a pure carbonate one, composed of ooids with some "mud". The overlying model of third order cycles corresponds to this second type of subsystem.

Another characteristic is the lack of true channels and the systematic occurrence of by-pass facies. The most proximal facies, the slope deposits of the Sumeini tectonic unit, do not show any evidence of such channels. In consequence, this system of coalescent lobes, that form large sheets deposits, seems to be directly fed by the shelf wedge with a wide by-pass area at the base of the distally-steepened ramp of the margin.

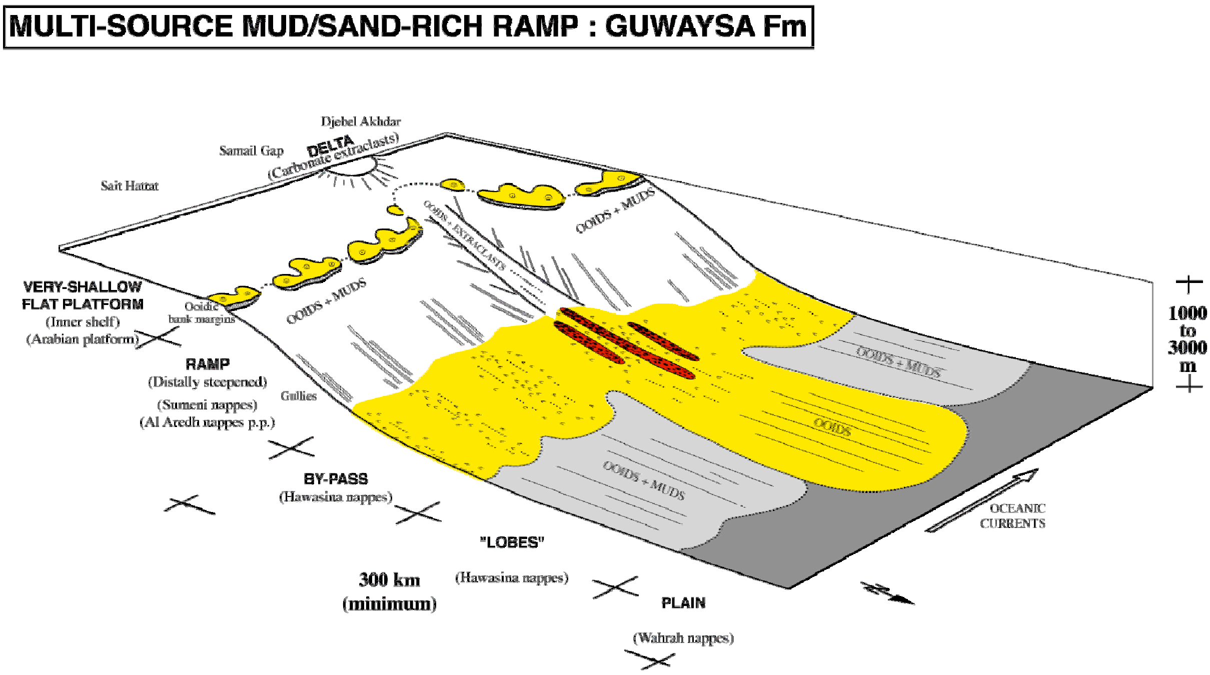


Fig.16 Possible 3D physiography of the Guwayza Fm deep-sea gravitary system

Friday 7th: DJEBEL BUWAYDAH

Triassic-Jurassic base-of-slope deposits

Triassic to Jurassic base-of slope deposits of the outer tilted block of the margin, upstream of the oceanic cruts

Log see Fig.5

X E56° 57.424’	Buwaydah Est	X E57° 05.626’
Y N23° 01.773’		Y N22° 51.977’

Notes

Saturday 8th : WADI MU'AYDIN

Jurassic platform deposits

Inner platform (lagoonal to protected marine) deposits time-equivalent to the deep-sea gravitary deposits of the Guwayza Fm
See Fig.7 for correlations platform / deep-sea plain

X E57° 40,332'
Y N23° 00,03'

Notes

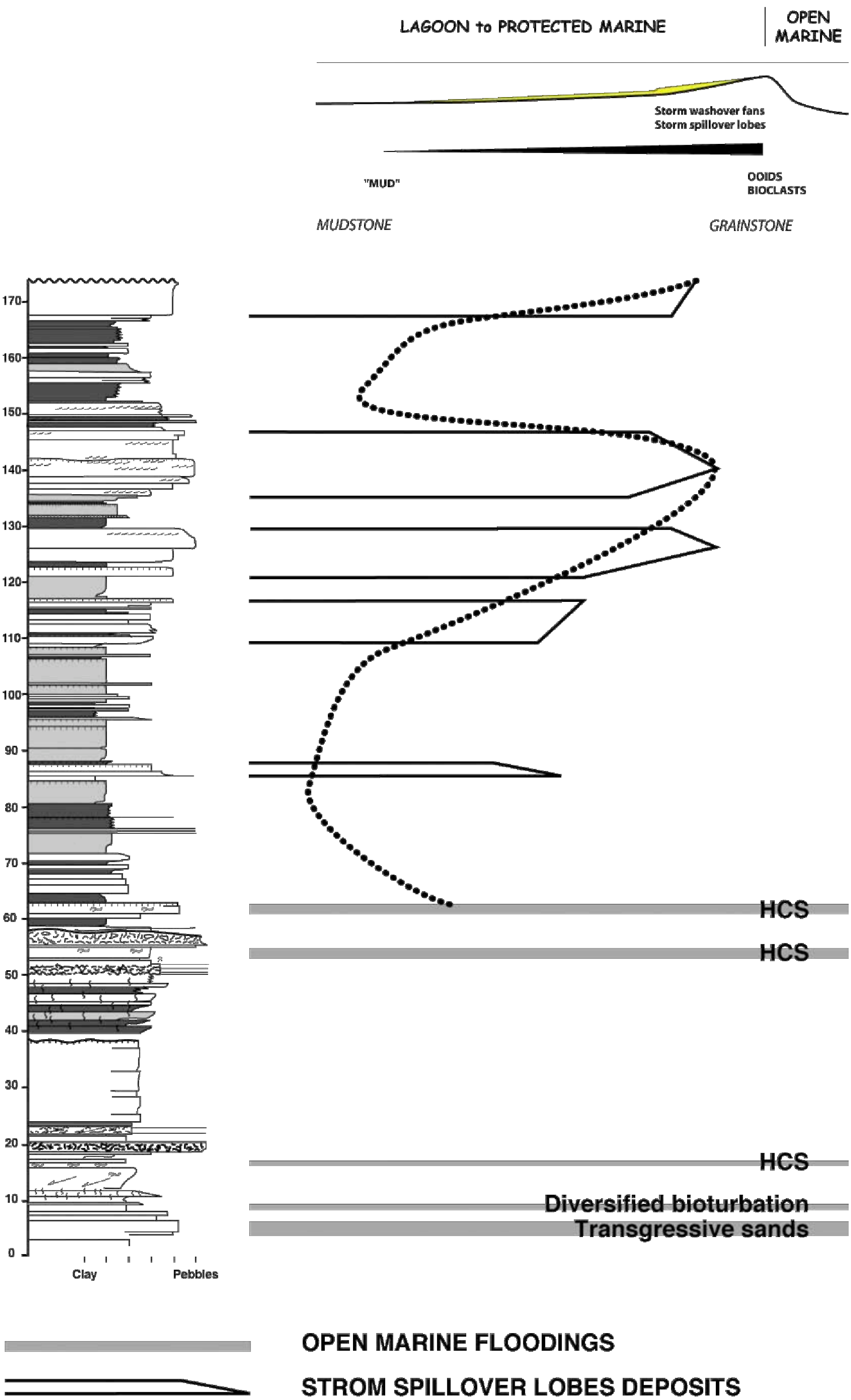


Fig. 17 Facies evolution along the Wadi Mu'Aydin section : the Jurassic Arabian Platform

Saturday 8th : WADI MU'AYDIN
Jurassic deep-sea deposits

Proximal facies of the Guwayza Fm (Late Toarcian to Oxfordian age)

X N23° 00' 06.8''
Y E57° 40' 02.7''

Notes

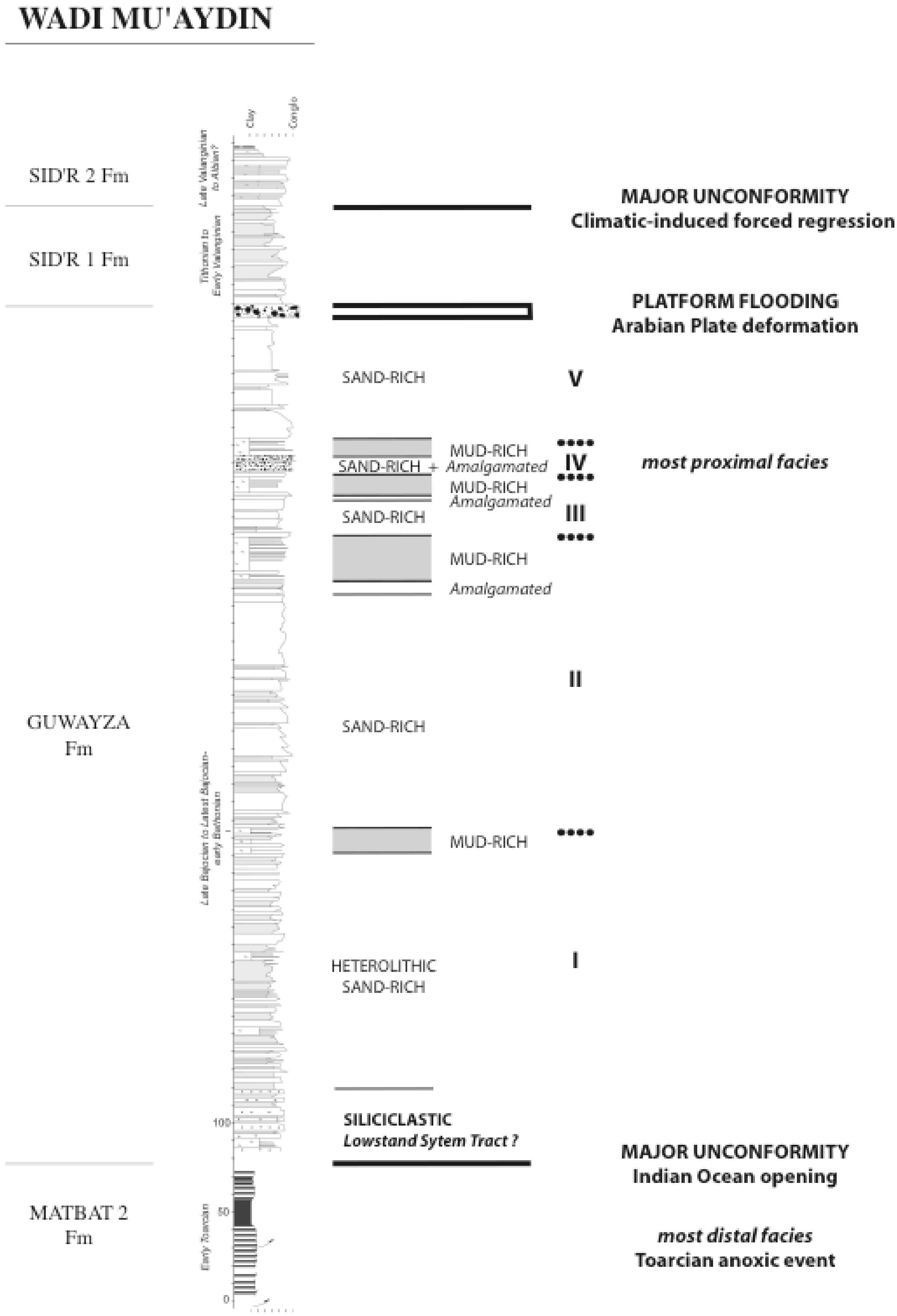


Fig.18 WadiMu'Aydin section

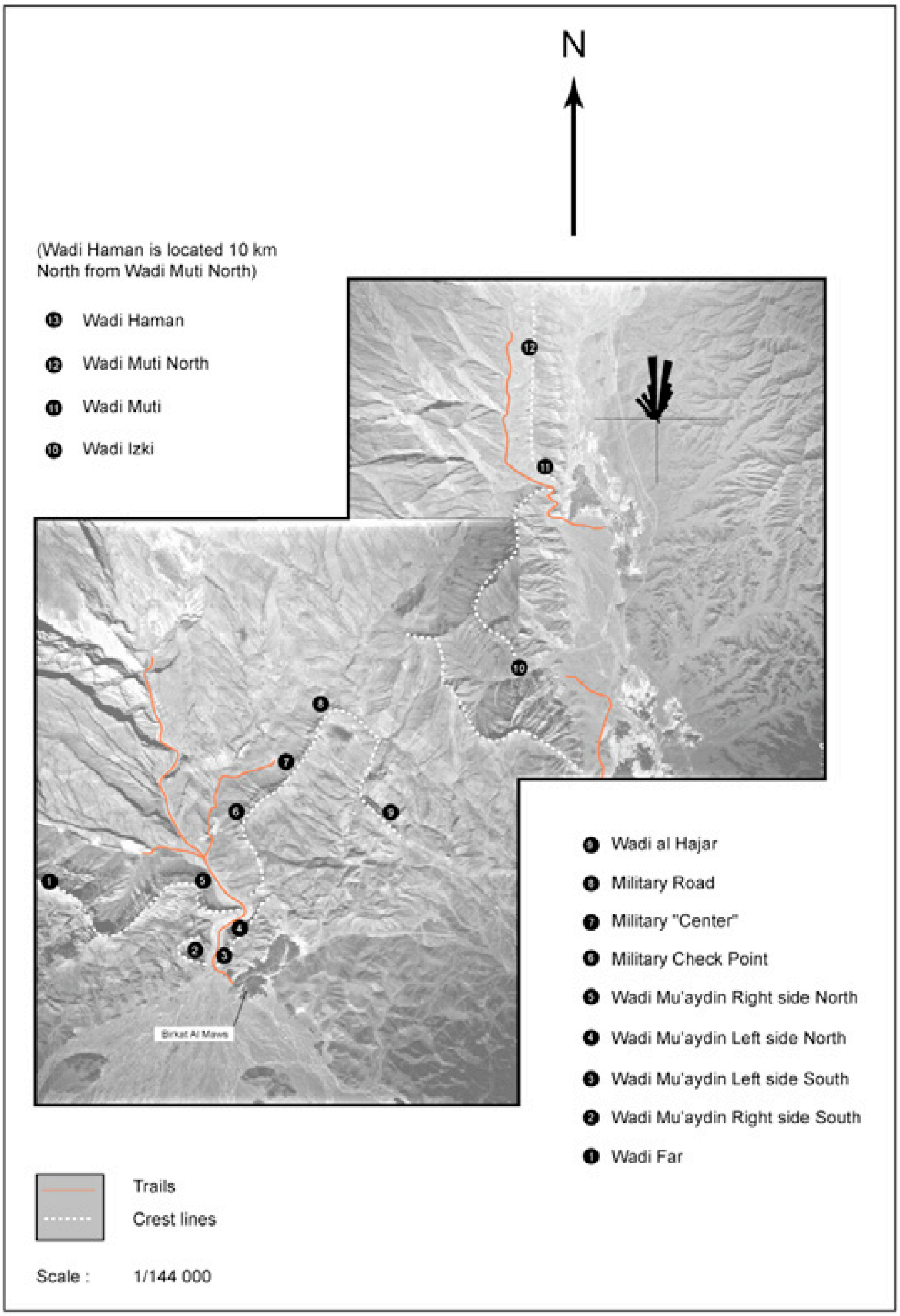


Fig.19 Guwayza Fm – proximal unit : correlations between Wad Mu'Aydin and Wadi Mut.i Location of the sections of Fig.20

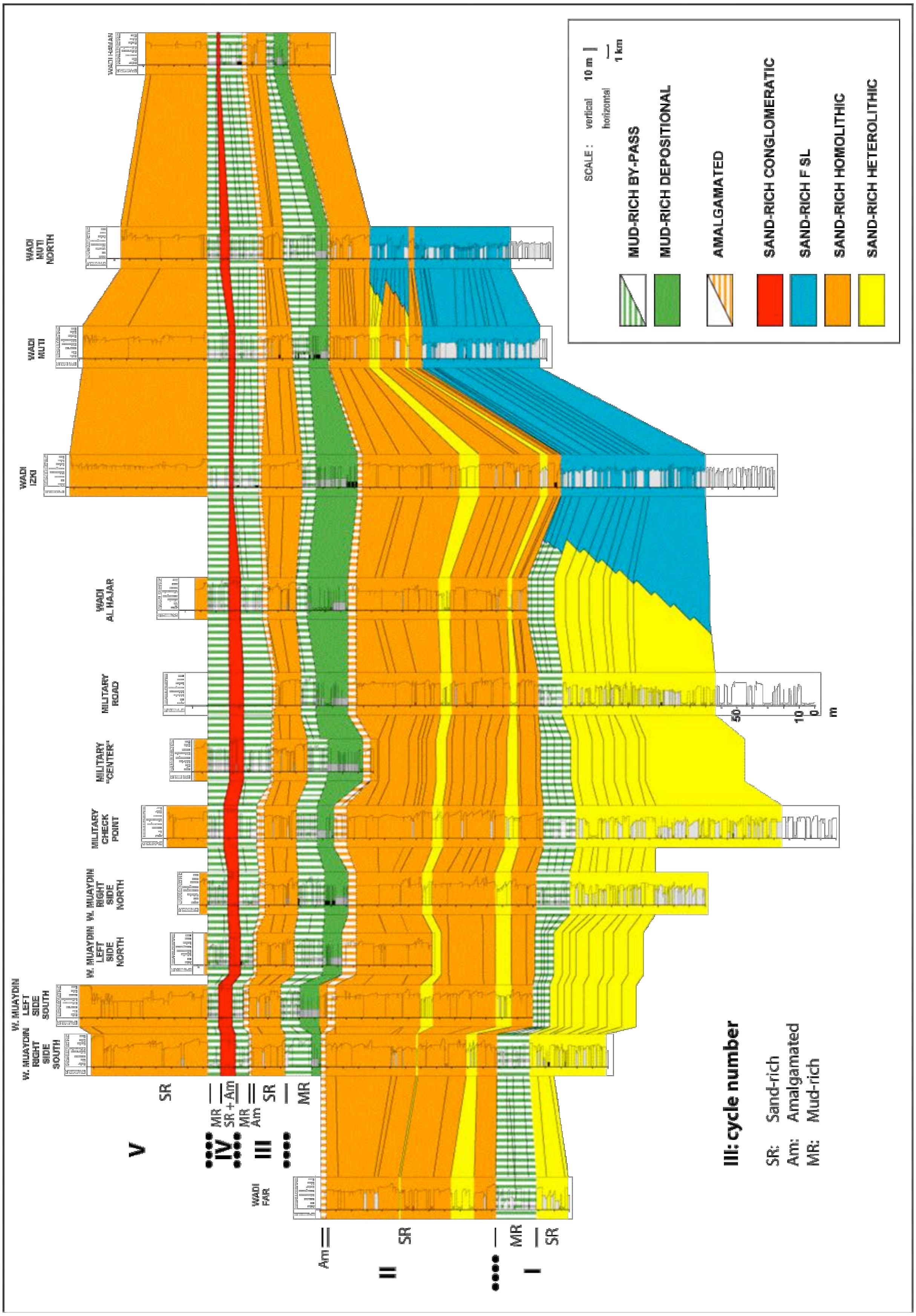


Fig.20 Guwayza Fm – proximal unit : correlations between Wad Mu'Aydin and Wadi Muti

Sunday 9th: WADI ANDAM

Jurassic to Cretaceous deep-sea deposits

Proximal facies of the Guwayza Fm (Late Toarcian to Oxfordian age)

X N22° 84.409’
Y E57° 99.367’

Notes

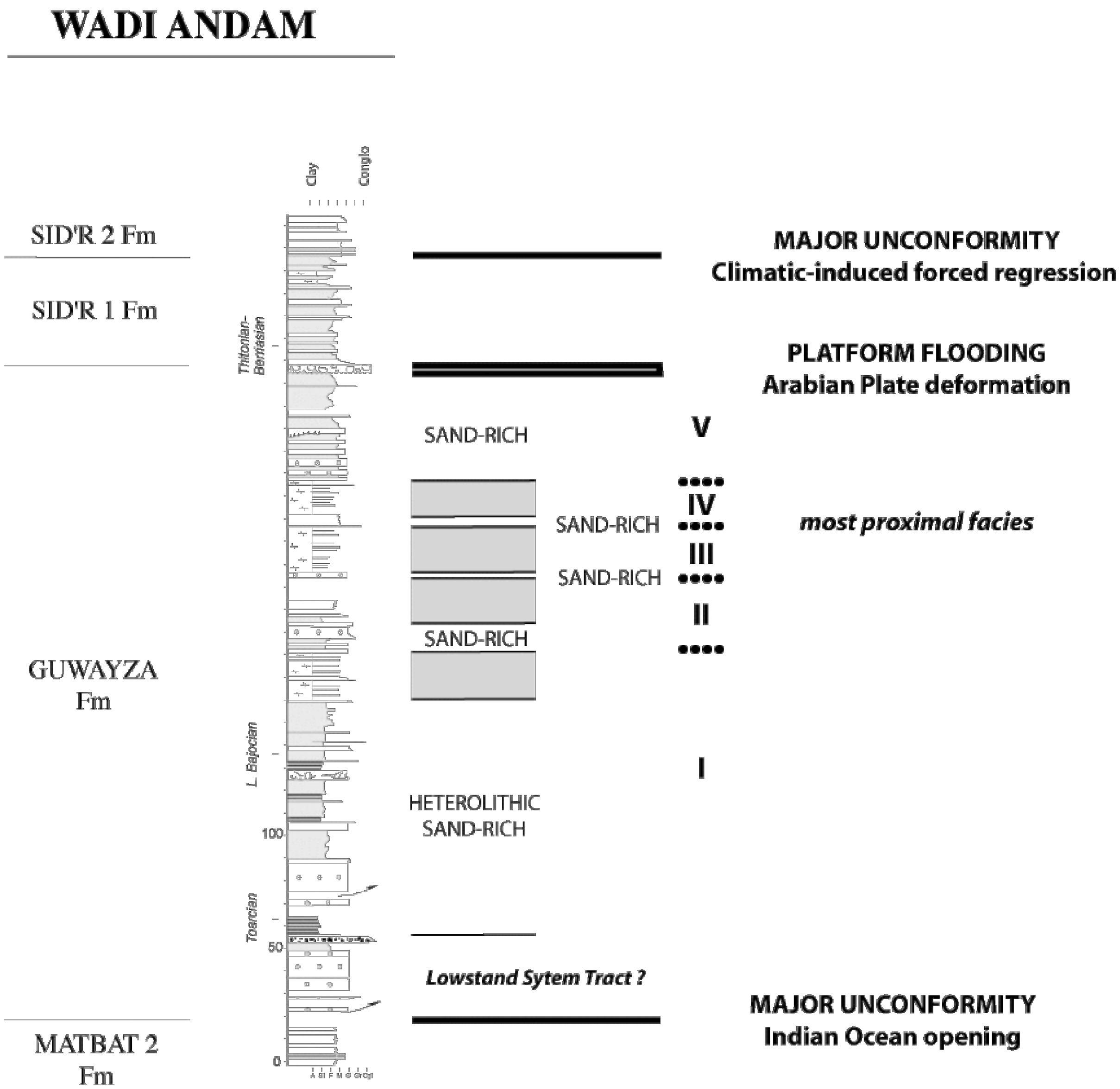


Fig. 21 Wadi Andam section

Sunday 9th: DJEBEL SAFRA

Jurassic to Cretaceous deep-sea deposits

Distal facies of the Hawasina / Hamrat Duru basin (Late Triassic-Upper Cretaceous)

X E57° 48’ 28.4’’
Y N22° 43’ 23.3’’

Notes

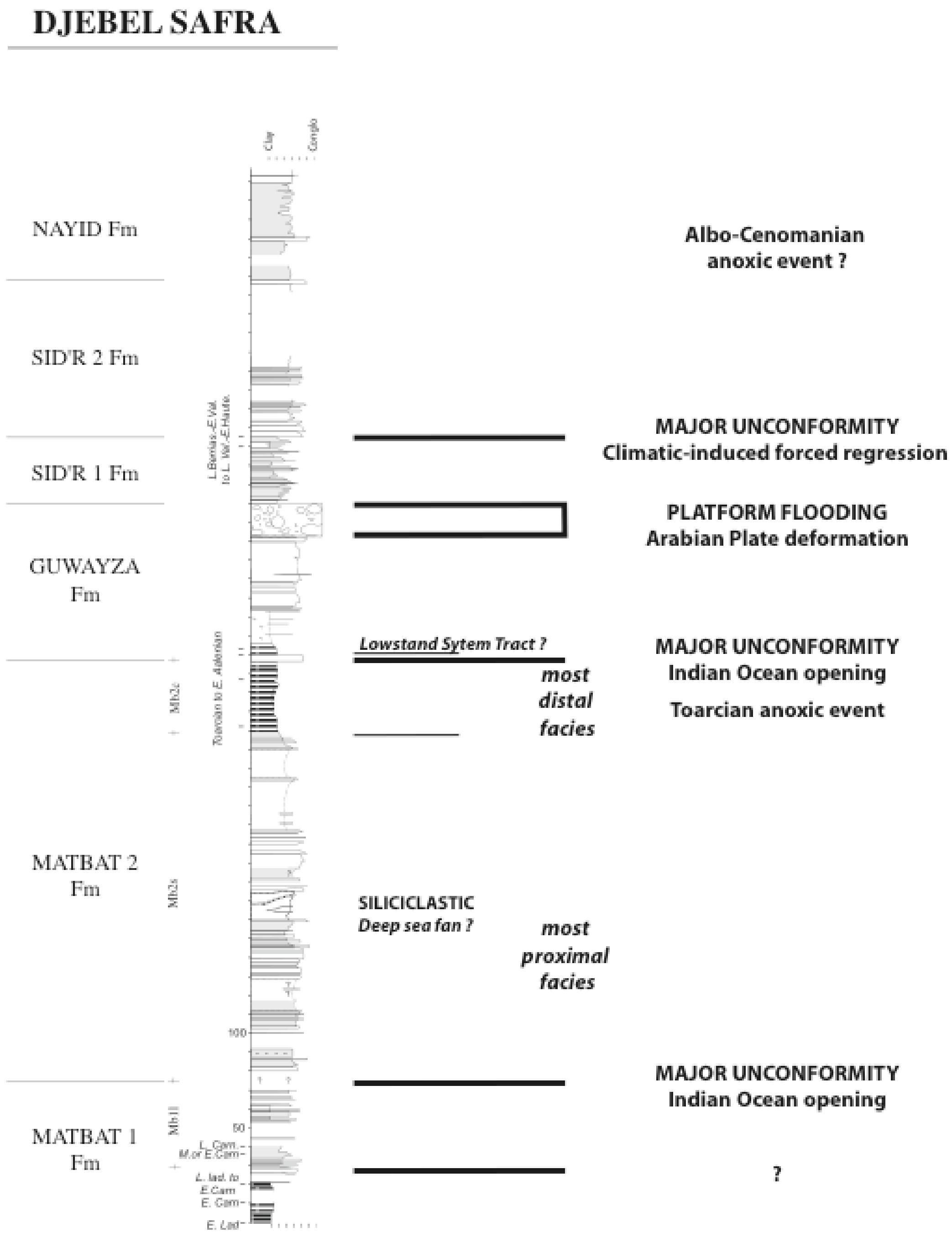


Fig.22 Djebel Safra section