38

N. Jb. Geol. Paläont. Abh.	161	3	271—308	Stuttgart, Mai 1981

New Stratigraphical and Structural Evidence for lateral Dislocation in the Jordan Rift Valley connected with a Description of the Jurassic Rock Column in Jordan

By

Klaus Bandel, Erlangen

With 12 figures in the text

BANDEL, K. (1981): New Stratigraphical and Structural Evidence for lateral Dislocation in the Jordan Rift Valley connected with a Description of the Jurassic Rock Column in Jordan. — N. Jb. Geol. Paläont. Abh., **161**: 271—308; Stuttgart.

Abstract: The Jurassic rock column of Jordan is about 450 m thick. It is split into 6 Formations, the Deir Alla, the Zarqa, the Dhahab, the Um Maghara, the Arda, and the Muaddi Formations. The depositional environment was that of a coast with continuously shifting shoreline after a basal transgression over terrestrial deposits. The two lower Liassic formations are mainly sandy, the Dogger starts with a limestone formation followed by a mainly sandy formation. In the upper two formations sand decreases in favour of clay, silt and limestone, and deposition was continuous into the lower Malm. The depositional environment of the Jurassic sediments is compared with that of the Upper Permian-Triassic sequence, based on the study of BANDEL & KHOURY (1981). Step-faulting and erosion of the Trias-Jura rock column during the terrestrial phase between Upper Jurassic and Lower Cretaceous is shown and their magnitude is demonstrated. Structural, stratigraphical, lithological and magmatic features of the Mesozoic rocks to the East of the Rift are related to those known from the West of the Jordan Rift. Mesozoic features are correlated to the margin of the continent and features connected to the rift make their appearence only in Tertiary time. Now a sinistral movement of over 100 km is documented which displaced the Arabian Penninsula from the Sinai-Palestine area.

Key words: Geological section Jurassic, litoral sedimentation, sandstone, limestone, erosion surface, coast, isoplethe map, rifting, strike-slip fault, Tertiary; Jordan.

Zusammenfassung: Die Stratigraphie der etwa 450 m mächtigen Juraabfolge Jordaniens wird dargelegt und die Schichtenfolge in 6 Formationen untergliedert. Die Ablagerung der Gesteine erfolgte im Küstenbereich. Auf die terrestrische Basis der Deir-Alla-Formation folgen Sand- und Kalksteine. Die Zarqa-Formation ist vorwiegend sandig und die Küste liegt im Aufschlußbereich. Auf die liassischen unteren Formationen folgt die kalkige marine Dhahab-Formation des Doggers. In der Um-Maghara-Formation rückt der Strand wieder in den Ablagerungsraum und verbleibt hier auch während der Zeit der Arda-und-Muaddi-Formationen. Der

0077-7749/81/0161-0271 $ 9.50

Sandgehalt der Gesteine nimmt innerhalb dieser drei Formationen nach oben hin ab, und die Ablagerungsgeschichte endet im Malm. Sedimentationsverhältnisse der Juraablagerungen werden mit solchen der Triasablagerungen verglichen, basierend auf der Studie von BANDEL & KHOURY (1981). Die tektonische Zerlegung und die Abtragung der Trias—Jura-Abfolge während der terrestrischen Phase zwischen Oberjura und Unterkreide werden aufgezeigt und in ihren Größenmaßstäben erfaßt. Fazielle, magmatische und strukturelle Daten der östlichen Seite des Jordangrabens werden mit denen, die von der anderen Seite des Grabens beschrieben sind, in Verbindung gebracht. Es wird aufgezeigt, daß die mesozoischen Eigenheiten der Gesteinsabfolge durch den Rand des Kontinents bestimmt werden und erst während des Tertiärs Merkmale in Erscheinung treten, die mit dem Graben korreliert sind. Nun erfolgte eine großräumige Lateralbewegung von über 100 km, nach der die Arabische Halbinsel gegen den Bereich Sinai—Palästina nach Norden verlegt erscheint.

Introduction

During the two years (1977—1979) that the author of this study was lecturing at the University of Jordan, many discussions and colloquia carried out in the Department of Geology and Mineralogy were centred around the problem of the origin of the rift valley. Is the Jordan-Dead Sea-Wadi Araba depression a graben structure mainly with vertical displacements?

Can a lateral displacement be expected along this geosuture of the Transjordanian Block against the Palestinian Block? If so, how much displacement?

Vertical movements mainly, perhaps connected to lateral displacement of 25 to 35 km at the most, are expected by BENDER (1968) and WIESEMANN (1969), in accordance with the ideas put foreward by PICARD (1943). Prof. BENDER visiting the Department of Geology and Mineralogy in 1978 presented his data and found wide support, especially among those Jordanian collegues who were and are connected to the NRA (Geological Survey of Jordan). In contrast, the recent publications on Triassic and Jurassic stratigraphy in Israel and the Sinai (FREUND 1970; DRUCKMANN 1974, 1977; GOLDBERG & FRIEDMAN 1974), the ideas put foreward by QUENNELL (1959) and BURDON (1959) that a sinistral movement of more than 100 km QUENNELL and 107 km (BURDON) were strongly supported. Corrections based on this assumption were also made in paleogeographic reconstructions of Triassic, Jurassic and Cretaceous strata. Recently SALAMEH (1980) came to similar results of a shift of 105 to 110 km when he correlated the structural highs of Suweilih, Amman, Es Salt-Ajlun as extensions of the Bayir Uplift with the Hebron-Ramallah structural highs on the west side of the rift valley.

The purpose of this study, thus, is to bring together as many data as possible that can shed light on this problem and to suggest an acceptable solution. To achieve this aim a description of the Jurassic rock column, as it is exposed in the area between Es Salt and the lower Wadi Zarqa and penetrated by the Ramtha 1 test well near Mafraq in North Jordan, is included and data from a recent description of the Triassic rock column by BANDEL & KHOURY are evaluated.

In the course of this study the author profited very much from discussions with his Jordanian and German colleagues in Amman. The problem dealt with here became obvious and more important due to the lectures presented by Prof. F. BENDER. Thanks are due to Prof. BENDER for stimulating research in this direction. Discussion with Dr. ELIAS SALAMEH throughout the planning and preparation of this study as well as his critical reading of the manuscript and his aid in every way is gratefully acknowledged. I am grateful to Prof. Dr. A. SIEHL and Mrs. HILARY PEKAREK for checking the scientific content of the text and for correcting the English.

The study was carried out within the framework of the University-Partnership Amman—Braunschweig and only possible with the help of the University of Jordan in Amman and the "Gesellschaft für technische Zusammenarbeit" in Eschborn.

Jurassic rock column in Jordan

Historical background

In the most recent account of Jurassic sediments in Jordan PARKER (1970) had applied the term Azab Formations to rocks of Jurassic age. This author stated that the Jurassic strata crop out in the side wadis of the Jordan valley in a region extending north-southwards for about 20 km. But he then concluded that the most southerly exposure is near Arda. This reflects rather well the incomplete picture of the Jurassic rock sequence in Jordan including the locality of the outcrops, even though the Geological Map of the Haschemite Kingdom of Jordan (1:250 000, sheet Amman, 1969) demonstrates clearly that Jurassic strata are also exposed south of Arda.

Even though Jurassic fossils from the Zarqa River have been described as early as 1859 by WETZSTEIN, the first authentic reports of Jurassic rocks in the Jordan Valley region were presented by COX (1925). Brachiopods from the Wadi Zarqa area were described by MUIR-WOOD (1925). AVNIMELECH (1945) noted that COX's designation of the said Jurassic outcrops as situated in the Jordan Valley is not accurate, because the outcrops actually are situated in the Wadi Zarqa. AVNIMELECH reports another Jurassic fauna which was collected south of Arda, perhaps in the Wadi Um Butma area.

PARKER (1970) relied on WETZEL & MORTON's (1959) measurements regarding the thickness of the Jurassic rock column. These authors had described a sequence of 220 m from the lower Wadi Zarqa near the Wadi Huni as the Jurassic rock column. They mentioned 75 m of dolomitic limestone with some marl and clay, overlain by 65 m of sandstone; shaly limestone and marl, and topped by 80 m of limestone, sandy limestone and sandstone. BENDER (1968, fig. 72) modified WETZEL & MORTON's data and gave a total thickness of about 310 m instead. The base of the Jurassic, according to BENDER, was preliminaryly placed where

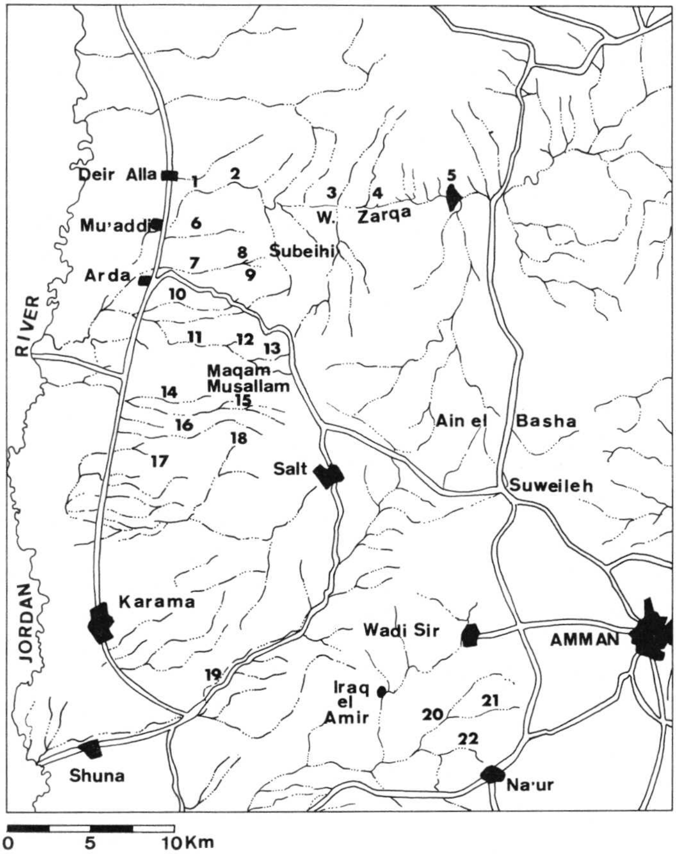


Fig. 1. Location map.
Location Numbers: 1 = Lower Wadi Zarqa; 2 = Wadi Tahuna; 3 = Wadi Abu er Ruweis; 4 = Wadi Huni; 5 = King Talal Reservoir and Dam; 6 = Wadi Shaban; 7 = Wadi Bin Faas; 8 = Wadi Ramad; 9 = Ain Khuneizir; 10 = Wadi Quseib; 11 = Wadi Nimr; 12 = Wadi Harratha; 13 = Urqub Um Maghara; 14 = Wadi Humra; 15 = Wadi Dafali; 16 = Wadi Um Butma; 17 = Wadi Farush; 18 = Wadi Mintar; 19 =Wadi Shu'eib; 20 = Wadi es Salt; 21 = Wadi es Shita; 22 = Wadi Na'ur.

50—70 m thick, massive limestones follow above predominantly clastic rocks of the "Triassic". In his account BENDER evaluated the unpublished report of VAN DEN BOOM & LAHLOUB (1962). He expressed the opinion, that the sediments of the Jurassic rock column only 10 km to the east of Wadi Huni in the area of the King Talal Reservoir contain fewer sandy intercalations and thus measure about 80 m less in thickness. It was interpreted that not only towards the east but also towards the south Jurassic sediments decrease in thickness. At the Arda road a 75 m thick massive limestone at the base was supposed to be overlain by 70 m of plant bearing sandstone and 70 m of fossil-rich limestone, marl and shale. WIESEMANN (1969, Fig. 53) thus expected the presence of only a 0—250 m thick sequence of Jurassic rocks in northern Jordan. The placement of the Jurassic-Triassic border by previous author's about 90 m above its actual place in the Wadi Huni area, still accepted by PARKER (1970), placed DRUCKMAN (1977) into considerable difficulties when correlating lower Jurassic beds on both sides of the rift. Nevertheless GOLDBERG & FRIEDMAN (1974), without mentioning a source for their data, had known about the lowermost Jurassic clay beds with their characteristic pisolits in the Wadi Zarqa area. These authors thought, that the pisolite clays form 25 m thick beds here and their source failed to inform them about the 20 m of limestone that follow just above these basal beds.

Description of the rock column

The sequence of exposed Jurassic rocks is 430—450 m thick and crops out between Wadi Samra, just west of Es Salt, and Wadi Zarqa, just east of Deir Alla. The Jurassic sequence penetrated by the Ramtha 1 test well near Mafraq in North Jordan measures 370 m in thickness. The outcropping sequence as well as that penetrated by the well is differenciated into 6 formations, the Deir Alla, Zarqa, Dhahab, Um Maghara, Arda, and Muaddi Formations.

Deir Alla Formation

The base of the Jurassic sequence in Jordan is exposed near the confluence of the Wadi Huni and the lower Wadi Zerka about 10 km east from the town Deir Alla in the Jordan Valley (Fig. 2). From Tell ed Dhahab to just north of Wadi Huni rocks belonging into the Deir Alla Formation are exposed, further to the east and west they disappear below level of Wadi Zerqa. The formation is 30 to 35 m thick and is again exposed in the base of Wadi en Nimr about 9 km to the south of Deir Alla (Fig. 3). Two members are differenciated, the Huni and the Nimr Members.

Huni Member

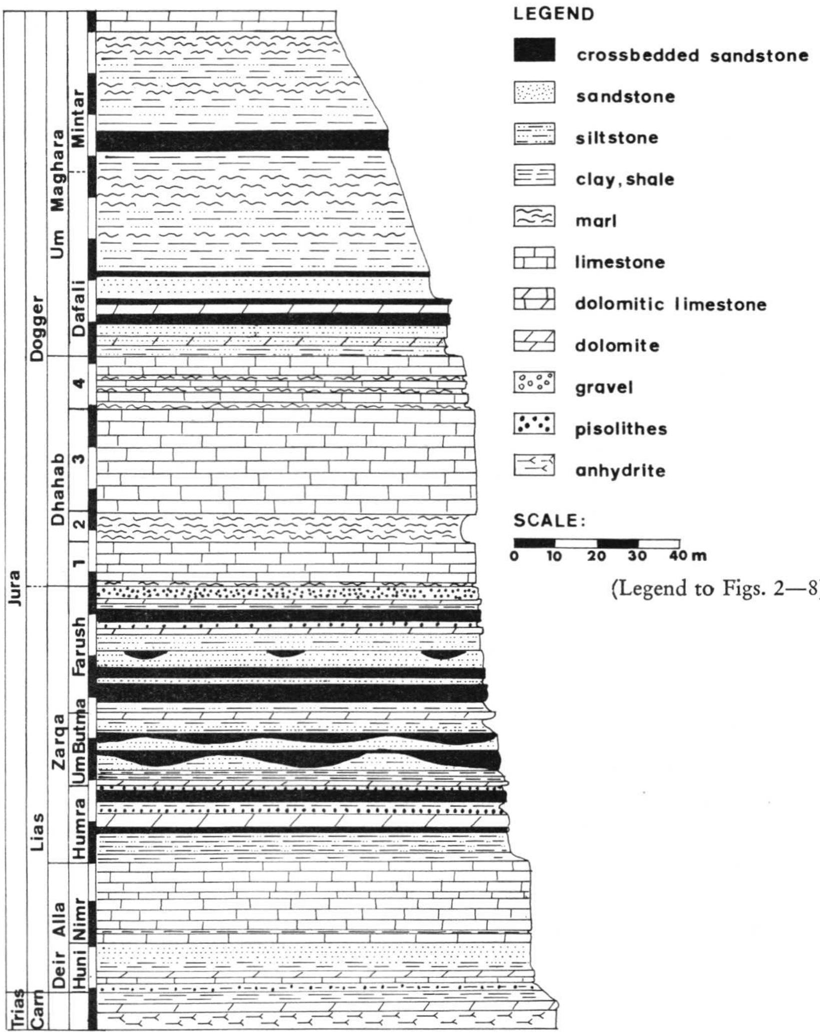
Rocks belonging to the Huni Member are only exposed down to their base just upstream from the confluence of Wadi Huni into Wadi Zarqa, just opposite the point where the road reaches the valley base (Fig. 2). Here clay overlies Triassic rocks of the Abu Ruweis Formation (BANDEL & KHOURY 1981). This formation consists of gypsum, clay-shale, dolomite and dolomitic limestone. The lower portion of the Huni Member is composed of brown, gray and conspicuously purple clay, often with hematitic pisolites in abundance. In some beds pisolites are accumulated and have been reworked from their original source into conglomeratic layers. In other beds pisolites are distributed in "at random" pattern, perhaps still in autochthonous orientation of formation within the soil. The pisolite bearing kaolinitic clays are variable in thickness from 0 to a few meters within a short distance. They are overlain by fossiliferous beds of thin bedded limestone with a fauna reflecting both fully marine conditions and Jurassic age of these beds. The thin shale-limestone succession in turn is overlain by bioturbated sandstone.

At Wadi en Nimr, (Fig. 3), below the base of this sandstone bed the clay is penetrated by fossil plant roots in original position of growth. This demonstrates that terrestrial conditions were established here after the first transgression of the Jurassic sea, while 9 km to the North marine conditions prevailed at the same time. This is also reflected in the structure and composition of the sandstone, which at Tell ed Dhahab in the Wadi Zarqa is fine grained and bioturbated while it shows unidirectional crossbedding and coarse grain size at Wadi en Nimr. In the subsurface of North Jordan, near Mafraq (Fig. 4), the Huni Member is 15 m thick and contains no sandy intercalations. Here the pisolitic clay and shales are overlain by ferruginous oolite and limestone.

Nimr Member

The 17—18 m thick sequence of the Nimr Member is well exposed in its southernmost outcrop in Wadi en Nimr (Fig. 3), from which it received its name. Just east of Tell ed Dhahab and just east of Wadi Huni the limestone sequence is also well exposed (Fig. 2). In the type section at Wadi en Nimr the Nimr Member is composed of a succession of limestone, dolomitic limestone, and marl. Especially in the lower portion of the member, sandy intercalations are included. These sands are quite coarse and contain conglomeratic layers with quartz gravel of up to 7 mm in diameter. The presence of sand and gravel reflects the closeness of the shore and the influence of rivers discharging into the sea nearby. The sands and gravels are totally churned up and have become mixed with marl and limestone. The limestones, in part, are fine-grained and also totally mixed up with a conspicuous crab burrow system preserved as last formed bioturbational structure in these sediments. In part limestones are oncolitic and contain a rich marine fauna.

At the Wadi Zarqa (Fig. 2) limestones of Nimr Member contain no sandy interlayers and in their bulk consist mainly of fine-grained limestone demonstrating a network of crab tunnel structures throughout as well as



(Legend to Figs. 2—8)

Fig. 2. Scetch of the rock column of Wadi Huni — Tell ed Dhahab section.

remains of marine organisms distributed at random. In the subsurface of North Jordan (Fig. 4) the Nimr Member is 21 m thick and consists of a basal limestone with ferruginous oolites overlain by marly limestone.

Zarqa Formation

The rocks of the Zarqa Formation are exposed extensively between Tell ed Dhahab and a few km downstream from the dam of the King Talal Reservoir in Wadi Zarqa. In full thickness they are also exposed at Wadi en Nimr (Fig. 3) and with the upper two members in Wadi Um Butma (Fig. 5) (about 14 km south of Deir Alla). Three members are differentiated in the 35—75 m thick Zarqa Formation, Humra, Um Butma, and Farush Member.

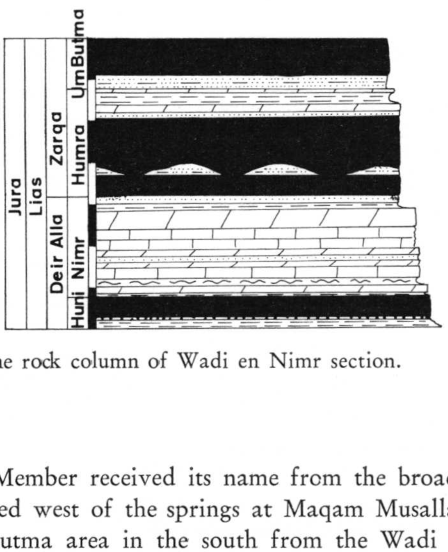


Fig. 3. Scetch of the rock column of Wadi en Nimr section.

Humra Member

The Humra Member received its name from the broad mountain ridge El Humra situated west of the springs at Maqam Musallam that separates the Wadi Um Butma area in the south from the Wadi en Nimr area in the north. In the type section of the Humra Member in Wadi en Nimr (Fig. 3), the rock sequence measures almost 25 m in thickness. It is composed of 3 massive crossbedded sandstone units mainly separated from each other by channel and flaser sands. The member is topped with bioturbated sandstone overlain by a dolomite unit.

In Wadi Um Butma only the uppermost few meters of the Humra Member are exposed consisting of silt and clay beds, bioturbated sandstone and dolomite. The first of these preserves a marine trace fossil fauna, the second holds some bivalve shells. In Wadi Zarqa (Fig. 2) the Humra Member measures 18 m in thickness, also with predominance of sandy units and a dolomitic top. The sandstones here are not pure. They show flaser structure mainly and have often been bioturbated. In addition, in the central portion of the Humra Member 3 m of dolomite have taken the place of sandstone and this unit is topped by ferruginous oolite.

In the Wadi en Nimr area deposition is mainly that of a river, and the sea only flooded the area occasionally, inundating it even further to the south at the end of Humra time. During most of this time the shore lay in the north of Wadi en Nimr, but south of Wadi Zarqa. Here sediments show the characteristics of marine deposition in the shallow sea and on intertidal flats. They consist of flaser structure, bioturbation and channels. The supply of sand from the nearby shore varies in consistence from fine sand to gravel. The transgression documented in the deposition of limestone in the central Humra Member present at Wadi Zarqa did not reach far south (9 km), but ended nearby in a sandy intertidal area.

Um Butma Member

In the type section in Wadi Um Butma (Fig. 5), about 5 km west from the beginning of the descent of the road from Suweilih to Arda, the Um Butma Member is 25 m thick. It is composed of a central sandstone unit with a conglomeratic base and 11 m of thickness underlain by flaser sand and strongly bioturbated sand and overlain by a laminated succession of sand, silt and clay. There are no traces of infaunal life in these beds but they contain abundant plant fragments. Only in the upper 2 m of sandy deposits bioturbation returned. Here also calcareous sand was mixed with the quartz sand forming sandstone. During diagenesis dolomitic matrix or sandy dolomite formed.

In Wadi Zarqa (Fig. 2) the Um Butma Member at Tel ed Dhahab measures 15 m in thickness, while just a few kilometers to the east in the area of Wadi Huni it is 24 m thick. This difference is due to the decrease in thickness of two lower sandstone units only. At Tell ed Dhahab 8 m of flaser sand with some small channels cut into them are equivalent deposits to 15 m of pure crossbedded sand of the Wadi Huni area. The upper portion of the Um Butma Member in the Wadi Zarqa area is characterized by flaser sands. It is topped by a sandy dolomite unit or dolomitic sand unit. This unit usually has been bored from above and the holes have been filled with ferruginous oolite and the surface has been encrusted by ferruginous material. The topmost layer often consists of ferruginous oolite.

The shoreline of the Humra transgression that was established in the area of Wadi Um Butma and to the south of it, moved northwards again and fluviatile deposits characterize sediments south and east of the lower Wadi Zarqa area. While in the Wadi Um Butma area fluviatile overbank deposits characterize most of the upper Um Butma Member, at the Zarqa area intertidal conditions have returned throughout characterized by flaser sands and channel fills. The member ends with a transgression during which marine conditions were established as far south as Wadi Um Butma.

Farush Member

The Farush Member has received its name from Wadi el Farush, 1 km south of the Wadi Um Butma. Here, as in the type section at Wadi Um Butma, the 23 m thick Farush Member is exposed (Fig. 5). It consists mainly of sand units which in general show crossbeds with graded bedding. Often quartz conglomerates with pebble sizes up to 7 mm form the coarse base of crossbeds and individual laminae. Only some flaser sands are intercalated with beds showing traces of bioturbation. A silty clay below the uppermost sand unit is laminated and shows no bioturbation.

In Wadi Zarqa area (Fig. 2) the Farush Member measures 24 m at Tell ed Dhahab and 26 m near Wadi Huni. Here sandstone is also the dominant rock type. In the lower part of the member, however, it is coarsely cross

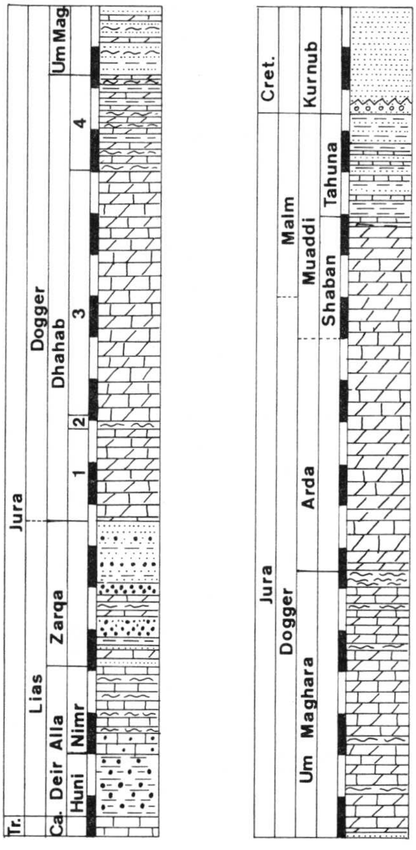


Fig. 4. Jurassic rock column of the Ramtha 1 test well near Mafraq.

bedded, while the bulk of the member shows flaser structure and traces of infaunal life. Commonly ferruginous hardgrounds, dolomitic cement and dolomite units are present, often connected with ferruginous oolites. The Farush Member in the Wadi Huni area ends with an crossbedded and bioturbated ferruginous oolite up to 2 m thick. In its upper portion it contains a rich marine fauna of molluscs, brachiopods and corals.

During Farush time the shore rapidly relocated itself northward after the Um Butma transgression again. At first it lay just north of the Wadi Zarqa area, but soon it established itself again in the area between Wadi Zarqa and Um Butma. It rarely reached as far as Wadi Um Butma. Here deposition mainly of fluviatile sands and a few silty and clay-rich overbank deposits characterize the terrestrial environment. A strong marine transgression marks the end of the Farush Member and of the Zarqa Formation.

The Humra, Um Butma and Farush Members can quite confidently be traced from one outcrop to the next. They compose about 60—75 m mainly of sandstone. In the Ramtha 1 well near Mafraq (Fig. 4) in North Jordan the Zarqa Formation is represented by 35 m of sediment only. The rocks were described as sandstone with calcareous cement, shale, some dolomitic beds and several beds of ferruginous oolites. From this rock description, it is quite evident that the area of deposition of these sediments lay further away from the sand- source but not in an off-shore area.

Dhahab Formation

The Dhahab Formation consists predominantly of limestone beds and has received its name from Tell ed Dhahab in the lower Wadi Zarqa (Fig. 2). Here the formation is well exposed in its full thickness. The Dhahab Formation can be traced from here, its northmost occurrence on the surface, towards the east near the dam site of King Talal Reservoire upstream of the Zarqa river. It is also exposed in its southernmost occurrence in the Wadi Um Butma area (Fig. 5) and between both outcrops again in Wadi en Nimr. Commonly the limestones are totally or partly dolomitized. But just about 1 km to the east of Wadi Huni they are preserved as limestones in their whole thickness and thus the type section was measured here.

The limestone is usually fine grained, totally churned up and shows the characteristic network of non-compacted tunnel systems of crab burrows. Marine fossils are present throughout. In the marly base as well as in marly interbeds they are mainly represented by brachiopods, while the limestones themselves contain a rich fauna and flora consisting of gastropods, bivalves, echinoids, crinoids, brachiopods, corals and calcareous algae. At Wadi Um Butma (Fig. 5) the Dhahab Formation consists of 4 parts. The first part consists of 6—7 m thick dolomitized limestone. The second is made up of marl and clay. The third is composed of 29 m of dolomitized limestone. The fourth consists of 7 m of interbedded marl and limestone which are separated from unit 3 by 1 m of sandy dolomite and dolomitic sandstone. These 43 m of sediments in Wadi Um Butma correspond to 54 m in the Wadi Zarqa area (Fig. 2). The unit 2 is also composed of marl and clay but it has decreased in thickness and the sand bed at the base of unit 4 has disappeared. The Dhahab Formation at Wadi Zarqa consists mainly of bioturbated, fine grained limestones. At the test well near Mafraq (Fig. 4) 84 m of limestone have been penetrated. Here the marly unit 2 has further decreased in thickness now composing a 2 m thick bed only. Thus the decrease in the amount of clay present in the deposits of the Dhahab Formation is clearly correlated with the distance from the shore. All limestones in the subsurface of Ramtha 1 well have diagenetically been transformed into dolomite even including the bedded marl and limestone unit 4.

The units of the Dhahab Formation increase in thickness and in percentage of carbonate towards the north. The small amount of terrigeneous material included in the Dhahab Formation indicates, that the sea had transgressed considerably further to the south as in the Zarqa Formation below and the shore lay quite a bit south of the last outcrops of this formation in the Wadi Um Butma area. Sediments are mainly those of the shallow open marine sea with an abundance of life in the well illuminated bottom sediment.

Um Maghara Formation

The beds of the Um Marhara Formation are well exposed between Wadi es Samra, 6.5 km west of Es Salt and the area around Urqub Um Maghara, a high ridge projecting between Wadi en Nimr and Wadi Qusaib. The Um Maghara Formation thus is exposed from the southmost outcrop of Jurassic rocks in Wadi es Samra to the area of the Zarqa river. Here it is exposed from the Wadi Tahuna area about 5 km east of Deir Alla to the base of the dam of the King Talal Reservoir. The type section lies in the uppermost extensions of Wadi Um Butma (Fig. 5), just uphill from where Wadi ed Dafali joins Wadi Um Butma. Three members have been distinguished, Dafali, Mintar and Ramad Members, composing between 85 and 125 m of sediment.

Dafali Member

The Dafali Member received its name from Wadi ed Dafali joining Wadi Um Butma just upstream of the exposure. The member measures about 35 m in thickness and is mainly composed of sandstone (Fig. 5).

Almost half of these sandstones show large scale crossbeds, are not bioturbated, contain layers with conglomerates of small sized quartz gravels and trunks of drift-wood. A little more than half of the sandstones is impure and shows flaser structure. These flaser sands are weakly to strongly bioturbated. Some thin sandstone beds are intercalated that have a dolomitic matrix and are completely churned up. Such units may be

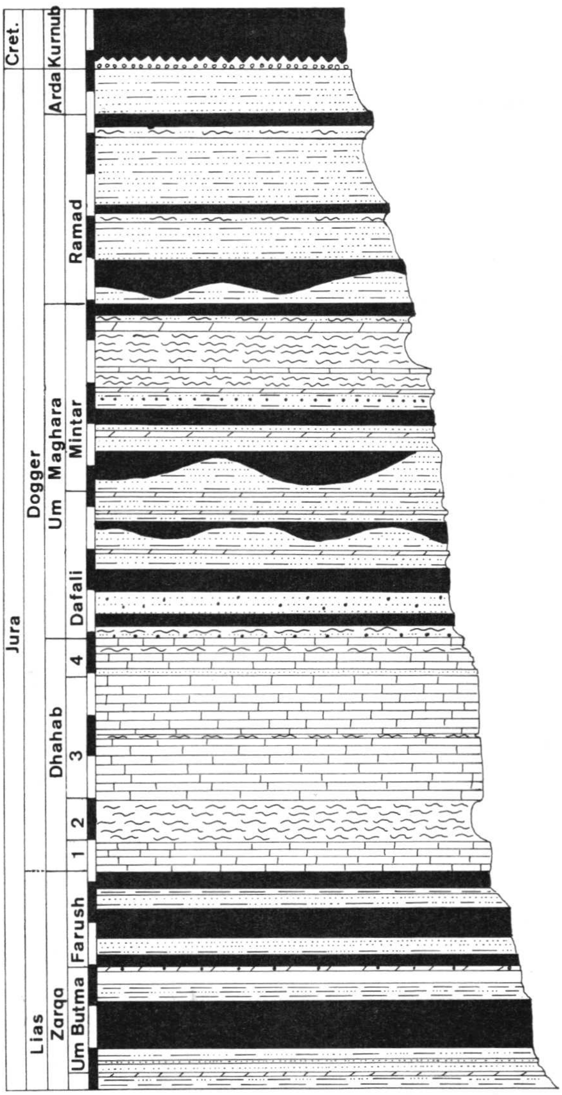


Fig. 5. Scetch of the rock column of Wadi Um Butma.

overlain by ferruginous oolites. The crossbedded sands form thick layers but may also cut wide channels into the flaser beds. The member ends with a bioturbated dolomite unit.

Equivalent beds at the Wadi Huni area (Fig. 2) in the lower Wadi Zarqa are of about the same thickness but much less sandy. Totally bioturbated marly sands and sandy marls at the base are overlain by 2 conspicuous beds of sandy dolomite and sandstone with dolomitic matrix. These alternate with flaser sands and crossbedded sands with abundant trace fossils or total bioturbation. The upper portion of the Dafali Member consists of marly sand and sandy marl with a rich marine fauna consisting mainly of brachiopods and oysters.

With the basal member of the Um Maghara Formation conditions have returned to the area that were similar to those below the Dhahab Formation in the Zarqa Formation. After the shoreline had moved to the south at Dhahab time it returned to the Um Butma area at Dafali time. Even further offshore, at the Mafraq area (Fig. 4) alternating beds of dolomite, sandy dolomite, sandy marl, sand and sandy limestone reflect this change. A renewed erosion on the Arabian-Nubian Continent in the south took place together with the regression of the sea.

Mintar Member

The Mintar Member has received its name from Rujm el Mintar situated just 1.5 km to the NW and overlooking the type section in upper Wadi Um Butma. The 41 to 44 m thick Mintar Member (Fig. 5) consists in its lower two thirds mainly of sandstone and in its upper third of marls and limestone. The basal flaser sandstone contains many trunks of drift-wood, quartz conglomerates and mudballs. Into the flaserbeds channels up to 8.5 m deep and over 50 m wide were cut and filled with pure sand showing unidirectional large scale crossbedding. The sands above are bioturbated, impure and show flaser type structure. Layers of ferruginous oolites are associated with them. The marl and limestone of the upper Mintar Member contains only little sand. A marine fauna consisting of bivalves, gastropods, brachiopods and crinoids is present.

Equivalent beds in the Wadi Huni area (Fig. 2), exposed on the slopes of Wadi Zarqa, are marly throughout. The depositional story of the Mintar Member thus demonstrates a short regression following the transgression at the top of the Dafali Member. The Wadi Um Butma area remained in the intertidal zone, while at Wadi Zarqa deposits of the shallow sea were laid down. Later the sea transgressed further south and shallow water marine conditions just offshore and outside of the intertidal sandflats are characteristic. The shore is to be expected only a few km to the south of Wadi Um Butma area.

Ramad Member

The member has received its name from the deep Wadi Ramad (Fig. 6) below the road from Suweilih to Arda, 5 km east of the village Arda. Here the upper 20 m of this member are well exposed. The Ramad Member is fully exposed in Wadi Um Butma (Fig. 5) and Wadi Harratha (Fig. 7). In the southernmost outcrop the member measures about 45 m in thickness and consists of sandstone throughout (Fig. 5). Flaser sands with silty partings are only found at the base of the member. Into it channels have been cut which are filled with crossbedded sand. The bulk of the member is composed of soft sandstone without traces of bioturbation. Often quartz conglomerates with pebble size reaching 1 cm are intercalated. Traces of two marine advances over these fluviatile deposits are found, one in the central portion and one forming the top of the member. These advances are characterized by churned up sand with fragments of shells of marine organisms (brachiopods mainly) at the base. They are followed by sandstone with dolomitic matrix and fishbone-like pattern of crossbedding, and they are topped by flaser sand with irregular ferruginous crusts.

In the Harratha section (Fig. 7), just 4 km to the North of the type section, the bulk of the Ramad Member is composed of sandy marl and marl containing an abundant marine fauna consisting mainly of brachiopods and oysters. Thus the shore line lay most of the time within the 4 km wide zone between Wadi Um Butma and Wadi Harratha (upper Wadi Nimr). But the upper 20 m of the Ramad Member at Wadi Ramad (Fig. 6) another 4 km to the North demonstrates that the shore line fluctuated very strongly and some times it regraded even further to the north. Here a very variable sequence is composed of fossiliferous shale, marl, silt and sand with plant fragments, clay with amber, a thin coal seam, dolomitic sandstone to sandy dolomite. This shows a continuous change back and forth between nearshore or intertidal marine and coastal terrestrial conditions with indications of a rich coastal vegetation.

The deposits of the Um Maghara Formation show very variable lithological composition and are about 125 m thick. They can be correlated to about 85 m of rock column penetrated in the Ramtha 1 test well (Fig. 4) near Mafraq. Here only the lower 20 m of this sequence contains sandy intercalations, while the upper portion consists only of limestones and marls. The limestone is mostly transferred into dolomite.

Arda Formation

The Arda Formation is 55 to 70 m thick and exposed well in the wadis north of the road descending from Ain Khuneizir to Arda (Suweilih-Arda) (Fig. 6). Two members are differenciated, Bin Fa'as and Ain Khuneizir, both named according to locations in the Wadi system (Wadi Bin Fa'as is a neighbouring valley of Wadi er Ramad), and a location on the road above the spring of Ain Khuneizir. The Arda Formation has received its name from the little village at the end of the wadi system about 5 km to the west in the Jordan Valley.

Bin Fa'as Member

The lowermost beds of the Bin Fa'as Member are exposed at Wadi Um Butma (Fig. 5) and Wadi Harratha (Fig. 7). While at Wadi Um Butma only soft fluviatile sands underlie the Upper Jurassic-Lower Cretaceous unconformity, sandy dolomite and dolomitic sand, shale and marl have taken the place of the sands just 4 km to the south from Harratha. Below the Arda road, in the type section (Fig. 6), the base consists of crossbedded sand with large trunks of drift wood abundant. Large lenticular sand bodies have been cut into silty interlayers and are overlain by flaser sand.

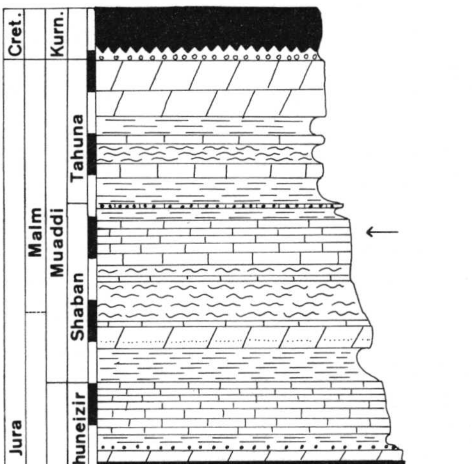


Fig. 6. Rock column of the Arda, Wadi Ramad, Wadi Bin Fa'as, Ain Khuneizir section. Arrow indicates the erosion surface at the Arda wadi system. Rocks above it are exposed at Wadi Shaban.

These continue into dolomitic sands which are overlain by ferruginous oolites. The bulk of the Bin Fa'as Member above this basal portion is composed of fossiliferous limestones and marls. The top of the member is formed by a sandy dolomite to dolomitic sandstone.

The shore line at the beginning of the Bin Fa'as Member was situated very close to the Arda area, while it then moved towards the south, to return to the area by the end of the Bin Fa'as time.

Ain Khuneizir Member

The lowermost beds of the Ain Khuneizir Member consist of silty shale with thin sideritic interbeds, plant fragments and amber present throughout (Fig. 6). The following crossbedded sandstone unit has been eroded into the upper portion of these beds. Dolomite and ferruginous oolite follow overlain by clay-stone. Fossiliferous limestones are present up to the top of the member.

The Ain Khuneizir Member is well exposed in Wadi Tahuna (Fig. 8), a side wadi of the lower Zarqa river just 5.5 km east of Deir Alla. The lower terrestrial deposits at the Arda area have been replaced here by marly and sandy beds with a very rich marine fauna. Whereas the central sandstone as well as the upper limestone are developed in about the same facies as in the Arda region. This demonstrates that during early Ain Khuneizir time the shore was situated between Wadi Tahuna and Arda, while later it shifted to the south of Arda. The shore can no longer be traced in detail, since rocks of the same stratigraphical position were eroded south of the Arda area.

Deposits that can be considered as time equivalent to the Arda Formation in the north of Jordan (Fig. 4) consist of 50 to 60 m of dolomite. This demonstrates that the deposition of these beds occurred well offshore away from coastal influence or continuous shifting of the shoreline.

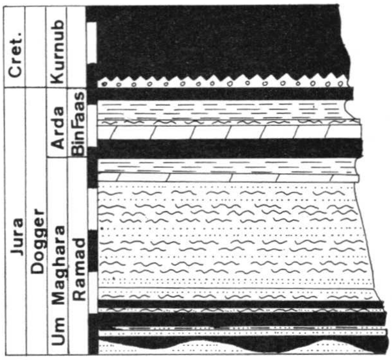


Fig. 7. Scetch of the rock column of the Wadi Harratha section.

Muaddi Formation

The 55—80 m thick Muaddi Formation has received its name from the town of Muaddi in the Jordan valley, just below those hills, where the beds of the formation are exposed and conspicuously truncated by the Upper Jurassic-Lower Cretaceous unconformity. The Muaddi Formation in all outcrops (Figs. 6, 8) and in the rock column penetrated by the Ramtha 1 test well (Fig. 4) is truncated by this unconformity. Two members are differenciated, the Shaban Member and the Tahuna Member.

Shaban Member

The Shaban Member received its name from Wadi Shaban situated 3 km to the east of the town of Muaddi, where the member is exposed almost in its total thickness and with the Tahuna Member preserved above. In the wadi system below the Arda road just to the east of Arda the Lower Cretaceous sandstone overlies the truncated limestones of the upper 10 m of the Shaban Member (Fig. 6).

The Shaban Member is a little more than 40 m thick both in the Arda-Shaban area (Fig. 6) as well as at Wadi Tahuna (Fig. 8) and in the Zarqa valley. In the area of Arda it consists of finely laminated clays in its lower portion, overlain by dolomite and dolomitic sandstone. This transition from non-marine to marine sediments is not observed in Wadi Tahuna, where the lower 15 m of the Shaban Member consist of marl. The following 25 m in all outcrops consist of marl and limestone with a rich marine fauna. The limestones often are characteristically oncolitic with algal encrusted components common. Conspicuous representatives of the fauna here are regular sea urchins with very thick short spines.

Tahuna Member

This member forms the uppermost portion of the Jurassic sequence exposed in Jordan along Wadi Zarqa from localities about 4 km to the east of Deir Alla to about 15 km upstream to the King Talal Reservoire. A maximum of about 35 m thickness is preserved at Wadi Tahuna (Fig. 8), about 5.5 km to the east of Deir Alla. The lower portion of the Tahuna Member consists of silty claystones with, intercalated sideritic, thin beds and no bioturbation. Further upwards, marls and shales are present into which limestone beds may be intercalated. These are partly oncolitic in texture, partly fine-grained and always fossiliferous. The member ends with up to 20 m of fossiliferous, fine-grained limestone, which due to the Upper Jurassic-Lower Cretaceous unconformity, a few m below the truncation, have usually been dolomitized. At the Ramtha 1 well (Fig. 4) the dolomites representing the Shaban Member in the subsurface of North Jordan is overlain by 28 m of limestone, clay and limonitic beds. Thus the lithological change between Shaban and Tahuna Members of the Muaddi Formation is well developed here. The Tahuna Member here is truncated below the upper limestone unit mentioned above.

The conspicuous difference of the Muaddi Formation to the Arda and Maghara Formations is the almost complete absence of quartz sand, although the laminated clay and siltbeds forming the base of the Shaban Member at the Arda area as well as the base of the Tahuna Member are terrestrial deposits. The shore line during early Shaban time was situated a few km north of Arda, and during early Tahuna time even further to the north of Wadi Zarqa. Thus it is probable that the transgressions in the later Shaban and Tahuna times did not reach much further southwards than before in the times of Arda and Um Maghara Formations. Clearly rivers no longer transported sand from the Arabian-Nubian Continent to these shores.

Comparison with the Jurassic sequence west of the rift

The Deir Alla Formation corresponds to the Mishhor and Ardon Formations of the Negev (Goldberg & Friedman 1974; Druckman 1977). At Makhtesh Ramon about 20 km southwest of the Dead Sea pisolite clays are present. They are interbedded with limestones and sandstones. This so

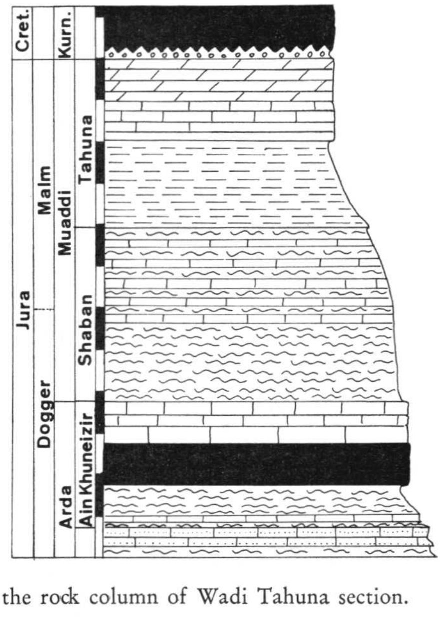


Fig. 8. Scetch of the rock column of Wadi Tahuna section.

called Mishhor Formation can be correlated with the Huni Member of the Deir Alla Formation. It is overlain by limestones similar to the Nimr Member in thickness, both at Makhtesh Ramon and about 40 km southwest of it at Areif en Naqa (DRUCKMAN 1977).

The three members of the Zarqa Formation correspond to the three members of the Inmar Formation of southern Israel. At Makhtesh Ramon the sediments deposited during Zarqa time are totally terrigeneous and show no signs of marine transgressions (GOLDBERG & FRIEDMAN 1974).

Only further to the north the Inmar Formation resembles the Zarqa Formation. At Djebel Maghara in the Sinai deposition in general was similar to that near the Zarqa river in Jordan but in contrast a much thicker sequence was deposited.

The prominent limestones of the Dhahab Formation in Jordan correspond to the Daya Formation in the Negev. In their thickness they are comparable to southerly wells as Heimar 1, Nafha 1 and 2 and Makhtesh Ramon (GOLDBERG & FRIEDMAN 1974). According to these authors in the eastern Negev clastic rocks occur in the lowermost part of the Daya Formation perhaps corresponding to the unit 2 composed of clay and marl in Jordan. In the eastern Negev also coastal proximity of these limestones is documented by tidal flat facies in the Makhtesh Ramon area.

The Um Maghara Formation and the Arda Formation with their continuously shifting sedimentary facies correspond to the Sherif Formation in the Negev and Djebel Maghara in Sinai. But the thickness of both these formations together usually is less than what is described by FRIEDBERG & GOLDMANN from southern Israel and Sinai. This becomes even more evident in the Muaddi Formation which can best be correlated to the Zohar and Kidod Formations in the Negev. Clastic rocks make up only a very small part of the Shaban Member of the Muaddi Formation the equivalent of the Zohar Formation. The Tahuna Member of the Muaddi Formation would actually best be correlated to the Kidod Formation of the Negev, and if so with that present near Kurnub.

The outcropping Jurassic strata in Jordan can be compared very well with the Jurassic strata and lithofacies, as are found in a belt about 20 km wide trending southwesterly present between the localities Kurnub and Makhtesh Ramon or Massada and the south tip of the Dead Sea.

Biostratigraphy

The lowermost Jurassic age of the Deir Alla Formation is plausible because it corresponds to the Ardon Formation of the Negev. The Ardon limestones in term outcropping at Makhtesh Ramon were dated by NEVO (1963) as Middle Liassic (Pliensbachian). According to BENDER (1968), who reviewed all previous literature on Jurassic fauna from Jordan, the rocks between Dhahab and Muaddi Formations should be placed between Aalenian, Bajocian and lower Bathonian in age. MOSHKOVITZ & EHRLICH (1976) supported these data and according to them the Um Maghara and Arda Formations represent Bajocian to Bathonian time. MOSHKOVITZ & EHRLICH studied the nannofossils of the upper calcareous portion of the Jurassic in the Negev. According to their results the Jurassic sequence in Jordan with the Muaddi Formation should have been deposited at Callovian to Oxfordian time.

Shore lines, subsidence and continental erosion during Triassic and Jurassic times

The sedimentary sequence starting with the Um Irna Formation of uppermost Permian to lowermost Triassic age (BANDEL & KHOURY 1981) and ending with the Muaddi Formation of lower Upper Jurassic (Malm) age forms one sedimentary cycle with a strong unconformity at its base and an erosional disconformity at its top. The rock column in Jordan formed by these sediments is about 1400—1500 m thick.

The unconformity at the base near Zarqa Ma'in is that between Middle-Upper Cambrium to Upper Permian. During the very long time of which sediments are now absent from the area, most probably terrestrial conditions prevailed. To the west during part of this time erosion had destroyed the Cambrian sediments down to the Precambrian sedimentary sequence, but subsequently deposition of Carboniferous strata above this erosional base is documented west of the Dead Sea (WEISSBROD 1969). In contrast to conditions in Jordan, conformable relations between the Permian and the lower Triassic sequence existed all over southern Israel, northern and central Sinai, whereas southwards overlapping Triassic deposits covered Upper Paleozoic relief (DRUCKMAN 1974 b). Only from about 65 km SW of the Dead Sea (Hameishar 1 well) (FREUND 1977) Permian-Triassic deposits similar to those described from the Suweilih 1 well in North Jordan overlie Cambrian sandstones (Fig. 9).

The shore during deposition of lowermost Triassic sediments in Jordan was situated north of the Dead Sea and south af Amman (BANDEL & KHOURY 1981). According to these authors during Scythian times the shore fluctuated back and forth between the area just south of Wadi Zarqa Ma'in and Wadi Mukheiris. It shifted within a zone of 15 to 20 km which reaches out into northwesterly direction from the northeastern shores of the Dead Sea (Fig. 9). The mainly Scythian Ma'in, Dardun and Ain Musa Formations were deposited along a coastal belt with continuous subsidence amounting to about 180 m. Terrestrial sediments were eroded from the Precambrian basement of the continent in the southeast. They were not transported very far and reached this zone of subsidence periodically. At the same time 190 to 290 m of sediments of very similar lithology were deposited in the area of the central Negev. Here the shoreline was situated about 60 km southwest of the Dead Sea (DRUCKMAN 1974). Lines of similar lithofacies strike from northeast to southwest.

During deposition of the Hisban Formation at Anisian time erosion came to a halt on the continent. Thus no influx of terrestrial clastic material reached the area, as well in Jordan as in the Negev. Thickness of the Hisban Formation near the NE end of the Dead Sea is similar to that reported from the Har'Arif area and striking northeast-southwest the Zarqa Main area. It reached further to the south than ever before since the beginning of deposition of Mesozoic rocks in the area.

During the remainder of Anisian time the shore in Jordan again shifted back and forth between Wadi Zarqa Main and Wadi Mukheiris. Only rarely, as in the upper Bahhath Member it reached the Naur area (Fig. 9) further to the north. The same regression of the sea following the Hisban transgression is reported from the area of the Negev, but here the actual shore line with its deposits has been eroded (DRUCKMAN 1974). The continent in the southeast during late Anisian time started rising again periodically and during late Mukheiris time and early Iraq al Amir time much sand with increasing maturity through time reached the area of subsidence at the continental margin. Thus clastics with decreasing grain size and continuously more carbonates kept pace with additional 260 m of subsidence after Hisban time.

With the beginning of Ladinian time, and the beginning of deposition of the Um Tina Formation, coarse terrestrial sediments were no longer deposited even though subsidence did not slow down. It is probable that the sea transgressed somewhat onto the continent, which at this time was most probably arid and did not deliver sediment. During Um Tina and Abu Ruweis times (Ladin-Carn) in the subsiding belt striking from NE to SW about 460 m of sediment were deposited. All these sediments formed under intertidal conditions and on tidal flats with occasional salinal ponds or lagoons. These arid sabkha belts probably covered a wide area between the Tethyan sea in the northwest and the continent in the southeast. DRUCKMAN (1974b) reported that during Carnian time the sea transgressed furthest south on the Sinai then ever before during the whole Triassic depositional history.

Fig. 9. Map demonstrating the reconstructed course of shore lines east and west of the rift. 1. Upper Permian Lowermost Triassic Um Irna Formation; 2. Anisian Hisban Formation; 3. the zones in which the shore shifted between N and S during deposition of Scythian and lower Anisian Ma'in, Dardun and Ain Musa Formations; 4. belt of shifting shore during upper Anisian Mukheiris and Iraq al Amir time; 5. and Um Tina and Abu Ruweis sabkha belt (Ladinian, Carnian). Data compiled from DRUCKMAN 1974 and BANDEL & KOURY 1981.

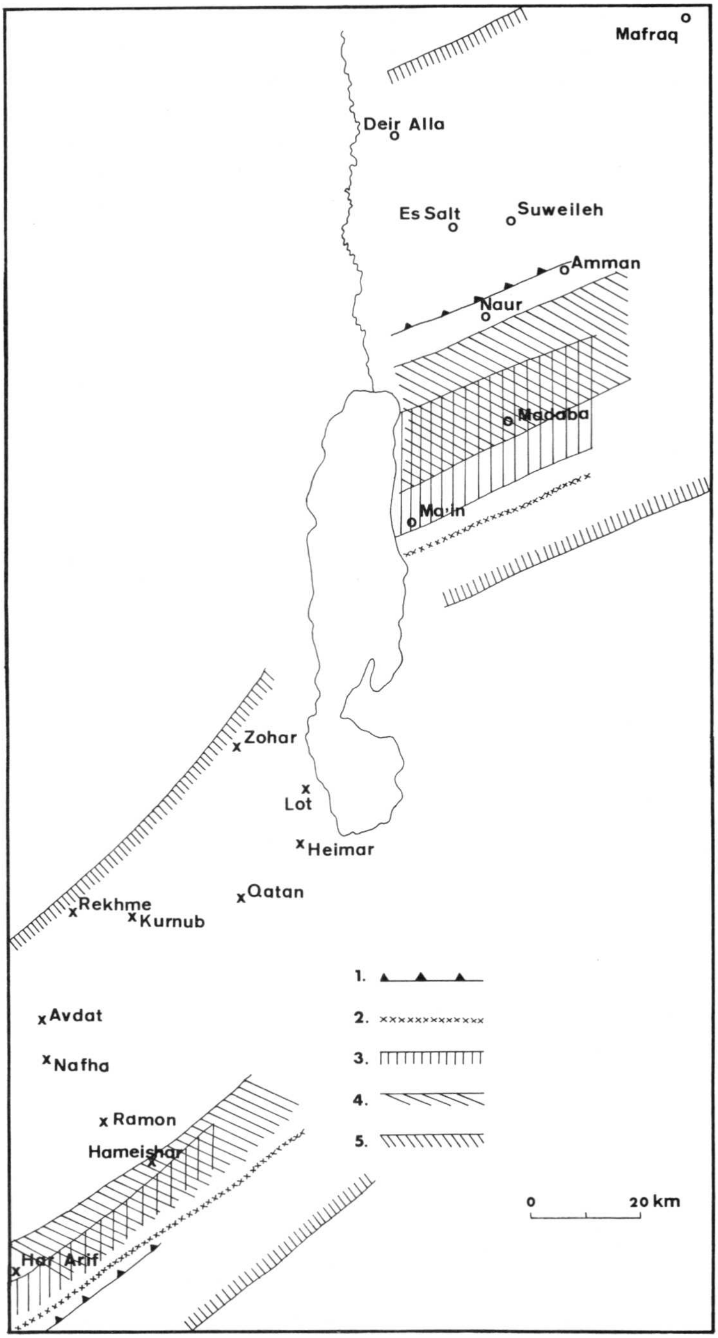


Fig. 9 (Legende see p. 292)

After deposition of the Carnian Abu Ruweis Formation the sea withdrew and regional emergence took place. During the terrestrial phase residual soils formed and only slight erosion occurred or not at all. Lateritic soil and ferruginous pisolites were formed in a NE—SW trending zone across North Jordan (Fig. 10). During the Liassic transgression pisolites were partly enriched in pisolite conglomerates. Similar pisolitic and lateritic soils were also formed in the Negev (Druckman 1974, 1977, Goldberg & Friedman 1974).

During the terrestrial phase in the latest Triassic and the earliest Jurassic times the continent to the south had remained stable and quiet. With Liassic Deir Alla time renewed sand deposition is the result of renewed erosion in the south. The shoreline now was established about 25 to 30 km north of its former position during Scythian and Anisian times. First sand deposition and consequently erosion on the continent during late Huni time came to a stop and coastal carbonate deposits thus formed in the shore area. The shore-line on the W-side of the rift could be traced in the Negev about 40 km SW of the Dead Sea (Druckman 1977) (Fig. 10). In the Negev north of the shore line during Deir Alla time evaporite sediments were deposited together with carbonates. This demonstrates that the climate was still dry. Now at Zarqa times (Lias) more humid conditions returned. Emergence of the continent accompanied by extensive freshwater run-off and subaereal weathering brought about the deposition of sandy deposits mainly. Usually during Liassic time the fluvial-deltaic deposits lie in the southmost-outcrops, while their marine intertidal or offshore time equivalents were deposited in the Wadi Zarqa area, just 10—20 km to the north. The shoreline finds its continuation in the Negev but with a northward bulge near the Dead Sea (Goldberg & Friedman 1974, Druckman 1977) (Fig. 10). Deposition during Zarqa time is clearly cyclic most probably reflecting cyclic upward movements and subsequent erosion on the continent. The more mature state of the sand as well as the better degree of rounding of quartz pebbles indicates a longer transport of terrestrial erosional products during Liassic times than at Scythian times, even though the size of the pebbles still indicates their source from weathered crystalline basement.

Fig. 10. Map demonstrating the northernmost line of intrusives into Triassic rocks (1); the presence of Dhahab Formation (lower Dogger) in the same thickness as in Tell ed Dhahab (2); the presence of Arda and Muaddi Formations (Dogger and lowermost Malm) in the same thickness as just east of Arda (3); the presence of the Nimr Member of Deir Alla Formation (Lias) in the same thickness as in its type section (4); and the presence of the Zarqa Formation in the same thickness as in its type section (5). For west of the rift data have been compiled from Goldberg & Friedman 1974 and Druckman 1977.

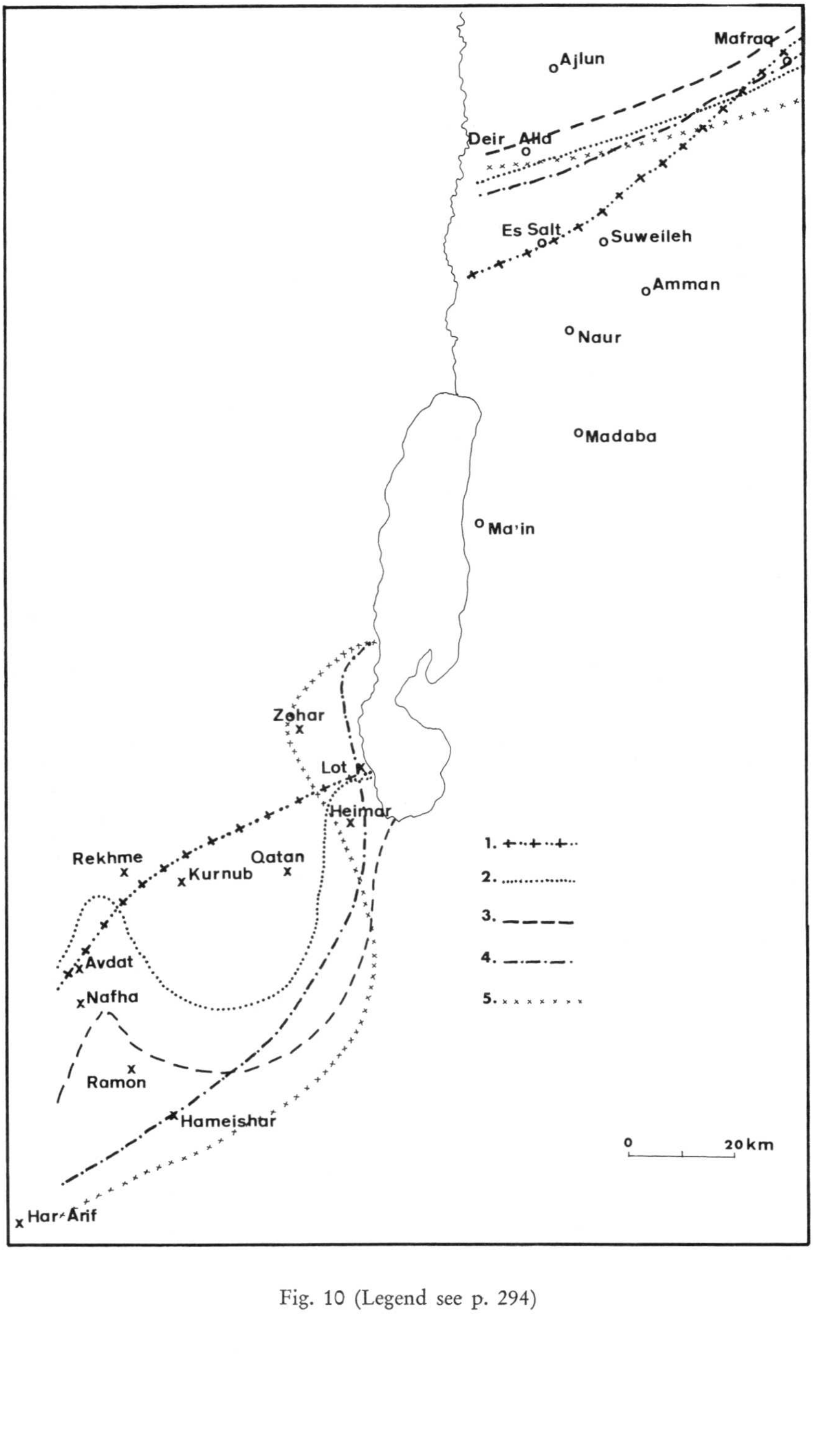


Fig. 10 (Legend see p. 294)

During Dogger at Dhahab time the former deltaic and coastal area was totally flooded and carbonate deposition in shallow offshore sea prevailed. While in the Negev fluviatile sands interfinger with equivalents of the Dhahab limestone, only little traces of this terrestrial influence is seen in the southernmost outcrop in Jordan. During Um Maghara and Arda time the conditions present prior to the Dhahab transgression reestablished themselves. The shore is present just south of Wadi Zarqa practically throughout Maghara time. At Arda time the sea periodically flooded more southerly areas. The last great sand mass as erosional product from the continent reached the area with the deposition of the base of the Ain Khuneizir Member.

Afterwards the continent stopped supplying coarse erosional products aside from clay and some silt.

Upper Jurassic-Lower Cretaceous Unconformity

The time elapsing between the Upper Jurassic regression of the sea and first deposition of Neocomian sandstones was perhaps not much longer than the time between Abu Ruweis Formation and Deir Alla Formation, when the sea regressed in the Carnian to return in Liassic time. But the impacts of both with about equally long periods of terrestrial phases were extremely different. While during the Triassic-Jurassic regression very little rock was eroded, the Jurassic-Cretaceous unconformity is connected to a very strong erosion of older rocks throughout Jordan. Thus sandstones of the lower Cretaceous Kurnub Group overlie Ordovician rocks at the Ras en Naqeb in the south of Jordan; Cambrian sandstones south of Wadi Mujib to the area just north of Petra; Triassic rocks of different age from just north of Wadi Mujib to south of Es Salt; Jurassic rocks from just south of Es Salt northwards. In the evaluation of erosion at the Jurassic-Cretaceous emergence we will concentrate on the northern deposits, where Cretaceous Kurnub sandstones overlie Triassic and Jurassic rocks (Fig. 11).

The magnitude of the eroded sequence was up to date obscured by the misinterpretation of actual rock column thicknesses of Triassic and to a lesser extent Jurassic strata. Thus WIESEMANN (1969) suggested the presence of a 0—190 m thick Triassic sequence and a 0—250 m thick Jurassic

---

Fig. 11. Map showing the erosional surface as it was before the transgression of the Lower Cretaceous Kurnub sandstones. The lines indicate the presence of strata in the north and their absence due to erosion in the south. 1: Erosion of Tahuna Member of the Muaddi Formation (Malm); 2: erosion of the complete Jurassic sequence; 3: erosion of the Hisban Formation (Anis); 4: erosion of the complete Triassic sequence. West of the rift data have been compiled from GOLDBERG & FRIEDMAN, 1974, DUCKMAN, 1974 and WEISSBROD, 1969.

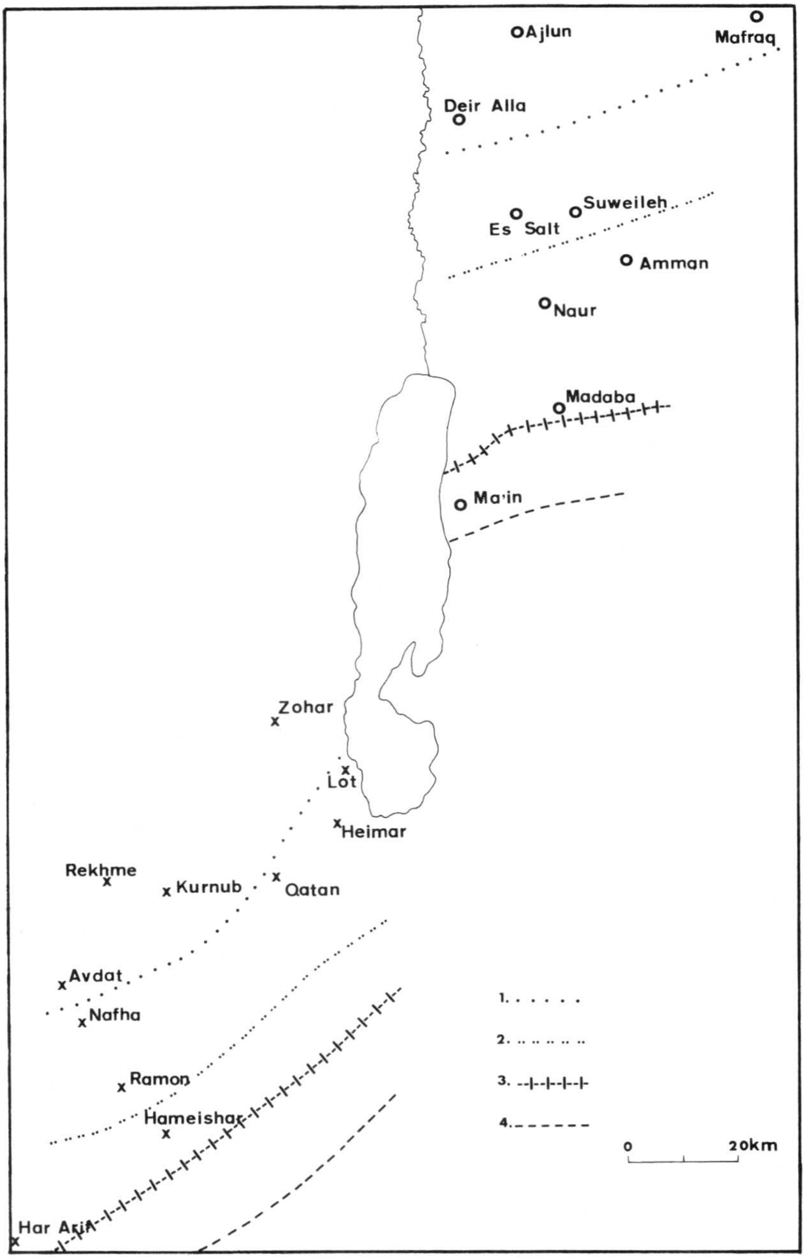


Fig. 11 (Legend see p. 296)

sequence in north Jordan. Thus a maximum thickness of 440 m for Triassic and Jurassic rocks together was taken into consideration. In addition it was assumed that some of this sequence wedged out towards the south because of non-deposition. The data presented here show that the Jurassic strata alone can account for the given thickness and the Triassic with a thickness of about 1000 m of sediment was not considered at all.

The unconformity between beds of older age and lower Cretaceous rocks was never observed to be angular. Often the contact is quite indestinct as for example in Wadi Dardun where silty sand overlies the sand-clay succession of the Mukheiris Formation, or in Wadi es Salt near Naur where silty Kurnub sand lies on shale of the Um Tina Formation, or also in Wadi um Butma where fluviatile sands of the Lower Cretaceous merge with fluviatile sands of the Middle Jurassic. At other places the unconformity is quite distinct demonstrating a conglomeratic base composed of gravel as for example in Wadi Ain Musa, where gravel of different lithologies overlie limestones of dolomitized Hisban Formation, or at the Arda area, on the slope of the valley opposite to the road, where a quartz pebble conglomerate overlies limestones of the Muaddi Formation. Here also, as in Wadi Ain Musa, dolomitization of this limestone is clearly correlated with the unconformity. At other localities a soil horizon may be preserved at the unconformity, as for example on the lowermost Mukheiris Formation. A dyke cutting through it is deeply weathered in the Wadi Hisban. On the Muaddi Formation exposed on the Arda road and below the King Talal Dam site soil-like deposits are preserved between limestone and sand.

There is never an angular unconformity seen in outcrops, even where a large area can be surveyed as near Arda or in the Lower Wadi Zarqa. If it appears as if angular truncation is present as in the case in the Wadi Naur area, closer examination showed that slope-sliding of Kurnub deposits across Triassic beds caused that impression. Thus erosion did not truncate folded rocks, but only faulted ones. These rocks were faulted in such a way that originally horizontal planes were not tilted at all. This vertical faulting reached quite some extent as can clearly be seen from Fig. 11.

In this staircase of step-faulted rocks, reconstructed in Fig. 11 for an area reaching from Wadi Zarqa to Wadi Mujib within a distance of about 75 km from north to south, about 1400 to 1500 m of sediments had been eroded prior to the deposition of the sandy Kurnub-Group. From one step to the next erosion of 40 to 50 m mainly of the Tahuna Member is observed between north and south of Muaddi. East of Arda Jurassic deposits are eroded down to the Bin Fa'as Member (100—120 m). Between Wadi Samra and Wadi Naur the remainder of the Jurassic rock column and almost half of the Triassic rock column are eroded (600—700 m). Between the Um Tina Formation of Wadi Naur and Wadi Hisban about 320 m of Triassic rocks have been eroded to the Hisban Formation. From here to

Zarqa Main a further 120 m of sediment have disappeared. According to BENDER (1968) at Wadi Mujib the Triassic is totally absent, which makes at least another 150 m of eroded rocks.

This step faulting did not end further to the south, at least not until reaching the area near the south end of the Dead Sea. This is indicated by the truncation of Cambrian rocks, which reaches further down in the Ghor Safi area than in the Zarqa Main area and the area of Suweilih. From the Suweilih 1 well Cambrian limestones are reported in a depth of about 260 m below the Permian-Triassic unconformity at about 1000 m well depth. About the same amount of Cambrian sandstone overlies carbonates at the eastern shore of the Dead Sea near the mouth of the Zarqa Ma'in river. This indicates about the same level of truncation of Cambrian sediments prior to the Permian-Triassic transgression. About 30 km south of Wadi Mujib near Ghor Safi, the Cambrian rock column ends with the carbonate unit, which indicates the erosion of additional 260 m of sediments, probably also just prior to the deposition of the Kurnub sands.

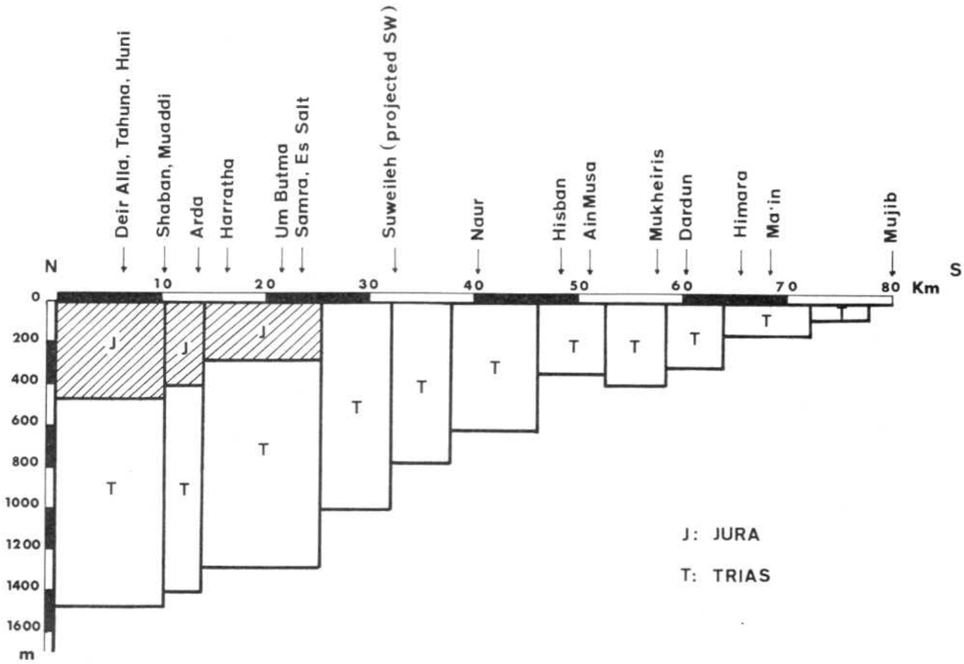


Fig. 12. Scetch demonstrating the step faulted, peneplained surface of the eroded Mesozoic rock column as it had been before deposition of the Lower Cretaceous Kurnub sandstones between the mouth of the river Zarqa (N) and the mouth of the Mujib river (S).

The fault bound erosion of older strata in a southwards ascending staircase (step faulting) is developed in Jordan as well as west of the rift in the Negev (Fig. 11). It again follows the continental margin (DRUCKMAN 1974, GOLDBERG & FRIEDMAN 1974). Off-shore of the continental margin, about 70—80 km northwest of the southern end of the Dead Sea sedimentation was continuous from the Jurassic into the Cretaceous (GRADER & REISS 1958). According to these authors just about 40 km to the south a gap is present between Jurassic and Cretaceous beds, demonstrating the action of a regressing sea from the Arabo-African Continent. The sea transgressed again in the Apt, the Alb and then even further in the Cenomanian. When during early Kurnub time the sea flooded onto the peneplaned surface, its shores did not follow closely the old lines that shores had followed in the Triassic and Jurassic but the sea usually lay further to the northwest. More data would have to be collected in Northern Jordan to reconstruct these shore lines. But again, as in Lower Triassic (Scyth, Anis), early Jurassic and early Middle Jurassic times Jordan lay within the shore area of an extensive delta (ABED 1978, BANDEL & HADDADIN 1980) until during the Cenomanian when the sea transgressed much further to the southeast.

Magmatic rocks

The Precambrian metamorphic basement was already peneplaned when about 510—560 million years ago (BENDER 1974) a volcanism erupted. It shed quartz porphyry and intruded andesites into a sedimentary series composed of arcosic conglomerates, silts and silicious clay beds, tuffs and ignimbrites. Near Wadi Abu Barqa, about 80 km south of the Dead Sea about 300 m of sediments, volcanic tuffs, intrusions and flow rocks overlie the metamorphic basement. Just north and not far to the southeast such a vulcano-sedimentary series between Precambrian basement and Cambrian sandstones is not present. Volcanism had stopped when during the lower Cambrium the sea transgressed over the peneplane in the east. Later it also inundated the rugged surface of the volcanic rocks and older sediments present between the area of Gharandal in the south and Wadi Fidan in the North.

BENDER (1974) suggested that this volcanism indicated the existence of a zone of structural weakness along the rift already at late Precambrian time. This would indicate a continued activity along the rift since that time. But WEISSBROD (1968) found sediments and igneous rocks extensively developed in the Negev which are of just the same character as present in the Wadi Abu Barqa area. According to Fig. 13 of WEISSBROD's study in a distance of about 80 km south of the Dead Sea on the W side of the rift some 500 m of these Precambrian rocks of the so-called Zenifim Formation are present. This is quite a bit more than overlies the crystalline basement of the other side of the Wadi Araba. To the north of Wadi Abu Barqa in addition Cambrian sandstones again overlie the metamorphic basement directly. Only near the south end of the Dead Sea near Ghor Safi Precambrian conglomerates underlie the Cambrian strata. This could be the most southerly counterpart of the Zenefim Formation on the eastern side of the rift. In the Negev this formation rapidly increases in thickness towards the NW and reaches a thickness of over 2000 m within 50 km. Lines of the same thickness of the Precambrian rocks composed of arkose, silt, mudstone, basalts, andesite trachytes and acidic volcanic breccia and tuff (WEISSBROD 1968) strike SW—NE, just like the shore-lines of Triassic-Jurassic deposits much later. These lines do not follow the direction of the rift, but they trace the margins of the Arabian-African continent (FREUND 1977).

The next more recent occurrence of igneous rocks in Jordan is that of dykes and sills present in the Triassic sedimentary series, in outcrops and in the wells of Suweilih and Ramtha. These igneous rocks are either diabase or gabbro and are of very similar chemical and mineralogical composition. It is likely that they have ascended from the same magma chamber (BANDEL & KHOURY 1981). The age of these rocks is older than Lower Cretaceous Kurnub sands. The reason being that the dykes are cut by the unconformity and together with the sills are weathered to a few m in depth below the unconformity surface. Such dykes and sills have not only invaded Triassic but also Jurassic rocks in the Negev (DRUCKMAN 1974, GOLDBERG & FRIEDMAN 1974). They are limited in their occurrence to a line from the southwest shore of the Dead Sea going roughly SW into the Sinai (Fig. 10). These high-alkaline igneous rocks (FREUND 1977) intruded most probably at the same time as the gabbro and diabase in Jordan, indicating a Jurassic age. In Jordan no intrusions are detected north of the area between Es Salt and Naur, and the direction of this border line with and without intrusions continues in a northeasterly direction. This Jurassic volcanism with a deep lying source thus follows the margin of the continent and no other lines.

A volcanism present in the lowermost Cretaceous of West Jordan covered extensive area with tuffs and flow material, in the Wadi el Malih, only about 25 km to the NW of Deir Alla. It composes a section of 230 m. The chemistry of these volcanics is quite different from that of the dykes and sills present in the area NE of the Dead Sea. No traces of volcanic deposits could be noted on the E side of the rift further to the east which is now so close to this extensive volcanism. This is the case although the Jurassic-Cretaceous border is very extensively exposed near Deir Alla. Just across from Deir Alla in the Wadi Fari'a 29 m of basalts and tuffs are exposed. This so-called Tayasir volcanics (MIMRAN 1972) followed steep fault planes in their path of ascent. The faulting is most probably closely connected with the intensive faulting which occurred in the terrestrial, erosive phase between latest Jurassic and earliest Cretaceous time. Thus it is most probably more recent than the gabbro and diabase intrusions, that intruded the unfaulted Triassic rocks in Jordan.

The most recent volcanism is connected to the formation of the rift and is of Miocene and subrecent age. It now follows a different line of ascent which is not connected to the continental margin, but to the rift.

Structures

Historical background

The following phenomena had to be explained:

1. Shore-lines and lithofacies pattern of Triassic, Jurassic and Cretaceous traced across the rift form roughly an S-shape with the right upper hook crossing Jordan, the vertical component following the Dead Sea and part of the Wadi Araba and the left lower hook crossing the Negev into Sinai.

2. An offset across the rift was observed regarding Precambrian porphyry bodies, Cambrian sandstone and copper and manganese mineralization. On the eastern side of the rift these lie more northerly than their equivalents on the western side.

3. Many structural elements, when correlated across the rift show a shift of considerable length.

To explain these and other features both on the Arabian continent on one side and the Palestine-Sinai on the other side, two main hypothesis have been presented.

A. A sinistral strike slip fault as an explanation for these phenomena was presented by SEIDLITZ (1931) and DUBERTRET (1932). The latter suggested a movement of 160 km on behalfe of facies displacement of Cambrian limestones and marine strata of the Jurassic. WELLINGS (1938) and QUENNELL (1958, 1959) suggested 107 km displacement mainly based on the dislocation of Precambrian igneous rocks and copper and manganese mineralization of Feinan and Timna. This was also followed by BURTON (1959). FREUND (1962) suggested 100 km displacement based on Lower Turonian facies relations. 1965 the same author estimated that the actual shift only amounted to 70—80 km. FREUND, ZAK & GARFUNKEL (1970), based on detailed correlation across the rift, returned to the 106 km displacement originally suggested by WELLINGS and QUENNELL. Also DE SITTER (1962) and NEEV & EMERY (1966) accepted displacement of about 100 km. In later publications JARRAR (1979) suggested 85 and SALAMEH (1980) 105—110 km of displacement.

B. A relative uplift of the eastern and western sides along the rift valley connected to a minor sinistral movement was first expressed by PICARD (1943) and the same author (1966 and 1968) denied the presence of any sinistral movement. DUBERTRET (1967) changed his opinion (expressed 1932) and refused to accept the theory of the presence of strike slip movements because it cannot be accounted for further in the north, in the Hermon area and the Lebanon. BENDER (1968) accepted a sinistral shear of only 25 to 35 km in Precambrian time. The same author 1975 stated that a structural zone of weakness (geosuture) or a major hinge line with the same trend of the rift already existed in the area throughout since Precambrium. Continued tectonic activity along the old zone of weakness resulted in quarz porphyry eruptions in Proterozoic and early Cambrian times. In the following geological history, according to BENDER (1968, 1975), a major paleogeographic divide with continued mobility of the geosuture in Paleozoic and Mesozoic times is responsible for the formation of S-shaped patterns of lithofacies lines. BENTOR & VROMAN (1954, 1960) also suggested a pre-Jurassic age for the fault on the eastern side of the Dead Sea and assumed that along this fault line the eastern side was raised during the Jurassic. Consequently, the sea coming from the north, progessed farther south on the western than on the eastern side. WIESEMANN (1969) expressed the opinion that the Transjordanian Block has only been moved very little towards the north. Other supporters of the graben hypothesis without lateral displacement are WETZEL & MORTON (1959) and HENSON (1956).

Many of the various differences of opinion in this matter are a result of the political situation in the area. As FREUND (1965) had stated, the present political situation prevents most geologists from visiting both sides of the Dead Sea depression in order to verify the evidence.

Discussion

1. A sinistral movement of about 100 km along the Jordan-Dead Sea-Wadi Araba rift can satisfactorally explain the diversity of structural evidences from the Red Sea area. For example Arabia separated from Africa due to a 6°—7° clockwise rotation of Arabia around an axis situated in the Mediterranean Sea. Also other structural features present in the rift valley find an explanation. But it is still an unsolved question how the continuation of this movement can be followed up further to the north, in Lebanon and Turkey, where up to now movements of only 10 to 15 km could be documented. But the Dead Sea fault system, according to FREUND (1965), is connected with the rifting of the Red Sea on one side and the folding of the Zagros-Taurus range on the other side.

2. A sinistral movement of about 100 km along the Jordan-Dead Sea Wadi Araba fault system is documented by the following stratigraphic evidence.

a) The Precambrian volcano-sedimentary series, which is present east of the Wadi Araba (Wadi Abu Barqa), but which is absent north of this area and is developed again in some conglomerates only just south of the Dead Sea, can be correlated with the volcano-sedimentary series present on the other side of the fault system south of Elat (JARRAR 1979) and in the Negev. In the area between both occurrences of Precambrian non-metamorphic rocks on both sides of the rift Cambrian sandstones overlies metamorphic basement.

b) Cambrian sandstones exposed from the NE-corner of the Dead Sea and known from the Suweilih 1 well in Jordan are absent from the W-side of the Dead Sea and can only be traced in the subsurface quite some distance south of the Dead Sea (south of Hameishar 1, FREUND 1977).

c) The Permo-Triassic transgression reached the area between Suweilih and the northeast corner of the Dead Sea while to the west marine deposites are present long before that time and the shore lay south of the Dead Sea (Fig. 9).

d) Triassic and Jurassic shore-lines and lithofacies lines in Jordan find their continuation with 100—120 km displacement to the south in the Negev area (Figs. 9, 10).

e) The lithology of the Lower Cretaceous Kurnub Group at the Wadi Zarqa area most closely matches that of the Negev (Makhtesh Ramon area), while to the west more calcareous deposits are included in these strata and the base is limnic.

f) The 430 m of Cenomanian and Turonian sediments present in the area of Amman in thickness and lithology can most closely be correlated to the Cretaceous sequence as it is present in Makhtesh Ramon (LEWY & RAAB 1976), while the rock sequence just across the Jordan to the west is quite different in regards to lithology and thickness.

g) The lithofacies and thickness of Senonian beds in the Amman-Ruseifa area correspond closely to those of the Negev (LEWY 1975, KOLODNY 1967). As in the Negev sedimentation south of the Ruseifa area stops in later Campanian time.

3. The following magmatic data fit into the scheme of an about 100 km displacement along the rift.

a) The presence of diabase and gabbro dykes and sills intruded into non-faulted Triassic strata south of Es Salt is continuous in Jurassic and Triassic strata south of the Dead Sea with trend from NE to SW (Fig. 10).

b) Volcanism present during early Cretaceous time in an area that is now just west of the mouth of the Zarqa river (Deir Alla) is documented by thick deposits of tuffaceous material between Jurassic and Cretaceous sediments west of the rift. No trace of this is seen now across the Jordan on the east side of the valley.

4. Structural data that give evidence for a 100 to 120 km displacement.

a) The porphyritic volcanism in South Jordan exposed at the east side of the Wadi Araba finds its continuation in the Timna Elat area.

b) The Precambrian deposits of the Saramuj conglomerate at the east side of the rift near the south end of the Dead Sea form the lowermost portion of the Precambrian series that reaches much further to the south on the west side of the rift. In the Negev this series increases rapidly in thickness towards the northwest and it follows the ancient margin of the continent in SW—NE direction.

c) This margin is continuously active and subsiding during later Paleozoic and Triassic time and subsidence is quite similar on both sides.

d) Areas of stronger subsidence in the form of basins separated from each other by highs that have been traced by DRUCKMAN (1974, 1977) and GOLDBERG & FRIEDMAN (1974) formed during the Upper Triassic and Lower Jurassic deposition find their continuation in Jordan, but with a displacement of about 100 km to the north. Thus the Avdat block in the Negev is the continuation of the Jordan block in N-Jordan as DRUCKMAN (1977) suggested.

e) During Jurassic time the continental margin began to be differenciated into a shelf area crossing northern Jordan and a hinge area following more or less the recent shores of the Mediterranean Sea. The shelf became narrower in southern Israel and wider in Jordan. This is reflected in the greater thickness of sediment deposited at the same distance from shore in the Negev and Sinai than at the same time in North Jordan.

f) The intensive faulting with faults trending NE—SW present in Jordan during uppermost Jurassic and lowermost Cretaceous is continuous in the Negev with the same trend, but a displacement of about 100 km is needed to correlate the different structures (Fig. 11). These faults follow the continental margin. They displaced blocks in a way that they moved only vertically without any tilting or bending.

g) In late Campanian, early Maastrichtian time tectonic activity resulted in the erosion of the Silicified Limestone Unit down to the Turonian Massive Limestone Unit just south of Ruseifa. Here emergence above sea level, erosion of Campanian, Santonian, Coniacian and upper Turonian strata, is indicated by shore breccia, and enrichment of phosphatic sand washed out from the eroded Silicified Limestone Unit. This emergence is connected to the Suweimi-Amman-Ruseifa fault, that was considered to be a time equivalent of the E-graben main fault (WIESEMANN 1969). This structure is clearly older than Maastrichtian and much older than the Dead Sea main fault.

It finds its continuation to the south of the Dead Sea. In some places of anticlines of the northern Negev (Ramon area) flints of the Campanian Mishash Formation unconformably overlie detrital limestones of the Shivta Formation (equivalent to about 40 m below the surface of the Massive Limestone Unit in Jordan) (ARKIN & HAMAOUI 1967). In its direction the Suweimi-Amman-Ruseifa structure and similar structures present to the north and the south of it follow the continental margin. In the case of the Amman fault it has been activated again later on.

h) Stratigraphic phenomena, like the presence of Carboniferous sediments west of the rift, or like a more rapid thickening of Jurassic strata west of the rift than east of it, can be explained by a narrower continental shelf in the area of the Negev. In N-Jordan, in contrast, the distance between coast and shelf slope was wider. But during Turonian time the edge of the shelf was not far away from the Amman region. In the Ajlun area rudist reefs are present during this time, a feature which in Israel and the Lebanon gives evidence of the edge between stable shelf and slope region (LEWY & RAAB 1976). The shelf during the Upper Cretaceous was extremely broad and very small sea level fluctuations resulted in great facies differenciation. In the area of Sinai and Negev, according to LEWY & RAAB (1976), the shelf at that time measured 200 to 300 km in width. This magnitude can be correlated to the evidence present in Jordan where the beach lay in the south (BENDER 1968, 1975) and the slope north of the Ajlun area.

After closer investigation there is nothing to indicate activity along the Araba-Dead-Sea-Jordan rift before Tertiary times in the rock column of Jordan. Structural features as well as shore lines, lithofacies borders and magmatic intrusions only follow the continental margin. They show no N—S trends but only NE—SW trends all through Precambrian to Upper Cretaceous times.

References

ABED, A. M. (1978): Depositional Environments of the Kurnub (Lower Cretaceous) Sandstones. — Dirasat, **5** (2): 31—44; Amman.

ARKIN, Y. & HAMAOUI, M. (1967): The Judea Group (Upper Cretaceous) in Central and Southern Israel. — Geol. Surv. Isr. Bull., **42**: 1—17; Jerusalem.

AVNIMELECH, M. (1945): New Jurassic Outcrop in the Jordan Valley. — Geol. Mag., **82**: 81—83; London.

BANDEL, K. & HADDADIN, A. (1980): The depositional Environment of Amber Bearing rocks in Jordan. — Dirasat, **6** (1): 39—62; Amman.

BANDEL, K. & KHOURY, H. (1981): Lithostratigraphy of the Triassic in Jordan. — Facies 4, 1—26; Nürnberg.

BENDER, F. (1968a): Geologie von Jordanien. — Beitr. region. Geol. Erde, **7**: 230 p.; Berlin (Gebrüder Borntraeger).

BENDER, F. (1968b): Über das Alter und die Entstehungsgeschichte des Jordangrabens am Beispiel seines Südabschnittes (Wadi Araba, Jordanien). — Geol. Jahrb., **86**: 177—196; Hannover.

— (1975): Geology of the Arabian Peninsula, Jordan. — Geol. Surv. Prof. Pap., **560-I**: 36 p.; Washington.

BENDER, F., BOOM, G. VAN DEN, BUSSE, R., FUTIAN, A., GRIEGER, J., HADDADIN, M., HEIMBACH, W., IBRAHIM, H., JERASAT, K., KHDEIR, K., LAHLOUB, K., LENZ, R., LILLICH, W., RUEF, M., SUNNA, B. & WIESEMANN, G. (1968): Geologische Karte von Jordanien, 5 sheets; Hannover (Bundesanst. Bodenforsch.).

BENTOR, Y. K. & VROMAN, A. (1954): A structural contour map of Israel (1:250 000) with remarks on its dynamical interpretation. — Bull. Res. Counc. Israel, **4** (2): 125—135; Jerusalem.

— (1960): The Geological Map of Israel on 1:100 000 scale, Ser. 1, Sheet 16, Mt. Sdom.-Geol. Surv. Israel; Jerusalem.

BURDON, D. J. (1959): Handbook of the Geology of Jordan. — 82 p., Amman/Jordan (Hashemite Kingdom).

DE SITTER, L. U. (1962): Structural Development of the Arabian Shield in Palestine. — Geol. en Mijnb., **41**: 116—124; Leiden.

COX, L. R. (1925): Bajocian—Bathonian outcrop in the Jordan Valley and its molluscan remains. — Ann. Mag. Nat. Hist., **9** (15): 169—181; London.

DRUCKMAN, Y. (1974a): The Stratigraphy of the Triassic Sequence in Southern Israel. — Geol. Surv. Isr. Bull., **64**: 92 p.; Jerusalem.

— (1974b): Triassic Paleography of Southern Israel and the Sinai Peninsula. Die Stratigraphie der alpin-mediterranen Trias. — Schriftenr. Erdwiss. Komm. Österr. Akad. Wiss., **2**: 79—86; Wien.

— (1977): Differential Subsidence during the Deposition of the Lower Jurassic Ardon Formation in Western Jordan, Southern Israel and Northern Sinai. — Isr. J. Earth-sci., **26**: 45—54; Jerusalem.

DUBERTRET, L. (1932): Les formes structurales de la Syrie et de la Palestine; leur origine. — C. R. Acad. Sci., **195**: 65—67; Paris.

— (1967): Remarques sur la fossé de la Mer Morte et ses prolongements au nord jusqu'au Taurus. — Rev. Geog. phys. Geol. Dyn., **9**: 9—16; Paris.

FREUND, R. (1961): Distribution of Lower Turonian ammonites in Israel and the neighbouring countries. — Bull. Res. Coun. Israel, **10G**: 79—100; Jerusalem.

— (1965): A model of the structural development of Israel and adjacent areas since Upper Cretaceous times. — Geol. Mag., **102**: 189—205; London.

— (1977): Updating the Stratigraphic Framework of Israel. — Isr. J. Earth-sci., **26**: 30—33; Jerusalem.

FREUND, R., GARFUNKEL, Z. & ZAK, I. (1970): The shear along the Dead Sea Rift. — Phil. Trans. Roy. Soc. Lond., **A 267**: 107—130; London.

GOLDBERG, M. & FRIEDMAN, G. M. (1974): Paleoenvironments and Paleogeographic Evolution of the Jurassic System in Southern Israel. — Geol. Surv. Isr. Bull., **61**: 44 p.; Jerusalem.

HENSON, F. R. S. (1956): Tectonic Problems of the Middle East. — 20th Int. Geol. Congr.; Mexico.

GRADER, P. & REISS, Z. (1958): On the Lower Cretaceous of Heletz Area. — Geol. Surv. Isr. Bull., **16**: Oil Div. Pap. 3; Jerusalem.

JARRAR, G. (1979): Geology and Geochemistry of the Wadi Um Sayala/Wadi Araba—Jordan. — Unpubl. Ms-Thesis, Univ. of Jordan; Amman.

KOLODNY, Y. (1967): Lithostratigraphy of the Mishash Formation, Northern Negev. — Isr. J. Earth-Sci., **16**: 57—73; Jerusalem.

LEWY, Z. (1975): The Geological History of Southern Israel and Sinai during the Coniacian. — Isr. J. Earth-Sci., **24**: 19—43; Jerusalem.

LEWY, Z. & RAAB, M. (1977): Mid-Cretaceous Stratigraphy in the Middle East. — Mid Cretaceous events, Museum d'Histoire Naturelle Nice, Annales, **4**: 3—20; Nice.

MIMRAN, Y. (1972): The Tayasir Volcanics, a Lower Cretaceous Formation in the Shomeron, Central Israel. — Geol. Surv. Isr. Bull., **52**: 1—9; Jerusalem.

MOSHKOVITZ, S. & EHRLICH, A. (1976): Distribution of Middle and Upper Jurassic Calcareous Nannofossils in the northeastern Negev, Israel and in Gebel Maghara, northern Sinai. — Geol. Surv. Isr. Bull., **69**: 47 p.; Jerusalem.

MUIR-WOOD, H. M. (1925): Jurassic Brachiopoda from the Jordan Valley. — Ann. Mag. Nat. Hist., ser. **9** (15), 181—192; London.

NEEV, D. & EMERY, K. O. (1967): The Dead Sea, depositional processes and environments of evaporites. — Bull. Geol. Surv. Isr., **41**: 147 p.; Jerusalem.

NEVO, E. (1963): The Jurassic strata of Makhtesh Ramon. — Summary of lectures presented at Makhtesh Ramon Symposium, Israel Geological Soc., 11—12; Jerusalem.

PARKER, D. H. (1970): Sandstone Aquifers of East Jordan. — F.A.O. Technical Report; Rom.

PICARD, L. (1943): Structure and Evolution of Palestine. — Hebrew Univ. Jerusalem, Geol. Dept. Bull., **4**: 135 p.; Jerusalem.

— (1966): Thoughts on the Graben System in the Levant. — Geol. Surv. Pap. Can., **66—14**: 22—32; Ottawa.

— (1968): On the structure of the Rhinegraben with comparative notes on Levantgraben features. — Israel Acad. Sci. Hum., **9**: 34 p.; Jerusalem.

QUENNELL, A. M. (1958): The structural and morphologic evolution of the Dead Sea Rift. — Q. J. Geol. Soc., Lond., **114**: 1—24; London.

— (1959): Tectonics of the Dead Sea Rift. — 20th int. Geol. Congr., 385—405; Mexico.

SALAMEH, E.: The Suweilih Structure. — N. Jb. Geol. Paläont. Mh. — [At print.]

SEIDLITZ, W. V. (1931): Diskordanz und Orogenese der Gebirge am Mittelmeer. — 649 p.; Berlin.

VAN DEN BOOM, G. & LAHLOUB, M. (1962): The Iron-Ore Deposit "Warda" in the Southern Ajlun District. — Unpubl. Rep. Germ. geol. mission Jordan; Hannover (Arch. Bundesanst. f. Bodenforsch.).

WEISSBROD, T. (1968): The Paleozoic of Israel and adjacent countries 1. — Geol. Surv. Isr. Bull., **47**: 34 p.; Jerusalem.

— (1969): The Paleozoic of Israel and adjacent countries 2. — Geol. Surv. Isr. Bull., **48**: 32 p.; Jerusalem.

WETZEL, R. & MORTON, D. M. (1959): Contribution à la Géologie de la Transjordanie. — Notes et Mem. Moyen-Orient, **7**: 95—191; Paris.

WETZSTEIN, A. (1859): Reise in die beiden Trachonen und um das Hauran-Gebirge. — Mitteilungen über Hauran u. d. Trachonen. — Z. Allg. Erdk.: 109—208; Berlin.

WILLIS, B. (1938): Wellings observations of the Dead Sea structure. — Bull. geol. Soc. Amer., **49**: 659—668; New York.

WIESEMANN, G. (1969): Zur Tektonik des Gebietes östlich des Grabenschnittes Totes Meer—Jordantal. — Beih. geol. Jb., **81**: 215—247; Hannover.

Manuscript received by the editor June 30, 1980.

Address of the author:

Dr. KLAUS BANDEL, Institut für Paläontologie, Loewenichstr. 28, 8520 Erlangen.