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Lithostratigraphy of the Triassic in Jordan

Lithostratigraphie der Trias in Jordanien

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SCHLÜSSELWÖRTER: LITHOSTRATIGRAPHIE - TRIAS-GLIEDERUNG - NAHER OSTEN - ARABISCH-NUBISCHER SCHILD - JORDAN-RIFT

INHALT - CONTENT

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A B S T R A C T

The Triassic sequence of Jordan east of the Rift-valley consists of an over 1000 m thick sequence of sedimentary rocks. These sediments were deposited near the shore, either under terrestrial conditions within the intertidal range just offshore, or under saline conditions in a sabkha lagoonal environment. Nine formations are described: Um Irna (80 m), Ma'in (40 m), Dardun (60 m), Ain Musa (80 m), Hisban (35 m), Mukheiris (90 m), Iraq al Amir (170 m), Um Tina (260 m), Abu Ruweis (200 m).

With the exception of large parts of the Um Tina and the Abu Ruweis Formations all other formations are exposed along the NE coast of the Dead Sea and the deep wadis just E and NE of it. Each formation is defined by a type section. The sedimentary rocks are intruded by dykes and sills composed of diabase and gabbro of uniform composition and older than Upper Jurassic in age. Comparison of Triassic rocks from the west side of the Rift (DRUCKMAN 1974, 1977) indicates that the facies and thickness of Jordanian Triassic rocks as well as the northernmost limit of intrusive rocks can only be fitted with those of the central Negev. A relative movement of the Arabian block against Palestine-Sinai of at least 100 km along the Rift is probable (BANDEL 1981).

Z U S A M M E N F A S S U N G

Die triassischen Ablagerungen Jordaniens östlich des Jordan-Totes Meer-Wadi Araba-Grabens bestehen aus einer über 1000 m mächtigen Folge von Sedimentgesteinen, die alle küstennahe Bildungen sind. Sie wurden entweder unter terrestrischen Bedingungen, innerhalb des Gezeitenbereichs oder im küstennahen Flachmeer abgelagert. Während sich in den

unteren 500 m der Trias periodische Aufwölbungen des Arabisch-Nubischen Kontinents im Süden und Südosten durch grobklastische Einschüttungen bemerkbar machen, erfolgte die Ablagerung der oberen 500 m im Gezeitenbereich ohne grobklastische terrestrische Einschüttungen am stark absinkenden Kontinentalrand mit stabilem Hinterland und beeinflußt durch salinare Gewässer.

Neun lithostratigraphische Einheiten (Formationen) werden ausgeschieden und beschrieben: Um Irna (80 m), Ma'in (40 m), Dardun (60 m), Ain Musa (80 m), Hisban (35 m), Mukheiris (90 m), Iraq al Amir (170 m), Um Tina (260 m), Abu Ruweis (200 m). Mit Ausnahme der größten Teile der Um Tina und Abu Ruweis-Formationen sind alle anderen Einheiten in den Seitentälern am Nordost-Rand des Toten Meeres und den tiefen Tälern nordöstlich davon aufgeschlossen. Jede Abfolge wird in einem Typusprofil dargestellt.

In die Sedimentgesteine sind schichtparallele und schichtdurchschlagene Gänge von Diabas und Gabbro eingedrungen. Diese magmatischen Gesteine sind vor-oberjurassischen Alters und dürften auf Grund der ähnlichen Zusammensetzung einen gemeinsamen Ursprung haben. Der Vergleich jordanischer triassischer Gesteine mit solchen, die von der westlichen Seite des Toten Meeres und des Wadi Araba beschrieben sind (DRUCKMAN 1974, 1977), zeigt, daß Fazieslinien und die Nordgrenze der vulkanischen Intrusionen nur dann miteinander in Verbindung gebracht werden können, wenn der Bereich der zentralen Negev zum Nordostende des Toten Meeres und Nordjordaniens entlang der Grabenstruktur der Jordan-Totes Meer-Wadi Araba-Senke um mindestens 100 km verschoben wird (BANDEL 1981).

1 EINLEITUNG - INTRODUCTION

Die ersten Beschreibungen triadischer Sedimente im Gebiet des Wadi Zarqa Ma'in (siehe Abb. 1) und am Toten Meer stammen von BLAKE (1936), BLAKE & IONIDES (1939) sowie von COX (1924, 1932). G. WAGNER (1934) verglich die fazielle Entwicklung der Trias mit dem deutschen Muschelkalk. Weitere lithostratigraphische Untersuchungen stammen von WETZEL (1947), WETZEL & MORTON (1959), LILLICH (1964) und PARKER (1970). Die zusammenfassende Darstellung durch BENDER (1968) stützt sich auf diese, teilweise revisionsbedürftigen Studien.

Von besonderem Interesse sind magmatische Intrusionen innerhalb der Sedimentgesteine (BURDON 1959, PARKER 1970).

Ziel der vorliegenden Arbeit ist die Beschreibung der lithostratigraphischen Einheiten in der Trias von Jordanien und eine Skizzierung der faziellen Entwicklung.

BLANKENHORN (1912) on his expedition from the hot springs of the Wadi Zarqa Ma'in to the hot springs of Ain es Sara in 1908 failed to discover Triassic rocks only because he used the southern slope of the wadi on his way towards the shore of the Dead Sea. BLANKENHORN only noticed Nubian Sandstone, oberlain by Upper Cretaceous marls and limestone, when he looked across Wadi Zarqa Ma'in. The spectacular outcrops of the lower Triassic rocks at the northern slope of Wadi Zarqa Ma'in remained undiscovered until BLAKE (1936) and BLAKE & IONIDES (1939) noticed them. Prior to this, COX (1924, 1932) had discovered Triassic sediments further north in the NE corner of the Dead Sea. He described the rock sequence as well as the fossils content.

When WAGNER (1934), attracted by these reports, visited the outcrops of the Triassic beds in Wadi Siyala, about 3 km south of Wadi Hisban, he was amazed by the similarity of these limestones with those of the "Muschelkalk" found in about the same stratigraphical position in Germany. WAGNER noted a great similarity in facies as well as in faunal content present in these limestones that were deposited so far from each other on different shores of the Tethys. His calculations regarding the thickness of these limestones were somewhat exaggerated with 70 - 100 m (actually little more than 30 m). WAGNER noted that the sequence of limestones in the Wadi Siyala ends with the Upper Jurassic-Lower Cretaceous unconformity and is overlain by Lower Cretaceous sandstone. In the neighbouring Wadi Ain Musa WETZEL & MORTON (1959) measured a section in which a 67 m thick limestone unit is overlain by 100 m of Triassic sediments, consisting of red and green clay with gypsum and yellowish white sandstone. This report is not only erroneous regarding the thickness of the limestone, but also failed to note the quite conspicuous unconformity between Triassic limestone and Lower Cretaceous sandstone exposed very well in Wadi Ain Musa.

The name Hisban Limestone for this calcareous unit of the Triassic rock sequence in Jordan was introduced by DANIEL (1959, 1963). BLAKE (1936) and BLAKE & IONIDES (1939) describing the occurrence of Triassic rocks at Wadi Zarqa Ma'in also found rocks of the uppermost portion of the Triassic sequence in Jordan in lower Wadi Zarqa where Wadi Huni joins it. BLAKE (1936) reported barren red sandstone only near the shore of the Dead Sea, a report that caused difficulties in the reconstruction of Triassic depositional environment by DRUCKMAN (1974, 1977).

According to PARKER (1970) WETZEL (1947) introduced in an unpublished report the term Zerka Group to hold Jurassic and Triassic rocks exposed in Jordan. PARKER (1970) further subdivided the Zerka Group into the Ma'in Formation and the Azab Formation. The Ma'in Formation of Parker is mainly based on the more detailed description of Triassic rocks exposed near the Zarqa Ma'in hot springs by LILLICH (1964). The same section had previously inspired WETZEL & MORTON (1959) to reconstruct the depositional environment of these rocks as derived from deposits of an ancient delta complex. The basal portion of the rock column presented by BENDER (1968) for the Triassic of Jordan is based also on the data of LILLICH (1964) and could in general be verified as correct. The central portion of the rock column in BENDERs study relies on WETZEL and MORTONs (1959) erroneous description of the Wadi Musa section. The upper portion of the Triassic in BENDERs scheme also includes all lower Jurassic limestones and sandstones which are exposed between the Triassic gypsum and the massive Jurassic limestones at the Wadi Zarqa (Dhahab Formation, BANDEL 1981).

Not only sedimentary rocks have been found in the Triassic rock column of Jordan, but BURDON (1959) also recognized dykes and sills exposed in the reddish sandy limestones and associated sandstones in the Wadi Udeimi, about 2 km south of the Wadi

Ain Musa and next to the Wadi Siyale. These magmatic intrusions into the sediments were erroneously characterized to be of acidic composition. WETZEL & MORTON (1959) had noted volcanic ash in the alternating sandy marls, clays and ferruginous sandstones underlying the Hisban Limestone at Wadi Ain Musa.

According to BENDER (1968) these authors had also noted a trachytic sill in these beds. Magmatic inclusions in the Triassic rock column in Jordan have a somewhat mysterious history. PARKER (1970) mentions the presence of volcanic ash intercalations 170 m below the top of Triassic dolomite-anhydrite-shale deposits, while no indication of these beds were found in the drill logs of the test well drilled between Suweilih and Baqa. From a well drilled near Mafraq we have got a sample of magmatic rocks.

The rather incomplete knowledge of the Triassic sequence in Jordan which is so well exposed in its lower portion in numerous easily accessible wadis (Fig. 1) has triggered the authors to carry out this study.

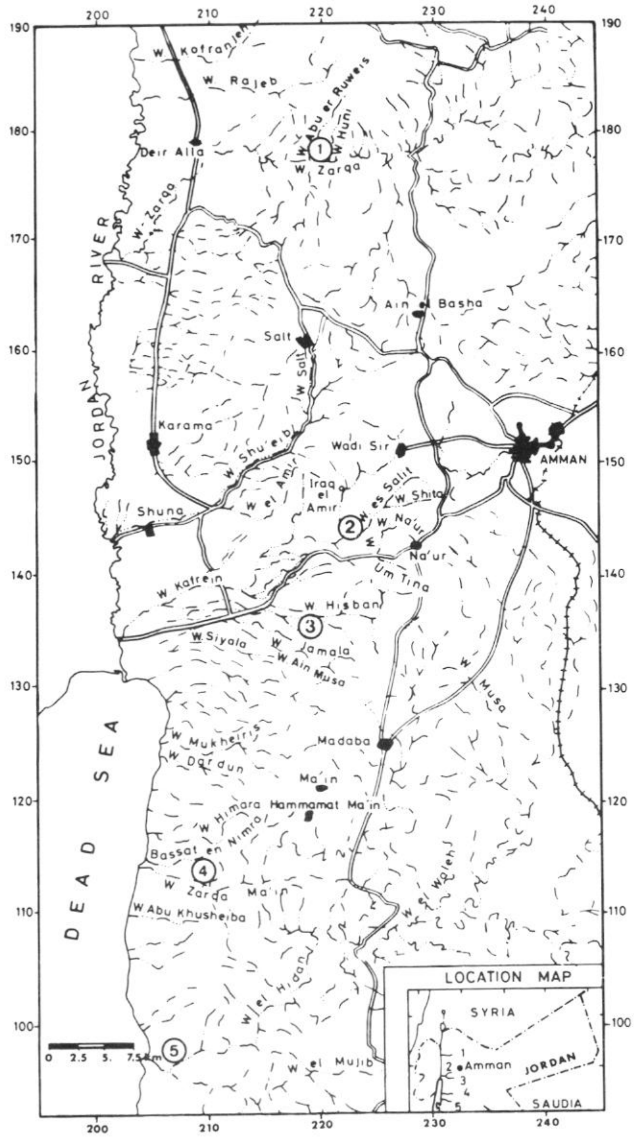

Fig. 1. Triassic lithostratigraphic units in Jordan. Location map. Numbers in circles refer to the type localities of the formations described in chapter 2. Numbers in the inserted map: 1 - Wadi Zarqa, 2 - Wadi Kafrein, 3 - Wadi Hisban, 4 - Wadi Zarqa Ma'in, 5 - Wadi Mujib.

Lithostratigraphische Einheiten in der Trias von Jordanien. Die in Kreise gesetzten Zahlen zeigen die Lage der im Abschnitt 2 beschriebenen lithostratigraphischen Einheiten. Die Zahlen in der kleinen Karte bezeichnen die Lage der Wadi Zarqa (1), Wadi Kafrein (2), Wadi Hisban (3), Wadi Zarqa Ma'in (4) und Wadi Mujib (5).

2 Triassic Rock Column - Schichtfolgen der Trias

Die Schichtenfolge wird in 9 lithostratigraphische Einheiten untergliedert. Die erste wird von der bis zu 85 m mächtigen, terrestrisch-fluviatilen Um Irna Formation gebildet, welche sich in 6 Untereinheiten aufteilen läßt. Jede Untereinheit beginnt in der Regel mit grobkörnigem Sandstein und endet mit entschichtetem Schieferton mit eisenoxydischen Pisoiden. Als zweite Einheit folgt die 35 bis 45 m mächtige marine Ma'in Formation, die sich in eine tonig-siltig-sandige und eine sandige Untereinheit aufgliedern läßt. Die folgende Dardun Formation wird etwa 60 m mächtig und ist in 4 Untereinheiten unterteilt. Die untere ist kalkig, die mittlere sandig, die obere kalkig entwickelt mit fossilreichen Lagen. Die oberste Untereinheit besteht aus einer Wechselfolge von tonigen, sandigen und kalkigen Lagen. Die vierte Einheit wird von der etwa 70 bis 80 m mächtigen Ain Musa Formation gebildet, die in das vornehmlich sandige, fluviatil-litorale Muhtariqa Member, das mittlere sandig-tonig-kalkige Jamala Member und das tonig-mergelige Siyale Member untergliedert wird. Die fünfte Einheit ist die Hisban Formation, die aus einer fossilreichen Kalk-Mergelabfolge von etwa 35 m Dicke besteht. Als sechste Einheit folgt die Mukheiris Formation, die in den unteren 30 m zunächst sandig-siltig, dann sandig-kalkig und fossilreich ist. Die mittleren 30 m sind tonig-siltig und zum teil terrestrisch ausgebildet, die oberen 30 m werden von einer Wechselfolge von Sand- und Siltsteinen eingenommen. Der Übergang zur nächsthöheren Einheit, der Iraq al Amir Formation, ist nicht aufgeschlossen. Die unteren 80 - 90 m dieser Einheit sind nur aus Bohrungen bekannt. Die oberen 90 m werden in das sandig-siltige Bahhath Member, das vorwiegend karbonatische Abu Yan Member und das vornehmlich tonig-mergeligen Shita Member untergliedert. Im letzteren setzt sich bereits eine lagunär-salinare Fazies durch, die auch die folgenden beiden letzten Einheiten charakterisiert. Von der Um Tina Formation sind nur die unteren 70 m mit einer Wechselfolge von laminierter Dolomiten und mergeligen Tonen aufgeschlossen. Die Einheit ist im Untergrund jedoch 200 - 250 m mächtig und enthält hier auch Anhydritlagen. Von der neunten Einheit, der Abu Ruweis Formation, ist nur der höchste Teil der etwa 200 m mächtigen Wechsellagerung von Tonschiefer, Dolomit und Anhydrit aufgeschlossen.

2.1 UM IRNA FORMATION

The type section is situated in the Wadi Himara about 3 km north of Zarqa Ma'in hot springs (Fig. 1). The formation has received its name from the mountain range that separates Wadi Zarqa Ma'in from Wadi Himara.

Rocks belonging to the about 85 m thick Um Irna Formation are exposed for about 8 km between Wadi Zarqa Ma'in and Humrat Ma'in (Fig. 2). Together with their base consisting of hard brown Cambrian sandstones they disappear below the level of the Dead Sea and below surface. Their top is formed by the first beds with abundant bioturbation.

The Um Irna Formation at Wadi Himara can be divided into 6 members, each of which shows a more or less characteristic gradation in grain size and composition. The base of

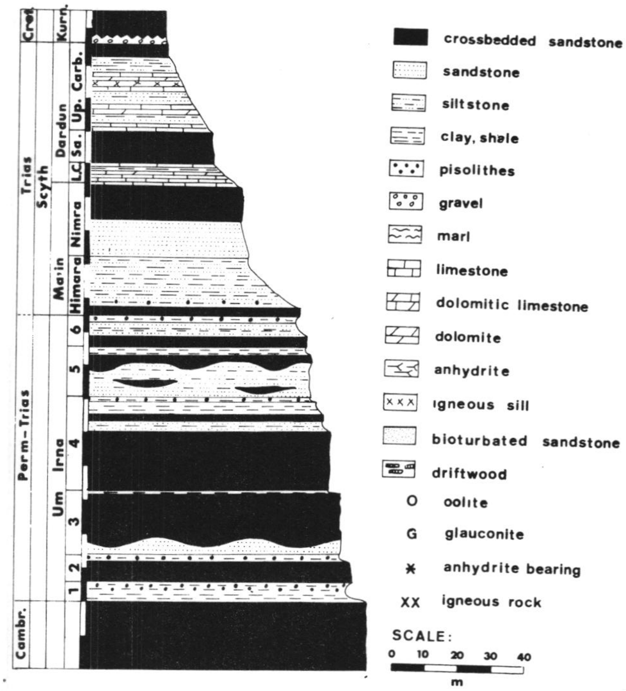

Fig. 2. Columnar section of the Bassat en Nimra, lower Zarqa Ma'in and Wadi Himara outcrops at the northeastern coast of the Dead Sea.

Säulenprofil der Aufschlüsse im Gebiet von Bassat en Nimra, im unteren Wadi Zarqa Ma'in und im Wadi Himara, Nordostküste des Toten Meeres.

each member, except the lowermost, consists of a coarsely grained crossbedded sandstone usually with a conglomeratic base. Individual crossbeds as well as their laminae are normally graded. The basal beds are overlain by laminated silt and clay beds. Bedding planes often show ripples and mud cracks. Layers may contain angular clay intraclasts and rounded mud balls. Into the fine grained beds, channels may be cut filled with crossbedded sand. The uppermost bed of each of the members is composed of non-laminated clay which in four of the 6 members in its upper portion contains irregularly distributed iron-oxidic pisolites.

These rounded pisolites may be up to 20 mm in diameter. They are most probably autochthonous. The lowermost member consists of silt and clay only and in its lowest part it contains abundant plant fragments within a grey clay. Accordingly the Um Irna Formation is composed of 6 sedimentary cycles of terrestrial deposits without any traces of bioturbation. The sediment deposited here has been eroded from the nearby Precambrian basement as it is documented by porphyrite pebbles and by often subrounded to angular quartz gravel (Ø to 5 mm) representing the coarse components of the basal portion of the cycles. These quartz grains were derived from weathered granitic rocks of the basement that must have been exposed to erosion not very far to the south. The cyclic deposition reflects cyclic erosion of the Precambrian basement of the Arabian-Nubian Shield during Um Irna time. Deposition of each of the graded mem-

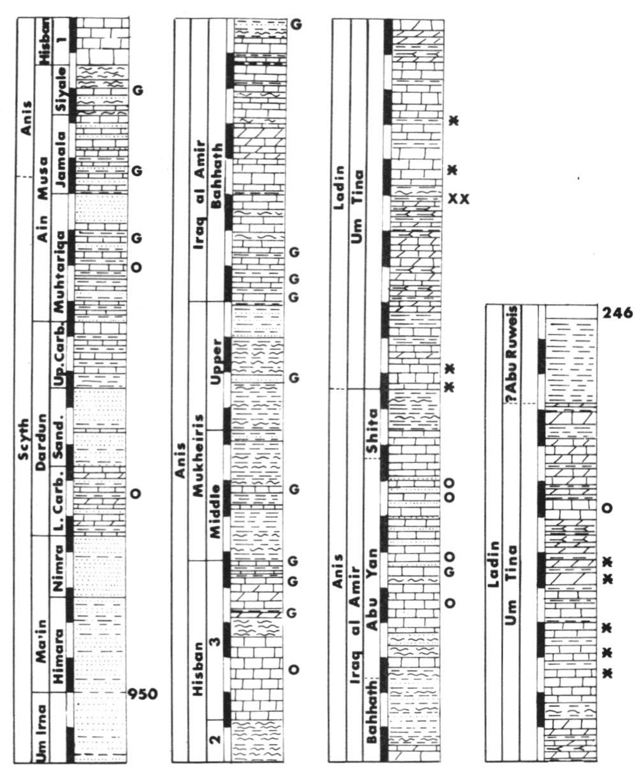

Fig. 3. Columnar section of the Suweilih well near Suweilih and Baqa. Depth - 246 to - 970 m below surface. For legend see Fig. 2.

Säulenprofil der Bohrung Suweilih zwischen Suweilih und Baqa. Tiefe - 246 bis 970 m. Legende siehe Abb. 2.

bers was probably rapid, followed by a long period of non-deposition during which the fine-grained topmost layers were weathered into a soil.

In the deep-well Suweilih 1 (Fig. 3), the whole rock sequence of the Triassic was penetrated with a thickness of 1000 m.

White to brown Cambrian sandstone with micaceous shale partings is overlain by varicoloured sandstone with yellow and tan limestone beds and shale. These lowermost 15 m are overlain by about 40 m of white and brown sandstone and some brown shale. The typical coloration and lithology of the following beds indicate that the Um Irna Formation about 50 km to the NNE, at least in its lower portion, was influenced by marine conditions and also has decreased in thickness from 85 to 55 m.

2.2 MA'IN FORMATION

The name Ma'in Formation has been applied to a unit between 35 and 45 m thick which is well exposed in Wadi Zarqa Ma'in and in all wadis up to Wadi Mukheiris about 13 km to the North. Further to the North the Ma'in Formation disappears below surface and can be recognized in the subsurface only in the Suweilih 1 well. Two members, the Himara Member and the Nimra Member, are distinguished. The base of the formation is characterized by the first occurrence of bioturbation and the purplish colour of the beds; the top is formed by the contact between sandstone and the limestone of the Dardun Formation.

Himara Member

The sequence was measured in Wadi Himara (Fig. 2) as well as in Wadi Dardun (Fig. 4). The name of the member is derived from Wadi Himara where it is very well exposed. The conspicously dark purplish beds of the Himara Member are seen in all the side wadis of the E side of the Dead Sea from Wadi Zarqa Ma'in to Wadi Mukheiris. While the Member is high up in the escarpment of the Ma'in area, it has reached almost the level of the Dead Sea at Wadi Mukheiris.

The member is about 15 m thick and consists of an alternation of thinly bedded sandstone, siltstone and clay often with considerable amount of carbonate. Burrows are present throughout, suface traces can be found on bedding planes together with ripples and mud cracks. Thin, pure dolomitic limestone beds are developed at Wadi Mukheiris, often with rippled surfaces and abundant bivalve shells.

Nimra Member

The Nimra Member measures about 20 m in thickness at Wadi Zarqa Ma'in and at Wadi Dardun (Fig. 2) and 25 m in Wadi Mukheiris (Fig. 5). The upper portion of the rock unit is composed of fine white sandstone arranged in crossbedded units of 50 to 150 cm thickness. In its lower portion flaser structure is pronounced and red and green silt and clay partings as well as carbonate rich beds are developed. Bioturbations are developed throughout, somewhat more common in the flaser beds. Some pure limestone units are included in the upper portion of the member in Wadi Mukheiris only. In the fine grained limestones, intraclast horizons are common, with intraclasts being often fragments of reworked burrows which, further up in the section, are characteristic for the limestones of the Hisban Formation.

In Suweilih 1 well (Fig. 3) the beds probably equivalent to the Ma'in formation measure about 45 m in thickness and consist of sandstones mainly intercalated with thin beds of shale and marl.

There is ample evidence indicated by dolomitic limestone, flaser bedding, mud cracks and ripple surfaces, lamination, bioturbation, marine bivalves and burrow remains for a deposition of the Ma'in Formation within the tidal zone or in very shallow water. The influence of the sea again is more pronounced in the northern section.

2.3 DARDUN FORMATION

Type Locality is the Wadi Dardun (Fig. 1) where a section is exposed, 60 m in thickness and showing all members (Fig. 4). Its base is formed by limestone beds and its top by the first bioturbated silty layers below the Ain Musa sandstone base. With exception of the uppermost member the three other members of this formation are extensively exposed at the northern slope of Wadi Zarqa Ma'in almost up to the lowermost hot springs. The complete formation is present also at Wadi Himara (Fig. 2) and Wadi Mukheiris (Fig. 5), all of the four members can also be recognized in the Suweilih 1 well (Fig. 3) even though the upper border of the formation can not be characterized with certainty here.

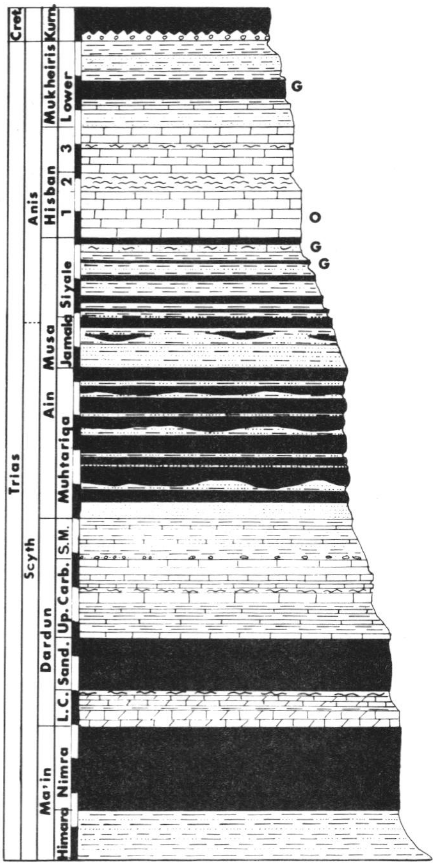

Fig. 4. Columnar section of the Wadi Dardun exposure at the northeastern coast of the Dead Sea.

Säulenprofil der Aufschlüsse im Wadi Dardun an der Nordostküste des Toten Meeres.

Lower Carbonate Member

This member measures about 11 m in thickness and consists of thinly layered dolomitic limestones, laminated shale with thin dolomite beds intercalated and of laminated marl. Bioturbation is observed throughout but does not destroy the lamination.

Sandstone Member

This member is about 15 m thick and composed of crossbedded white sandstone with very uniform grain size. In its uppermost portion; a layer with dolomitic and marly intraclasts is developed.

Upper Carbonate Member

This member is 23 m thick and composed of laminated limestones and dolomitic limestones mainly. Intercalations of shales and mud cracked laminites as well as intraclast layers are found within the lower

10 m of the unit. Often one rock type grades laterally into the other. Bioturbation features are present throughout only rarely obliterating the original sedimentary structures. Pure sparry and micritic limestones with echinoidal fragments occur. The upper part of this member consists of marl and fine laminated and bioturbated limestone showing layers with clay pebbles.

Sandy Member

This member measures about 12 m in thickness and consists of bioturbated sandstone beds mainly. Intraformational conglomerate layers are present with pebbles of limestone and shale. Up to 0.8 cm in diameter wide angular or only little rounded quartz grains are found as well as purplish and greenish silt and shale. Carbonate beds are thin and show rippled surfaces and often bivalves on their bedding planes.

The sediments of the Dardun Formation very clearly reflect in their composition the vicinity of land in the south and the increased influence of the sea towards the north. At Wadi Mukheiris (Fig. 5) the Dardun Formation contains sand only in subordinate amount. At Wadi Dardun sandstone forms a 15 m thick unit whereas the thickness is about 20 m in the Suweilih 1 well (Fig. 3). Sandstone is present almost throughout in the Zarqa Ma'in area. Marine shallow water conditions reached the Dardun area during the deposition of the central part of the Upper Carbonate Member. This is indicated by the deposition of some crinoidal limestone. Otherwise stromatolitic lamination, intraclast beds, clay balls, mud cracks and dolomitization indicate deposition on intertidal mudflats. The sand is well sorted in the lower parts of the Dardun Formation but not in the Sandy Member of this unit. Small angular to subrounded quartz pebbles as well as intraformational conglomerates indicate a relative uplifting of the Precambrian shield in the south resulting in a renewed erosion of the crystalline basement and in the deposition of coarse detrital sediment originating from the erosion of carbonate and clay sediments which have been deposited in a near-coast environment.

2.4 AIN MUSA FORMATION

The formation name is derived from Wadi Ain Musa (Fig. 1), where below the confluence with Wadi Jamala a sequence encompassing most of this formation is exposed (Fig. 6). The Ain Musa Formation consists of three members: Muhtariqa Member, Jamala Member and Siyale Member. The rocks of the about 70 - 80 m thick Ain Musa formation south of Wadi Dardun are cut by the Upper Jurassic-Lower Cretaceous unconformity, the uppermost beds of the formation disappear below the surface north of Wadi Hisban. The base of the formation is characterized by a massive sandstone and its top by the contact to the massive limestone banks of the Hisban Formation.

Muhtariqa Member

The Rujm el Muhtariqa hill, situated at the end of the Wadi Ain Musa is the type-locality of this member. In the lower Wadi Ain Musa the upper 12 m of this sandstone member are exposed. North of this outcrop the Muhtariqa Member appears in the Suweilih 1 well (Fig. 3) with 8 m of middle grained to coarse white sandstone on top of an underlying sequence similar to that of Wadi Mukheiris. At Wadi Dardun (Fig. 4) the whole member is well exposed and composed of sandstone with flaser

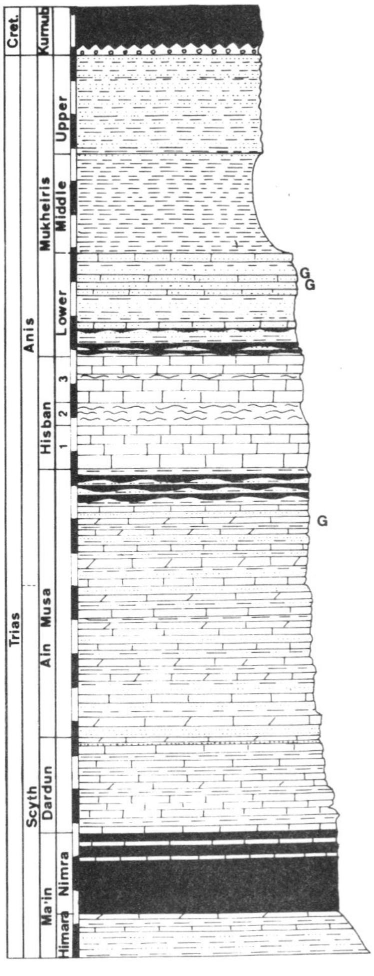

Fig. 5. Columnar section of the Wadi Mukheiris exposure, northeastern coast of the Dead Sea. For legend see Fig. 2.

Säulenprofil der Aufschlüsse im Wadi Mukheiris an der Nordostküste des Toten Meeres.

structure in its lower part and coarsely crossbedded sandstone units separated from each other by silty partings in its upper part. The Muhtariqa Member measures 45 m in thickness. Only the lower beds show traces of infaunal life while further up, undisturbed laminations of crossbeds are seen. Layers with clay balls, unidirectional crossbed inclination, quarz pebble layers and the common occurrence of drift wood indicate fluviatile influence in these beds, while the flaser beds at the base more likely are deposits of a intertidal or shallow water environment. Only 4 km to the north, in Wadi Mukheiris (Fig. 5) the Muhtariqa Member is represented by a sequence consisting of sandstone beds, limestone layers, dolomitic limestone beds and siltstones; similar to those beds considered as equivalent in Suweilih 1 well (Fig. 3).

Jamala Member

The unit exposed below the confluence of Wadi Jamala with Wadi Ain Musa has received the name from Ain el Jamala, a refreshing spring that issues from the ground of Wadi Jamala. The Jamala Member of the Wadi Ain Musa locality (Fig. 6) consists of

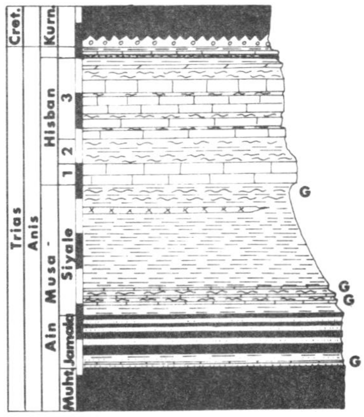

Fig. 6. Columnar section of the exposures in Wadi Ain Musa and Wadi Hispan at the northern coast of the Dead Sea. For legend see Fig. 2.

Säulenprofil der Aufschlüsse im Wadi Ain Musa und im Wadi Hispan an der Nordostküste des Toten Meeres.

intercalated siltstones claybeds and sandstones. Near the base of the member, a limestone bed occur which contains glauconite sand and an intraformational conglomerate composed of shale pebbles. This limestone bed is intercalated within more or less carbonate-rich sandy flaser beds. Silt and shales follow together with crossbedded, hard sandstones. The later show current marks on bedding planes and large trunk fragments of drift wood.

Trace fossils (crab burrows, *Chondrites*) are present throughout and demonstrate that the whole 15 m of the Jamala Member in Ain Musa area were deposited in marine environment with fluviatile influence.

The Jamala Member at Wadi Dardun (Fig. 4) is somewhat thicker (18 m) and more sandy in composition, but generally of similar lithology. A dolomitic bed at the top of the member contains randomly distributed angular to rounded quartz pebbles up to 5 mm in size which habe been mixed into the limestone matrix by bioturbation.

Siyale Member

The Siyale Member is exposed at Wadi Ain Musa (Fig. 6) above Jamala Member and forms a gentle slope overlain by the hard rocks of Hisban limestone. The name is received from Wadi Siyale just south of Wadi Ain Musa. At Wadi Ain Musa, about 30 m of clay and marl compose this member. Here the base of Siyale Member contains three fossiliferous bioturbated calcareous beds; the upper two beds yield much glauconite. The gray, green and purple marl was deposited in a marine environment, this is demonstrated by bioturbation, the occurrence of glauconite and the common presence of shells of *Lingula*. The upper part of the Siyale Member is exposed at Wadi Hisban 3.5 km to the NE with fossiliferous marl beds and claystone. In Wadi Mukheiris (Fig. 5) the lower portion of the Siyale Member can not be separated from the Jamala Member. In its upper portion the Siyale Member contains some sand filled channel deposits. At Wadi Dardun (Fig. 4) the rock column of Siyale Member is much thinner. Here only about 24 m of sediment are developed composed of glauconitic limestones and sandstones, bioturbated greenish clay and some crossbedded sandstone units. The member is fossiliferous especially in the calcareous beds. At the Suweilih 1 well (Fig. 3) the Jamala Member can be differentiated from the Siyale Member only provisionally. The whole Ain Musa Formation at Suweilih as well as at Wadi Mukheiris is composed of a succession of sandy and shaly limestones, shales and shaly sandstones of 60 - 70 m in thickness. At Suweilih glauconite is present in several levels indicating a marine depositional environment. In Wadi Mukheiris (Fig. 5) bioturbational features are present throughout; the existence of shallow water intertidal conditions is indicated by crossbedded channel-filled sands in the uppermost portion of the Siyale Member. South of Suweilih 1 well and Wadi Mukheiris the influence of the Arabian-Nubian Continent on the sedimentation is documented by fluviatile sandstone units of the Muhtariqa Member, channel-fillings, intraformational conglomerates and angular quartz grains.

2.5 HISBAN FORMATION

The name Hisban Limestone for rocks of the Hisban Formation was proposed by R. WETZEL (1947). The name is derived from Wadi Hisban (Fig. 1), where all members of this formation are well exposed (Fig. 6). The section measured in Wadi Dardun (Fig. 4) is about 35 m thick. Here it is undisturbed from dolomitization and truncation and better exposed than in Wadi Hisban. South of Wadi Dardun the rocks of Hisban Formation are eroded by the Upper Jurassic-Lower Cretaceous unconformity and sediments above belong to the Lower Cretaceous Kurnub Sandstone. From here the Hisban Formation can be traced along the slopes of the mountains bordering the Dead Sea. North of Wadi Hisban, Triassic beds disappear below the Cretaceous sediments.

The Hisban Formation consists of bedded limestones with marly intercalations. The bulk of the limestone is characterized by calcareous, lithified burrow systems, all of the same undulating type. Usually these burrows are preserved in-situ within the more marly limestone matrix.

The burrows cause a very characteristic grey mottling in the yellowish-white rock, or, if the rock surface is weathered, they extend over the eroded matrix as an irregular network of 0.5 to 0.7 cm wide massive cylindrical rods. The tubes are of oval outline with a shallow concave groove on one side. The burrows were lithified prior to the sediments.

This is documented by intraclast beds and layers with intraclasts composed of fragments of these burrows. Similar intraclast limestones have been noted in the Nimra Member of the Ma'in Formation in Wadi Mukheiris and also at the same locality in some limestone beds of the Ain Musa Formation. This shows that calcareous sediments with the characteristical bioturbational features of the Hisban limestones were formed in the offshore area before the Hisban Formation time.

Marly beds of the Hisban Formation usually yield a rich fauna composed mainly of oysters and brachiopods. Often glauconite sand is mixed by. Beds rich in clay usually exhibit different types of well-preserved trace fossils, as well as *Lingula*.

In Wadi Hisban a reddish claystone occurs containing large oyster shells. No such bed is seen in Wadi Dardun within the marly interlayer above the basal limestone unit but a crinoidal limestone is found here lacking in Wadi Hisban. The great similarity between the northernmost outcrop of Hisban Formation in Wadi Hisban and the southernmost at Wadi Dardun (distance about 18 km) as well as the lack of indications for a coastal environment at Wadi Dardun, shows that the Hisban Formation probably extended onto the Arabian-Nubian Continent which at Hisban time remained stable. The greater thickness of Hisban Formation in the Suweilih 1 well (Fig. 3) and the lesser thickness of Mukheiris Formation above may indicate that the formation of Hisban limestone type continued during the Mukheiris time. Oolitic beds included in the limestones at Suweilih indicate a deposition in shallow water similar as in the outcrops near the Dead Sea.

2.6 MUKHEIRIS FORMATION

The formation is named after the Wadi Mukheiris (Fig. 5), the last most northern deep Wadi ending directly at the shore of the Dead Sea. The Mukheiris Formation is understood to encompass all sediments preserved above the limestones of Hisban Formation up to the Upper Jurassic-Lower Cretaceous unconformity surface. The formation is about 90 m thick and can be split into 3 members:

Lower Member of the Mukheiris Formation

The Lower Member is about 30 m in thickness. The lower 15 m consist of crossbedded sandstone beds, up to 1,5 m thick, forming channel-fillings in silt and clay beds.

The upper 15 m of the Lower Member consist of calcareous sandstone intercalated with sand and clay. A marine depositional environment of these beds is indicated by strong bioturbation throughout and by the presence of glauconitic sand. Some beds are rich in fossils (shells of bivalves and cephalopods, bones of reptiles).

Middle Member of the Mukheiris Formation

The Middle Member consist of 30 m of clay and green or purple silty shales. Fossils (mainly *Lingula*) are found only in the lower few meters of the sequence. The higher laminated beds yield no fossils.

Upper Member of Mukheiris Formation

The unit is about 30 m thick and consists ofa succession of sandstones, clay claystones and siltstones. The sandstones are bioturbated or crossbedded. Some beds contain conglomeratic layers with quartz pebbles measuring up to 6 mm in diameter. Drift wood is found locally. Plant fragments are common on bedding planes of the silty, laminated claystone. The Upper Member is truncated by an unconformity and overlain by the Lower Cretaceous sandstones of the Kurnub Group.

To the NE, in Wadi Ain Musa, the Kurnub sandstones overly directly limestones of Hisban Formation. Further to the NE in Wadi Hisban (Fig. 6), a few meters of the Lower Member of Mukheiris Formation are preserved below the truncation. They consist of claystone with *Lingula*, bioturbated silty sandstone and bioturbated marl. There is no indication of crossbedded channel sands as in Wadi Mukheiris. In Wadi Dardun (Fig. 4) channel sands are absent too. Here the Lower Member is present in nearly total thickness, but shows a composition with sandy beds, often bioturbated and with current-marks and driftwood on bedding planes. Bioturbated dolomite and glauconitic marly sandstone characterize the upper border of the 15 m thick lower part of the "Lower Member".

The upper part, 11 m thick, consists of silty claystone interlayered with silty sandstone near the base of the Lower Cretaceous sandstone.

In the Suweilih 1 well (Fig. 3), about 70 m of sediment can be correlated lithologically with the Mukheiris Formation exposed at the Dead Sea. The deposition of limestones at Suweilih seems to have continued from Hisban to Mukheiris times. The Lower Member of the Mukheiris Formation represents marine deposits with strong calcareous influence in Dardun and Mukheiris as well as in Hisban. The uppermost 21 m of Hisban limestone at Suweilih are rich in glauconitic sand, with gray mottled limestone at the base. These glauconitic limestones can be considered as the time equivalent of the Lower Member. The gray and brown shales at Suweilih may correspond to the Middle Member. Regarding this as valid correlation the Middle and the Upper Member of the Mukheiris Formation at Suweilih measures about 70 m in thickness, which is only a little more than at Wadi Mukheiris where 60 m are preserved. In contrast to the arenaceous Upper Member at Wadi Mukheiris

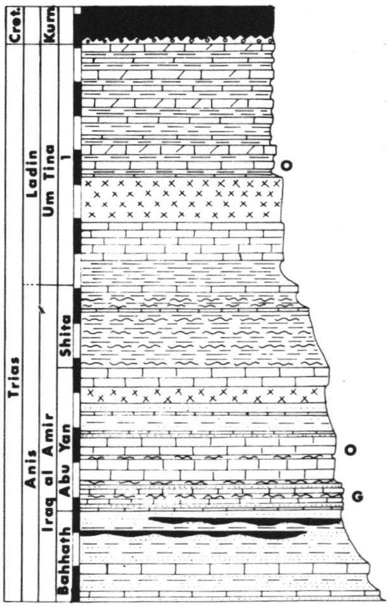

Fig. 7. Columnar section of the Wadi Naur and Wadi es Salt exposures, west of Naur. For legend see Fig. 2.

Säulenprofil der Aufschlüsse im Wadi Naur und im Wadi es Salt, westlich von Naur. Legende siehe Abb. 2.

only little sand is found at Suweilih, within a 9 m thick sequence together with varicolored shales and grey marls.

The transition of beds of the Mukheiris Formation (Fig. 5) to the following Iraq al Amir Formation (Fig. 7) is not exposed, but the Suweilih rock column (Fig. 3) indicates that there is no additional sediment of this formation to be expected.

2.7 IRAQ AL AMIR FORMATION

In Wadi es Salt and lower Wadi Naur just W of Naur (Fig. 1) Triassic rocks are exposed (Fig. 7). The Iraq al Amir Formation is exposed here because a shallow dome-shaped structure with low inclination on the eastern side and a steep slope on the W-side is cut by the deep wadi for a distance of approximately 1,5 km. The Iraq al Amir Formation is named after the location of a beautiful hellenistic temple that was built in the lower Wadi Sir near its confluence with Wadi Naur (Fig. 1). Three members have been differentiated within this rock unit: Bahhath, Abu Yan, and Shita Member. The upper boundary of the formation is characterized by the laminated stromatolitic carbonates of the basal Um Tina Formation.

Bahhath Member

The rocks of the Bahhath Member are exposed in Wadi Naur below its confluence with Wadi es Salt only. The Bahhath Member is about 26 m thick and received its name from the strong spring of Ain Bahhath sending its water into Wadi Shita, only a little more than 1 km to the north. The sediments mainly consist of fine sandstone, silt, and clay beds, into which two 1.5 and 2.8 m thick massive units of nodular limestones are intercalated. These limestones are fossiliferous and strongly bioturbated. Detrital sandy and silty beds between them are laminated, crossbedded, or totally bioturbated. Bioturbated sandstones usually are rich in oyster shells. Well preserved plant fossils are common on bedding planes of silty clay beds. Drift wood is present in these beds as well as some small sand-filled channels.

Abu Yan Member

This member predominantly consists of carbonate rocks and shows a total thickness of about 38 m. Good exposures occur at the confluence of Wadi es Salt and Wadi Naur. The lower 8 m are very fossiliferous nodular limestones and marls with bioturbated intercalations of layers rich in sand and glauconite. The fauna consists of abundant bivalves, gastropods, brachiopods and vertebrate remains. This lower part is overlain by about 9 m of coarse-grained limestone with shell coquinas and oolites, and a 10 m thick bioturbated silty sandstone rich in shells, with thin intercalations of fossiliferous limestone beds. The top is formed by 5 m of massive locally dolomitized limestones.

Shita Member

The Member received its name from Wadi Shita which discharges into the Wadi Naur just down of the disappearance of Triassic outcrops below surface. The Shita Member is approximately 25 m thick, and composed of gray shale and marl, and with 2 m of hard limestone at the top. The marls and clays are bioturbated, some layers are rich in marine fossils (oysters and other bivalves, echinoderms). The limestones in the lower part of the section are intraclast limestone with a yellowisch matrix and grey mottles. The intraclasts are due to fragments of burrows that were lithified before the surrounding sediment became indurated, similar to the Hisban Formation. In the upper part, laminated algal limestones are interbedded with marly limestones containing a rich marine fauna.

The base of Iraq al Amir Formation in the Wadi Naur area is not exposed. From the rock column of the Suweilih well (Fig. 3) it is evident that the first traces of anhydrite in the rock column can be most probably correlated with the Lowermost parts of laminated algal-mat limestones top of the Iraq al Amir Formation, which are found 150 m above the top of the Mukheiris Formation (Fig. 3). This would indicate a gap of about 80 - 90 meters of sediment belonging to the Iraq al Amir Formation not exposed between the outcrops of the Dead Sea area (Fig. 5) and the Wadi Naur (Fig. 7). Therefore it seems that only the upper 90 m of Iraq al Amir Formation are exposed, the total thickness of this formation then would be 170 to 180 m.

Generally the influence of coarse terrestrial erosional products is decreasing during the time of the deposition of the Iraq al Amir Formation. While the Bahhath Member is still sandy with a predominance of silt, sand becomes less dominant in Abu Yan Member and is practically absent in Shita Member. In the following Um Tina Formation no more sand reaches the depositional area in the Wadi Naur region, the Suweilih region and in the area of North Jordan near Mafraq (Ramtha test well, Fig. 8). The facies of the sediments of the Iraq al Amir Formation indicates a deposition in a shallow sea with open-marine conditions. The lower Bahhath Member sediments may have been, in part, deposited in a coastal environment. The uppermost limestones of the Shita Member in Wadi Naur demonstrates clearly a major break in the depositional history. It consists in its lower part of the typically mottled limestone formed in the far-coast shallow-water carbonate environment from the time of deposition of the Ma'in Formation onward into that of the Iraq al Amir Formation. The upper portion of this unit and the following two formations of the Triassic rock column are characterized by laminated, often dolomitic limestones associated with evaporites, indicating a restricted environment with only meager terrigenous influence shown by the sedimentation of clay.

2.8 UM TINA FORMATION

Near the confluence of Wadi es Salt and Wadi Naur (Fig. 1), and in Wadi Um Tina, 1 km south of Wadi Naur, about 70 m of interbedded dolomitic limestones and marly grey clays are exposed (Fig. 7). All the sediments are characterized by laminated parallel or wavy stromatolitic structures. The rocks of lower Um Tina Formation are bioturbated, whereas in upper parts of the section burrows are rare in comparison with the dominant stromatolitic limestones and marly shales. At the base oolitic beds are exposed. Layers with intraclasts and mud-cracked beds are frequent. In the uppermost, slightly dolomitic limestones oval, cushion-like stromatolitic bodies occur in all the three wadis.

The thickness of the Um Tina Formation increases to the northeast. About 200 m of alternating shales and dolomitic limestones and anhydrite were found in the Suweilih test well (Fig. 3) and 250 m of such sediments at the Ramtha 1 test well (Fig. 8). Anhydrite is usually distributed randomly within the various types and does not form distinct rock units.

2.9 ABU RUWEIS FORMATION

The uppermost part of Abu Ruweis Formation is only exposed in the northernmostoutcrop of Triassic sediments in the lower Wadi Zarqa between the confluence of Wadi Huni and Wadi Abu Ruweis (Fig. 1), from which the formation received its name. The exact thickness of the formation in this outcrop can not be measured because of strong sliding effects and anhydrite dissolution.

In the Mafraq area (Ramtha 1 well, Fig. 8) the Abu Ruweis Formation is about 200 m thick and composed of alternating layers of clay, shale, dolomite and anhydrite. Its base is defined by the first thick bed of anhydrite and its top by the first Jurassic rocks. In the Wadi Zarqa dolomitic laminated marls and limestones, clays and anhydrites are exposed. The anhydrite is laminated and forms thick units. Beds with anhydrite intraclasts embedded within a marly matrix demonstrate a near-shore supratidal sabkha environment with salinar pools, probably extending very far onto the continent to the south, and influenced periodically by the northern open sea. Terrigenous influx is minor, no freshwater is discharged into the basin. The depositional basin subsided from the beginning of the Um Tina time to the

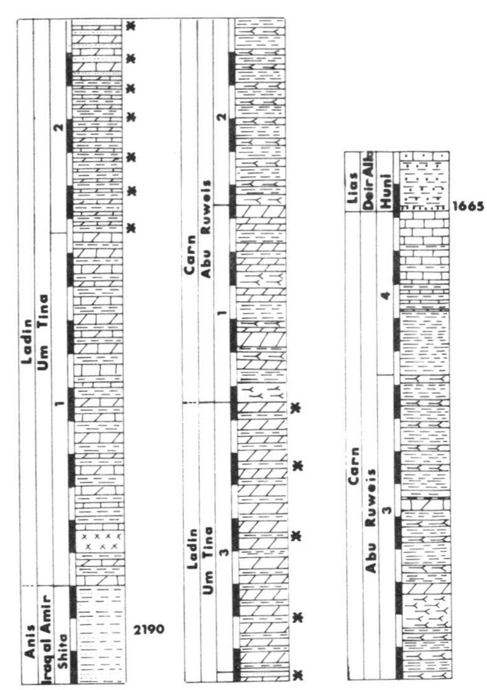

Fig. 8. Columnar section of the Ramtha 1 well near Mafraq. Depth - 1665 to 2190 m below surface. For legend see Fig. 2.

Säulenprofil der Bohrung Ramtha 1 bei Mafraq. Bereich zwischen 1665 m und 2190 m. Legende siehe Abb. 2.

end of the Abu Ruweis time for 540 m at the Mafraq area and probably for the same interval at the Wadi Zarqa area. During the subsidence sedimentation was rapid enough to keep the area at sea level. Sediments were formed under sabkha conditions within the inter-and supratidal regions. In the area of Suweilih sediments of the Abu Ruweis Formation were largely eroded before the deposition of the Kurnub Sandstone on the erosional surface formed by clays and leached evaporites took place.

3 IGNEOUS ROCKS - VULKANITE

Gänge vulkanischen Gesteins durchsetzen die verschiedenen Einheiten der triassischen Schichtenfolge sowohl in schichtdurchschlagender als auch schichtparalleler Form. Außer im Bereich des Wadi Zarqa sind Vulkanitgänge in allen Aufschlüssen und auch in den beiden Bohrprofilen von Suweilih und Mafraq anzutreffen. Die Gänge setzen sich in die liegenden Schichten des Kambriums fort und wurden im Hangenden während der oberjurassisch-kretazischen Erosionsphase abgetragen.

Die vulkanischen Ganggesteine bestehen aus porphyrischem Diabas oder grobkristallinem Gabbro und sind im unverwitterten Zustand vornehmlich aus Plagioklasen (Labradorit) und Pyroxenen (Augit und Pigeonit) zusammengesetzt. Die Minerale sind durch Kontaktmetamorphose und Verwitterungsprozesse unterschiedlichen Alters häufig sekundär umgewandelt.

Occurrence

Dykes and sills of igneous rocks have been found distributed throughout the Triassic rocks in Jordan with exception of Wadi Zarqa area. At Zarqa Ma'in, a weathered sill is exposed about 11 m below the Kurnub Sandstone within the upper Sandy Member of the Dardun Formation. The weathering took place during Upper Jurassic and Lower Cretaceous. At the base of the rock-cliffs of the Bassat en Nimra (Fig. 1), a dyke penetrates Cambrian rocks exposed at the shore of the Dead Sea just north of the mouth of the Zerqa Ma'in river. It is perhaps the same dyke that cuts the rocks of the Ma'in Formation almost vertically at the slope of the Um Irna Massive. Between this locality and Wadi Himara, dykes and sills of different thickness between 20 cm and 2 m are found in beds of the Ma'in and Dardun Formations. In Wadi Himara, at the contact between Cambrian sandstones and clays of the Um Irna formation a massive, thick dyke penetrates hard Cambrian sandstones and bends into horizontal position to form a sill that follows the lithological border between coarse sandstone and clay.

In Wadi Dardun no dykes and sills were noted. In Wadi Mukheiris the beds of the Dardun Formation exhibit sills of different thickness. A conspicuous dyke cuts through a succession of sandstone, shale, and limestones in the Ain Musa Formation. A very solid and thick sill is present in the lower part of the Wadi Hisban (Fig. 1), intruding into the

Siyale Member of the Ain Musa Formation. A dyke is exposed also in Wadi Hisban cutting the Hisban Formation and is truncated by the Upper Jurassic-Lower Cretaceous unconformity. The Upper Jurassic-Lower Cretaceous weathering was effective some meters down the magmatic rocks of the almost vertical dyke. In Wadi Naur area two conspiceous sills are exposed (Fig. 7) reaching a thickness of 30 m. The lower one has intruded the lithological border between silty sand and limestone in upper Abu Yan Member of Iraq al Amir Formation. It can be traced in the same stratigraphical position in all the Triassic outcrops of Wadi Naur. This sill seems to be splitted into two parts separated by a breccia consisting of magmatic and sedimentary rocks. The upper sill intruding the lowermost Um Tina Formation is well exposed in Wadi es Salt, Wadi Naur and Wadi Um Tina.

Composition

Both of the thick sills in Wadi Naur area mineralogically are of the same composition. Labradorite crystals (1-4 mm) and clinopyroxenes (augite and pigeonite) constitute the bulk of the rock. A small percentage of hypersthene is present. Plagioclase crystals are mainly labradorite showing albite seldom Carlsbad twinning. In several thin sections plagioclase crystals are replaced by analcite. Other alteration products of plagioclase are sericite, saussurite and clay minerals. The Fe-Mg minerals often are highly altered to chlorite, iron oxides and amphiboles. In some samples a complete alteration to chlorite, hornblende, and biotite was noted. Muscovite and sericite are also present and are probably alteration products. Brown relict rims of pyroxenes are still existing. Cristobalite and chalcedone replace large pyroxenes and feldspars.

The lower sill is characterized by large plagioclase (labradorite) phenocrysts embedded in a diabasic matrix. Vesicular texture is also noted. Amygdaloid cavities are filled partially or completely with zeolites and calcite. Diabasic texture is dominant in all rock samples, but ophitic texture is present too. All rock samples from Naur area are diabasic dykes and sills with a diabase poryhyry sill (lower sill).

The dykes and sills present in Lower Triassic beds of Zarqa Ma'in and Wadi Himara show the same mineralogy and texture as those of Wadi Naur area. They are diabasic rocks with highly altered plagioclase and pyroxenes. Chlorite and iron oxides are the common weathering products. Rims of altered pyroxenes still exist. Calcite occurs as replacement mineral. The diabasic rock of the dyke penetrating Cambrian rocks near Bassat en Nimra at the shore of the Dead Sea is similar to that of the sills and dykes in Triassic sediments above. The rocks of the sill are also comparable with those of the lower sill at the Naur area since they are diabase porphyries. The rock is highly weathered and altered to chlorite and iron oxide, most probably due to the extensive salt erosion, now just above Dead Sea Level and only a few decades ago below sea level of the highly saline Dead Sea.

A very interesting rock type was discovered in a sill at the base of the Triassic beds in the Wadi Himara. Here the neighbouring sediments of the igneous rock are metamorphosed. An argillaceous matrix surrounds angular, fine grained quartz and feldspar crystals. The angularity of the grains is attributed to the large abrasion of these crystals. Iron oxides are abundant within the matrix. The dyke itself is of gabbro type. It is the first time such a rock type has been recorded in Jordan. Plagioclases and anhedral clinopyroxenes form the essential constituents. The plagioclase is of labradorite-bytownite composition with albite-pericline laws of twinning. Clinopyroxenes are mainly augite. Hypersthene is present as well as hornblende which alters to chlorite. Biotite also alters partially into chlorite. Muscovite, sericite, and saussurite occur as alteration products. Magnetite, ilmenite and hematite are present as minor constituents. The general texture is hypidiomorphic granular. The rock is typical gabbro.

In Wadi Naur the upper sill (Fig. 7) is overlain by well crystalline dolomite (calcite occurs as a minor constituent) and is underlain by limestone with little dolomite. At the base exist some thin greenish beds which consist of dolomite, plagioclase and quartz. These highly altered carbonate beds are results of contact metamorphosis. The bed above the lower sill at Wadi Naur consists of well crystalline dolomite with crystal diameters around 5 mm.

An ignous rock sample from the Ramtha 1 well near Mafraq (exact depth unknown) can be correlated with sills and dykes present in the Triassic outcrops. The rock consists of 56,77 % labradorite, 18,90 % orthoclase, 3,90 % quartz, 14,61 % ironoxides and 5,82 % mafic minerals. The original texture of the sill sample is destroyed. Most probably the sample comes from a diabasic dyke in the lower Um Tina Formation (see Fig. 8), the position of the sill is hypothetically only and has been attributed to a prominent marker bed in the electrolog.

4 Comparison with the Triassic Rock Column west of the Dead Sea - Vergleich mit der Trias-Entwicklung westlich vom Toten Meer

Die Triasablagerungen der nördlichen Negev entwickeln sich aus einer marinen permischen Sedimentserie (WEISSBROD 1968). Die terrestrische Um Irna Formation Jordaniens findet westlich des Wadi Araba keine Entsprechung. Die Ma'in und Dardun Formationen können mit der unteren und mittleren Zafir Formation der Negev verglichen werden (DRUCKMAN 1974). Die Ain Musa Formation entspricht der oberen Zafir Formation der zentralen Negev. Die Hisban Kalke werden durch die Ra'af Formation, und die Mukheiris Formation und Iraq al Amir Formation durch die Gevanim Formation des Makhtesh Ramon Gebietes vertreten. Die Um Tina Formation kann mit der Mohilla Formation im Untergrund der Negev verglichen werden (DRUCKMAN 1974, 1977). Vulkanite mit gleichem Chemismus wie in Jordanien sind südlich einer vom Südende des Toten Meeres nach Südwesten verlaufenden Linie in die Sedimente der Trias und des Jura eingedrungen (FREUND 1977).

The Triassic sediments exposed at the surface and at numerous wells in the northern Negev (Fig. 9) rest on marine Permian limestones and dolomites (WEISSBROD 1968). Only 54 km SW of the southern end of the Dead Sea (Hameishar 1 well) the Permo-Triassic sequence overlies Cambrian beds

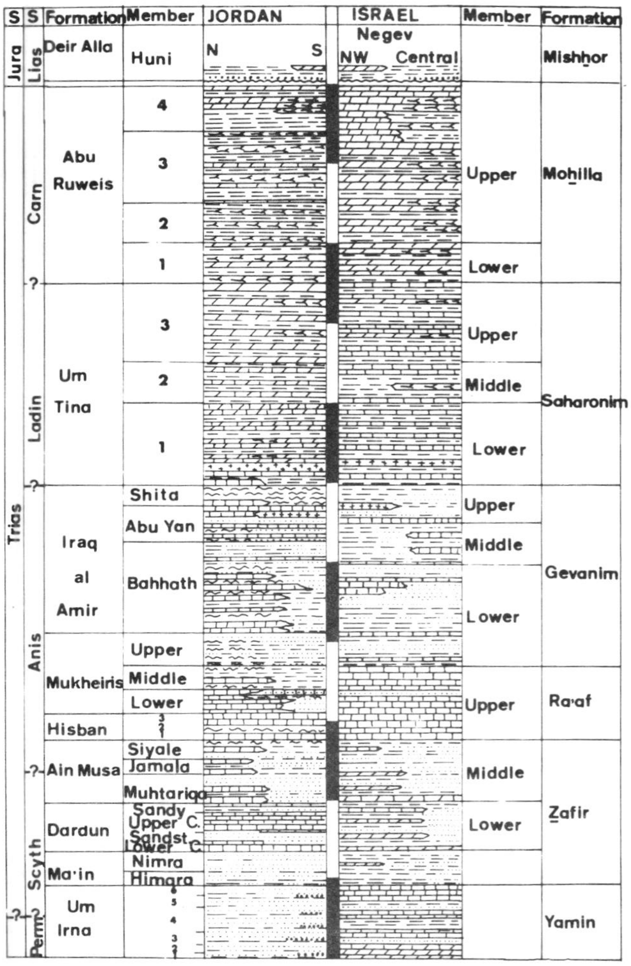

Fig. 9. Correlation Chart of Triassic Sequences East and West of the Dead Sea (modified, after DRUCKMAN 1974). Lithostratigraphic legend see Fig. 2. Total thickness about 1000 m.

Korrelation der Trias-Folgen östlich und westlich vom Toten Meer (modifiziert nach DRUCKMAN 1974). Legende siehe Abb. 2. Gesamtmächtigkeit etwa 1000 m.

(FREUND 1977) with a similar lithology as indicated in Suweilih 1 well (dolomitic limestones at the base (DRUCKMAN 1974). A sequence as represented by Um Irna Formation between Wadi Himara and Wadi Zarqa Ma'in has no counterpart west of Wadi Araba. In contrast to that the Ma'in and Dardun Formations with nearly 100 m in thickness can well be correlated with the Lower, Middle and the lowermost Upper Member of Zafir Formation in the Negev and correlate also with sections like that of Hameishar 1 well (DRUCKMAN 1974). The Ain Musa Formation with nearly 100 m sediment can be correlated with the Upper Member of Zafir Formation above the basal limestone beds. Again the rock column of Hameishar 1 well, 54 km SW of the Dead Sea correlates best.

The Hisban Formation corresponds to Ra'af Formation, especially that of Har'Arif outcrops and Hameishar 1 well in the Negev where it is also about 30 m thick (WEISSBROD 1968). The upper Mukheiris Formation and the Iraq al Amir Formation correspond to the Gevanim Formation (DRUCKMAN 1969, 1974), especially that of Makhtesh Ramon. The lower Middle Member of Gevanim Formation of this Triassic outcrop about 50 km SW of the southern end of the Dead Sea corresponds well with the Bahhath Member of the Iraq al Amir Formation in lithology and in thickness (DRUCKMAN 1974). The Abu Yan Member with glauconitic and bone-bearing beds at the base and limestone and sand at the top corresponds quite well to the upper part of Middle Member of Gevanim Formation where it is dominated by limestones, as in Makhtesh Qatan 2 well about 20 km SW of the southern end of the Dead Sea. The Shita Member of Iraq al Amir Formation is similar to the Upper Member of Gevanim at Makhtesh Ramon in thickness but contains less sand.

The Um Tina Formation of Jordan can be correlated with Saharonim Formation of the Negev. The Abu Ruweis Formation characterized by anhydrite beds corresponds with the Mohilla Formation (DRUCKMAN 1974, 1977).

The contact to the Jurassic rocks in the Negev is characterized by pisolitic clay and marl (DRUCKMAN 1977, GOLDBERG & FRIEDMAN 1974), which in the outcrops at Wadi Zarqa as well as in the subsurface of Ramtha 1 well also occur in Jordan.

The abundance of dykes and sills in Jordan of similar chemistry may indicate a common source. All sills and dykes had intruded before the erosive phase at the Upper Jurassic-Lower Cretaceous boundary. Dykes and sills have also intruded into Triassic and Jurassic rocks SW of the Wadi Araba penetrating a zone E of a line from the southern end of the Dead Sea to the south west. Jurassic rocks in Jordan exposed along the escarpment of the Jordan valley N of Es Salt are not intruded by diabase. According to FREUND (1977) the intrusive rocks S of the Dead Sea area are of the same chemistry as those south of a line crossing Jordan in northeastern direction.

5 BIOSTRATIGRAPHY - BIOSTRATIGRAPHIE

Die Um Irna Formation enthält eine oberpermische Pollen- und Sporenflora. Die Dardun Formation führt Conodonten des Skyth (BENDER 1968). Auf Grund von Ammonitenfunden ist der Hisbankalk in das Anis einzustufen (PARNES 1975). Die Anis-Ladin-Grenze fällt in der Negev mit dem Wechsel vom normal marinen Milieu zum salinaren Milieu zusammen und liegt demnach in Jordanien im Grenzbereich zwischen den Iraq al Amir und Um Tina Formationen. Das Alter der Abu Ruweis Formation ist unbekannt, möglicherweise gehört die Formation zum Teil in das Karn (DRUCKMAN 1977). Nach einer Sedimentationslücke folgen Sedimente des unteren Jura (BANDEL 1981).

The lowermost member of Um Irna Formation sampled at Bassat en Nimra could be dated with the help of pollen grains as Upper Permian. Dr. W.A. Brugman (Utrecht) determined *Lueckisporites virkkiae* POTONIÉ et KLAUS 1954, *Nuskoisporites dulhuntyi* POTONIÉ et KLAUS 1954 and *Playfordiaspora crenulata* (WILSON) FORSTER 1979 from the dark argillaceous shales above the contact to the Cambrian sandstones. The oldest biostratigraphically dated beds in the Triassic of Jordan belong to the Upper Carbonate Member of the Dardun Formation from Zarqa Ma'in. From these BENDER (1968) reports conodonts of Scythian age. HIRSCH (1975) described similar conodonts from the lower Zafir Formation and the uppermost Yamin Formation of the Negev, also assuming a late Lower to early Upper Scythian age. Therefore comparable beds present in the Suweilih 1 well may be of similar age and may be a time equivalent of the terrestrial upper Um Irna Formation.

COX (1932) had stated an Anisian age for Hisban limestones. But the boundary between Scythian and Anisian is shown to lie below the Hisban Formation by PARNES (1975) according to ammonites. In the Negev the Anisian/Ladinian boundary lies just above the top of the Gevanim Formation.

Judging Druckman's (1969) study of this formation from Makhtesh Ramon the boundary between Anisian and Ladinian corresponds approximately to a change from the open marine to salinar facies respectively between the Iraq al Amir and Um Tina Formation. The transition from the Ladinian to the Carnian is placed into the upper portion of Saharonim Formation by PARNES (1962, 1977). This boundary is not exposed in the Jordanian sections; it should be situated somewhere in the upper portion of Um Tina Formation. At what time Triassic deposition came to a standstill remains debatable; PARNES (1977, Fig. 2) and DRUCKMAN (1977, Figs. 4, 5) place the uppermost anhydrite bearing beds into the Carnian. Thus there is quite a gap of time until sedimentation starts again in the Lower Jurassic.

6 Results

The Triassic rock column of Jordan consists of about 1000 m of sediments, of which about 600 m are exposed at the surface, the rest is known from two wells only. This sequence is differentiated into nine formations:

(1) Um Irna Formation with 6 cycles of graded terrestrial deposits in which each cycle is terminated by a paleosoil. Possibly at least partially marine equivalents of this formation have been found in the Suweilih 1 well in a depth of 1000 to 940 m below surface. Sedimentation started in upper Permian according to pollen data.

(2) Ma'in Formation with marine silty and sandy deposits in the basal Himara Member, which becomes more calcareous towards the north, and sandy deposits in the Nimra Member demonstrating an offshore character towards the north. Age: Scythian.

(3) Dardun Formation can be differentiated into 4 members at the type locality, all of which demonstrate a near-shore to intertidal deposition with the open-marine influence.

(4) Ain Musa Formation with 3 members of which the lower Muhtariqa with fluviatile sands wedges out rapidly towards the North and rocks thus lithologically become very similar to the middle Jamala Member. The upper Siyale Member is variable in thickness. It shows a normal marine character like the limestone of the

(5) Hisban Formation, an open-marine shallow-water carbonate with a fauna of Anisian age.

(6) The marine influence only slowly decreases during the deposition of Mukheiris Formation, which in its two younger members show increasing terrestrial conditions.

(7) The change between terrestrial coastal conditions and marine ingressions can be seen also in the Iraq al Amir Formation and its Bahhath Member. The sediments of this formation become increasingly marly and calcareous with decreasing amount of quartzsand.

(8) With the begin of Um Tina Formation the open sea had no longer direct connections with the evaporitic intertidal zones as shown by the very restricted fauna. The deposits are characterized by laminated algal mats.

(9) In the Abu Ruweis Formation anhydrite deposits are common.

(10) The sea withdrew completely, terrestrial conditions without deposition but with soil formation only continued through Norian time and until the Lower Jurassic marine ingression.

A major difference can be stated between the lower 500 m of Triassic deposits and the upper 500 m. The Arabian-Nubian Continent during deposition of the lower 500 m, at Skythian and Anisian time, periodically rose up, and shed its erosional products often after very short transport into the coastal area. From upper most Anisian time (Iraq al Amir Formation) the continent became very stable and did not influence the sedimentation any more by coarse material.

During Ladinian and Carnian time sedimentation of carbonates, shales and evaporites kept pace with about the same amount of subsidence as in the time before, always keeping sedimentation up to or just above sea level. When this subsidence stopped in Carnian time, deposition finished.

The intrusion of diabase and gabbro into Triassic sedimentary rocks occurred in a zone that follows roughly the ancient coast line in Jordan as well as in southern Israel and Sinai. It runs from NE to SW and indicating that this zone of subsidence along the Arabian-Nubian Continent is caused by movements in the deeper crust. This lineament characterized by nearshore facies and magmatic intrusions crosses the new North to South orientated geosuture of the Rift and is displaced by it for at least 100 km.

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