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Palaeoecological and diagenetical significance of a silicified soft bottom fauna of Campanian age (Qatrana Unit, Jordan)

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With 27 figures

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Abstract

Silicification during early diagenesis preserved the delicate shells of a fauna that originally lived in and on muddy, aragonite-rich, predominantly calcareous sediment. The silicified shells are connected in their origin to the formation of flint nodules and chert layers. The fauna documents a fully marine environment in the shallow sea with soft bottom substrate that was in early deposits usually fully aerated submerged, partly nonoxic within the sediment and, in later deposits, formed within the intertidal regime. This shelf sea covered Jordan during Campanian time and was part of the Tethys Ocean. In a basically tropical environment sea water was influenced by cold upwelling currents resulting in a continuous eutrophication that caused a high production of organic material. The silica-rich skeletal remains of planktic organisms were the source of chertization within the sediment and local replacement of aragonitic shells by quartz.

Zusammenfassung

Die Verkieselung erfolgte während der frühen Diagenese und bewirkte die Erhaltung von auch sehr zarten Schalen einer Fauna, die im und auf dem schlammigen Boden unter marinen Umständen lebte. Das Sediment war reich an Aragonit und bestand vorwiegend aus Kalkschlamm. Die verkieselten Schalen entstanden im Zusammenhang mit der Bildung von Feuersteinknollen und Kiesellagen. Die erhaltene Fauna belegt ein marines Milieu in flachen Meer, welches anfangs einen durchgehend mit Sauerstoff versorgten Boden besaß, später auch Bedingungen mit sauerstoffarmen Böden aufwies und zuletzt im Gezeitenbereich lag. Das Schelfmeer bedeckte Jordanien während des Campan

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und gehörte zum Tethys Ozean. Hier stieg in tropischen Klimabedingungen kaltes Tiefenwasser auf, welches sehr nährstoffreich war und im Prozess einer kontinuierlichen Überdüngung zu einer hohen Planktonproduktion führte. Dadurch wurde dem Sediment viel organisches Material zugeführt und zudem die an Kieselsäure reichen Skelette von Organismen. Letztere bildeten die Quelle für die Kieselsäure, die bei der diagenetischen Entstehung der Kiesellagen vornehmlich den Aragonit ersetzen.

1. Introduction

When BANDEL & MIKHEL (1985) reconstructed the course of diagenesis and deposition of the phosphatic beds of the Campanian Ruseifa Formation in Jordan, they stated, that the shallow shelf sea of the Tethys Ocean covered much of Jordan during Campanian time, and that this water was highly productive due to upwelling. Therefore a fine-grained, predominantly carbonate muddy sediment formed in which organic material was abundant. It created conditions within the sediment which caused phosphorite particles to form during early diagenesis. Commonly these particles represent originally soft fecal pellets that, thus, turned into hard sand-sized grains. They also demonstrated that deeper down in the sediment aragonite dissolution and chertization were steps of diagenesis that occurred after phosphatization had been completed. Evidence of erosion on raised former sea bottom along fault systems and on the top of synsedimentary folds that originated due to sediment load on water rich sediments demonstrated that some layers of muddy and sandy sediments were transformed into chert under a cover of at least 10 m of overburden. Only along with the silicification of whole beds, concretionary layers, or single mudclasts aragonite dissolution took place on a larger scale. This resulted in the formation of the much compacted chalky and marly layers between chert and phosphate beds. It was during this late diagenetic process that the sediment lost most of its aragonitic fossil content. While the beds of the Amman Formation formed on the shallow shelf and below the intertidal regimen, with begin of the deposition of the rocks of Ruseifa Formation structural unrest connected to periodical lowering of sea level resulted in the appearance of island chains from which former marine deposits were eroded and phosphatic particles redeposited nearby in offshore sand bars. Near the beach oysters formed settlements and reefs and seaward of these muddy intertidal flats were present. The depositional area locally varied much so that the thickness and the lithology of the deposits of Amman and Ruseifa Formations are very variable (SHINAO & BANDEL, 1998).

2. The fauna

When viewing some surfaces on the chert beds and larger flint nodules in the area of the outcrops of Amman and Ruseifa Formations west of Irbid, the east of Amman, along the Wadi Zerqa near Zerqa and Suchna, or on the old King's Highway at the northern rim of Wadi Mujib many fossils may be detected. These are predominated in some layers by baculitids, rarely by other ammonites. Others have many solemyid, nuculid and other palaeotaxodont or lamellibranch bivalves. Common are beds predominated by turritellid gastropods and others by scaphopods. Other beds have a mixture of these, sometimes a predominance of naticid, cerithiid or aporrhaid gastropods. Sometimes ringiculid gastropods predominate. When the layer of transition between chert and chalky or marly limestone is extracted and dissolved in weak acid, a very well preserved silicified microfauna is found in the residue. Here numerous foraminifera, predominantly pelagic ones may form the bulk of the fossils. Alongside many and commonly rather delicate shells of ostracods, bivalves,

gastropods, cephalopods and others are found. These indicate that the silicification took hold of shells in which no compaction and no dissolution as well as destruction of organic material had occurred. In the layers right next to the silicification front this is quite different. Here shells are flattened, broken and deformed right next to the well preserved ones, and a few millimetres further there is no trace left of them in the chalk, marly chalk, or chalky limestone, except of rather large and originally thick shells or originally calcitic shells. Within the chert beds or flint nodules shells may be preserved as traces, but altered and often quite indistinctly visible.

Among the cephalopods the common occurrence of their embryonic shells, the ammonitellae, is evident (BANDEL, 1982, Pl. 13, figs. 1, 2, 6). Here the delicate tubercules that form the ornamental pattern of the ammonitellae are preserved in every detail (figs. 12-14). In their interior the organic siphuncular tube and originally aragonitic septae and walls are preserved. The transition of ornament of the embryonic shell to the teleoconch is clearly represented (BANDEL et al., 1982, text fig. 1D). The absence of the growth line pattern on the ammonitella helped to interpret its mode of growth, which according to BANDEL (1982, 1986) was formed totally as primary shell, still fully attached to the mantle tissue, and, thus, in the shelter of an egg case. Besides numerous baculitid shells with the coiled ammonitella succeeded by an uncoiled, almost straight teleoconch (fig. 14) there are several other ammonitellae belonging to several other ammonites, most of which are normally and planispirally coiled (figs. 12, 13). The size of the ammonitellae differs somewhat in the range of 0,5 to almost 1 mm; within a single species it is the same.

Scaphopoda are very numerous in some layers (fig. 11) and are preserved in all size classes. These molluscs represent carnivorous animals of prey which usually hunt for foraminifera and actively bury through the soft sediment. Their presence in large numbers in some beds indicates the original abundance of prey. Many minute juvenile along with further grown to fully grown large specimen are evidence for a life close to their location of preservation. The early death of many individuals can commonly be explained, since shells may bear a round hole (fig. 4), as is excavated by naticid gastropods in order to reach their prey in the protection of their shell.

Scaphopods prefer soft substrate as living environments as do the naticids that feed on them. Both also need a well oxygenized environment in which they hunt their prey usually burying through the sediment. Naticid shells in all size ranges are found, many of the shells also having a drilling hole indicating that larger naticids fed on smaller naticids. These carnivorous gastropods also fed on other molluscan prey, as well as on ostracods. Naticid shells may be extremely well preserved with their embryonic shell still showing the tuberculated surface (BANDEL, 1993, Pl. 12, Fig. 3). Also the larval shell can be distinguished from the teleoconch. This is generally so for all the other gastropods encountered besides the naticids. Most of these are provided with an embryonic shell that is clearly distinguished from the larval shell. The larval shell formed while the planktotrophic larva swam in the sea, while the embryonic shell formed within the shelter of the egg mass. Often only the earliest teleoconch is preserved connected to the teleoconch, demonstrating that many larvae metamorphosed to benthic life, but afterwards were not able to continue to survive or fell victim to animals of prey.

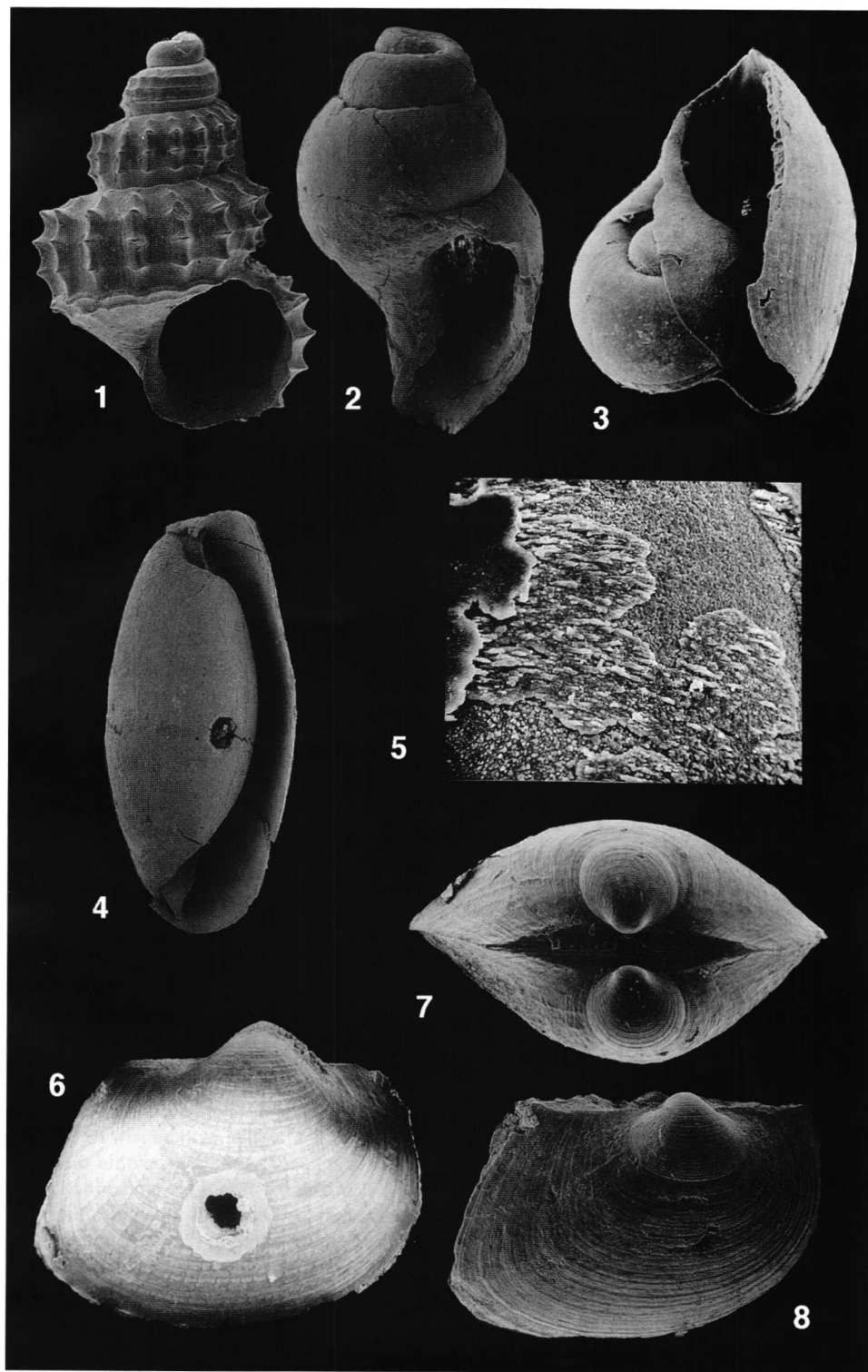
Several gastropods that can be encountered in great number can provide us with good information regarding the palaeo-environment. Ringiculid cephalaspidean gastropods hunted small organisms, mainly foraminifera, small molluscs and ostracods within the upper sediment

layers. Their modern representatives prefer soft bottoms on the shelf below wave base. In the Amman and Ruseifa Formation they occur with several species and are common in many layers. Other cephalaspideans, such as several species of bullomorphs probably fed on algal mats. Here the early ontogenetic shell is later included in the teleoconch (figs. 3, 4) and can not longer be detected. Here also all ontogenetic stages have become preserved with the sinistral protoconch connected to the early dextral teleoconch and successive covering of the protoconch by the later. In the small heterostrophic ? *Omalogyra*, probably related to the modern *Anomalorbis* group the sinistral embryonic shell is ornamented by tubercles and clearly differentiated from the larval shell which again is distinguished from the teleoconch by an apertural rim (BANDEL, 1988, Pl.3, fig.1).

Algal food from diatom mats or thickets of filamentous algae have probably been collected by a small cerithid gastropod (fig. 1), that is very common. In contrast to these snails that moved about to collect their food *Turritella*- related gastropods and aporrhaid gastropods collected food in a sessile way by burying shallowly within the sediment keeping contact to the surface and pumping water through their mantle cavity. Here suspension is filtered from the water by mucus that covers the ctenidia. Cilia on the branches gill keeps the water moving. Some layers in the Amman and Ruseifa Formation have very many turritellid shells preserved which also nowadays are good indicators of nutrient rich water passing by their living place. All these gastropod shells usually had their periostracum covers still in good condition, including the organic ornament of the embryonic and larval shell, when they became silicified. In some cases the shells were eroded somewhat, and here the original shell structure is preserved, demonstrating crossed lamellar structure or similar precursor structures as are found right below the periostracal layers now transformed into quartz (fig. 5). This transformation was such, that minute structural details in the size range below 1 micron have been preserved.

The mode of life of not so common, but usually present gastropods belonging to the Pyramidellidae, the Ctenoglossa and the Eulimidae tells us, that their hosts must have been living here as well. Pyramidellidae suck blood or other body liquid from worm and mollusc hosts. Ctenoglossa of the cerithiopsidan type usually are parasites in sponges, and Eulimidae have different echinoderms as host. The opercula of serpulid worms are preserved in the silicified fauna (figs. 22, 23), indicating that polychaete worms lived here too, attached to some kind of secondary hardground that has not yet been encountered. Of echinoderms, up to now, only remains of the delicate spines of irregular sea urchins have been found, but no larger skeletal remains are preserved. But the presence of holothurians should be expected, but has not yet been proven.

Figs.1-4. Different silicified gastropods; 1: cerithiid of 2,5 mm height with larval ornament differing from the adult ornament; 2: protoconch of a planktotrophic larva of a neogastropod that is 1 mm high and preserved as it is right after metamorphosis to benthic life; 3: bullomorph cephalaspidean with 1 mm high shell that shows the transition from the sinistral larval shell to the dextral teleoconch; 4: bullomorph, 4 mm high shell with the hole that was drilled by a naticid. **Fig.5.** The etched surface of a gastropod shell with originally acicular aragonitic biomineral structure that has remained preserved during silicification. About 1000 times magnified. **Figs.6-8:** Different arcoid bivalves; 6: The 2,5 mm wide shell has the prodissoconcha (larval shell) clearly separated from the shell of the benthic stage; 7: the umbo of the 2 mm wide shell with both valves of the prodissoconcha; 8: the same as 7 seen from the side.



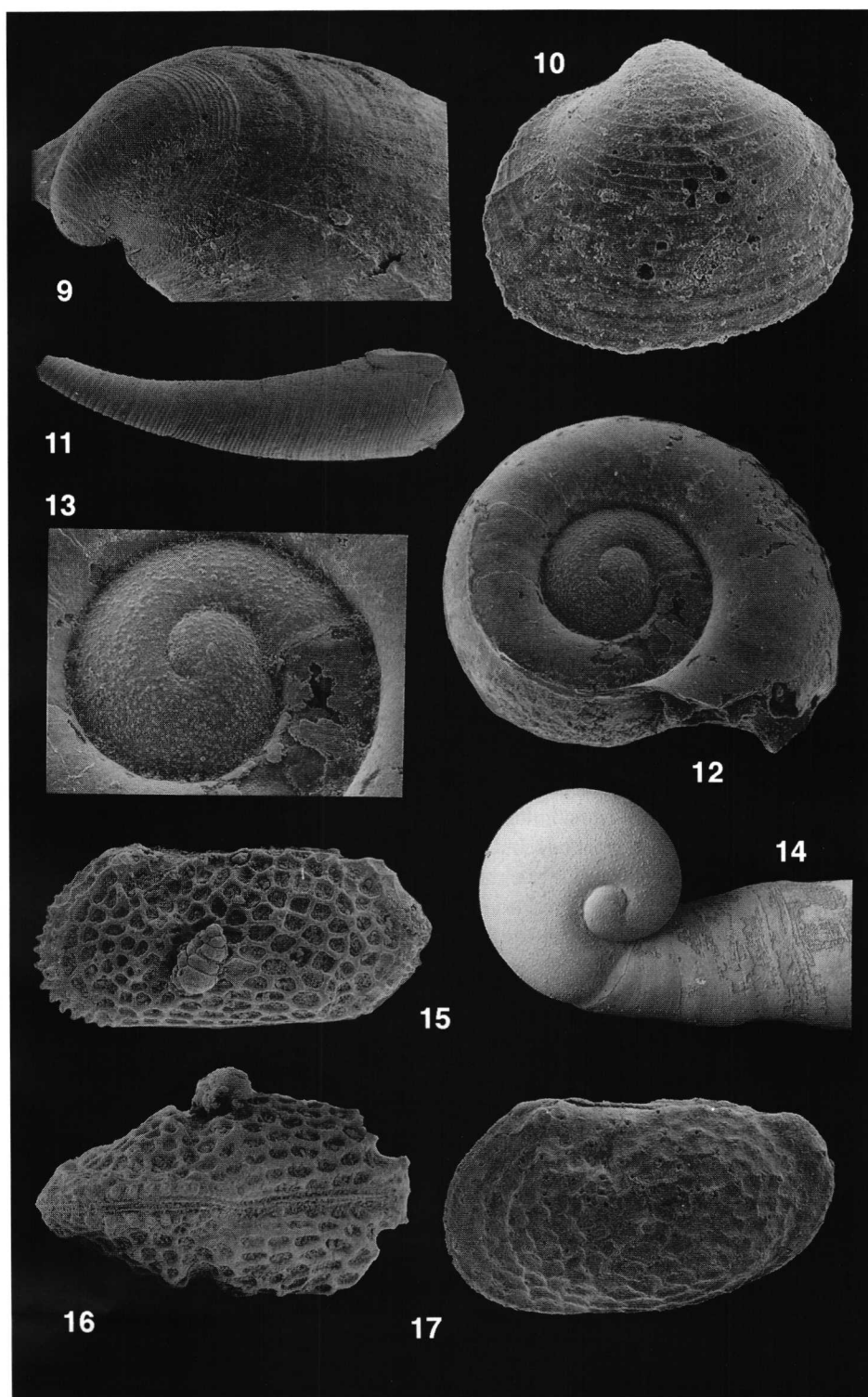
The rich gastropod fauna contains also some representatives of the higher Caenogastropoda, usually only present with their large early ontogenetic shells attached to a little portion of the teleoconch (fig. 2). It is well possible, that many of the species actually did not live here in this environment of a muddy bottom, but metamorphosed here from pelagic life only to die shortly afterwards. These ancestral neogastropods have usually been carnivorous.

Among the bivalves there are several protobranch, arcoid and heterodont bivalves (figs. 6-10). Many of the bivalve shells have been drilled by the carnivorous naticids. Nuculoids as are usually common with *Nucula*-like shapes, but also *Yoldia*-like species that may have burried deeper down. Booth nowadays live on and in soft bottom environments in the fully marine environment. Nuculoids usually collect their food by licking deposits from the sediment surface. Also different species of heterodont lamellibranchs are found, some of which grew to large size. These have probably lived more or less shallowly buried within the sediment keeping contact to the water above and filtering suspended food from it. Mytiloids are also present, but only small shells have been encountered. They lived attached by byssus and have apparently had difficulties growing to larger size. The arcoids present may also have lived within the sediment as is the case with many modern representatives of this group, while others live byssally attached.

Some layers have solemyoid shells, often still with both valves attached to each other. This indicates that during their life time the sediment had an anaerobic character, since solemyids keep contact to the surface to bring into it aerated water, while they pump from the sediment hydrogen sulfide rich anaerobic water to feed the symbiotic bacteria which they culture in their gill. The layers holding these bivalves, thus, give evidence for anaerobic conditions in the sediment just below sediment water interface.

The fauna indicates rather well that the bottom substrate was soft mud. Here scaphopods searched for their prey, probably mainly consisting of benthic foraminifera (figs. 24, 26, 27) that may consist of a specialised fauna, as suggested by REISS (1988), but probably not one characteristic to low oxygen environment, but rather to soft substrate bottom. The benthic foraminifera described by REISS (1962) according to the interpretation of REISS (1988) indicate an oxygen depleted environment. Such a fauna may very well have lived in times when also *Solemya*-like bivalves found good living conditions. Ostracods are preserved with quite a number of different species (figs. 15-19). Many species of ostracods in the Mishash Formation appear to be endemic to the region (HONIGSTEIN, 1883, 1984). The large number of bivalve larval shells which did not continue to grow after settling to the ground

Fig. 9: Arcoid bivalve with the embryonic shell at the tip of the umbo succeeded by the larval shell with regular ribs and the shell of the benthic juvenile. Prodissoconcha 0,35 mm wide. **Fig. 10:** The 0,25 mm wide prodissoconcha of a bivalve with narrow rim of the benthic stage. **Fig. 11:** The 3 mm long tube of a scaphopod with early benthic shell differently ornamented than later shell. **Figs. 12, 13:** The 0,5 mm wide ammonitella (embryonic shell) of a coiled ammonite has a characteristic pattern of tubercules. **Fig. 14:** The ammonitella of the baculitid ammonite with about 1 mm in diameter is quite large and coiled, in contrast to the juvenile shell. **Figs. 15-17:** Ostracodes, 15 and 16, the same strongly ornamented species of about 1 mm in width seen from the side and along the gape; a different species with 0,9 mm wide valves.



is an indication for the special conditions of soft mud here. There must have been many larvae for example of the oysters, which formed large colonies along the shore during Ruseifa times. Young oysters are only rarely found in most layers with a rich silicified fauna, while such shells form coquinas in others or grew to full adult size in some beds.

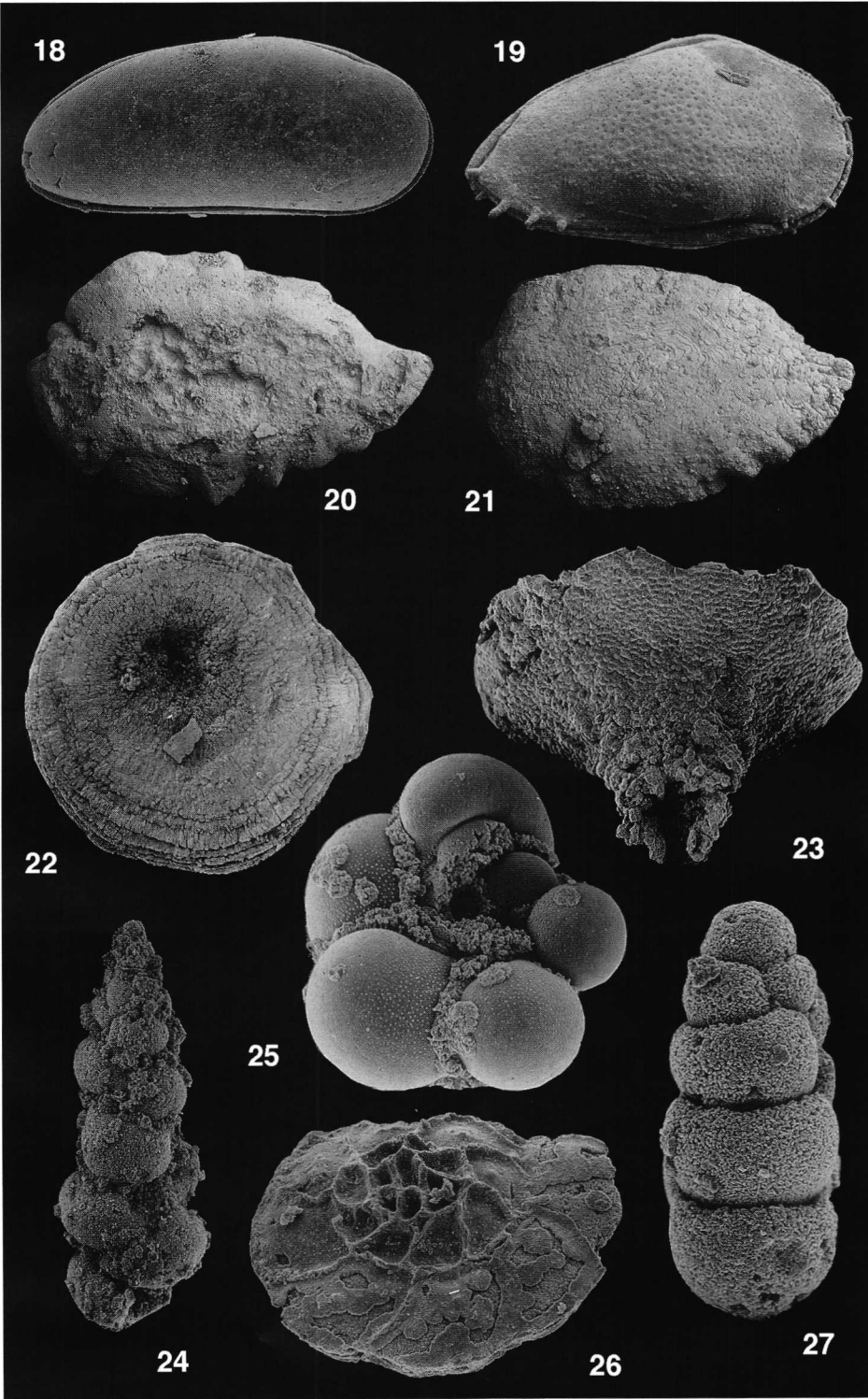
REISS (1988) suggested that this fauna had little competition and predatory pressure was low while large amounts of food were available. For most of the faunas encountered this is quite unlikely to be correct, since those animals which nowadays prey on foraminifera, like scaphopods and ringiculid gastropods were available, in many of the preserved silicified layer in great profusion. All kinds of shelled animals were the source of food to the naticids, as is evidenced by the drill holes found in many shells and by the many naticid shells present alongside.

The presence of numerous fishes are indicated by otoliths (figs. 20, 21). Usually their silicification is not very good. Teeth of all kinds of fish are present as well, but they can also be found in the chalky beds next to the silicified fauna due to the preservation of phosphatic skeletal remains in the diagenesis of the limestones and chalks.

3. Reconstruction of the environment according to the fauna

All molluscan groups encountered with exception of those that lived on other animals or on vegetation, indicate that the bottom substrate was soft. Most of them lived in aerated sediment, but solemyids clearly indicate that conditions were also present during which the substrate was anaerobic, while water above must have been oxygen rich. Most of the shells of the molluscs encountered consisted of aragonite alongside organic material. The shells of the layer right next to the silicification surface are not deformed. When shells are enriched in thin coquina beds their sorting is poor, so that they have been winnowed out from fine sediment staying more or less in place. Many of the bivalves and the ostracodes are still preserved with both valves attached to each other, so that they have moved very little or not at all after their death. The fauna holds also many shells that have come from the open sea. These are not only the cephalopods, but also the large amount of shells of veliger larvae of bivalves as well as gastropods. While many of the beds in the Amman Formation and the lower portion of the Ruseifa Formation demonstrate silicified shells in contact between chert beds and chalky beds, the cherts of the upper portion of Ruseifa Formation commonly have no fossils but display silicified clay clasts, which may be bored or not on their surface. They, thus, indicate the original muddy surface of the desiccated intertidal flat had either been settled upon by infaunal life, or it had been hostile to it.

Figs. 18-19: Ostracods of about 0,8 mm in width with smooth (18) and with ornamented and spinose shell. **Figs. 20- 21:** Otoliths of fish which are not so delicately silicified. 20, 1 mm wide; 21, 2 mm wide. **Figs. 22-23:** The originally calcitic, about 1 mm wide operculum of a serpulid worm seen from above (22) and from the side (23) with the originally prismatic construction still seen in the silicified fossil.; **Figs. 24-27:** Three benthic and one pelagic (25) foraminifera with delicate preservation in the secondary silicified fossil form, which in 26 shows an incomplete replacement of the outer shell layer. Size: 24 = 0,6 mm long, 25 = 0,3 mm wide; 26 = 0,5 mm wide; 27 = 0,2 mm long.



The present and absent fauna in a section like that found in Wadi el Ghafer in Irbid (SHINAQ & BANDEL, 1998) or at Ain Ghazal in Amman (BANDEL & MIKBEL, 1995), thus indicates that the muddy bottom of a shelf sea with high organic production was settled by a rich benthic life. Later on conditions on the bottom deteriorated as the sea became shallower until sabqa conditions of a muddy intertidal regime formed. Here life was mainly represented by cyano-bacterial mats.

Regarding preservation of fossils it is quite evident that diagenesis altered the original composition of the fauna very strongly. Wherever cherts formed within the muds of the Amman Formation and the lower Ruseifa Formation a fauna has been preserved. In the chalky limestones, and the marly, sometimes strongly bituminous cherts and limestones next to them fossils have usually been destroyed and commonly a fine lamination has appeared, which in most cases had originally not been present in the sediment. The carbonate muds, in contrast had been churned by bioturbation. Only originally large shells, like that of larger ammonites, and originally calcitic shells like those of oysters have been preserved. The original shell rich composition of the sediment is also preserved in such layers, where during early diagenesis calcareous concretions formed. Here the totally bioturbated and richly fossiliferous composition of the sediment can be made visible again by thin sectioning these concretions.

When currents spread the cold or cool water over the shallow broad shelf of the Arabian-Nubian Continent, that is the northern Gondwana shelf with its warm climate, it rapidly warmed up, and a rich fauna and flora of planktic and nektic organisms developed. Their skeletal hard parts as well as fecal pellets rained to the sea floor forming carbonate muds rich in organic matter. Predominantly diatoms and silicoflagellates and to some extent radiolarians flourished (SOUDRY et al., 1981; MOSHKOVITZ et al., 1983). They jointly with sponges contributed biogenic silica to the sediment that was available in the diagenetic formation of chert. Productivity of the fertile water of the shelf was so high that organic deposits were not totally decomposed by rich benthic, soft bottom fauna comprising among others molluscs and crustaceans. While the former left their shells in abundance, the latter excavated their burrow systems now found in profusion. The rich organic matter provided phosphorus for the formation of phosphate deposits again by way of diagenetic processes connected to erosion.

4. Data on the stratigraphic position

The Qatrana Unit represents the central portion of the Belqa Group (QUENNEL & BURDON, 1959; WETZEL & MORTON, 1959), which holds the chalky Umm Ghudran = Ain Ghazal Formation at the base (mostly Coniacian), the Amman Formation with much chert (Santonian and Campanian), the Ruseifa Formation (Campanian) with much phosphatic sand in the centre, and the chalky-marly Muwaqqar Formation (Maastrichtian) at the top (BANDEL & MIKBEL, 1985; SHINAQ & BANDEL, 1998). The equivalent of the Qatrana Unit in Jordan is called Mishash Formation in southern Israel (SHAW, 1947), which is underlain by the chalky Menuha Formation and is overlain by the dark marly-chalky Ghareb Formation (KOLODNY, 1967).

The Amman Formation (as defined and first published by BANDEL & GEYS, 1985) is characterised by intercalated chert beds, cherts, marly cherts and limestones. The name of Amman Formation is taken from the capital city of Jordan, where it forms most of the bedrock (MASRI, 1963; BANDEL & MIKBEL, 1985). The latter authors selected the type section

of Amman Formation at the cliffs of Ain Ghazal near the sewage treatment plant of the city of Amman in Jordan, and thus, the spring of the Zerqa River. BENDER (1968, 1974) had preferred the term "Silicified Limestone Formation". POWELL (1988) used the term Amman Silicified Limestone Formation, a name that was also utilized by ABU-JABER et al. (1997) in their discussion on the formation of the silica beds. The Amman Formation was determined to belong to the Campanian with ammonites (NAZZAL & MUSTAFA, 1993), and thus, agrees in age with the Mishash Formation (REISS, 1955, 1988; REISS et al., 1985; PARNES, 1956, 1964; SOUDRY et al., 1985; MOSHKOVITZ et al., 1983; GVIRTZMAN et al., 1989; LEWY, 1990; see here for more literature).

The Ruseifa Formation (as first published by BANDEL & GEYS, 1985) was defined in the Ruseifa phosphate pits (BANDEL & MIKBEL, 1985). It is distinguished from the Amman Formation at its base by the occurrence of first thick phosphate beds, and the Muwaqqar Formation above by the disappearance of phosphate beds and chert, as well as the appearance of massive marl and chalky marl instead. Ruseifa Formation consists of a heterogenous lithology of medium-thick beds of phosphorite, which are intercalated with thin-medium-bedded chert, marl, chalky marl, microcrystalline limestone and oyster-coquinal grainstones. The formation discussed by BANDEL & MIKBEL (1995) and SHINAI & BANDEL (1998) was described from the Ruseifa-Wadi Es Sir area around Amman and area around Irbid. It is equivalent to the "Phosphorite Member" of BENDER (1974), the upper part of Calcaires a Silex de Qatrane (WETZEL & MORTON, 1959), the upper part of the Amman Formation (MASRI, 1963), the upper part of the B2 Silicified Limestone Phosphorite Formation (MACDONALD, 1965). In the Negev it is equivalent to the phosphorite series member of the Mishash Formation (SOUDRY et al., 1985), and thus, the upper, more phosphatic portion of the Mishash Formation. A distinction of lower chert rich deposits and overlying phosphatic deposits in Jordan had already been carried out by KRUTSCH (1911). According to NAZZAL & MUSTAFA (1993) the Campanian Maastrichtian boundary lies in the top of the Ruseifa Formation with the possibility that there was an interval of non deposition of some kind as interpreted to form the base of the Ghareb Formation (REISS et al., 1985).

5. Discussion of the proposed models of the depositional environment

During Cenomanian and Turonian time Jordan was part of a shallow warm sea with the production of carbonate produced in large part by benthic animals. The coast of the sea lay far in the SE of the country and periodically the sea withdrew from much or part of the area of modern Jordan during periods of low water level in the Tethys Ocean (BANDEL & GEYS, 1985). The margin of this shelf to the more open ocean was characterised by a fauna containing rudist bivalves (MUSTAFA & BANDEL, 1992; BANDEL & MUSTAFA, 1994), while the more restricted shelf had oysters (AQRARAWI, 1993) as representative of the most common macrofossils.

During the Coniacian the type of sedimentation switched from predominantly benthic sediment production to predominantly pelagic material with the deposition of coccolith chinks (BANDEL & GEYS, 1995). In comparable units in the Negev LEWY (1975), REISS et al. (1985), and LIFSHTIZI et al., (1985) also recognised that the basal chink is of Late Coniacian age, while the middle part of this chalky Menuha Formation is Santonian in age. The lithologic change from detrital carbonate sand of upper Wadi Es Sir Formation to carbonate muds of Umm Ghudran Formation reflects a change in temperature, chemistry and depth of the water of the Tethys Ocean. From Coniacian time onward pelagic sediments characterise deposition. The carbonate muds were deposited in the open Sea and they provided suitable

conditions for a rich benthic fauna (opposite view on similar chalky deposits in Israel, see REISS 1988).

During deposition of Qatrana Unit in Jordan and Mishash Formation in southern Israel at Campanian time (BLANKENHORN, 1921; CHAVAN, 1948; REISS, 1955, 1988; REISS et al., 1985; PARNES, 1956; LEWY, 1969, 1990; see here for more literature) upwelling currents intensified resulting in a flow of nutrient rich waters over a bottom whose relief became gently undulated in response to folding and faulting (BANDEL & MIKBEL, 1985). The sea water of the shallow open sea was rich in dissolved mineral carbonate, phosphate and silica. This water came from the open Tethys Ocean and probably was recharged in mineral content by upwelling currents that came from the depth of the ocean.

According to REISS (1988) the paleolatitude of 8-15°N on the margin of the Tethys Ocean resulted in the path of the easterly trade winds blowing from the NEE. According to his interpretation these created a circulation pattern of 28-32°C warm surface water. This would lead to a coastal upwelling of only slightly cooler, nutrient rich, but according to this interpretation also oxygen deficient midwater that was also more saline than that of the open sea.

The phosphogenic belt of the Cretaceous in the south eastern Mediterranean stretches from Morocco to Turkey. As KOLODNY (1980) stated the late Cretaceous sequence of southern Israel and Jordan of the Mishash and Qatrana units are part of that belt. It has been associated to areas of upwelling of deep waters to the surface. Here Si and P are considered as nutrient elements and both come mainly from organisms. Organic matter tends to be preserved particularly under conditions of oxygen deficiency such as those which develop in areas of high fertility. If decomposed early enough during diagenesis organic matter can contribute phosphorous to the interstitial water toward apatite formation. STEINITZ (1977) suggested a hypersaline- evaporitic stage in the early diagenesis of Mishash cherts. But he also noted that most of the deposition occurred under normal marine conditions, due to the presence of marine shells. This suggests an environment of extreme salinity fluctuations. KOLODNY (1980) noted a depletion in 13 C in Mishash carbonates as diagenetic results from high productivity coupled with density stratification and intermittent anoxic conditions. A wide range of hydrographic conditions were suggested for the Mishash sea from hypersaline evaporitic to fresh water, for well aerated and well mixed water to a stratified water mass anoxic at its bottom, sabkha evaporite formation changing with fresh water and dry flats.

LEWY (1990) considered that during deposition of most of the Mishash sediments bottom illumination and aeration was reduced, leading to restricted conditions, and only during short periods there were normal bottom conditions. This also reflects the interpretation of REISS (1988) based mainly on the peculiar and species poor foraminiferal fauna found in these beds. He suggested that this would also explain the poor diversity of diatoms and silicoflagellates as was noted by MOSHKOVITZ et al., (1983), and poor diversity of ostracods noted by LIFSHITZI et al., (1985). They had interpreted their results as indicative of restricted environment, at least west of the Rift. This is not so in Jordan, where wherever diagenesis permits a look at the fossils, there is a rich fauna. The idea of a restricted fauna had also been picked up by ABU JABER et al., (1997) who also relied in this regard on publication by ABED & KRAISHAN (1991). They regarded the fauna as a low diversity fauna, quite unlike that of a modern fauna of upwelling currents conditions as found along the Chilean - Peruvian coast. Due to this erroneous assumption they came to the conclusion, that even though biogenic silica in the Qatrana Unit was similar to these upwelling zones the silica should have come from other sources, preferably the subsurface. ABU JABER et al., (1997)

also considered molluscs and especially gastropods to represent poor environmental indicators, while actually the opposite is true. These animals represent mostly benthic forms, and they have been living in and on the sediment. Their habits are in many cases well known, and their ecological requirements can be reconstructed quite well from their modern relatives.

REISS (1988) mentioned a low diversity assemblage of marine organisms that lived under low oxygen conditions and among or below bacterial mats. According to REISS (1988) on top of chert layers a fauna of some pelecypods, small gastropods and baculites occurs, but only here. But their presence actually indicates, that conditions in Israel were quite similar to those in Jordan, as can be expected due to the original closeness of depositional environments. The observations of REISS (1988) according to which the fauna was depauperate and poor in species can not be confirmed though, and this impression is the result of diagenetic effects. The data reported above indicate that such interpretations may only explain the deposition of some beds of the Qatrana unit, while others were deposited under quite more favourable and more fully marine conditions.

SHINAQ & BANDEL (1998) demonstrated that in northern Jordan, and here the area near Irbid, during deposition of Amman Formation the shore lay in the far south of Jordan. Near the top of Umm Ghudran - Ain Ghazal Formation first layers with phosphatic fecal pellets are found representing the onset of a phosphorite diagenesis that characterizes the following Amman and Ruseifa Formation ceasing only with the onset of Muwaqqar Formation. Phosphatisation of fecal pellets occurred in the soft mud due to interstitial solutions rich in phosphate ions and fixation of these to the organic matter and mucus. When periodical currents washed across the muddy bottom calcareous shells as well as phosphatized pellets and skeletal particles were winnowed out and enriched in sands, now intercalated with the fine-grained beds.

SOUDRY & CHAMPETIER (1983) suggested that cyanobacterial mats colonized the semi-emerged to shallow submerged Campanian flats in the Negev and bound the diagenetic phosphate particles, periodically supplied by tidal currents. The majority of phosphate grains were derived by the reworking of phosphorites that formed within the flats, such as intraclasts, peloids, phosphatized sheath bundles, phosphatic coated grains. Other grains including bone fragments and coprolites were derived from the adjacent marine floor. Winnowing of the non-phosphatic fine fraction and high density of apatite enhanced the concentration of the phosphate material. So they interpreted a double type of formation, replaced and in place formation.

Silicification of some beds occurred after some compaction had occurred, but before the minute aragonitic shell remains had dissolved. Transformation of fine-grained beds into chert occurred when beds were covered by several meters of sediment. Muds were formed due to increased deposition of carbonate skeletal remains of planktonic organisms, while chert was formed due to the solution and redeposition of siliceous skeletal elements (sponge spicules, diatom and radiolarian skeletons) in the sediment.

Small scale fold-like syndimentary structures with an amplitude of few meters to wave length of about 5-25 m do not continue into the underlying and overlying beds. Most diapiric folds and domes are found in the lower beds of Amman Formation that overlie the chalky Ain Ghazal- Umm Ghudran Formation directly. Water released during diagenesis of the marly chalks pushed up the well bedded mud-sand intercalations of the deposits of the Amman Formation into diapiric mounds. Intraformational folds in the Mishash Formation have been described by RATH (1881); BLANKENHORN (1905), LEES (1928), PICARD (1931),

KOLODNY (1967), STEINITZ (1981). The latter two favoured a tectonic explanation, even though they observed that the folds of a magnitude of 1 to 30 m in most cases fade out rapidly, both upwards and downwards. Probably fold formation is connected with faults that follow the margins of the Arabian-Nubian Continent and cross the rift lineament. BANDEL & MIKBEL (1985) noted that at places where sliding and synsedimentary folding occurred, and also where beds came to the surface of the sea bottom due to current erosion that had lain in several metres depth, no chertization had occurred. Thus silicification of beds in the Amman and Ruseifa Formation occurred deep within the sediment, but at shallower depth than aragonite dissolution and compaction flattening delicate shells.

BANDEL & MIKBEL (1985) demonstrated that in the area of Tel Es Sur, just south of the Ruseifa phosphate mines, sea bottom was raised above sea level so that a chain of islands formed. From these sediments of the Amman Formation were eroded and redeposited in shoal sands in the north. These authors noted that at places where sliding, and synsedimentary folding occurred and also where beds came to the surface of the sea bottom due to current erosion that had lain in several metres depth, no chertization was present. According to their observations in the field at the Tel es Sur ridge south of Ruseifa silicification occurred deeper than 10 m in the sediment.

Faults running roughly from the NE to SW are connected to the phosphate beds also in other areas than that of Ruseifa. In the Al Hasa area BEERBAUM (1977) noted the cooccurrence of horst and graben structures and phosphate enrichment. SHILONI (1981) correlated uplift and erosion of Mishash Formation (equivalent of the Amman Formation west of the Jordan Rift) with the redeposition and enrichment of phosphorite found in Beer Sheva valley. Movements during and after deposition of Mishash Formation were also described by FLEXER et al. (1970) and GILAT & HONIGSTEIN (1981) in Galilee. Synsedimentary tectonics has been recognized by BARTOV & STEINITZ (1977) in the Negev.

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