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Development of Sedimentation Along the Saudi Arabian Red Sea Coast

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ABSTRACT. Synrift sediments along the Arabian Red Sea coast are generally subdivided into a basal continental unit, a transgressive marine series, an evaporitic formation and a final mixed clastic-carbonate sequence. These facies changes mark characteristic steps of the geodynamic evolution. Detailed studies were carried out in the northern part of Midyan and along the coast between Aynunah and Yanbu as well as around Jizan. Findings of fossils and new absolute age determinations provide a better understanding of the chronological development.

The Oligocene and Miocene synrift sediments are exposed at different places. In the Midyan area continental and marine units can be distinguished. They range from Rupelian to Serravalian in age, and exist generally with greater thicknesses within the axial part of the graben basin.

The oldest synrift deposits of southwestern Arabia are formed by an association of non-marine sediments, volcanics and volcanoclastics. They are coeval with marine strata at the northern Red Sea and prove that early rifting in the Oligocene occurred along the entire length of the then Red Sea basin.

The Pliocene-Pleistocene sequence is separated by a major late Miocene unconformity. These younger sediments along the coastal plain consist mainly of calcareous sandstone or calcarenite with intercalations of reef and littoral or fluviatile sandstone and conglomerate.

Introduction

During the last twenty years, several differing models on the structural evolution of the Red Sea have been reported. Due to lack of chronological data, they deviate from each other mainly by the timing of the different tectonic events. In the last years, the results of detailed stratigraphic investigations, especially from the Egyptian margin, were published (El Heiny and Martini 1981, Scott and Govean 1985, and Montenat *et al.* 1986). For the Arabian Red Sea margin, only a few stratigraphic data were reported (Skipwith rearrange them by year 1973, Vasquez-Lopez 1981, Schmidt and Hadley 1984), without detailed dated profiles. Therefore, the reported ages of the sedimentary sequence could not be used for the interpretation of the geodynamic development of the rift system.

From 1982 to 1988, a joint scientific project on the sedimentary and structural evolution of the Arabian Red Sea margin was carried out by the King Fahd University of Petroleum and Minerals in Dhahran, and by the University of Karlsruhe (Germany). Field investigations were made in the Midyan area, along the northern Red Sea coast between Aynunah and Yanbu and in the southern area between Qunfudhah and Jizan, as well as on Farasan island (Fig. 1). The initial stratigraphic results of this project were published by Dullo *et al.* (1983) and Hötzl (1984). More recent data were given by Voggenreiter *et al.* (1988), Bayer *et al.* (1988), and Voggenreiter and Hötzl (1989). This report summarizes the results on the sedimentation of the rift basin along the eastern Red Sea margin.

Prerift Sequence

The Red Sea divides the originally connected Nubian and Arabian crystalline shield area. Deformed and consolidated during the Panafrican orogeny, this area formed a stable block during Paleozoic and Mesozoic time. Erosional processes dominated, and only during short periods sedimentation spread over the marginal parts of this area. Therefore, the Pre-

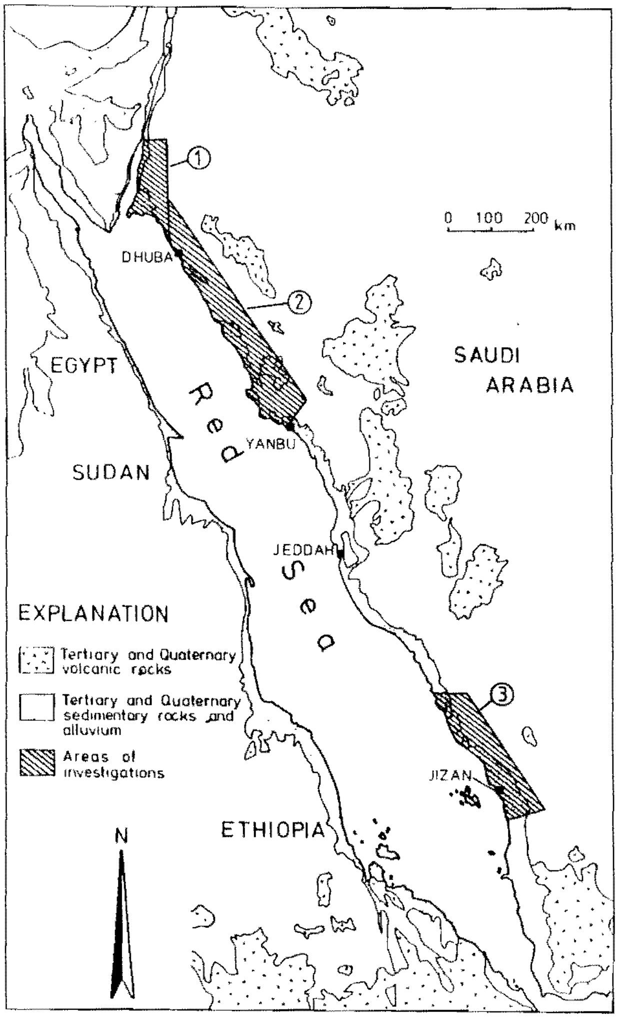

FIG. 1. Areas of investigation along the Saudi Arabian Red Sea cost :
1. Midyan peninsula, 2. northern Red Sea coast between Aynunah and Yanbu, 3. southern Red Sea coast between Al Qunfudhah and Yemen border.

cambrian rocks prevail at the basis of the synrift sediments in vast areas along the Arabian Red Sea coast.

In the southern Red Sea area, in Yemen and the adjacent Jizan area, the Proterozoic rocks are overlain discordantly by the Paleozoic Wajid sandstone (Powers *et al.* 1966, and Dabbagh and Rogers 1983). This sequence is covered again discordantly by the fine-grained Jurassic Kohlan sandstone (Geukens 1966), which shows intercalations of red shaley and silty layers. The upper part of this sequence transfers into the fossiliferous limestones of the Jurassic Amran Formation. Locally, the limestones are superposed by a carbonate cemented sandstone, which is correlated with the Cretaceous-Tertiary Tawilah Formation in Yemen (Geukens 1966).

The northern part of the Red Sea was influenced by Upper Cretaceous and Paleogene transgressions from the Mediterranean. The appertaining sediments, with a thickness up to 500m, extend from the Gulf of Suez along the Egyptian side southward to Wadi Sharm el Qibli, and were originally deposited even further to the south (Said 1962, and Purser and Hötzl 1987). The complete sequence includes the fluviatile Nubian sandstones and the littoral Quseir shales of Cretaceous age. They are overlain by the Paleogene phosphatic limestones, which are terminated by Eocene cherty limestones of the Thebes Formation. On the Arabian side these pre-rift sediments are mainly restricted to a few small remnants preserved in protected narrow structures (Usfan, Azlam and Aynunah grabens). They indicate an extension of the connected sedimentary environment from North Africa across the Red Sea to Saudi Arabia.

Remnants of the Paleocene-Eocene sediments can be found southward up to the area of Jeddah. The partly marine Usfan and Shumaysi formations are considered very important evidence for the flat relief condition in the Red Sea area at that time. The two formations are separated by a gap representing the Upper Paleocene. In the upper Shumaysi Formation, a shallow marine foraminiferal assemblage with *Elphidium latidorsatum* was found during the investigations. It gives a Late Eocene (Barthonian) age (Braga and Grünig 1975) not older than 45 m.y. (Roscher *et al.* 1990). The uppermost part of the Shumaysi Formation already shows synsedimentary extensional tectonics corresponding in its orientation to the later Red Sea rift system.

Analogous with the Shumaysi Formation could be a remnant of a marine sandstone, which was found in the Midyan region 10 km north of Maqna, close to the shore. It contains an echinoid fauna with *Clypeaster moianensis, Clypeaster boussaci, Amblypygus dilatatus, Ovicylpeus lorioli* and *Echinolampus africanus* (Roscher *et al.* 1990). They represent the same Barthonian age (Late Eocene), as it was found for the upper Shumaysi Formation.

Synrift Sediments

1. Areas of Investigations

The Red Sea still covers nearly the whole graben basin, leaving a narrow coastal plain or zone between the sea and the uplifted graben shoulder, where synrift sediments are exposed. These sediments represent mainly the marginal facies of the basin, which is characterized by the interlocking of mighty but irregular clastic sequences with all types of littoral and shallow marine sediments. Due to the frequent facies changes and the lateral thinning, a lithologic correlation of detailed profiles is generally difficult even over short distances. Nevertheless, the different tectonic stages with varying sea levels led to forming characteristic main units, which are time conformable along the coast but partly diachronic across the Red Sea to the Egyptian margin (Bayer *et al.* 1988).

The sedimentary sequence of the eastern Red Sea margin was studied in three different regions (Fig. 1). The northernmost area is the Midyan peninsula (Fig. 2) opposite to the southern part of Sinai (lat: 28° 00′ to 28° 15′). The Tertiary sediments there are partly up to 70 km in front of the master fault bordering the uplifted graben shoulders. Having in mind the lateral displacement of Midyan and the whole Arabian plate (Bayer *et al.* 1988) over a distance of more than 100 km along the Aqaba-Levant shear zone, it becomes clear that the older synrift sediments there represent those

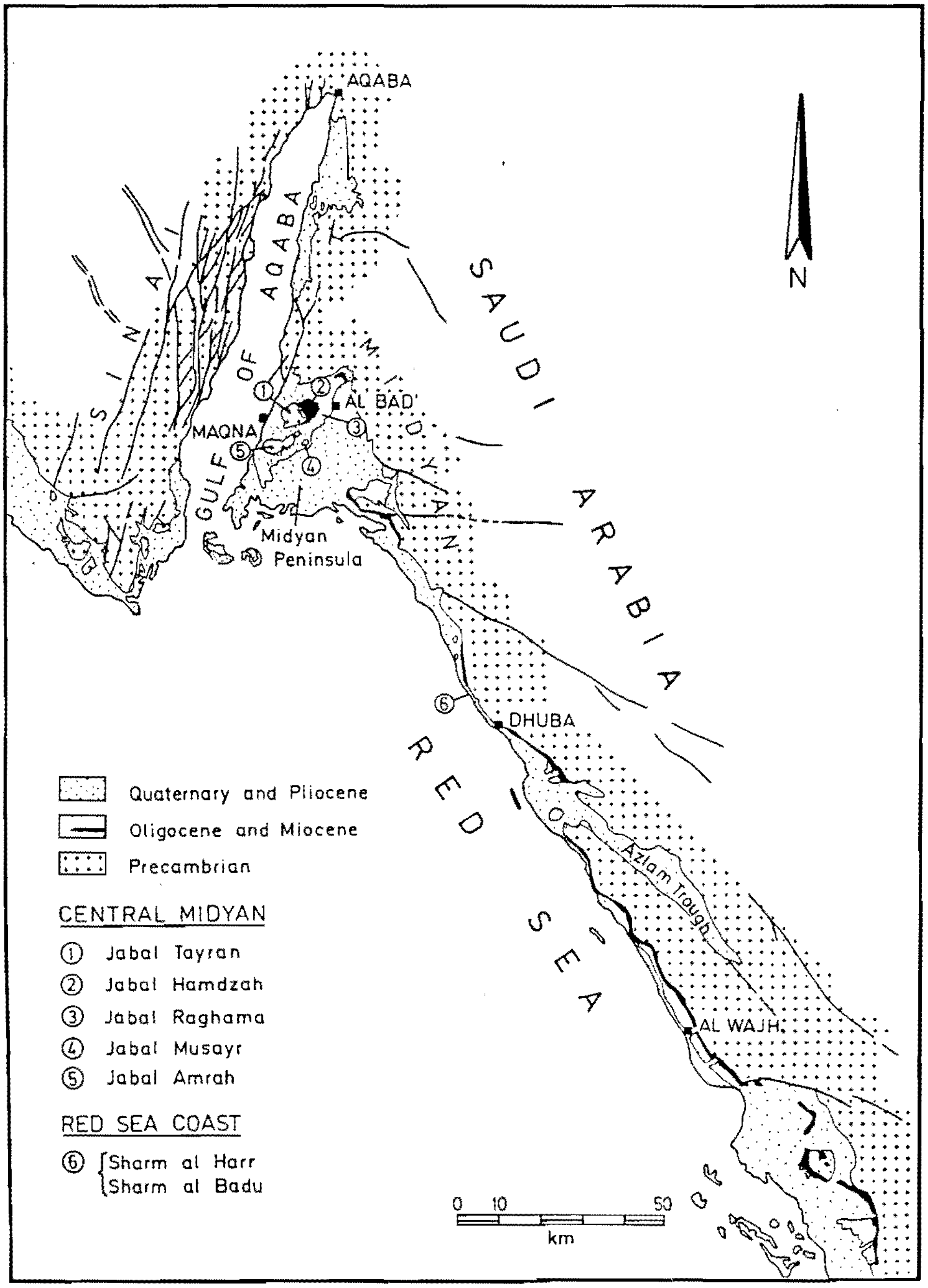

FIG. 2. Sketch map of the Northwestern Arabian Red Sea coast with principal localities studied in this area.

of the originally central graben basin. The spur of Midyan is, therefore, the only place where sediments of the more central basin are exposed, since all other central parts are covered by the Red Sea.

The second area of investigation is the narrow coastal strip from Aynunah southward to Yanbu (lat: 24° to 28°) over a distance of nearly 400 km. Today, as well as at the synrift stage, this strip has always been the marginal part of the basin with characteristic interlocking of continental and marine sediments.

The third region of more detailed study is situated at the southern part of the Arabian Red Sea coast. It is the area between Al Qunfudhah and the Yemen border (lat: 16° 15′ to 18° 40′). The main investigations were carried out in the surrounding of Jizan. The southern part was included in order to compare the sedimentary development there with those along the entire Red Sea. From previous publications, it is known that the marine sediments are rare along the southern coastal strip. Widespread volcanic rocks are typical for this area.

2. Midyan Peninsula

The older synrift sequence of this area can be divided into four units (Fig. 3) ranging in age from the Rupelian to the Serravalian (approx. from 34 to 14 Ma B.P.). They are overlain discordantly by the Plio-Pleistocene deposits. The nomenclature proposed by Clark (1985) in the geological map of the Al Bad' quadrangle is mainly used in this paper. The lithological subdivision is more or less identical with the units given by Dullo *et al.* (1963). Other deviant proposals were made by Bokhari (1981) and Zakir (1982).

Sharik Formation

The reddish to pinkish continental sequence is composed of torrential-like boulder sediment, conglomerate, arkosic sandstone and subordinate siltstone. Components of the generally poorly sorted conglomerate derive mainly from the crystalline basement. In the coarser parts of the sections, sandstone components, chert and locally silicified limestone pebbles also occur. The succession covers a relief in which the northeast-tilted antithetic blocks dominate. In the marginal depressions, the sediments reach a thickness of more than 600 m, but in some places these sediments tend to thin and even disappear completely towards horst structures.

Thick conglomerate beds with deep gullies and channel fillings were developed along the crystalline basement north of the connection line Maqna-Al Bad'. The more axial part of the graben basin is represented by the outcrops around the Jabal Tayran east of Maqna in the central part of Midyan peninsula, where sandstone dominates. In some places, their origin of the *in situ* weathered granite is still exposed.

The age of this continental sequence dated as Rupelian can be recognized only in some underlying remnants of Eocene cherty limestones (Le Nindre *et al.* 1986) and in some silicified pebbles of this limestone in the basal clastic sequence as well as in the overlying marine unit for which a Late Oligocene age may be proved.

Musayr Formation

Light colored, yellowish to gray marine sediments are deposited conformably on the Sharik Formation at Jabal Hamzah, where a complete profile is exposed with a thickness of 60 m. Clark (1985) reports about an unconformable superposition of limestone at Jabal Musayr, over a tectonic and topographic high of the crystalline basement at that time. The Musayr Formation is composed mainly of limestone and intercalated calcareous sandstone. Even within the limestone a great variety of microfacies ranging from mudstone over packstone to framestone can be observed. The faunal assemblage includes varying horizons with echinoids, oysters, large foraminifers, as well as corals and algae.

The sequence could be examined only in the Central Midyan area, where the limestone cap the structural highs: they grade into sandy deposits within the depressions. The yellowish to pink sandstones contain locally large echinoids and oysters. West and north to Jabal Tayran (east of Maqna) gypsifereous rocks up to 35 m thickness probably mark the transition between the older continental and marine environments.

The age of this sedimentary unit was first assigned by Dullo *et al.* (1983) as Late Chattian age. Further investigations proved that both planktonic zones N2 and N3 *(Mio-gypsinoides complanatus, Operculum complanata)* are included (Bayer *et al.* 1988) and finally a new sampling campaign in 1988 along the northern slope of Jabal Hamzah revealed the existence of foraminifera from the planktonic zone N1 *(Nummulites vascus, Nummulites fichteli, Victoriella sp., Operculina complanata)*. Therefore, this marine sequence comprises the whole Chattian, so that the underlying clastic sediments belong to the Rupelian.

Nutaysh Formation

This essentially clastic sequence overlies, with slight unconformity, the Upper Oligocene reef limestone. In its lower part, brownish sandstone predominates with characteristic intercalations of reef limestone, while in its upper part greenish to yellow marls and siltstones

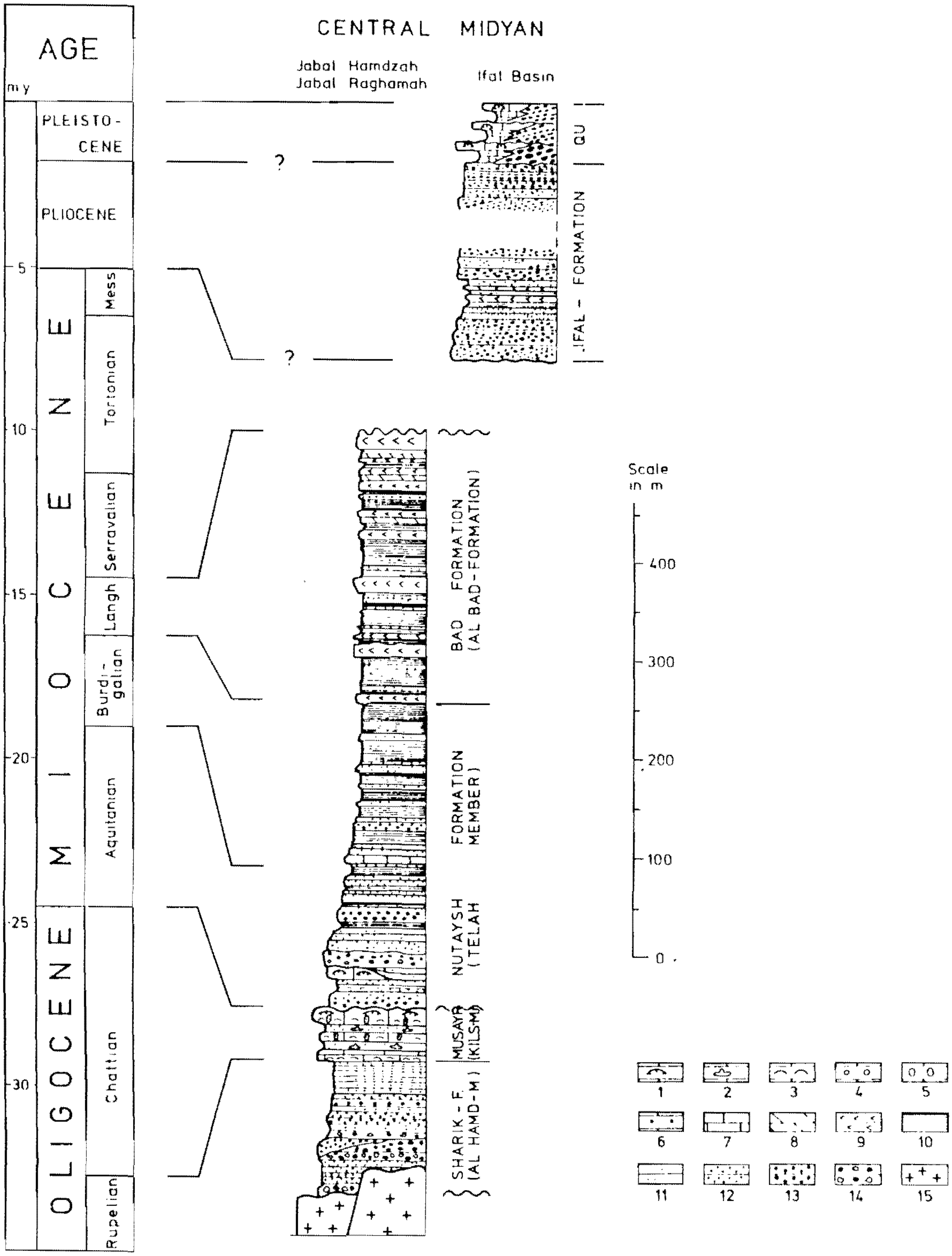

FIG. 3. Generalized stratigraphic sequence of the synrift sediments central Midyan area. Formation name according to Clark (1985) in paranthesis according to Dullo *et al.* (1963).
Legend :
1 = corals and algae, frequent reefs, 2 = echinoids, 3 = mollusks, mostly oysters, 4 = oolitic carbonates, 5 = large foraminifera, 6 = foraminifera, 7 = limestone, 8 = dolomite, 9 = gypsum, 10 = marls and clayey silts, 11 = fine sandstone, 12 = medium-grained sandstone, 13 = coarse sandstone, 14 = conglomerate with cherts (open circles) and crystalline basement fragments (filled circles), 15 = crystalline basement.

prevail. The total thickness of the formation exceeds 300 m.

Especially the lower part of the sequence seems to reflect increased vertical tectonic activity. Large fans with polimict conglomerate were deposited in front of the rift escarpment. The conglomerate beds thin towards the main graben basin, where the sequence generally becomes finer-grained and forms graded cyclic succesions. Similarly, in vertical section, silty and marly sediments prevail in the upper part where they include planktonic forminifera (Globigerina Marls). Fringing reefs are intercalated. They were developed around islands as well as on the marginal fault steps.

An Aquitanian to Burdigalian age is suggested for the entire formation. For the lower reefal intercalations, the Aquitanian age was already given by Dullo *et al.* (1983) by finding *Miogypsina intermedia.* New samples from the bases of the Nutaysh Formation, only a few meters above the Musayr limestone at the northeast corner of Jabal Hamzah, contained planktonic fauna with *Globigerinoides quadrilobatus primordius,* which is characteristic for the N4 planktonic foraminifera fauna and others of probably Burdigalian age (N6) could be found in reef intercalations of the upper part of the sequence similar to the limestone north of Al Bad'.

Bad Formation

The Bad Formation is characterized by a cyclic alternation of marl-shale and gypsum-anhydrite beds with a total thickness of about 300 m. It developed directly and conformably on the marly, upper Nutaysh Formation. The lithological change is marked by the intercalations of thick gypsum and anhydrite layers. Beside the marls, a few siltstone and fine-grained sandstone beds are intercalated. Limestone and dolomite layers occur in the upper part.

The Globigerina fauna of the Bad Formation (Fig. 4) belongs to the zone of *Orbulina suturalis-Globorotalia foshi peripheronada* in the Gulf of Suez (El Heiny and Martini 1981) and corresponds to the planktonic zone N9 (Blow 1969). The Nullipora limestone at the

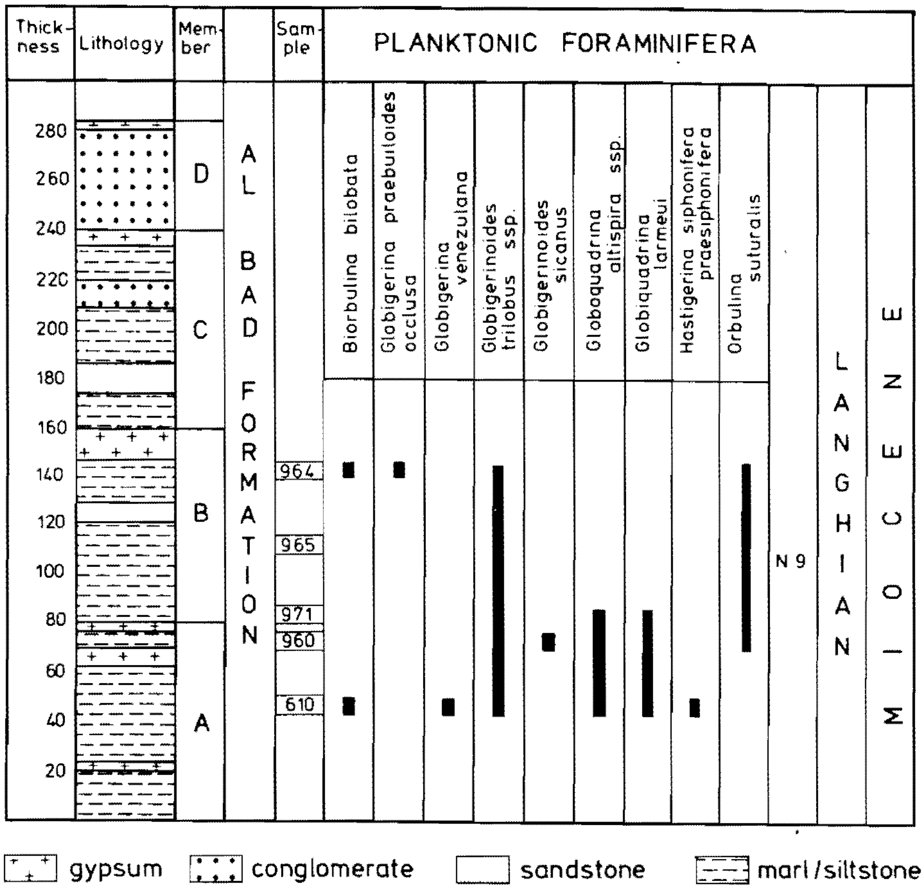

FIG. 4. Assemblages of planctonic foraminiferas from the Baid Formation of the lower section of Jabal Raghamah, central Midyan.

top contains *Miogypsina cf antillea*, a species confined to the planktonic zone N10 (Clarke and Blow 1969). A former age designation of the Nullipora limestone as Late Miocene (Tortonian; Dullo *et al.* 1983) thus has to be revised.

Ifal Formation

The Ifal Formation, following the original designation introduced by Bokhari (1981), is composed of rhythmic-bedded fluviatile sandstone and conglomerate showing frequent crossbedding. They are of reddish grey or yellow color, and consolidated partially by calcite and gypsiferous cement. The rock fragments include quartz gravels as well as basement components. Within or above the reddish-grey basal sequence, silts, clayey sabkha sediments and sporadic gypsum layers are intercalated.

Because of lateral tectonic displacement, the former offshore position of Midyan peninsula progressively became an embayment, situated between the rising blocks of Sinai and eastern Midyan (Bayer *et al.* 1988). Large quantities of coarse and medium grained debris, up to 2000 m thick, were deposited in the Ifal basin. We have, so far, no possibility of age-dating the whole sequence of this clastic formation, The sequence overlies the Middle Miocene sediments of Midyan with an angular unconformity, and is superposed again with an angular unconformity by Quaternary alluvial fans and terraces. Essentially, the Pliocene age has to be assumed for this sequence, but Early Pleistocene could also be correct for the upper part of this sequence.

Quaternary

Marine and terrestrial terraces at different levels (up to elevations of 50 m at the coast) form the youngest sedimentary sequence. They overlie the sediments of the Ifal Formation with pronounced unconformity. Continuity of tectonic activity is documented by basin-ward tilting of older terraces and vertical displacement even of the youngest terraces along the coast of the Gulf of Aqaba.

3. Northern Red Sea Coast

The investigated coastal section from Aynunah to Yanbu (Fig. 2) shows a relatively narrow sedimentary strip. The master fault with the uplifted Precambrian basement behind it passes generally very close to the sea. The outcrops of the synrift sediments are generally restricted to a strip of less than 5 km wide, in parts even of less than 1 km wide. An exception is the section south of Al Wajh to Umm Lajj, where the crystalline margin recede, leaving a coastal plain up to 35 km wide.

Due to the superposition of young alluvial fans, the outcrop conditions for the older sediments are rather poor, so that only restricted profile sections could be exposed. In addition, strong block faulting, rapid facies changes, repeated erosional phases as well as sedimentation impede correlation of the profiles. The complete absence of fossils in the continental sequence and the lack of leading fossils in the littoral facies proves to be a further disadvantage.

Because of these problems, the classification of the sediment sequences in the different sections was left open. Though certain direct lithologic comparisons along the coastal strip and even with Midyan are possible, only general group names may be used till a more detailed regional stratigraphic correlation is possible. According to earlier literature the synrift sediments were put into the now split Raghama Formation (Vazquez-Lopez, 1981). In connection with the geologic surveying for the maps at 1:250,000 scale, different local names were partly used for the same sediment unit (Bigot and Alabouvette 1976, Pellaton 1979 and 1982a,b).

Within the frame of our research project a typical cross section of this marginal synrift facies was worked out from the area between Sharm al Harr and Sharm al Bad' north of Dhuba. The stratigraphic profile is shown in the drawing of Figure 5. A short description is given below.

Group M1

The exposed rocks of this group consist mainly of reef limestones and the appertaining talus slopes, which cover, in an impressive way, the marginal fault step of the basement with steep inclination (Fig. 6). Like a bearing wall, the limestones flank the crystalline fault scarp and have conserved it from weathering and erosion. Thereby, the old morphology (Lower Miocene) had been preserved including some previous breakthrough valleys, which were covered by this transgression of the sea. The elevation of these escarpments up to 80 m above sea level is relatively constant along the northern coast line, proving a stable relief and small vertical displacement since that time. Good examples of these reefs can be found at the bent escarpment behind Aynunah, around Dhuba and in front of Wadi Azlam.

The limestones are abundantly dolomitized and partly show a remarkable mineralization with lead, zinc, copper and barium (Vazquez-Lopez 1981). Due to the accretion of these limestones to the basement scarp and their superposition by younger sediments, no older synrift sediments are generally exposed. Only at a few localities in intersected wadis courses, con-

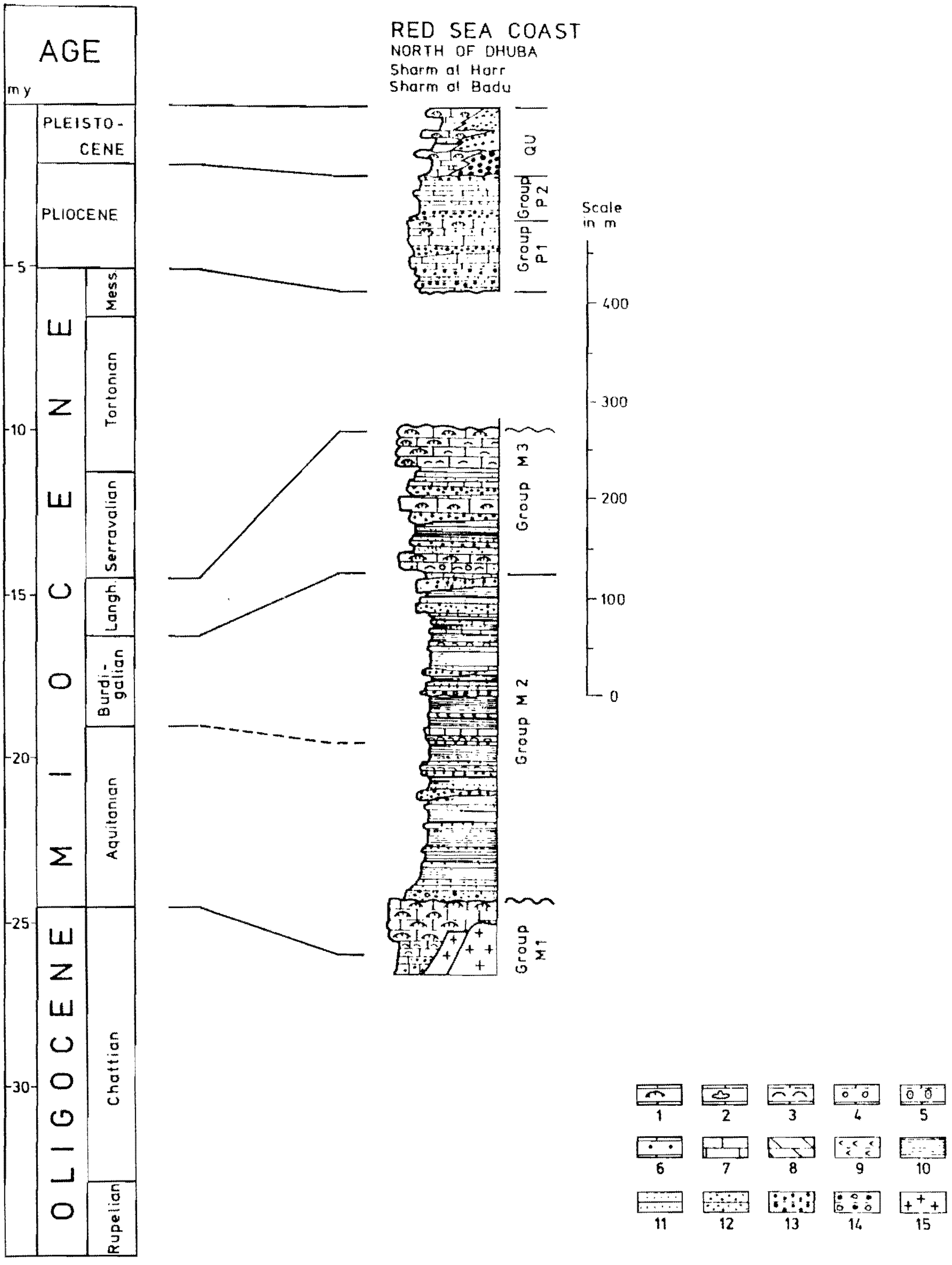

FIG. 5. Generalized stratigraphic sequence of the marginal synrift sediments along the northern Red Sea coast, mainly according to Kern (1985).
Legend :
1 = corals and algae, frequent reefs, 2 = echinoids, 3 = mollusks, mostly oysters, 4 = oolitic carbonates, 5 = large foraminifera, 6 = foraminifera, 7 = limestone, 8 = dolomite, 9 = gypsum, 10 = marls and clayey silts, 11 = fine sandstone, 12 = medium-grained sandstone, 13 = coarse sandstone, 14 = conglomerate with cherts (open circles) and crystalline basement fragments (filled circles), 15 = crystalline basement.

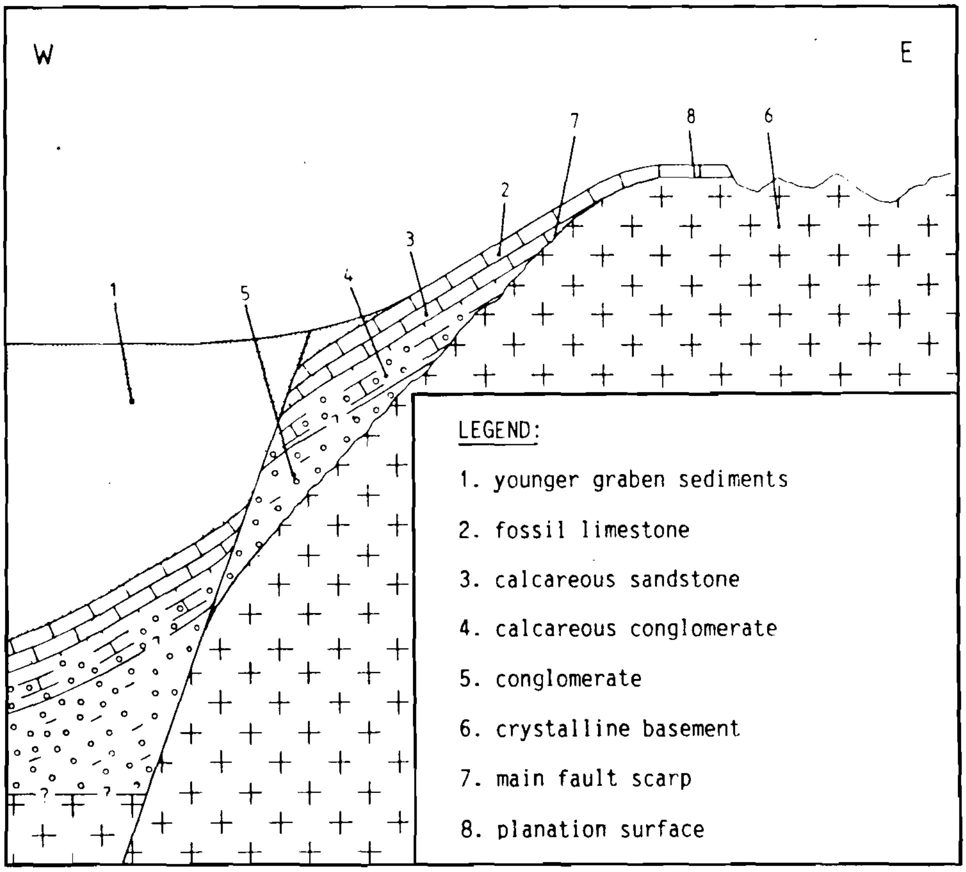

FIG. 6. Schematic profile of the accretion of Lower Miocene reef limestones on the Precambrian conserving the fault plane and old peneplain. The limestones are now mostly dolomitized and frequently include some hydrothermal mineralization.

glomerate can be found below, belonging probably to an older clastic group, as it can be found further to the south at Jabal Dhaylan (Vazquez-Lopez 1981). Foraminifera assemblages from the limestones north of Dhuba, including *Amphistegina oucklandia* and *Gypsina vesicularis* var. *discus*, belong to the Burdigalian. An Aquitanian to Burdigalian age has been suggested for the entire group.

Group M2

The unconformable clastic sequence (cp. Fig. 5) consists of yellowish to reddish-brown psammitic sediments of low lithification. In the lower part, after a basal coarse sandstone sequence, a thick interbedding of clayey siltstones and thinly layered sandstone beds have been developled. The upper part shows again an increase of the coarse-grained sediments such as sandstone and conglomerate. Intercalations of Sabkha sediments, limestones and oyster beds indicate an increasing marine influence. The total thickness may range to more than 300 m. Locally, at the mouth of old drainage systems, the whole sequence is composed only of conglomerates. Late (?) Burdigalian age has to be assumed from the underlying and overlying sediments.

Group M3

Mixed siliclastic and carbonate series represent this littoral sequence, which shows at first transgressive character. Calcareous sand and calcarenite with echinoids and molluscus, as well as reef limestone are the main components. Thick conglomerate layers occur locally in front of the rift escarpment. In the upper part, regressive phase is indicated by gypsum layers. They are generally eroded in the north of Dhuba, but show a wider distribution southward. The regressive phase led to withdrawal of the sea from at least the marginal graben zone, causing there a subsequent long phase of erosion. By some findings of *Neoalveolina melo* the early Langhian age is suggested.

Group P1 and P2

The sediments of groups P1 and P2 overlie the partly eroded and block-faulted older groups with an angular unconformity. In their composition they already reflect the environmental conditions of today's coastal strip. Calcareous sediments deposited in littoral and near shore environment prevail in areas near the coast, while back to the hinterland lagoonal facies interlocks with continental sediments. Coarse clastics are important only in front of river mouths.

The generalized sequence of about 180 m is subdivided into the lower echinoid calcarenites (group P1) which laterally change into reefs and local intercalations of conglomerate. The upper group P2 shows an increasing share of interbedded fluviatile to littoral sandstone and conglomerates. Though there are rich layers of macrofossils (echinoids and shells, corals and algae) and benthonic microfauna, there is a lack of planktonic fauna for an exact stratigraphic determination. Due to the indopacific fauna elements a Middle (?) to Late Pliocene age is assumed. Foraminifera from one sample of the echinoid sands (P1) collected near Dhuba, indicate even a late Pliocene age, so that Early Pleistocene could be possible for the uppermost part.

Group Q (Quaternary)

A sequence of marine and terrestrial terraces unconformably overlie Pliocene sediments. Caused mainly by eustatic sea level changes and only subordinately by vertical tectonics, three main terrace systems can be recognized (Jado and Zötl 1984). The oldest terrace system, whose reef platform is situated 30-50 m above sea level is associated with extremely coarse, boulder-like, alluvial fans. The second system, with elevations of 15-25 m is often subdivided by steps situated at 15-18 m, and by another at 20-22 m. The terraces above 20 m are frequently tilted slightly, while the younger terraces are generally not tilted, though they might be affected by faults.

The third terrace occurs between 6 and 10 m and represents the last interglacial high sea level dated by uranium/thorium at about 95,000 to 120,000 years (determination by Mangini, University of Heiderlberg). A small terrace or wave cut notch located 2 m above the present sea level is related to the Holocene transgression. The terrace levels are relatively constant along the NW Arabian Red Sea coast confirming minor vertical displacement during the Quaternary.

The recent sedimentation along the Red Sea coast is characterized by alluvial fans relating to the mountainous hinterland and sloping gently towards the sea. Partly reworked by wadi systems, they grade into coastal sabkhas developed as wide littoral plains or into reef assemblages of the narrow and steeper parts of the coast.

4. Southern Red Sea Coast

Contrary to the northernmost Red Sea coast, in the southern section, the synrift sediments are generally more monotonous with prevailing continental sequences. Although it is a coastal plain, the Tihamat Asir (Fig. 7) on average reaches a width of more than 40 km, where exposures of the older sediments are rare. Pleistocene and recent alluvial fans, sloping gently from the basement margin to the sea, cover most of the plain. For the Jizan area, a more or less continuous subsidence during the Quaternary, causing accumulation of sediments up to a thickness of more than one thousand meters could be proved by geophysical investigations and drilling (Gillman 1968 and Müller 1984). The young tectonic activity is emphasized by intensive magmatism, which is documented by numerous volcanic zones as well as in the extended lava field of the Harrat al Birk (Fig. 7).

The older sediments are exposed more in the marginal blocks, which were less affected by the subsidence of the basin. Normally, synrift sediments transgress over the crystalline basement showing thick lateritic weathering (Pallister 1987). From Ad Darb to the Yemen border, a small zone of Mesozoic sediments is preserved in front of the escarpment. Old Tertiary prerift sequences are restricted to the vicinity of Jeddah (Usfan and Shumaysi formations). It is interesting to note that the Shumaysi Formation at its top is intercalated with intermediate to acid volcanic tuffs. These volcanic layers can be correlated to similar deposits in southwestern Arabia (Liyyah Formation). The Shumaysi Formation is overlain by a suite of Late Oligocene to Early Miocene basalt flows (Schmidt and Hadley 1984). One of these flows yielded the age of 20.1 Ma (Coleman *et al.* 1979).

The oldest synrift-deposits of southwestern Arabia are represented by the Jizan Group rocks (Schmidt *et al.* 1982), which are divided into five formations (Fig. 8).

Conglomerate and sandstone (Ayyanah Formation) rest unconformably on saprolitic to lateritic weathered Proterozoic basement rocks (Schmidt *et al.* 1982). The Ad Darb Formation (basaltic volcanics and volcanoclastics) contains the oldest rift related magmatic rocks in the Jizan coastal plain. These two basal units are overlain by a widespread association of dacitic to rhyolitic lavas and ignimbrites (Liyyah Formation) intercalated with finely laminated non-marine sediments (Baid Formation, Fig. 8).

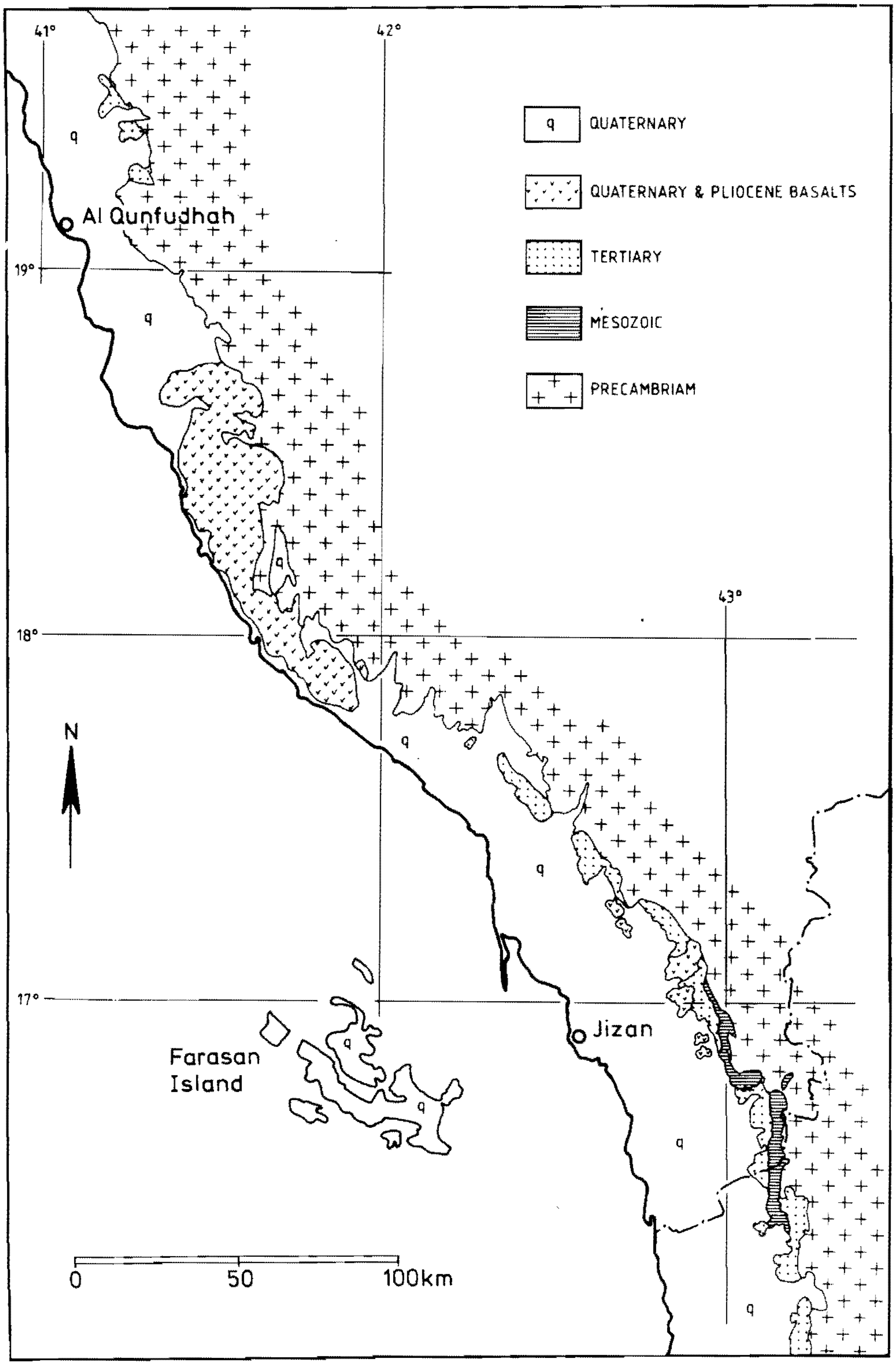

FIG. 7. Geologic sketch map of the southwestern Arabian Red Sea margin with the coastal plain (Tihamat Asir) and with the wide basalt area of Harrat al Birk in the central part.

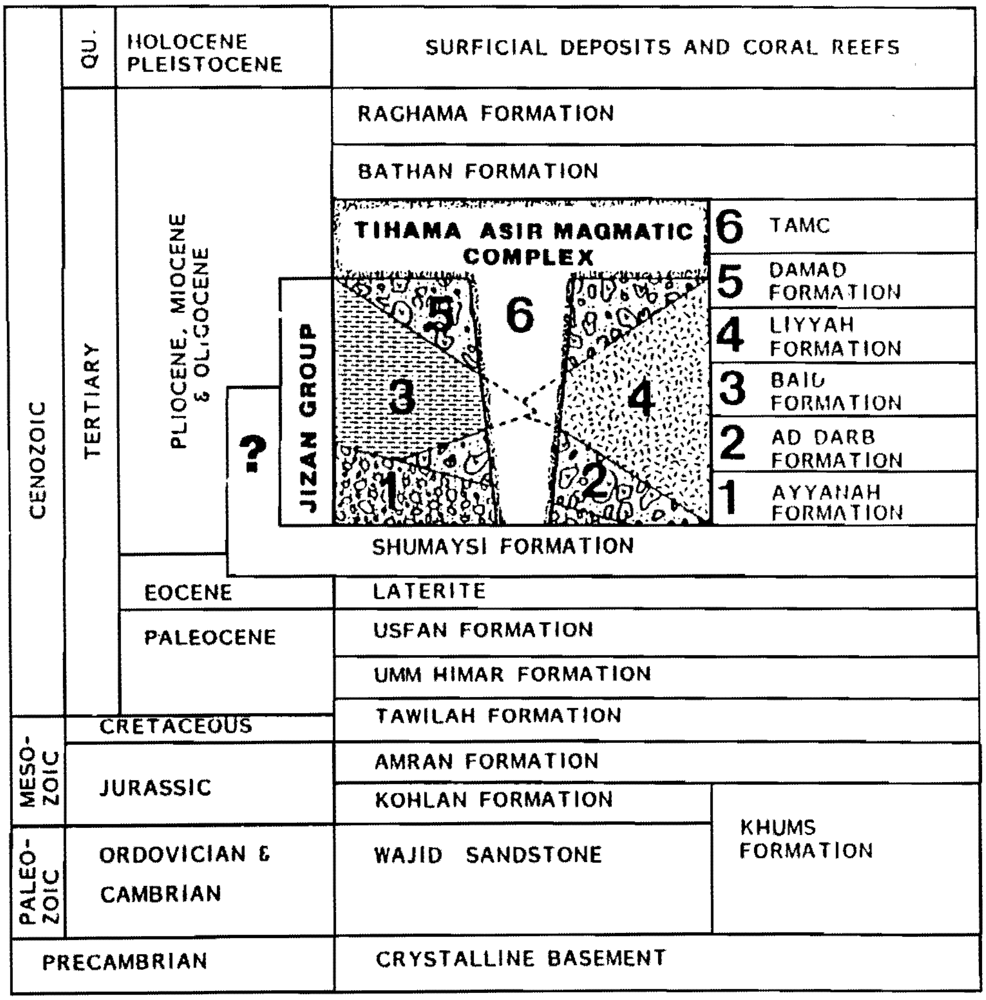

FIG. 8. Generalized stratigraphic succession of Southwest Arabia along the Red Sea coast (according to Schmidt *et al.* 1982, and Voggenreiter *et al.* 1988).

The Baid rocks (Gillman 1968) contain a large amount of volcanic material derived from the explosive activity of the Liyyah volcanism. The Baid Formation was probably deposited in lakes between the eruptive centers. The environment of Liyyah and Baid depositions, therefore, resembled that of the present day East African Rift valley. Although fossils are not uncommon in Baid rocks (Madden and Whitemore 1983, and Schmidt and Hadley 1984) age constraints are poor. Based on the fossil assemblage, Schmidt and Hadley (1984) suggest the age of 30-20 Ma for the Baid Formation.

Our investigation (Roscher 1989, and Roscher and Miklich 1990) have shown that the mostly laminated sediments consists of volcanic tuffs and inorganic precipitated silica. The percentage of terrigeneous silt is small. Today , the sediments form kryptocrystalline cherts with grain sizes less than 1μ; the SiO_2-content is higher than 80%. The occurrence of chert nodules, evaporitic pseudomorphoses and authigenic zeolites confirm an alkalic sweet water environment of the type of Lake Magadi in East Africa. The lowering of the pH values in the alkalic brine during summer rain periods causes a seasonal rhythmic precipitation of the silica. The cyclic repeating of thin seasonal layers every eleven years documents probably the sunspots cycle (Fig. 9).

In certain layers of the Baid Formation, a rich fish fauna can be found (Roscher and Miklich 1990). The assemblage without real perches (genus *Barbus*), which appeared first time in Miocene, but with *Arabocharax n. gen.* and *Astatotilapia* shows remarkable similiarity with an Oligocene fauna from Somalia. Together with additional radiometric data (see below)

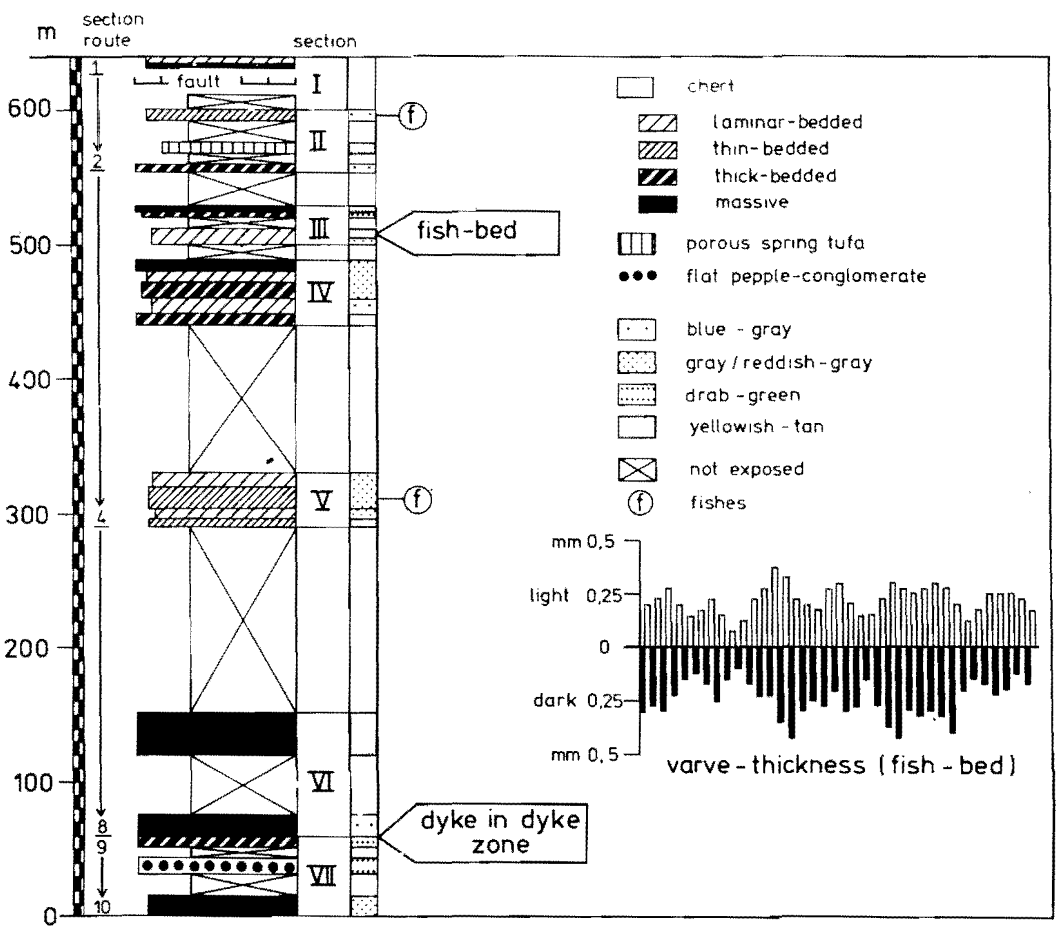

FIG. 9. Schematic sequence of the Baid Formation south of Ad Darb. The measured 3.5 km long section is located in an east west orientated small wadi 2 km south of the village of Ad Darb. Number I to VII represent the exposed parts of the profile from west to east. The diagram on the right site shows the varve bedding of the fish bed and the layer thickness depending on an eleven year cycle.

of syn- and post-sedimentary magmatites of 32 to 27 Ma (Early and Middle Chattian, Late Oligocene) is assumed.

All the rocks described above for southwest Arabia are known to have been intruded by the Late Oligocene to Early Miocene Tihamat Asir Magmatic Complex (TAMC). The complex (Coleman *et al.* 1972, 1977, and 1979) comprises a basic dike swarm, several gabbro bodies and granophyres. Dikes in Proterozoic rocks, at the base of the escarpment, are scarce; they become increasingly abundant to the west culminating in a zone of dike-in-dike intrusion, where almost no screens of country rocks remained (Bohannon 1986). Zones of dike-in-dike intrusions are arranged en-echelon over the coastal plain. Based on field observations, we were able to distinguish between several generations of dike intrusion. The majority of dikes trend between N and N 140° E directions. Dikes, which are striking to the northwest, are, in general, younger than north trending dikes. Geochemical observations (Coleman *et al.* 1977, Bohannon 1986, and Henjes-Kunst and Voggenreiter 1989) revealed the tholeiitic nature of the dike swarm. Age determinations of different dike samples (Henjes-Kunst and Voggenreiter 1989) yielded ages between 26 and 18 Ma and, thus, are consistent with recently published ages for dikes in the adjacent Yemen Arab Republic (Capaldi *et al.* 1987).

North to the Harrat Al Birk volcanic field, the Jizan Group rocks are overlain by coarse polymict conglomerates (Bathan Formation-Schmidt *et al.* 1982). This formation reflects an enhanced uplift of the eastern

Red Sea graben shoulder. Correlations between the sequence encountered in the deep well Mansiyah-1 north of Jizan and the formations described above are not unambiguous (Gillman 1968, Ahmed 1972 , and Fairer 1983). The Baid Formation may in part be a lateral equivalent of the "infra evaporitic" sequence and the "continental series" (Miocene (?)-Pliocene) may correlate with the Bathan Formation. The intercalated thick evaporite series, outcropping in the salt dome of Jizan and in those of Farasan Islands may belong to Middle and Late (?) Miocene. Alkali-olivine basalts and unconsolidated, mainly clastic sedimants of Quaternary are the youngest deposits in the Jizan coastal plain (Dabbagh *et al.* 1984).

Conclusion

The study of the sedimentary sequence along the Arabian Red Sea coast by the joint research group of the King Fahd University of Petroleum and Minerals, Dhahran, and the University of Karlsruhe, Germany, yielded new results, which improved the understanding of the development of that tectonic basin :

1. The dating of marine Oligocene sediments from Midyan could prove, for the first time, the early existence of this basin. Coeval clastic sequences from the south indicate the uniform beginning of the rift development over the whole length of the Red Sea and the Gulf of Suez. The first break up of the rift has now to be assumed as Late Eocene or Early Oligocene.

2. Up to the end of Early Miocene, the rift basin showed a more or less steady development with increasing subsidence and asymmetric widening of the basin, especially to the west. The worldwide high sea level has led to a pronounced cliff line marked by fringing reefs. Used as a topographic reference level, it confirms relatively small subsequent vertical displacement of the northern and middle Arabian Red Sea margins.

3. The initiation of the evaporitic sequence is mainly due to eustatic lowering of the sea level, which led to the separation from the Tethys and formed a closed basin in the Red Sea trough. While in the peripherally higher parts, the sedimentation is restricted to the Middle Miocene and later on was followed by an erosional break; the evaporites including thick salts were deposited in the deeper central basin up to the Pliocene. The lack of coarser clastic material in the peripheral parts indicate a phase of tectonic quiescence at least concerning the vertical uplift of the rift shoulders.

4. The Pliocene sedimentation was stimulated by reactivated tectonism, which led to the intrusion of the sea from the Indian Ocean and terminated the phase of erosion along the Arabian Red Sea margin. At Midyan preceding (Upper Miocene) and synsedimentary continuing deformation of transgressional type indicates the beginning of the sinistral shear movement along the Aqaba-Levant-system, whereby a new plate boundary was created.

5. The further passive opening of the Red Sea by the drift of the Arabian Plate reactivated block faulting along the whole Arabian Red Sea coast. The Pliocene and Pleistocene sedimentary sequence shows several angular disconformities. A new incipient vertical tectonic of the South Arabian rift margin can be deduced from thick clastic sequences in the Tihamat Asir, which were accompanied by strong volcanic activity.

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تطــور الترسيب على الساحــل السعــودي للبحر الأحمر

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المستخلص . يمكن أن تقسم الرسوبيات على الساحل السعودي للبحر الأحمر والمتزامنة مع انشقاقه إلى ترسبات قارية في القـاعـدة يليها ترسبات مصاحبة لغمر مياه البحر ، فترسبات ملحة تبخرية ثم ترسبات فتاتية جيرية مختلطة . ويدل تغيير هذه السحنات على الخطوات المميزة في تطوير القوى الحركية الأرضية . لقد أجريت دراسات مفصلة على مناطق شمال البحر الأحمر وجيزان ، وكان للعثور على متحجرات جديدة واستنتاج الأعمار المطلقة الفضل في تطوير فهمنا للتسلسل الزمني للأحداث الجيولوجية .

ونجد أن ترسبات أزمان الأوليجوسين والميوسين المتزامنة مع انشقاق البحر قد حفظت وظهرت في عدة أماكن . ويمكننا أن نميِّز أربع وحدات (طبقات) من هذه الترسبات . ففي منطقة مدين ، نجد أن هذه الوحدات تبدأ من الأسفل بطبقات فتاتية حمراء . كما تمثل هذه الوحدات عموما سحنات ترسيب بحرية عميقة تكونت في الجزء المحوري من الخسيف . وتتراوح أعمار هذه الترسبات ما بين الروبيليان إلى السيرافاليان .

ونجد أن أقدم الترسبات المتزامنة مع الانشقاق في جنوب غرب الجزيرة العربية يتمثل في تزامل ترسبات غير بحرية (تكوين البيض) مع الترسبات البركانية والبركانية الفتاتية من مجموعة جيزان . ويمكننا من خلال فحص مجموعة المتحجرات الحيوانية في تكوين البيض وبيان النظائر في الصخور النارية المتزامنة مع - أو الأصغر من - الرسوبية تحديد عمر الـ (أوليجوسين - من ٢٧ إلى ٣٢ مليون سنة) لصخور البيض .

ومن هذا يتبين لنا أن عمر هذا التكوين يتكافأ مع عمر الطبقات البحرية في شمال البحر الأحمر ويبرهن على أن الانشقاق المبدئي قد حدث على طول حوض البحر الأحمر في ذلك الوقت .