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The sea in the Jordan Rift (Northern Jordan) during Oligocene/Miocene transition with implications to the reconstruction of the geological history of the region

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with 3 figures and 3 plates

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Abstract

During Late Cretaceous and Paleogene the shelf of the Arabian-African Continent in the area of north-western Jordan was differentiated into basins and swells, but received pelagic sediment, predominantly chalk. In the basin at the Wadi al Arab near Irbid deposition was not interrupted when the Cretaceous ended. With the end of the Eocene and begin of the Oligocene the sea withdrew and the area was uplifted and eroded. Rivers formed which in contrast to those of southern Jordan that continued across the land to end in the Mediterranean Sea ended in a newly forming and strongly subsiding rift valley. This depression was connected by a seaway to the north of Jordan with the Indo-Pacific Ocean in which sedimentation continued with perhaps an intermission during the late Chattian (transition from latest Oligocene into the Miocene). The shore of the sea within the northern Jordan Rift is documented from the modern slope and base in the Jordan Valley between Shuna near Yarmouk River and Wadi al Qarn near Abu Habil to the south. The sections near Waqqas documents flooding of the eroded Paleogene, near shore deposition, the presence of a shallow warm sea with rich marine fauna during the Aquitanian and its change into a salty environment with only cyanobacteria living during the Burdigalian. Into the near-shore environment rivers coming from the east deposited pebbles documenting erosion that uncovered continuously older beds of Paleogene age above to Late Cretaceous age below. An ancient river bed exposed near Awsara to the north of Ajlun Dome can be fitted with the near-shore marine deposits of Tayba Formation near Abu Habil exposed at almost Jordan River level. From a chalky bed found here a fauna of foraminifers is evaluated. Miocene deposition ended under the influence of very salty water and following sedimentation was that of Pliocene rivers and lakes. The Jordanian outcrops are related to subsurface data from the Rift only a few kilometers to the NW of Shuna. The Jordan Rift was active during the early Miocene, the graben became deepened and salt was deposited. The Dead Sea Transform fault has its position to the West of the exposures at Shuna, Waqqas and Abu Habil. Deformation was again strong during the end of the Pliocene,

and subsidence continues.

Zusammenfassung

Während der späten Kreide wie auch im Paläogen lagerten sich auf dem Schelf des Arabisch-Afrikanischen Kontinentes im Bereich NW Jordaniens pelagische, kreidige Sedimente ab. Die Oberfläche war in Schwellen und Becken gegliedert und im Becken des Wadi al Arab bei Irbid erfolgte der Übergang von der Kreide ins Tertiär kontinuierlich. Mit Ende des Eozäns und Anfang des Oligozäns zog sich das Meer zurück, und die Region wurde gehoben und erodiert. Es bildeten sich Flusssysteme, die im Gegensatz zu jenen des südlichen Jordaniens nicht im Mittelmeer endeten, sondern sich in einen sich neu bildenden und stark absinkenden Graben im Bereich des nördlichen Jordan Grabens ergossen. Diese Senke war über eine Meerestrasse mit dem Pazifischen Ozean verbunden, in der sich die Meeres-Sedimentation fortsetzte, vielleicht mit einer Unterbrechung im späten Chattium, d.h. dem Übergang vom Oligozän zum Miozän. Die Küste dieses Meer lag im Bereich des heutigen Jordangraben-Randes und ist zwischen Shuna in Norden und Abu Habil im Süden aufgeschlossen. Das Profil bei Waqqas dokumentiert die Überflutung erodierten alttertiären Untergrundes, küstennahe Ablagerung mit Austernsiedlungen und das Vorhandensein eines warmen seichten Meers mit reicher Fauna während des Aquitaniums. Im Burdigalium wurde dieses Meer salziger und nur noch bakterielles Leben war möglich. In das absinkende Becken wurden Flussschotter eingebracht, die eine kontinuierliche, allmählich bis in die Kreideablagerungen zurückgreifende Abtragung des Hinterlandes belegen. Ein in paläogene Sedimente eingegrabenes Flussbett tritt bei Awsara am nördlichen Rand der Ajlunschwelle auf; es könnte seine Fracht im Meer dort abgelagert haben wo heute bei Abu Habil auf Jordan-Flussniveau ein entsprechendes Profil in der Tayba Formation aufgeschlossen ist. Eine kalkige Schicht aus dieser Abfolge lieferte eine Foraminiferen-Fauna, die ausgewertet wurde. Die Befunde aus Jordanien lassen sich mit Daten in Verbindung bringen, die aus einer über 4 000 m tiefen Bohrung nur weniger Kilometer nordwestlich von Shuna bekannt sind. Demnach war der Jordangraben seit dem Übergang von Oligozän zum Miozän aktiv, wurde anschließend stark vertieft und mit Salinar-Ablagerungen verfüllt. Die Hauptstörung im Jordan-Tal lag und liegt westlich der jordanischen Aufschlüsse von Shuna, bei Waqqas und im Wadi al Qarn westlich von Abu Habil. Eine starke Verformung erfolgte noch einmal im Pliozän; seither setzt sich die Absenkung des Grabens fort.

1 Introduction

The Jordan –Dead Sea Rift valley is a large geological structure that forms part of a much greater system including the East African Rift zone, the Red Sea, Gulf of Aqaba and the Wadi Araba depression. It is continuous to the north even though less evident in modern geographic morphology due to volcanic rocks disguising the morphology (see SCHANDELMEIER et al., 1997 for maps and SCHANDELMEIER & REYNOLDS, 1997 for references). The existence and formation of this Jordan Rift is intimately connected with the history of the collision of the African-Arabian continental plate with that of Eurasia.

Interpretation of the time involved during which this structure formed and during which movements occurred within and along it differs among authors. According to BENDER (1968), for example, the Jordan Rift represents a rejuvenated Pre-Cambrian structure (geo-suture), while SCHULMAN (1959) suggested that it represents a simple graben expressed strongly since the early Pleistocene. But since the studies of MICHELSON (1982) and MARCUS & SLAGER (1985) it has become quite evident that the Rift has been subsiding since the Miocene. Regarding the age of deposits found in the Jordan Rift different opinions have been expressed. WETZEL & MORTON (1959) and BENDER (1968, 1982) considered a sedimentary series exposed along the eastern flank of the Rift Valley between the mouth of the Wadi el-Arab in North Shuna and Wadi Tayba to be of a questionable Oligocene and safer Miocene age. SCHANDELMEIER & REYNOLDS (1997) stated from their assembled references that in Jordan late Oligocene deposits are found only on the margins of the Wadi-Araba-Dead Sea rift comprising calcareous sandstones, chalky marls and shales and some conglomerates, deposited in an alluvial fan and lacustrine environment (ANDREWS, 1992). MICHELSON (1982) noted marine Oligocene on the Golan Plateau which was interpreted to have been connected with the Persian Gulf system through the Damascus Basin.

The Mid-Tertiary deposits described by WETZEL & MORTON (1959) and BENDER (1968) from northern Jordan are actually very easy to find, even though they have not been referred to in any detail by many of the researchers dealing with the Jordan Rift and Neogene history of the area. The exposure of these deposits is especially good near the little town of Waqqas (fig. 1). From here we describe a section through a sequence that provides evidence for the ingression of the sea into the early Jordan Rift and subsequent changes from deposition in marine environment to such under saline conditions. The rock sequence exposed here also indicates that to the east lay mountains, and rivers coming from there transported gravel into the sea and that during deposition the ground not only subsided but also became inclined towards the west.

Fig. 1: Map of the region of Waqqas.

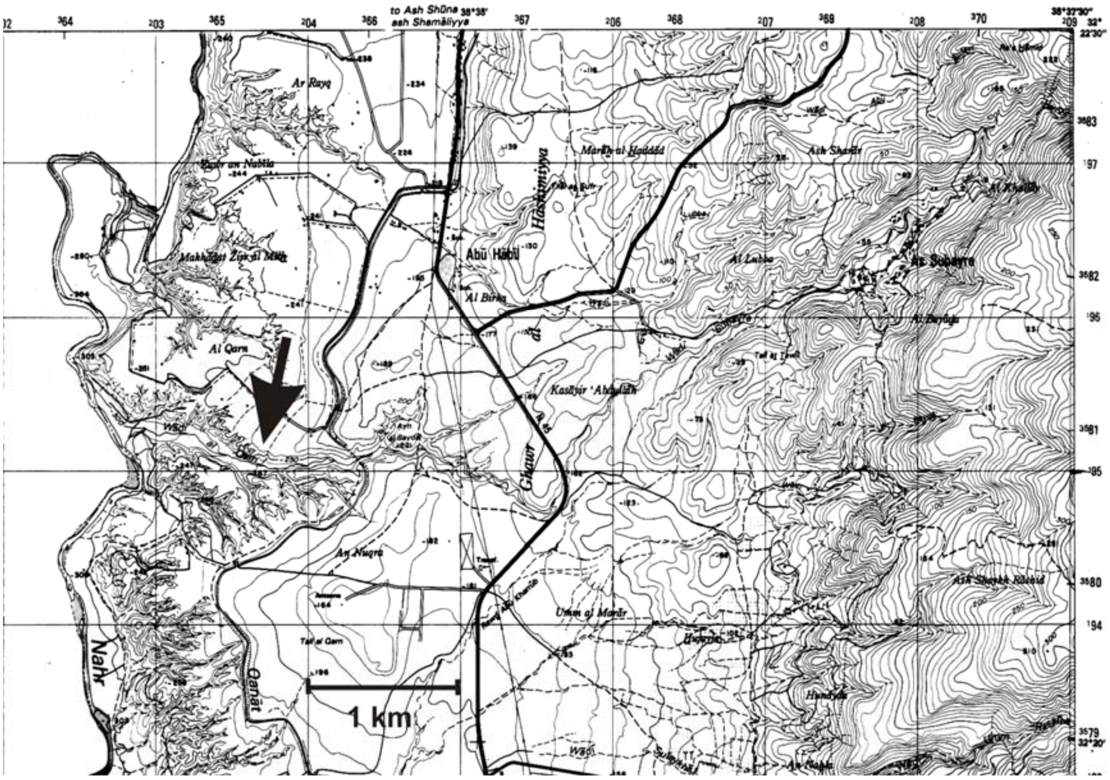

Fig. 2: Map of the region of Abu Habil.

The marine deposits are exposed also between the towns of Shuna in the North and Abu Habil (fig. 2) in the South and in exposures high up on the flanks of the Jordan Rift near Waqqas and low down to level of the River Jordan near Abu Habil. BENDER (1968) suggested that during the Oligocene the Wadi Araba-Jordan geosuture was utilized by ingressions of the Sea and this view is here supported. A narrow marine ingression coming from the Tethys or better the Pacific Ocean reached the northern Jordan Rift. According to the interpretation of BENDER (1968) salt began to be deposited in the Rift later, during the Miocene and Pliocene, which can be supported by the rocks exposed near Waqqas.

2 About the sediments formed before collision of the Arabian Plate with the Eurasian Continent

As had been concluded by BENDER (1968) predominantly chalky pelagic sediments were deposited over most of Jordan during the Paleogene. These deposits represent a continuation of the conditions that had been established during the Late Cretaceous. Differences in sediment thickness indicate a structuring of the Jordanian shelf area of the Tethys Ocean into highs and lows. Northern Jordan was still covered by the Tethys Ocean forming part of the Afro-Arabian Continent. During the Late Eocene the western part of the Tethys Ocean still encompassed and covered the area of what became later the Mediterranean Sea and also the area of the later Paratethys Sea.

The depositional basins in Jordan during Paleogene time to almost the end of the Eocene were rather different in size and the amount of subsidence as is evidenced by great differences in their thickness. The mobility of the crust of the shelf area in northern Jordan had initiated during the Late Cretaceous, Campanian time as was for example documented by BANDEL & MIKBEL (1985) in the region just south-east of Amman. But to the north of that region marine chalky deposition continued to form in Jordan lasting to the end of the Eocene, when most of the area was lifted above sea level and became land. The time of deposition of predominantly pelagic sediments on the shelf area in northern Jordan had begun in the Late Cretaceous.

WETZEL & MORTON (1959) named the Paleocene sediments in Jordan the Taqia Marl Formation. This formation was differentiated by BENDER (1968) as Chalk-Marl unit and Chert-Limestone unit. But BENDER (1968) included also Cretaceous units within the Lower Chalk-Marl and Eocene units within the Chert-Limestone unit. Later they, in part, received the name Muwaqqar Formation, which includes both Maastrichtian and Paleocene sediments (POWELL, 1989). The town Muwaqqar lies about 20 km to the SE of Amman and the name was first used by MASRI (1963) in an unpublished report. Muwaqqar Formation west of the Rift is equivalent to the Ghareb and Taquiye formations (SHAW, 1947; FLEXER, 1968 & 1971; BARTOV et al., 1972).

The Um Rijam Formation includes white chalks of Eocene age (POWELL, 1989) (Chert-Limestone unit of BENDER, 1968 and WOLFART, 1962), which according to WETZEL & MORTON (1959) have in Jordan also been called Sara Chalk Formation. Its now generally accepted name is derived from the Jabal Um Rijam SE of the little town Jurf ed Darwish on the Desert Highway in the At Tafila region of southern Jordan. It is unconformably overlain by Oligocene to Neogene deposits. West of the Rift it is called the Avedat Group.

These Maastrichtian to Eocene chalky units are well exposed in Wadi al-Arab west of Irbid, Wadi Shelalla north-east of Irbid, and in Wadi Yarmouk just east of Hemma. In the later region near the Yarmouk river the Muwaqqar Formation measures about 300 m in thickness and the Um Rijam is thought to be more than 200 m thick (POWELL, 1989). In Wadi Shelalla and in Wadi al-Arab the Paleocene sediments form a continuation of the Maastrichtian deposits. An interruption of sedimentation is observed, before the whitish chalks of the Eocene appear, clearly visible in the field and is characterized by its commonly reddish brown chert intercalations. The irregularity of the former depositional surface is clearly indicated by differences in thickness of the chalks of the Paleocene, which are much thicker in the valley of the Yarmouk, than in Wadi Shelalla, and these are thinner than in the end of Wadi al Arab in the Jordan Rift.

From own observations carried out 1999-2001 (in the course of the doctoral thesis of SHATNAWI) it can be stated, that in Wadi Shelalla the transition from the Cretaceous into the Paleocene lies within the same facies of more or less bituminous chalk with large concretions, one of which preserves a narrow and local bed with oysters. The Paleocene deposits here are not very thick. They begin in a facies of bioturbated bituminous chalk ending in a more solid bank which is overlain by bituminous marl, again chalk (all about 4 m thick), and a marl bed (about 1.5 m thick). Into the solid bank caves had been excavated by people during ancient times. The unit forms the base to a massive bed of yellow coloration with characteristic umbrella-like trace fossils (pl. 1, fig. 2). They consist of a vertical tube that penetrates the yellowish bed for about 100 cm and forms radiating horizontal branches at its lower end, each of them about 50 cm long. The upper surface of the about 110 cm thick bank is penetrated by *Thalassinoides* crab burrows that reach down for about 20 cm. This yellow bed represents a marker that is also found in the Wadi al-Arab, but it is thicker there and, in addition to the trace fossil, also contains sponges. In Wadi Shelalla the yellow marker bed is overlain by marly chalk with some more bituminous layers which represents the top of the Paleocene (about 3.5 m). It is overlain by white chalk with

chert beds which represents the begin of the Eocene chalk series (Um Rijam Formation) and into which conspicuous antique cave buildings, irrigation tunnels, and graves have been excavated. This chalky unit is exposed extensively in the Wadi Shelalla on its way to the Yarmouk river.
In the Wadi al-Arab the transition from Cretaceous into the Paleocene is more inconspicuous and lies within normally bioturbated chalks of the Muwaqqar Formation (pl. 1, fig. 1). Well visible are *Ophiomorpha-Thalassinoides* like crab burrow systems. The boundary from the Cretaceous to the Tertiary is documented only by a change in the composition of the planktonic foraminifera (discovered and documented by BILAL SHATNAWI in his field work to a doctoral thesis). The Paleocene has a concretion layer in its lower part, about 15 m above the boundary layer and continues as Muwaqqar to the marl that forms the base of the yellow marker bed with similar trace fossils as noted in Wadi Shelalla. The sequence between concretions and yellow marker bed is somewhat obscured due to slope movements, but may be about 20 m thick. The yellow bank contains the same trace fossils and is with 5 m much thicker than in Wadi Shelalla. Also the sequence of Muwaqqar-like marls above the marker bed is here thicker, but the change from marl into the typical white Eocene chalk (Um Rijam Formation) is similar and also rapid as is the case in the outcrops at Wadi Shelalla. In northern Jordan as well as in central Israel the chalks of Um Rijam Formation contain rock forming amounts of pelagic foraminifers. They are thus sediments that originate from the waters of the open Tethys Ocean.
During middle and late Eocene this pelagic sediment is laterally replaced by nummulitic limestone (BENDER, 1968). In southern Jordan such limestones are, for example, exposed at the end of Wadi Gharandal on the eastern flank of Wadi Araba. Similar deposits are also known from southern and northern Israel (HIRSCH, 1990) and Syria (PONTIAKOV et al., 1967). They indicate deposition in very shallow water that was penetrated to the bottom of the sea by light and they lived not far from a coast. The nummulites (monospecific *Nummulites ghizehensis* FORSKAL) of Gharandal have also been described by AVNIMELECH (1936), and those from the Carmel in north Israel by BENJAMINI (1984). In the Negev coral reefs have formed during the Eocene indicating the closeness of a coast line as described by BENJAMINI & ZILBERMAN (1979), which is evidence for the closeness of the coast here.
Within the calcareous beds of the section near Abu Habil, described below, foraminifers from the Paleocene and Eocene are common, but also many that have lived at late Eocene and early Oligocene times. They document that the later sea within which the sediments formed eroded sediments as young as early Oligocene. Thus, marine deposition of the Um Rijam type in northern Jordan continued into the Oligocene. According to the determinations carried out by Dr. KLAUS NUGLISCH such species are for example *Chiloguembelina victoriana* BECKMANN, *Globigerina ampliapertura* BOLLI, *Globigerina officinalis* SUBBOTINA, *G. ouatchitaensis* HOWE & WALLACE, *Pseudohastigeria* spp., *Paragloborotalia optima* (BOLLI), all of which lived also during the Early Oligocene.

3 About the time of collision of Arabia with the Eurasian Continent

During the Eocene the region of the Mediterranean Sea was connected with the Indo-Pacific Ocean and that Ocean lay to the North of Africa-Arabia. This portion of the Tethys disappeared subsequently due to the subduction of its oceanic crust below Eurasia. This Tethys Ocean extended to the west into the Mid-Atlantic and to the east into the Pacific and was still existent about 35 Million years ago (RÖGL, 1998). According to SCHANDELMEIER et al. (1997) Jordan lay at about 20 to 25° North during Lutetian time, about 46 Ma ago. According to SCHANDELMEIER et al. (1997) in the interval between the mid Eocene and the late Oligocene (Lutetian to the Chattian stage, 46-24 million years ago) Africa drifted northwards for some 650 km. But according to their paleogeographic reconstruction the area between Damascus and Amman during the late Oligocene lay far away from the sea while the Jordan Rift was already active. The activity in the Rift can be confirmed, while the former reconstruction of the position of the sea at that time has to be corrected.
A similar paleogeographic reconstruction of the Middle East during the Oligocene was presented by STEININGER & RÖGL (1984) and is also seen in RÖGL (1998). It shows a wide sea between Arabia and Africa on one side and the Eurasian Continent on the other side. But the area of southern Syria, Jordan, Palestine and Israel according to their reconstruction was covered by land, even though WETZEL & MORTON (1959) and BENDER (1968) had documented that the sea had reached the North of Jordan at about that time and left its organisms as fossils in the sediments there. MOUNTAIN & PRELL (1990) reconstruct the position of Arabia in regard to Asia with a wide gap to the north of the Persian Gulf which has disappeared since the last 20 million years, due to subduction and compression in the Zagros area (RÖGL, 1998). The final closure of the Tethys Ocean and the creation of the Mediterranean Sea occurred during the Oligocene. It resulted in the collision of Africa and its Adriatic and Arabian subplates with the Eurasian Plate and its subplates.

4 Establishment of the geological conditions which still characterize the region

During early Oligocene RÖGL (1998) reconstructed the situation according to which much of Arabia is represented by land. But with mid Oligocene and early Miocene there must have been more flooding coming into the Syrian and northern Jordanian area than is indicated is his reconstruction. The evidence for that will be shown below, but had already been presented by WETZEL & MORTON (1959) and BENDER (1968), when it was noted that the remains of marine animals such as pectinid bivalves and echinoderms of Oligocene-Miocene age were present in sandstones exposed between Shuna and south of Mashara in NW Jordan.

At Oligocene time the Negev was part of a regional peneplain that was in turn part of an extensive low relief terrain drained by low gradient streams which did not leave any sediment (ZILBERMAN, 1992). In the Late Oligocene or Early Miocene this flat landscape was deformed and a tectonic relief was established along the Rift valley. Local streams deposited the “Base conglomerate” eroding a relief of 30-150 m (ZILBERMAN, 1989). At the eastern side of the Wadi Araba exposed for example at Jebel Harun near Petra this conglomerate is 120 m thick (“syntektonisches Konglomerat” of BENDER, 1968). Fluvial-lacustrine sediments of at least 100 m thickness covered the basal conglomerate in parts of the Negev. The top layer contains chert pebbles of Paleogene derival (GARFUNKEL et al., 1974) coming from the eastern side of the Jordan Rift system in the south (BENTOR & VROMAN, 1957; GARFUNKEL & HOROWITZ, 1966). On the eastern side of the rift it was named Dana Conglomerate Formation and overlies unconformably Eocene chert- limestone of the Um Rijam Formation (POWELL, 1988).

The boundary along the Red Sea and the Suez rift were already formed at the end of the Oligocene or at the beginning of the Miocene, at 25 to 20 Ma ago (GARFUNKEL, 1988) and the Dead Sea transform fault formed not later than Mid Miocene times. By the end of the Miocene at about 5 My ago about 2/3 of the total offset had already taken place. During the early Miocene, regional fluvial system indicated that southern Israel, Jordan and Sinai formed a continuous landscape which drained to the West and NW, as had been suggested by PICARD (1943, 1951), BENTOR & VROMAN (1957), GARFUNKEL & HOROWITZ (1966). According to the reconstructions of HOROWITZ (1979), during Oligocene time most of Jordan was uplifted high above sea level, as were Palestine and Israel. Marine Oligocene as connected with the Persian Gulf system through the Damascus Basin was noted on the Golan height (HOROWITZ, 1979). CHAIMOV et al. (1990) demonstrated that in western Syria and eastern Lebanon the Palmyride fold belt obliquely intersect the roughly north trending Dead Sea transform fault system. This Dead Sea fault system shows evidence of more than 100 km of left-lateral displacement since mid-Tertiary time south of its intersection with the Palmyrides and only 25 km motion north of the juncture in Lebanon and western Syria (CHAIMOV et al., 1990). The Palmyrides are an intracratonic mountain belt formed since the late Oligocene, which strikes obliquely to the Dead Sea fault system. Here plate motion along this fault system was in part picked up and deviated into paths parallel to the margin of the Arabian plate. This may have resulted in the formation of the depression of the Damascus Basin through which the waters of the Pacific Ocean have reached as far as the depression formed by the Dead Sea Rift in Northern Jordan. CHAIMOV et al. (1990) suggested that the fold belt of the Palmyrides during the late Oligocene resulted in 20 km of crustal shortening. They connected this with the movement in the Jordan Rift that resulted in a 110 km displacement as had been noted by QUENNELL (1958) and supported on the western side of the rift by FREUND et al. (1970) and on the eastern side by BANDEL (1981).

5 The exposures of the Neogene sequence, Tayba Formation

The Late Cenozoic in northern Jordan is well exposed within the slope of the Jordan Rift between North Shuna just to the south of Lake Tiberias and the town of Waqqas about 30 km to the south. Again it is exposed further south in the eastern Jordan Rift valley in the area between the town Abu Habil and the Jordan River. This occurrence is probably connected to exposures just to the west of the town Awsara at the northern margin of the high of the Ajlun Dome (fig. 3).

BENDER (1968) reported outcrops in Wadi Tayba (= Wadi Taiyiba) which ends in the Jordan Valley in Waqqas. Here he reported an about 40 m thick series of glauconitic sandy marls and lime stones with *Chlamys judaica* COX, 1934 which had been placed in the Oligocene by WETZEL & MORTON (1959) and called Tayba Formation. At North Shuna about 40 m glauconitic sandy limestones with *Echinolampas*, *Clypeaster* and “*Pholadomya*” were noted by BENDER (1968) and also included in this Oligocene series.

In North Shuna (= Ash Shuna) at the northern slope of the valley of Wadi al Arab the town extends onto the slope. Here the chalks of the Paleogene Um Rijam Formation is overlain by sandstone and limy sandstone which in layers is rich in bryozoan remains and small fragments of coralline algae (pl. 1, fig. 3). On some beds pectinid bivalves belonging to at least three different species (pl. 3, fig. 6 & 7) and ribbed and smooth oysters occur.

Heterodont bivalves are preserved only as fillings, indicating that they had both valves in place when covered by the sand. The only gastropods noted were *Turritella*-like elongate shells preserved as impressions and as steinkern. Also large serpulid worm tubes as well as irregular sea urchins of the *Clypeaster*-type are present here with their calcitic shell preserved. The sandy deposits form cliffs since beds have been deformed to almost vertical position. Houses have been constructed on this cliff forming part of the old town of Shuna (= As Shuna = North Shuna) with steep slope to the creek of the Wadi al-Arab below (pl. 1, fig. 3).

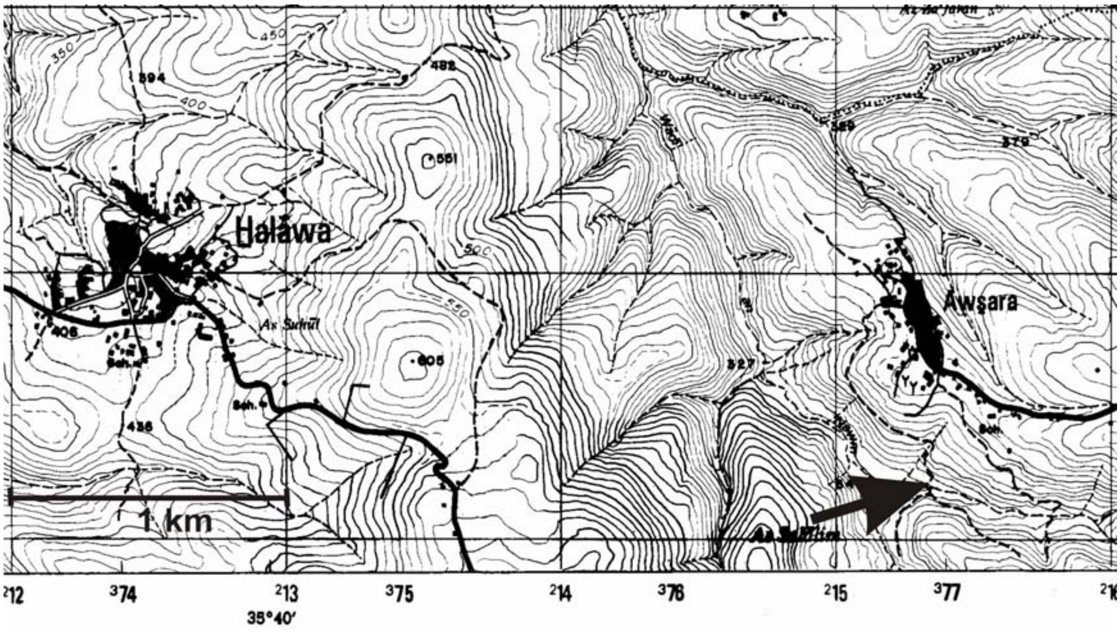

Fig. 3: Map of the region of Awsara.

One of the sea urchins was determined as belonging to the group around *Echinolampas* which today lives on coarse sand bottoms within the shallow sea at about 10 to 50 m of depth (personal communication ANDREAS KROH). During the Oligocene and Miocene *Echinolampas* represented a characteristic sea urchin of the shallow subtidal coarse sands found in the Mediterranean bioprovince as well as in the Paratethys, and obviously also in the sea that reached northern Jordan at that time. During the Miocene *Echinolampas* lived within the shallow sea between 0 and 50 m depth. This was also the living environment for the thick shelled pectinids, one of them resembling *Amussiopecten* with about 18 ribs with rounded shape and rounded interspaces as they occur in the Late Oligocene and Early Miocene (BALDI et al., 1999). Another one has broader interspaces and fewer ribs resembling *Aequipecten*, and there are two more species.

About 3 km to the north of Waqqas steep almost vertical sandstone beds form a cliff (Tall Sayrawan). Its western flank is composed of a calcareous sandstone or sandy limestone containing the moulds of large heterodont bivalves and being bioturbated by crab burrows of the *Thalassinoides* type. The 3 m thick unit is overlain by sand and gravel layers of about 10 m in thickness. About 8 m of sandstone with abundant crab burrows follow and the section ends with a conglomerate with mostly brown chert pebbles, which usually are well rounded.

These beds are exposed more or less continuously up to the exposure near Waqqas. This outcrop is well seen from the road climbing up the mountain slope from Waqqas to Tayba. Looking north half way up the slope the section exposed on the northern slope of Wadi Qusayba is seen in full extent (pl. 1, fig. 4).

In this section the whole sequence from the sea flooding the eroded Paleogene base to the change over into deposition within a salinal environment is well exposed (pl. 1, figs. 4-7). Here the sandy Oligocene-Miocene of Tayba Formation (following the use of WETZEL & MORTON, 1959) overlies chalky Paleogene that consists of either chalks, sometimes with chert, or strongly lithified re-crystalized chalks. The transition from the Paleogene to the Neogene is almost concordant, but sharp and the angle formed between beds is inconspicuous. The layers have an inclination of about 30° towards the Jordan Valley. No erosional debris or other intermediating beds are present between both strata, the base of the Tayba Formation and the top of the chalks of the Paleogene (pl. 1, fig. 4, arrow). The Paleogene chalky limestone had been used by ancient people to excavate their graves, most of which had now newly been excavated by treasure hunters.

The basal portion of the Tayba Formation is overlain by quartz rich coarse sandstone having more or less carbonate in it and in some layers is tinted rather green by glauconite. The sandstone is strongly bioturbated and the well visible burrows are of the type formed by crabs, sometimes with their walls constructed like brick-work with fecal pellets. Within the length of the outcrop the thickness of this bed decreases from north-east to south-west, from 6 m to 4 m. Above follow about 6 m of nodular limestone forming a bed of about equal thickness throughout the outcrop. It consists of sediments that has been intensely bioturbated by crabs and holds layers containing fossils (pl. 1, fig. 5, lower bank). One conspicuous layer has many oysters, commonly still with both valves connected to each other, indicating that they still rest in their original living position (pl. 3, fig. 8). A layer above them holds steinkerns of heterodont bivalves, many of them still with both valves in contact and a fauna of large gastropods. Among them the steinkerns of *Turritella*, *Ficus* (pl. 3, fig. 3), *Cassidaria/Galeodea* (pl. 3, fig. 1), *Natica* (pl. 3, fig. 2), *Strombus*, *Xenophora* (pl. 3, figs. 4,5) can be recognized. Also there are crusts consisting of stony corals (pl. 3, fig. 10), the boring bivalve *Lithophaga* (pl. 3, fig. 9) as well as cardiids with both valves still in place are present. The gastropods can not to be determined to species level, but their generic characters are preserved. In addition to the ones determined there are several undeterminable remains of larger neogastropods and of heterodont bivalves.

This unit is clearly less inclined than the following bed that disappears towards the top of the outcrop and at its base measures about 8 m in thickness. It consists predominantly of red sand with some interlayers of gravel and also layers with clasts that have in part been penetrated by burrowing organisms (pl. 1, fig. 5, central beds). Above it follows a gravel into which layers of stromatolitic limestone are locally intercalated. About 100 m towards the Jordan Valley this sequence of gravel and stromatolites being more than 5 m thick is exposed well and covered by a coarsely grained limestone. It in turn is covered by a cellular dolomite (pl. 1, fig. 7, arrow). Such rocks form when salt is leached out from deposits of salt, gypsum and limestone. This cellular dolomitic limestone bed is covered by a gravel which is the base to a limestone caliche (pl. 1, fig. 4, arrow).

This sequence shown on plate 1 in figure 4 in full length presents evidence of the flooding of the eroded Paleogene rocks by the sea. At first deposition was close to the shore with oysters growing on beach rock surfaces. Later the water was deeper and settled by a fauna of tropical gastropods, with *Strombus* giving evidence of sea grass, *Turritella* of water rich in suspension for feeding, *Cassidaria* for the presence of sea urchins which it hunted, *Natica* for mollusks which it hunted, *Xenophora* for relatively quiet water in which algal food could be collected. Corals lived here and larger colonies were bored by *Lithophaga*.

This marine environment was covered up by alluvial gravel which came to rest within the sea and near its shore so that beach rock formed that had been penetrated by crabs. Onto these gravels in shallow water cyanobacterial crust grew locally producing stromatolitic beds. Here salinity was no longer that of the normal marine environment, but conditions were more saline so that life was reduced to such organisms which were able to tolerate higher salinity such as cyanobacteria. The salinity rose further and saline deposits formed, which later were partly leached again leaving the characteristic cellular dolomite. The whole was than covered by alluvial gravel.

Just to the south of Tayba road the whole sequence is also exposed in the slope of Wadi Tayba above the southern part of the town Waqqas. Here the Paleogene chalky limestone containing layers with flint is overlain by about 3,5 m of sand with glauconitic grains and well preserved crab burrow systems. This layer can be traced downhill for about 150 m and increases in thickness. Its base is never a soil or a bored surface, but the chalk-sand contact is without transition. Pectinid shells as well as clypeasteroid sea urchins are present here. Above, this sand grades into limy beds with large foraminifera (genus *Lepidocyclina*, pl. 2, fig. 4). There are also spines of regular sea urchins, small brachiopods, bryozoans, octocorals, calcareous sponges and some pectinids and oysters. This layer my be up to 1 m thick and is overlain by about 3 m of sand with crab burrows of the *Thalassinoides* type. The next 1-2 m of sand are coarsely cross bedded. And the following about 5 m thick sandstone is again bioturbated. It is topped by 1 m thick limestone without fossils, overlain by conglomeratic beds of 2 m and a stromatolitic limestone layer. These two limestone beds can be correlated with the stromatolitic intercalation in gravel beds as noted in the upper part of the Waqqas section. The following beds consist of about 6 m of pebble deposits, a red soil separating it from about 5 more meters of such conglomeratic layers.

Going east from the Jordan Valley and east of the rift into the Jordanian highland (ENE of Abu Habil), just to the west of the little town Awsara on the eastern slope of the little valley here, the truncated chalky limestones of the Eocene are exposed (fig. 3). Only about 20 to 50 m below the typical white chalky limestone of Um Rijam Formation with brown flint beds intercalated with the Muwaqqar facies of dark more bituminous chalks is developed and exposed when going up or down the usually dry valley. The Paleogene chalky limestone has been truncated probably during late Oligocene time with a slight unconformity. A layer containing characteristic large, up to more than 1 m wide concretions lies in the southern part of the valley quite some distance below level of erosion and the overlying alluvial deposits, while in the northern part of the exposure formed by the

western side of the valley it lies directly below this surface.
The alluvial deposits consist of a mixture of more or less rounded brownish flint pebbles of different size and character as found in the Um Rijam Formation, limestone concretions as they occur in several layers of the Paleogene sequence, and well rounded pebbles of white chalky limestone. This gravel is coarse but components are rounded and somewhat sorted, clearly they represent no talus of some kind of slope. The gravel has been deposited on a rocky base formed by the pelagic sediments of the Um Rijam Formation without any sand or soil intercalations. Above the 10-15 m thick gravel there may be a red soil horizons, which is thin in the south of the exposure and much thicker in the north, indicating that the filled valley was rather wide and had its lower portion further in the north. The basement of Paleogene lime stones as well as the fluviatile deposits above it have been deformed into a wide syncline so that there is the impression of a relatively deep former valley. But this is not the case and the alluvial deposits overlie a relatively indistinctly inclined Paleogene base. The gravel indicates that erosion of Paleogene rocks did not occur far away, but the river ran through a wide shallow valley.
The gravel of the Awsara river deposits may agree in composition with the oldest deposits as exposed near the Jordan in the Wadi al Qarn to the west of the village Abu Habil, while the upper gravel here also hold pebbles of Cretaceous rocks (fig. 2).
The sequence near Abu Habil is exposed in the small valley of Wadi al Qarn that is incised in the flat Jordan plane above the final level of the Jordan with its steep sides. Wadi al Qarn forms a small side valley of the Jordan River and south of the hills of Jebel Qarn just east of the main road. Here 150 to 200 m of conglomeratic to sandy-silty, well bedded sediments are exposed. The exact thickness of the series is difficult to evaluate due to the quite intensive faulting especially near the eastern end of the outcrop in Wadi al Qarn and not far from the Ghor Canal that crosses the wadis in a bridge. In the middle portion of the sequence beds may be in vertical position but also folds are present (pl. 2, fig. 1).
From top to bottom conglomerates are present, forming especially extensive layers in the top most section exposed closest to the slope towards the Jordan river and in part directly overlain by beds deposited in the Lisan lake during the last ice age. These conglomerates consist of limestone gravel and hold large pebbles which are usually well rounded. But chert pebbles may have more or less angular shape. Among these pebbles many flints have the characteristic light brownish color of those found within the Eocene chalks of Um Rijam Formation. But there are also limestone pebbles that contain *Nerinea*- like gastropod shells and therefore are of Cretaceous age. The beds below the conglomerate are fine grained reddish sands and silts which commonly display the filling of smaller and larger channels. The fine grained deposits are often laminated horizontally or have fine cross laminar bedding (pl. 2, fig. 3). They usually have been bioturbated by a number of different organisms producing fine burrow structures (pl. 1, fig. 8), as well as larger ones, the later representing the characteristic network of thalassinoid crab burrows. Such bioturbation indicated the influence of marine conditions from the top to the bottom of the section. Shallow intertidal conditions are displayed by the presence of mud-cracked surfaces and layers composed of desiccation shards and laminar bedding as formed by algal mats here and there (pl. 2, fig. 3). The deposits of the shallow sea and lagoonal environments have commonly been crossed by channels coming from rivers and being filled with gravel. Also synsedimentary fracturing of beds and slumping toward a general easterly direction was noted. Two white chalky beds are intercalated (pl. 2, fig. 2), which contain many foraminifera (pl. 2, figs. 5-10), besides ostracods and fragments of small mollusks.
From these chalky layers Foraminifera were extracted and determined by K. NUGLISCH. Accordingly, they represent a mixture of reworked species from the chalky base with Paleocene to Eocene age and species that have lived during the Oligocene and the early Miocene.
Of the genus *Acarinina* that existed from the late Paleocene to the middle Eocene the species *A. acarinata* SUBBOTINA (Paleocene to early Eocene), *A. bullbrooki* (BOLLI) (Eocene), A. *colomi* (BERMUDEZ) (early Eocene), *A. intermedia* SUBBOTINA (Paleocene), *A. matthewsae* BLOW (middle Eocene), *A. pentacamerata* SUBBOTINA (middle to late Eocene), *A.* ? *praeangulata* (BLOW) (Paleocene), *A. rotundimarginata* SUBBOTINA (late Eocene), *A. soldadoensis angulosa* (BOLLI) (Eocene) are present. In the genus *Chiloguemblina* the species *C. crinita* (GLAESSNER) (Paleocene to early Eocene), *C. cubensis* (PALMER) (late Eocene to Oligocene), *C. victoriana* BECKMANN (late Eocene to early Oligocene) were found. *Globigerina* is present with the species *G. ampliapertura* BOLLI (late Eocene to Rupelian), *G. angulisuturalis* BOLLI (late Oligocene), *G. angustiumbilicata* BOLLI (late Eocene to early Miocene), G. *diplostoma* REUSS (middle Miocene), *G. inaequispira* SUBBOTINA (Eocene), *G. officinalis* SUBBOTINA (late Eocene to early Oligocene), *G. ouatchitaensis* HOWE & WALLACE (late Eocene to early Oligocene), *G. posttriloculinoides clinita* CHALILOV (late Eocene), *G. praebulloides* BLOW (late Eocene), *G. pseudoampliapertura* BLOW & BANNER (late Eocene). *Globigerinatheka* ? *subconglobata luterbachi* BOLLI (Eocene), *Globoquadrina hornibrooki* (BRÖNNIMANN) (Paleocene to early Eocene), *Globoquadrina* ? *tripartite* (KOCH) (late Eocene to early Miocene) are present. Interesting is *Globorotaloides pseudokugleri* (BLOW) (late Oligocene to early Miocene) representing a good time marker. *Guembelitria stavensis* BANDY is from the middle Eocene.

The genus *Igorina* lived during the late Paleocene and early Eocene and is represented by *I. braedermanni* (CUSHMAN & BERMUDEZ) (Eocene), *I. pseudoscitula* (GLAESSNER) (early and middle Eocene), *I. pusilla* (BOLLI) (Paleocene), *I. tadjikistanensis* (BYKOVA) (Paleocene to Eocene). From the genus *Morozovella* that lived during the middle Paleocene to middle Eocene, the species *M. aequa* (CUSHMAN & RENZ) (Eocene), *M. apanthesma* (LOEBLICH & TAPPAN) (Paleocene to early Eocene), *M. conicotruncata* (SUBBOTINA) (Paleocene), M. *lehneri* (CUSHMAN & JARVIS) (middle Eocene), *M. quetra* (BOLLI) (Eocene), *M. spinulosa* (CUSHMAN) (late middle Eocene), *M. subbotinae* (MOROZOVA) (Eocene), *M. velascoensis* (CUSHMAN) (Paleocene to Eocene), M. *woodi* (EL NAGGAR) (late Paleocene) were determined. *Praegloborotalia opima* (BOLLI) is from the Chattian, *Parasubbotina varianta* (SUBBOTINA) from the Paleocene as is *Praemurica* ? *inconstans* (SUBBOTINA).
The genus *Pseudohastigerina* is represented by *P. micra* (COLE) from Eocene to early Oligocene and *P. naguewichiensis* (MJATJUK) from the late Eocene to early Oligocene. *Subbotina* is represented by *S. angiporoides* (HORNIBROOK) (Oligocene), *S. corpulenta* (SUBBOTINA) (late Eocene), *S. linaperta* (FINLAY) (middle to late Eocene), *S. trivialis* (SUBBOTINA) (early Paleocene), *S. velascoensis* (CUSHMAN) (Paleocene to early Eocene). The genus *Truncorotaloides* is present with *T. aculeata* (JENKINS), (middle to late Eocene), *T. collactea* (FINLAY) (Eocene), *T. haynesi* SAMANTA, *T. libyaensis* (EL KHOUDARY), *T. topilensis* (CUSHMAN), and *T. rohri* (all three late middle Eocene), *T. pseudotopilensis* (SUBOTINA) (early and middle Eocene). *Turborotalia* is represented by *T. boweri* (BOLLI) (middle Eocene), and *T. cerroazulenensis* subspecies *frontosa* (SUBBOTINA) and *pomeroli* (TOUMARKINE & BOLLI) (middle Eocene to early Oligocene).
In addition *Cibicides ungerianus* (D'ORB.) (Oligocene to Miocene), *Hanzawaia bouean*a (D'ORB.) (Oligocene - Miocene), *Dentalina soluta* REUSS (Oligocene), *Uvigerina cocoaensis* CUSHMAN (Eocene to Oligocene), *Uvigerina nuttali* CUSHMAN & EDWARDS (Oligocene), *Uvigerina jacksonensis* CUSHMAN (Oligocene), *Uvigerina lappa* CUSHMAN & EDWARDS (Oligocene), *Tenuitellinata juvenilis* (BOLLI) (Oligocene to Miocene), and *Heterolepa perlucida* (NUTT.) (Oligocene) were determined.
Species like *Pseudohastigerina* spp. give evidence of Lattdorfian age (earliest Oligocene), *Globigerina ampliapertura* documents Rupelian time, and *Globigerina angulisuturalis*, *Chiloguembelina cubensis* and *Praegloborotalia opima* indicate the early Chattian. The final portion of the Oligocene is not documented by foraminifera but the Aquitanian of the early Miocene is indicated by *Globorotaloides pseudokugleri* and *Globigerina dichotoma*, both of which are of better preservation than most others, indicating that they may not have been redeposited like most of the others. Aquitanian foraminifers are the last ones and there is no trace of a Burdigalian species present.
The composition of the micro-fauna indicates that after the end of deposition in the environment of the Tethys Ocean marine deposition continued in the area from which micro-fauna could be washed into the region of the northern Jordan rift. The only time not represented is the latest Oligocene. Material from early and middle Oligocene most probably was not derived from the area to the east of the outcrops, because this region had been uplifted and eroded with rivers transporting the products of that process into the area in which the studied sections are found. One of these rivers is probably still documented in the gravels deposited near Awsara, described above. Oligocene marine deposits that provided the foraminifers encountered in Wadi al Qarn near Abu Habil may have come from the region of the Damascus Basin in the NE. The marine deposits of the Tayba Formation were emplaced during latest Oligocene and most likely the Aquitanian of the early Miocene.
Resuming the observations it can be assumed that about 24 million years ago the area now occupied by the Jordan valley in northern Jordan between the towns of Abu Habil and North Shuna was inundated by the sea coming from the north, and most probably connected to the Indo-Pacific Ocean via the Damascus Basin. What is now the steep eastern slope of the Jordan rift valley at that time represented the shore, with unknown width of the sea in western direction. All outcrops from North Shuna to Waqqas are in more or less continuous contact with each other, while that further in the south at Abu Habil is more isolated. But this exposure in Wadi al Qarn fits rather well with the river deposits found to the east of the Jordan Rift in the highland near Awsara. This former river probably dumped its gravel at the shore near Abu Habil. If that is so, the Dead Sea Transform fault supposedly situated in the eastern side of the Jordan valley and acting not only in displacing rocks downwards but also having a strong lateral component appears to have not displaced these deposits. The strongly tectonized outcrop in Wadi al Qarn probably still lies to the east of the transform, which should have its place near the modern incision of the River Jordan.
The Late Cenozoic near shore marine and fluvial deposits in northern Jordan record two episodes of valley incision, one in the transition from Oligocene to Miocene and the other during the Miocene. The upland erosion surface delivered sand in the first episode documenting a low relief early Oligocene landscape. It coincides with the time of world-wide rising sea-level between the late Oligocene and the middle Miocene. After the rupture of the normal marine conditions rivers began to cut deeper into the Paleogene chalks bringing calcareous pebbles and the characteristic brown chert towards the Jordan Rift. In it marine conditions prevailed until they changed into salinal facies. This may very well have been in connection with similar deposition in the sea strait

connection to the Indian Ocean. A later Pliocene episode reports a period of strong crust and pisolite formation with valley incision following that resulted in a redeposition of these pisolites exposed at the road and within the Wadi al Qarn next to the bridge containing the Ghor Canal.

6 About the post-Miocene history of the northern Jordan Rift

A borehole (Zemah 1) next to the southern end of Lake Tiberias and just north of the mouth of the Yarmouk into Jordan River in Kinrot Valley on the west side of the Jordan penetrated almost 4 250 m (MARCUS & SLAGER, 1985). Outcrops nearby are of the Ubediye Formation of early Pleistocene age and late Pleistocene basalt which is overlain by Lisan Formation formed only about 20 000 years ago. The base of the well consists of about 7 m of red beds with conglomeratic material with pebbles of Cretaceous and Eocene limestones in silty, sandy and marly matrix. According to the data extracted from the analysis of the pollen grains it is early Middle Miocene in age. It is interpreted as alluvial fan deposit. MARCUS & SLAGER (1985) compared it with the Hordos Formation that has been described by MICHELSON (1982) from the Golan Height. Here it is up to 400 m in thickness and suggested to be of early Miocene to middle Miocene age.

In Zemah 1 well 2 800 m of evaporitic and igneous rocks follow, topped by fine grained limestone barren of fauna. This salt rich unit lies between the Miocene Hordos Formation (quite possibly the same as Tayba Formation in Jordan) and about 160 m of marly clay and and sand of Pliocene age with ostracods indicating brackish and hypersaline conditions of deposition. Above that about 700 m follow mainly composed of basalts that have been dated as about 4.5 Ma. The remaining about 500 m of limestones, clays, conglomerates and sands have been dated by pollen and spores to represent about half of pre-glacial and half of glacial Pleistocene.

This sequence encountered in the drill site not far from North Shuna indicates that the Dead Sea Transform lies between the well and the town. The beds encountered in the well indicate that the Jordan Rift had subsided considerably since the middle Miocene time. The Jordan Rift was, therefore, actively subsiding and during that time also the major strike-slip fault with horizontal movement of about 110 km as suggested by QUENNELL (1958), FREUND et al. (1970), and BANDEL (1981) was probably simultaneously active. According to the reconstruction of HOROWITZ (1979, fig. 4.3) a narrow tongue of the Persian Gulf reached the area of Lake Tiberias at middle Miocene time and a connection of the Mediterranean into a basin south of the present Dead Sea existed. But both these are not reconstructed as being connected to each other, and they may have existed at quite different times. The more than 900 m of salt documented from Zemah 1 well by MARCUS & SLAGER (1985) are represented in Tayba Formation only by the thin cellular dolomite bed almost at the top of the section. The rift to the west of Waqqas, therefore, should have subsided considerably, and if the salt is not of much younger age, the seaway must have been at least periodically open for quite some time to deliver the salt.

During the Late Burdigalian some 18-17 million years ago the Indo-Pacific-Mediterranean seaway was closed, and also its appendix to the Jordan Rift. From that time onward there is the evolution of the Neogene Mediterranean bioprovince and the first mammal exchange across Palestine occurred (THENIUS, 1979; STEININGER et al., 1985). During the Burdigalian Eurasia was invaded by quite a number of mammal groups from Africa and the land bridge was also used by Eurasian mammals including the felines, canids, hyaenids, equids, advanced rodents and lagomorphs, which are not known from Africa prior to 12 Ma (TCHERNOV, 1988).

It is only during the Pliocene that deposition continued documented at the Ghor canal near Abu Habil by lake deposits from which BANDEL (2000 & 2001) described the species of *Melanopsis* and *Theodoxus*. These Pliocene deposits were formed in a lake with fresh water, while MARCUS & SLAGER (1985) noted evidence for brackish water in beds that could be of similar age and were deposited not far to the north of that lake in the area of modern Lake Tiberias.

The Pliocene lake deposits as well as the Tayba Formation below them were folded, faulted and displaced before Pleistocene beds were deposited on top of them. Above the very evident angular unconformity horizontal gravel and clay beds of the Pleistocene-Holocene are developed. These have intercalated clay and sand, often rich with *Melanopsis* and *Unio*.

The sequence exposed in the Jordan valley near the mouth of Wadi al Qarns confirms MARCUS & SLAGER (1985) who suggested that after the deposition during the Miocene and connected subsidence there was a time of little deposition before during the Pliocene deposition resumed followed by deformation that may be related to a more intense sinistral strike-slip motion and subsequent subsidence that is still continuous.

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Literature

ANDREWS, I.J. (1992): Cretaceous and Paleogene lithostratigraphy in the subsurface of Jordan. - Subsurface Geology Division Bulletin 5, Geology Directorate NRA, Amman: 1-60.

AVNIMELECH, M. (1936): Études géologiques dans la region de la Shephala en Palestine. - Trav. Lab. Geol. University of Grenoble, Vol.20.

BALDI, T.; LESS, G. & MANDIC, O. (1999): Some new aspects of the lower boundary of the Egerian stage (Oligocene), chronostratigraphic scale of the Paratethys area. - Abhandlungen der Geologischen Bundesanstalt, 56/2: 653-668.

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. - Neues Jb. Geol. Paläont., Abh., 161: 271-308.

BANDEL, K. (2000): Speciation among the Melanopsidae (Caenogastropoda). Special emphasis to the Melanopsidae of the Pannonian Lake at Pontian time (Late Miocene) and the Pleistocene and Recent of Jordan. - Mitt. Geol.-Paläont. Inst., Universität Hamburg, 84: 131-208.

BANDEL, K. (2001): The history of *Theodoxus* and *Neritina* connected with description and systematic evaluation of related Neritimorpha (Gastropoda). - Mitt. Geol.-Paläont. Inst., Universität Hamburg, 85: 65-164.

BANDEL, K. & MIKBEL, S. (1985): Origin and deposition of phosphate ores from the Upper Cretaceous of Ruseifa (Amman, Jordan). - Mitt. Geol. Paläont. Inst., Universität Hamburg, 59: 167- 188.

BARTOV, Y.; EYLAL, Y.; GARFUNKEL, Z. & STEINITZ, G. (1972): Late Cretaceous and Tertiary stratigraphy and paleogeography of Southern Israel. - Isr. Jour. Earth Sci., 21: 69-97.

BENDER, F. (1968): Geologie von Jordanien. Beiträge zur Regionalen Geologie der Erde, Band 7.- Gebrüder Bornträger; Berlin; 230 S.

BENJAMINI, C. (1984): Stratigraphy of the Eocene of the Arava Valley (eastern and southern Negev, southern Israel). - Isr. Jour. Earth Sci., 33: 167-177.

BENJAMINI, C. & ZILBERMAN, E. (1979): Late Eocene coral reefs of the western Negev, Israel.- Isr. Jour. Earth Sci., 28: 42-46.

BENTOR, Y.K & VROMAN, A. (1957): The geological map of the Negev, 1:100,000. Sheet 19: Arava Valley, with explanatory notes. - Isr. Geol. Surv., 117 p.

CHAIMOV, T.A.; BARAZANGI, M.; AL-SAAD, D.; SAWAF, T. & GEBRAN, A. (1990): Crustal shortening in the Palmyride fold belt, Syria, and implications for movement along the Dead Sea fault system. - Tectonics, 9: 136-1386.

FLEXER, A. (1968): Stratigraphy and Facies development of Mount Scoups Group (Senonian-Paleocene) in Israel and adjacent countries. – Isr. Jour. Earth Sci., 17: 85-114.

FLEXER, A., (1971): Late Cretaceous paleogeography of Northern Israel and its significance for the Levant Geology.- Palaeogeography, Palaeoclimatology, Palaeoecology, 10: 293-316.

FREUND, R.; GARFUNKEL, Z.; GOLDBERG, M. & WEISSBROD, T. (1970): The shear along the Dead Sea rift.- Phil. Trans. Roy. Soc. London, A9267: 107-130.

GARFUNKEL, Z. & HOROWITZ, A. (1966): The Upper Tertiary and Quaternary morphology of the Negev. - Isr. Jour. Earth Sci., 15: 101-117.

GARFUNKEL, Z.; BARTOV, J.; EYAL, Y. & STEINITZ, G. (1974): Raham Conglomerate - new evidence for Neogene tectonism in the southern part of the Dead Sea Rift. - Geol. Mag., 111: 55-64.

HIRSCH, F. (1990): Apercu de l'histoire phanérozoique d'Israel.- Jour. Afr. Earth Sci., 11: 177-196.

HOROWITZ, A. (1979): The Quaternary of Israel. - Academic Press, New-York, 394 p.

MARCUS, E. & SLAGER, J. (1985): The sedimentary-magmatic sequence of the Zemah 1 well (Jordan-Dead Sea Rift, Israel) and its emplacement in time and space. – Isr. Jour. Earth Sciences, 34: 1-10.

MASRI, M. (1963): Report on the geology of the Amman-Zerga area. - Central Water Authority Amman. unpubl.

MICHELSON, H. (1982): Geological survey of the Golan Heights (with some remarks on exploration for hydrocarbons). - Tahal report for Oil Exploration (Investments) Ltd., August 1982, 34 p.

MOUNTAIN, G.S. & PRELL, W.L. (1990): A multiple plate tectonic history of the southeast continental margin of Oman. - In: ROBERTSON, A.H.F. & RIES, A.C. (eds.): The geology and tectonics of the Oman region. - Geol. Soc. Spec. Publ., no. 49: 725-743.

PICARD, L. (1943): Structure and evolution of Palestine. - Bull. Geol. Dep. Hebrew University 4 (2-4): 134 p.
PICARD, L: (1951). Geomorphology of Israel. Part 1: The Negev. - Research Council of Israel Bulletin, 8G: 1-30.
PONTIAKOV, V.P.; KAZMIN, V.G.; MIKHAILOV, I.A.; RAZVALIAYEV, A.V.; KRASHENINNIKOV, V.A.; KOZLOV, V.V.; SOULIDI-KONDRATIYEV, E.D.; MIKHAILOV, K.Y.; KULAKOV, V.V.; FARADZHEV, V.A. & MIRZAYEV, K.M. (1967) The Geology of Syria, Part 1, Stratigraphy, Igneous rocks and Tectonics. Damascus: Syrian Arab Republic. - Ministry of Industry, Department of Geological and Mineral Research.
POWELL, J.H. (1988) The geology of the Karak area, map sheet No. 3152III, - The Hashemite Kingdom of Jordan Ministry of Energy and Mineral Resources, Natural Resources Authority: 1-7 & 95-102.
POWELL, J. H. (1989): Stratigraphy and sedimentation of the Phanerozoic rocks in central and south Jordan; Part B, Kurnub. Ajlun and Belqa groups. Bulletin 11, The Hashemite Kingdom of Jordan Ministry of Energy and Mineral Resources, Natural Resources Authority: 161 pp.
QUENNELL, A.M. (1951): Geology an Mineral Resources of (former) Trans Jordan. - Colonial Geology and Mineral Resources, 2: 85-115.
QUENNELL, A.M. (1958): The structural and geomorphic evolution of the Dead Sea Rift. - Quart. Jour. Geol. Soc. London, 114: 1-24.
RÖGL, F.(1998): Palaeogeographic considerations for Mediterranean and Paratethys seaways (Oligocene to Miocene). - Annalen des Naturhistorischen Museums, Wien 99A: 279-310.
SCHANDELMEIER, H. & REYNOLDS, P.-O. (1997): Palaeogeographic- Palaeotectonic Atlas of North-Eastern Africa, Arabia, and adjacent areas: 160 p.; Balkema, Rotterdam.
SCHANDELMEIER, H.; REYNOLDS, P.-O. & PUDLO, D. (1997): Chapter 15 The early Tertiary, Oigocene (Chattian, ca. 24 Ma). In: SCHANDELMEIER, H. & REYNOLDS, P.-O. (eds.): Palaeogeographic- Palaeotectonic Atlas of North-Eastern Africa, Arabia, and adjacent areas.- Balkema, Rotterdam: 97-105.
SCHULMAN, N. (1959): The geology of the Central Jordan Valley.- Bull. Res. Council Israel, G 8: 63-90.
SHAW, S.H. (1947): Geologic Map on a scale of 1:250,000 southern Palestine, with explanatory notes.- Gov. Palestine Press, Jerusalem: 42 p.
STEININGER, F.F. & RÖGL, F. (1984) Paleogeography and palinspastic reconstruction of the Neogene of the Mediterranean and Paratethys. - In: DIXON, J.E. and ROBERTSON, G.S. (eds.), The Geological Evolution of the Eastern Mediterranean. G.S. Spec. Publ., 17: 659-668.
STEININGER, F.F.; RABEDER, G. & RÖGL, F. (1985): Landmammal distribution in the Mediterranean Neogene: A consequence of geokinematic and climatic events. – In: STANLEY, D.J. & WEZEL, E.-C.: Geological evolution of the Mediterranean basin: 559-571, New York, Springer.
TCHERNOV, E (1988): The palaeobiogeographical history of the southern Levant. In: The zoogeography of Israel (Y. Yom-Tov & E. Tchernov, Eds), Junk, Dordrecht.
THENIUS, E. (1979): Afrikanische Elemente in der Säugetierfauna Europas.- Annales Geol. Pays Helleniques, t. hors serie 1979, fsc.III: 1201-1208.
WETZEL, R. & MORTON, M. (1959): Contribution a la Géologie de la Transjordanie.- In: Notes et Mémoires Moyen-Orient, 7:95-173.
WOLFART, R. (1962): Zur Geologie und Hydrogeologie des Irbid-Distriktes (Nord Jordanien). - Geol. Jb., 79: 445-478.
ZILBERMAN, E. (1992): Remnants of Miocene landscape in the central and northern Negev and their paleogeographical implications. - Geol. Surv. Isr. Bull., 83:1-54.

Plate 1

Fig. 1: Wadi al-Arab downstream of the road crossing it to Umm Qays with the slopes exposing chalks of the Muwaqqar Formation and the arrow indicating the transition from Cretaceous to Tertiary strata.

Fig. 2: Wadi Shelalla with the arrow pointing at the marker bed above the transition from the Cretaceous into the Paleocene and just below the transition into the Eocene. This massive bed is of yellow coloration and bears characteristic umbrella-like trace fossils.

Fig. 3: North Shuna at the northern slope of the valley of Wadi al Arab with the Paleogene Um Rijam Formation (exposed in the slope at the right) unconformably overlain by Tayba Formation forming the ridge (arrow) due to the almost vertical sandstone with conspicuous pectinids bivalves.

Fig. 4: Exposure of the section of Tayba Formation (details in figs. 6 & 7) just NE of Waqqas. The view is from the small road leading from Waqqas to Tayba. The arrow indicated the position of the top layers seen also in fig.7.

Fig. 5: The section seen on the right side of the slope in fig. 4 with black lines indicating the bedding planes. The lower bed holds oysters and marine fossils.

Fig. 6: Detail to fig. 4 with the arrow indicating the base of Tayba Formation on the Paleogene chalk.

Fig. 7: The left side of the section seen in fig. 4 in more detail with the arrow pointing at the layer of salinal deposits.

Fig. 8: Detail of rocks from Wadi al Qarn with the coin 25 mm wide. The laminated beds have been burrowed through by crabs.


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Plate 2

Fig. 1: In the upper Wadi al Qarn the layers of Tayba Formation have become strongly affected by deformation and perhaps also by synsedimentary slumping.

Fig. 2: Chalky layer within the sequence of the Tayba Formation in Wadi al Qarn that holds rich microfauna.

Fig. 3: Detail of rocks exposed in Wadi al Qarn with lamination, mud cracking and mud clast layers.

Fig. 4: Thin section of the large benthic foraminifera *Lepidocyclina* (about 3 mm wide) from the slope above Wadi Tayba near Waqqas.

Fig. 5-10: Samples of the foraminifera which were extracted from the chalky bed seen in fig. 2 from Wadi al Qarn and representing late Oligocene to early Miocene species of the genus *Globorotaloides* (about 0.2 mm wide), figs. 5 & 6: *Globigerina* with about 0.4 mm width (figs. 7-9); *Paragloborotalia* (0.3 mm wide) fig. 10.

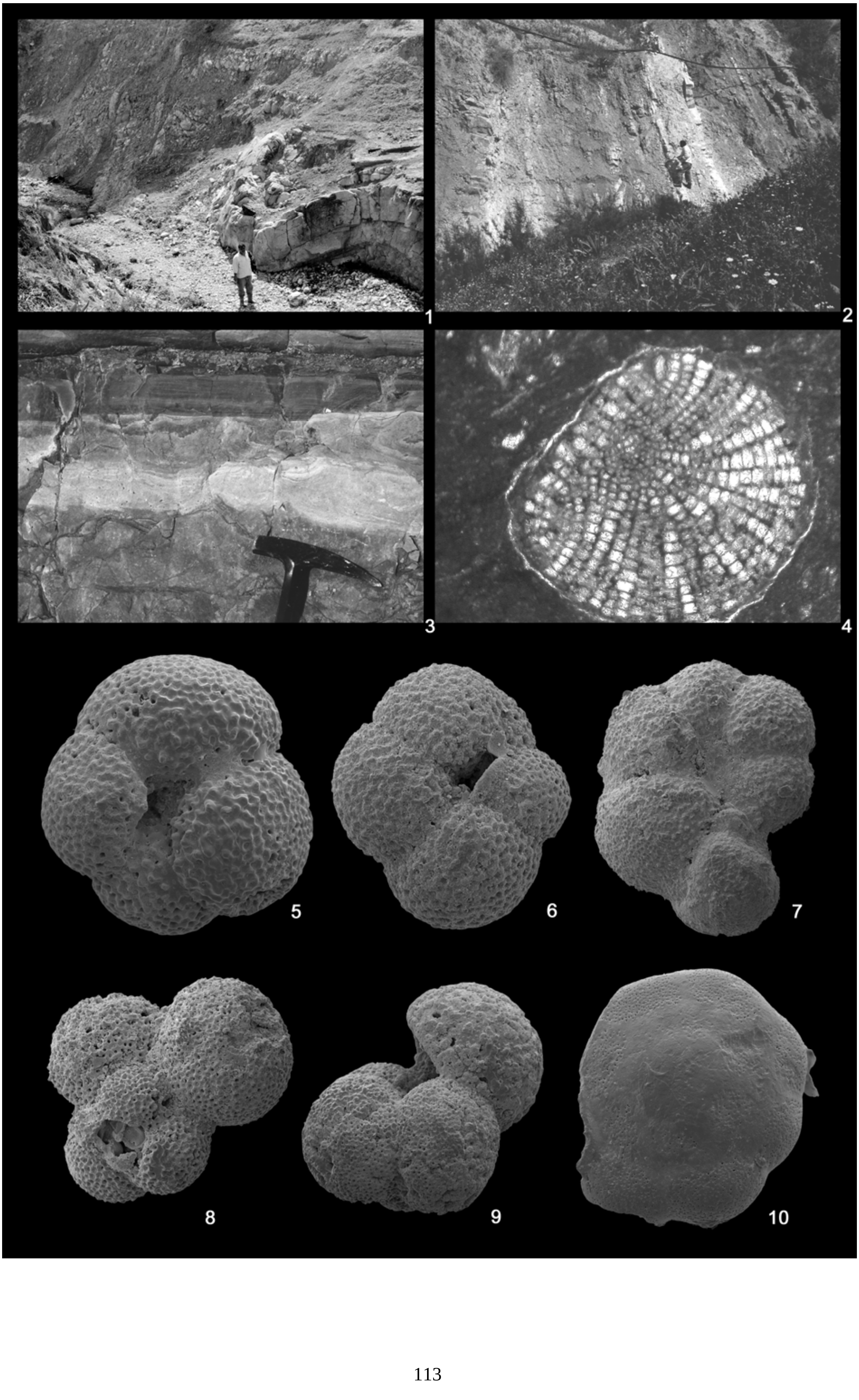
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Plate 3

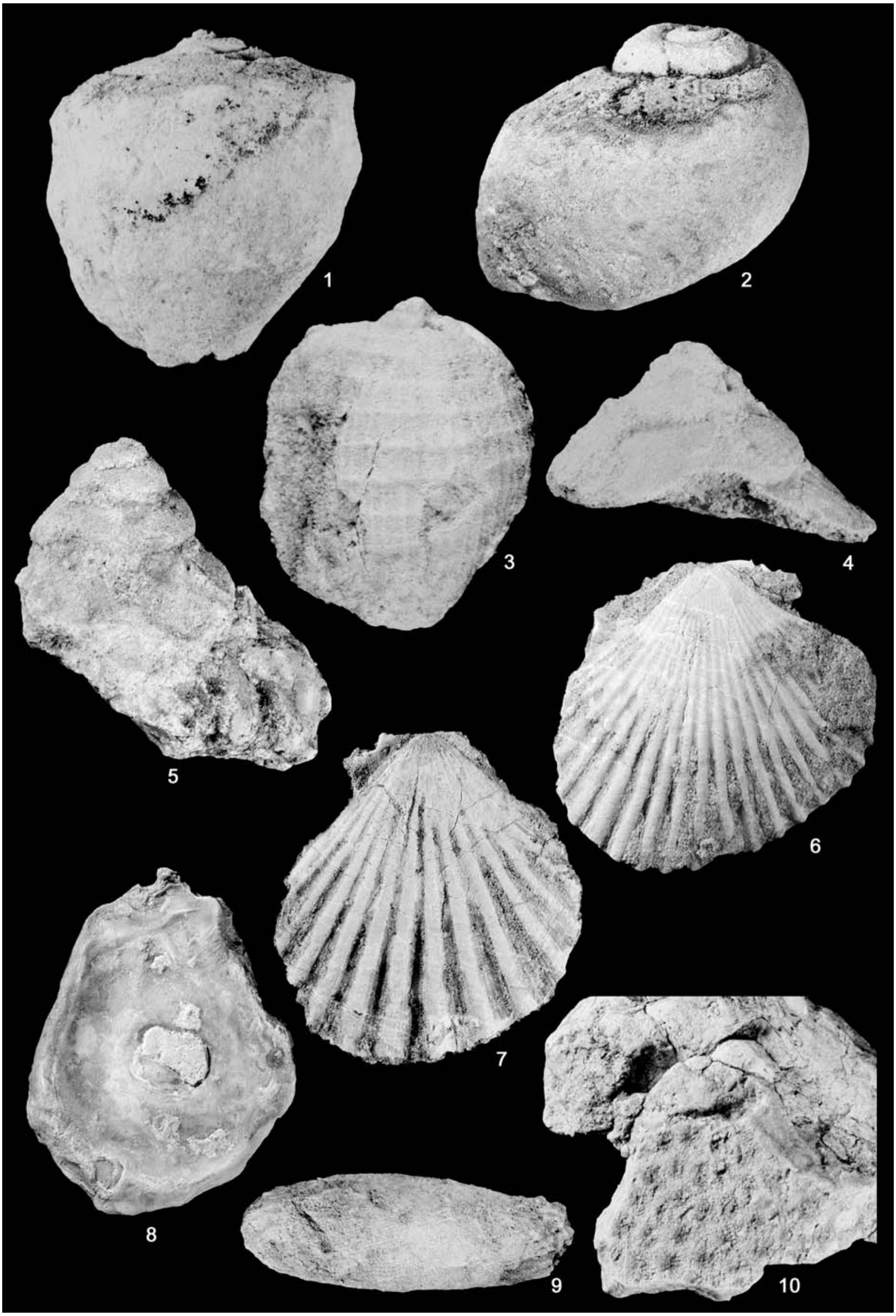
Fig. 1-5: Gastropods from the section just NE of Waqqas; fig. 1: *Cassidaria* sp. (35 mm); fig. 2: Steinkern of a naticid gastropod (30 mm), fig. 3: *Ficus* (33 mm); fig. 4: *Xenophora* (30 mm wide), fig. 5: *Xenophora* (20 mm high).

Fig. 6-7: Pectinid bivalves from North Shuna (6= 50 mm, 7= 40 mm wide).

Fig. 8: The flat valve of an oyster from Waqqas (80 mm wide).

Fig. 9: Filling of the drill hole of a boring bivalve from Waqqas (about 50 mm long).

Fig. 10: Colonial coral from Waqqas (approx. 30 mm wide).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Paläontologie, Stratigraphie, Fazies
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