Macroaquatic fossils in the Pliocene- Pleistocene deposits of Jordan and their living environments as compared with surviving relatives.

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DISSERTATION
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Ikhlas Khalaf Alhejoj
Karlsruhe Institute of Technology, October 2013

DEDICATION

This thesis is dedicated to
my parents
To my husband, ***Belal Massadeh****, and my daughter*
Alma*.*

Ikhlas

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ABSTRACT

Deposits of Pliocene- Pleistocene age from different parts of Jordan were studied. Those stemming from lakes, creeks and rivers in the Jordan Valley contain fossils which are predominantly those of molluscs and ostracods, rarely of crabs. Those of saline lakes also include diatoms. Corals form a dominant part of the fossil reefs near Aqaba. The localities and formations dealt with in this study include Al Qarn Formation, pre-Lisan deposits of ancient Jordan River, Lisan Lake Formation, Halat Ammar Lake Formation (Mudawwara Lake), compared to those of Azraq Lake, Hasa Lake and Jafr Lake deposits, and the raised Pleistocene coral reefs of Aqaba. The fossil gastropods which were encountered in the fossil fresh water deposits belong to 12 genera and have been determined as 16 species and such belonging to the genera Theodoxus, Melanopsis, Melanoides, Bithynia, Hydrobia, Ferrissia, Islamia Armiger, Planorbis, Ancylus, Gyraulus, Galba, and Valvata were described. Bivalves were found to be less diverse and less commonly occuring molluscs. They are represented here by species belonging to only five genera Unio, Corbicula, Cardium (Cerastoderma), Brachidontes and Pisidium, including the species from salty Halat Ammar Lake and from modern King Abdullah Canal.

Some of the encountered species are new to science and are here described for the first time include; *Melanopsis salamei* n.sp., *Ferrissia urdunica* n. sp., *Melanoides abuhabili* n. sp., *Planorbis n.sp., and Islamia jordanica* n. sp from Al Qarn Formation. A new species of *Melanopsis* living in Wadi Atum that issues into the Dead Sea was discovered and is documented here.

Theodoxus and *Melanopsis* have lived in the shallow fresh water environment since more than one Million years in the Jordan Valley, and they are present in the lacustrine and fluviale fossil fresh water deposits of the Al Qarn Formation, the deposits of a fossil spring pond of Aramshi Formation, in the river sediments of the Paleo-Jordan as it flowed before the Lisan Lake formed more than 80.000 years ago, and in the deposits of creeks and swamps along the shore of Lisan Lake were fresh water entered the Lake, as for example at Wadi Hammeh.

Theodoxus and *Melanopsis* still represent indicators of pure and clean fresh water in modern Jordan and their occurrence in ancient sediments can be interpreted as indicators for the environmental conditions during the deposition of the ancient

sediments. *Melanoides* is nowadays usually found on muddy ground, and that was the same on the limy mud in the ponds that formed Aramshi Formation. *Melanoides* can also tolerate some brackish conditions, but the companians of *Theodoxus* and *Melanopis* in the rocks of Aramshi Formation place these deposits into the environment of fresh water. Certain groups of aquatic organisms can be referred to brackish environments such as diatoms belonging into the relation *Rhodopalodia* and *Nitzschia* as are found in Lisan Formation. Their dominant presences in distinct thin layers of the finely bedded Lisan diatomites reflect annual changes in the salinity of the surface water of this ancient lake.

The presence of certain ostracods in the sediment Late Pleistocene brackish Halat Ammar Lake (Mudawwara Lake) are a good example of salt tolerant fauna which is present with two species *Cyprideis torosa* and *Candona* sp which are also present in the fossil fauna of deposits of Lake Azraq, Hasa and Jafr Paleo-lakes as is also discussed and compared here. The occurrence of the brackish water bivalve *Cerstoderma* and *Brachidontes* –the later being a sea water species that can also be found in the littoral zone of the Gulf of Aqaba - confirms the interpretation of the salinity of fossil Halat Ammar Lake. The occurrence and composition of aquatic fauna within the fossil deposits allows estimating the environmental conditions as they have existed during the formation of the studied formations. These data can also be employed to reconstruct improvements or deterioration of water quality within the environment encountered, for example in the reconstruction of the extent of the influence of brackish water into the side valley of ancient Lake Lisan.

While the fossil molluscs and ostracods are good indicators for former conditions of the environment, they are no help for reconstruction of the age of the ancient sediments. They have not changed sufficiently to be used as stratigraphical markers. In case of *Melanopsis* of Al Qarn Formation some of which have characteristic shell shapes compared to the species of later times, including those of the Jordan River more than 50000 years ago, a comparison with the different variants of species of *Melanopsis* as are living nowadays in Jordan call for caution and prohibit their use as stratigraphic markers. The composition of their calcareous shell that could be used and employed for radiometric dating has also to be taken with reservations, especially in case of the molluscs from Halat Ammar Lake. Here the analysis by scanning electronic microscope has shown that diagenetic changes have occurred in the shell. This refers also to the fossil corals in the ancient raised reefs near Aqaba. Here transitions of primary aragonitic shell to calcitic replacements are commonly present.

Thus an age dating on such shells would not provide reliable dates for the time of their live, since shell material changed during diagenesis at some unknown time after the shell has been secreted by the animal.

Several Pleistocene coral reefs with their lagoons and beaches are preserved on a gravel fan coming from the mountains in the north and ending in the Gulf of Aqaba. In these terraces the paleo- shore is recognized by wave washed pebbles and beach rock and often still attached to them oysters, and barnacles. Also the partly calcitic shells of *Nerita* present, representing a snail that also nowadays lives in the intertidal zone. The former shallow lagoon with calcareous sand and single coral heads is also recognized along with typical bivalves which belong to the pectinids, spondyids and limids with a shell which is originally at least partly calcitic, and also some *Tridacna*, which grew very thick shells. The fringing coral reef with corals connected to each other in dense growth is preserved, even though coral heads are often recrystallized. Originally calcitic shells of sea urchins have commonly been preserved as well with the sand-dollar in nearshore position, spines of *Diadema*, *Echinometra*, *Tripneusthes* characterizing the lagoon and the thick spines of *Heterocentrotus* and *Eucidaris* in the reef, as is the case today in the living reef. These calcitic shells can also not be used for age determination, since they have originally been porous- with the fine holes filled subsequently by calcite growing into them at some stage of diagnesis. The reef terraces reaching a position of up to 70 m above sea level provide evidence for structural unrest that strongly affected the northern side of the Gulf of Aqaba along the Jordanian coast. The age of the fossil reefs at the coast of the Gulf of Aqaba in Jordan is not known but it can be assumed that they fomed on and during deposition of a large fan that came from the mountains and has its top portion since eroded away.

In the present study, fossilized gastropods have proved to represent very useful indicators for the interpretation of the paleoenvironment. The species of the genera *Theodoxus*, *Melanopsis*, and *Melanoides* are abundant in the ancient deposits and their correlation with living representatives in Jordan document their stability as indicator species. They are thus part of the frame used to describe the quality of the water as it is still flowing in Jordan. The pulmonate gastropod *Physa* has not been present in the fossil faunas of the Jordan Valley and has since settled all rivers. It can be regarded a good indicator of water polluted to quite some degree above that tolerated by *Melanopsis*, while the other members of that group of Gastropods, especially *Planorbis*, *Gyraulus* and *Ancylus* have almost disappeared from running or standing fresh water in Jordan.

Bithynia and *Valvata* have disappeared all together. Also the bivalves *Unio* and *Pisidium* have become rare and only live in the northern part of King Abdulla Canal, with the addition of *Corbicula* that is probably a new addition to the fauna of Jordan since it did not live in ancient River Jordan, as is also the case with *Falsipyrgula*. *Melanoides* tolerates also brackish water, as does *Hydrobia* and *Prosostenia* as they did in the past, and all three can be utilized in the characterization of water quality, in that case in regard to salinity. The common gastropods are used in the frame that has been constructed in this study to characterize degrees of pollution of existing water from Zarqa River to Mujib River and from the Jordanian highland to the Jordan Velley and the Dead Sea. That frame has been improved and added to by the most obvious and visible aquatic animals living in water bodies.

ZUSAMMENFASSUNG

Fossilhaltige Ablagerungen pliozänen und pleistozänen Alters in Jordanien wurden untersucht. Jene unter ihnen, die in Seen, Flüssen und Bächen des Jordantales entstanden, enthalten vornehmlich Mollusken als Fosslien daneben auch Ostrakoden und einige Krebsarten. Ablagerungen, die in salzigen Seen entstanden, bestehen zum Teil aus Diatomeen. Korallen und ihre Verwitterungprodukte bilden hingegen den vornehmlich Bestandteil rezenter und fossiler Riffe bei Aqaba. Die untersuchten Lokalitäten sind die der Al Qarn Formation, die Ablagerungen im Bereich des Jordanflusses zur Zeit vor der Bildung des Lisan-Sees, die Ablagerungen des Lisan-Sees und seiner Zuflüsse, die Sedimente der Halat Ammar Lake Formation aus der Region von Mudawwara im Südosten Jordaniens im Vergleich zu den fossilen Seen von Azraq, dem Hasa See und den See, der die Jafr Senke füllte, sowie die gehobenen fossilen Korallen-Riffe und ihre Lagunen südlich von Aqaba.

Hierbei wurden in den Süßwasser-Ablagungen Schnecken gefunden und beschrieben, die 10 verschiedenen Gattungen angehören und von denen 16 Arten unterschieden werden konnten. Hierbei wurden Arten der Gattungen *Theodoxus, Melanopsis, Melanoides, Bithynia, Hydrobia, Armiger, Planorbis, Ancylus*, *Gyraulus*, *Galba*, und *Valvata* beschrieben. Muscheln treten hingegen seltener auf und gehören den Gattungen *Unio*, *Corbicula*, *Cardium* (*Cerastoderma*), *Brachidontes* and *Pisidium* an, wobei die Arten aus dem salzigen Halat Ammar See und dem heutigen König Abdalla Kanal eingeschlossen sind. Einige der vorgestellten Arten sind noch unbeschrieben, und werden hier neu vorgestellte. Sie enthaten *Melanopsis salamei* n.sp., *Ferrissia urdunica* n. sp., *Melanoides abuhabili* n. sp., *Planorbis n.sp. und Islamia jordanica* n. sp von Al Qarn Formation. In der Literatur noch unbekannte Art von *Melanopsis* im Bach des Wadi Atun wurde angetroffen und wird hier also beschrieben.

Theodoxus und *Melanopsis* sind bereits seit über einer Million Jahren Bewohner des Süßwasser-Milieus im Jordan-Tal und kennzeichnen die See-und Fluss-Ablagerungen der Al Qarn Formation, besiedelten den Quelltümpel und anschließend den See in dem die Aramshi Formation entstand, sowie auch das Flussbett des Paläo-Jordan bevor das Tal vor mehr als 50000 Jahren vom Lisan See überflutet wurde. Bei der Entstehung dieses salzigen Sees wurden auch die vom Süßwasser beeinflussten Seitenzufüsse des Lisansees, wie zum Beispiel im Wadi Hammeh beeinträchtigt.*Theodoxus* und *Melanopsis* sind auch heute noch jene Schnecken, mit deren Hilfe in Jordanien saubere

Süßwasserquellen und Bäche erkannte werden können. Ihr Vorkommen in fossilen Ablagerungen belegt deren Bildung in reinen Süßwasser. *Melanoides* lebt heute gerne in ruhigen Wasser auch schlammigen Boden, wie er auch auf dem Boden der Gewässers aus dem die Kalksteine der Aramshi Formation entstanden. Dort lebte *Melanoides* zusammen mit *Theodoxus* und damit im Süßwasser.

Einige Gruppen im Wasser lebender Organismen können auch den Salzgehalt des Wasser widerspiegeln, wie etwa die Kieselalgen aus der Verwandtschaft der *Rhodopalodia* und *Nitzschia* aus der Lisan Formation dies tun. Die Dominanz der ersteren dieser Diatomeen belegt einen geringeren Salzgehalt der Wasserschichten des fossilen Sees als das Vorherrschen der zweiten Gattung, einzelne Lagen in den laminierten Diatomiten der Lisan Formation reflektieren die Jahreszeiten. Das heutige Vorkommen bestimmter Ostrakoden stimmt überein mit der Rekonstruktion eines großen brackigen Gewässers im Südosten Jordaniens des Halat Ammar Sees während des Pleistozäns, in dem *Cyprideis torosa* und *Candona* sp lebten, welche auch zu ähnlichen Zeiten in der Azraq Senke, in dem durch Verwerfungen gebildeten Hasa Stausee und in der Jafr Senke existierten. Beide Ostrakoden sind auch heute noch in Brackwassertümpeln und Seen Jordaniens anzutreffen.

Die Zusammensetzung der aquatischen Fauna einer fossilen Ablagerung erlaubt die Rekonstruktion der zu früheren Zeiten existierenden Umweltbedingungen. Auch Veränderungen, wie zum Beispiel das Erscheinen des salzigen Lisanssees im Flusstal des Jordan wird in der Zusammensetzung der Fauna reflektiert, es wird also die Verschlechterung der Lebensbedingungen der Lebewesen nachgezeichnet. So ist das Eindringen des salzigen Wassers des Lisansees in die Seitentäler mit dem Zurückweichen vom *Melanopsis* belegt.

Leider können die fossilen Mollusken nichts Genaueres über das Alter der Schichten aussagen, da die seither aufgetretenen Veränderungen der Gehäusegestalt bei Mullusken wie bei Ostakoden zu gering sind. Die Unterschiede, die sich zu Beispiel im Falle von *Melanopsis* der Al Qarn Formation erkennen lassen oder die die Arten aus dem Jordan-Fluss vor über 50000 Jahren betreffen sind nicht größer als jene, die sich zwischen heute in verschieden Gewässern Jordaniens lebenden Varianten oder Arten von *Melanopsis* fetstellen lassen. Daher sind diese verschiedenen Gestalten der *Melanopsis* Schale nicht als stratigraphische Indiatoren nutzbar. Auch der Wert der kalkigen Schale bei der Alterseinstufung mit Hilfe der C14 Methode oder anderer Altersmessungen mit Hilfe der Halbwertszeiten instabiler Elemente ist nicht gegeben. So ist bei den Molluskenschalen der Ablagerungen des Halat Ammar Sees eine Umkristallisation zu beobachten, die bei der frühen Diagenese Aragonit durch Kalzit ersetzte, was auch für die fossilen Korallen der gehobenen Riffe mit Lagunensedimenten südlich von Aqaba gilt. Beides ließ sich mit Hilfe des Rasterelektronemikroskopes an den Schalen sehr gut nachweisen.

Die Ablagerungen pleistozäner Riffe und ihrer Lagunen und Strände auf bzw. in Verzahnung mit den fossilen Schuttfächern südlich von Aqaba wurden interpretiert. Hierbei ist der Vergleich mit den heute existierenden Riffen und ihren Lagunen und Stränden hilfreich, denn die gleichen Tiere besiedeln und besiedelten beide sowohl das rezente wie das fossile Riff. An den Stränden bildeten sich „beach-rock" Barren und den Gezeitenbereich besiedelten Seepocken sowie die Schnecke *Nerita*. In der Lagune wachsen einzelne Korallen wie sie auch fossil erhalten sind, während von den zahlreiche heute hier lebenden Mollusken nur solche mit kalzitischer Schale, von denen *Pecten*-Verwandte, *Spondylus*, Austern und *Lima*-Verwandte erhalten blieben, fast alle andern mit Ausnahme der sehr dickschaligen *Tridacna* aber aufgelöst wurden. Das aus aufeinander wachsenden Korallen bestehende Riff ist auch erhalten, auch wenn die aragonitischen Korallen meist stark zu Kalzit umkristallisiert sind und löcherig wurden.

Seeigel sind primär kalzitisch und oft erhalten, in frühere Strandnähe etwa der Sandddollar (Clypeaster), oft sind die Stachel von *Diadema* sowie *Echinometra* und *Tripneustes* in den Sedimenten der Lagune bei näherer Betrachtung erkennbar und die sehr soliden Stachel von *Heterocentrotus* aus dem eigentlichen Riffbereich sind häufig und gut erkennbar.

Die heutige Lage der Riffe in bis zu 70 m Höhe über dem Meersspiegel belegt die strukturelle Unruhe des jordansichen Ufers des Golfes von Aqaba. Trotz der starken Diagenese ermöglichen die erhaltenen meist ursprünglich kalzitischen Skelettreste eine gute Rekonstruktion ihres Ablagerunsraumes auf dem Schuttfächer, der von Norden kommt, dessen Ursprung aber inzwischen weggeräumt wurde. Das Alter der fossilen Riffe konnte somit nicht genauer erfaßt werden, als dass sie mindestens so alt sind wie das letzte Pluvial welches den Schuttstrom produzierte. In dieser Studie wird gezeigt, dass sich fossile Molluskeschalen sehr gut dazu nutzen lassen, ein ehemaliges Ablagerungmilieu zur rekonstruieren. Arten der Gattungen *Theodoxus*, *Melanopsis*, und *Melanoides* werden häufig in den alten Ablagerungen angetroffen. Sie belegen zudem, daß sich ihr Vorkommen im Untersuchungsgebiet unter genau definierten Lebensbedingungen seit langer Zeit nicht verändert hat. Sie können daher sehr gut als Bio-Indikatoren genutzt werden, wie es in dieser Arbeit der Fall ist. Mit ihrer Hilfe wird ein Rahmen zur Untergliederung der Organismen geschaffen, der dazu dient die Qualität der Fließgewässer Jordanien zu beschreiben. Die pulmonate Schnecke *Physa* war noch nicht in der fossilen Fauna Jordaniens präsent, hat aber inzwischen alle Fließgewässer besiedelt. Sie eignet sich gut als Bioindikator für recht stark verschmutztem Gewässer, in denen *Melanopsis* nicht mehr leben kann. Andere Vertreter der fossilen Schneckenfauna wie *Planorbis*, *Gyraulus* und *Ancylus* sind fast völlig aus den jordanischen Fauna der Fließgewässer verschwunden. Arten von *Bithynia* und *Valvata* fehlen inzwischen ganz. Die Muscheln der Gattungen *Unio* und *Pisidium* sind selten geworden, leben aber noch im nördlichen Abschnitt des King Abdulla Canal, wo inzwischen auch *Corbicula* sehr häufig auftritt. Letztere ist ebenfalls neu für Jordanien und kann im alten Jordan Fluss nicht vor. Das Gleiche gilt auch für die kleine Schnecke *Falsipyrgula*.

Melanoides toleriert zu einen gewissen Grad auch brackisches Wasser, wie im Falle des Karama Rervoirs belegt werden konnte und zudem die Grenzwerte bestimmt werden konnten. Eine gewisse Toleranz von Salz im Wasser gilt auch für *Hydrobia* und *Prosostenia* und es war wohl auch in der Vergangenheit ähnlich, wie die Schnecken des Halat Ammar Sees bezeugen und auch Faunen, die am Übergang vom alten Jordan Fluss zum Lisan See vorkommen. Die Schnecken der Gattungen *Theodoxus*, *Melanopsis*, *Physa*, *Prosostenia*, *Melanoides* und in geringerem Maße *Ovatella*, *Bulinus* und *Galba* lassen sich gut im Bioindikatoren-System nutzen. Ergänzt durch die Ansprache auch anderer, gut erkennbarer Wassertiere, besonders diverser Würmer und Insektenlarven wird dabei ein System zur Erkennung der Wasser-Qualität vorgestellt, mit welchem the Verschmutzunggrade im Bereich zwischen Zarqa Fluss im Norden und Mujib Fluss im Süden und dem Hochland im Osten sowie dem Jordantal im Westen beschrieben werden kann.

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Abbreviations	Definitions
KAC	King Abdullah Canal
DSB	Dead Sea Basin
TIB	Tiberias Basin
Bsl	Below sea level
Asl	Above sea level
SEM	Scanning electronic microscope
Ma	Million
mg/L	milligrams per liter
meq/l	milliequivalents per liter.
Ppm	parts per million
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand

1. INTRODUCTION OF THE STUDIED MACROFOSSILS

1.1 Tectonic and geological setting of Jordan

The history of Cenozoic deposition in Jordan reflects the structural evolution of the area and relates to the geological development of the Arabian Plate. It was formed as part of Gondwana Land when that land collided with Eurasia and broke into a number of smaller plates. One of these is the Arabian Plate. During this process the Tethys Ocean between both Gondwana and Eurasia was subducted and its epicontinental seas withdrew during the Eocene from that part of Gondwana that is now Jordan. This process led to the disappearance of both the Tethys that separated Gondwana from Eurasia and the deep sea that lay between Arabia and what is now Turkey and Iran (Fig 1.1). In Late Eocene, and thus more than about 35 million years ago, the sea left the northern shelf area of the southern continent and Jordan became land, a process coinciding with the end of the Tethys Ocean, and the begin of the history of the Mediterranean Sea. The surface of Jordan that had been covered by the shelf sea fell dry and became eroded with rivers transporting, among other material, gravels and eroded Paleogene and Cretaceous sediments towards the Mediterranean Sea. Later the transport of that material was intersected and dumped into the newly formed depression of the Jordan Rift.

The Arabian Plate separated from Africa as a result of the collision of Gondwana continent with the Eurasian continent during the Eocene. In a first step the Red Sea-Gulf of Suez Graben developed during Late Eocene and Oligocene as a result of a simple shear fault due to accelerated movements in the eastern part of the underlying astenosphere (VOGGENREITER et al., 1988a; VOGGENREITER et al., 1988b). In a further step the Dead Sea transform fault system was initiated with the beginning of the spreading process at the Gulf of Aden during the Upper Miocene causing the northward movement of the Arabian Plate, which continues according to the ongoing spreading process, till recent. Due to the oblique alignment of the Dead Sea transform fault compared to the Red Sea – Gulf of Suez Graben the transform movement caused a passive widening of the Red Sea south of Sinai, which on its part initiated a spreading process starting in the southern part of the Red Sea at about five million years ago (BAYER et al., 1988; PURSER & HOETZL, 1988; VOGGENREITER et al., 1989).

Along the Dead Sea Transform fault system a sequence of pull-apart basins (Gulf of Aqaba, Dead Sea, Lake Tiberias), interrupted partly by transpressional segments were formed in the consequence of the sinistral transform movement which caused untill today a lateral displacement of Jordan of around 110 km north of the Sinai-Levante area (QUENNELL, 1959; FREUND et al., 1970; GARFUNKEL et al., 1981; ABED & HELMDACH ,1981; BANDEL, 1981).

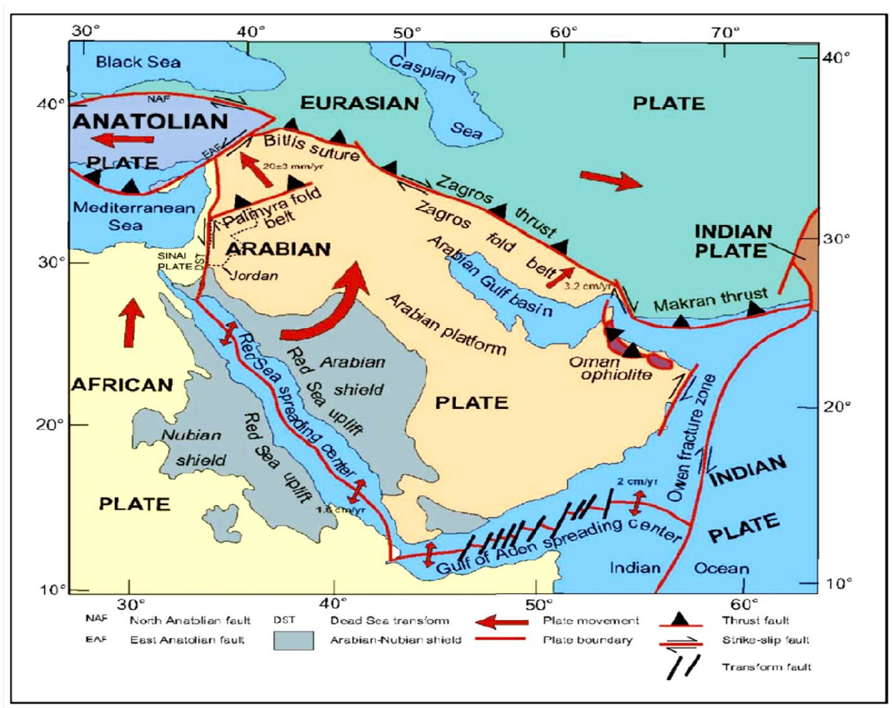


Figure 1.1: Tectonic plate boundaries in the Near East (JOHNSON, 1998).

The northern part of Jordan was last flooded by the remnant of the Tethys Sea coming from the east when it flooded part of the Arabian plate during Late Oligocene. This sea also covered much of eastern Jordan and its near shore deposits have been preserved near the Oases of Azraq and Jafr depression (BENDER, 1968; HIRSCH, 2005; ZACHOS et al., 2007), and within the area of the eastern slope of the Jordan Valley between Lake Tiberias and the town of Masharia (BENDER, 1968; BANDEL & SHINAQ, 2003).

BENDER (1968, 1982) considered the sedimentary series present between the mouth of the Wadi el-Arab in North Shuna and Wadi Tayba to be of a questionable Oligocene and a of more safe Miocene age.

The beach deposits of that Late Oligocene sea are well preserved just to the east of the town of Waqqas but now in an inclined position of its strata dipping towards the Rift Valley. BANDEL & SHINAQ (2003) noted in the Waqqas section that sediments with a fauna of the normal sea in the latest formed deposits within the section and thus during early Miocene changed to deposits as forming in a salty environment with dolomitic beds as is typical for salty lagoons.

The Al Qarn region in the Jordan Rift Valley, just to the west of the town of Abu Habil shows a thick sequence of marine deposits which end in fluviale conglomerates. The gravel beds which under- and overlie Al Qarn Formation are evidence for relatively strong erosion near the margin of the northern Jordan Rift during the general time of their transport and deposition. Ghor el Katar Formation which was typified as exposed 2 km SSE of Kureiyima a town to the north of Deir Alla and south of Abu Habil (BENDER, 1968) may include lake deposits resembling those of Qarn Formation. Like the deposits of Al Qarn Formation also the strata which contain the Ubaydiya Formation SW of Lake Tiberias have a strong dip towards the Jordan River. They have also been deformed along the faulting which accompanies the Rift Valley on both sides (NIMROD, 2012). Its depositional environment has been interpreted to represent a river discharging its sediment load into a lake surrounded by swamps. Here the sea also deposited some limy beds with a rich fauna of marine foraminifera which allow the dating of the strata as of latest Oligocene and Early Miocene age (BANDEL & SHINAQ, 2003). This Tayba Formation represents a marine deposit of latest Oligocene and early Miocene age based on an assemblage of foraminifers including species such as *Cibicides*, *Hanzawaia*, *Dentalina*, *Uvigerina* and *Heterolepa*, which determine and confirms that age. Also, molluscs, sea-urchins and skeletal remains of other marine organisms confirmed the age and the origin of the fauna which most likely connects to the Pacific Ocean (BANDEL & SHINAQ, 2003; BANDEL & SALAMEH, 2013).

Between the Early Miocene and the Latest Miocene, thus for more than 10 Million years the geologic history of Jordan as well as that of the later Jordan Rift is still unresolved. This is largely due to the continental conditions with erosional processes. Other sediments deposited later in the Rift have been deeply buried by later deposits. It is possible that some of the large amounts of salt that form part of the filling of the deep pull-apart basins, as also documented in the dissertation of INBAR (2012) have formed from the evaporation of sea water since the beginning of the rifting process in the late Miocene. A borehole (Zemah 1) next to the southern end of Lake Tiberias and the mouth of the Yarmouk River into Jordan River on the west side of the Jordan penetrated almost 4250 m (MARCUS & SLAGER, 1985), much of it consisting of salt. INBAR (2012) evaluated these data in great detail in his thesis.

According to the stratigraphic column presented by him, the formations following the Miocene are: Gesher Formation, Cover Basalt forming the boundary of Pliocene to Pleistocene, Erk el- Ahmar- , Ubadiya- , Naharayim- (INBAR used also Naharaiyim), and Lisan-Formation. The cover basalt was dated as between 5 and 3 Million years of age by SHALIV (1991). According to INBAR (2012) this is not a very exact age determination, and may well be doubted.

The initial Rift Valley thus filled with sediments derived in part from the Mediterranean Sea as salt, by lacustrine deposits formed in lakes, by fluviale and terrestrial sediments derived predominantly from the erosion of the Eastern highlands, and by the products of volcansim. But from the time of Early Miocene to the end of the Miocene, the Messinian stage, no records of sedimentation within the Jordan Valley were recognized. During this strange period of the Messinian stage, when much of the water of the Mediterranean Sea evaporated due to the closure of its connection to the Atlantic Ocean, a deep Valley or canyon was probably eroded that extended from the Mediterranean Basin near modern Haifa and connected with the Jordan Rift Valley.

The Mediterranean Basin lay deeper than 1000 m bsl for several 100.000 years and became connected to the Jordan Rift which may have reached an altitude below sea level at that time as it has now, but still much less than the Mediterranean Basin. When the Messinian stage ended and the Mediterranean Basin was flooded again, the canyon that extended from the region of Haifa (and can still be noted in the contours of the continental slope there) to the Rift Valley connected somewhere north of modern

Masharia, in Jordan, passing the area of the ancient Scythopolis (Beit Shean, Beisan) in Israel. Thus salty water from the Mediterranean Sea can very well have entered the Jordan Rift and here evaporated in hot Arabian Air- to leave the huge amount of salt that has been recognized in drill holes below Lake Tiberias and below the Dead Sea (BANDEL & SALAMEH, 2013).

The Gesher Formation has been recognized from the northern Jordan Valley just south of Lake Tiberias overlying Messinian and post Messinian Pliocene sediments. The freshwater sediments of the Gesher Formation consist of 20-50 m of limestone, clay and marl which were deposited in a lake that predates the Cover Basalt (SCHULMAN, 1962). Cover Basalt forms the boundary between the Pliocene and Pleistocene (SHALIV, 1991). The sediments of Gesher Formation have been interpreted to be formed partly in a lake in which freshwater molluscs belonging to genera as *Melanopsis*, *Melanoides*, *Viviparus*, *Dreissena* and *Hydrobia* (HOROWITZ, 1979) lived. Similar fauna were noted from Tel Hai limestone, which is found further north in the Beqa'a in Lebanon. But the fauna collected from Gesher Benot Ya'aqov as exposed near Lake Tiberias is determined to be only 780000 thousand years old by HELLER & SIVAN (2001), while it was considered to be more than 1 Million years old (HOROWITZ, 1979, 2001). Most interesting is the presence of the gastropod *Viviparus* and the clam *Dreissena*. The age determination of the Gesher Formation is obviously still problematic. Quaternary deposits which were only locally recognized are mainly freshwater sediments and have been placed in the Erk el- Ahmar Formation, Ubeidiya Formation, Al Qarn Formation, pre-Lisan Jordan deposits, and Lisan Formation (Table1.1).

HOROWITZ (1979) reconstructed the presences of three successive lakes in the Jordan Valley, the Gadot-Lake, the Erk el- Ahmar Lake and the saline Dead Sea-Lisan Lake. According to ROSENFELD et al., 2012, the Gadot Formation is a lacustrine deposits exposed to the north of Lake Tiberias, including several species of ostracods; *Cyprideis torosa*, *Candona neglecta*, *Ilyocypris gibba*, *Ilyocypris bradyi* and *Darwinula Stevensoni*. *C.torosa* and *C. neglecta*. Ostracods species indicate that the environment of deposition was fresh to slightly brackish water. The age of the Gadot Formation, K-Ar radiometric dating to ranges between 1.6-0.9 Ma.

The Erk el- Ahmar Formation is exposed just southwest of the confluence of the Yarmouk into the Jordan (TCHERNOV, 1975; HOROWITZ, 1974). It is composed of clay, marl, silt, sand, and conglomerate and its age was considered to represent Late Pliocene to early Pleistocene (PICARD, 1965; TCHERNOV, 1975) and it is considered older than the Ubeidiya formation.

BLANCKENHORN & OPPENHEIM (1927) found species of *Melanopsis* from the railroad crossing over the Jordan called Djisr el Medjami and called the deposits containing it the "Melanopsis Stufe" which according to HELLER & SIVAN (2002) represents the outcrop that later received the name Erk el- Ahmar. Its exposure lies about 7 km south of Lake Tiberias on the western side of the Jordan and was dated as 1.8-1.5 Ma years old (HOROWITZ 1974, 1979), 2 million years (BRAUN, 1992) and was regarded as considerably younger than 1 million by HELLER & SIVAN (2001). Here *Bithynia* is present among others and the bivalve *Dreissena* along with species of *Pisidium*, *Unio* and *Corbicula*. BLANCKENHORN (1918) noted *Dreissena* layers also in the Orontes deposits of Pleistocene age. In that lake and creek snails determined as *Theodoxus jordani* lived with variation of their shells resembling those still noted from Lake Tiberias. Also, *Viviparus* was recognized from Erk el- Ahmar which is not known from Jordan. It was assumed that *Viviparus unicolor* (OLIVIER, 1804) as determined from Erk el- Ahmar Formation is still living in the Nile system. Its presence also in the waters of Erk el- Ahmar Formation was interpreted to demonstrate the existence of hydrological connections between the old Nile system and the Jordan Valley during the Pliocene-early Pleistocene (TCHERNOV ,1975). But *Viviparus unicolor* may also have reached the water in the Jordan Valley attached to the feathers or feet of water birds since the small juveniles have a solid shell and an operculum that closes and seals the aperture tightly, so that a transport that way is quite feasible. Rather similar species lived also in the North- that is the lakes of the Paratethys Basin of that time.

Ubeidiya (also spelled Ubadyie, Ubaydiya) Formation was dated to up to 1.4 Ma years old but has since been interpreted to be of much younger age by HELLER & SIVAN (2002). It is found in an outcrop 3 km southwest of Lake Tiberias (SCHULMAN, 1962).

It is described as about 30 m thick and consisting of alternating limnic and fluviale deposits in strongly inclined position. Bedded clay and silt, oolitic limestone (probably washed and size-sorted terrestrial oncoids) and soft chalk contain *Melanopsis*, plant, fish remain which are followed by conglomerates holding implements as well as bones that have been attributed to *Homo erectus*. Its depositional environment was interpreted to represent a river discharging into a lake with swamps. Bones of a fossil species of dogs (*Canis*), of hippopotamus, gazella, deer (*Praemegaceros*), fossil horse (*Equus*) and also small shrews (*Crocidura*) were excavated from the beds of Ubeidiya Formation (TCHERNOV 1988, HOROWITZ 2001). The gastropods mentioned to occur from Ubeidiya Formation are *Valvata saulcyi*, *Bulimus hawaderiana* (=*Bithynia*), *Lymnaea lagotis*, *Planorbis planorbis*, *Gyraulus piscinarum*, and *Ancylus fluviatilis*. Thus gastropods from this locality closely resemble those recognized from Al Qarn Formation and also *Viviparus* as well as *Dreissenia* were obviously no longer living here. The Ubeidiya is considered to overly Erk el- Ahmar and to be older than Naharayim, which in turn is considered to represent the base to the Lisan (NIMROD, 2012). Deposits of Samra Lake are exposed in the Jordan Valley and Dead Sea Basin. WALDMANN et al., 2007 & 2009, described the stratigraphy and sediments deposited in Lake Samra that occupied the Dead Sea basin between 135.000 and 75.000 years ago. This information is combined with U/Th dating of primary aragonites in order to estimate a relative lake-level curve that serves as a regional paleo-hydrological monitor. Also the presence of a Lisan Lake as precursor of the Dead Sea Lake has been proposed. The Lisan Foramtion is a brackish water Formation. A description of this Formation is found in Chapter 4 on the Lisan deposits and their shore terraces. Lisan Formation is covered by evaporite-free Damya Formation in the central Jordan Valley (ABED &YAGHAN, 2000).

The Dayma Formation is fresh to brackish formation composed mainly of clay, silt, sand, and some gravels with no evaporites and containing fresh water gastropods and fresh to brackish ostracods which lived in Dayma Lake between 16.000–15.000 to 12.000 years ago (HOROWITZ, 1979; ABED, 1985; ABED &YAGHAN 2000; LANDMANN et al., 2002 et al., 2002). The Plio-Pleistocene rock sequence of the Dead Sea Group at the Dead Sea Basin consists of Sedom, Amora, Samra and Lisan Lake (ZAK, 1967).

The salt that forms now the hill of Sodom and Amora at the western side of the Dead Sea and which pushed up the Lisan peninsula was deposited at that time, in addition to the salt that lies below Lake Tiberias and below Karama.

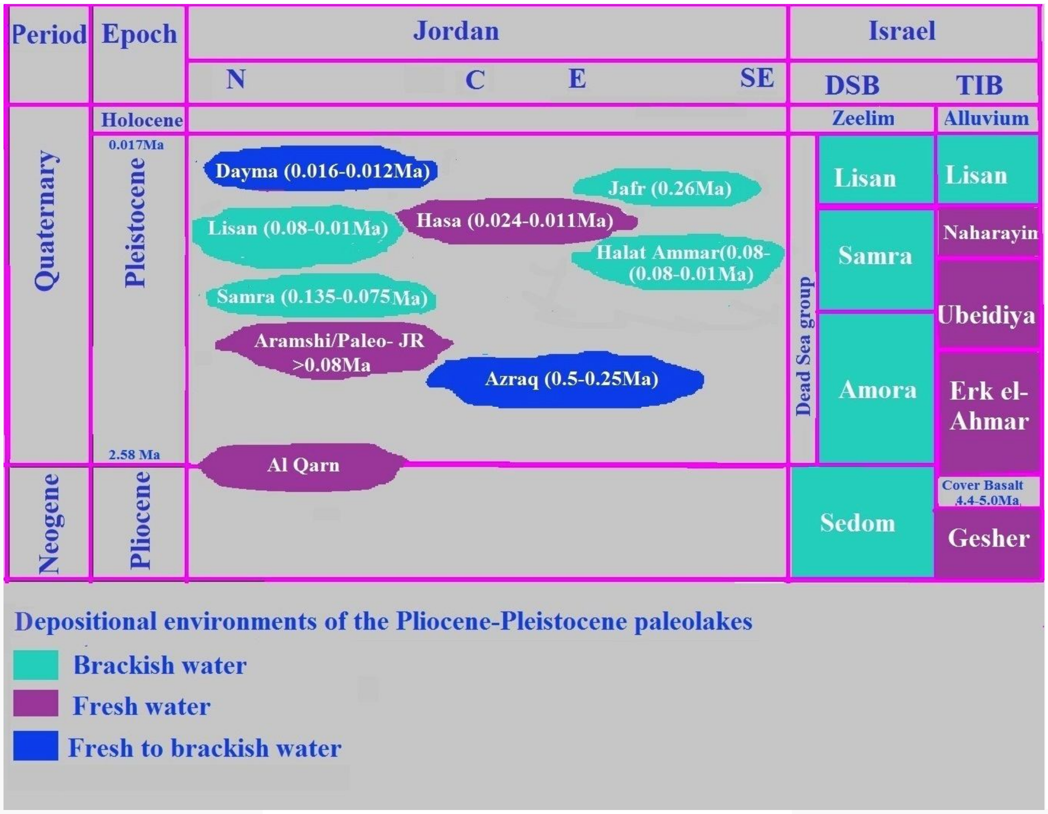
These salty formations of Plio-Pleistocene time were named Sedom and Amora a long time back. The Amora salty deposits are covered by debris coming from the highlands especially those of Jordan, but also the Judean mountains- with Jerusalem almost as high as Amman by now. More description of Pliocene- Pleistocene deposits and their fossilized fauna (e.g., Gastropods, bivalves, ostracods, crabs, diatoms, and coral reef) of Jordan, including Al Qarn Formation, pre-Lisan deposits of Jordan River , Lisan Formation, Hasa lake deposits , Halat Ammar (Mudawwara Lake), Azraq Lake and Jafr Lake deposits and Aqaba coral reef terraces are studied in this thesis work in details.

Table 1.1: The Tertiary- Quaternary Formations of the Jordan Valley (TIB; Tiberias Basin, DSB; Dead Sea Basin).

Period	Epoch	Jordan		TIB	Israel	DSB	
Quaternary	Holocene	Alluvia	Alluvial fans, Gravel, Clay	Alluvium	Gravels, Sand, clay	Zeelim	Sandstone, Gravels, Rocksalt
	0.0117 Ma						
	Pleistocene	Dayma	Siltstone, Clay, Limestones Sandstone	Lisan	Marl, Sand, Gravels. Aragonite	Lisan	Chalk
		Lisan	Gypsum, Aragonite facies, Diatomite facies	Naharayim	Gravels, Basalt, Limestones	Samra	Sandstone, Chalk
		Samra	Chalky marl, Conglomerate	Ubeidiya	Limestones, Chalk clay, Conglomerate		
		Kufranjeh	Gravels, Marl				
		Abu Habil	Conglomerate, Pisolitic limestone	Erk el- Ahmar	Clay, Marl, Slit, Sand, Conglomerate	Amora	Chalk, Rocksalt
		Ghour El-Katar	Conglomerate, sandstone, Marl				
	2.50 Ma						
Tertiary	Pliocene	Shagur	Sandstone, Conglomerate, Limestone	Cover Basalt	Basalt	Sedom	Rocksalt, Gypsum
		Ikheim	Marl, Limestones	Gesher/Fajas Tuff	Chalk, Dolomite/tuff		
	5.33 Ma						
	Miocene	Saham	Sandstone, Conglomerate Limestones, Marl	Bira/Intermidiate Basalt	Marl	Hazewa	Gravel
				Umm Sabune	Conglomerate		
		Waqqas Conglomerate	Conglomerate, Siltstone, Limestone. Marl	Horodos/Lower Basalt	Conglomerate Basalt		
				En Gev	Sand,		
	23.03 Ma						
	Oligocene	Taypa	Limestone	Sustia	Dolomite.Marl. Limestone, Sandstone		

After: ZAK, 1967; BEGIN et al., 1974; HELMANN & BRAUN, 2000; MOH'D, 2000b; HAZAN et al., 2005; NRA, 2011, INBAR 2012.

Table 2.1: Pliocene- Pleistocene Lakes along the Jordan Rift Valley and other sites in Jordan (TIB; Tiberias Basin, DSB; Dead Sea Basin, Paleo JR; Pre-Lisan deposits of Jordan River).



Information about the Pliocene- Pleistocene Lakes in the area are derived from different studies including those in the following sources; ZAK, 1967, NEEV & EMERY 1967; NEEV & HALL, 1976; HUCKRIEDE & WIESEMAN, 1968; ABED, 1985; ABED &YAGHAN, 2000; HEIMANN & BRAUN, 2000; LANDMANN et al., 2002; ABED et al., 2008; MACUMBER , 2008; WALDMANN et al., 2009; PETIT MAIRE et al., 2010; BANDEL & SALAMEH, 2013.

1.2 Objectives

The main goal of this study is to determine the taxonomy and ecology of the aquatic invertebrates especially molluscs, but also crustacea, echinoids, corals and diatoms to identify the depositional environment of the Pliocene-Pleistocene deposits from different sites and formations in Jordan. Organisms recognized from the fossil record in Jordan are compared with their living relatives predominantly from fresh water environments in Jordan with special emphasis on their mode and way of life and their place and significance within the community of organisms.

The objectives of this study are to:

- Study the geology of the Pliocene- Pleistocene deposits which contain the different fossil species.
- Investigate the fossil fauna throughout the Pliocene- Pleistocene deposits in different sites of the study area especially for their use as indicators for the reconstruction of the paleoenvironment.
- Identify the taxonomy of the fossil fauna to species level based on measurement and description of morphological characters and ontogeny of the shell aided by scanning electronic microscope (SEM) and comparison to living relatives and accompanying fauna by binocular microscope.
- Identify and characterize some new species of gastropods from Al Qarn Formation.
- Test the mineralogical structure of the shell is nacre or whether the carbonate material is of calcite or aragonite structure and whether the shells are affected by diagenetic alteration.
- Check the validity for the use of fossil fauna in studied sediments for age dating purpose by studying the morphology and mineralogical structures of the shells or skeletons of fossils by SEM.
- Compare the molluscan occurrence in the Pliocene- Pleistocene deposits from the investigated formations with modern mollusca living in Jordan.
- Compare the depostional environments of Hasa, Azraq and Jafr Lakes based on the faunal fossil contents and type of sediments.

- Study the beach deposits and their fossil to determine the paleo depotional environment by comparing these fossils with their living relatives in the Gulf of Aqaba
- Use fossils as evidence for the evaluation of the degree of tectonic movements that has taken place since they have been deposited.
- Shedding light on the great gaps which are still present in the relatively recent part of the history of the Jordan Rift Valley from the end of the Messinian stage of about 5 Million years ago to the Holocene.

- Use the data extracted from the fossil fauna of the Pliocene to Pleistocene in Jordan to analyze the living fauna, especially in regard to its usefulness as biological indicator species and character species for faunal assemblages that indicate the degrees of water pollution.

1.3 Materials and methods

The studied fossils mainly belong to the aquatic invertebrate group collected from the Pliocene- Pleistocene deposits in the selected study area. The sampling and collecting method of the fossils includes the steps of:

- Field work; About forty fossil samples were collected from different formations and time scales in the study area between 2010 and 2013. The well preserved fossils were usually gathered from unconsolidated sediments which could simply be washed through a screen to extract the fauna. In case the fossil fauna occurs in solid massive rocks as is the case in Aramshi Formation where molluscs fossilized in massive limestone rocks another method had to be applied. Here the sample of the rock with the preserved fossil was extracted from the cliff by using hammer and chisel and then delivered to the Lab. Here it was cut vertical to the bedding plane and the rock surface polished to document the gastropods it contained in sections. Furthermore during the field work the geology and lithology of the study areas were studied and documented by photographs.

- Laboratory work had to go through several stages for preparing the sampled fossil and to identify them and is summarized as follows:
- In the University of Jordan the fossil material was washed from the sediment with water by using screens of a set of sieves (200, 500 μm) and afterwards the shells were selected from the dried sample. To be documented, they were cleaned in water with the help of a bath in water and application of ultasonic shaking, and after that the fossils were dried. The specimens are sorted and separated under a binocular microscope S6 D Leica with magnification of 6.3x - 40x and those of larger size were documented by digital camera (Fig1.2) supported by SMART project. Afterward they were placed in plastic boxes with the name of exaction place of the location from which the fossils have been collected (e.g., date of collection, and type of fossils, to which rock formation they belong).

- The micro structural and morphological features of the mollusc shells and other tiny fossils such as ostracods and diatoms were investigated under a scanning electron microscopy (Fig 1.3) after cleaning, separation and sorting processes of the specimen. They were placed on stubs for scanning by using an electron microscope, in the University of Hamburg, (Klaus Bandel) and an EVO50-Zeiss microscope of the Free Berlin University, (Steffen Mischke). Before photographing the specimen, the samples that had been glued to the surface of the stub were coated with gold in a coating device working with vacuum.
- The procedure requires fitting apparatus, a screen for washing, an ultrasonic cleaner and last not least coating with gold in a special machine before the stub with the fauna can enter the SCAN. The massive solid rock samples containing fossil fauna were cleaned and polished for the study with binocular microscope.
- Taxonomic determination of the sampled fossils to species level is based on the literature and was in the case of the molluscs checked by Klaus Bandel and based on palynological studies regarding the diatoms while ostracod samples were determined by Steffen Mischke, Free Berlin University. About 18 genera of gastropods and other aquatic fossils were determined, here with 20 species of gastropods described in details on the bases of their morphological features with their ecological conditions. New species were determined and documented including: *Melanopsis salamei* n.sp., *Ferrissia urdunica* n. sp., *Planorbis sp., Melanoides abuhabili* n. sp., and *Islamia jordanica* n. sp.

- Environmental interpretation of the data by the combination of fossil fauna types and the sediments embedding them and their remnants of fossilized flora. This lead to clear indication about the prevailing paleoenvironment.

Figure 1.2: Binocular microscope S6 D Leica with magnification of 6.3x - 40x supported by digital camera for sorting and documentation of the samples.

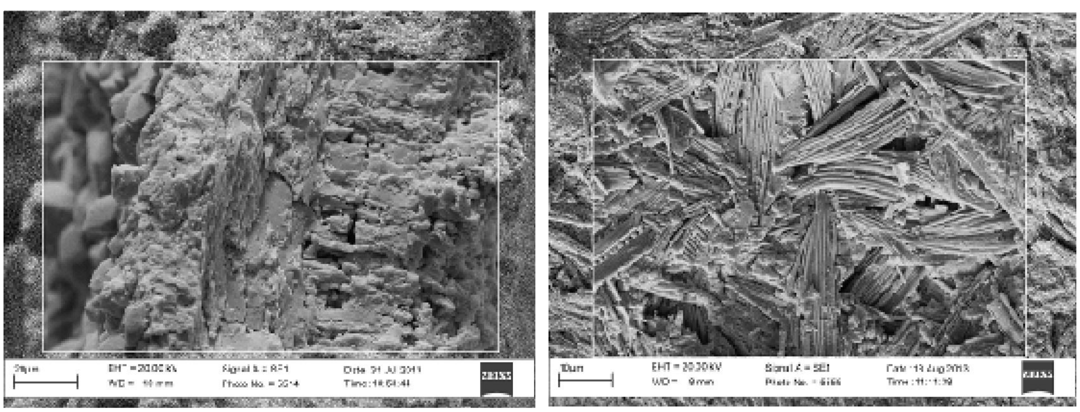


Figure 1.3: Examples of a SEM pictures; a. illustrating the shell of Hydrobia recrystallizion and transformed from aragonite into calcitic structures (Halat Ammar), b. The SEM picture showing the morphological details of the flattened Rhopalodia diatoms from Lisan deposits (near Abu Habil village in the Jordan Valley).

The fossil and sediment materials were studied and collected from several locations and formations (Fig 1.4&1.5) include Al Qarn Fromation, Aramshi Formation, pre-Lisan deposits of ancient Jordan River, Lisan Formation deposits and their shore terraces, Halat Ammar Lake Formation (Mudawwara Lake), Azraq Lake, Hasa Lake and Jafr Lake deposits, and the raised Pleistocene coral reefs of Aqaba.

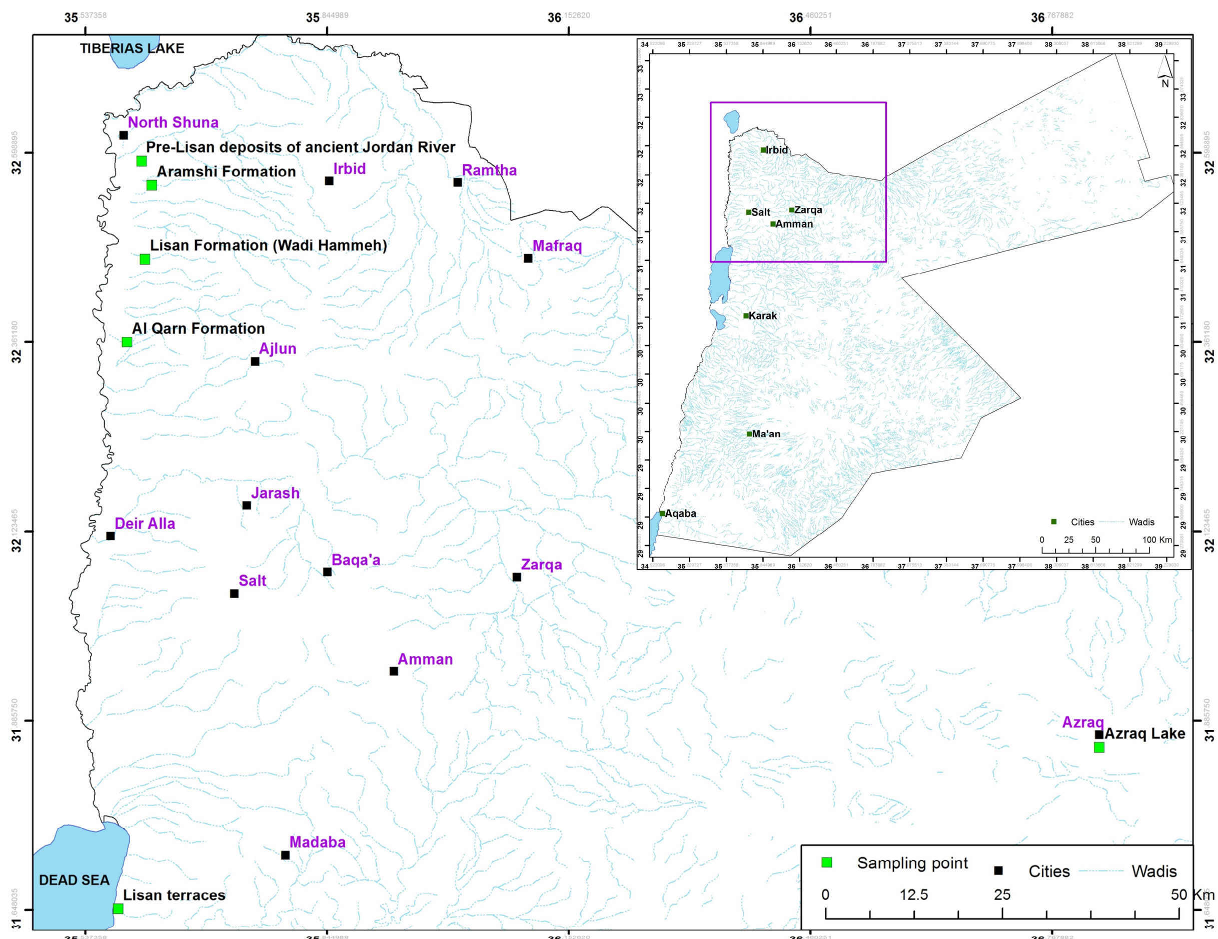


Figure 1.4: Location map of the study area in north Jordan, showing sites of Al Qarn Foramtion, Aramshi Formation, Lisan deposits, and Azraq Lake.

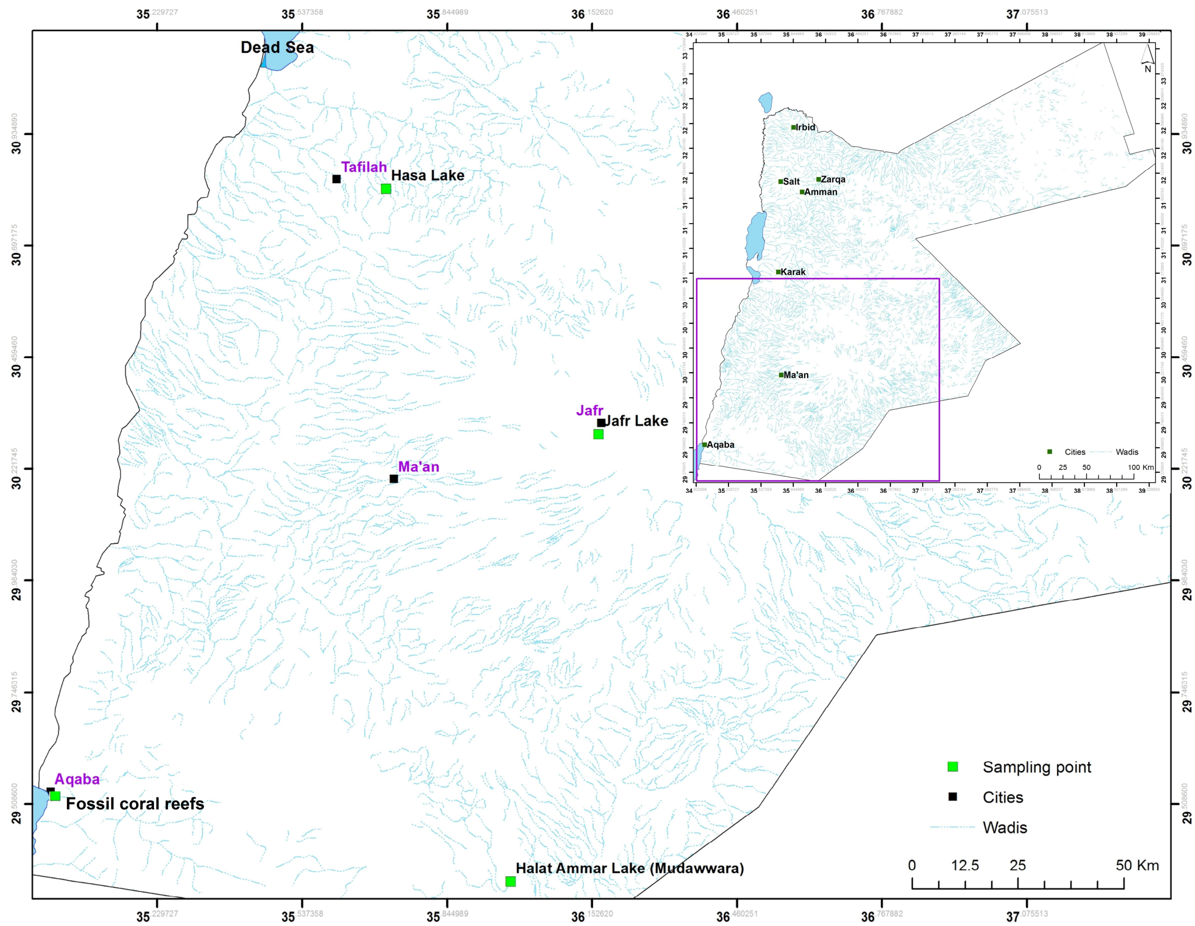


Figure 1.5: Location map of the study area in south Jordan, showing the sites of Hasa, Jafr and Mudawwara Lakes in addition to Aqaba raised coral reefs.

2 AL QARN FORMATION

2.1 Lithology and fossil content of Al Qarn deposit

Al-Qarn Formation is exposed at the eastern banks of the King Abdullah Canal (KAC) west of the village Abu Habil and south of Jebel al Qarn and transected by Wadi Qarn (Fig 2.1). It overlies the Oligocene-Miocene deposits of Tayba Formation with angular unconformity (BANDEL & SHINAQ, 2003). The Tayba Formation is considerably older and was in part formed under marine conditions and obviously has been deformed before Al Qarn-Formation was deposited so that an angular unconformity exists at their contact (Fig 2.2).

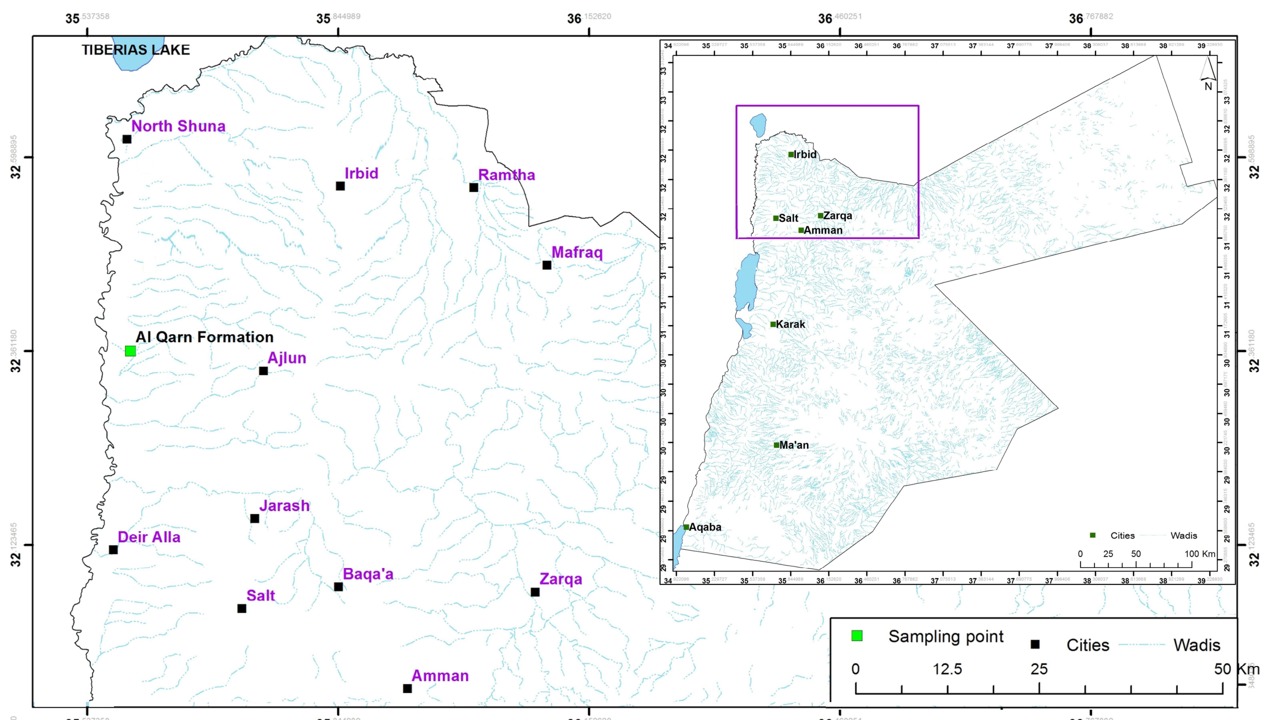


Figure 2.1: Location map of Al Qarn Formation in the Jordan Valley area.

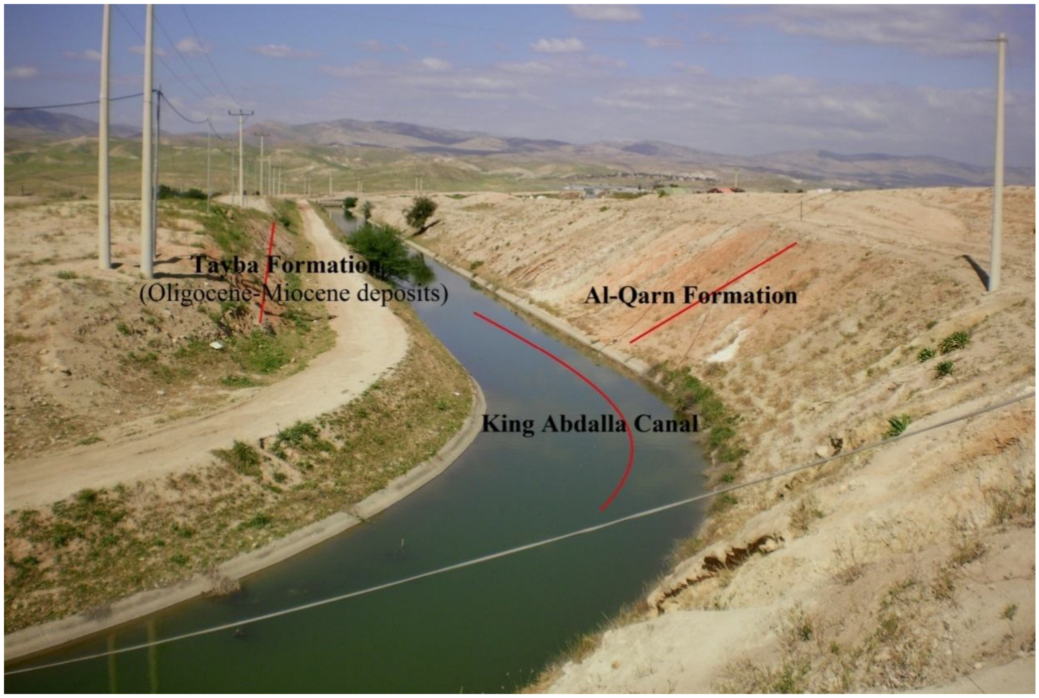


Figure 2.2: Al Qarn Formation is exposed at the eastern banks of KAC; west of the village Abu Habil and south of Jebel al Qarn.

The sediments of Al Qarn Formation consist of a series of fluviale gravel with an intercalation of fine marly sand deposited in quite water of a lake. In a sequence of fluviale gravel about 25 m of lacustrine deposits are intercalated, which are again covered by gravel (Fig 2.3a). The whole formation is inclined with a dip of about 50° towards the Jordan Valley (Fig 2.3b).

Much of the carbonate, especially larger particles, represent pisolites which have formed in soil and have become reworked by erosion were sorted according to size (Fig 2.4). Particles may be concentrated in coarse gravel composed of oncolites or fine beds with smaller coated grains concentrated which resemble oolites but have a very different origin. While the pisolites were derived from terrestrial environment and formed in soil, the ooides of an oolite form on shoals of sand in the shallow sea.

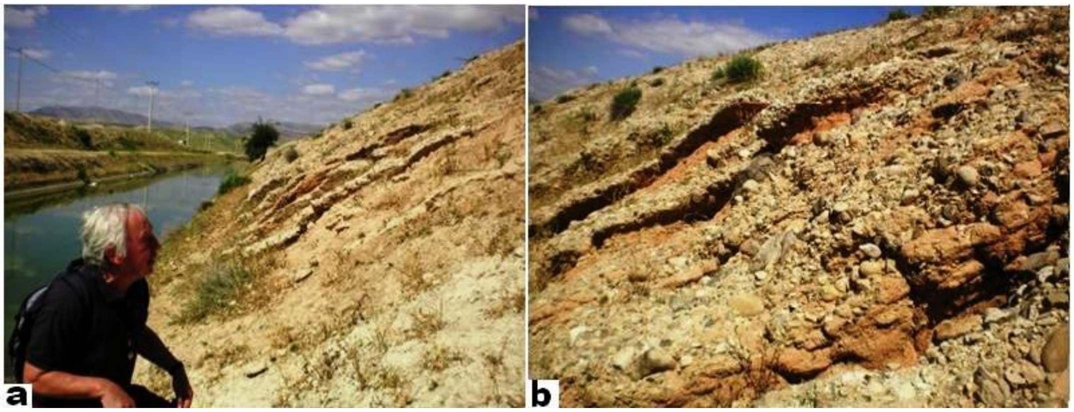


Figure 2.3: a. The Lake deposits of Al Qarn Formation composed of fine quartz sand mixed with marly calcareous sand, b. Al Qarn strata dipping about 50° towards the center of the Jordan Valley, (Al Qarn Formation west of Abu Habil and transected by Wadi Qarn).

The fluviale gravel is composed predominantly of material that has been eroded on the eastern highland and consists of Paleogene to Late Cretaceous material, consisting predominantly of flint and limestone exposed along the slopes and the highlands to the East of the Jordan Rift. The sequence of Al Qarn Formation outcropping along the canal is best exposed on its eastern side, while the western side along the small road at the canal margin in part belongs to the Tayba Formation of Oligocene- Miocene age (Bandel & Shinaq 2003). The contact is structural and represented by a fault, and exposed Tayba beds further to the west of the canal and seen in the Wadi Al Qarn have a much steeper dip towards the Jordan River than that of the beds of the Al Qarn Formation. A gravel layer above the lake deposits as exposed on the SE slope of the road is composed of large pisolites with concentric composition. The base of the sediments with the fauna is formed by a fault and below it beds of gravel dipping towards WNW. The lake deposits of Al Qarn Formation have thus been tilted and displaced in connection with the movement along the Jordan transform fault.

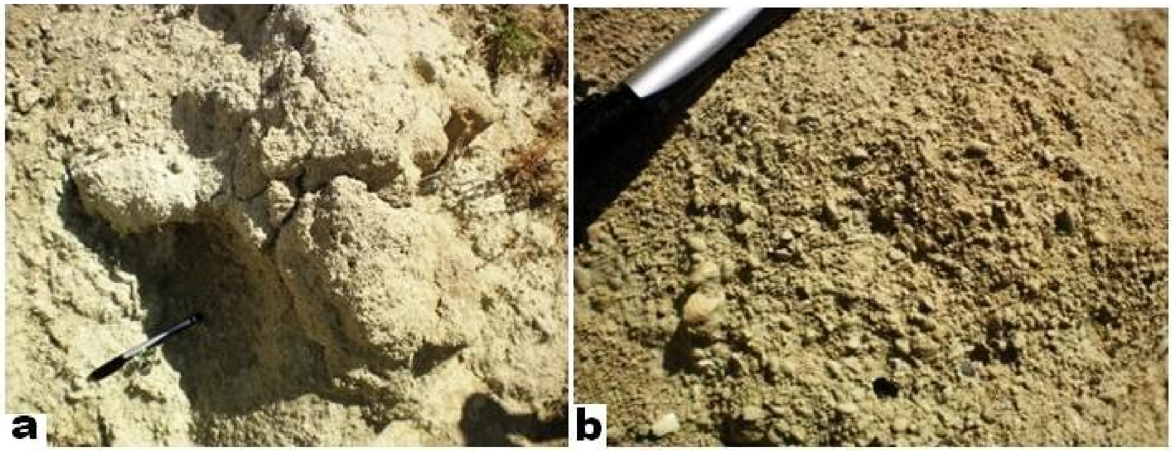


Figure 2.4: a. Small pisolites resembling oolithes in Al Qarn Formation, b. Al Qarn pisolites are exposed at the eastern banks of KAC next to the village Abu Habil and south of Jebel al Qarn.

The sediments of Al-Qarn Formation with a fauna predominantly consisting of freshwater and land molluscs are composed of fine quartz sand mixed with marly calcareous sand of about 25 m in thickness (Fig 2.4a) and with its strata dipping with about 50° towards the center of the Jordan Valley(Fig 2.4b). The sequence is exposed along the canal to the north of the bridge in which the canal crosses the road. A gravel layer above the lake deposits as exposed on the SE slope of the road is composed of large pisolites with concentric composition. The base of the sediments with the fauna is formed by a fault and below it beds of gravel dipping towards WNW. The lake deposits of Al Qarn Formation have thus been tilted and displaced in connection with the movement along the Jordan transform fault. The sediments of Al Qarn Lake Formation with a fauna predominantly consisting of freshwater and land molluscs are composed of fine sand with calcareous intercalations.

The lake in which Al Qarn Formation was deposited contained no more *Dreissena* and *Viviparus* which became extinct in the area since the formation of Gesher Lake. Al Qarn Lake formed in late Pliocene or early Pleistocene and only in the northern part of the Rift in Jordan. It formed above river gravel and was subsequently covered by river deposits carried here from the rising highlands to the east. The rivers periodically transported pisolites which had grown as concentric cyano-bacterial crusts within the soil and were washed from it when this soil was eroded. Floods transported them into the river and from there into the basin of the Jordan Rift. Before and after the events of more or less local soil erosion the river gravel was predominantly composed of eroded Paleogene and Cretaceous sediments.

The pisolites with concentric composition grew in the soil by the activity of cyanobacteria which formed around a central particle and during their growth pressed the soil next to them to the side, so that round ball-like bodies of almost pure limestone grew and during their growth in the soft soil added one concentric crust after the other up to sizes as large as a fist. The pisolites exposed in the outcrop next to the canal and the road that passes under it through the bridge formed by the canal, are secondary deposits (Fig 2.5). They had originally been washed from the slopes when the soil surrounding them was eroded and the pisolites contained in it were carried by a river. The calcareous pisolite pebbles have since been deformed by pressure when the strata were affected by the Formation of the Jordan Rift and due to that in part acquired angular shape (BANDEL & SALAMEH 2013).

Calcretes (caliche) covers an extensive area over calcareous bedrock by upward percolation of ground water through surface evaporation. When Al Qarn Lake existed climatic conditions were more humid than today so that the pisolites formed in the soil. During strong rains they were washed from the soil and concentrated in channels which continue down-slope to be deposited as river gravel.

The concentric calcareous pisolites formed in soils on the hill sides and mountains nearby and to the east. Original soil still containing oncolites (= pisolites) of different sizes is exposed in many places along the eastern slopes of the Jordan Rift. Next to the road from Waqqas to the highland and to the village Tayba a small former erosion channel is exposed that has been filled with pisolites. These were washed from the soil next to it and such soli containing them is still preserved next to the canal. This a small about 5 m wide channal is filled with reworked pisolites and is, for example, exposed on top of the slope to the rift SE of Waqqas right next to pisolite rich soil untouched by erosion.(Fig 2.6). Near KAC similar and larger pisolites compose the gravels of a whole layer intercalated with ordinary river gravel. The gravel beds are here inclined as well but with a smaller dip of only about 30°.

Figure 2.5: Pisolite outcrop of Al Qarn Formation located next to the KAC and the road that passes under it through the bridge, west the village Abu Habil and south of Jebel al Qarn.

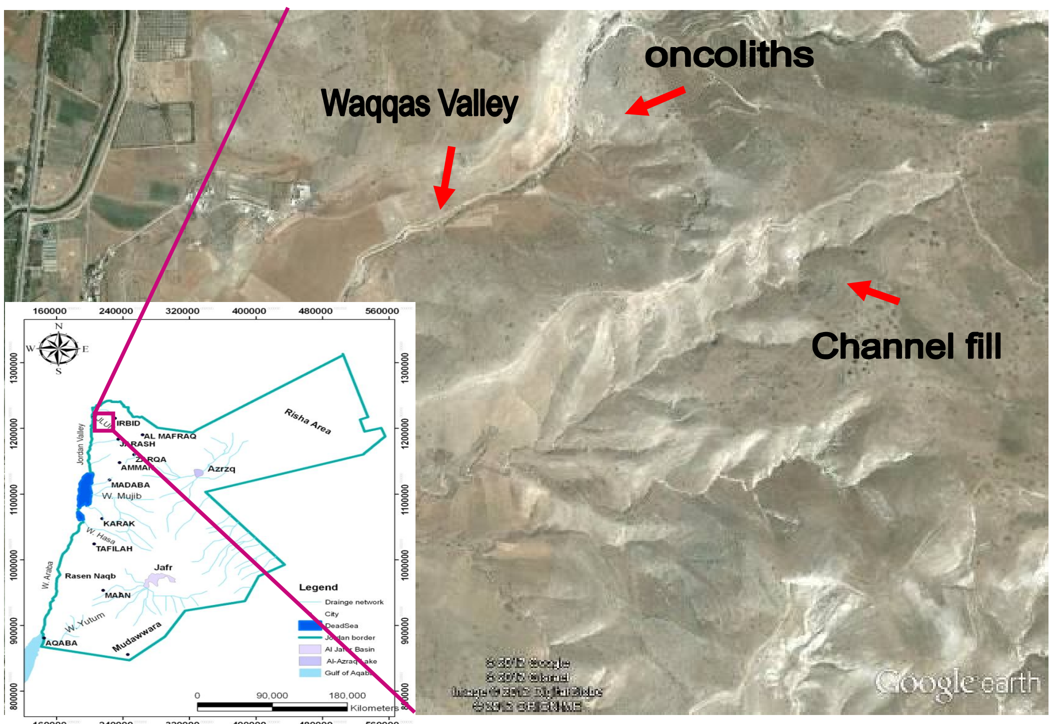


Figure 2.6: Locality of the abandoned road near Waqqas with oncoliths and the Miocene outcrop at Waqqas Valley (Upper- northern one). The canal with abundant oncoliths is exposed at the eastern end of the Wadi in the center of the picture with the road at its northern upper edge (Image source, Google Earth).

The fine marly sands of the Al Qarn Formation are of lacustrine origine. The marly deposits in the Al Qarn sequence are partly consolidated by calcareous cement. In the beds with well preserved fauna the sand is still unconsolidated and no dissolution of shell took place, aragonitic shell substance is still preserved and no cement was formed. The sediments of these beds could simply be washed through a screen to extract the fauna. In the field the presence of the fauna is spotted easily by shells of the common *Melanopsis* (Fig 2.7). While they are well preserved in one layer, they have been dissolved in others, but only after they had been consolidated by cementation. These sandstones thus have numerous cavities which document their former presence. Here the calcareous components including the aragonitic shells became dissolved and partly redeposited as cement.

The fauna of molluscs is rich and holds besides small bivalves of the *Pisidium* type and rare badly preserved shells of *Unio*, several gastropods including species of *Melanopsis* quite visible in the field in addition to *Theodoxus*, *Melanoides*, *Bithynia*, several small hydrobioids, *Ancylus*, *Gyraulus*, *limned* species, and *Valvata.* A variety of stylommatophoran pulmonate species and the caenogastropod *Pomatias* were washed into the lake where the marly sands were deposited. They had formerly lived near it on land. The land snails have thin shells in which the original organic shell material was decomposed so that the shells did not survive the washing of the sediment by which the shell material was isolated. But their initial whorls are more solid and well preserved. Here shape and size of the embryonic whorls documents that they belong to land snails. Their early life usually begins in relatively large eggs with much yolk available to the embryo and the young hatch with a much larger shell than is found among the species of freshwater gastropods. Species determination of land snails can be of value in the reconstruction of the climate, since data are well known regarding the living land snails of the Levant. Determination of the land snails from Al Qarn Formation could be undertaken, by comparing the embryonic shell of living Jordanian land snails with those of the fossil ones. This would be a major work, which has not yet been carried out.

Figure 2.7: Freshwater gastropods (*Melanopsis*) in Al Qarn Formation outcrop next to KAC south of Jebel al Qarn at the Jordan Valley in northern Jordan.

Fragments of vertebrate bones are present as well as teeth, also a large one that could belong to a crocodile. Ostracods (Fig 2.8& 2.9) and crab claws of *Potamon* (Fig 2.10) present the crustacean inhabitants of the lake. The fresh water crab *Potamon* still lives along most creeks and rivers in Jordan, as amphibious animal with rapid movement on land as well as in water. During day times it usually hides in burrows it excavates at the margin of creeks. Most gastropods from Al Qarn Formation still have living relatives in Jordanian fresh water creeks and ponds, with the exception of *Bithynia* and *Ancylus.*

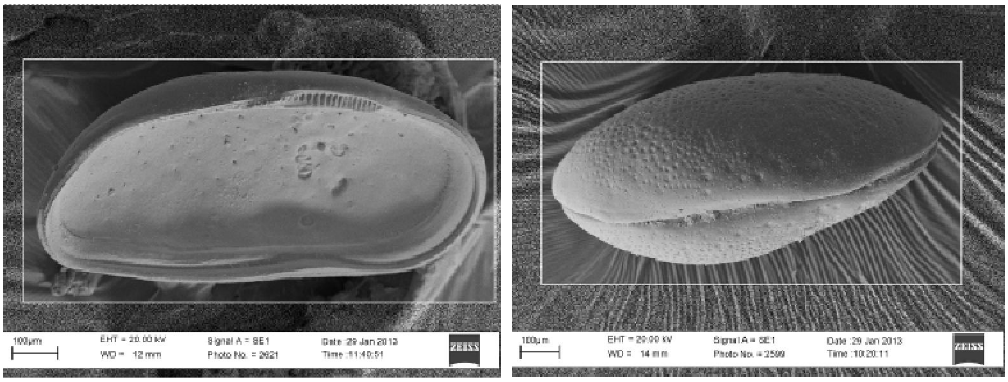


Figure 2.8: Different species of ostracod collected from Al Qarn Formation next to KAC, west of Abu Habil and transected by Wadi Qarn at the Jordan Valley, the scale bar is 100µm.

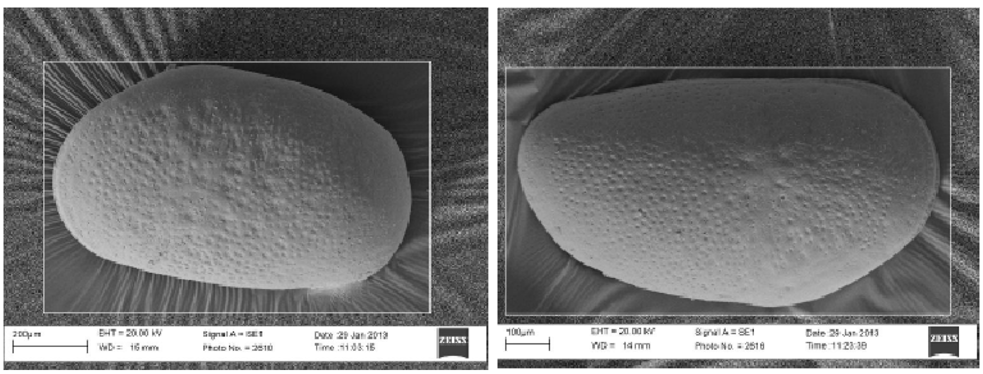


Figure 2.9: Well preserved ostracods sp from Al Qarn Formation next to KAC, west of Abu Habil and transected by Wadi Qarn at the Jordan Valley,the Jordan Valley, the scale bar is 100µm.

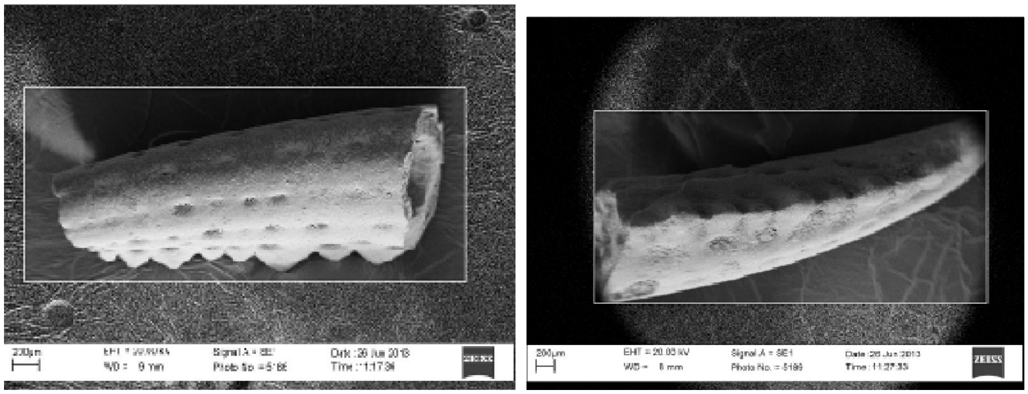


Figure 2.10: Claw of Potamon from Al Qarn Formation next to KAC, west of Abu Habil and transected by Wadi Qarn at the Jordan Valley, the scale bar is 200µm.

2.2 Descripton and discussion of the molluscs of Al Qarn Formation

Superfamily Rissooidea

Family Bithyniidae

Genus Bithynia

Bithynia is a member of the Caenogastropoda with a calcareous operculum that has a characteristic concentric composition. It lives all over Europe represented by a few species. The species from Al Qarn with the shell about 5 mm high and 3 mm wide consists of 5 whorls. The absence of the umbilicus and pointed conical shape are characteristic to the genus. The operculum is thick and concentrically lined on the outside with small spiral nucleus which provides protection from crab attack. Living species filter phytoplankton from the water with their gill and collect additional food with the snout. *Bithynia* from Al-Qarn Formation differs (Fig 2.11 & 2.12) from *Bithynia hawaderiana* from Lake Tiberias as illustrated by TCHERNOV (1975, FIGS 12-13) by having a less rounded body whorl.

Bithynia LEACH, 1818 as *Bithynia tentaculata* LINNEUS, 1758 is a characteristic gastropod of the fresh water noted from many European ponds and lakes (WENZ 1938, FIG.1616 as *Bulimus*). This snail of around 10-12 mm high and 6-7 mm wide shell has rounded whorls and calcified operculum and lives in lakes by collecting organic particles from the bottom within the illuminated zone and by filtering phytoplankton from the water with the gutter of its gill. The animals live for a year, sometimes even more than two years. Females produce 20-40 eggs which are held in an angular capsule glued in a row onto hard substrates. From these, crawling young hatch after about two weeks of development within the capsules. The embryonic shell from Bithynia from Al-Qarn Formation has a similar shape as that of *Bithynia tentaculata* reflecting a similar mode of development and hatching.

From Jordan *Bithynia syriaca* BLANCKENHORN, 1897, *Bithynia multicostata*, and *Bithynia hawaderiana* BOURGUIGNAT, 1853 were noted. *Bithynia hawaderiana* from Lake Tiberias was described by TCHERNOV (1975, FIGS 12-13). Accordingly, the about 5 mm high and 3 mm wide shell consists of 5 whorls without umbilicus and of pointed conical shape. In the smooth shell the spire occupies about half shell height.

Sutures are shallow and the aperture is of oval shape with simple margin that is continuous all around. It has an upper angle and a thickened inner lip that covers a narrow umbilical furrow. The operculum is thick and concentrically lined on the outside with small spiral nucleus. In this study and during 2011-2013, no living species of *Bithynia* were found in Jordan. Its occurrence in KAC may be expected by immigration from Lake Tiberias.The species from Al-Qarn Formation can be the same that was determined as *Bithynia phialensis* (CONRAD, 1852) by SCHUETT (1983) and is synonym with *Bithinia hawadieriana* that was described by BOURGUIGNAT (1853) from Lake Hula. According to HOROWITZ (1975, FIG.12-13, 1979) this modern species of Lake Tiberias had been living in the ponds of Ubeidiya Formation. From the Erk el- Ahmar Formation the genus is represented by *Bithynia syriaca*. SCHUETT (1988) considered *Bithynia syriaca* to represent a fossil representative of *Bithynia phialensis*. SCHUETT (1988, PL.3, FIG. 29) described a *Bithynia applanata* BLANKENHORN, 1897 remarking that it is very similar to the recent species. It is not the same but closely related to the ancestor of the modern form. All these species could be the same and they all fall into the varieties of the Bithynia as was noted from Lake Hula and may still live in Lake Tiberias. HOROWITZ (1979) suggested to determine in Erk al- Ahmar Formation *Bithynia multicostata* and *Bithynia syriaca*.

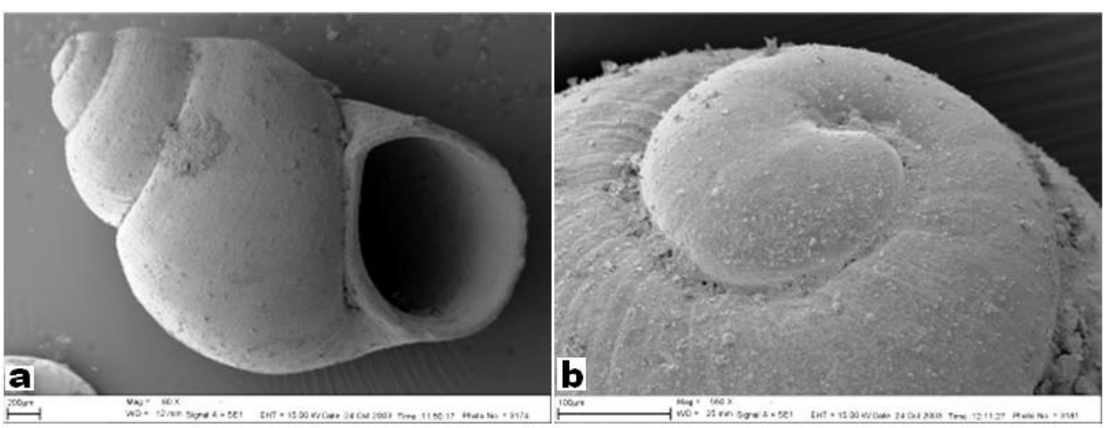


Figure 2.11: a. Bithynia from Al Qarn Formation next to KAC, west of Abu Habil at the Jordan Valley, the scale bar is 200µm, b. Bithynia Protoconch collected from Al Qarn deposits, the scale bar is 100µm.

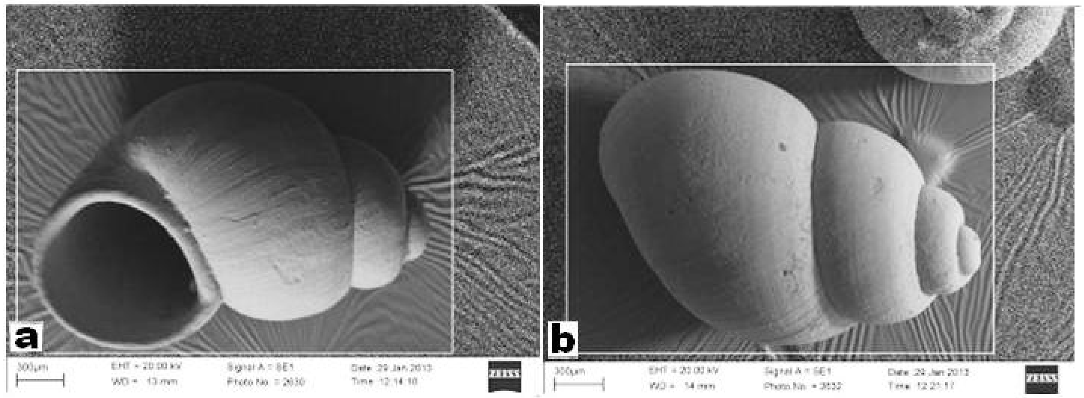


Figure 2.12: a. Fully grown Bithynia from Al Qarn Formation next to KAC,the scale bar is 300µm, b. Lateral view of Bithynia shell from Al Qarn formation, west of Abu Habil at the Jordan Valley,the scale bar is 300µm.

The first whorl of the shell is the embryonic shell that was formed before the young snail left its egg capsule crawling and benthic (Fig 2.13). Shell growth within the egg capsule occurred on an embryo developed beyond the veliger stage and is marked by simple straight lines of growth. The time just at or after hatching is well documented by an increased density of increments of shell growth and by first signs of shell fracturing. This only occurred when the small snail left the shelter of its egg capsule (BANDEL, 1982). The small snail, at that stage of development carried a shell of about 0.75 mm in size.

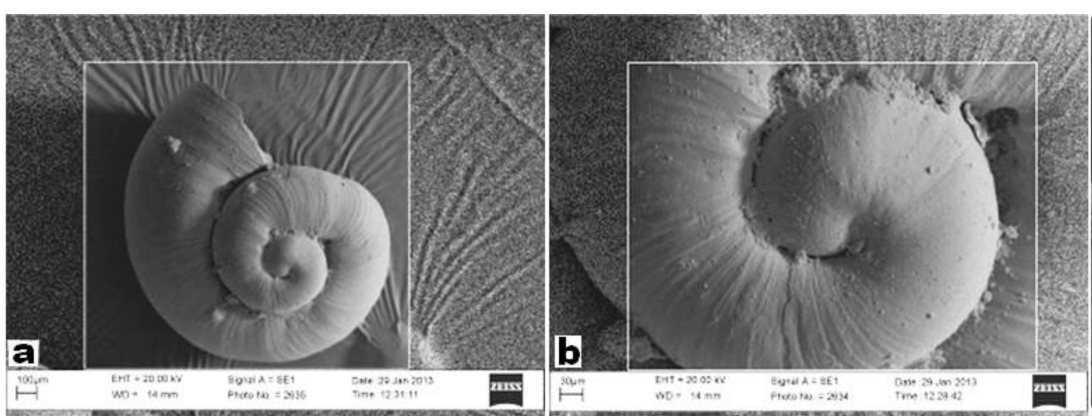


Figure 2.13: a. Juvenile shell of Bithynia from Al Qarn Formation, (The scale bar is 100µm), b. the first whorl of the embryo, succeeded by the shell of the juvenile, west of Abu Habil at the Jordan Valley, the scale bar is 30µm.

Subclass Nerimtimorpha

Superfamily Neritioidea

Family Neritidae

Genus Theodoxus

Theodoxus occurs in almost all clean springs and creeks in Jordan. The species of this genus which lived in Al Qarn Lake were very similar in shell shape to those that live in the Yarmouk River, in Lake Tiberias, in the northern part of KAC, and in the Orontes (BANDEL 2001). *Theodoxus* has a short shell with few whorls with a thin outer calcitic layer and a thick inner aragonitic layer. The color pattern lies within the outer calcitic layer and can be well preserved in fossil shells and also in case of the specimens from Al Qarn Formation (BANDEL, 2001, FIGS 36-40). Ornament often consists of stripes in zigzag pattern which is very variable within the same species. The color varieties of the now living populations have often been placed in different species according to such patterns, and due to that a profusion of names has been created in the description of fossil representatives of *Theodoxus*. Not only color but also the shape of the shell may vary from simple and rounded and as wide as high to higher than wide and angle at their apical side and/or a groove on the side.

Among the now living *Theodoxus* in Jordan those individuals living in the Yarmouk River and in the northern part of KAC also in portion next to the outcrop of Al Qarn Formation may have a corner around their apical shell portion and striped shell pattern. Such shell varieties can also be detected on the specimen of *Theodoxus* from Al Qarn Formation (Fig 2.14).

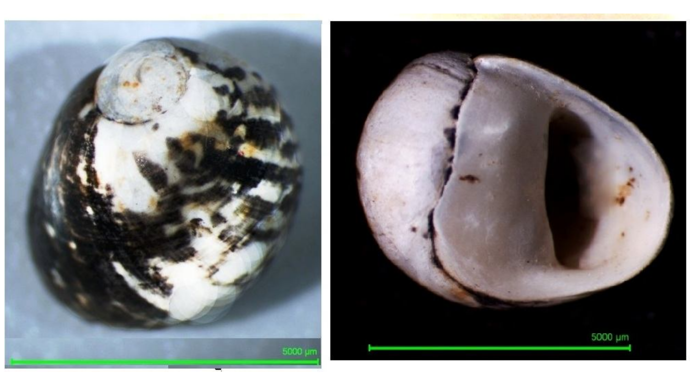


Figure 2.14: Theodoxus from Al Qarn Formation next to KAC, west of Abu Habil at the Jordan Valley, the scale bar is 5000µm.

The individuals of *Theodoxus* which lived in the waters of Al Qarn Formation had a calcareous operculum with a peg on its inner side with which it was held in place when the animal withdraw into its shell (Fig 2.15). This protection is quite effective and can prevent the crab *Potamon* to use *Theodoxus* as food. Crabs resembling modern *Potamon* from Jordan's rivers and creeks also lived in Al Qarn Lake as preserved parts of their claw document. Fossil *Theodoxus* thus had to protect itself from attacks of the crab as well.

HOROWITZ (1979) noted *Theodoxus jordani* unchanged from the base of the Pleistocene to recent times in different fresh water localities. A list of species from Israel is presented by HELLER (1993), and BANDEL (2001) who described the fossil and recent species of this genus from Jordan.

Theodoxus from Al Qarn Formation is fairly common and has a usual pattern of axial zebra stripes on white background preserved. A species with a little higher whorl and depression on the side was called *Theodoxus orontis* BLANKENHORN, 1897 (SCHUETT, 1988 PL. 2, FIG.9) from Pliocene deposits in the Orontes Valley. They resemble closely shapes as occurring in modern populations of *Theodoxus jordani* of the Lake Tiberias (=Kinneret), illustrated by HELLER (1993). The species name for this variety of a slightly higher shell with constriction, therefore, is not needed.

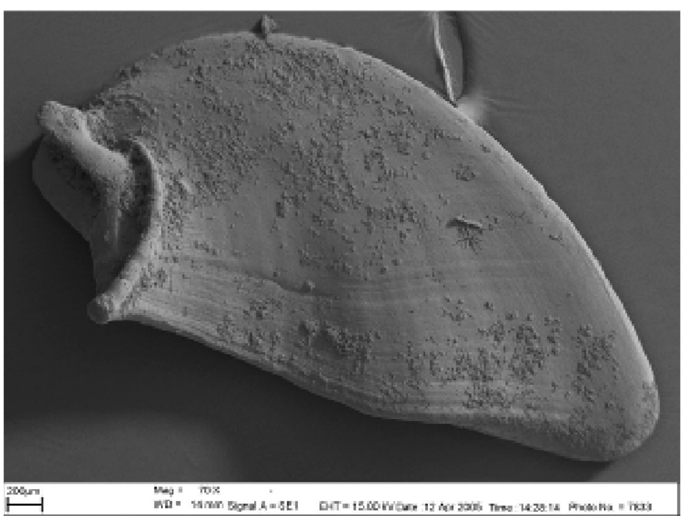


Figure 2.15: Operculum of *Theodoxus jordani* seen from the inner side with the peg,Al Qarn Formation west of Abu Habil at the Jordan Valley, the scale bar is 200µm (Al Qarn Formation next to KAC, the Jordan Valley in northern Jordan).

The embryonic shell composes the first whorl and is clearly set off from the teleoconch by its usually uniform, commonly white color. It has rounded shape and measures approximately 0.8 mm acrosss. With begin of the teleoconch the mode of calcification of the shell changes and the following outer layer of the teleocnch is calcitic. This change is also documented on the outside by the presence of long needle-like crystallites visible from the margin of the embryonic shell with the teleoconch (Fig 2.16 a). The teleoconch consists of about 2.5 whorls with pattern of color by irregular dark zigzag ribbons on light background. About 4 to 7 broad ribbons may be present on the first whorl of the teleoconch. This zigzag pattern is very variable among different individuals within the species.

The shape of a shell with one teleoconch whorl is usually hemispherical with rounded apex and flattened base, and width is larger that height (Fig 2.16 b). The inner lip of the aperture is smoothly covered by callus and has a straight inner (columellar) edge without teeth. In the second whorl of the teleoconch the relative height of the whorl increases and whorl sides have become more or less flat. In many individuals a shoulder develops and may form a rounded ridge that may or may not be accompanied by a depression below it.

Fully grown shells are higher than wide, reach 10 mm in height and 9 mm in width. The callus cover of the inner lip can be rounded and the columellar edge may appear evenly concave. The calcified operculum is provided with a ridge and a peg representing a solid structure on the inner side of the columellar margin. With this peg on its inner side the operculum is held in place when the animal is withdrawn into its shell.

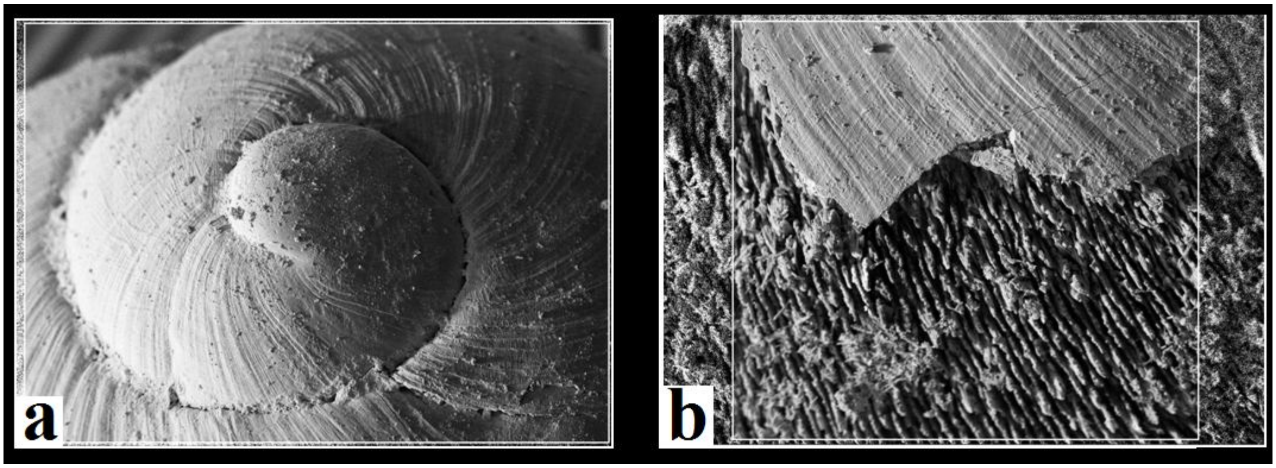


Figure 2.16: *Theodoxus* cf. *jordani* from Al Qarn Formation near KAC, west of Abu Habil at the Jordan Valley Jordan Valley; a. The shape of a shell with one teleoconch whorl is usually hemispherical with rounded apex and flattened base, b. Original mineralogy outer layer of the teleocnch has changed to calcitic structure with of long needle-like crystallites.

Superfamily: Cerithioidea

Family Thiaridae Troschel 1857

Genus Melanoides OLIVIER, 1804

They were well represented in Al Qarn Lake and individuals differ only little from the species that still lives in Jordan. Here they prefers muddy ground in the very shallow water of lake margins or in puddles next to running water. The ornament on the juvenile shells is characteristic. Among gastropod shells from Al Qarn Formation individuals of Melanoides occur quite rarely, and they closely resemble the modern *Melanoides tuberculata* (MUELLER, 1774) (Fig 2.17 & 2.18). That species has been noted to occur in the formerly large shallow lakes at Azraq, in muddy creeks polluted by waste water near Hemma at the Yarmouk and from here along the Jordan to the Dead Sea, periodically in large numbers in Karama Reservoir and to its southernmost creeks including the deposits of an ancient Roman water basin in northern Wadi Araba. From Lake Tiberias TCHERNOV (1975 FIG. 10-11) documented the species.

Melanoides tuberculata (MUELLER, 1774) lived in late Pliocene in the Greek islands of Kos (WILLMANN, 1981) and at the same time in Rhodos. In the Near East *Melanoides* also appear with the Pliocene as was noted by BLANKENHORN & OPPENHEIM (1927) and TCHERNOV (1973, 1975). According to SCHUETT (1983) this species now has its northern margin of occurrence in the area of the Orontes (STARMUEHLNER, 1976).

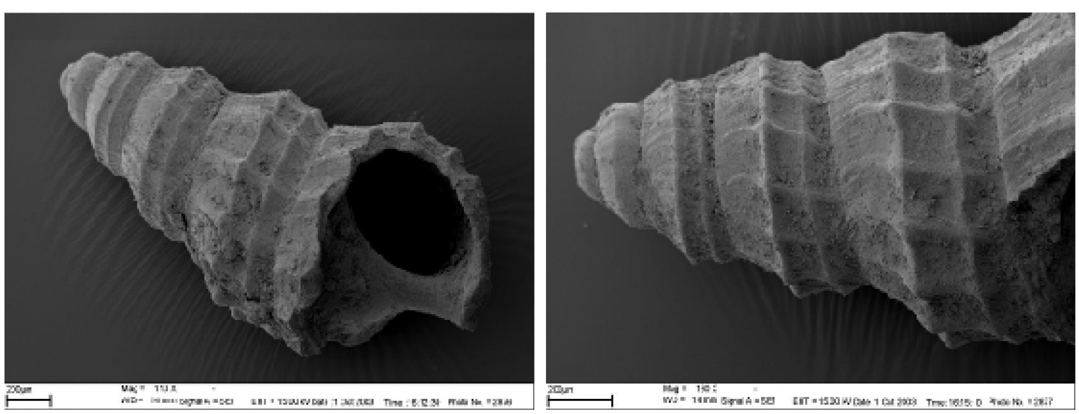


Figure 2.17: a. Melanoides tubercula from Al Qarn Formation, b. Melanoides tubercula whorls, Al Qarn deposit next to KAC in the northern Jordan Valley, the scale bars are 200µm.

***Melanoides abuhabili* (new species)**

Melanoides abuhabili differs from *Melanoides tuberculata* (MUELLER, 1774) living in the Jordan Valley (Fig 2.18) by characters of the first whorls of the teleoconch. They are ornamented by two spiral ribs crossed by axial ones, these in the first whorl of the teleoconch are close to each other and weak, while on the second they are placed more distant to each other and of the same strength as the spiral ones and in the third whorl the axials are even more distant. Approximately 30 axial ribs feature the first whorl, approximatel 20 are on the second whorl of the teleoconch and the third has about 12. In case of *Melanopsis tuberculata* more than 40 axial ribs feature the first three whorls of the teleoconch and later axial ribs become dominant while the lateral ones decrease in size. The reticulated ornament of the first whorls of the teleoconch thus changes to an axially ribbed ornament. The species was collected by us at the type locality of the Al Qarn Formation next to KAC in the northern Jordan Valley.

Melanoides abuhabili has the embryonic first whorls with irregular shape as is characteristic to *Melanoides tuberculata* as well. The early whorl of the teleoconch has reticulate ornament of the first whorl with many fine axial ribs and two spiral ribs. In the second whorl of the teleoconch a pattern with axial and spiral ribs of similar strength forms a reticulate ornament. The later whorls of the teleoconch continue with a widely reticulate ornamental pattern, but whorls beyond the fourth whorl of the teleoconch have not been encountered, and only 4 specimens of the new species are present. The apical angle is approximately 40° while that of *Melanopsis tuberculata* has around 30°.

In the living *Melanoides tuberculata*, as they also are present in the KAC next to the outcrop of Al Qarn Formation, the first three whorls of the teleoconch have a densely reticulate pattern and the wider ornament with axial ribs becoming dominant appears only within the fourth whorl of the teleoconch.

Melanoides abuhabili from Al Qarn Formation occurs rarely. It resembles closely the modern *Melanoides tuberculata* that lives in muddy places of creeks, and periodically in large numbers in Karama Reservoir when water is not very salty and also lived in the large shallow lakes which were present at Azraq Oasis.

From Erk el- Ahmar Formation, TCHERNOV (1975a, pl. 2, fig 7) documented a species called *Melanoides dadianus* Oppenheim 1918 that had been founded based on individuals from the Neogene of Asia Minor. In the specimen from Erk el- Ahmar the early part of the shell is not present, and thus it may represent the same species that is here described as *Melanoides abuhabili*.

TCHERNOV (1975a, pl. 3, figs 1-2) also documented a *Melanoides tuberculata* from Erk el- Ahmar, which also does not show the early formed shell. In case of this being the same species as that living in Lake Tiberias, as was assumed by him, it is also not *Melanoides abuhabili*.

A third *Melanoides jordanicus* TCHERNOV 1975 has weak ornament and thus differs as well. TCHERNOV (1975a) noted that the adult shells of *Melanopsis jordanicus* and *Melanopsis dadianus* are less slender than *Melanopsis tuberculatus*, which relates them to *Melanopsis abuhabili*.

HELLER & EHRLICH (1995) noted the tolerance of *Melanopsis tuberculatus* of Israel to polluted water. *Melanoides tuberculatus* is a partheogenetic species and thus large population consists only of females. A single individual can start a whole new generation. Rarely also males occur as has been recognized from individuals living in the region by Livshits & FISHELSON (1983) and recognition of males and females were confirmed by HELLER & FARSTAY (1989, 1990) from Israel.

Melanoides tuberculata lived in the late Pliocene of Kos (WILLMANN, 1981). In the Nile and especially the many irrigation channels connected to it in Egypt *Melanoides tuberculata* lives in masses and represents one of the most common gastropods present in modern Egypt (SCHUETT; 1983 fig 8, own observations).

In Jordan *Melanoides tuberculata* prefers muddy ground in the very shallow water of lake margins or in puddles next to running water.

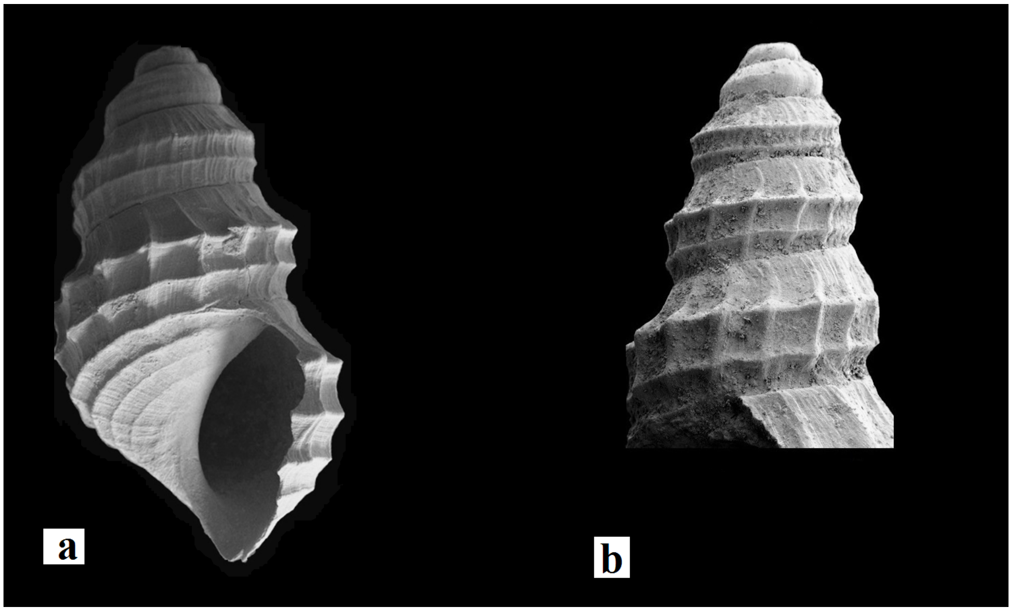


Figure 2.18: *Melanoides abuhabili* was collected from Al Qarn deposit in eastern banks of KAC next to the village Abu Habil and south of Jebel al Qarn; *a*. *Melanoides abuhabili* has the embryonic first whorls with irregular shape, b. The first whorls of the teleoconch are ornamented by two spiral ribs crossed by axial ones.

Family Melanopsidae H. & A. Adams 1854

The oldest representative of *Melanopsis* in Jordan is found in Al Qarn Formation (BANDEL, 2000; BANDEL, 2007). The shell of *Melanopsis* is up to 4 cm high, has a cyrtoconoid outline with the body whorl more or less inflated and whorls of the spire hardly rounded and smooth or ornamented by axial and/or spiral ribs. Both types of ornaments are present in the Al Qarn fauna and also occur among the modern species living in Jordan, with some distinctions. Al Qarn *Melanopsis* is somewhat intermediate in shape in between the species as they lived during the Pliocene in lakes connected to the Paratethys (now they are exposed, for example, on Kos Island) and the species living in Jordan up to date. The egg-shaped aperture has a rounded outer lip, a short anterior channel and a smooth inner lip with a characteristic posterior callus pad. The young hatch when developed to the crawling stage with a shell of 0.2-0.4 mm in diameter. They grow up within eggs which are distributed on the bottom substrate one by one and are difficult to detect since they are covered with mucus.

Melanopsis is often attacked by the crab *Potamon* which can crack the shell beginning at its aperture. The operculum of *Melanopsis* is organic and not as protective as the calcareous one of *Theodoxus*. Still *Melanopsis* represents the most remarkable gastropod found in running freshwater in Jordan. In a clean stream individuals may be very common and present on each pebble in the stream bed.

Genus *Melanopsis* FÉRUSSAC, 1807

The shell has a cyrtoconoid outline with the body whorl more or less inflated and whorls of the spire hardly rounded and smooth or ornamented by axial and/or spiral ribs. The size ranges from about 1 to 4 cm shell height. The aperture is depressed egg-shaped with a regular rounded outer lip, anterior channel, and a smooth inner lip which is usually thickened by a posterior callus pad. There is no umbilicus. The protoconch is simple, not clearly demarcated from the teleoconch, and about 0.2-0.4 mm across. The type to the genus is *Buccinum praemorsum* LINNÉ, 1758 determined in fresh water rivers and springs in southern Spain, and the Maghreb (AZPEITIA MOROS 1929). Regarding ontogeny, the usual type is that of hatching from single egg as crawling young after metamorphosis.

Of the four *Melanopsis* species described from Al Qarn Formation by BANDEL et al (2007), two have been considered to be extinct (*Melanopsis aaronsohni, Melanopsis* *tchernovi*) whereas two have been interpreted to still occuring in the Levant (*Melanopsis buccinoidea*, *Melanopsis costata*). The *Melanopsis costata* as suggested by BANDEL et al (2007) may also be interpreted as consisting of two species, one with and the other without a distinct shoulder besides the rounded axial ribs. These two varieties, in the general shape of their shell, are thus similar to *Melanopsis buccinoidea* without and *Melanopsis tchernovi* with shoulders but otherwise with a smooth shell.

Melanopsis costata OLIVIER, 1804, has a slender fusiform shell with up to ten whorls and reaches a size of up to 3.3 cm in height. Shell shape is that of a slender *Melanopsis buccinoidea*, with ornament of 12 to 15 rounded ribs which are continuous across the whorl forming an even curve pointing forwards in the rounded transition of the whorl sides into the base (Fig 2.19). Ribs are usually continuous onto the base but may become less distinct here. According to BANDEL (2000, FIGS 72-75) and to HELLER et al (1999, FIG 4B) the main feature of *Melanopsis costata* is the presence of the ornament of axial ribs on each flattened whorl and an usually slender relatively large shell with rounded upper whorl side.

Melanopsis costata differs from *Melanopsis buccinoidea* by the ornament and from *Melanopsis noetlingi* of the pre-Lisan deposits of the Jordan River by more widely spaced axial ribs and higher last whorl.

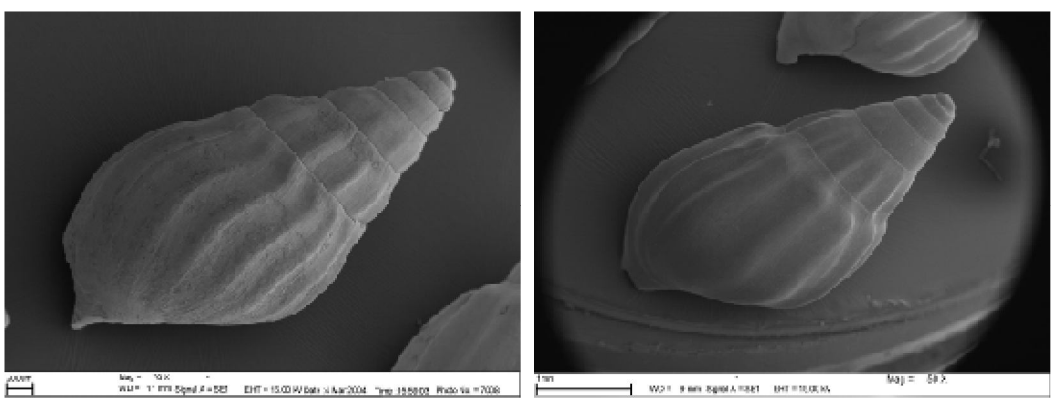


Figure 2.19: Juvenile shell of Melanopsis costata from Al Qarn Formation near eastern banks of KAC next to the village Abu Habil and south of Jebel al Qarn, the scale bar is 200μm.

Species of the *Melanopsis costata* group still living in Jordan have no stair-like spire. There is little difference to *Melanopsis multiformis* Blanckenhorn, 1897 from the Pliocene of the mid Orontes area regarding shell shape. Also *Melanopsis obediensis* PICARD, 1934 from the Pleistocene deposits of Obedieh (Ubeidiya), just SW of Lake Tiberias, is similar (PICARD 1934, PL.7, FIGS 30-44). But its ribs are more curving and there is a median lobe in the outer lip which is absent in *Melanopsis blanckenhorni*. BUKOWSKI (1893, PL.3, FIG 15, PL.4, FIGS 1-4) noted from lake deposits of Rhodos members of the *Melanopsis costata* group which he named *Melanopsis orientalis* for elongate shells with stair-like short spire, *Melanopsis biliottii* for similar ones but nodes on the ribs near the peripheral corner and posterior concave whorl sides.

Among the individuals of Al Qarn Formation the ones with a shell with stepped spire were determined as *Melanopsis orientalis* by BANDEL (2000 FIGS 104, 107-110) and were placed with *Melanopsis costata* in BANDEL et al (2007, FIG C). But these individuals could also be interpreted to represent an independent species since it differs as much from *Melanopsis costata* as the species determined as *Melanopsis tchernovi* differs from *Melanopsis buccinoidea* that is by the presence of a shoulder below the suture. A comparison of the juvenile shell of the *Melanopsis orientalis* from Kos with that of the similar individuals from Al Qarn Formation show differences, and thus the shoulder bearing *Melanopsis* with axial ribs could receive a different name (Fig 2.20).

Melanopsis costata “stepped” in BANDEL et al. (2007, FIG 3 B) and determined as *Melanopsis orientalis* in BANDEL (2000 FIGS 104, 107-110).

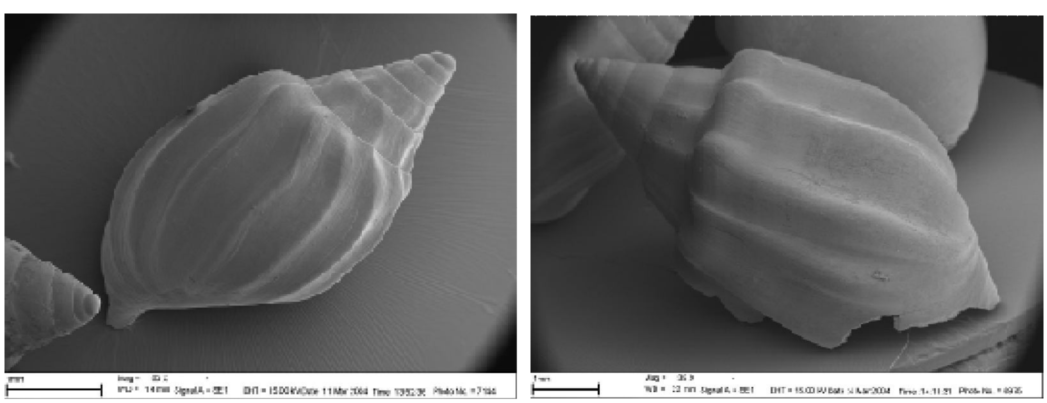
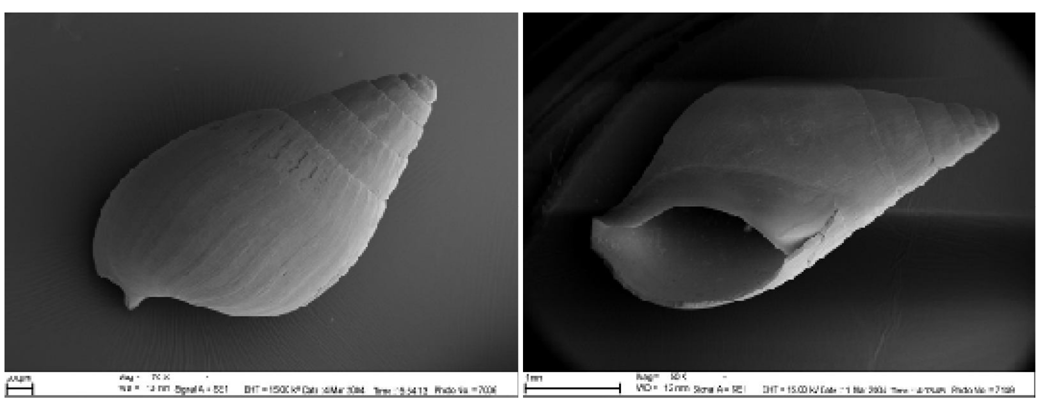


Figure 2.20: Juvenile shells of *Melanopsis costata* (sp),= *orientalis* from Al Qarn deposit next to KAC in the northern Jordan Valley Formation, , the scale bar is 1µm.

Melanopsis buccinoidea FÉRUSSAC, 1823, differs from the type species of the genus *Melanopsis praemorsa* by a more rounded cylindrical shape (BANDEL, 2000, FIG.1). The shell is smooth, consists of 8 to 9.5 whorls and usually reaches a height of around 25 mm and a width of about 12 mm. The spire is pointed and the growth of whorls occurs with regular increase in width. The body whorl is evenly rounded with the aperture taking about half of shell height. Its posterior portion is a narrow slit formed between the thickened callus pad of the inner lip and the evenly curving outer lip. Between these a deep and narrow slit is present that is closed further within the shell lumen. The anterior portion of the aperture is drop-like in shape and ends in a narrow short and distinct siphon notch. The protoconch has three quarters of a whorl without growth lines and from there on growth lines up to the hatching point which occur with about 1.5 whorls (RIEDEL, 1993).

The species has occurred in the area of the Jordan Valley since the existence of the Lake preserved in the deposits of Erk el- Ahmar and that of Lake Ubeidiya to the south of Lake Tiberias and it also lived in the Al Qarn Lake (Fig 2.21). The species has thus for more than 1 million years existed in the area with a basically unchanged shell shape together with Melanopsis costata as was documented by HELLER et al. (1999), BANDEL (2000), HELLER & SIVAN (2002, Fig 3A), BANDEL et al. (2007, Fig 3A).



The scale bar is 200µm the scale bar is 1µm

Figure 2.21: Juvenile shells of *Melanopsis buccinoidea* from Al Qarn Formation in the eastern banks of KAC next to the village Abu Habil and south of Jebel al Qarn.

Melanopsis aaronsohni BLANKENHORN & OPPENHEIM, 1927, according to BANDEL et al (2007) it had been determined as *Melanopsis vandeveldi* BUKOWSKI, 1895 by BANDEL (2000, Figs 111-112) who relied on Bukowski (1895, Pl.4, Figs 5-11). The shell is fusiform and consists of at least eight whorls. These form a conical spire with distinct sutures but not stair-like spire. The type of *Melanopsis vandeveldi* is found in the Pliocene deposits of Rhodes. This species can be interpreted to represent a hybrid of *Melanopsis costata/ orientalis* with *Melanopsis buccinoidea* with ribs but without the stair-like spire. There is some similarity with the modern *Melanopsis tingitana* from Morocco but has some peculiarities and was therefore interpreted by BANDEL (2000) to be the same species as the fossil *Melanopsis vandeveldi* which is closer in shape. Both of these have disappeared in the general area during the Pleistocene but survived in the western Mediterranean realm. But when the juvenile shell is taken into consideration *Melanopsis aaronsohni* appears closely related to the species of *Melanopsis buccinoidea* group as they live in Jordan. With a more slender shells shape and relatively higher spire *Melanopsis aaronsohni* comes close to *Melanopsis bandeli* that lives in spring water in the Jordan Valley near Pella (BANDEL, 2000, Figs 80-83, 85-93) and also in a spring in the upper Zarqa Valley a few km below Suchna.

BANDEL, SIVAN & HELLER (2007) related this species from Al Qarn Formation with *Melanopsis aaronsohni* and compared it to a fossil species from Erk el- Ahmar that is preserved in the collection in the Hebrew University at Jerusalem.

Melanopsis tchernovi HELLER & SIVAN, 2002 *(= M. dufouri = M. hammamensis* GASSIES, 1901), according to the description of BANDEL (2000, Figs 139-142) this species was determined as *Melanopsis dufouri.* Its cylindrical shell resembles that of *Melanopsis buccinoides* in general shape but has a stair-like spire. It was connected to similar looking *Melanopsis* species from Northern Africa, but even more with similar individuals as described from Erk el- Ahmar by HELLER & SIVAN (2002). Thus this determination was adopted by BANDEL et al. (2007, Fig 3B) for this species from Al-Qarn Formation (Fig 2.22). Whorl sides are smooth or slightly concave or convex with two low ridges and grooves. The shoulder, thus, is accompanied by a rounded ridge a slightly concave area, which follows succeeded by a swelling that forms the greatest shell width, a further shallow groove and a swelling that forms the rounded transition to the base. The shell with 15 mm in height and 8 mm in width consists of between 8 and 9 whorls of which the first 5 are conically coiled with flattened sides and the sixth developing a shoulder. A more slender shell with 17 mm in height measures only 7 mm in width. The aperture has a curving inner lip with concave frontal portion and a thick callus pad in its posterior part.

Remarks: *Melanopsis tchernovi* HELLER & SIVAN, 2002 originated according to HELLER & SIVAN (2002, Fig 3F) from Erk el-Ahmar. *Melanopsis. tchernovi* from Jordan probably formed hybrids with *Melanopsis buccinoidea* and with *M. orientalis/costata* which lived together in the same lake. A species determined as *Melanopsis delessei* from the Pliocene of Kos has an almost identical shell shape (WILLMANN 1981, PL.8, FIGS 19-21).

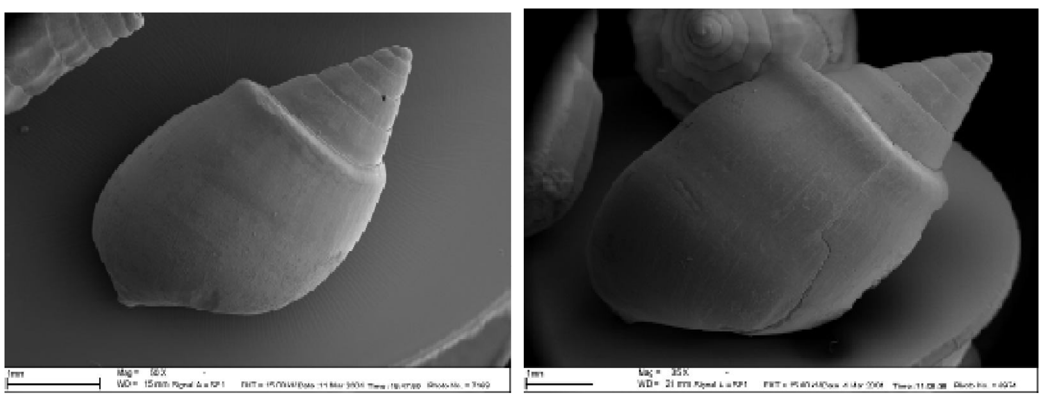


Figure 2.22: Juvenile shells of *Melanopsis tchernovi* from Al Qarn deposit next to KAC next to the village Abu Habil and south of Jebel al Qarn, the scale bar is 1μm.

Of the four *Melanopsis* species found at Al Qarn, two are extinct (*Melanopsis aaronsohni*, *Melanopsis tchernovi*) whereas two occur in the Levant also today (*Melanopsis buccinoidea*, *Melanopsis costata*) (BANDEL et al., 2007). The similarities among these species and also the transitions observed between them and later living species which were interpreted to represent independent species document that *Melanopsis* is a rather special genus. BANDEL (2001) studied many species of this genus especially such which lived in the depositional environment of the Paratethys and suggested that in the development of species groups which are interconnected by their morphology interbreeding between species played an important role. When the species which have survived in Jordan are interpreted in this respect it becomes evident that interbreeding appears to be still going on.

Melanopsis salamei (new species)

The shell of ***Melanopsis salamei*** has the last 4-5 whorls of the teleoconch are ornamented with strong axial ribs and have a shoulder below the suture and the ribs may form a node at its edge. The juvenile shell in contrast is smooth and without shoulder up to the fifth whorl. The shape of the shell changes after three juvenile whorls with smooth surface and straight suture to one with axial ornament in the fourth whorls and strong ornament and angular shape only in the fifth whorl. The shell with 8 whorls may be 3 cm high. Holotype, origin of the name and type locality: The individual in figure 2.23 represents the holotype. It was collected by us at the type locality of the Al Qarn Formation next to KAC in the northern Jordan Valley.

Melanopsis salamei had been placed with *Melanopsis costata* **"**stepped" in BANDEL et al. (2007, fig 3) and was determined as *Melanopsis orientalis* in BANDEL (2000 figs 104, 107-110). But these individuals can also be interpreted to represent an independent species since it differ as much from *Melanopsis costata* as the species determined as *Melanopsis tchernovi* differs from *Melanopsis buccinoidea*, that is by the presence of a shoulder below the suture.

Melanopsis salamei differs from the similar *Melanopsis paraecursor* SCHÜTT & ORTAL, 1993 as described by HELLER & SIVAN (2002a) from Erk el- Ahmar by having a less dense pattern of ribs. As was noted by HELLER & SIVAN (2002a) *Melanopsis multiformis* BLANCKENHORN 1897 is also of similar shape, but its shell has a broad tubercle in the upper part of each rib and there are more ribs on each whorl.

Melanopsis obediensis Picard 1934 from the Pleistocene deposits of Ubeidiya is similar (PICARD, 1934, pl. 7, figs 30-44), but has a shorter and more rounded shell (HELLER & SIVAN, 2002b, figs 3 E-G).

Species from the *Melanopsis costata* group still living in Jordan have no stair-like spire. Also similar is *Melanopsis multiformis* BLANCKENHORN 1897 from the Pliocene of the mid Orontes area regarding shell shape, but as the species name indicates, the shape of individuals that had been placed here by BLANCKENHORN (1897) could also be interpreted to hold a number of different species.

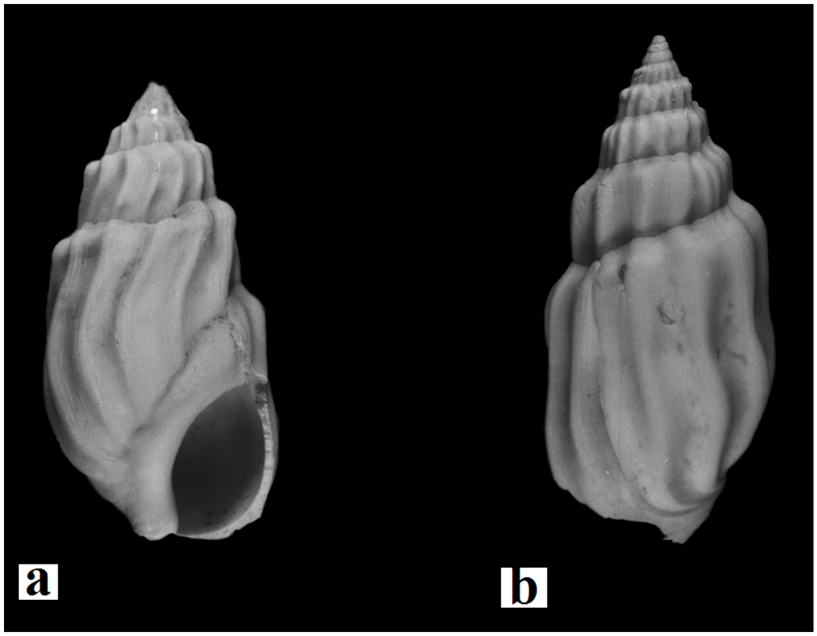


Figure 2.23: *Melanopsis salamei* (new species) was collected from Al Qarn Formation, KAC next to the village Abu Habil and south of Jebel al Qarn.

in the northern Jordan Valley; a. *Melanopsis salamei* with the last 4-5 whorls of the teleoconch are ornamented with strong axial ribs , b. The juvenile shell in contrast is smooth and without shoulder up to the fifth whorl

Superfamily Valvatoidea

WENZ (1938) knew only members of the *Valvata* relation forming the superfamily Valvatacea which lived in fresh water and were restricted to the northern Hemisphere. PONDER (1991) found marine relatives living in the sea grass environment of tropical seas, and called them Cornirostridae. Fresh water Valvatidae are united with marine Cornirostridae in the superfamily Valvatoidea of the Heterostropha (= Heterobranchia). Marine species with similar characters of their shell have been recognized in deposits as old as Devonian (BANDEL & HEIDELBERGER 2002) and transition from the sea to the environment of fresh water was interpreted to have occurred during the time of sea regression from Central Europe at the end of the Jurassic (BANDEL, 1991).

The shell is trochiform to discoidal, variously ornamented with a heterostrophic protoconch that coils in sinistral mode. The embryonic shell thus coils around the same axis in left mode while the succeeding teleoconch coils to the right, but both may have secondarily become planispiral. The aperture is simple. In living species several features of the anatomy are distinctive. For example the gill and especially the pallial tentacle are characteristic (RATH, 1988). The osphradium has a unique anatomy and lies on the left side right besides the pallial opening (HASZPRUNAR, 1985, 1988). Also the morphology of the sperm is characteristic (HEALY, 1991). The gill is unusual and covered by cilia all over and differs from that of the other gill bearing gastropods (SALVINI-PLAWEN, 1981). It is usually exposed in front of the aperture, when the animal is active. A feature that unites with the Caenogastropoda is the taenioglossate radula found in the Valvatidae of fresh water, an amazing similarity or convergence even though their relation to each other ranges back well into the Paleozoic (FRYDA & BLODGETT, 2001).

Family Valvatidae GRAY, 1840 (= Valvatidae THOMPSON, 1840)

According to WENZ (1938) *Valvata* and relation have usually a small to very small thin shell that is lowly spiral to plane in shape with open umbilicus with few rounded whorls that may be smooth or bear spiral lines or more rarely spiral ribs. The aperture is round and thin and closed by a multi-spiral round operculum with central nucleus. According to RIEDEL (1993) and BANDEL & RIEDEL (1994) the protoconch consists of a planispiral whorl with characteristic ornament of spiral ribs and crossing collabral lines. The characteristic genus is *Valvata*.

The Valvatidae of the fresh water developed alongside the Planorbidae which have species sometimes with a quite similar shell. Their history also ranges back in time for several hundred million years into the Jurassic (WENZ & ZILCH, 1960; BANDEL & RIEDEL; 1994). The protoconch distinguishes *Valvata* from *Gyraulus* and from other small species with planispiral shell (BANDEL, 1991; RIEDEL, 1993). Even though Planorbidae are also members of the subclass Heterostropha (=Heterobranchia) among the Gastropoda, they belong to a different branch than the Valvatoidea. That of the Valvatoidea appears to have evolved from the Allogastropoda latest at Triassic time (BANDEL, 1996). The branch of the Planorbidae is that of the Euthyneura (lung snails) and their ancestral species in the Triassic are apparently very similar to those of the Valvatoidea. During the Jurassic both groups, Valvatoidea and Planorbidea were distinct from each other and each of them became well recognizable.

Genus *Valvata* O.F. MUELLER, 1774

Valvata has a small trochiform shell consisting of three whorls and with a little more than 2 mm in diameter. This species is common in lake deposits and can be found, in some creeks in Jordan, still living in the area extending from a spring in Wadi Rum in the south to one in Jerash in the north (SCHUETT, 1988). It prefers clean fresh water and has thus become rare in Jordan. At time of Formation of the deposits of Al Qarn Formation it occurred commonly and is similar but not related to *Gyraulus* that also has a preference to plant rich environments and was also common in Al Qarn Lake, but occurs nowadays only rarely in the fresh water of Jordan.

The type to the genus is *Valvata cristata* O.F. MUELLER from central Europe. The embryonic shell was described by HADZISCE et al (1976) and RIEDEL (1993). WENZ (1938, Fig.1320) based the genus on the very lowly spiral *Valvata cristata* MUELLER 1774 with smooth rounded whorls from Middle Europe. According to GRAHAM (1988) the genotype is *Nerita piscinalis* MUELLER, 1774, a species with higher shell.

Two species of *Valvata* can be recognized from Al Qarn Formation, one with almost plane shell and the other with higher shell. *Valvata cf. cristata* shell is small and almost plani-spirally coiled with rounded whorls and wide umbilicus. The embryonic shell consists of one planispiral whorl.The *Valvata* species living in Europe differ in shell shape, with the planispiral *Valvata cristata* about 3 mm in size, with *Valvata naticina* MENKE, 1845 that has a low shell and rounded whorls, *Valvata piscinalis* with the shell about as wide as high (up to 5 mm) but of quite variable shape, *Valvata pulchella* STUDER, 1820, also quite variable regarding shell shape and less tightly coiled as *Valvata naticina* and up to 4 mm in size (Fig 2.2a). Shell shape regarding size and more or less trochispiral coiling is within each species rather variable and all European species have rounded whorls. The common *Valvata tricarinata* from the United States, in contrast, has three spiral keels. It resembles fossil species from the Paratethys such as *Valvata kamirensis* and *Valvata heidemariae* as described by BANDEL (2010).

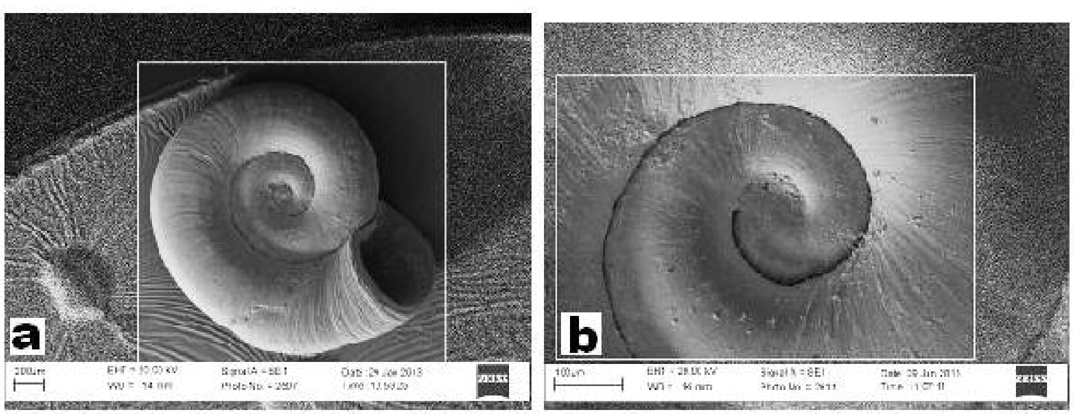


Figure 2.24: a. Valvata cf. cristata from Al Qarn Formation, the scale bar is 200μm, b. Valvata cf. cristata whorls, Al Qarn Formation next to KAC in the northern Jordan Valley, the scale bar is 100μm.

Valvata (Cincinna) saulcyi BOURGUIGNAT, 1853, has a trochiform shell that consists of three whorls, a little more than 2 mm in diameter (SCHUETT, 1988, Pl.3, Fig 26). The modern *Valvata saulcyi* was encountered in a spring in Wadi Rum and in the Roman bath-pond at Jerash in 1978. It also occurred in the southern pool at Azraq oasis (own collection). Neither near Jerash nor in the pool of Azraq living individuals of *Valvata* can still be encountered.

HOROWITZ (1979) noted *Valvata* species at “modern” Lake Hula and in the fossil deposits of Ubeidiya and Erk el-Ahmar Formations. SCHUETT (1983) suggested that this species represents the replacement to *Valvata piscinalis* in the area of Syria and south of it. TCHERNOV (1975: pl. 1, Fig. 4) suggested that *Valvata saulcyi* represents the only species that lived throughout the Neogene and Pleistocene of the Levant. The species is encountered in Al Qarn Formation as documented by BANDEL (2010, Figs 52–53).

SCHUETT (1988, Pl.3, Fig.26) described a variety with upstanding embryonic shell portion from the Pliocene of the Orontes Valley as *Valvata saulcyi pliocaenica*. TCHERNOV (1975, Pl.1, Fig 4) found *Valvata saulcyi* to represent the only species that lived throughout the Neogene and Pleistocene of the Levant and it had been determined as *Valvata cristata* by BLANCKENHORN (1897). Obviously two species of Valvata lived in Al Qarn Lake (Figs 2.25-2.27). .

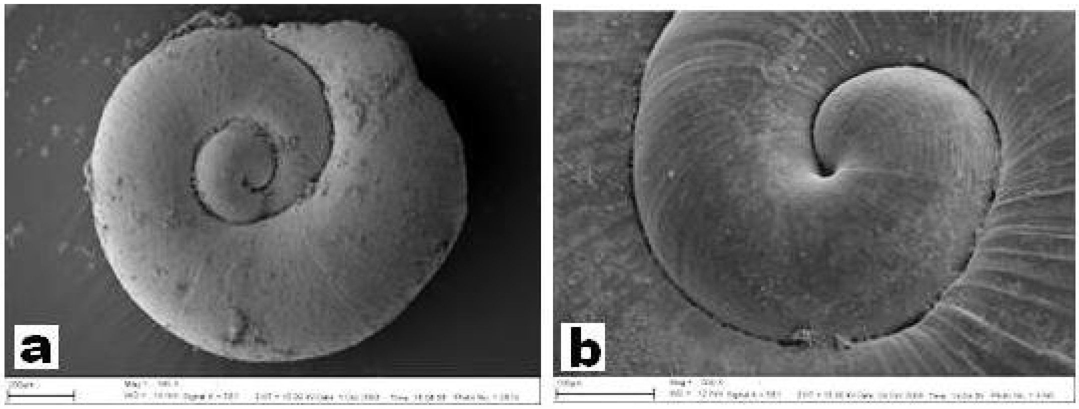


Figure 2.25: a. *Valvata saulcyi* with the embryonic whorl that is coiled to the left and ornamented by fine lines, from Al Qarn formation, the scale bar is 200µm, b. First umbilical view and second apical view, from Al Qarn formation, the scale bar is 100µm.

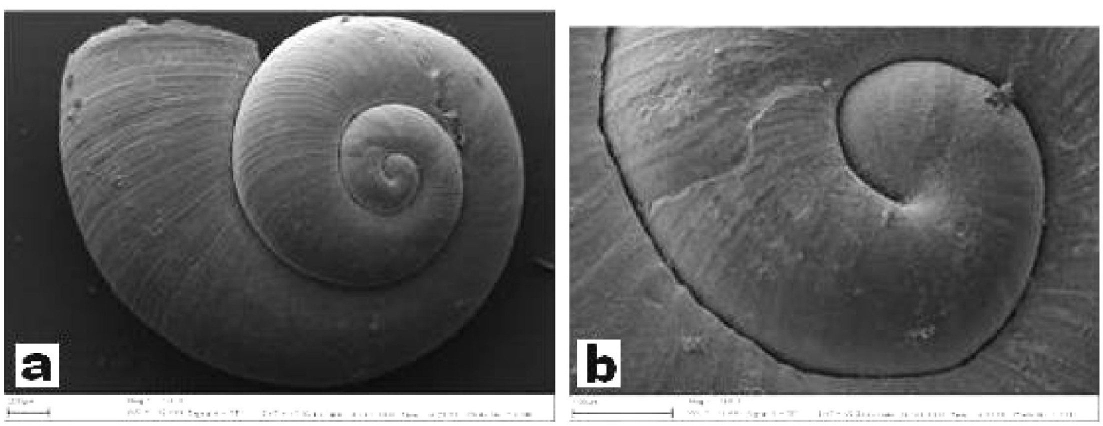


Figure 2.26: a. *Valvata saulcyi* with the shell of the early hatched juvenile recorded by first repaires fracture was collected from Al Qarn Formation next to KAC in the northern Jordan Valley, the scale bar is 200µm,b. The early hatched *Valvata saulcyi*, the scale bar is 100µm.

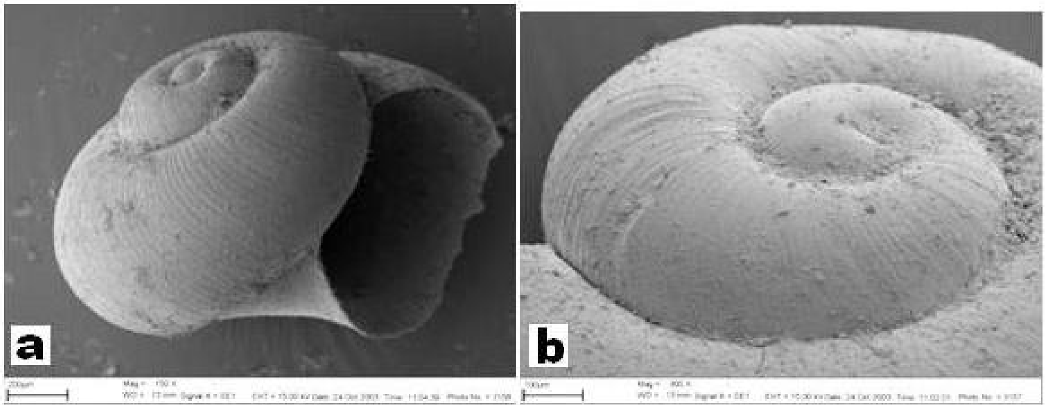


Figure 2.27: a. Valvata from Al Qarn Formation next to KAC south Abu Habil in the northern Jordan Valley, the scale bar is 200μm, b. dorsal view, showing whorls and apex of Valvata from Al Qarn Formation next to KAC west Abu Habil in the northern Jordan Valley, the scale bar is 100μm.

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Family Valvatiform Hydrobioidea

Several species which live in freshwater or slightly brackish environment have convergent shell shape with *Valvata* but belong into quite different relation among the gastropoda. BODON et al. (2001) documented quite convincingly that low valvatiform gastropods with small shell that have a flat or low spire and rounded whorls, more or less wide umbilicus, and less than 4 whorls may belong to a number of anatomically quite distinct genera. A number of species of that type live around the Mediterranean Sea with distinct and sometimes geographically relatively limited areas of occurrence. BANDEL (2010, Figs 69-81) noted some of them from Al Qarn Formation.

Genus *Horatia* BOURGUIGNAT, 1887

A species from Al Qarn Formation (Figs 2.28 &2.29). resembles cf. *Horatia* as of the Pontian of Lake Balaton region in Hungary . The specimen of the sand pit near Papkesi close to the eastern end of Lake Balaton closely resembles that from the Jordan Valley (BANDEL; 2010 Figs 77-81).

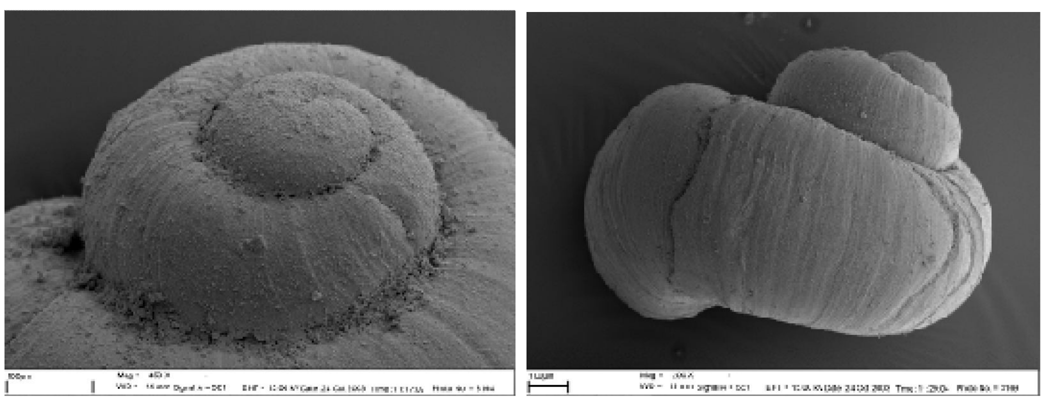


Figure 2.28: *Horatia sp.* was collected from Al Qarn Formation next to KAC in the northern Jordan Valley west Abu Habil, the scale bar is 100µm.

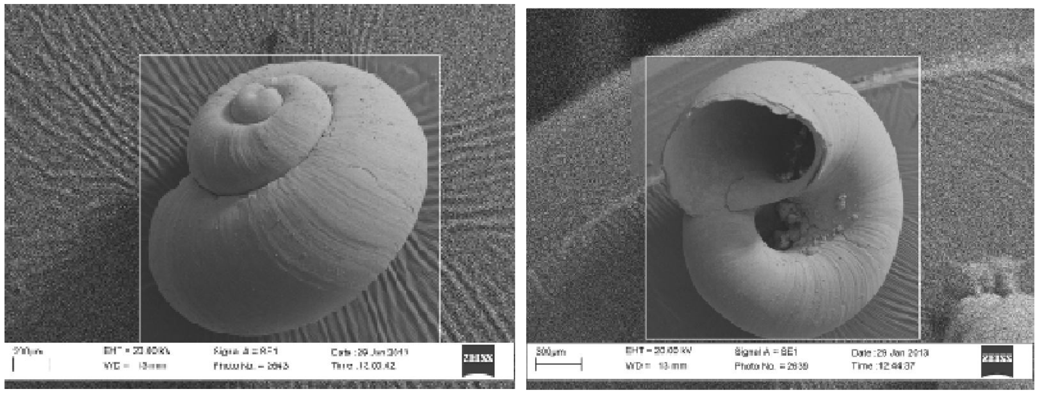


Figure 2.29: *Horatia sp* from Al Qarn Formation next to KAC, west Abu Habil and south wadi Al Qarn in the northern Jordan Valley, the scale bar is 200µm.

BODON et al. (2001) described *Hauffenia* POLONERA, 1898 which is restricted to the area of Slovenia and near it. The shell of *Hauffenia* is characterized as small valvatiform to planispiral with the surface of the protoconch covered by small pits. The type species *Hauffenia tellinii* (POLLONERA, 1898) consists of up to 3.5 rapidly growing convex whorls, is small and almost planispiral, with the protoconch with irregular pit ornament. Among living species the anatomy is the most important characters besides the shape of the shell. The shape of the genitalia distinguishes from *Horatia* BOURGUIGNAT, 1887 which has basically the same characters of the shell (BODON et al., 2001), but with the shell a little higher in the type species *Horatia klecakiana* BOURGUIGNAT, 1887 and the protoconch of the same ornament. It resembles *Islamia* RADOMAN, 1973 that is distributed from the Iberian Peninsula around the Mediterranean with somewhat spotty distribution. *Islamia* usually has a more highly coiled shell and is based on *Islamia servaini* BOURGUIGNAT, 1887. All three genera are considered related to the Hydrobiidae. The mode of development of *Horatia*, *Islamia*, and *Hauffenia* is from yolk-rich eggs. Young snails hatch crawling with a shell of about 1.5 whorls, trochispiral coiling mode and ornament by small pits and ridges in irregular orientation or arranged to form spiral ribs (BINDER, 1967). In case of such spiral ornament convergence is not only among the species of hydrobiid relation but approaches shapes as found among Valvatidae. The latter usually have an ornament of the embryonic shell consisting of spiral ridges, but in contrast to the Hydrobioidea have planispiral whorls of the protoconch.

Cf. *Horatia* from Al Qarn Formation has the same shape as that of the Pannonian of Lake Balaton region (BANDEL, 2010, Figs 77-81). Characteristic is also the detachment of the body whorl.

Genus *Hydrobia* Hartmann, 1821.

Hydrobia cf. *acuta*

It has shell with 4.5 whorls is 1.7 mm high and almost 1mm wide (Fig 2.30). Whorls are evenly rounded and smooth with only inclined growth lines as sculptural elements. The relative hight width relation of the whorls changes during growth and older shells appear to be more slender than younger shells. The aperture is evenly rounded and the inner lip simple with no umbilical opening and just a pit at the anterior end of the margin of the inner lip.

Only two shells of juvenile individuals of this *Hydrobia* like species were encountered, which document their presence in the waters in which Al Qarn Formation was deposited. They lived here only rarely. In the Jordan River that flowed near here before salty Lisan Lake flooded the area and in fresh water ponds in Jordan gastropods with similar shells were encountered and determined by SCHUETT (1983, fig 4) as *Paludina musaensis*. According to TCHERNOV (1975a, pl. 1, fig 5) *Hydrobia acuta* that had also been determined as *Hydrobia fraasi* Blanckenhorn 1897 was widely distributed since the Neogene in the Mediterranean region of Europe and in Mesopotamia. Tchernov determined the species from the fauna of the Erk el- Ahmar Lake. Here it has a 7 mm long and 5 mm wide shell.

A *Hydrobia ventrosa* was mentioned by NELSON (1973) to live in the Druze and Shishan pools at Azraq Oasis, and it may be a related species, but according to own observations has a less slender shell.

Hydrobia and many related members of the Hydrobiidae have different species often with very similar shells (WILKE et al., 2001), and the two incompletely grown shell encountered in Al Qarn Formation can not be described sufficiently well to determin their species. The structure of the shell has crossed lamellar composition, as is usually present in members of the Hyrobiidae. The shell from

Al Qarn Formation is fractured near its margin, and that fracture revealed a well preserved and simple crossed lamellar structure with the argagonitic composition of the shell unchanged.

Figure 2.30: Hydrobia cf. acuta shell from Al Qarn deposits next to KAC south Abu Habil in the northern Jordan Valley, the scale bar is 200μm.

Genus *Islamia* Radoman 1973

Species *Islamia jordanica* (new species)

The embryonic shell is trochispiral and consists of 1.5 whorls with granular ornament.The succeeding teleoconch has 1.5 whorls with rapid increase in width and evenly rounded shape, ornamented only by growht lines. The aperture is rounded with solid margin and inclined position. Shell size is approximately 1 mm wide and high with 0.3 mm wide protoconch. It was found at the locality of the Al Qarn Formation next to KAC in the northern Jordan Valley.

The small trochispiral shell consists of only three whorls (Fig 2.31 a). When fully grown, growth line pattern becomes more irregular and denser as is the case in the juvenile shell. Most of the teleoconchs have simple straight and fine growth lines, but the plane of the aperture is inclined in regard to the axis of coiling. The evenly rounded whorls of the protoconch have an ornament that displays a simple and irregularly distributed grain- groove pattern. Growth lines appear only near the end of the embryonic shell. Its margin is documented by stong increments of growth and may be thickened (Fig 2.31 b). During their life time some of the small gastropods had been attacked and had repaired the chipped shell margin again.

Among the valvatiform Hydrobioidea discussed by BANDEL (2010) a group of species from the Late Miocene and the Pliocene of the Paratethys was described. One determined as cf. *Horatia* from Al Qarn Formation was compared to these (BANDEL, 2010, pl.7, fig 77). The species from the Al Qarn Formation was interpreted to closely resemble species belonging to the genus *Horatia* since it is very close in shape to a species determined as cf. *Horatia* from the Pannonian of Lake Balaton region in Hungary (BANDEL, 2010, pl.7, figs 78-81).

Characteristic to both, the species from Al Qarn Formation and its similar counterpart from the Late Miocene to Pliocene of sand pit near Papkesi close to the eastern end of Lake Balaton in Hungary, is also the slight detachment of the body whorl in fully grown idividuals. But the species here described from Al Qarn Formation also resembles *Islamia* Radoman 1973 that is distributed from the Iberian Peninsula around the Mediterranean with somewhat spotty distribution. *Islamia* usually has a more highly coiled shell and is based on *Islamia servaini* (BOURGUIGNAT 1887) (=*Islamia valvataeformis* (MOELLENDORFF 1873)) that lives in the southern Balkan area. A cf. *Islamia* was also noted to occur in the Pannonian and Pontian lake deposits of the area of modern Lake Balaton in Hungary, and is very similar to the here described species.

BODON et al. (2001) have reviewed this group of small sized gastropods. These species have a shell shape as is found among the living genera *Hauffenia*, *Islamia*, *Heraultia* and *Horatia* (BODON et al. 2001). *Horatia* BOURGUIGNAT 1887 has basically the same characters of the shell (BODON et al. 2001), but with the shell a little higher in the type species *Horatia klecakiana* Bourguignat 1887 and the protoconch of the same ornament. The protoconch of *Heraultia* BODON, MANGANELLI & GIUSTI 2001 is very close in shape as that of Pannonian deposits (BANDEL 2010 pl. 6, fig 70).

Among living species of this group of genera with rather similar shell shape the anatomy is the most important characters defining the living species besides the shape of the shell. The shape of the genitalia distinguishes species and all four genera are considered related to the Hydrobiidae and belong to the subfamily Belgrandiinae. The mode of development of *Horatia*, *Heraultia*, *Islamia*, and *Hauffenia* is from yolk-rich eggs. Young snails hatch in the crawling stage and with a shell of about 1.5 whorls of trochispiral coiling mode and an ornament by small pits and ridges in irregular orientation or arranged to form spiral ribs as had been noted also by BINDER (1967).

For the new species from Al Qarn Formation the genus *Islamia* was selected since its type species is living in the SE Mediterranean region in fresh water lakes and in age comes close to the Jordanian fossil snail.

Regarding the life habits of *Islamia* and relation little is known. The shape of the protoconch indicates hatching from an egg mass as crawling young, and the small size of the gastropod feeding on small particles.

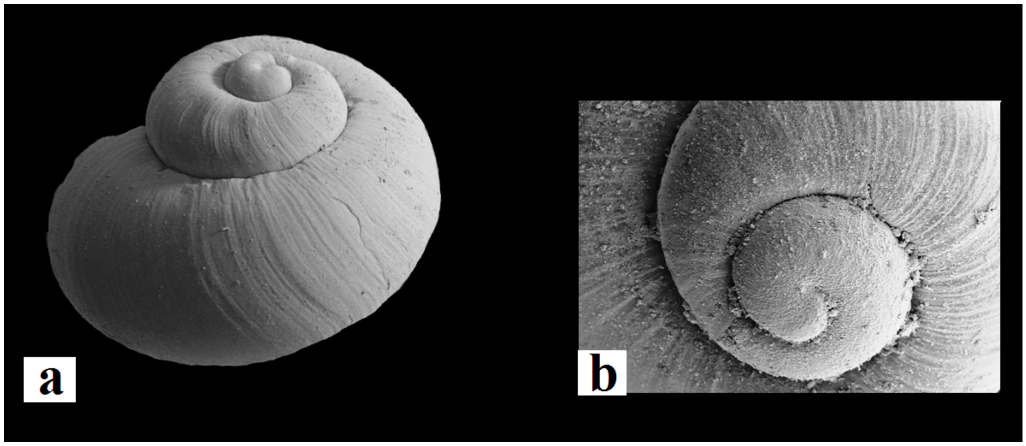


Figure 2.31: *Islamia jordanica* (new species) was collected from the eastern bank of KAC west Abu Habil village and south Wadi Al Qarn, in the Jordan Valley; a. The small trochispiral shell consists of only three whorls, b. The embryonic shell appears with stong increments of growth lines.

Superfamily Lymnaeoidea

Family Lymnaeidae Rafinesque 1815

Genus *Galba* Schrank 1804

The small shell with pointed spire is conical and sutures between whorls are deep. Shell size is up to 4 mm high and 2 mm wide and the aperture a little higher than the spire. The outer lip of the aperture is thin and evenly curving and the inner lip is reflexed over the surface of the whorl below. The type *Galba truncatula* (O.F.MUELLER) (*Buccinum*)= *Galba pusilla* Schrank is from central Europe. Species occur in Europe as well as Africa (BROWN, 1980, Fig. 76d) and can be interpreted as subgenus of *Lymnaea*.

Among the shells documented from Al Qarn Formation juvenile specimens of Galba or Lymnaea are present (Figs 2.32-2.34). HOROWITZ (1979) noted this species or a very similar one also from Ubeidiya Formation and from Erk el- Ahmar Formation.

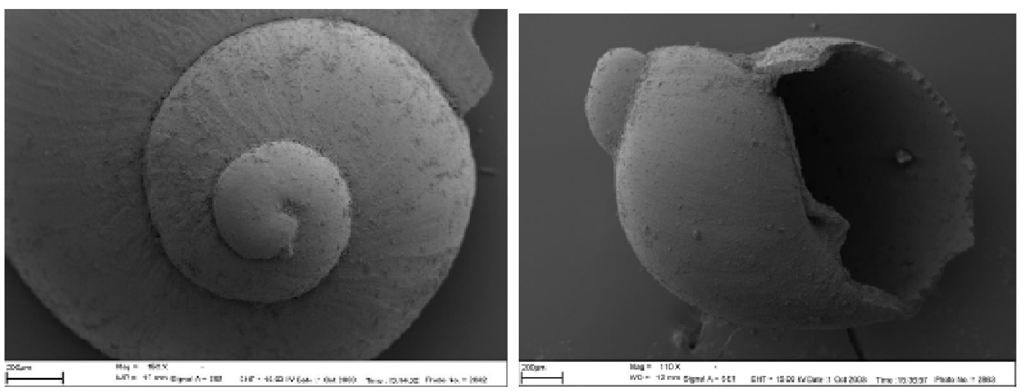


Figure 2.32: *Galba* sp was collected from Al Qarn Formation next to KAC in the northern Jordan Valley, the scale bar is 200µm.

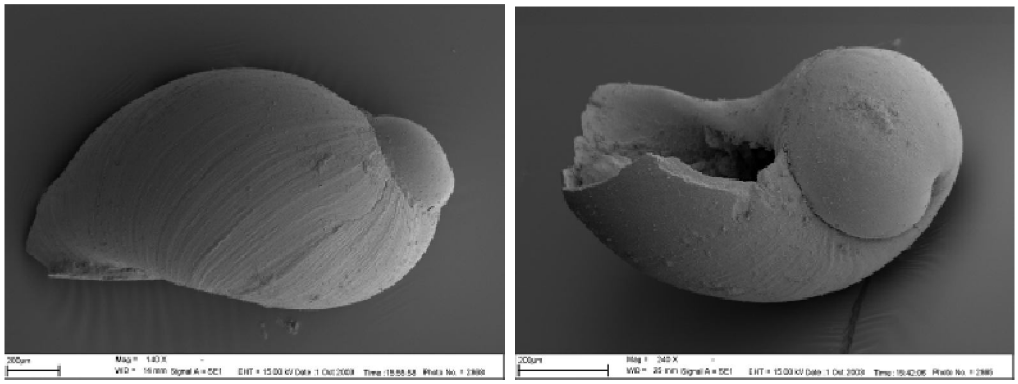
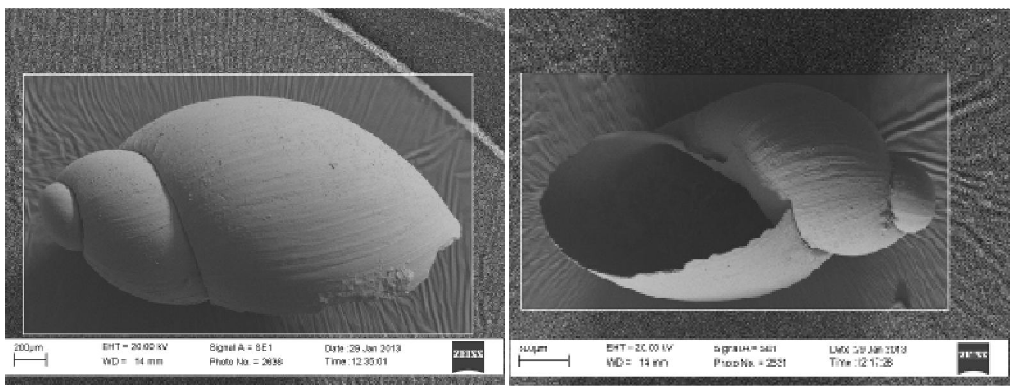


Figure 2.33: *Galba* or Lymnaea are present in Al Qarn Formation next to KAC south Abu Habil in the northern Jordan Valley,the scale bar is 200µm.



(The scale bar is 200µm) (The scale bar is 300µm)

Figure 2.34: Galba species from Al Qarn Formation next to KAC south Abu Habil in the northern Jordan Valley.

Superfamily Planorboidea

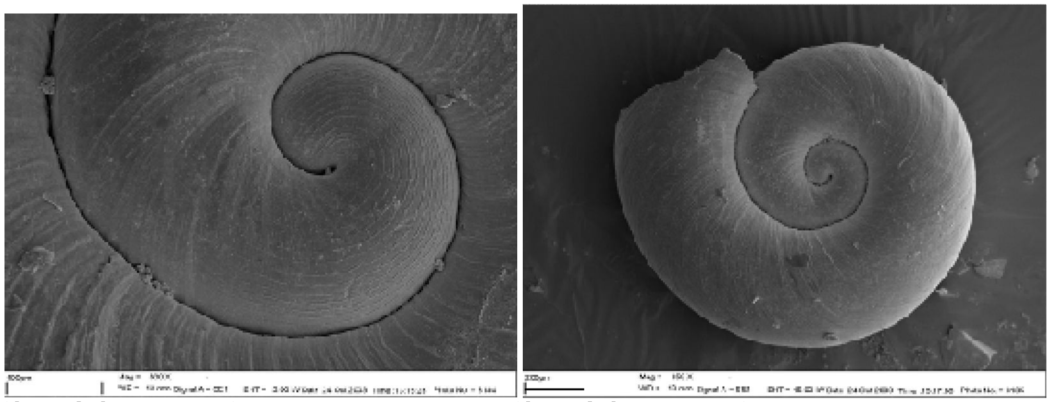
Family Planorbidae RAFINESQUE, 1815

The shell is mostly coiled in planispiral mode. Development of the eggs continues in the spawn until crawling young hatch with a shell of a little more than one whorls. Usually the protoconch is coiled in a plane, but sometimes a slight sinistral twist is preserved. Ornament of the embryonic shell usually consists of spiral striation (WALTER, 1962; RIEDEL ,1993), *Planorbis* grows to about 10 mm in size of the shell that bears a keel or edge.

Genus *Planorbis* MUELLER, 1774

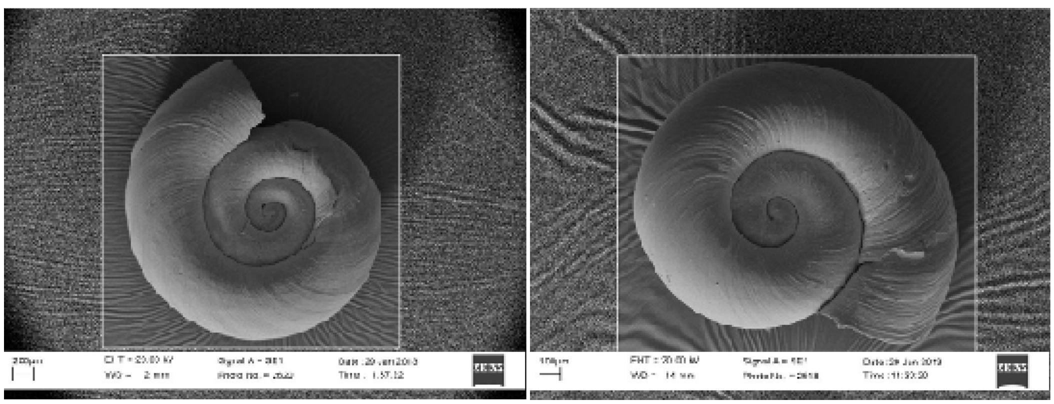
The size of the shell is 10-20 mm and whorls are bluntly angular or carinate. The type is *Helix planorbis* LINNAEUS, 1758 from Europe. Juvenile shells probably belonging to *Planorbis planorbis* were extracted from the deposits of Al-Qarn Formation (Figs 2.35& 2.36). Here whorls are plane on the apical side, convex at the wide umbilicus. The suture is deeper on the lower side than on the upper side. Collabral growth lines form a regular pattern.

Its shell when hatching is of 0.6 mm in diameter and consists of 1.3 whorls. Transition from the protoconch to the teleoconch is gradational. The dextrally coiled shell has a more rapid increase in whorl width as in the embryonic shell, more ornament of growth lines and a more flattened whorl flank (Fig 2. 36). Early teleoconch whorls may be rounded and the keel develops later. The protoconch of *Planorbis planorbis* resembles that of *Gyraulus* but is larger (BANDEL et al., 2001). *Planorbis planorbis* (LINNE, 1758) as described by SCHUETT (1983 Fig 13) according to HOROWITZ (1979) was also noted from the Ubeidiya Formation and Erk el- Ahmar Formation.



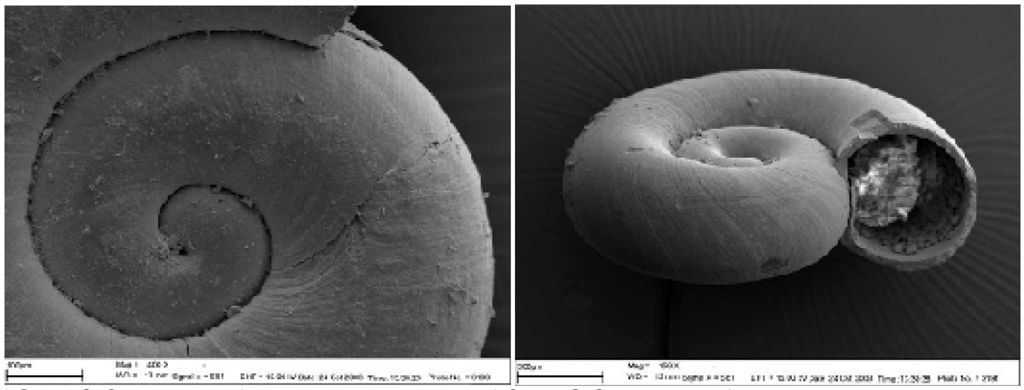
(the scale bar is 100μm) (the scale bar is 200μm).

Figure 2.35: Embryonic whorl of Planorbis from Al Qarn Formation next to KAC west Abu Habil in the northern Jordan Valley.



(the scale bar is 200μm) (the scale bar is 100μm).

Figure 2.36: Planorbis with fully grown individuals from Al Qarn Formation next to KAC west Abu Habil village, in the northern Jordan Valley.



(The scale bar is 100µm) (The scale bar is 200µm).

Figure 2.37: End of the embryonic phase in this specimen from Al Qarn Formation (next to KAC west Abu Habil in the northern Jordan Valley) is documented by a fractured shell margin, and juvenile shell from the same locality.

Planorbis new species:

The fully grown shell measures only 3 mm in width, but has the protoconch as in Planorbis planorbis that grows to 10 mm in size with 6 whorls. Here only 3 whorls are present, but the closeness of growth lines near the end of the shell appears to indicate that it was fully grown. It thus grew only to about half the size and half the number of whorls as found in living species of Planorbis planorbis from Jordan. BROWN (1980) found Planorbis planorbis from Egypt to sometimes growing only to a size of 5 mm in diameter. this species needing a more detailed description with a differential characterisation to the closest neighbors.

Genus *Gyraulus* CHARPENTIER, 1837

The planispirally coiled shell consists of 3 whorls with inclination of the aperture indicating dextral coiling mode. This small size planorbid usually has a more rapid increase in shell width than found in *Planorbis*. Species are found worldwide and occur in any kind of fresh water environment with normal chemistry. Shells resembling those of *Gyraulus* are present from Lower Jurassic onward with very similar shell shape, size and ornament (BANDEL 1991; BANDEL & RIEDEL 1994). Among these fossil species for example *Gyraulus loryi* (COQUAND, 1855) from the Weald (Jurassic-Cretaceous transition) has the same shape of its shell and the same type of micro-sculpture of its protoconch as present in living species.

BANDEL (2010, Figs 172-189) noted that species of *Gyraulus* occur in Al Qarn Formation.

Gyraulus piscinarum (BOURGIUGNAT, 1852)

The small planispiral shell has a flattened apical side and the umbilical side is concave with rounded whorls (Fig 2.38). It collected 1978 from a spring at Wadi Rum (BANDEL) and described by SCHUETT (1983, Fig14). The protoconch of *Gyraulus* resembles that of *Valvata* in shape and ornament. In contrast to *Valvata* its margin is not straight but inclined, and increase in shell diameter is more rapid (BANDEL 2010, Figs. 177, 179, 187). Of the two species that could be placed with Gyraulus from the Al Qarn Formation (Fig 2.39 &2.40) one can be a *Gyraulus*, the other is more like *Armiger*, which is also a *Gyraulus* when the anamtomy of living species is compared.

According to HOROWITZ (1979) such species are known from Pleistocene deposits in the Ubeidiya and Erk el- Ahmar Formations. *Anisus* STUDER, 1820 has the shell very low and lower side almost straight and plane with 5-8 whorls, reaches a size of 10 mm. The type to the genus is *Anisus vortex* LINNAEUS 1758 and according to HOROWITZ (1979), *Anisus spirobis* was found, together with *Segmentina nitida* in the deposits of the early middle Pleistocene in the northern Jordan Valley.

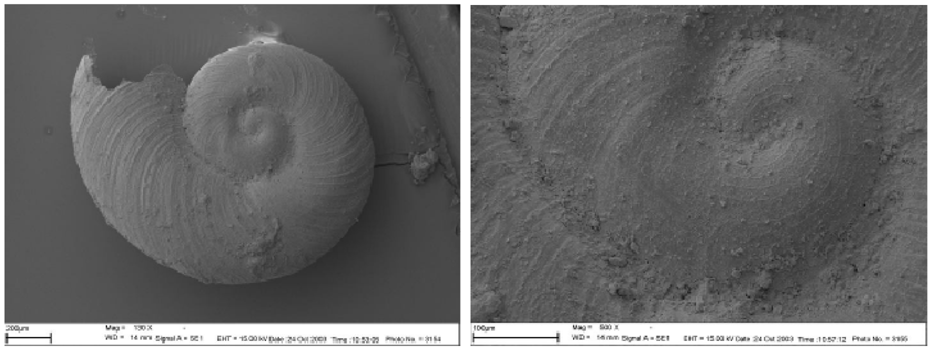
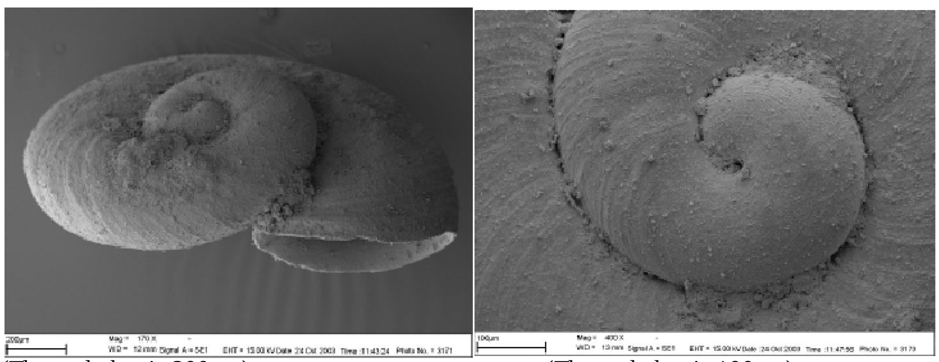


Figure 2.38:a. Gyraulus from Al Qarn Formation next to KAC, south Wadi Al Qarn, in the northern Jordan Valley, the scale bar is 200µm, b. juvenile shell and ornamented embryonic shell, the scale bar is 100µm.



(The scale bar is 200µm) (The scale bar is 100µm).

Figure 2.39: Gyraulus with coiling a little deviating from the Al Qarn Formation deposits next to KAC west Abu Habil and south Wadi Al Qarn in the northern Jordan Valley.

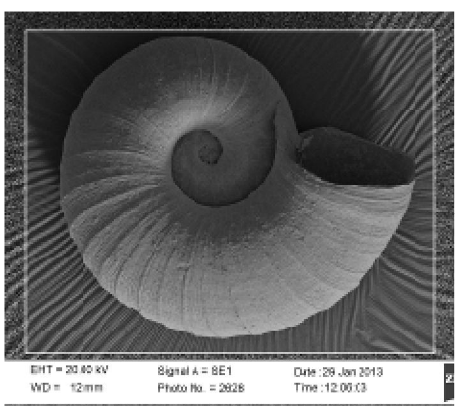


Figure 2.40: Umbilical view of Gyraulus from Al Qarn Formation next to KAC south Abu Habil in the northern Jordan Valley, the scale bar is 100µm.

Genus *Armiger* HARTMANN 1843

Armiger usually has a shell that is less than 3 mm in diameter (Fig 2.41). BANDEL (2010) determined individuals from Al Qarn Formation to resemble *Armiger crista* that is the type to the genus (BANDEL 2010, Figs. 174–175, 182–183, 186–187). These closely resemble individuals which live in a lake in Romania. *Armiger crista* (LINNÈ, 1758) occurs in Europe and North Africa and represents the type to the subgenus. *Armiger crista* has up to 2.7 rapidly increasing whorls with flattened top and rounded base. The periphery is angled, the angle being to the upper side. The last whorl detaches from the penultimate whorl and is only loosely attached to its upper side. The shell is almost flat on the upper side and deeply concave on the lower side. The whorls are traversed by ridges. The shell is 2.2 to 3 mm wide and 0.5 to 0.9 mm high (WENZ & ZILCH, 1960: FIG. 362). GLÖER & MEIER- BROOK (1998) considered *Armiger crista* as a member of the genus *Gyraulus*. The dextrally coiled shell has a more rapid increase in whorl width, more ornament of growth lines and a more flattened whorl flank.

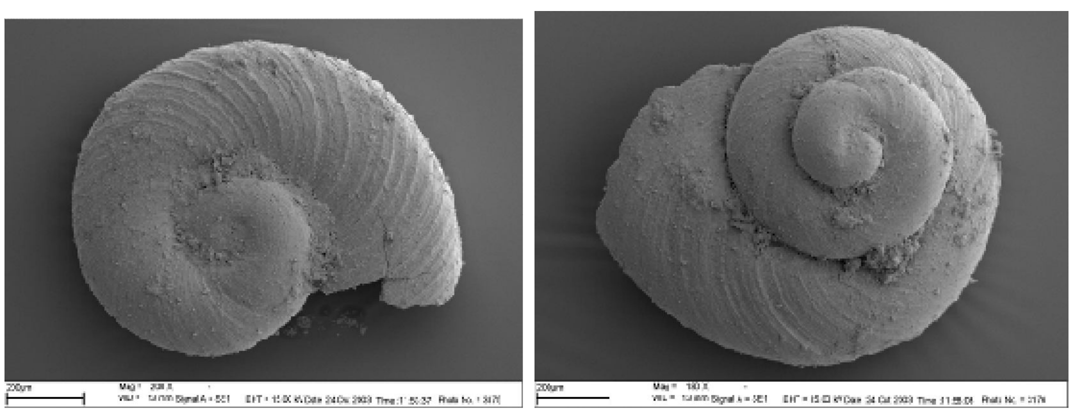


Figure 2.41: Armiger crista-like- Gyraulus from Al Qarn Formation next to KAC south Abu Habil in the northern Jordan Valley, the scale bar is 200µm.

Limpet-like Planorboidea Rafinesque 1815

Ancylidae and Ferrissiidae according to WENZ & ZILCH (1960) are very similar small limpets. All species included here are of small size and live below water surface. The small limpet has its living environment in areas with moving fresh water, either in streams or at the wave washed shore of lakes. WENZ & ZILCH (1960) interpreted the limpet-like Ancylidae to have developed from the Planorbidae and suggested that the oldest fossils belonging to that group are from the Oligocene of Europe, but BANDEL & RIEDEL (1994) described fresh water gastropods from the Late Cretaceous Santonian of Hungary at Ajka with characters of the shell closely resembling those of modern *Ancylus*. Thus limpet-like Planorboidea among the basommatophorans have been living in the fresh water environment since Cretaceous times.

Family Ancylidae

Genus *Ancylus*

The genus *Ancylus* O.F. Müller 1774 is a small freshwater limpet belonging to the Pulmonata (Basommatophora). Their eggs contain much liquid yolk and during early ontogeny the embryo grows so rapidly in size that the shell calcification is retarded and finally a limpet shape has been reached. A coiled shell is no longer present at all, as is characteristic to the living species of the group. *Ancylus* hatches with about 1 mm large cap-like shell. The specimens from Al Qarn are quite characteristic, but the genus has not survived in Jordanian waters. *Ancylus* is usually attached to some object, a stone or another shell and it grazes on algal covers. The individuals of Al Qarn Lake lived on the submerged stems of reeds or on larger shells of molluscs that live near the beach with currents produced by the waves. *Ancylus* lives in European running water. The Ancylidae were revised by HUBENDICK (1964).

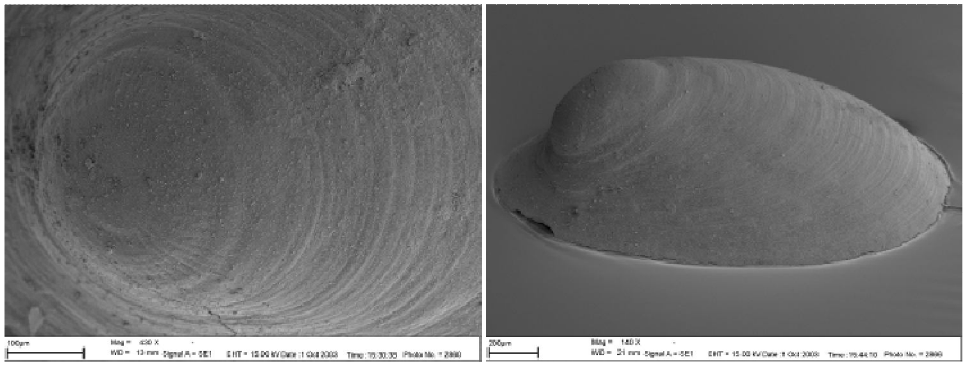
All of them are of small size and live below water surface and gas exchange occurs between the roof of the pallial cavity and blood directly. Gas exchange from water to tissue is often aided by folds which extend into the wide open pallial cavity.

Limpet-like Basommatophora which resemble *Ancylus* are known since about the Santonian (BANDEL & RIEDEL, 1994). While WENZ & ZILCH (1960) considered the Ancylidae to have developed from the Planorbidae only late in geological history, their oldest records are from the Santonian of Hungary (BANDEL & RIEDEL, 1994).

Ancylus lives in running water of streams and creeks in Europe, the Asiatic region (Middle East) neighboring Europe and Northern Africa, also Ethiopia, with exception of the Nile province. *Ancylus fluviatilis* lives in running water and is nearly always found on stony bottoms, while the similar limpet *Acroloxus lacustris* prefers stagnant water and is usually found on big aquatic plants. These small gastropods with a cap shaped shell live submerged and attached to hard substrates. Their wide open pallial cavity serves in the exchange of gases between water and blood.

Species *Ancylus fluviatilis* MUELLER, 1774 has a cap-like shell with its apex pointed, in posterior position and twisting towards the right (Fig 2.42). The shell has a reticulate ornamental pattern. During development of the embryo yolk is taken from the yolk-rich liquid of the egg in such quantities that the shell calcification is retarded until the limpet shape of the adult shell has been reached. A coiled shell is no longer present at all and the torsion of the visceral mass is not reflected in the shape of the shell at all (BANDEL, 1982). According to RIEDEL (1993) one to three eggs of about 0.1 mm in diameter are found in an egg mass of a round cupola. They hatch with about 1 mm large cap-like shell. These small gastropods live submerged and attached to hard substrates that their wide open pallial cavity serves in the exchange of gases between water and blood.

In the Al Qarn deposits the shells of the small limpet are not common. BLANCKENHORN & OPPENHEIM (1927) report of an *Ancylus lacustris* that was found in gravel deposits of Yarmouk River by NÖTLING (1886, PL.23, FIG 14). The genus *Ferrisia* with species *Ferrisia clessiniana* (JIKELI, 1882) according to HOROWITZ (1979) is also determined as *Acroloxus lacustris* of Lake Hula and was also found in the Pleistocene deposits in the Ubeidiya but not of the Erk el-Ahmar Formations. It is probably the same species here described as Ancylus fluviatilis.



(The scale bar is 100µm) (The scale bar is 200µm).

Figure 2.42: *Ancylus fluviatilis* from Al-Qarn Formation next to KAC south Abu Habil in the northern Jordan Valley.

Genus *Ferrissia* Walker, 1903

Ferrissia urdunica **(new species):**

It is small limpet with growth lines as ornament has a hemiglobular embryonic shell with a small central pit from which radial grooves and ridges arise which still on the embryonic shell branch. They end in the margin of the embryonic shell and its transition into a low non coiled cup like shell with long-oval aperture.

Holotype, origin of the name and type locality: The individual on (Fig 2.43a) represents the holotype. It was collected by us at the type locality of the Al Qarn Formation next to King Abdulla Canal in the northern Jordan Valley.

The small limpet has very fine radial ridges on its apex, that is taken by the embryonic shell (Fig 2.43b). The apex is evenly rounded and has a central narrow rounded pit. The fully grown shell appears to have had only 2 mm in maximal diameter with evenly rounded aperture that is a little narrower in the back than in front. The apex lies slightly towards the left and nearer to the end of the shell than to its front.

The embryonic shell measures approximately 0.4 mm in width and has almost circular outline. Its central part forms a low depression with a narrow central pit. From the margins of this pit approximately 25 narrow grooves separated from each other by broader, low and rounded ridges arise and continue over the surface of the cap-like embryonic shell. The distance of the gooves to each other remains similar, so that new ones arise between the ridges and approximately three times as many grooves as in the center reach the margin of the embryonic shell.

The time of hatching from the egg is indicated by strong growth lines and later by a change in ornament and slope inclination. While the embryonic shell is a cup with circular outline the teleoconch is of oval outline with broader front than back. The fully grown shell has the protoconch just behind the middle of the cap-like shell and width of the shell is about half of its length. The protoconch lies on the left side of the limpet with increments of grow denser to each other on the left side than on the right. Ornament of the teleoconch consists only of increments of growth.

During development of the embryo, in case of *Ancylus,* yolk is taken from the yolk-rich liquid of the egg in such quantities that the embryo rapidly increases in size and shell calcification is retarded up to the point of growth when a limpet shape has been reached reflecting the shape of the adult shell even before hatching from the egg. A coiled shell is no longer present at all and the torsion of the visceral mass that is also present in the soft body is not reflected in the shape of the shell. In case of Ferrissia urdunica the shell of the tiny limpet was calcified when the animal had hatched from its egg case. Here the margin of the embryonic shell was fractured when the animal had just hatched and the limpet teleoconch was grown attched to it.

The same kind of ontogeny as can be interpreted from the characters of the embryonic shell of *Ferrissia urdunica* is present in several of the limpet like basommatophorans such as *Ancylus*, living *Ferrissia* and *Acroloxus,* which all occur in the Mediterranean regions. They can be distinguished from each other by anatomical features (HUBENDICK, 1970), but apparently also by the ornament of their embryonic shell.

It is assumed that also in case of *Ferrissia urdunica,* that its young hatched from their egg case when their shell consisted of an about 0.4 mm large cap. In case of *Ancylus fluviatilis* the embryonic shell is larger and its transition into the teleoconch less strongly noted in the change of ornament, which represents a good difference to what is seen in *Ferrissia,* where the margin of the embryonic shell is much better set of from the begin of the teleoconch, in shape as well as in ornament. The embryonic shell of *Acroloxus lacustris* is larger (0.5 mm) and it is of a more oval shape. It also has the change in ornament from axial ribs and grooves of the embryonic shell to growht lines on the teleoconch (RIEDEL, 1993), but the axial ribs are fewer, coarser and they do not increase in number towards the margin of the embryonic shell. As in *Ferrissia* the central portion of the protoconch is flattened with a small groove, and not formed by an irregular depression as is found in *Ancylus fluviatilis*.

These small gastropods live submerged and attached to hard substrates. Their wide open pallial cavity serves in the exchange of gases between water and blood. The ontogeny is charcterized by the dealing with much yolk. Yolk is taken from the albuminous liquid of the egg in such quantities that the shell calcification is retarded until the limpet shape of the adult shell has been reached. A coiled shell is no longer present at all and the torsion of the visceral mass is not reflected in the shape of the shell (RIEDEL, 1993; BANDEL & RIEDEL, 1994).

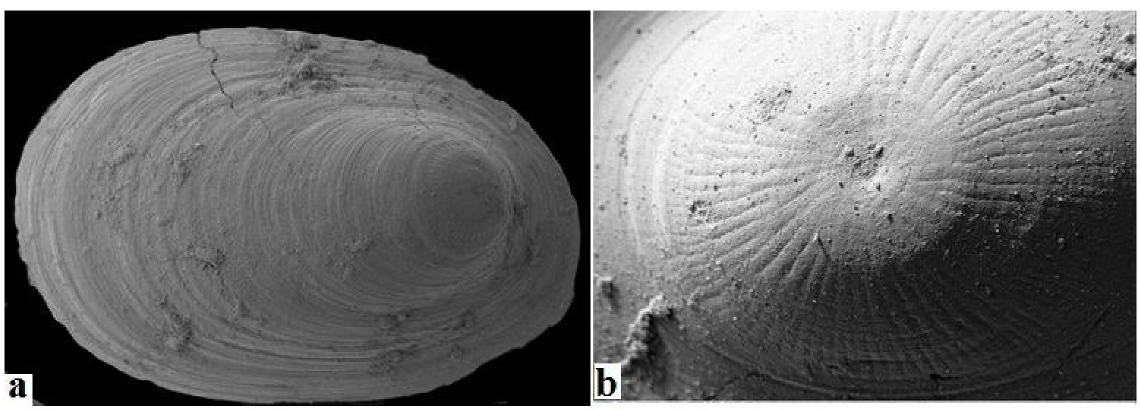


Figure 2.43: *Ferrissia urdunica*, new species from Al Qarn Formation, next to KAC west Abu Habil village and south Al Qarn area in the northern Jordan Valley; a, General morphology of *Ferrissia urdunica*, b.The embryonic shell of *Ferrissia urdunica* with very fine radial ridges on its apex.

Bivalvia

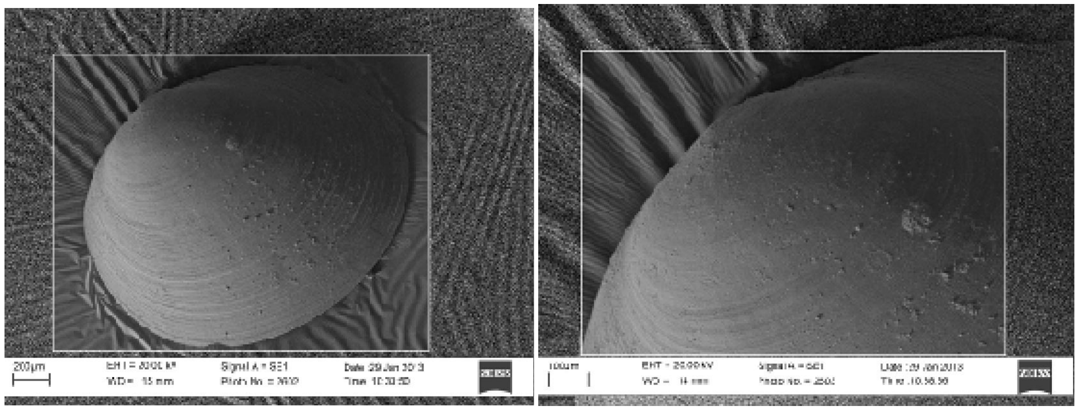
The extant bivalves of Jordan belong to Unio, Corbicula and Pisidium, of which Pisidium is well represented in Al Qarn Formation and Unio was found only in the form of brittle fragments in the field and could not be saved. It probably is the same or very similar to the Unio as found in the fossil Jordan River deposits and as living in KAC.

Family Sphaeriidae

Genus Pisidium

Pisidium casertanum (POLI, 1795) was collected in Jordan in the year 1978 from the spring in Wadi Hisban, and in a spring near the bridge across the Zarqa (Old Jarash bridge, now destroyed) and the small lake in the Roman Pool on the highway Amman-Jerash by BANDEL and was described by SCHUETT (1983, Fig.16). HOROWITZ (1979) found it in modern Lake Hula and the fossil lake of Ubeidiya Formation. Several other species of *Pisidium* were described from the middle Pleistocene, and *Pisidium* also occurs in the lake in which Al Qarn Formation was deposited.

Pisidium annandalei PRASHAD, 1925 with its valves small and a fine concentric pattern of ribs and a characteristic groove of the ligament was found in the springs in Hisban and Wadi Sir 1978, and described by SCHUETT (1983 Fig.15). HOROWITZ 1979 determined the species from Hula lake together with *Pisidium casertanum*. Several other species of *Pisidium* were described from the middle Pleistocene. A Pisidium sp. was described by NELSON (1973) to occur in Azraq Oasis. TCHERNOV (1973, 1979) suggested that *Pisidium pirothi* represents an Ethiopian element that entered the Jordan Valley. The Pisidium from Al Qarn Formation was not determined to the species (Figs 2.44-2.46).



(The scale bar is 200µm) (The scale bar is 100µm).

Figure 2.44: Pisidium from Al Qarn Formation, next to KAC west Abu Habil in the northern Jordan Valley.

The small shell is not uncommon, sometimes preserved with both valves still in contact.

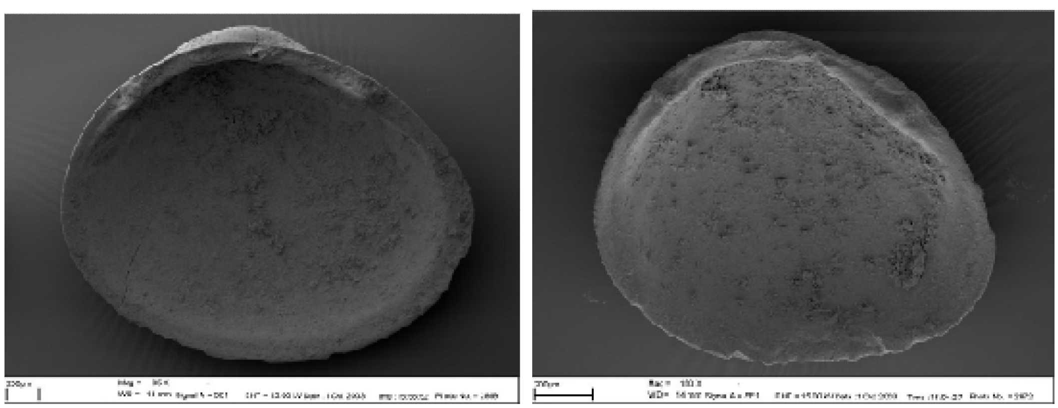


Figure 2.45: Pisidium from Al Qarn Formation next to KAC west Abu Habil in the northern Jordan Valley, the scale bars are 200µm. .

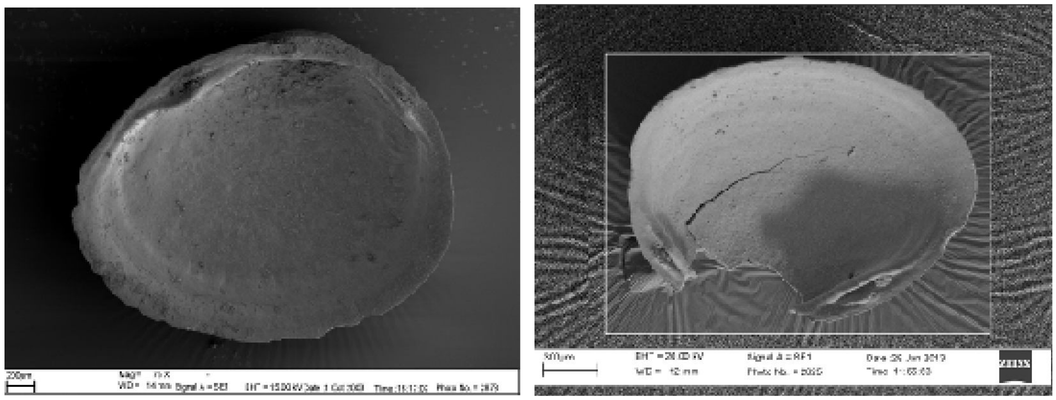


Figure 2.46: Pisidium from Al Qarn Formation next to KAC west village Abu Habil and south of wadi Al Qarn in the northern Jordan Valley, the scale bars are 200µm.
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3 PRE- LISAN AND LISAN AND LISAN DEPOSITS

3.1 Pre-Lisan deposits of ancient Jordan River and Aramshi Formation

3.1.1 PaleoJordan River deposits

Ancient river beds filled predominantly with gravel are exposed to the south and west of Irbid along the banks of the roads to Amman and to North Shuna. The time of formation of these river beds has not been well established up to date. The pebbles found in their beds may have joined the conglomerates that were deposited in the Jordan Rift at the time of Ubaydiya Formation and also that of Al Qarn Formation and certainly before the time of the existence of Lisan Lake. When that lake formed the valleys coming from the eastern highlands had already been eroded more deeply into the slope than is indicated by the position of these gravel filled former river channels. The beds of Al Qarn Formation had been deformed and eroded by the meandering Jordan River before the Valley was flooded by Lisan Lake. The ancient Jordan River came from the North of the Rift Valley and issued into the Paleo-Dead Sea. Its deposits are exposed along the steep slopes of the Zhor that is the river plain formed by modern River Jordan. From near Deir Alla to the north up to North Shuna the slopes of the Zhor expose fluvial sands, gravels and marls which are usually overlain by the laminated sediments formed during the existence of the salty Lake Lisan. Near the Yarmouk River entering the Jordan River these fluviale deposits below the Lisan Formation are called Naharayim Formation. A Lake Samra was supposedly a precursor of Lisan Lake (MACUMBER, 2008). This Lake Samra has been postulated to have been present in the Jordan Valley before Lake Lisan came into existence (BEGIN, 1975). The Samra Lake occupied the Jordan Rift Valley between 135.000 and 75.000 years ago (WALDMANN et al., 2007& 2009). The reconstruction of the level changes at Lake Samra in the Dead Sea Basin was described by WALDMANN et al., 2009. They concluded that Samra stood at an elevation of -340 mbsl during most of the last interglacial. This level is relatively higher than the average Holocene Dead Sea (-400±30 m bsl). Between 120.000 and 85.000 years ago. Lake Samra rose to -320 m bsl while it dropped to levels lower than -380 mbsl at 135.000 and 75.000 years ago, reflecting arid conditions in the drainage area. ABED& YAGAN (2000) described the uppermost Pleistocene deposits in the Jordan Valley contain the Lisan

Lake and the Damya Lake, the later interpreted to have existed 16.000 to 12.000 years ago.

The Damya Formation was deposited in fresh to brackish lacustrine conditions. Further down-river from the mouth of the Yarmouk and in stratigraphical position also below the Lisan marls, for example near Al Qarn Hills west of Abu Habil and west of Masharia, fluvial sands containing locally gastropod shells belonging to *Melanopsis* and *Theodoxus* and also of two species of the bivalve *Unio* are found (Fig 3.4). Two species of ostracods are present; include *Heterocypris salina*, *Cyprideis torosa* and *Ilyocypris sp*. All Ostracods species in this study were determined by MISCHKE (2013). One of these localities lies on the slopes near the border police station south of the mouth of the creek that originates in Ain Jirn that begins at the spring of Pella and ends here in River Jordan. These deposits of ancient River Jordan are gravel, sand and fine sometimes somewhat calcareous deposits of quiet river arms that were laid down before Lisan Lake expanded and flooded the river bed as far up to the north of the Dead Sea as the mouth of Yarmouk River. The sands and gravels of the former river are well exposed along the military road next to the Jordan just to the south west of the exposure of the Tayba Formation between north of Deir Alla and south of Masharia.

Figure 3.1: Unio from fossil Jordan deposits older than Lake Lisan, near Al Qarn Hills west of Abu Habil and west of Masharia, the scale bar is 5000µm.

In Jordan nowadays two species of *Unio* live in KAC near to its intake from the Yarmouk River and they also live in Lake Tiberias. The *Unio* of the Paleo-Jordan deposits do not differ from the now living species. Shells of *Theodoxus jordanicus* are present in the fluviale beds of ancient Jordan and have just the same character and shape as that of the modern species living in Jordan, especially those nowadays found in the KAC. But in the genus *Melanopsis* FÉRUSSAC, 1807 with the shell with a cyrtoconoid outline with the body whorl more or less inflated and whorls of the spire hardly rounded and smooth or ornamented by axial and/or spiral ribs, BANDEL (2000) recognized 6 species from the pre Lisan sands. The ancient Jordan River according to differences in the morphology of their shell had *Melanopsis buccinoides*, *Melanopsis costata*, living in it as well as *Melanopsis noetlingi*, *Melanopsis saulcyi*, *Melanopsis jordanica*, and *Melanopsis blanckenhorni*.

Melanopsis buccinoidea FÉRUSSAC, 1823 of the ancient Jordan River is quite like that which is still living and like the most common variety or species (BANDEL 2000, Figs 20-24). The shell is smooth, consists of 8 to 9.5 whorls and may have a height of around 25 mm and a width of about 12 mm. Its spire is pointed and the growth of whorls occurs with regular increase in width. The body whorl is evenly rounded with the aperture taking about half shells height. Its posterior portion is a narrow slit formed between the thickened callus pad of the inner lip and the evenly curving outer lip. The anterior portion of the aperture is drop-like in shape and ends in a narrow short and distinct siphon notch.

The species occurred in the area of the Jordan Valley since the existence of the Erk el-Ahmar lake and Ubeydiya lake, it lived also in the Al-Qarn lake and thus for more than 1 million years, as well as in ancient Jordan River. *Melanopsis costata* OLIVIER, 1804 with its slender fusiform shell with up to ten whorls reaches a size of up to 3.3 cm in height. Shell shape is that of a slender *Melanopsis buccinoidea*, with which it probably forms and has formed hybrids. More than 9 whorls compose the shell and the straight ribs are usually continuous onto the base and may have a weak posterior swelling just below the suture which may be accompanied by a shallow furrow on the whorl side anterior of it. The ornament consists of 12 to 15 rounded ribs which are continuous across the whorl forming an even curve pointing forwards in the rounded transition of the whorl sides into the base. Ribs are usually continuous onto the base but may become less distinct here.
Melanopsis costata has a longer spire than *Melanopsis saulcyi* and the ribs of *Melanopsis noetlingi* are stronger, and the stair-like whorl shape, from the fifth whorl onwards, distinguishe it from *Melanopsis blanckenhorni*. BLANCKENHORN (1897) suggested that

the type locality of *Melanopsis costata* lies in the region of the middle Orontes in Syria and here in a canal for irrigation. SCHUETT (1988, Pl.1, Fig.4) remarked that a more likely place at which the original *Melanopsis costata* was collected was near Homs in Syria and had received the name *Melanopisis praemorsa costata* (OLIVIER, 1804). HELLER et al. (1999, Fig 4B) and BANDEL (2000, Figs 72-75) suggested that the most characteristic features of *Melanopsis costata* represent its ornament of 9-14 axial ribs on each flattened whorl and the usually slender relatively large shell (around 2.5-3 cm high) with rounded upper whorl side.

Melanopsis noetlingi BOURGUIGNAT, 1886 has a conical spire and with pronounced suture, 14 ribs on the last whorl and these are about as wide as the interspaces. The fossil *Melanopsis noetlingi* differs from the recent *Melanopsis costata* by an ornament of more narrow and pronounced axial ribs. *Melanopsis blanckenhorni* has the spire more stair-like and not conical as *Melanopis noetlingi* of *Melanopsis costata*. PICARD (1934) distinguishes a similar *Melanopsis obediensis* by the presences of more curving ribs than those of *Melanopsis noetlingi* and the *Melanopsis costata* as he interpreted it, could be determined as *Melanopsis blanckenhorni*.

PICARD (1934) also noted close similarity with *Melanopsis biliotti* from the Pliocene of Rhodos as described by BUKOWSKI (1893, Pl.3, Fig15, Pl.4, Figs 1-4). *Melanopsis noetlingi* can be recognized with several typical individuals from two distinct localities from fluvial sands of the cliff next to the road on the Jordan. One locality lies west of Abu Habil and the other west of Deir Alla. Both locations are in their position well below the Lisan marls (BANDEL, 2000 Figs 105-106). OPPENHEIM (1927) suggested that *Melanopsis noetlingi* had its original locality (type locality) in fluvial sands below the Yarmouk basalt and that the type species is 25 mm high shell and 10 mm wide and an aperture that is less than half shell height.

Melanopsis saulcyi BOURGUIGNAT, 1853 has, in addition to axial ribs also some spiral elements on it whorls and that the shell is about 15 mm in height smaller than *Melanopsis costata*. The spire is also shorter than that of *Melanopsis costata* (BANDEL 2000, Figs 78-79, 84).

The type locality is Tartus in Anatolia (SCHUETT, 1983). Compared with *Melanopsis costata, Melanopsis saulcyi* is shorter and has a well developed row of nodes below the shoulder. Compared with living *Melanopsis bandeli* it has a shorter spire and fewer spiral ornamental elements. In regard to *Melanopsis blanckenhorni* the spire is less stair-like.

Melanopsis saulcyi is found in the Pleistocene sands especially just below the Lisan Marl but it was also found to live in the springs and the creek of Pella. Here it lived side by side with *Melanopsis buccinoidea* without interbreeding. Not far from there at the little creek and pond near Tell Murashad to the west of Marsharia in the Jordan Valley it was noted to live together with *Melanopsis bandeli* and here forming hybrids with it.

Melanopsis saulcyi closely resembles *Melanopsis kotschyi* Philippi representing an Iranian member of the *Melanopsis costata* group that was described from Lake Niris to the east of Schiraz in the southern Iran (STARMUEHLNER& EDLAUER). HELLER (1998) recognized the spirally and axially ribbed *Melanopsis saulcyi*, which only partly resembles the species determined as *Melanopsis saulcyi* by BANDEL (2000). HELLER et al (1999), in addition, included *Melanopsis cerithiopsis* of MIENIS (1983) into their concept of the species *Melanopsis saulcyi*. MIENIS & ORTAL (1984) preferred to regard it a subspecies to *Melanopsis praemorsa cerithiopsis*, which is difficult to hold up (BANDEL, 2000).

Melanopsis jordanica (ROTH, 1839) has its shell with shorter and more rounded shape than *Melanopsis blanckenhorni* and *Melanopsis noetlingi*. The shell is short with rounded whorls and simple solid axial ribs from top at the suture and to the base (BANDEL 2000, Figs 127-12). Shells as those illustrated by BLANCKENHORN (1897, Pl.10, Figs 20-21) from the Jordan River were also illustrated by HOROWITZ (1978, Fig 5,111) from Ubeydiya Formation. *Melanopsis jordanica* occurs in the sands of the ancient Jordan River well below the Lisan Marl together with *Melanopsis blanckenhorni*. PERES (1945) suggested that this species is derived also from the Jordan and from Lake Tiberias under the name *Melanopsis jordanicensis* Roth and that it is characterized by its short shape and ornament resembling that of *Melanopsis costata*.

Melanopsis blanckenhorni SCHUETT, 1988 occurs in the gravels and sands exposed below the Lisan marls along the slope to the Zor in the Jordan Valley (BANDEL 2000, Figs 97-103).

The type locality is from the banks of the middle Orontes in Syria and from here SCHUETT (1988, Pl.3, Figs 18-20) described the shell that is ornamented by about 12 strong ribs, of more or less slender shape and has a staircase-like spire. Strong ribs that continue from suture to base distinguish this species which was determined by BLANCKENHORN (1897, Pl.10, Figs 9-10) as *Melanopsis costata*.

Melanopsis blanckenhorni resembles *Melanopsis orientalis/costata* that is found in the oldest fauna with *Melanopsis* in Jordan from the Al Qarn Formation (BANDEL 2000, Figs 107-110, BANDEL et al 2007, Fig 3C). PICARD (1934) included shells with the shape of *Melanopsis blanckenhorni* in *Melanopsis noetlingi*. It differs from the shells of living individuals with straight ribs such as *Melanopsis costata* as shown by HELLER et al. (1999, Fig. 4B) by its distinctly stair-like spire. *Melanopsis turriformis* PICARD, 1934 from Ubeydiya differs by having a more slender shell, more ribs in each whorl and a less stair-like spire.

From Nahayarim Formation, that is from beds overlying the Yarmouk Basalt and being overlain by the Lisan Formation pollen have been analyzed. They document that the flora which produced these pollen resembled that growing here today except for those species missing which have been introduced to the area by men (HOROWITZ, 2001).

The sands of the Jordan River are cut by channels of different sizes filled with gravel. Some of these channels, during the deposition of the sediment contained quiet water in which mud was deposited. It may be calcareous and some may hold minute pisolites resembling oolites. The side fans of debris coming from creeks that entered the Jordan Valley often reached almost the center of the Valley and thus the ancient Jordan River. This situation differs from the condition as it is nowadays where fans of debris only reach to the margins of the Jordan Rift Valley but not the actual area of the Zor. From that it can be assumed that the Jordan River in the times before being flooded by the Lisan Lake flowed in Valley with a more concave shape with debris fans of its side creeks advancing to the river (BANDEL & SALAMEH, 2013). This situation can also be interpreted as representing a time span during which more erosion on the highlands resulted in lager gravel fans deposited in the Jordan Valley, which therefore reached the river. Nowadays the Jordan River erodes its bed predominantly into pre- Lisan deposits and the coarser debris of creeks and rivers coming from the highlands are deposited on the margins of the Jordan Valley plain quite some way from the Zhor plain. The Zhor has been eroded into the former lake bed of Lisan Lake and nowadays exposes and has cut into the beds of a Jordan River that flowed there before Lisan Lake flooded.

3.1.2 Aramshi Formation deposits

Aramshi Formation forms the almost flat carbonate rock plate that covers Tall al Mudawwar that lies about 2 km north of Waqqas next to the village Fathiyin or Aramsh. (Fig 3. 2 & 3.3).

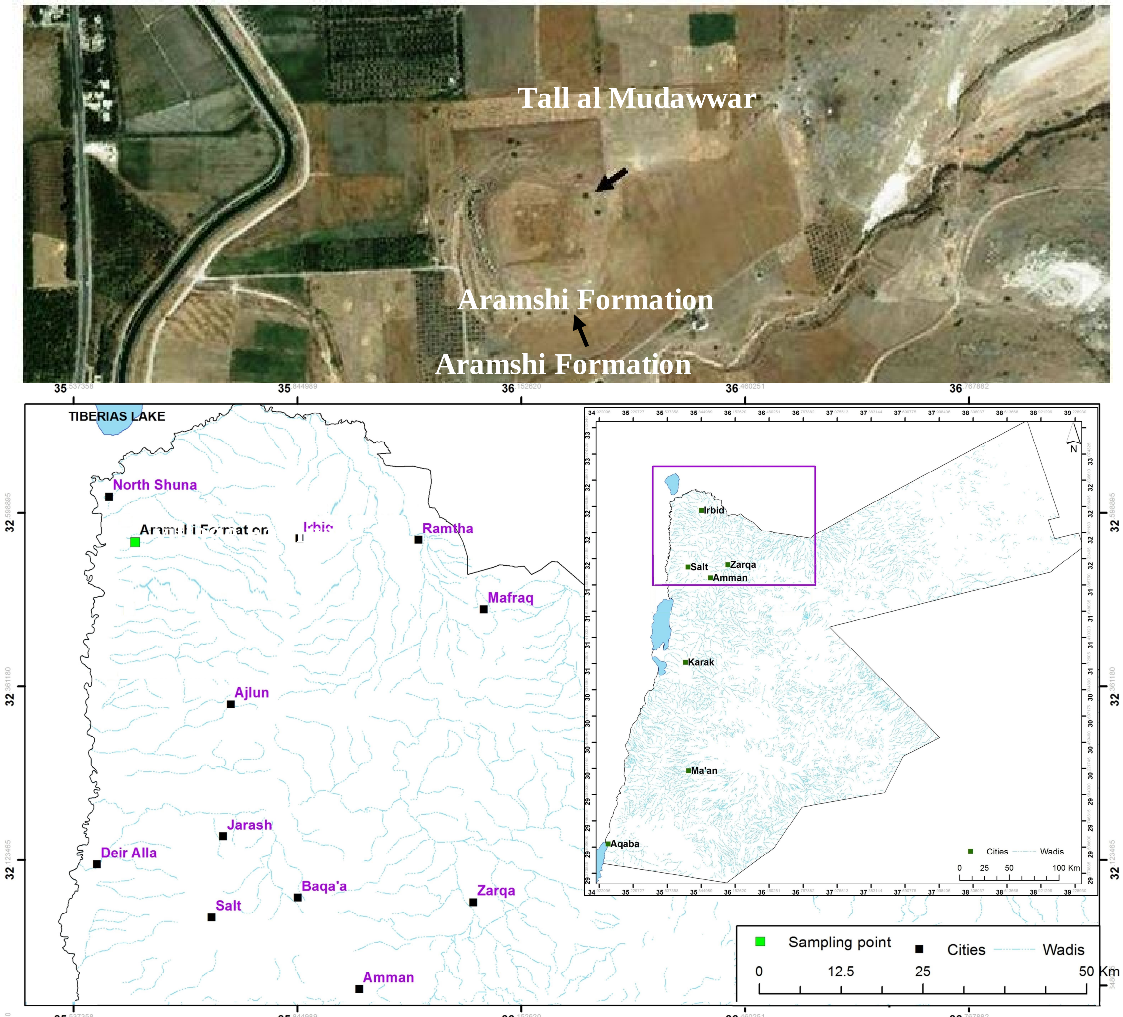


Figure 3.2: Location map of Aramshi Formation in the Aramshi hill next to KAC with the main road to the west.

This carbonate deposit rests on the top of a small truncated basalt sill. The massive solid limestone at the base holds many gastropods of which *Theodoxus* is most clearly recognized but also *Melanopsis, Melanoides* and small planorbids occur (Fig 3.3 &3.34). The basal gastropod rich layer is overlain by a massive solid limestone with roots and *Stromatactis* like structures as well as pisolites. Stromatactis is a cavity filling usually with calcite crusts forming the top and filling here the cavity and with sediments with horizontal stratification- at the time of their formation- at the base of the cavity- thus these structures present evidence for some former body in the limestone that became dissolved- and the resulting cavity was filled afterwards deposited suspension grains of the pore liquid – that is the water circulating through the sediment- and with cement crust deposited as concentric layers closing the remaining cavity. The top of Tall al Mudawwar was the site of an ancient village, while the modern village lies on its southern base.

Figure 3.3: Aramshi Formation is exposed about 2 km north of Waqqas next to the village Fathiyin appears with an almost flat carbonate rock plate that has a slight dip to the NW.

The whole deposit appears to have been surrounded and flooded by the Lisan Lake at times forming an island composed of the solid carbonates of Aramshi Formation. The age of the Aramshi is unclear and it is probably younger or older than Al Qarn Formation but it is clearly older than Lisan Formation having an angle disconformity with it is deposits and thus being unconformably overlain by the Lisan Formation. Depositional environment is that of a clear shallow lake provided with water from springs and surrounded by gentle morphology with soil in which pisolites developed. The lake had a bottom consisting of pure carbonate mud which was the living environments of molluscs as are still living in fresh water in Jordan. This fine mud was transformed into a very solid and hard limestone by diagenesis. The age of Aramshi Formation may also resemble that of Ubeidiya Formation. In that case it would be older than Al Qarn Formation. But age determination is not possible except for stating its deposition prior to the Formation of Lisan Lake.

The Aramshi spring lake may have existed at a time when further to the East there were also more humid conditions. Around that time the lake region that was periodically present in the Azraq area was visited by human hunters (neandertalers) which left their hunting tools and the bones of their prey which consisted of camels (*Camelus*), hartebeests (*Alcelaphus*), wild boars (*Sus*), rhinoceroses (*Dicerorhinus*), aurochs (*Bos*), horses or asses (*Equus*) and elephants (*Elephas*) (as in Olszewski 2009).

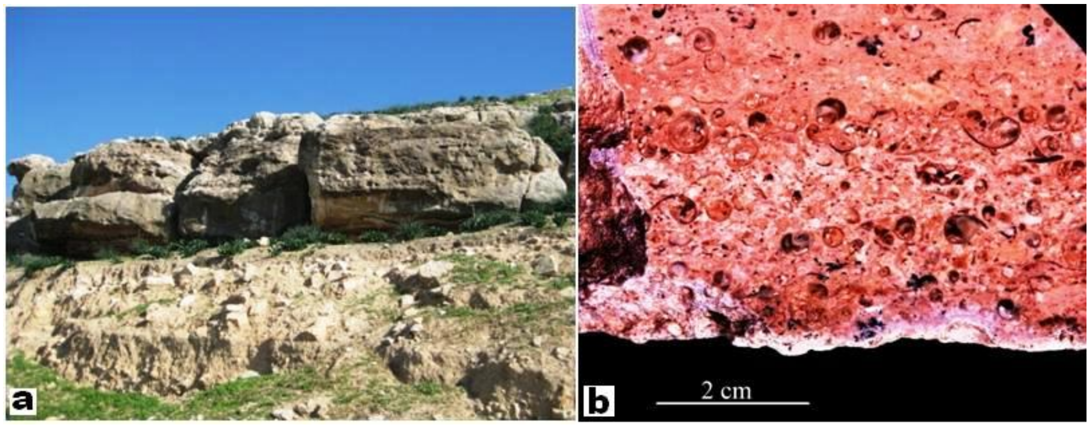


Figure 3.4: a. Aramshi Formation composed of massive solid limestone beds, b. The polished section of the limestone documents freshwater gastropods including Theodoxus, Melanopsis, Melanoides and small planorbids which lived in the lake that formed Aramshi Formation (Aramshi Formation near the village Fathiyin or Aramshi 2 km north of Wadi Waqqas).

A travertine deposit at the southern end of Masharia town forms a hill. The spring is forming these deposits with dipping towards the south. It was deeper in the valley at a level below highest Lisan lake level and lies above the deposits of the Pre-Lisan Jordan. This travertine (calcareous spring tufa) had formed before the existence of Lisan Lake and presents evidence for a fresh water spring that existed in that place for some time. The spring thus had its place above the Jordan River at its eastern Valley margin before the time this area has been flooded by rising Lisan Lake, thus at least more than 50.000 years ago.

Travertine has formed at many springs of Jordan often within mats consisting of cyanobacteria, but also on plants. Its origin is from the water which is saturated with bicarbonates passing on its way through the subsurface through carbonate rocks or with sources of bicarbonates surrounding areas of ancient volcanic activities. Cyanobacteria and plants need CO_2 for their photosynthesis and thus utilize CO_2 from the Hydro-Carbonate and reduce it to Carbonate. $CaCO_3$ which is much less soluble in water than $Ca(HCO_3)_2$ and is deposited near or on the CO_2 breathers, thus calcifying them. In addition, when thermal water saturated with respect to bicarbonate discharges to ground surface, it releases CO_2 and carbonates precipitate. Travertine in Jordan formed near springs with normal temperature of the water have a more irregular growth of lime than those formed near springs with thermal water. This difference is based on the mats of cyanobacteria which grow faster in case of the warm or hot water springs and thus spread over a larger surface which grows to a mat. That can very well be observed in the area of the thermal springs of Zarqa Ma'in where both types of springs, normal temperature and hot occur close to each other. The travertine hill near Masharia was formed by a spring with normal water temperature. Probably also the type of lime formed differs, with thermal water commonly aragonitic crystals precipitate, while with normal water temperature predominantly calcite precipitate. The limestones of this deposit are quite different of those of Aramshi Formation and those of the spring, while the later predominantly formed as deposits in a lake.

3.2 Lisan deposits and their shore

The sediments below those deposited in Lake Lisan are clearly deposits from a river by origin and were laid down by a former Jordan River. Transition from these fluvial sands to deposits of Lisan Lake document well, that the waters of the lake came slowly, and the area turned into a swamp at first with much organic material entering the sand. This transition is well exposed in the slope to Jordan River west of the town of Abu Habil and its position in the sedimentary column is documented by the Lisan Marl that overlies it and into which it grades. As soon as the lake had flooded the soil finely layered (varved) sediment was deposited that in its composition reflected differences of sediments formed during winter and summer. Life within the lake was quite restricted and only microbial organisms may have settled the bottom substrate which could not disturb (bioturbated) the fine bottom mud. Water of the Lisan Lake provided the living environment for some species of diatoms, but the salinity of the water throughout existence of Lake Lisan was so high that gastropods and bivalves never entered the lake, even though springs and creeks issuing into the lake usually contained them. Lake Lisan formed from about 80 thousand years ago and existed throughout the time to around 11 thousand years ago (NEEV & EMERY, 1967; NEEV & HALL, 1976; MACUMBER, 2008). The Lisan Formation is thus a product of the Lisan Lake during the time when glaciers of the Würmian/ Weichselian ice age covered much of Europe between 80.000-15.000 years ago (KAUFMAN et al., 1992; HEIMANN & BRAUN, 2000).

The finely laminated Lisan marl received its name from the Lisan Peninsula extending like a tongue into the Dead Sea and which is composed of finely laminated sediments of the lake and the ancient Dead Sea. Lisan Lake was up to 240 km long extended from the southern margin of Lake Tiberias to south of the Dead Sea. The lithology and sedimentation rate of Lisan Lake varied in the different parts of the Lisan formation and reflect change in the environmental conditions.

The Lisan Formation is divided into two members containing the Lower Laminated Member and the Upper White Cliff Member according to BEGIN et al. 1974.based on lithology and fossils fauna content mainly diatomite. They also classified Lisan deposits into three facies: gypsum facies in the west of the Dead Sea, aragonite facies north of the Dead Sea up till Marma Feiyad, and diatomite facies further north.

According to ABED &YAGHAN (2002) the Lisan Formation can be divided into three members, Lower Laminite, Middle unit of massive Clays, and Upper Laminites in east and west of Ghor el-Katar area and near to Karama dam. Also they suggested that during Last Glacial Maximum about 23.000–22.000 to 16.000– 15.000 years ago, the Jordan Valley had cold, dry climate records a rather similar paleoclimatic trend with the monsoon affected North African Sahara, Arabia and SE Asia where cold dry climatic and that caused of shrinkage of Lisan Lake. The incoming fresh water of paleo Jordan River and other springs surrouned the Lisan Lake, which produce a separation of the water into two layers with different water salinities , an upper less saline and a lower brine water body (KATZ et al., 1977; STEIN et al., 1997). In addition to the Jordan River in the north, other source of fresh water contributed substantially to the water budget of the lake and most of the deep canyons, as for example that of the River Zarqa Ma'in had been filled with gravel up to the highest level of Lisan Lake (BANDEL & SALAMEH, 2013) (Fig 3.5).

Figure 3.5: The outlook is from the basalt plateau- but the other side exposes sedimentary rocks of Triassic and Cretaceous age, the flat terrace of the valley is formed by young sediments deposited during high sea level stage of Lake Lisan. The small gorge has been eroded since the regression of the lake.

The offshore deposits of Lisan Formation mainly consist of calcareous sediments and silts containing abundant diatoms (NEEV& EMERY, 1967) (Fig 3.6 a). The white laminae of the lower laminated series (Lamiated Bed) have been described as consisting of usually monomineralic composition, mainly of aragonite needles, frequently associated with diatom frustules (MEISTER 1968; BEGIN et al., 1974) (Fig 3.6 b). The dark laminae are said to be composed mainly of calcite associated with clay. This composition is understood when, as today, the summers were hot and dry causing chemical sediment deposition in the lake, and the winters were more humid causing rivers to discharge muddy fresh water into the lake which formed a fertile less salty surface layer that enabled the diatom to growth in the phytoplankton.

Figure 3.6: a. Lisan lake formation in the Jordan Valley, the light colored sequence which is covered red reddish sequence belong to lake deposits of Lisan Lake in just to the west of the Al Qarn bridge southwest Abu Habil village and next to the military station., b. Lisan Formation as exposed in the same location.

In the central Jordan Valley some of the characteristic paper-like sediment can be composed of almost pure diatomite. In the white laminae euryhaline diatoms of the *Nitzschia vitrea* ecostratigraphic zone are present, while the dark zones have more fresh water forms.

Nitzschia has usually straight and needle-like frustules and the genus contains many different forms, (Fig 3.7), which were split into different genera by ROUND et al. (1990). A *Rhopalodia gibberula* eco-stratigraphic zone contains with euryhaline species also rare freshwater forms (MEISTER, 1968). *Rhodapalodia* is a diatome with solitary cells and linear lanceolate frustules which may contain endosymbiontic cyanophytes that lives in freshwater or marine (Fig 3.8).

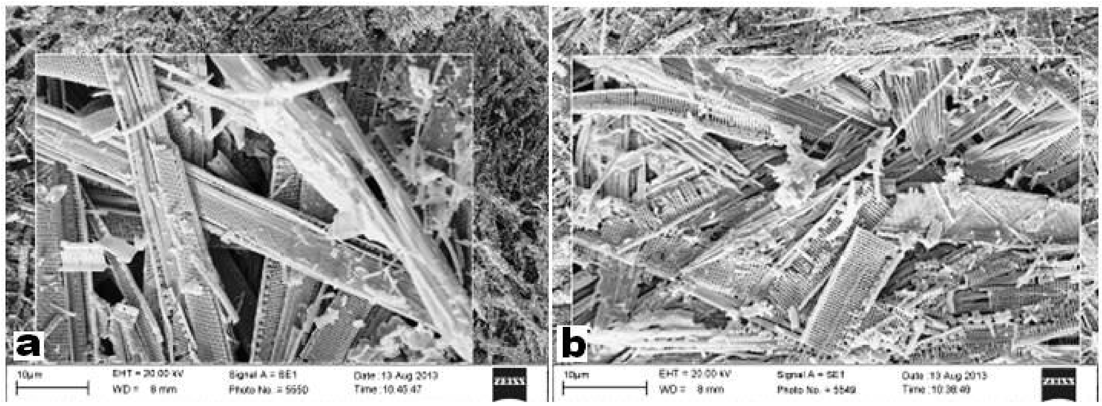


Figure 3.7: a. Nitzschia sp from from Lisan beds, west of the Al Qarn bridge southwest Abu Habil village, the scale bar is 10µm. b. Nitzschia predominates from Lisan Formation in the same location, the scale bar is 10µm.

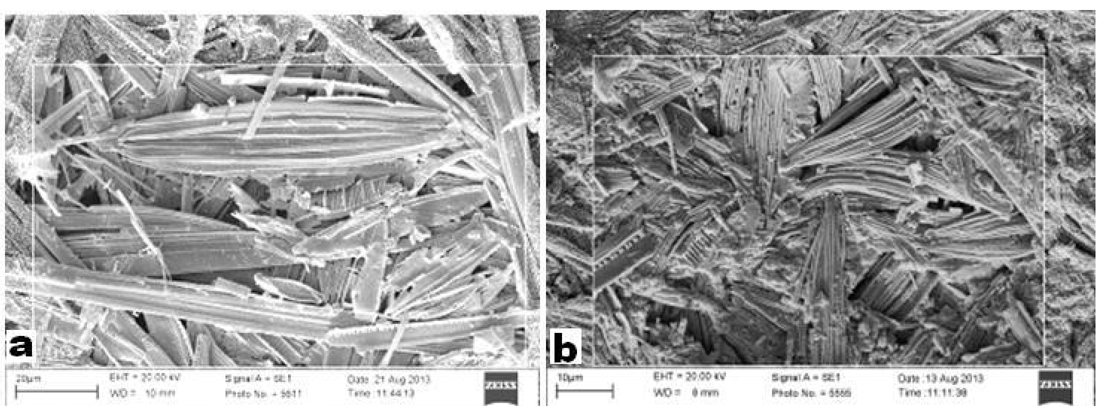


Figure 3.8: a. Flattened Rhopalodia together with a few fine sand grains from Lisan Formation, west of the Al Qarn bridge southwest Abu Habil village, the scale bar is 10µm. , b. Rhodopalodia sp from Lisan Lake, in the same location, the scale bar is 10µm.

Differences have been noted regarding the total diatoms content in the central Jordan Valley and the Dead Sea Basins. In the southern basin the upper laminated 15 m of the White Cliff Bed is composed of two units with gypsum near their top. The white laminae contain more gypsum as the laminated beds below and sulphur concretions are found. These layers belonging to the actual Dead Sea Basin contain no diatoms.

The former shore of Lisan Lake has left its deposits in the area north of Masharia at several places. In Wadi Hammeh, a westerly flowing tributary of the Jordan River enters the northern Jordan Valley about 30 km S of Lake Tiberias (Fig 3.9). The sediments of Wadi Hammeh interfinger there with the deposits of Lake Lisan according to MACUMBER & HEAD (1991). They found pebble and boulder beds forming beach ridges at about –150 m bsl at the mouth of the Wadi Hammeh. According to their description and MACUMBER (2008) the ancestral valley has partially been filled with 60 m of fluvial and swamp sediments including pebble bands and conglomerates and beds of clays and silts. They distinguished the Wadi Hammeh Conglomerate at the base, overlain by the "Black Clay" and the "Knob Limestone". The Knob Limestone is a massive travertine consiting of reeds casts and Melanopsis shells. It is overlain by the Balck Clay unit at Wadi Hammeh (MACUMBER, 1992 a).

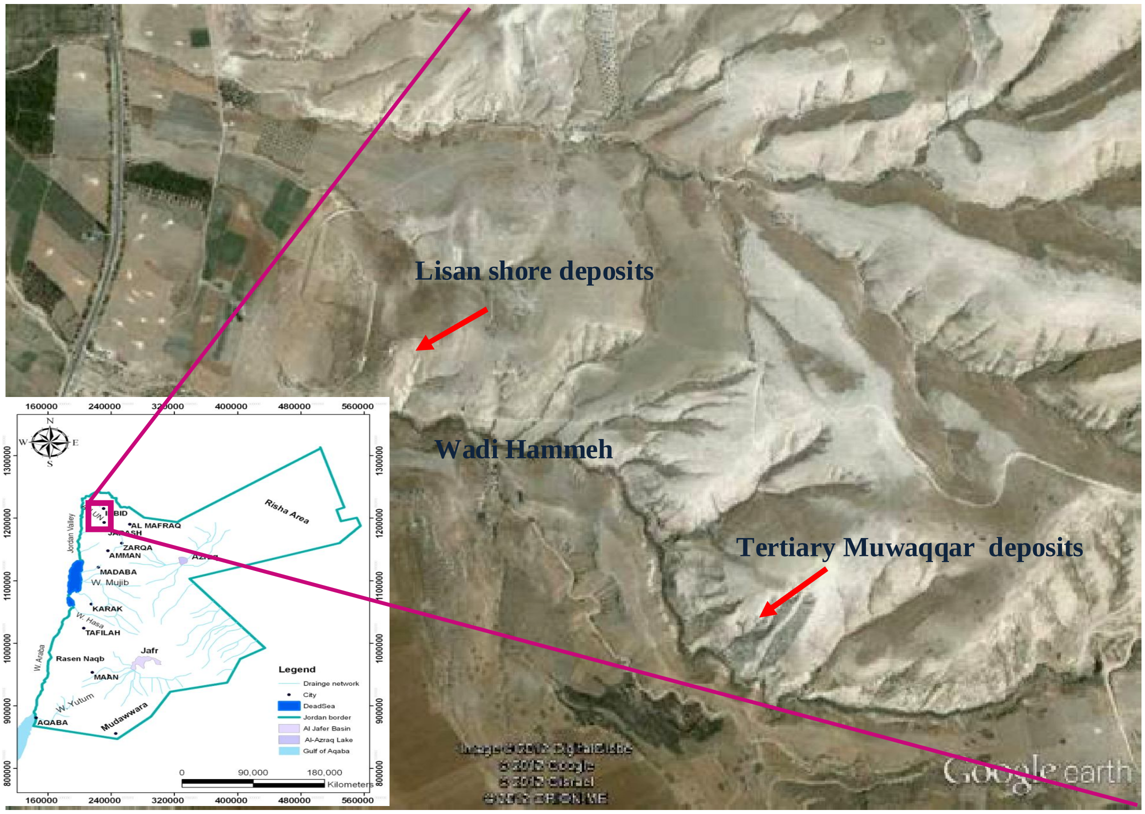


Figure 3.9: Wadi Hammeh with mineral water spring at the right and the margin to the Lisan Lake exposed next to the indistinct road to the left on the slope just above the field in the North of the creek (Image source, Google Earth).

Own observations indicate that black clay represents weathered clay of the Cretaceous to Tertiary Muwaqqar sequence exposed on the side and upstream in Wadi Hammeh and interfingering with the gravel(Fig 3.10 & 3.11). During rainy periods the soil on top of the Muwaqqar marls was washed into the flooded former Valley, and could settle in this quiet bay of Lake Lisan. The ancient shore near the confluence of former Wadi Hammeh with Lisan Lake is well exposed at the northern margin of the Valley (Fig 3.12).

Next to it a spring with fresh water flowed most of the time and near it reeds and other vegetation formed the nucleus for calcification and the formation of travertine. In the soil around the spring also pisolites grew. Smaller particles of carbonates were washed from the spring area to the beach of the lake and here were sorted according to size by its waves and by coastal currents produced during windy periods.

Thus on the ancient beach, layers of calcareous sand formed with the particles having concentric construction. Next to these sands at more quiet periods a muddy shore developed on which the mud during small changes in water level of the lake dried. The sherds of dried mud were washed together when lake level rose again and now form layers of inter-clasts.

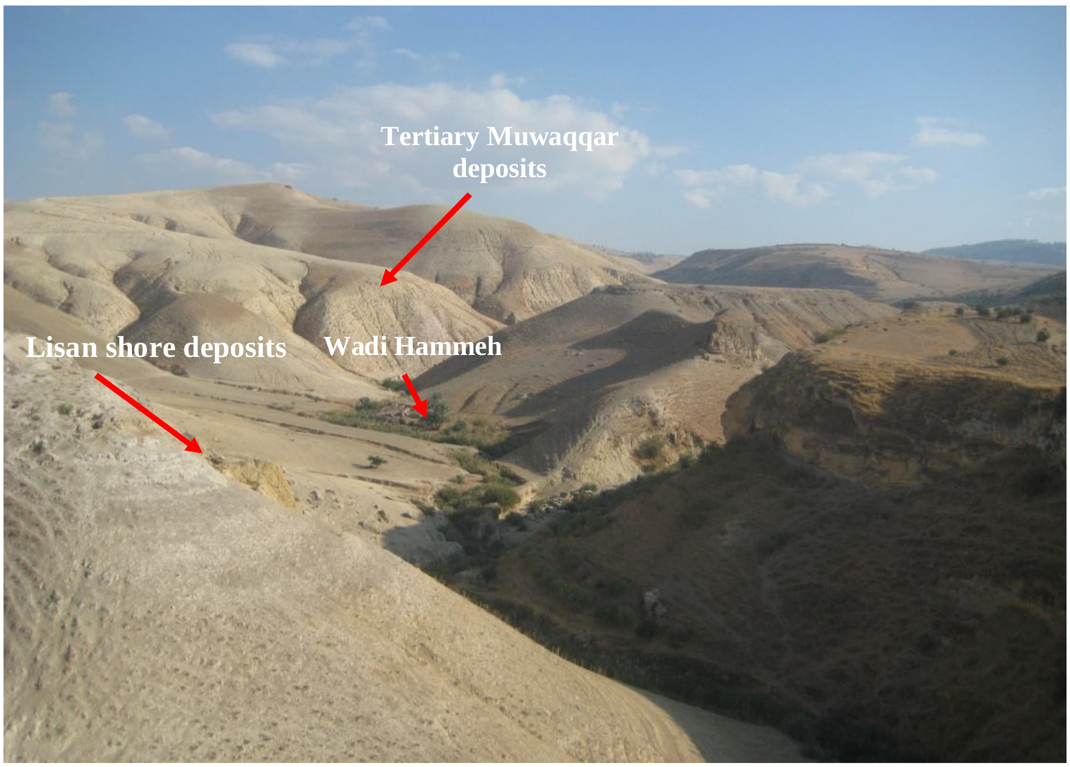


Figure 3.10: View upstream into Wadi Hammeh with the ancient valley filling and central gravel bed eroded out to form an isolated mound in the end of the median ridge. The valley floor at Lisan time is the flat plain at the right side of the picture. Tertiary Muwaqqar sequence appeared on the side and upstream in Wadi Hammeh, (In the Jordan Valley at Pella near Abu Thablah hot spring).

At the mouth of Wadi Hammeh thus an intercalation of washed travertine debris and mud layers with clasts and sherds of dried mud surfaces present evidence of the former shore of Lisan Lake at about –15m bsl. Obviously, the lake level fluctuated perhaps even reflecting hot summer time with evaporation higher than the more moist winter time with more water flowing into the lake. The small calcareous grains were produced near the spring and sorted according to their size by the waves of the lake resembling sometimes closely an oolite. But the concentric calcareous sand-sized grains here have quite a different origin than the ooids which form shoals in the tropical sea and usually compose oolitic limestone.

Figure 3.11: Northwest end of Wadi Hammeh, at Pella near Abu Thablah hot spring in the Jordan Valley, with the former gravel fan into Lake Lisan exposed in the slope and shore deposits found at the outcrop of the horizontal upper layers. The deposits of the Lisan Lake are exposed at the base of the slope and above the Jordan Valley floor.

Figure 3.12: Soft marly sediment of the former Lake Lisan shore that consist of mud with clasts and sand of oolitic fabric. Exposure at the end of the north-western slope of Wadi Hammeh, at Pella, northern of Jordan Valley.

During the long history of Lisan Lake water level fluctuated, at low stands exposing and at later high stands covering the slopes next to the springs repeatedly. It has been reconstructed that water level during the existence of the lake has changed for about 100 m up and down, and sea level was reconstructed as highest of around 25.000- 26.000 years ago (BARTOV et al., 2002&2003). These ages need to be regarded with reservations. The result is a very complex mix of generations of former Valley slopes and gravel channels that have been successively consolidated by the calcareous deposits of the springs, causing problems in their reconstruction (MACUMBER, 2008). Whenever the lake level dropped, the creek in Wadi Hammeh incised into the deposits laid down before and caused the flanks of the filling to become unstable and, when consolidated by a calcareous cement to slide down in smaller and larger boulder of angular shape. Thus, boulders may represent deposits of a former pebble filled channel which therefore can have quite inclined bedding (Fig 3.13).

Other such boulders consist of fine calcareous sand deposited in a creek with smaller flows into which small pebble channels were eroded, with inclined bedding of the different boulder differing from each other. The last pebble channels which formed next to the travertine mass are still found without slumping, but are cut by the last formed slope when Lake Lisan finally withdrew from the area at around 15.000 years ago and relatively rapidly concentrated into the Dead Sea. In the upper Valley level, behind the travertine bar, the muddy creek deposits of the Lake high stand, are preserved and contain *Melanopsis* (Fig 3.14). The shells of *Melanopsis* were utilized by MACUMBER & HEAD (1991) to determine the age of the deposits.

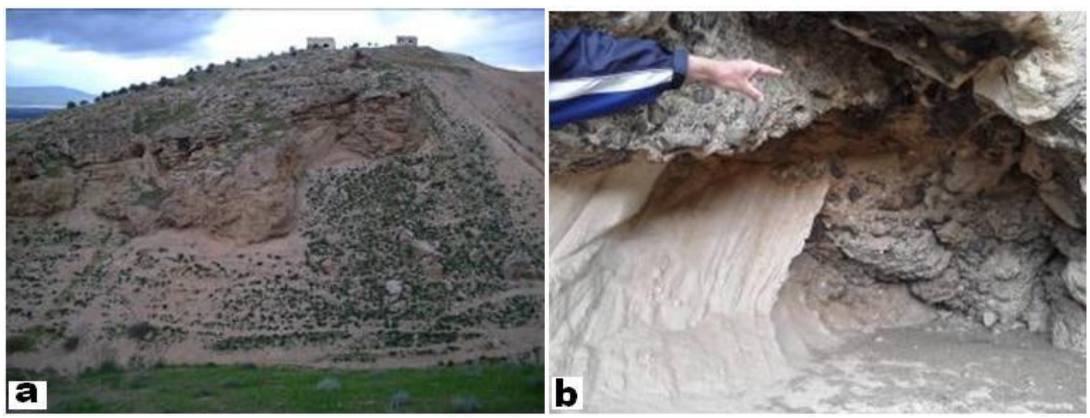


Figure 3.13: a. Northern slope of the end of Wadi Hammeh, at Pella in the northern Jordan Valley, with the travertine deposits of the former springs below the houses and the rocky slope below with diverse remnants of consolidated sediments of several generations of fill sediments that had been consolidated by the calcareous depositions of the springs. b. Fluctuations in Lisan Lake levels have caused a complex mix of generations of former Valley slopes and gravel channels in Wadi Hammeh, two such fragments one composed of finer sediment, the other one of coarse grave are seen next to each other.

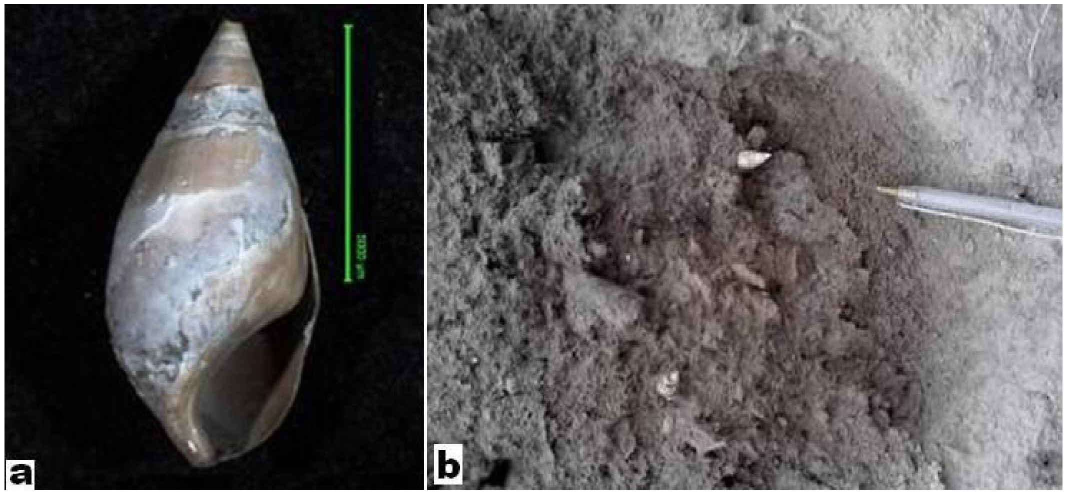


Figure 3.14: a. Melanopsis from the part of Wadi Hammeh, near Abu Thablah hot spring in the Jordan Valley, that had been fresh water swamps when Lake Lisan was at high level, the scale bar is 5000µm, b. Deposits of the muds near to the lake but in fresh water environment are bioturbated by plants, crabs and other soil living animals.

The northern side of the end of Wadi Hammeh exposes a top part formed by travertine material of a former spring which periodically mineralized and solidified sediment of the slope (Fig 3.15). Since this had occurred repeatedly on slope deposits at different levels of the lake entering the valley, cementation by mineral water, erosion and cemented sediments blocks become instable and fell or slid down the slope when undercut by erosion, just to be subsequently covered again with new sediment. This back and forth of sedimentation succeeded by erosion and renewed sedimentation produced a very complex pattern. The cementation of loose Valley fills and their becoming uncovered by renewed erosion occurred several times. The cemented former Wadifills preserved on the slope and on the bed rock now present a complex puzzle of sediment relicts.

This reflects that during the existence of Lisan Lake Wadi Hammeh was repeatedly flooded, repeatedly filled by sediment and subsequently deposits were eroded when lake level fell. This occurred several times, until final shrinking of the lake below the level of the Ghor and into the Dead Sea.

Figure 3.15: Travertine debris at the upstream end of the travertine cliff and spring travertine in place is exposed on the northern slope of Wadi Hammeh near Pella, Jordan Valley.

Fossilized stems and roots of the reed *Phragmites* and remnants of other grasses and bushes such as *Tamarix* are common in the travertine present on the edges of the Valley. Here upwelling carbonate rich ground water emerged as out-seepage in the lower parts of the water courses around the margins of Lake Lisan. *Melanopsis* shells have been analyzed and their age was determined by radio-carbon analysis to be about 15.000 to 30.000 years (MACUMBER & HEAD, 1991), but such age determinations are somewhat dubious. The carbon in the calcium- carbonate that is used by the snail for the construction of its shell has in part been derived from Cretaceous limestones and only an unknown portion of it comes from the air. The soil sequence present next to the Valley consists of an upper soil of light color, somewhat reddish containing abundantly oncoids of different shapes and sizes. Below it with a sharp boundary the soil is more clay- rich and has remains of roots or a clearly developed root horizon. This is an indication of a wetter period. At localities near streams which periodically or continuously shed their water into Lake Lisan clay beds take the place or are intercalated with the laminated authigenic Lisan deposits. The authigenic deposits consist often of thin, up to 1 mm layers interchanged with layers which also contain clay and fine sand. The aragonite crystals in the upper of these formed in the surface water of the lake that was recharged during the rainy winters and evaporated during hot, dry summers. But the fine material may also represent diatomite and its composition can be almost totally silicious. The material of the sandy layers comes from dust blown in from the sides of the lake and from turbid flood water entering the lake. Thus these layers reflect the change of fresh water recharge in the rainy winter and evaporation and dusty winds at summer. In case the water evaporated even more, gypsum was precipitated during summers, as is the case in the saltier water approaching the salinity of the Dead Sea, and has reported to form the upper portion of Lisan deposits further south in the Jordan Valley.

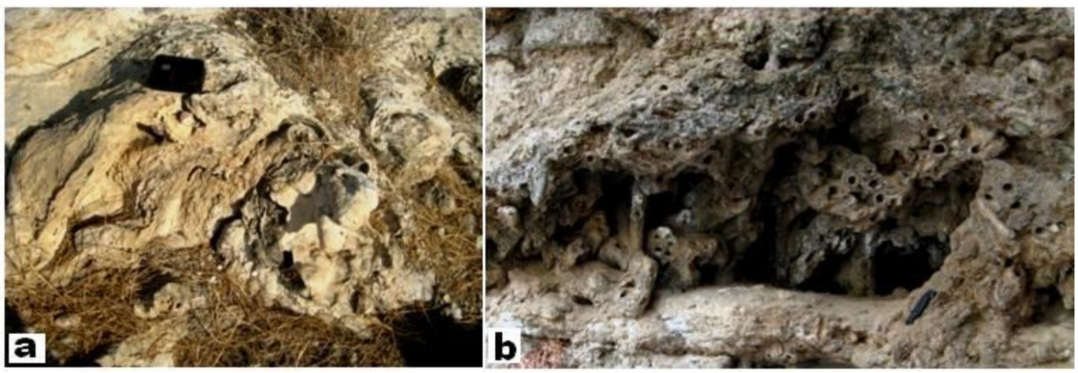


Figure 3.16: a. Wadi Hammeh travertine with Stromatactis structures, (that is calcitic crusts following the former surface in the upper part of the cavity and stratified sediment in its lower part), b. fossilized reeds and coated remnants of other plants (grasses) formed in the spring area (North of the Pella in the Jordan Valley).

The Lisan Lake changed frequently their level between the high stand of 180 -150m bsl at about 27.000–25.000 to the that of the present Dead Sea with about 423m bsl, reflecting large changes in paleoclimatic conditions in the area (BEGIN et al., 1974; LANDMANN et al., 2002; BARTOV et al., 2002& 2003). The retreat of Lake Lisan left behind several terraces extended across the whole Rift Valley engraving its former beaches along its slopes. Lisan Lake is started its retreat at about 17.000-15.000 years ago (BEGIN et al., 1974; SCHRAMM et al., 2000; BARTOV et al., 2002, 2003). The maximum level of Lisan Lake at 180m bsl based on Lisan terraces and their marl deposits exposure (NEEV&EMERY , 1967; BEGIN et al., 1974; LANDMANN et al., 2002).

BARTOV et al. (2002& 2003) reported that the lisan lake level was reached about 160 m bsl during 27.000–25.000 years based on stratigraphic and chronological evidences. Its low stand was reconstructed by MACHLUS et al. (2000) by correlating fan-delta and lacustrine deposits in Perazim Valley, southwest of the Dead Sea. They found the minimum lake stand about 330 m bsl was reached at 47.000 years and lasted for 3.000-4.000years.

In eastern part of Jordan Valley terraces are very well imprinted in the mountain slopes along the eastern Dead Sea and can easily be traced from aerial photos of the region.

Near Deir Alla a maximum level of 164m bsl of the Lake Lisan water was measured, while 160 m bsl were determined at Wadi Hammeh just to the north of Pella (MACUMBER, 2008).

Terraces at 150 m bsl were measured in the Wadi Araba to the south of the Dead Sea and sea level at - 150 to - 165 m bsl is interpreted to represent the highest stand at around 25.000 years ago (BANDEL & SALAMEH, 2013).

Directly in the steep slope next to the Dead Sea the uppermost terrace that was formed by Lisan Lake is often a quite visible plane within the otherwise steep slope of the highland to the Rift. Here travertine is related to the ancient and sometimes still active springs. Often large boulders of travertine formed at different times and different lake levels are still present on the slopes. The terrace not far to direct road from Madabah to the Dead Sea runs over mount Nebo. On Fig 3.17 there is a part of the new "PanoramaRoad" Which goes from the Dead Sea at first Hammat Main about half down the slope has a very conclusive beach preserved. It lies on a flat terrace which indicates the highest stand of Lake Lisan at about 170 m bsl and also, most probably water level during most or much of the time of its existence. Lisan and also, most probably water level during most or much of the time of its existence. On the terrace above the Dead Sea the former long term beach of Lake Lisan left characteristic deposit, as there are beach rock from the beach proper and stromatolites which grew in the shallow water next to it.

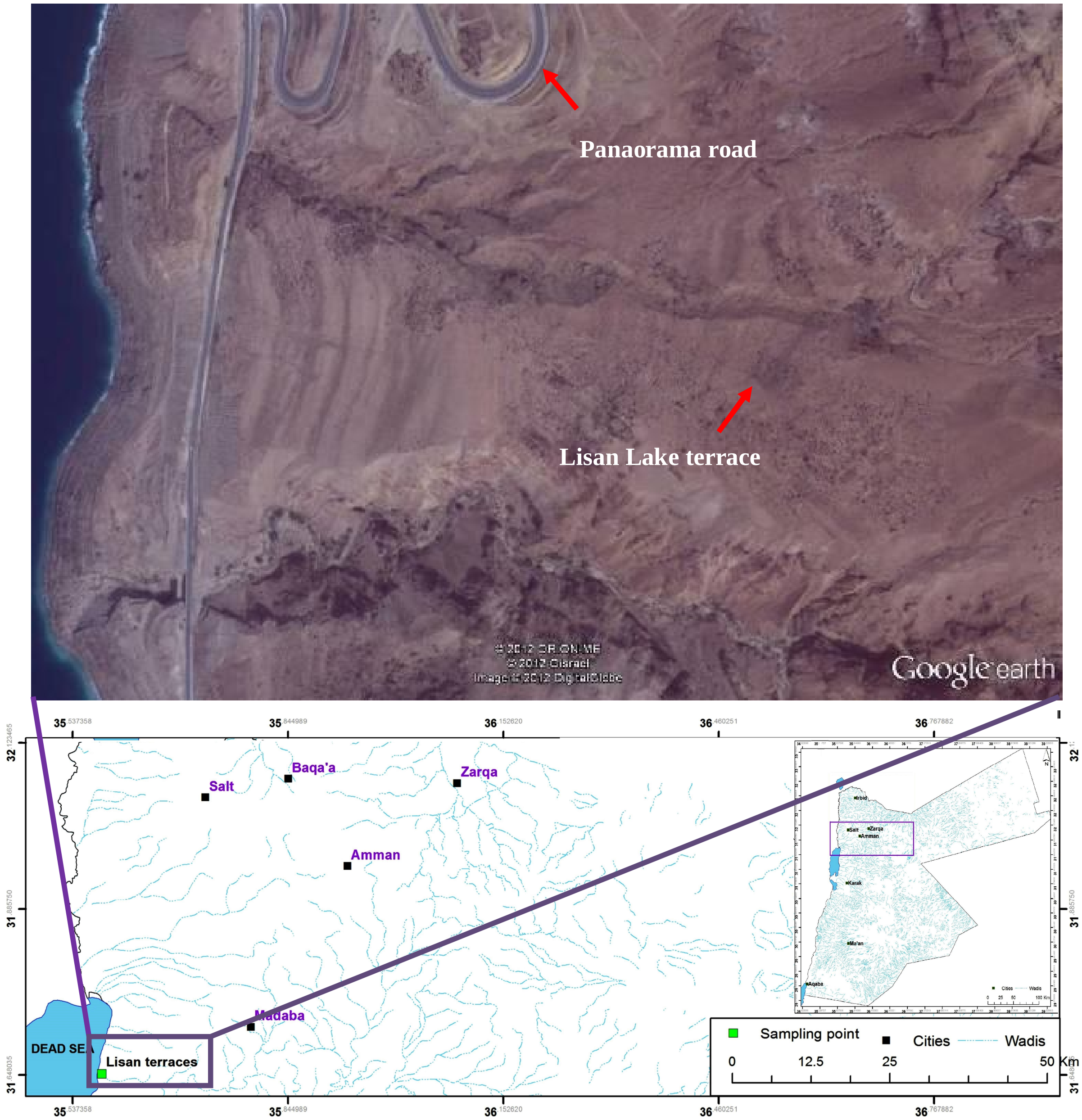


Figure 3.17: Lisan terraces north of Zarqa Ma'in close to the new Panorama Road at about 170 m bsl which can be seen as lines following the contours, with the studied one; the uppermost, just below the rocky shore to the right (Image source, Google Earth).

Evidence for the long time of its existence can be seen in its comparativel large size when related to the many other terraces present in the slope. At a single locality above the terrace the deposits formed by an ancient spring are especially well developed. From here large travertine boulders have fallen onto the plane of the terrace (Fig 3. 18). The waves of the Lisan Lake here had not only carved the terrace but also had been active in assembling a sandy beach in which a solid and massive beach rock formed (Fig 3.19). That rock ledge exposed still in the place of its origin is partly composed of laminated, often crossed laminated former sands and of angular fractured particles of older, reworked beach rocks (Fig 3.20).

The material of the beach consisted predominantly of calcareous sand formed by wave action from the carbonate covers formed around the plants which grew next to the springs above the beach. A long time of relatively stable water level that carved this uppermost terrace is indicated by the integration of former reworked beach rock in the beach rock ledge that is still found here at place. The size of this terrace as the largest of them all indicated also that highest lake level probably was also present for the longest time of lake existence. It represents no evidence, though, for a constant water level for a long time. Water may have gone up and down, but did not reach higher levels.

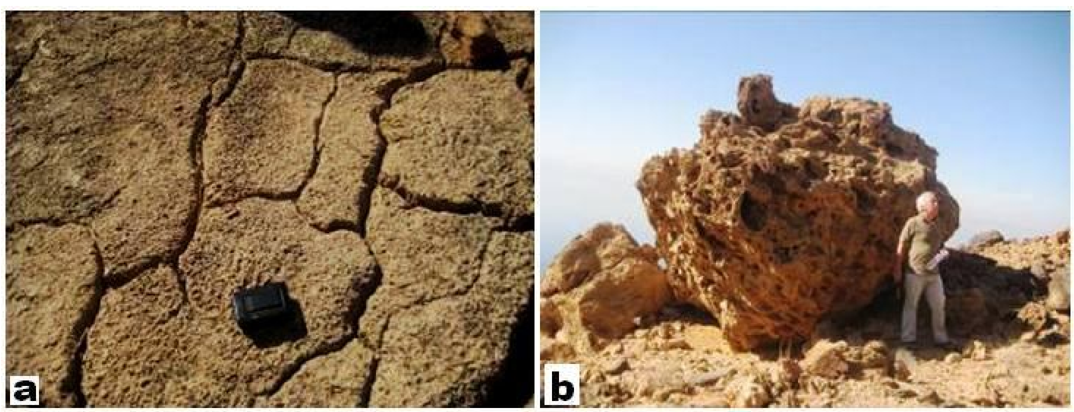


Figure 3.18: Lisan terrace near the new "PanoramaRoad" Which goes from the Dead Sea at first Hammat Main about half down the slope has a very conclusive beach preserved; a. cracked surface of the beach rock plate at studied terrace of Lisan Lake, b. Block of the travertine that had formed at near the spring above the beach and has subsequently broken down to be placed next to the beach on the platform formed by erosion of the waves of Lake Lisan.

Figure 3.19: a. Angular bolder beach rocks from the Dead Sea terraces of Lake Lisan, near Panorama Road Dead Sea,b. View from the plane of the terrace towards the south with the main upper terrace well incised in the slope, Location north of Zarqa Ma'in close to the new Panorama Road Dead Sea.

Figure 3.20: A beach rock of Lake Lisan has formed from cross-bedded beach sand, location Panorama Road Dead Sea-Hammad Main about 1km east of deviation from Dead Sea road at elevation.

Very important information can be learned from this ancient beach. Numerous stromatolites forming nodules and knolls lived in the former lake water at this place (Fig 3.21). This water may have been quite salty since similar cyanobacterial knolls of the shape just as these stromatolites still form in the Dead Sea at places where fresh water enters it just below sea level and near the shore. So hat similar conditions prevailed. The water of Lake Lisan was probably also layered with a lower brine and an upper, less saline water body. The thickness of the upper water may have been only a few meters.

Figure 3.21: Stromatolites as they are below the former beach, still is a position as originally formed in the shallow water of salty Lake Lisan, location Panorama Road Dead Sea-Hammad Main about 1km east of deviation from Dead Sea road.

The lake level also caused the corresponding ground water level to be raised and springs discharged their groundwater higher up than today, as it is documented by many sintercones and sinterformations along the Jordan Valley.

Lake Lisan ended in the North near the mouth of Yarmouk River near Menahemya on the western side of the valley and its salty waters did not enter the basin filled with ancient Lake Tiberias, which during the period of existence of Lake Lisan held fresh water with the characteristic fauna, of which especially *Melanopsis* living near and on the beach with its aragonitic shells provide the data by which the age of the lake in its different portions was established (BOWMAN& GROSS 1993, HAZAN et al., 2005, WALDMANN et al., 2010). Here, as in the rivers, creeks and springs entering Lake Lisan the fauna of the fresh water had it is limits and did not enter the lake in which only a specialized life adapted to salty water consisting among others of cyanobacteria on the ground and diatoms in the plankton was present. Former beaches of the Lisan Lake can still be recognized along the former southern and eastern shores of that lake and for example at the mouth of Wadi Tayan former beaches are not only seen well from above, but also when crossing them on the ground .

The shrinking of the Lisan Lake is caused on one hand by the change of climate from more wet to dry conditions after the maximalglaciation at the end of Pleistocene. On the other hand in part it could had been speeded up as the result of the reduction of the catchment area from around 157 000 km2 to about than one fourth of that area.

Reason for that reduction is the spread of basalt flows of the Jabal Arab-Druz blocking the drainage. Water coming from the east, after that, remained in the area of Azraq Oasis, Sirhan Basin, Damascus Oasis and others (SALAMEH & AL FARAJAT, 2006). These basins were since then filled with sediment. Thus Lake Lisan shrank rapidly in size from relatively high stand about 17.000 years ago to about the level of the Dead Sea 13.000 years ago. Volcanic eruptions, which blocked the watershed to the east lowered the amount of water that entered the valleys of Yarmouk and Zarqa rivers. Gravel streams and even lava flows coming from the volcanic areas connected to the high regions of Jebel Druz volcano may have been the reason (SALAMEH & AL FARAJAT, 2006). Between Zarqa and Azraq depression a watershed thus was formed by that debris that lies only 20 m above the Azraq depression. Between Azraq oasis and Zarqa a bed of fluviale gravel and of playa basins is found which represents the former river and water flow to the west and is also weakly inclined towards the west. The volcanic rocks which blocked the flow of water to the west are also found exposed in the Zarqa as well as in the Yarmouk valleys (BESANCON et al., 1984; MACUMBER, 2008).

During most of the Holocene the Dead Sea level fluctuated around – 400 m bsl (KADAN, 1997, Neev & EMERY, 1995). An additional lake was formed as a result of the blockage due to the gravel fan in the Azraq depression it had 600 km2 in size. The lake was surrounded by a zone of reeds and had trees along its shore. Into it small deltas were deposited from water coming along shallow depressions from the East, North and South. A similar development can be observed in the Jafr Basin. Its central part is filled with 32 m of Pleistocene sediments with ostracods, and molluscs of fresh water origin covered by limy sediment of about 5 m thickness formed in brackish water containing ostracods and bivalves (HUCKRIEDE & WIESEMANN, 1968). Gravel beds coming from Jebel Druz in the SE produced a separation of Wadi Sirhan and the Wadi Dhuleil area which connected to the Zarqa River.

4 PLIOCENE-PLEISTOCENE PALEOLAKE DEPOSITS OF JORDAN

4.1 Halat Ammar Formation (Mudawwara Lake)

The Halat Ammar Formation (MASRI, 1987) occupies an area of about 7 square kilometers northeast of Al-Mudawwara Police station, at the main road from Maan to Tabuk, close to the Saudi Arabian Border in Southern Jordan. From samples collected by Tariq al Harithi at the localities that had been indicated by Masri the fauna was studied. According to several studies such as ABED et al., 2000, PETIT-MAIRE et al., 2002, ABED et al 2008 , the lithological description of the Halat Ammar deposits at that places the Halat Ammar Formation overlies Paleozoic sandstones and siltstones and is here about 8 m thick. From top to bottom the section begins with a gravel layer which includes the up to 20 cm thick unit holding the molluscs. The coquina forms cross bedded banks within the gravel. Below this fossiliferous top layer there is a more than one meter thick layer of conglomerates with pebbles consisting of Precambrian crystalline rock as well as Paleozoic sandstone. Below it there are deposits of a lake predominately composed of marls which hold beds of gypsum, dolomitic limestone and halite. These beds comprise about 5 m of thickness. Below them there are sands with some few burrow structure (possible roots) and a few chert pebbles derived from the eroded Paleogene deposits originally found to the west and north (Fig 4.1 & 4.2). The lake existed in a position of about 700 m above sea level, thus 100 m lower than the lake bottom of Lake Disi in the west (MASRI, 1987).

Rain during the more wet periods connected to one or several of the ice ages provided water for the existence of a large shallow lake, the Halat Ammar Lake that has also, later, been called Mudawwara Lake (PETIT MAIRE et al., 2010), on the flat highland in the Mudawwara region (same as Lake Halat Ammar of Masri 1987, which has priority). PETITE MAIRE et al. (2010) suggested that Lake Halat Ammar existed during the equivalent of the Eemian warm period before the last ice age in Europe. According to their interpretation the Lake was formed at the same time as lakes in the Sahara in central Libya, in Southern Tunisia and in Northern Mali.

The large Shati palaeo-lake in Libya was dated by 22 Th/U analyses as having existed around 130 thousand years ago and in Egypt, at Bir Tarfawi, they interpreted the calcite deposits as having formed under humid conditions between 140.000 and 100.000 years ago. Th/U analysis of Cardium / Cerastoderma shells from Halat Ammar deposits indicated to PETIT-MAIRE et al. (2010) a similar age fitting into the time of the last interglacial in the North and older than 80 thousand years ago when Lake Lisan began to form in the Jordan Rift. But they assumed that the shells of Cerastoderma/ Cardium were not affected by diagenetic changes of their original construction, which can be shown to be erroneous.

But the comparison with Lake Lisan proof rather an age comparable with the last glaciations. During the time of the last ice age there was much more rain in Jordan than before and after causing the growing extension of Lake Lisan. The effect of more wet periods during the last glacial periods in the northern part of the Arabian Peninsula is also confirmed by HÖTZL & ZÖTL (1978) from Quaternary sediment studies in the Arabian Peninsula up to Damascus basin. Only in the northern part late Plesitocene lake deposits comparable with the maximum of the last glacial period are wide spread, in contrary to lake deposits in the middele and southern part of Arabia, which are connected to warm interglacial periods and are caused by northward movement of monsoonal rains.

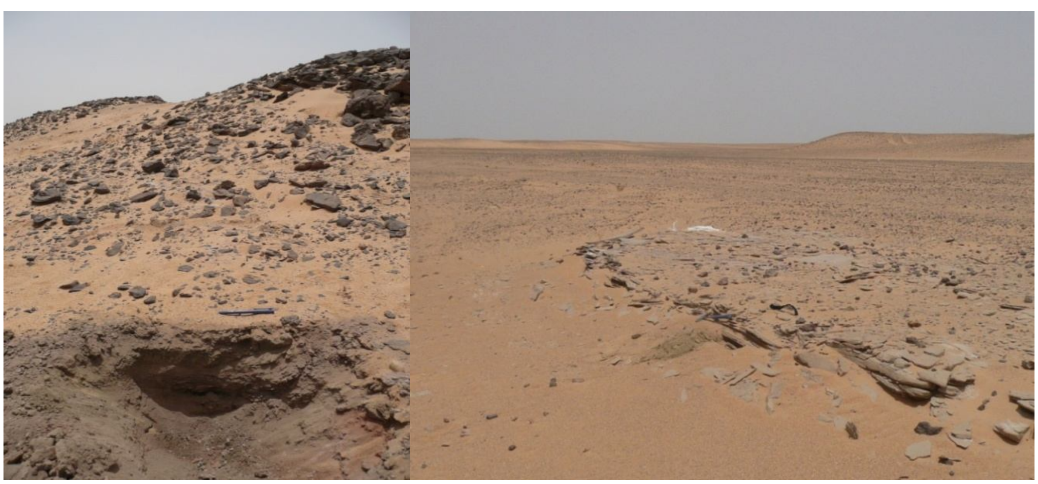


Figure 4.1: Marls beds from Halat Ammar Formation which are covered by Paleozoic sandstones, about 120 km SE of Ma'an city and 7 km east of Mudawwara police station close to the Saudi Arabian Border in Southern Jordan.

Figure 4.2: a. Halat Ammar Formation is locally exposed SE of the village Mudawwara in Jordan in trenches cut by construction works, b. Shells of the bivalves, mainly Cardium from Halat Ammar Formation, about 120 km SE of Ma'an city and 7 km east of Mudawwara police station close to the Saudi Arabian Border in Southern Jordan.

The whole lake deposit is described as of about 12 m in thickness and the lowermost sandy beds have traces of a former system of roots. Shells of the bivalves *Cardium* (*Cerastoderma*) and *Brachidontes* and a small gastropod that resembles *Hydrobia* compose much of the sediment (Fig 4.3).

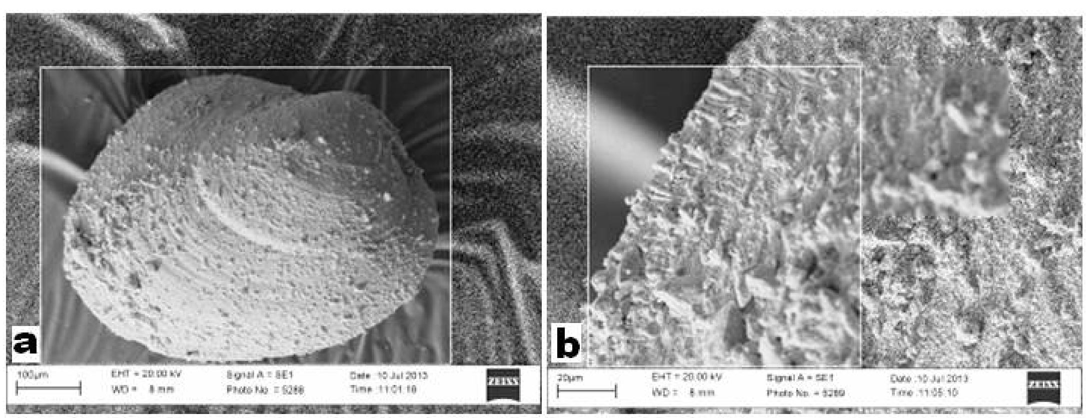


Figure 4.3: a. Brachidontes shell from Halat Ammar Formation, about 7 km east of Mudawwara police station close to the Saudi Arabian Border in Southern Jordan, with larval shell well set off from adult shell, the scale bar is 100µm, b. Biocrystallite pattern of the outer calcitic layer has continued and influences the direction of growth of cement, the scale bar is 20µm.

The most common ostracod of Lake Halat Ammar, *Cyprideis torosa* is also very common in a small pond formed by a modern creek of a brackish spring near Karama dam reservoir in the Jordan Valley (Fig 4.4). Other ostracods can belong to *Candona* species which also occur commonly in water with variable salinity. Often individuals of bivalves and ostracods are preserved with both valves still connected to each other. These animals were obviously killed before reaching full age and without valves detached from each other after death when water level fluctuated. *Cardium* may have been carried by birds to Halat Ammar Lake (Fig 4.5). *Cardium* (*Cerastoderma*) closes its shell by contracting two about equal muscles and the shell gapes again when muscles are relaxed the elastic ligament pushes valves to open. *Cerastoderma* reproduces by shedding eggs and sperms into the water. Inside the fertilized egg the embryo develops and hatches provided with a shell. It swims as larva feeding on plankton for a few days until it settles to the ground. *Cardium* occurs relatively common in lakes with salinity approaching that of the sea.

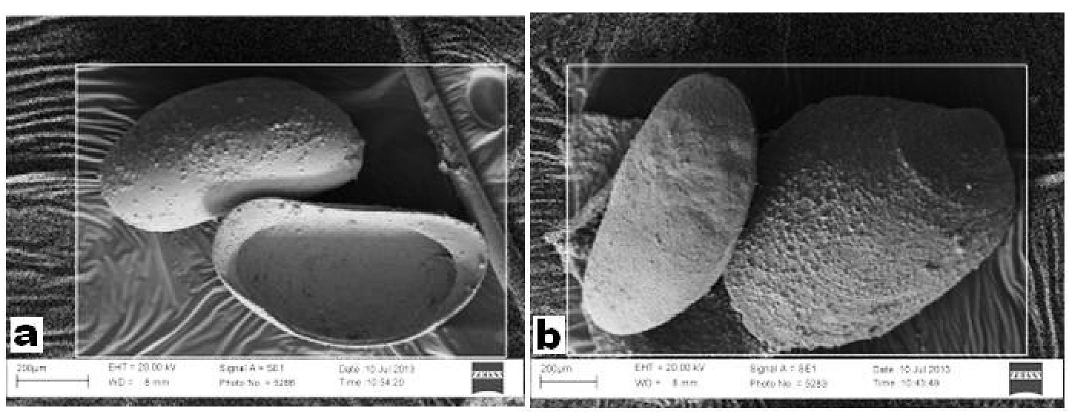


Figure 4.4: a. Cf. Candona from Pleistocene Halar Ammar Lake, the scale bar is 100µm.b. Cyprideis with juvenile Brachidontes from Halar Ammar Formation, about 7 km east of Mudawwara police station and next to the Saudi Arabian Border in Southern Jordan., the scale bar is 100µm.

Brachidontes in contrast is also common in the deposits of Pleistocene Halat Ammar Lake and has the same or a very similar species living in the Gulf of Aqaba. In contrast to Cardium it is attached by byssus threads to stones, or algae or sea grass. The shell of this Brachidontes is ovoid in shape with the hinge of many small teeth. The shell is composed of a thin calcitic outer layer and nacreous inner layer. Brachidontes has an ovoid interdissoconcha (special juvenile shell of approximately 0.5 mm in width) besides a normal prodissoconcha (larval shell). The shell of the veliger hatching from the egg measures a little more than 0.1 mm and the larval shell is about 0.3 mm in diameter. The food of Brachidontes is the same as that of Cardium and it is also filtered from the surrounding water. On the blades of sea grass in the lake also the small hydrobiid gastropod collected its food consisting of unicellular algae.

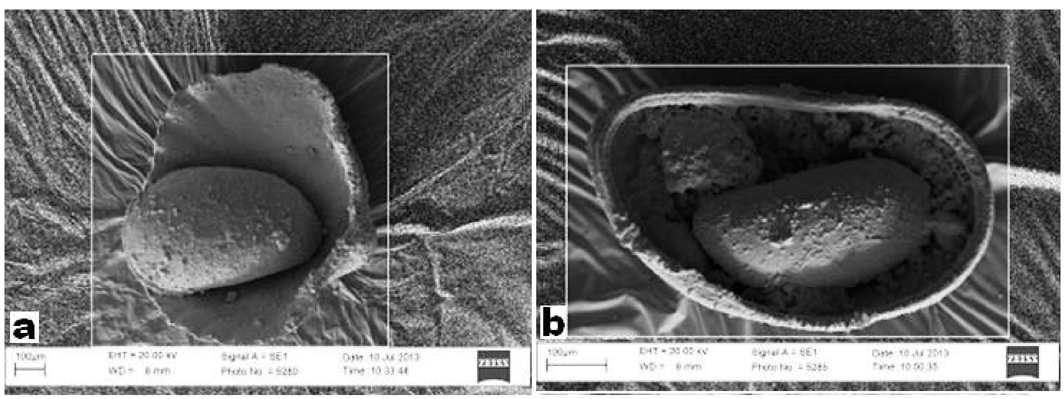


Figure 4.5: a. Cerastoderma with ostracod from Halat Ammar Formation, the scale bar is 100μm, b. two different species of ostracodes from Halat Ammar Formation, about 120 km SE of Ma'an city and 7 km east of Mudawwara police station close to the Saudi Arabian Border in Southern Jordan, the scale bar is 100μm.

PETIT-MAIRE et al. (2010) determined the dominant bivalve species as Cerastoderma glaucum, which tolerates salinity between 3‰ and 60‰, also Brachydontes cf. pharaonis and Abra sp.were determined, as well as Hydrobia sp. and Melania tuberculata. (may be determined as Cardium sp., Brachidontes sp., Hydrobia- Prososstenia sp, and Melanoides tuberculata). The ostracod Cyprideis torosa was found to be more common than Candona gr. neglecta. Cyprideis may occur in high density and Candona was noted to be abundant in other levels. But determination of ostracode species from these shells covered by a thin veneer of cement may be difficult. Two benthic Foraminifera belonging to Ammonia and Elphidium were also noted but not seen in the samples which were studied. Both foraminifera had also been encountered in the Saharan Shati paleo-lake, and both species live in brackish to salty shallow waters.

PETIT-MAIRE et al. (2010) interpreted an evolution of the lake with water salinity decreasing by interpreting a faunal change from a more salt loving species with Abra, Cardium and Hydrobia to a more fresh water adapted fauna with Melanoides and Brachidontes. They also detected the remains of charophytes and from their presence or absence assumed water depths of the lake as becoming deeper than 5 m locally and thus no light for the growth of the Chara relation. Oogonia of Chara were also not found to be contained in the studied sample. Lake level they assumed as above 720 m altitude.

The shell show a transformation of the former aragonitic crossed lamellar into a granular structure which is clearly secondary. Also in the shells of Brachidontes most of the nacre has been transformed into granular calcite and the crystallites of the outer calcitic layer continued growth into single large cement needles. Thus the age determination carried out on such shells affected by diagenesis that changed the original construction of the shell is of limited value. The crystallization changed the type of crystals by transforming much of the original aragonitic crossed lamellar structure of Cardium / Cerastoderma and of the nacreous structure of Brachidontes into calcitic material and in addition produced a cover of calcitic crystals of cement on shell surface as well as new growths if cement in dissolution cavities (Figs 4.6 -4.9).

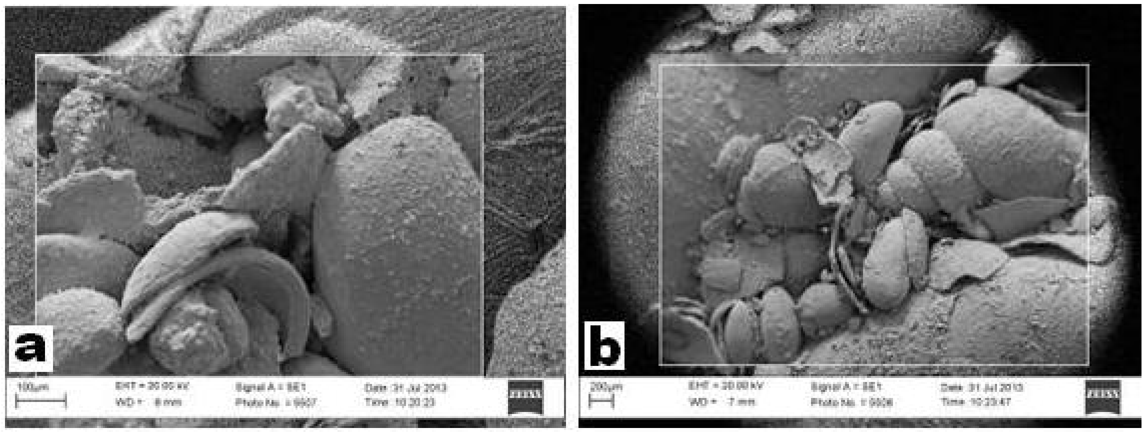


Figure 4.6: a. Ostracodes with cement crusts, the scale bar is 100μm, b. Hydrobia tiny bivalves and ostracodes; about 7 km east of Mudawwara police station close to the Saudi Arabian Border in Southern Jordan, the scale bar is 100μm.

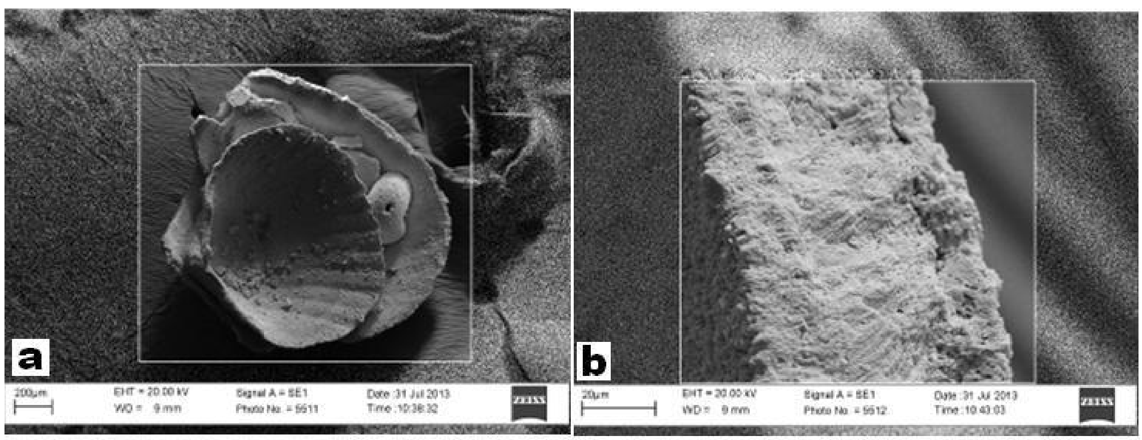


Figure 4.7: a. Cardium shells from Lake Halat Ammar, the scale bar is 200μm, b. Cardium shell fractured with thick cement layers and transformed crossed lamellar that is no longer aragonitic, about 120 km SE of Ma'an city and 7 km east of Mudawwara police station close to the Saudi Arabian Border in Southern Jordan, the scale bar is 20μm.

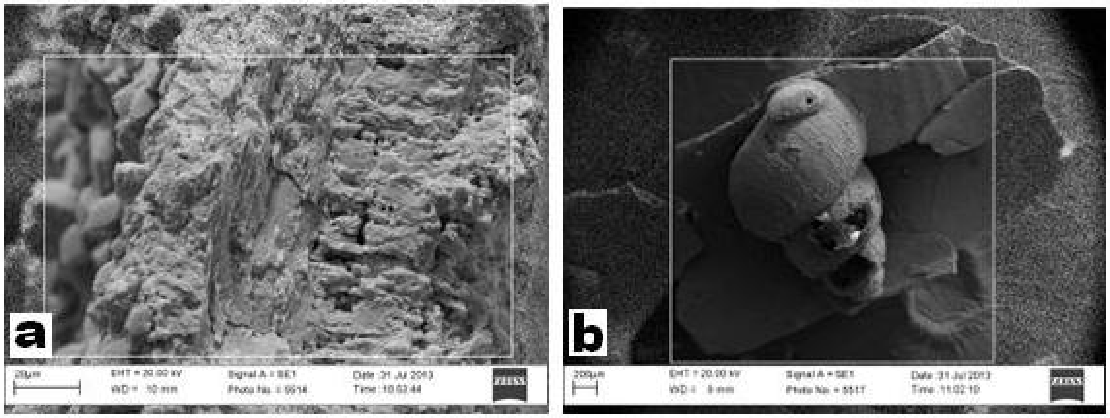


Figure 4.8: a. Shell walls transformed into calcitic structures (from Lake Halat Ammar, the scale bar is 20µm, b. recrystallized Hydrobia shell from Lake Halat Ammar about 120 km SE of Ma'an city and 7 km east of Mudawwara police station close to the Saudi Arabian Border in Southern Jordan, the scale bar is 200µm.

These examples of shells as preserved in the Halat Ammar Foramation document quite well that the shell substance can no longer be utilized for age determination. In contrast fossils from Al Qarn Formation show well preserved shells (Figs 4.9- 4.12):

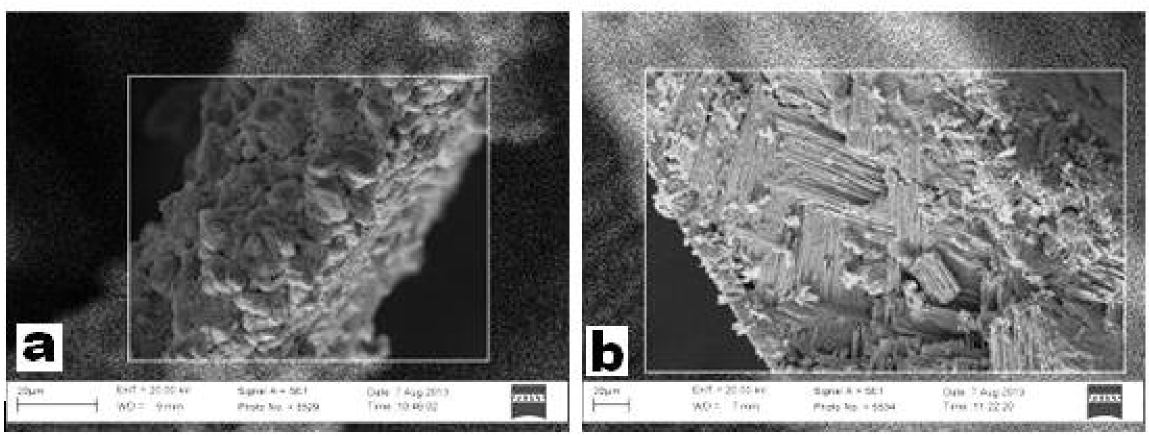


Figure 4.9: a. Formerly crossed lamellar structure of a Hydrobia transformed into coarse calcite compared to well preserve crossed lamellar structure of a Theodoxus as present (b) in Al Qarn Formation west Abu Habil and south Wadi Al Qarn, the scale bar is 200µm.

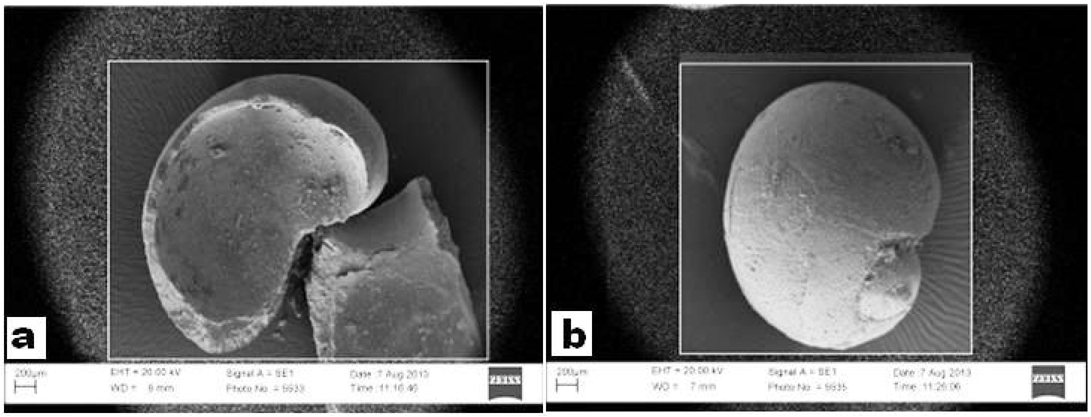


Figure 4.10: a. Well preserved fossils showing the inner walls of Theodoxus are all resorbed- as is documented by this broken shell, and a small juvenile Theodoxus- both from Al Qarn Formation,close to KAC southwest Abu Habil in the north of Jordan Valley, the scale bar is 200µm, b. The crossed lamellar structure seen in the illustration above is form that Theodoxus, the scale bar is 200µm.

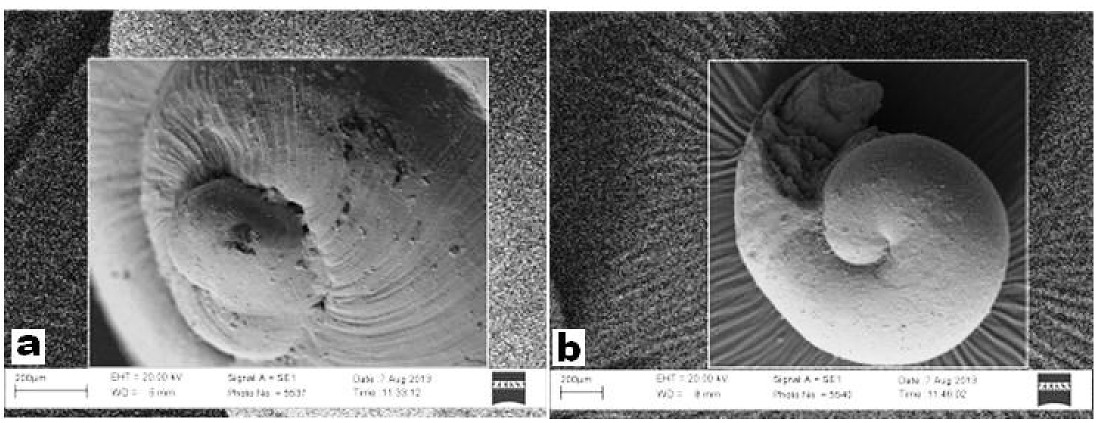


Figure 4.11: a. Embryonic whorls of Theodoxus from Al Qarn Formation, near KAC west Abu Habil village and south Wadi Al Qarn, as well as the structure of the fine thin calcitic layer as is characteristic to Theodoxus and in which the color has preserved, , the scale bar is 200µm, b. Theodoxus with the embryonic whorl of a stylommatophoran land snail that lived near the AlQarn Lake. The young hatched as crawling miniature adult as is the case in modern land snails in Jordan, the scale bar is 200µm.

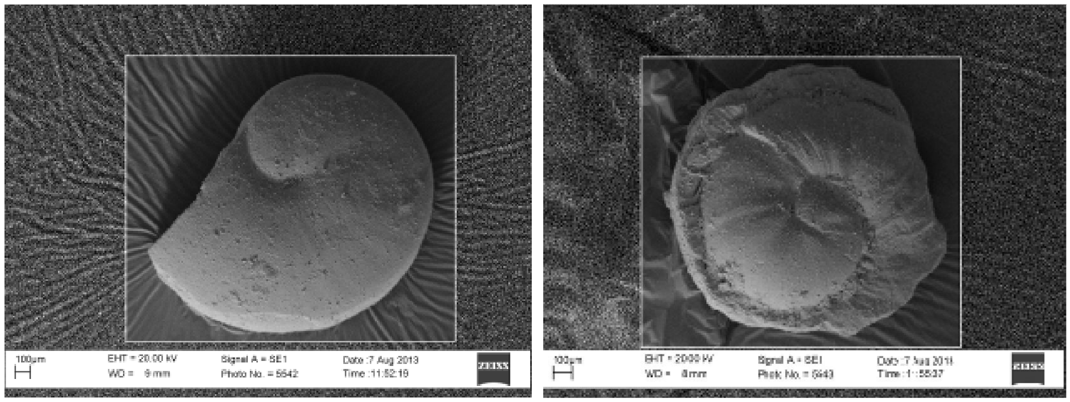


Figure 4.12: Even larger embryonic whorl of a land snail from Al Qarn Formation, and of a third species, close to KAC southwest Abu Habil in the north of Jordan Valley, the scale bars are 100μm. These land snails can only be determined by comparison with living snails of the region- since their adult shell are not preserved in the fossil record- since they are too thin.

4.2 Hasa , Jafr and Azraq paleolakes

As summarized by MACUMBER (2008) the studies of SCHULDENREIN & CLARK (1994) and others have indicated the presence of a large lake that occupied the upper part of Wadi Hasa that reached a maximum level of 815m. Its water level, thus, lay much higher than that of Lake Lisan, which has never reached the level of minus 180 m bsl. The exit of the lake lay above the modern canyon and that has since been excavated again, with former canyons filled with gravel almost at the same level as the modern canyon exposed when walking up on the rivers level. The sediments of the former lake are preserved locally when covered by spring tufa. This lake was 18 km long and locally 4 km wide and its western edge lay 40 km from the edge of margin of the Jordan Rift. The lake was accompanied by archaeological sites. These have been dated to have existed at around the time when also Lake Lisan was filled that is at around 27.000 to 15.000 years ago.

It is suggested that the lake was tectonically initiated, and its time of existence is still problematic. MACUMBER (2008) suggested that it may have been much shorter lived than lakes such as that filling the Jordan Valley (Lake Lisan) or those that existed in the Azraq area and the Jafr Basin. Lake Hasa may have existed from Upper Palaeolithic times around 26.000 years ago into the Epipaleolithic period to about 19 thousand years ago. The marls of the lake deposits now form a terrace and the bottom of the lake was replaced by pools and swamps when the new canyon eroded. Cut was initiated by the shrinkage of Lake Lisan at least 10 thousand years ago. But that timing is interpretation and needs to be confirmed.

In the Jafr Basin a large lake had been in existence, covering an area of around 1000–1800 km^2 (HUCKRIEDE & WIESEMANN, 1968) resulting in the deposition of 25 m of limestone and marl- present below the mud flat of Qa Jafr (Figs 4.13-4.14). And also the area of the Azraq Oasis had been covered by a large lake. The Jafr Lake was present during the times when also the Lake Lisan was in existence. Jafr marls dated by HUCKRIEDE & WIESEMANN, 1968 suggest an age of 26.000 years ago, which fits with Lake Lisan. The age of Azraq Lake is 500.000-250.000 years (DAVIES 200, 2005; KHOURY, 2003). Recent dating of Azraq Formation by ABED and colleagues (2008) based on U/Th method indicates that the Lake has existed at 330.000 years.

They found that the Formation contains one or several shallow freshwater bodies with different salinities from fresh to brackish water, covering an area of about 50 km wide within the Azraq Basin (Fig 4.15).

First people entering the scene within the Pleistocene were hunters following the large animals representing their game. On their way they also collected roots, fruits and seeds from wild plants. They stayed near water and migrated between places with vegetation as did the animals they hunted. The shape of their tools changed with time, from relatively coarse implements to instruments of finer fabric. Simple pebble tools were found in Ubeidiya Formation of about 70.0000 years, possible made by *Homo habilis*. Azraq and Al-Jafr Basin were nodes on a chain of ancient lake basins that stretched from northwestern Saudi Arabia to northeastern Syria during the wetter times of the Ice Age (Pleistocene) (HOROWITZ, 1979). They formed an inland corridor for occupation by *Homo erectus*. The sites have yielded many of heavy-duty butchering tools chipped from local deposits of flint. The tools are cleavers, a form of hand axe that could be resharpened by striking distinctive flakes from the cutting edge. Animals such as elephants and rhinos were hunted when they came for water.

According to Olszewski 2009 the older Palaeolithic ranged from 450.000 to 150.000 years ago. The middle Palaeolithic lasted until 45.000 years ago, and the upper Palaeolithic ended 16.000 years ago, succeeded by the Epipalaeolithic until 19300 years ago.

KROEPELIN (2009) documented that in the 9th millenium the desert of the eastern Sahara changed from deadly desert to savanna- grassland and lakes formed. Here food was provided predominantly first by hunting and later after domestication by cows. In the Near East during that time grains changed to the predominant source of food. Thus during the Neolithic Revolution development of people may have been quite different in the Sahara Region and near the Jordan. While in Jordan agricultural mode of life evolved which in the fifth millenium spread to Middle Europe in the Sahara region cattle dominated societies evolved (KUPER & KROEPELIN, 2006).

Figure 4.13: Jafr Lake was present in all those areas now presenting light colored Qa bottom and somewhat beyond it, near the city of Ma'an in the southern Jordan.

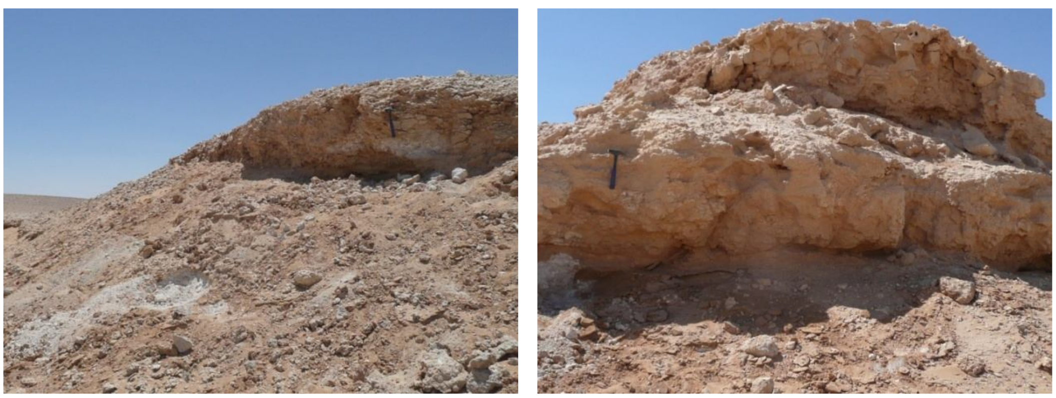


Figure 4.14: Outcropping of Jafr Lake deposits in the Jafr Basin, near the city of Ma'an in southern Jordan.

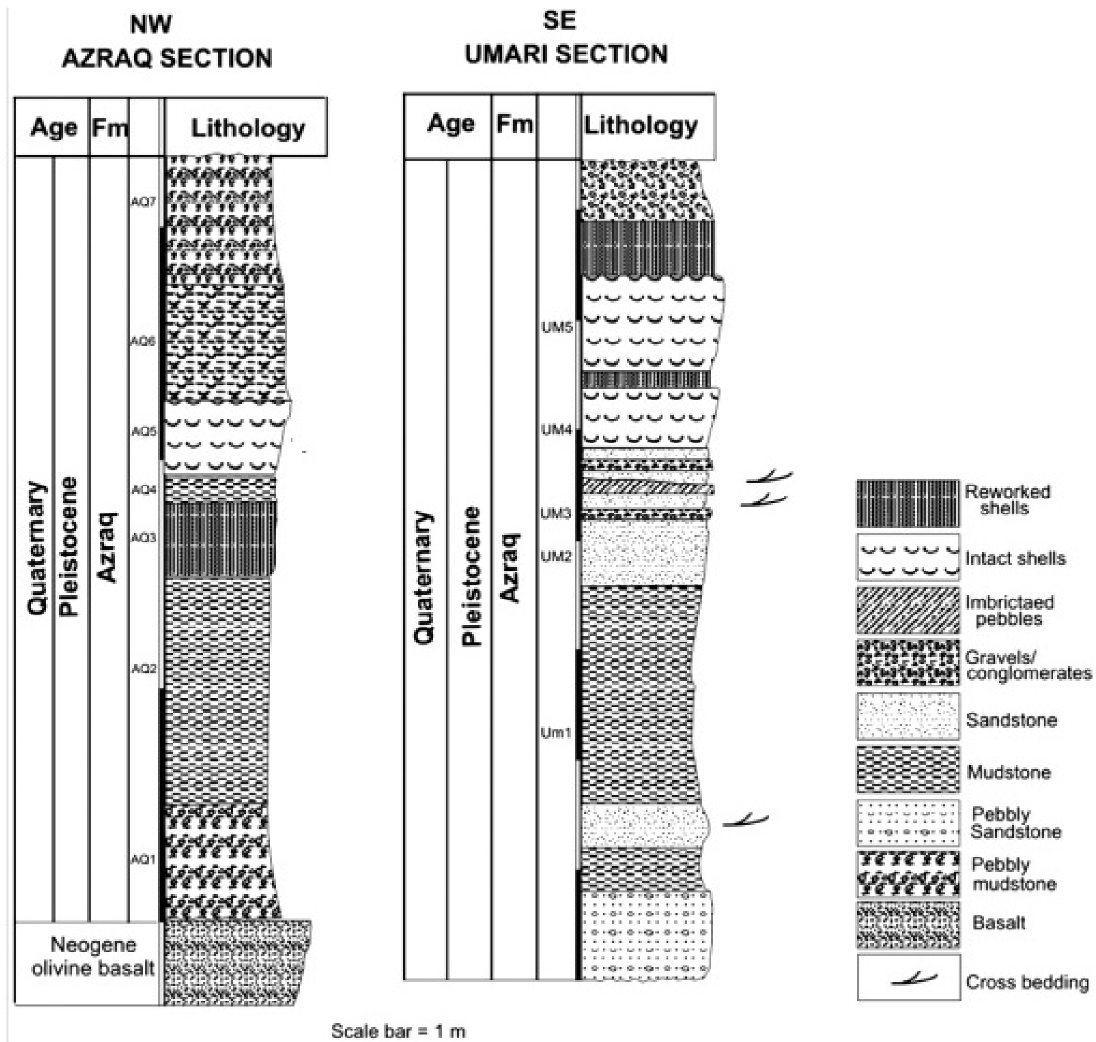


Figure 4.15: Lithology of the the Azraq and Umari sites in the Azraq Basin in eastern Jordan (ABED et al., 2008).

5 GULF OF AQABA , FOSSIL BEACHES AND REEFS

5.1 Introduction of the fossils coral reef terraces in the Gulf of Aqaba

The deepened and widened Red Sea communicated with the Indian Ocean through the straits of Bab-el-Mandeb supposedly during the Pliocene and only after the Middle Miocene stage. Before, and during the Miocene salt had been deposited in the Red Sea basin (FRIEDMAN, 1972). The Bab - el - Mandeb is today 27 km wide with some islands in it and is, compared to the bulk of the Red Sea (proper), relatively shallow, up to 310 m deep. The Gulf of Aqaba has been interpreted to have formed later than the Red Sea and that it served during the Miocene and Pliocene as erosion channel which drained much of Arabia. It is the continuation of the Jordan-Wadi Araba-Rift Valley and its history is connected to it.

As soon as the Red Sea entered the Gulf, terraces formed where the sea eroded into the slopes of the margins of the gulf. Here activity of waves transformed the shore and currents transported eroded material. Next to the beach, usually corals settled in illuminated water and soon reefs started forming which subsequently created a ridge which commonly formed the barrier to a protected lagoon with shallow water. Here deposits formed which covered the former beach. They are composed predominantly of calcareous material that was produced in the coral reef and by the organisms which lived in the shallow water of the lagoon.

The level of the Red Sea has changed several times during the last million years reflecting the changes of water level in the world oceans, several such terraces formed along the shores of the Gulf of Aqaba. At the Jordanian coast up to five terraces can be recognized with the highest now present at about 75 m above sea level (Al-SAYARI et al., 1984; BANDEL & SALAMEH, 2013). But these terraces do not need to be related only to rising of falling sea level but have definitely also been influenced by the fact, that the Jordan-Dead Sea- Wadi Araba- Gulf of Aqaba Rift Valley is a structurally instable area, in which in general, the central portion of the rift subsided, while its margins rose.

The depression of the rift is thus accompanied by mountains on both its sides.

A fully developed terrace consists mainly of beach deposits, those of the shallow lagoon and the fringing coral reef, while deposits from the seaward front of the reef are not recognized.

At the southern locality near the border to Saudi Arabia a coastal portion with influence of the sea reaching onto the land is preserved, while further to the north the coast was formed by a rapidly rising fan of continental debris coming from the highlands in the North and East. Land here rose rapidly next to the sea and the actual beach was covered by pebbles and was quite narrow and quite similar to its modern shape with only few more extended sandy portions meeting the sea (Fig 5.1).

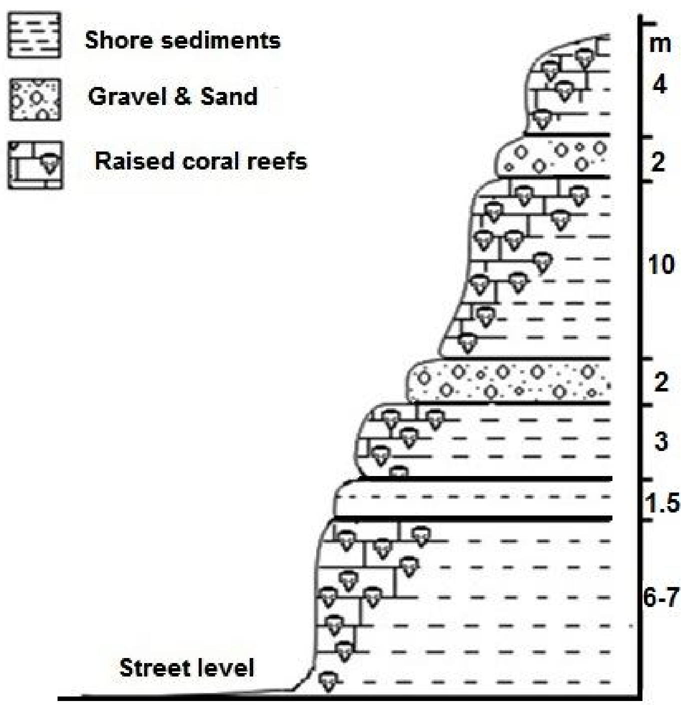


Figure 5.1: Vertical profile showing the relationship of raised reef terraces and the shore sediments or alluvial sands and gravels forming along the drainage wadis.

The terraces noted at dry Valley outlets south of the Jordanian Marine Station represent a prominent feature in the southern portion of the Jordanian coast of the Gulf of Aqaba (Fig 5.2). The ancient beach lines can be traced to continue to the south into Saudi Arabia. Since much construction work is being carried out along the Jordanian coast these traces of former sea levels will become less evident and will soon have disappeared (e.g compare AL-SAYARI et al., 1984).

The structural component to be considered in the interpretation is documented by the circumstance that the terraces exposed next to the Jordanian coast have a slight dip towards the south and near the Royal Diving station not far from the border to Saudi Arabia one of the ancient terraces is seen even to merge with the modern terrace. But here in that general region a former sea level has left its traces on top of the foot-mountains in the fan of debris of the coastal range, but it is here not developed with reef deposits.

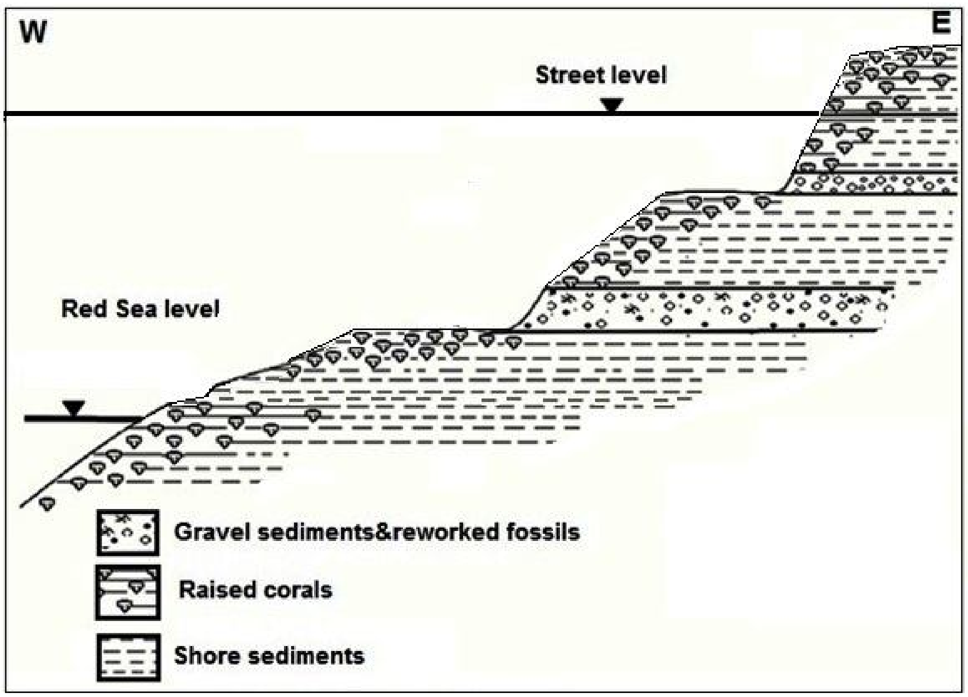


Figure 5.2: Cross section of a part of the uplifted fossil reefs (East of the Marine Station).

At the present shores recent coral reefs and the lagoon produced behind them are found with an inclination towards the sea, the fossil reefs farther from the sea gradually become less inclined, horizontal and further east even dipping landwards. This is a proof of the uplift of the land rather than a drop in sea level. The dip angles of beach sediments at the shoreline range from 5-10˚ due west, decreasing gradually to the east due to the uplift movements. In about 500 m east of the shore, the raised reefs and the old beach sediments become almost horizontal and further east the dip gradually increases to 5-7˚ but due east (Fig 5.3 &5.4).

Figure 5.3: Recent coral reef and beach sediments have inclination of 5 to 10˚ dip in a westward direction, towards the sea, south of Tala Bay Aqaba Hotel, Aqaba.

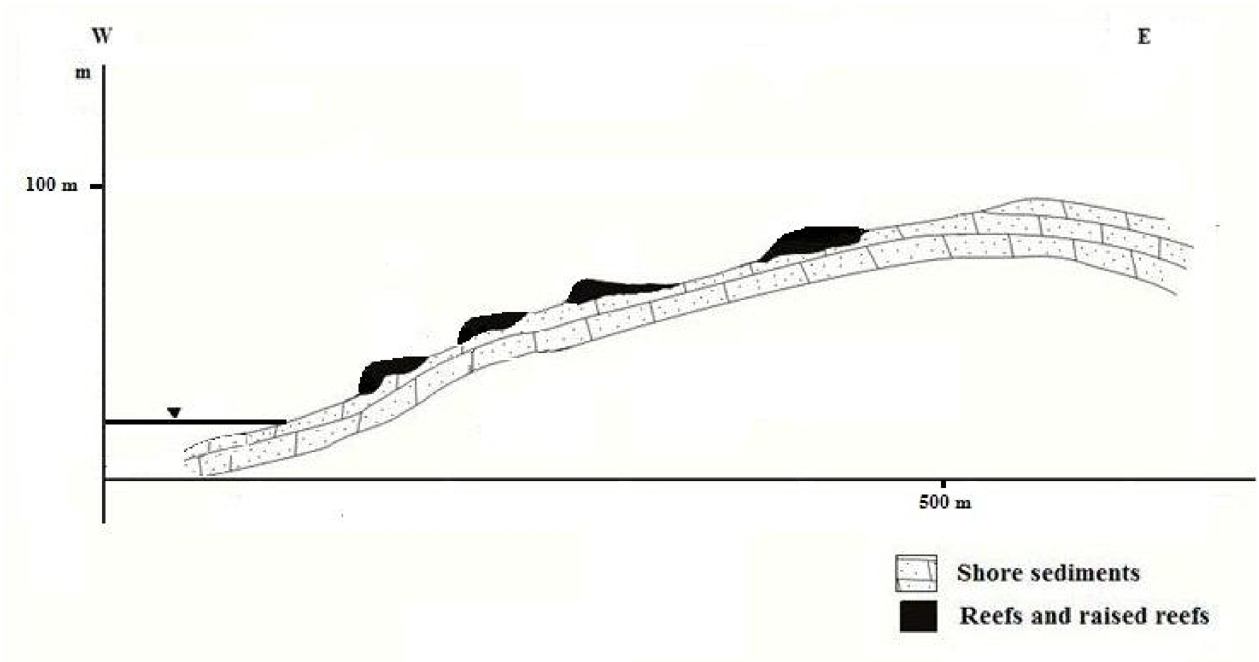


Figure 5.4: Geologic cross section W-E showing living and raised reefs (collapsing reef portions were removed from the drawing).

Beach and reef terraces were also found along the southern coast of Gulf of Aqaba and have been studied on the Miyan side by AL-SAYARI et al. (1984) and on Sinai site by GVIRTZMAN et al. (1992). The ages of the reef terraces on at southern Sinai were determined by Thorium/Uranium method and the reefs dated to have formed around 110.000 years for the lower terraces, the middle terraces are supposedly 200.000-250.000 years old and the upper at about 25 m above sea level even older. Similar ages for the fossil shore and fringing reef along the coast south of Aqaba are problematic since here the sediments of the fan into which former shore lines were eroded and onto which the fringing reefs with their lagoon were deposited clearly document, that the highest terrace is the one formed latest, clearly in altitude above the lower ones and after that they were in part covered by terrestrial deposits of the fan. The fossil terraces found near the Jordanian shore, thus, had formed in a different sequence with the highest, about 75 m above sea level, produced as the last (BANDEL & SALAMEH, 2013).

The Gulf of Aqaba might had been dry during the Messinian (late Tertiary) and its history from that time of about 5 Million years ago to the Holocene still needs to be determined. In Pleistocene times when glaciers covered much larger regions around the North and South-pole than today, water level of the oceans periodically took up a position considerably deeper than today, up to approximately 110 m below present sea level. Since the begin of the Pleistocene about 2.7 Million years ago about ten main cycles of cold and warm climate occurred of which the early cycles were less pronounced than the last four (GRIBBIN, 1982).

Ice ages were named according to their furthest advance to the south in case of the inland ice coming from the North. In northern and central Europe Saale Ice Age at approximately 200 - 125 thousand years ago reached the river Saale in central Germany. During the last warm time between 127,000–117,000 years ago years (Eem Interglacial) and the warm period before the Saale Glacial time about years ago (Holstein Interglacial) sea level rose even higher than it is now (SIROCKO et al., 2005). The fixation of much water as ice covering the continents caused the world ocean to drop below its recent level by up to 180 m.

During the Eem interglacial the level of the sea rose up to 6 m above modern sea level (OVERPECK et al., 2006). The last Weichsel Ice Age lasted from approximately 110,000 to 12,000 years ago thousand years ago and ice reached River Weichsel in Poland (CLAYTON et al., 2006). So much ice was fixed on the continents during this last ice age that the Mediterranean Sea was separated into two parts connected to each other only by a narrow channel between the Italian Peninsula and Africa. The water bodies of the Mediterranean Sea were thus separated from each other and the water held within them was heated differently. While in the western part it has been reconstructed to around 7°C (today around 22°C), in the eastern part it was warmer with 18°C (today around 26°C).

The Gulf of Aqaba is connected to the Red Sea by the Straits of Tiran which is 13 km wide and its bottom lies at its deepest part 290 m below sea level. The deepest part is near the Sinai shore in that part of the Gulf of Aqaba and the other parts of the straits are much shallower and only about 70 m in depth and may have thus been land during glacial times.

In Bab el Mandeb, the entrance of the Red Sea from the Indian Ocean and even more so at the Straits of Tiran at the entrance from the Red Sea to the Gulf of Aqaba sea ways were even narrower and shallower than they are today, and may even have been closed at times. There exists even a hypothesis that around 60.000 years ago man could cross from Africa to Arabia by foot.

5.2 Paleoecology and Sedimentology of fossil coral reefs of the Gulf of Aqaba

At the Jordanian shore a terrace connected to a fringing coral reef has almost continuously developed, nowadays interrupted by modern construction of the harbor. It is still well developed near the Marine Science Station of Jordan and for some distance to the south of it. Here usually corals produced a solid reef frame with a steep drop towards the Gulf and a shallow flat lagoon towards the land. This flat terrace with its lagoon was and is produced predominantly by coral growth at its seaward edge and the sediments here consist of coral debris mixed with the carbonate skeletons of all the organisms which lived there. To it materials coming from the land are added. Due to the aridity of the land terrestrial material may have little influence except in places where dry Valleys end and occasional flash floods bring debris with them. The beach consists of sand or pebbles and usually has a hard bank near the high tide line consisting of beach rock.

In all these zones numerous characteristic animals live of which those producing a calcitic shell are of special importance when the actual conditions are to be compared with those found in the fossil environment.

Modern distributions of corals on the lagoon flat and in the reef on its seaward side were studied intensively by MERGNER & SCHUHMACHER (1974). They noted that the stony corals (Scleractinia) in the lagoon belong predominantly to 7 species, *Cyphastrea microphthalma*, *Favia pallida* (Fig 5.5a), *Montipora tuberculosa* (Fig 5.5b), *Favia melicerum*, *Goniastrea retiformis* (Fig 7.6a), *Pavona decussate* (Fig 7.7a), *Stylophora pistillata* (Fig 5.7b), and *Favia melicerum*. The Hydrozoa *Millepora exaesa* is present as well. The illustration documents a few of the coral as they are growing in the shallow lagoon and the edge of the reef (as taken from the internet). These coelenterates can also be recognized from the fossil reefs.

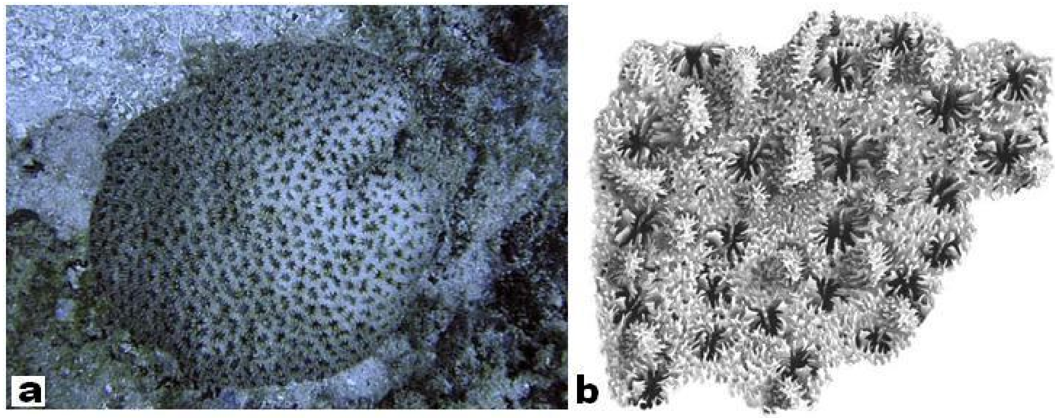


Figure 5.5: Different types of coral, a. *Favia pallida* coral, b. *Montipora tuberculosa* (Source, http://coral.aims.gov.au).

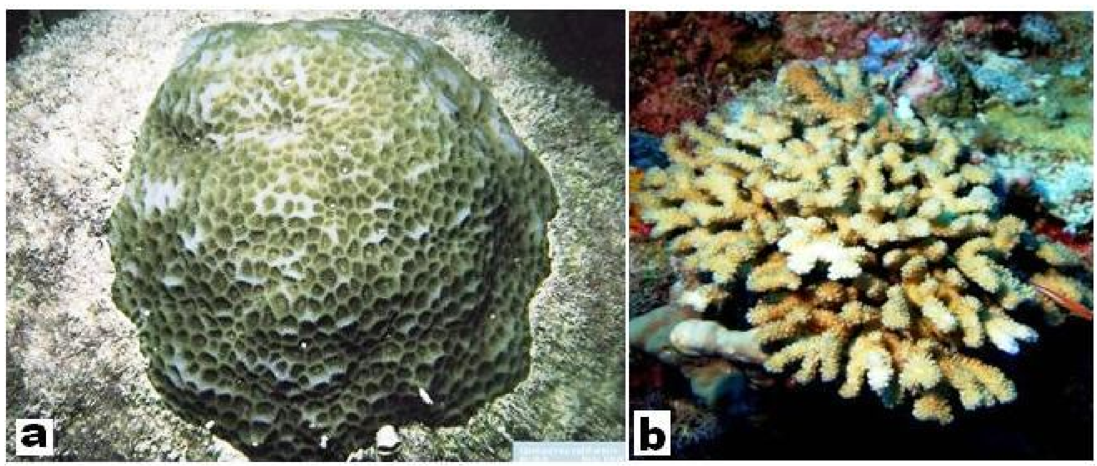


Figure 5.6: a. *Goniastrea retiformis* (Source, http://www.panoramio.com/), b. *Acropora variabilis* (Source, http://commons.wikimedia.org/).

Figure 5.7: a. *Pavona decussate,* b. *Stylophora pistillata (*Source, http://www.aquaportail.com/

Figure 5.8: *Platygyra lamellina* (Source, http://www.aquaportail.com/)

Especially the remains of the echinoids are well preserved in the fossil deposits since their skeleton is originally composed of calcite. Here the sand-dollar *Clypeaster* (Fig 5.9a) is locally well preserved (locally). It lives nowadays in the sandy portions of the bottom of the lagoon, well hidden in it when alive. Its shell is rapidly destroyed after death and when the animal had come to the surface, thus a well preserved corona indicates that the sand-dollar died in living position, when still in the sand. The thin hollow spines of *Diadema* (Fig 5.9b) are recognized when the fine sediment sand of the lagoon is studied, while of the corona only fragments are found. *Diadema* in the modern lagoon grazes growths from surfaces just below low water level and the animals move up and down with the tides. They are thus not easily covered by debris and before becoming integrated in the sediment of the lagoon their shells were destroyed and fragmented.

In case of *Echinometra* (Fig 5.10) and *Tripneustes* it happened similar but the remains are less common, also reflecting their modern occurrence in the reef and the lagoon. They are nowadays found next to corals or larger debris in the deeper parts of the lagoon and do not move about as much as is the case with *Diadema*. With their hard teeth they constantly erode the hard carbonate material predominantly consisting of dead corals and reduce it to sand size while feeding on algae which grows on these surfaces. But also their shells had usually been fragmented before being included in the sediment of the lagoon and spines are small and more solid than those of the hollow ones of *Diadema*. Fragments of the corona of *Heterocentrotus* are easily recognized due to the large scars on them left by the spines, but very common and easily recognized in the field are their large spines. *Heterocentrotus* nowadays is the characteristic large and colorful sea urchin that lives among the corals near the reef edge and can solidly protect itself against being washed away or being preyed upon by larger fish by anchoring between the solid coral with its large and long spines (Fig 5.11). These are transformed during early diagenesis rapidly into solid mono-crystalline structures and thus well protected against erosion. They are one of the most obvious fossils encountered in the sediments of the former lagoon and among coral growths as well as coral rubble.

The mode of diagenesis preserves even the thin corona of the irregular sea urchin *Lovenia* (Fig 5.11b) which is nowadays common in sandy areas in the lagoon. MERGNER & SCHUHMACHER (1974) recognized *Clypeaster* and *Lovenia* (as living and moving in the sand).

The irregular sea urchin *Lovenia* lives well hidden in the sediment and as the sand-dollars in that position can be preserved, while those sea urchins which live on the sediment as the cidarids and the regular sea urchins with less solid spines (*Echinometra*) are usually present with fragment of their shell. *Tripneustes* (Fig 5.12) is living in a similar way in that region (MERGNER & SCHUMACHER, 1974).

The echinoderm skeletal elements are usually porous in their structure but their calcite biocrystallites are so well ordered and arranged in such a way, that during early diagenesis each skeletal element turns into single calcite crystals. This can be recognized easily in case of the large spines of *Heterocentrotus*. A spine of the living species will break as a bone with no sharp corner, while a spine from the fossil location will displace a smooth crystal surface of a calcite when broken in two.

Fossil reefs connected to a lagoon behind it and also that of the former beach are well preserved just above the road along the shore just south of the Marine Station of Jordan.

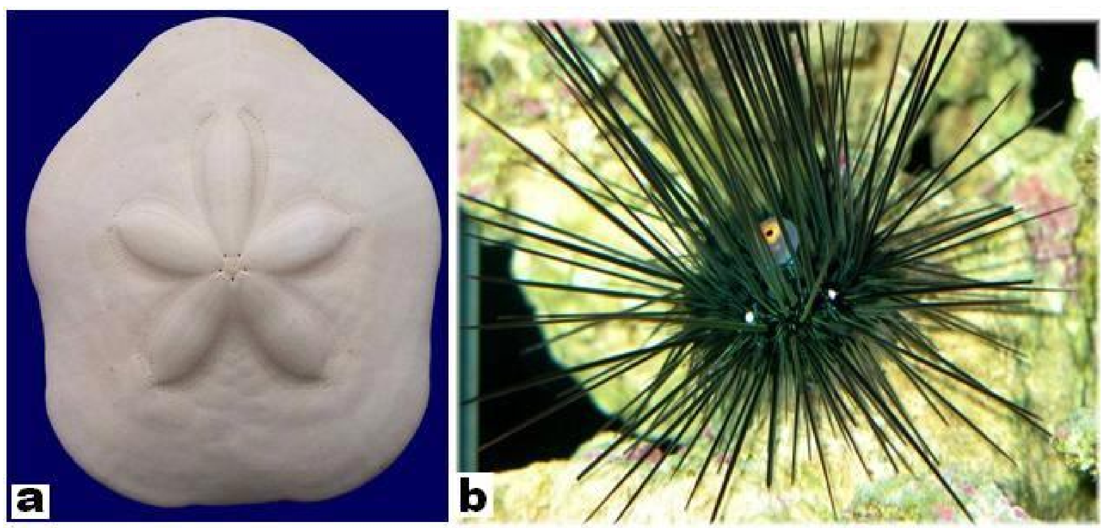


Figure 5.9: a. Clypeaster (source, http://www.echinoids.nl/), b. Diadema (source, http://www.aquariumslife.com/).

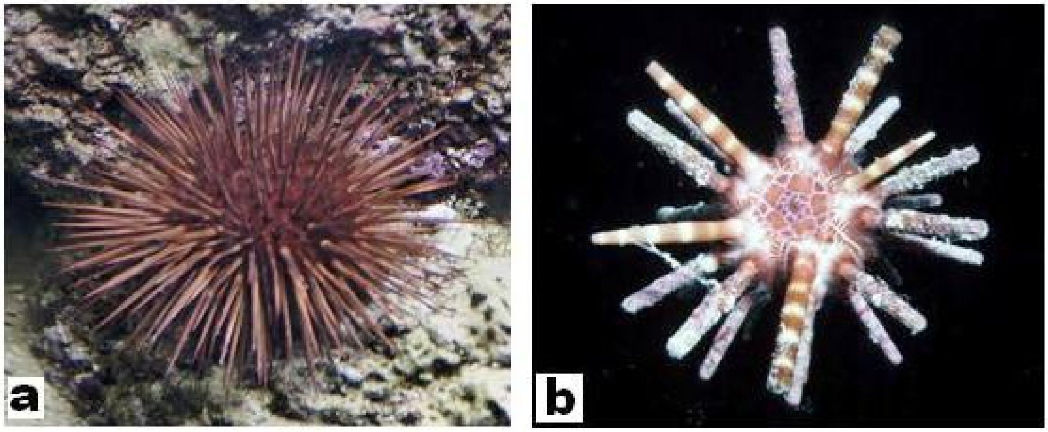


Figure 5.10: a. Echinometra (Source, http://en.wikipedia.org/), b. Eucidaris (Source, http://www.flmnh.ufl.edu/).

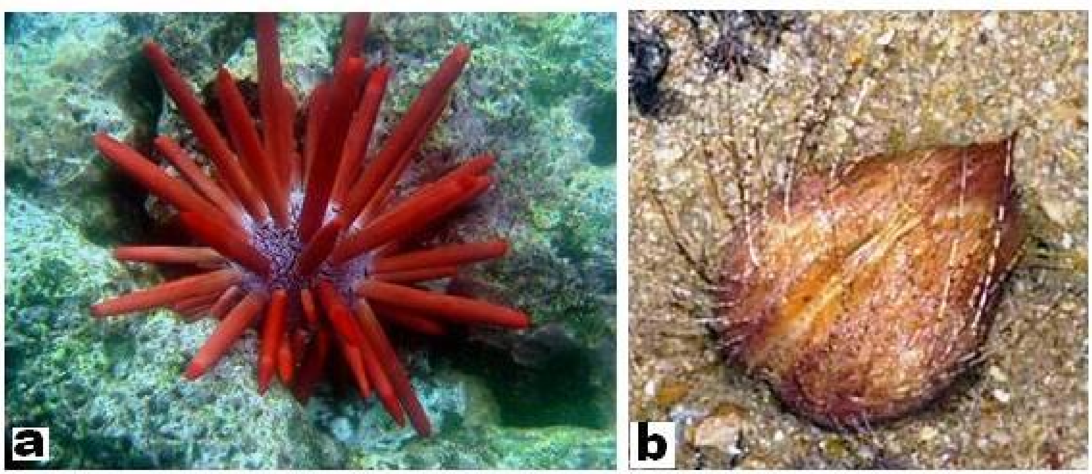


Figure 5.11: a. Heterocentrotus mamillatus (Source, http://en.wikipedia.org/), b. Lovenia (Source, http://www.wildsingapore.com/).

Figure 5.12: Tripneustes gratilla (Source, http://www.aquaportail.com/).

Ancient shore lines as connected to the lagoon and reef sediments were preserved on the fan of detritus washed down by occasional rains and floods from the mountains which accompany the coast. The mountains are composed predominantly of crystalline rocks of Precambrian age and fan sediments consist of mostly angular particles eroded from them, only rarely pebbles consisting of red sandstone occur in a high layer that is at about the position into which the highest terrace has been eroded. The highest of the terraces found on this fan lies at about 75 m above sea level (approximately the right margin of Fig 5.13). Its position, so high up and thus well above a possible former rise of sea level, indicates that sea level change alone cannot have been responsible for its place on the terrestrial fan. Thus its position is an evidence for structural unrest that strongly affected the northern part of the Gulf of Aqaba along the Jordanian coast.

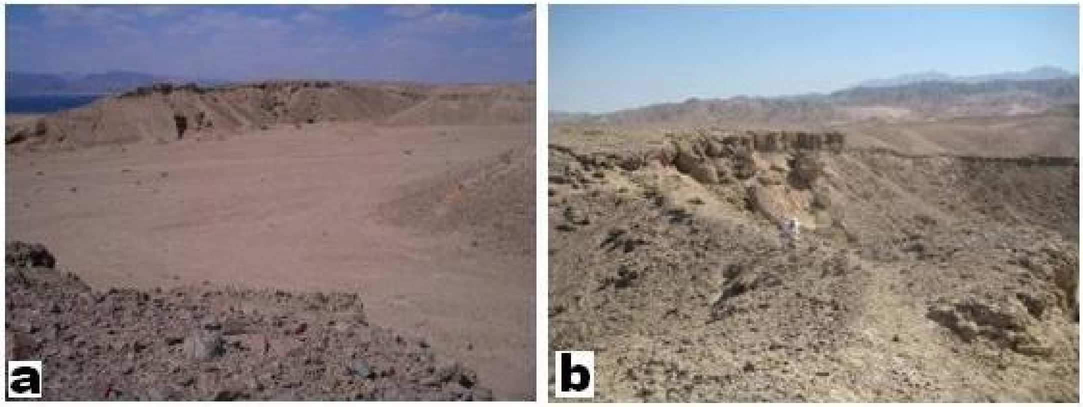


Figure 5.13: a. The northern sides of the dry valley with three of the terraces are located north of the Marine Science Station; about 500 east of the recent coast line, the wadi section shows the highest terrace at 75 m over the recent sea level. The highest terrace is caped by a reef showing clearly the transition from the reef to the lagoon and finally to the shore line. The three terraces, b. Middle terrace in dary Valley about 500m east of the shoreline (North of the Marine Science Station) with top at 55 m above sea level.

The middle terrace is capped by massive coral debris and corals in growths position. In the frontal part reflecting the former position of the lagoon near the reef edge and lower coral growths mostly still in former growth position further in the back with transition to the former shore still preserved. This middle terrace formed during an extended period of growth with stable water level. It is the fossil counterpart to the modern reef, lagoon and beach as is present near the Marine Biological Station in the protected portion of the Jordanian shore. The highest fossil shore is found on the terrace ridge in the background (Fig 5.14).

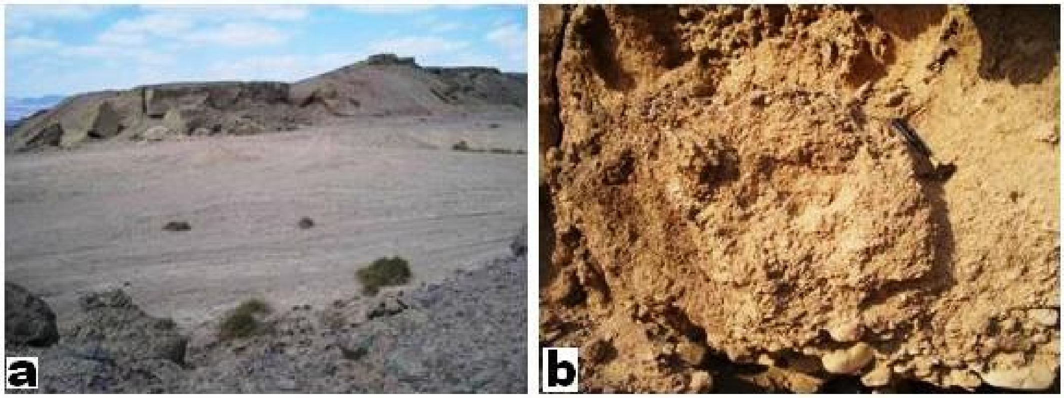


Figure 5.14: a. On the northern terrace step two reef terrace levels can be seen, in north of the Marine Science Station, about 500 east of the recent coast line. The adjacent flat terrace includes the transition to a small back reef partly lagoonal zone with well preserved beach pebbles next to the slopeto the next terrace step. Beach washed pebbles were covered by fan sediments composed of angular debris which is still forming the steep slope between the two terraces. The middle part of the picture is occupied by the modern Valley bottom which was formed by subsequent erosion cutting into the former reef and lagoon terraces and filled up now partially by alluvial sediments, b. details of the reef sediments with, b. details of the reef sediments with a large coral block surrounded by lagoon debris that covers beach deposits.

The formation of the fan of debris of erosion coming from the North and East to the Jordanian coast occurred predominantly at the time of low level of the oceans during the cold periods of the Pleistocene when weather was more humid and rains transported much material from the mountains. While the sea level sank during times of glaciations the climate changed to less arid in Jordan. Within the Weichsel/Würm glacial it rained so much in Jordan that the Dead Sea could expand considerably to form the Lisan Lake. But the even larger ice ages of the Elster and Saale could have produced similar weather conditions with more rain in Jordan.

The fossil reef terraces represent evidence for a shore environment with pebbles, beach rock, shallow lagoon with calcareous sand and single coral heads, and fringing coral reef with corals connected to each other in dense growth (Figs 5.15-5.17). The sediments which were present on the seaward side of the fringing reef are usually not preserved in the fossil terraces. Of the originally rich fauna of molluscs encountered on the beach, the gastropod *Nerita* has become preserved, since it has a thick outer calcitic shell layer (Fig 5.18). Oysters settle here and their fossil shells are also encountered on the former beach. Within the tidal zone large barnacles (*Tetraclina*) cover boulders, and have also become preserved since their shell is calcitic.

From the fauna of the lagoon containing many species of bivalves and gastropods pectinids (*Pecten* and *Spondylus*) some *Lima* as well as oysters still are found. Most others originally having an aragonitic shell have been dissolved or especially when provided with a large shell, as is the case in *Conus*-species are present as internal fills (steinkerns). Sanddollars (Clypeasters) are present, even though they appear to have a much more delicate shell than is present among the Gastropoda, for example the large Trochidae, Strombidae and Muricidae which were definitely present here. At some places on the beach with less wave action that is today characterized by the presence of quartz sand many hermit crabs occur each with a gastropod shell as home. Such assemblages with the thick shells of naticids and strombids as preferred by hermit crabs are preserved in such a sandy layer between and next to the fossil reefs (Fig 5.15). The overgrowths of the gastropod shell by calcareous algae document that they have been used by the crabs after their producers had died.

Within the shallow water of the lagoon as well as in the reef itself the large bivalve *Tridacna* is living today. Their thick solid shell can also be found in the fossil terraces that formed in that environment. These massive bivalves are anchored with their byssus to the substrate and in that position they are often also found as fossils documenting that they have not been moved from their original living position. They can be found today in the shallow lagoon below low tide water surface in well illuminated water as well as in the reef, since they live with symbiontic algae in the tissue of their mantle.

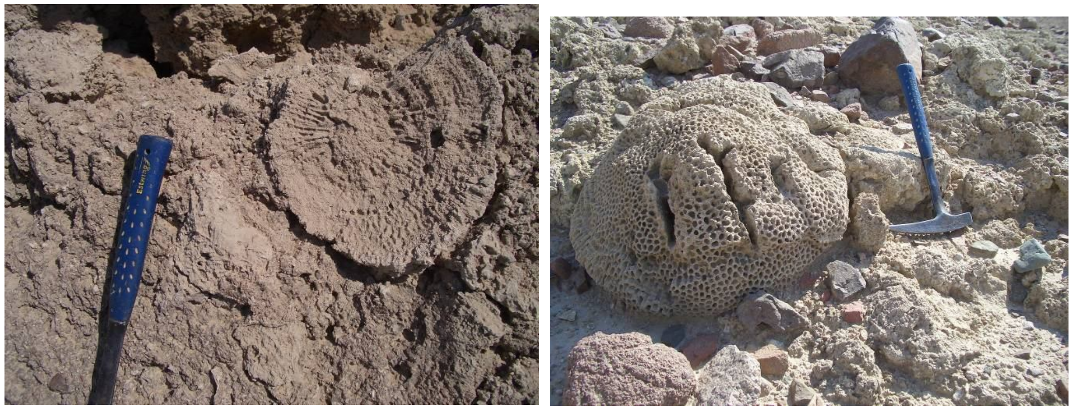


Figure 5.15: Corals from the fossil reef sediments of the terraces north of the Marine Science Station, about 500 east of the recent coast line. On the left side one from the bottom side included in the debris that formed the deposits of the lagoon; on the right side a species of *Goniastrea* as it was washed to the former beach and included within the beach pebbles, just in time when the beach was covered by fan debris and no further wave corrosion occurred, location

Figure 5.16: Fossils from the reef terrace north of the Marine Science Station, about 500 east of the recent coast line. a. Fossil corals of the *Stylopora* type which had grown in the shallow lagoon, b. the extremely thick shell of *Tridacna* with both valves in place as it was living in the shallow water of the lagoon.

Figure 5.17: Fossils from the reef terrace south of Aqaba, south west of Tala Bay Aqaba Hotel, Solid spine of *Heterocentrotus* in the fossil reef deposits, the coronae of the irregular sea urchin *Lovenia* and the sand-dollar sea urchin *Clypeaster* together with some of the more solid thick shell gastropods of naticid and strombid relation, which were carried by hermit crabs.

In the actual reef, corals usually have a very rugged preservation, commonly they are predominantly preserved with their filled spaces, while the actual aragonitic skeleton has become rudimentary and often is even newly (re)crystallized and transformed into calcite (Fig 5.19). The coralline algae in contrast are well preserved, since their original composition is calcitic. *Lithothamnion* forming crust and growing in the shape of irregular pebbles (form) nowadays are found in the shore area and on the edge of the reef to the open sea, and their fine-grained calcareous skeleton is well preserved and recognized well in the fossil reef and its debris.

In case the reef or parts of it were incorporated in beach rocks before becoming part of eroded terraces preservation can be better. Here voids between skeletal remains were closed earlier during rock formation (diagenesis) by calcitic cements, better protecting the originally aragonitic structure of the corals from decomposition.

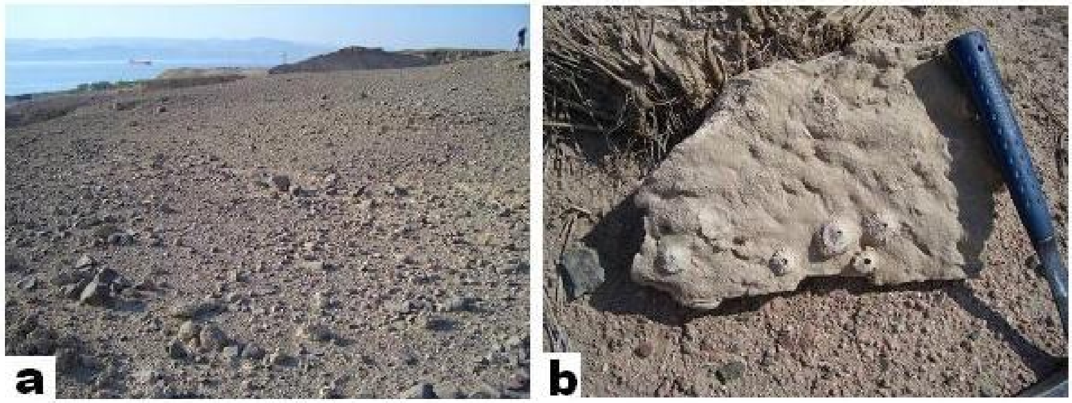


Figure 5.18: a. The marine terrace south of Aqaba with typical beach fauna with *Nerita* and oysters of the same species as on the beach nowadays, b. A coral slab settled by the characteristic barnacles (*Tetraclita*) and oysters are part of the solidified beach consisting of beach rock (North of the Marine Science Station, about 500 east of the recent coast line).

Figure 5.19: fossil reef terraces north of the Marine Science Station, about 500 east of the recent coast line at elevation 50 m asl with diagenetic changed fossils; a. dissolved aragonite shells, as that of the bivalves and solidified calcitic shells, as that of the sand-dollar, b. Corals of the *Acropora* type which grew in the shallow lagoon are rooted on shore pebbles and are covered by gravels of the shore.

The deep depression of the Gulf of Aqaba with the shore up to 120 m lower in Late Pleistocene than today absorbed the sediments washed from the mountains through Wadi Araba from the North as well as via small wadis from East. The fan with the fossil beaches and reef preserved in its lower part is today totally cut off from its former source in the highlands and new erosional channels were cut by later occasional rain floods. The head waters of the fan were parasitized by a gorge through which the road to the harbor was constructed and that has since been cut into the crystalline rock north of the fan. Debris washed from the hinterland in the east will now reach the Gulf of Aqaba by way of a different canyon. This situation provides data to the interpretation to the relative time during which the fan of debris was formed into which ancient beaches were cut by the Gulf of Aqaba. AL SAYARI et al. (1984 a and 1984 b) assume from the terrace developments in the southern part of the Golf of Aqaba as well as from the terrace development along the northern Red Sea that the highest alluvial fan terrace was formed during the Late Pliocene or Earlist Plesistocene in connection with an intensive wet periods with extreme rain discharge.

The beaches were active during this phase as well as during the following periods with lower sea levels during the Pleistocene when the process of the fan development was still going on by adapting to the new base levels. While the highest beach terrace interfingering with the oldest fan may form a marker layer for the Late Pliocene the following deeper terraces are without an clear absolute dating difficult to classify because of the extreme changing sea levels during the glacial periods , where even higher terraces could be much younger then deeper ones, which are partly still below the recent sea level.

In the case that the beach formed during a pluvial period, which might have occurred at the time of one of the three last ice ages, sea level may had been up to more than 100 m deeper thanthe actual sea level. The classification and parallelization of the marine terraces over a certain distance become even more difficult due to clear indication of much tectonic activity of the area as it documented north-east of the Marine Science Station of Aqaba. The area has been raised while the bottom of the gulf was sinking. The structurally formed depression of the Gulf (and it rising) swallowed up also all the debris that has since been washed down the new canyon that was eroded into the fan after its emplacement.

Many of the mountains of crystalline material to the east of the harbor and of the Marine Science Station had apparently been covered by the large fan and have since been exposed by erosion, representing clear evidence of quite strong uplifting of the north-eastern side of the Gulf since the time of the fan formation and the growth of fossil reefs and their connected terraces during emplacement.

Since the fossil terraces show a dip towards the south, apparently the northeastern side of the gulf has risen up, while on the other western side at Eilat the area sank. Thus the position of the fossil reef terraces document the rather strong structural motions occurring along the Gulf of Aqaba- Wadi Araba, Dead Sea and Jordan Valley geo-suture structure within geological short times. Field observations show that block of rocks from Cretaceous age found with the aragontic Precamberian rocks which they coverd by Cambiran deposits that indicates that differential displacement affected on the northen coast of the Gulf of Aqaba.

Figure 5.20: The lower dissected fan with one main terrace plain in the right upper part of the picture, Section between Aqaba city and Aqaba harbor (Image source, Google Earth).

Figure 5.21: The fan has been eroded next to the crystalline ridge (location, south of Aqaba, opposite site to Tala Bay Aqaba Hotel). The former coast line lies near the coast road, the highest beach on the sharp ridge above the double house and the lowest beach next to the coast road on both sides of the flat wadi base. Construction work has obscured the shape of the terraces, while the original fan is seen with modern erosion channels, of which the most prominent ones use former ones in general, (Image source, Google Earth).

Among the terraces with their reefs three had obviously been formed during distinctly different times. Beside the recent reef-lagoon platform and the slightly developed cliff notch about 1,5 m above the sea level, which is asumed to be a relict of the Flandrian transgression of Mid-Holocene (AL-SAYARI et al., 1984a). Of those preserved to the North of the Marine Science Station, the oldest is the one closest to the road. Here a transgressive character is noted with the lower one overprinted and partly overgrown by several higher ones. Subsequently the higher layers may be fused to each other. These layers hold the coral ridge, the sediments of the lagoon and the pebbles of the beach with rounded coral debris and the characteristic *Nerita* as indicator fossil. One can split these deposits into several ones on the southern side of the dry valley, while it forms one unit on the northern side. During reef growth the sea level was rising and the mountains were sending down their debris. Since the deposition of the fan was continuous during terrace growth it is difficult to distinguish different stages. Next to former beaches sometimes sand is intercalated in the fan deposits and within this sand concretions had formed. Such cementation of the quartz sand presents evidence for the addition of sand from the beach that included carbonate particles derived from skeletal elements. This lower terrace is well set off from the median terrace by 10 m of angular fan debris.

The exposed median terrace is developed with reef edge, extended lagoon deposits including thickets of branching corals and beach with partly large and well rounded pebbles. The uppermost and youngest terrace has only the beach with rounded pebbles, beach-rock, sand-dunes and a few washed shells. In the zone of rounded beach worn pebbles overlie thick fan deposits consisting of angular material covering the terrace below. The modern base of the wadi has a slightly stronger dip towards the sea than the general dip of the fan and thus the consecutive terraces are exposed at both sides.

Figure 5.22: a. Fan (with fossil reefs) coming from the mountains on the right is corroded and cut by younger erosion channel b. The same mountain range and the reef platform in front- of the middle reef lagoon, north of the Marine Science Station with elevation about 60 m above recent sea level.

In the southern part of the large fan and near the hotels but on the opposite side of the coastal road sediments exposed can be interpreted to have formed in a salty intertidal to lowly supratidal flat with deposits of salty lakes and mud flats.

Here an intercalation is found with gravel beds below and above the horizontal deposits of a salt water filled lagoon that was periodically filled with fresh water and later again with salt water (Fig 5.24& 5.25).

The sandy to even finer grained laminated deposits present evidence of a changing environment. Some layers have root systems preserved, and were thus formed when fresh water was available in the sediment supporting the growth of larger plant. In other layers the burrow systems of crabs are preserved, thus indicating that conditions for crabs to settle here were only of short live time. Other layers have a fine lamination as is produced when cyanobacterial mats cover the substrate and catch fine suspension and fix it in their growth. Such laminated layers are over and underlain by cross bedded layers of sand, some of which have herring-bone cross-beds. These present evidence of changing current directions as present on a flat intertidal area. These deposits, now present on the top of the steep sided hills next to the coastal road present evidence for their formation within the level of the sea, and in contrast to modern conditions in the area of a flat lagoon that was connected to fresh water run-off as well as to the sea.

The fossil reef sediments consist of gravels on which coral reefs developed and the gravels are underlain by weakly cemented siltstone and sandstone. The fossil coral reefs themselves are covered by weakly cemented gravels and cross-bedded sandstone (Fig 5.26).

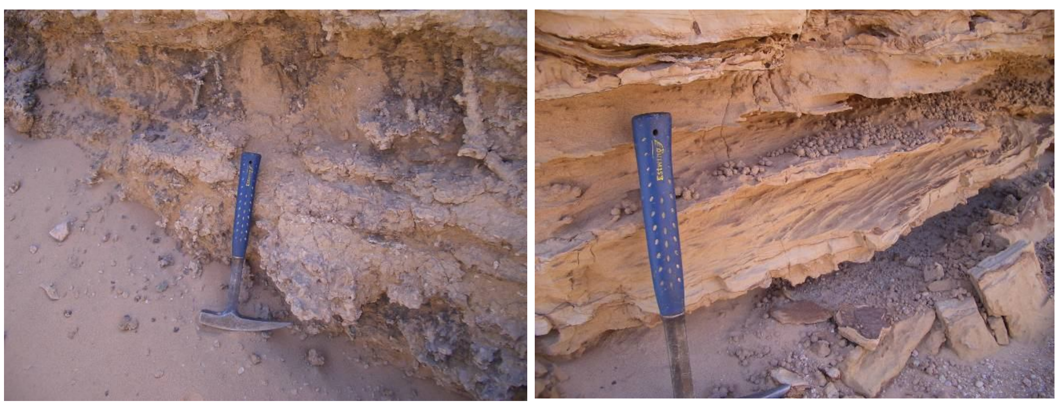


Figure 5.23: Crab burrow and root system in the intertidal lagoon beds at the southern Jordanian coast, and cross-beds of shore deposits with gypsum concretion in layers (Location, South of Aqaba, opposite site to Tala Bay Aqaba Hotel).

Figure 5.24: Near shore deposits in the environment of flat lagoon, intercalation of silt and sand in shallow water deposits with hardened cemented pebble bearing beach-rock top and now forming the top of the terrace hills (Location, South of Aqaba, opposite site to Tala Bay Aqaba Hotel).

Figure 5.25: Interfingering of the sediments of the Wadi fan with sediments along a flat coast documented as is present in the south of the Jordanian coast terrace sequence (Location, South of Aqaba, opposite site to Tala Bay Aqaba Hotel), and reef and lagoon deposits imprinted in the fan above the Marine Science Station seen.

Figure 5.26: Laminated fine grained sand as forms when algal mats hold suspension and fine-sand of the former lagoon, and below and above cross beds of intertidal character (Location, South of Aqaba, opposite site to Tala Bay Aqaba Hotel).

6 MACRO- BIOINDICATORS

6.1 Introduction to macrobioindicators of Jordan

In this study aquatic macrofauna found in different water bodies in springs, creeks/rivers and ponds in Jordan were studied as indicators of water purity. Water, especially, in semi- arid countries, such as Jordan (with unpredictable seasonal rainfall) subjected to scarcity of water and to an ever- increasing demand from the rising human population) represents a great problem for scientist, planner and policy makers. Surface water resources in Jordan can be negatively impacted by development through the addition of urban, industrial, and sewages. So it is important to protect Jordans surface water resources in order to keep these aquatic systems in a healthy and productive condition.

One of the main aims of the present study is to use aquatic fauna as bioindicators for water status in Jordan. Aquatic fuana are describing not only the water quality but also reflect their habitat conditions.

The selected size of organisms to be used as bio-indicators is larger than about 0.5 mm, so that they can be seen with the naked eye (macro-organisms). The smallest animals to be considered in the study belong to the Ostracoda, representing tiny crustaceans. The largest are frogs and crabs. Several groups of animals and plants can be utilized to characterize the quality of water. Annelid worms, the larvae of insects, mites (arachnids, spiders), gastropods and crustaceans may belong to the common aquatic animal species in Jordan (BANDEL&SALAMEH, 1981). Less common but often quite indicative to specific environments are some sponges, different worms, fish, and decapodan crabs.

In section 8.1 the species or groups of species that are characteristic to a certain environment of the water and its degree of pollution will be characterized. Here the specific communities for specific environments such as clean water of different types, weakly to strongly polluted water and water affected by different degrees of salinity will be described and characterized. Examples will be mentioned for specific places in Jordan.

The abundance of aquatic macrofauna depends mainly on the physical and chemical properties of the water they are living in. Further, aquatic organisms are known to respond to changes in the quality of water which enables their use as bioindicators (MCGEOCH 1998; DZIOCK et al., 2006). The term bioindicator species was used by KOLKWITZ and MARSSON, in 1908 regarding the impact of pollution on aquatic organisms (ROSENBERG& RESH, 1996). Because of their extended residency periods in specific habitats and the presence or absence of particular aquatic species in a particular environment these can be used as bio-indicators of specific environmental and habitat conditions (ROSENBERG & RESH, 1993).

Scientists have traditionally assessed the status of the water quality by measuring physical, chemical and biological parameters (e.g., temperature, chemicals dissolved in water, nutrients, among others phosphorus, pH, conductivity, aquatic species) but, in later years there has been a global trend to improve the quality control to complement their judgment by the use of biological indicators such as diatoms, macro algae (diatoms are algae- thus distinguishing micro and macroalgae), macro invertebrate or fish (OLIVEIRA & CORTS 2006; OLIVER & BEATTIE, 1993). Using biological indicators to estimate the habitat characteristics and its water quality is vital and is different from measurements of physiochemical character measuresments of water quality. Several reasons and advantages can be summarized for the importance of bioindicators such as:

- The organisms living in the water have to deal with every character of their environment and thus react to them. Once the reaction becomes known it can be used for the characterization of the environment (ROSENBERG & RESH, 1993).
- Animals occur in spring, creek, rivers and lake waters with a good number of different species of very different systematic groups.
- Biomonitoring methods give scientists accumltive information about the water condition for long term changes during the occurrence of those organisms, like a videotape. In contrast, the classical measurements of the physical and chemical parameters characterize the information that was accurate only at the time of sampling, similar to a “snapshot” (ALBA-TERCEDOR 1996; ROSENBERG, 1998).
- Biological indicator techniques are relatively rapid assessments which take shorter time than chemical testing (RESH et al., 1995). Once the bio-indicators are recognized, the quality of the water as well as changes occurring or having occurred can rapidly be assessed.
- The long life time of macrobioindicators (e.g, worms, insect, and mollusk) could show the water quality condition changes for more than one month and sometimes for several years. Whereas Microgoraminsms (e.g, Protozoa, bacteria) reflect the water quality for short periods (some weeks).
- Also finally, bioindicator organism collection and identification techniques are less expensive in comparison to chemical analysis and other methods of water testing. One needs the general knowledge of the biological system to which the animals belong and rapid comparison of species can be carried out with a picture-catalogue in the field. Final species determination for more detailed analysis needs only a microscope.

Bioindicator organism techniques were the object of interest of many authors around the words. Several studies have been performed in Europe, USA, Australia and other countries by using aquatic biota as bio-indicators in order to monitor the quality of surface water. These model studies are available and the way in which they have been carried out can also be utilized in Jordan. In Jordan only one study in the early eighties

(BANDEL & SALAMEH, 1981) has been carried out where the status of the water resources in Amman- Zarqa area was studied by correlating the hydrochemistry of a water source to its hydrobiology, those authors were able to assign grades of pollution to the different sources ranging from 1 for the best water quality to 10 for heavily polluted water. This study can be utilized for the present work and even improved. Other historical examples for bioindicators since the beginning of the twentieth century by using macro-invertebrates to assess water quality and degrees of pollution in rivers subject to sewage contamination can be traced back to the pioneering work of two German scientists, R. KOLKWITZ and M. MARSSON, in the early 1900s. Their publication on saprobity (degree of pollution) led to the development of indicator organisms. KOLKWITZ and MARSSON (1902, 1908, 1909) were the first or among the first to exploit these effects and present a practical system for water quality assessment using biota. Their system, known as the Saprobic system, has been used mainly in Central Europe. In the beginning, bio monitoring was performed on micro-organisms but after a while macro-invertebrates as bio-indicators rapidly gained in importance (cf. BARTCH & INGRAM, 1966; MACKENTHUN, 1969; SLADECEK, 1973; ROSENBERG& RESH,, 1993; HERING et al., 2004). In Jordan where water sources are small and rivers in international considerations, except the Jordan River are not found, only small surface water flows of generally few tens to few hundreds of liters persecond are found. Such small discharges are vuluernable to small amount of pollutants. Hence, the fast recognition of changes in their quality is very essential for water users, especially, when that water is used as a source of drinking water. As an example on that is the water of KAC and its feeding sources, which is used after purification for the drinking water supply of Amman. Pollution events along KAC have taken place more than one time a year since the operation of the drinking water supply from KAC. The pollution events were not detected before the polluted water reached the inhabitants and caused sickness and public unrest and interruptions in the water supply.

The problem was that the water samples collected for quality checks require transportation to the laboratories and rigorous chemical and physical time-consuming analyses.

Biological indicators disappearance or appearance can easily show that something happened to the water quality. It needs only a trained person controlling the canal water. Such appliciation of bioindicator results can save time, health detriments, trouble in purification plants and social unrest.

6.1.1 Objectives

The aims of the aquatic bioindicators study are:

- Investigate the occurrence of aquatic organisms in running surface water of springs, creeks, rivers and stream located in the area extending from River Zarqa in the north to River Mujib in the south to correlate their abundances with water quality parameters (e, g., temperature, pH, conductivity, biological dissolved oxygen and chemical dissolved oxygen).

- Analyses water quality in the different locations having different ecological conditions in different seasons.

- Study the fauna species collected along wadi courses taxonomy based on morphologic desriptions and living environments.

- Use aquatic fauna as indicators of environmental conditions and its use as a key to past water qualities.

- Create Jordanian Biomonitoring System for Watercourses (JBSW)” to idetifiy and classifiy water qualities including: fresh water, brackish water, mineral water, thermal water, good water and poor water qualities).

6.1.2 Methdology

The method applied here is to use aquatic fauna and flora in evaluating the quality of the water. This was done by assessing selected physical characters such as: (water temperature, pH (acidity) and conductivity) which were measured in the field and chemical data such as nitrate, phosphate, hardness (calcium, magnesium and total hardness), BOD (Biochemical oxygen demand) and trace elements (e.g.: Copper, iron, zinc, boron) which were analyzed in the laboratory. Data were assembled from each site from which fauna and flora were collected and determined. The aim is to use that information to evaluate the water status in Jordan. Samples of living organisms were collected from 24 sites selected from 7 localities, mostly running water. The study area extends from north Jordan to its central part (Zarqa River, Wadi Hisban, Wadi Shueib, Wadi Shita, Karama reservoir-area, Wadi Mujib and Wadi Atun) (Fig 6.1). Organism samples were collected during the late winter to early spring time, from December to April from the chosen localities. From each selected locality the organisms were isolated and determined according to their place in the taxonomic system as far as possible.

Most collecting was carried out with a sieve of 0.5 mm but also coarser nets were applied. Water plants and rocks were washed in the screen. Those aquatic animals that cling to rocks, boulders, aquatic plants and often found under the rocks were collected with a pair of forceps were brushed off. The living organisms were handled with care not to damage them and they were carried to the laboratory in sufficient amounts of fresh water from the site. Also freshly collected animals were placed in alcohol right in the field as to preserve their skeletal characters in well conditions. After the study in the laboratory, selected individuals were placed in 70% ethyl alcohol.

In some cases the organisms stack in sieves, on plants or on fine sediments so they were rinsed carefully in order not to lose them. Fine sediment samples were also collected. For example in Ostracods collection method, after collection the samples were transferred into plastic bottles. The bottles were sealed, labeled and placed in a cool box with cold temperature condition for transport to the laboratory.

In the laboratory the material was searched for aquatic organisms which were then placed into beakers- dishes containing water from the same sampled site and 70% alcohol added for identification. Aquatic biota sample analysis includes taxonomic identification. Freshly collected organisms in the laboratory were documented by using S6 D Leica stereomicroscope with magnification of 6.3x - 40x, connected to a digital camera. The collected organisms were determined according to their place in the taxonomic system as far as possible.

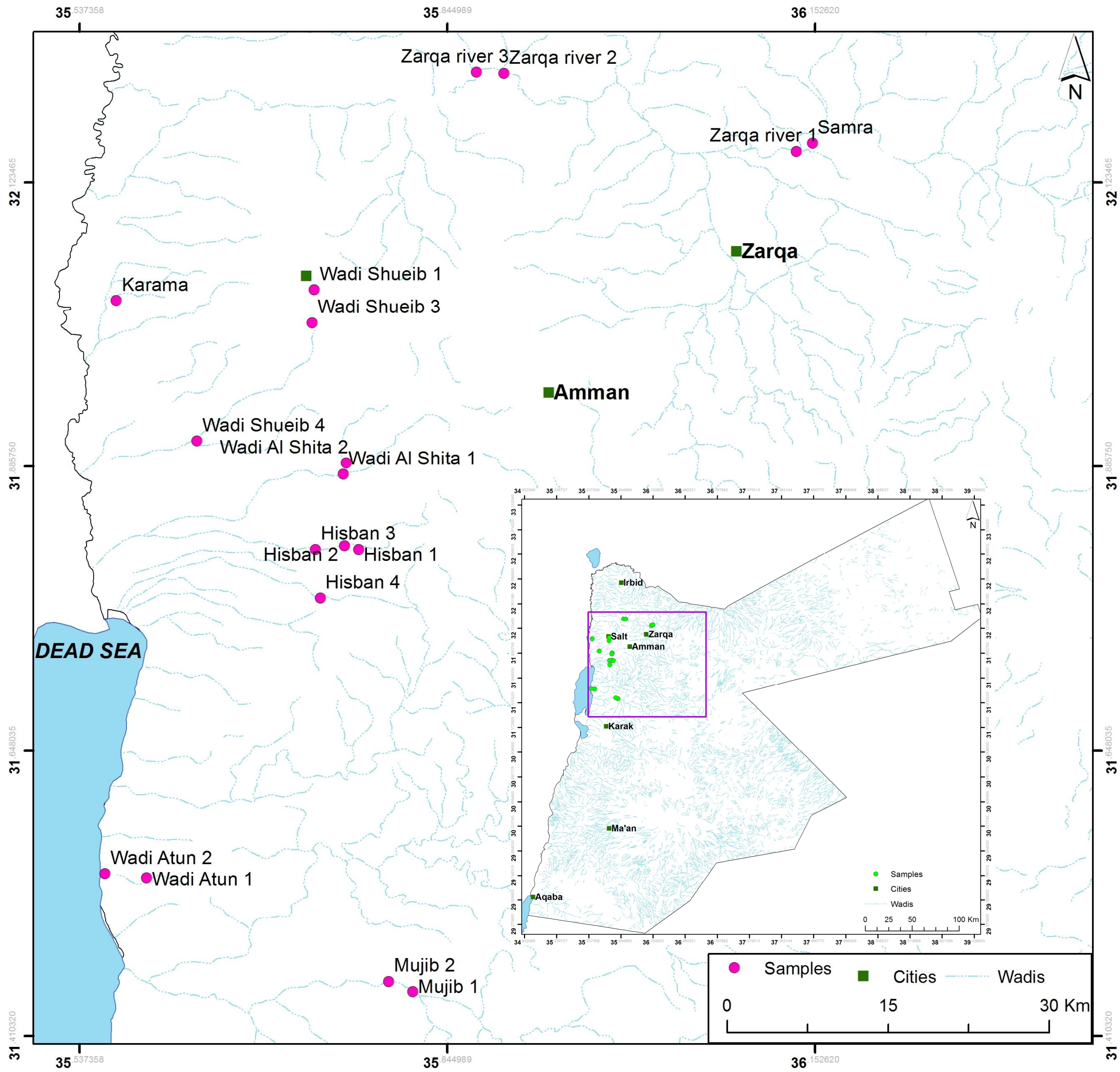


Figure 6.1: The study area covers wadis pouring into the Jordan Valley and the Dead Sea, extending from Zarqa River in the north through Karama reservoir-area, Wadi Shueib, Wadi Hibsan, Wadi Shita, and Wadi Atun to Wadi Mujib in the south.

6.2 BIOINDICATORS FAUNA OF JORDAN

Many groups of aquatic macro fauna have been used and proposed as indicators of water quality including mollusca group, insect group, crustaceans group, and Mites groups were mainly observed and discussed in this chapter with related chemical, physical and biological parameters as given in section below.

6.2.1 Aquatic molluscs as indicators of environmental conditions in Jordan

Molluscs group is represented by bivalves and gastropods in Jordan with about 20 species. They were found on rocks, logs, or dead leaves in springs, brooks, ditches, streams, and lakes, with different water qualities including fresh water and brackish water bodies. Here, 7 species of non-pulmonates plus unknown number of varieties of Melanopsis, plus 4 pulmonates were studied in present work. Bivalves were documented with species of the genera Unio, Pisidium, Sphaerium, and Corbicula.

Genus Unio has a distinct and characteristic mode of development of its off-springs which includes a parasitic phase of its juveniles as parasites in fishes (HERBERS, 1914; BANDEL, 1988). The eggs are held in large brood pouches which are connected to the gills. When the youngs have evolved to be ready for hatching (Glochidia-Stage) they have a bivalved shell that is mineralized and connected by the elastic ligament. This elastic ribbon holds the shell apart. The Glochidia are expelled into the water by the mother-clam often when it senses the contact to a fish. The exact conditions for the two species of Unio living in the KAC are not known. But it can be assumed from comparison in other places and with other similar species of Unio that such a contact between bivalve siphon and fish also results in the expulsion of larvae next to the fish. Larvae at this stage have secreted a long byssus thread and their shell is wide open. When the fish sucks in water through the mouth to expell it along the slits of the gill for breathing- the larva has to come in contact with the tissue of the gill, get attached to it with its gluy byssus thread. When the sensory cilia of its mantle margin come in contact with the tissue of the fish, the strong shell muscle of the larva contracts and pull the valves together. They have at their margin a strong thorn, which- when everything works well- penetrates the tissue of the gill of the fish. This irritation of tissue results in the reaction of the tissue to encapsule the penetrating bivalve larva and include it in a blister. This is what the bivalve needs to successfully continue it is life- all larvae which are not lucky enough to get hooked to fish tissue will die.

The bivalve Unio has an aragonitic shell and long oval shape. Its hinge is reduced in size and consists of a few low teeth. Unio belongs to the fresh water group of the Palaeoheterodonta among the bivalves which exists since Triassic time and has evolved a distinct mode of reproduction by parasitic larvae (Glochidia). Due to this adaptation the bivalve can move to all areas in a river system which can be reached by some fish living in it. Females of species of the Unionidae have their gills transformed into large pockets in which several hundred-thousand eggs are brooded until their shells have grow, and they are ready to hatch. These Glochidia have two valves with a hook on their margin and a strong muscle connecting them with each other. When a fish comes in contact with the exhalent siphon of the bivalve the larvae are expelled. They have their valves gaping and a special gland of the foot spins a sticky mucus thread. Thus several individuals are usually connected with each other by their mucus threads and form groups of individuals. When they come into contact with the skin, or even better the gill of the fish, a sensory hair reports this to the large retractor muscle which contracts. Thus the valves close and their marginal hooks penetrate the skin of the fish. The parasitic Unio in case of the species from KAC is in an unknown fish. But still this fish is obviously living here, since the life cycle continues in the canal until the bivalve has reached a stage of development inside of the cyst and fed by body liquid of the fish that allows it to change its parasitic existence to the one of a free living bivalve. It opens the cyst, drops to the bottom of the canal and continues life as a normal bivalve by pumping water over its gills, catching organisms of the phytoplankton with it and channeling that food to the mouth with aid of ciliary activity along the branches of the gill.

Unio terminalis BOURGUIGNAT, 1852 lives in the Ghor canal and was found alive in 1999 near Mashara. This canal at times in its northern section holds predominantly water that is derived from the Yarmouk River and the peace water coming from Israel (Fig 6.2).

Figure 6.2: Unio terminalis from Israel- same as in KAC (sources From Oz Rittner "Inland water molluscs of Israel").

HOROWITZ (1979) found *Unio terminalis* in the modern Lake Tiberias and also noted its occurrence in the Pleistocene Ubeidiya Formation. SCHUETT (1983) determined it as subspecies Unio terminalis terminalis from the Jordan and noted that another subspecies with *Unio terminalis* delicatus lives in the Orontes. These species may have arisen from a stem lineage of the Pannonian region that has also produced U. tigridis of the Euphrates and Tigris. This whole area from Jordan to the delta of Euphrates and Tigris was considered to represent the Syrian refugial area. The same species is *Unio littoralis* (Potomida).

Unio semirugatus LAMARCK, 1819 has the shell of rhomboidal shape (Fig 6.3). This species lives in KAC and was found alive in 1999 near Mashara.

Figure 6.3: Unio semirugata from Israel (sources From Oz Rittner “Inland water molluscs of Israel”).

HOROWITZ (1979) determined it as well from Lake Tiberias and as fossil from Ubeidiya Formation. SCHUETT (1983) considered U. semirugatus to represent a subspecies of *Potomida littoralis* (LAMARCK, 1801) representing a circum-mediterranean species with 7 subspecies. MIENIS (1986) noted Potamida littoralis in his checklist of molluscs from Israel (according to BABA 2000). Both species lived in the Jordan River before the area was flooded by the Lisan Lake.

The sands below the Lisan Marls to the West of Abu Habil locally have shells of both species. In the beds of Al Qarn Formation Unio occurs rarely and badly preserved- thus not determined to the species.

Genus Corbicula, in contrast to Unio, releases juveniles after a period of brooding similar as is the case in Sphaerium and Pisidium (ZIEGLER, 1885; MEISENHEIMER, 1901; BANDEL, 1988). The miniature adults are released directly without intermediate parasitic stage as in Unio or planktotrophic stage as for example Cardium or Brachidontes which lived in lakes that had existed for some time in Jordan in the Azraq and Mudawwara region during the Quaternary, or with most bivalves which develop in the sea at the Gulf of Aqaba. The shape of the shell differs strongly from that of Unio, and also its composition is different. While the shell of Unio is composed predoinantly of aragonitic material with nacre structure, that of Corbicula consists of aragonitic material in the crossed lamellar structure.

Since several bivalves are connected by their byssus threads the process of attachment to the host is improved. The tissue of the fish reacts to the irritation of skin penetration by growing around the bivalve larva and inclosing it in a cyst. The glochidia thus enclosed by tissue of the fish feed from lymphatic- liquid of the fish for an extended time that may last several months. As soon as the larva has grown as parasite of the fish and during this growth it changs shape of shell and body organization into that of a small juvenile and it breaks away from the cyst and falls to the ground of the water at a locality to which the fish has moved by then. From there on and until adult stage is reached, often several years later, Unio behaves like many bivalves, is half buried in the ground and filters phytoplankton from the water of the river. In Jordan nowadays two species of Unio live in KAC near to its intake from the Yarmouk River and they also live in Lake Tiberias, together with a Corbicula that may have been living here since the Pliocene but may also have become introduced here by man in recent times, originally coming from south-eastern Asia. The Unio of the Paleo-Jordan deposits does not differ from the now living species.

Corbicula fluminalis (MUELLER, 1774) (Fig 6.4) lives in KAC and was found alive in 1999 near Mashara. It was also noted 2013 in the sediment of the canal and it thus still living in it. HOROWITZ (1979) noted it as species in modern Lake Tiberias and the fossil lake of Ubeidiya Formation. The species lives around the Mediterranean Sea. It is often interpreted to have become introduced from eastern Asia, which can, obviously, not be the case since it is found as a fossil species that lived in the Jordan Valley also during the Late Pliocene. TCHERNOV (1973) found as mollusca of Lake Tiberias Corbicula fluminalis also the species Theodoxus jordani, Pyrgula barroisi, Bulimus hawaderiana, Melanopsis praemorsa, M. tuberculata, Unio terminalis, and U. semirugatus.

Figure 6.4: Corbicula fluminalis from Israel (sources From Oz Rittner “Inland water molluscs of Israel”).

There may in fact be two species present, an introduced population of C. fluminea and the native Corbicula fluminalis. However, the two species are often mixed together. The names themselves are sometimes confused in the literature (e.g. by being called '"Corbicula fluminata"). In order to distinguish the two species the ratio of width and height needs to be determined. In case of C. fluminea it is on average 1:1. In C. fluminalis it is smaller (1:0.97). But since there is variation and considerable overlap in shape, the best character for differentiating the two species from each other is the number of ribs on the grown shell. Corbicula fluminea has 7 to 14 ribs per cm, Corbicula fluminalis 13 to 28. This character can be noted as soon as specimens have reached a size of 5 mm. The shell seen from the side and looking at the opening between the shells in case of C. fluminalis is rounder, almost heart-shaped, while C. fluminea has a slightly flatter tear-drop shape like shape and a notched broad end. Small specimens of C. fluminalis are almost spherical, while those of C. fluminea are somewhat flattened. Corbicula fluminalis has a more swollen, pointed and protruding umbo (RAJAKOPALet al., 2000) (Fig 6.5). According to observations that have been carried out in the case of Corbicula fluminalis and Corbicula fluminea from the Rhine River both species differ in regard to their reproductive habits. While C. fluminea changes sex during its life, C. fluminalis was noted to have sexes separate and was only rarely hermaphroditic. The juveniles of C. fluminea are crawling and have a shell with 200 µm. The youngs are ready to hatch from the mother in case of C. fluminea between May and September while in case of C. fluminalis hatching occurs between October and March. In the Rhine, the bivalves need one year of growth to be sexually mature and measure 1 cm and afterwards may live for 10 years. During reproduction they can release several hundred off-springs a day and as a whole about 8000 in a year.

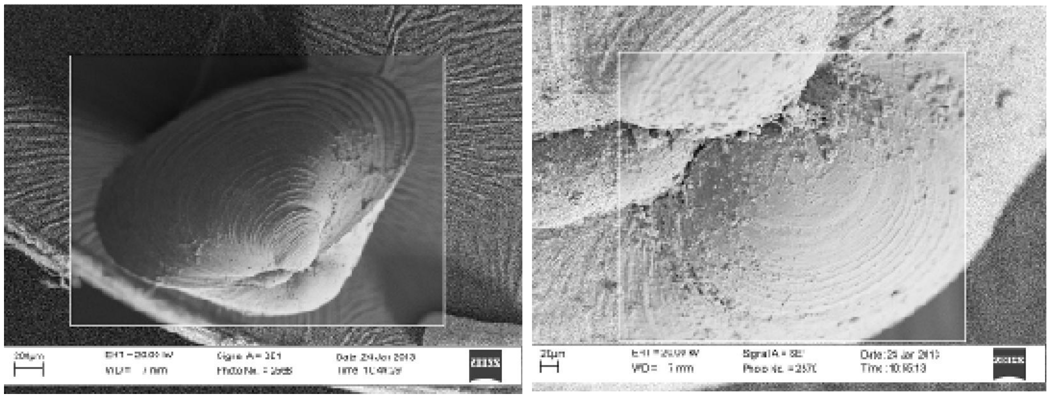


Figure 6.5: a. Corbicula fluminalis with juvenile shell, the scale bar is 200µm, b. detail of the Corbicula fluminalis embryonic shell that consists of the straight hinge veliger-shell and the added juvenile shell that had grown within the brood pouch of the female, and clear a change to changes in benthic life, the scale bars is 20µm.

Genus Pisidium, here the female broods the young in a pouch and releases them when they are quite far developed (BANDEL, 1988). This brood pouch can hold only a few individuals, but their chances of survival are very high when they hatch, due to their relatively large size. They then reach maturity quite rapidly, so that a settlement of a body of water with Pisidium can occur in little time, once a female has come to the water- quite possibly attached to water birds.

Pisidium casertanum (POLI, 1795) was collected in Jordan in the year 1978 from the spring in Wadi Hisban, and in a spring near the bridge across the Zarqa (now destroyed) and the small lake in the Roman Poole on the highway Amman- Jerash by BANDEL and was described by SCHUETT (1983, Fig.16). HOROWITZ (1979) found it in Lake Hula and the fossil lake of Ubeidiya Formation. Several other species of Pisidium were described from the middle Pleistocene, and Pisidium also occurs in the lake in which Al Qarn Formation was deposited.

Pisidium annandalei PRASHAD, 1925 with its valves small and a fine concentric pattern of ribs and a characteristic groove of the ligament was found in springs in Hisban and Wadi Sir in 1978, and described by SCHUETT (1983, Fig.15). HOROWITZ (1979) determined the species from Hula Lake together with Pisidium casertanum. Several other species of Pisidium were described from the middle Pleistocene.

A Pisidium sp. was described by NELSON (1973) to occur in Azraq Oasis. TCHERNOV (1973, 1979) suggested that *Pisidium pirothi* represents an Ethiopian element that entered the Jordan Valley. In this study no Pisidium was encountered, even though much sediment in creeks and rivers was investigated for ostracods. Thus Pisidium appear to have become rare in the waters near Amman and the Dead Sea.

Living individuals belonging to the genera *Theodoxus*, *Pseudamnicola*, *Hydrobia*, *Falsipyrgula*, *Melanopsis*, *Melanoides*, *Valvata*, *Ovatella*, *Galba*, *Bulimus*, and *Physa* were encountered during the study and *Planorbis* and *Gyraulus* had been noted before, but not during the search in this study.

Superfamily Neritoidea, Genus *Theodoxus*, *Theodoxus (Neritaea) jordani* (SOWERBY, 1832) occurs in all clean springs and creeks in Jordan to the Dead Sea area (BANDEL 2001, Figs 32-35). The specimens of the population from the Ghor Canal have their embryonic shell composed of the first whorl. It is clearly differentiated from the teleoconch by its usually uniform, commonly white coloration. The teleoconch consists of about 2.5 whorls, as is also the case in *Theodoxus* from Pella and other springs in Jordan. But in the latter coloration and shape of the teleoconch differ considerably. With the onset of the teleoconch the most common pattern of coloration is that of somewhat irregular, commonly zigzag-shaped dark ribbons on light background. About 4 to 7 such broad ribbons commonly feature the first teleoconch whorl. But also totally black, and more rarely, totally white color morphs exist.

The most characteristic feature of the first teleoconch whorl is the appearance of a distinct but not always well developed flattened apical side of the whorl with more or less well developed corner. The shape of a shell with one teleoconch whorl is hemispherical with rounded apex and flattened base. The shell is wider than high. The inner lip is smooth; callus covered and has a straight. In the second whorl of the teleoconch the relative height of the whorl increases and whorl sides flatten more or less. In many individuals the shoulder corner develops into a rounded ridge and a depression is found below it. In other individuals no such ridge is present and the sides are more or less flattened. The shell is now higher than wide (up to 10 mm high and 9 mm wide). The callus morphology of the inner lip changes to more round bulging form and to evenly concave. The color pattern of axial ribs may continue but ribs may also fuse marginally to form a pattern of white dots or fuse totally to turn into uniform black. There are also mixtures of such colorations or after renewed shell growth one pattern changes into the other.

A total transition in shapes can be noted between forms called *Theodoxus orontis* BLANKENHORN, 1897 and *Theodoxus jordani* by SCHUETT (1987 Pl.2, Figs 1,2). The first represents the variety with a depression on the whorl side, and the second the variety with somewhat flattened sides of the last whorl (BANDEL, 2001, FIGS 12-20).

The operculum is calcified and provided with a ridge and a peg representing a solid structure on the inner side of the inner lip. *Theodoxus jordani* was found in Azraq (now extinct here), springs of the creeks near Jerash, several springs of creeks that go into the Zarqa River and in springs of the the creeks at the eastern side of the Dead Sea (Fig 6.6).. Springs in Wadi Shueib, Shita spring, springs in Wadi Hisban and clean parts of River Mujib below the dam site have large populations (Fig 6.7).

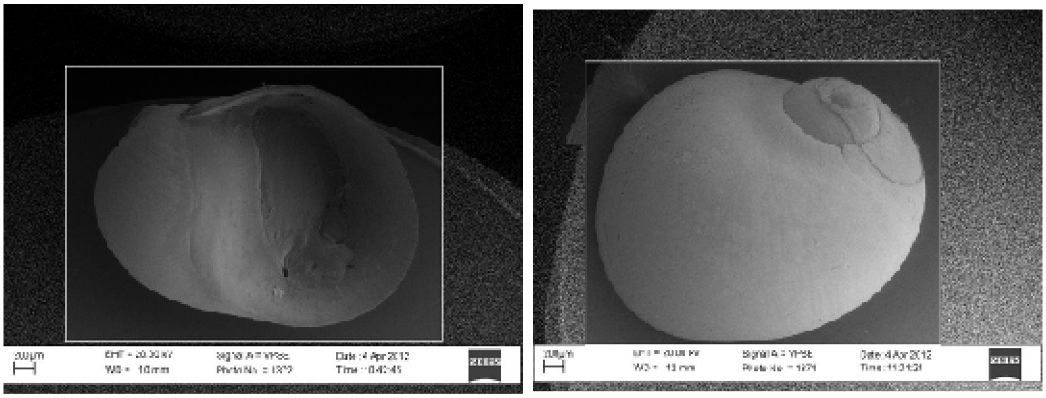


Figure 6.6: Theodoxus from Wadi Hisban, the scale bars are 200μm.

Figure 6.7: a. Theodoxus on the margin of KAC in March 2013,b. Large number of theodoxus and Melanopsis at Wadi Mujib creek.

Remarks: A species with a little higher whorl and depression on the side was called *T. orontis* BLANKENHORN, 1897 (SCHUETT, 1988 pl.2, Fig.9) from Pliocene deposits in the Orontes Valley. They resemble closely shapes as occur in modern populations of *T. jordani* from the Lake Kinneret, illustrated by HELLER (1993). The species name for this variety of a slightly higher shell with constriction, therefore, is not needed. In the KAC from its origin near Yarmouk River some times as far as to its merging with water of the Zarqa River can have a rich fauna of *Melanopsis* and *Theodoxus*. The living *Theodoxus jordani* here is very similar to that found in the Pliocene (BANDEL, 2001).

TCHERNOV (1973, 1979) suggested that numerous freshwater elements invaded the Jordan Valley during the Pliocene from Syrian inland waters, among them *Theodoxus jordani*. This species according to his opinion has been isolated from the Orontes population since the middle Pleistocene. HOROWITZ (1979) noted that *Theodoxus jordani* has not changed from the base of the Pleistocene to recent times. SCHUETT (1983) noted that *T. jordani* also occurs in the Orontes as well and in Jordan. SCHUETT (1983) stated that this species can be differentiated from *Theodoxus anatolica*, *Theodoxus nilotica*, and *Theodoxus mesopotamica*, while TCHERNOV (1975) considered all these to represent the same species.

According to NELSON (1973) the ponds of Druze and Shishan of Azraq oasis held *Theodoxus macrii*. This species was very common in Shishan pool with 400 specimen within 100 square centimeters, and was even more common than Hydrobia spp. When these pools were visited again 1979 no *Theodoxus* was found alive. And sometimes later when the water dried up, also *Melanopsis* died out, and even *Melanoides* disappeared.

The type to *Theodoxus jordani* and the subgenus *Neritaea* as illustrated by WENZ (1938, Fig.1038) lives in the Jordan, and nowadays in the Ghor Canal between Yarmouk River mouth and Zarqa river mouth. From cleaning out the canal near Abu Habil (Jordan) a fauna of several hundred individuals of all sizes was recovered (spring 2001).

TCHERNOV (1975) He considered it to be a very variable species including *Neritina karasuna* BLANCKENHORN, 1897, and *Neritina orontis* BLANCKENHORN 1897. The genus Neritina is not appropriate even though its shells are convergent to those of Theodoxus. Specimens of T. jordani according to TCHERNOV exhibit smoothed shells, or single, double-, or triple keeled shells, including all transitional stages. As are found in the Sea of Galilee. The double keeled Theodoxus orontis described by BLANCKENHORN (1897) from the Pliocene of the Orontes is identical with Theodoxus jordani that inhabited Lake Hula in sub-recent times (TCHERNOV, 1975) and lives in the Sea of Galilee. Very similar individuals are present in the northern portion of the KAC. In the Erk el- Ahmar the smooth shelled forms predominate (TCHERNOV, 1975, Pl.1, Fig.1) but keeled ones are present as well. They are well ornamented with black and white stripes and zigzags.

Theodoxus in Jordan is clearly restricted to clean water. That is in creeks it only occurs near the spring, since most water courses below are polluted more than *Theodoxus* can tolerate. Its tolerance is less than that of *Melanopsis* which occurs even below and connected to some pollution. But streams, as that of the Zarqa have neither *Theodoxus* nor *Melanopsis* surviving, and only near the Jordan Valley *Physa* may occur sporadically in that river. Below Mujib dam Mujib River has turned to such a low degree of pollution that *Theodoxus* reappears. The begin of KAC near its connection to Yarmouk river hold *Theodoxus*, and the species can spread to the south in that canal periodically reaching the area near Deir Alla. Jordan River is free of this snail, but also relatively clean looking water such as that of the lower Wadi Al Hasa has no *Theodoxus*.

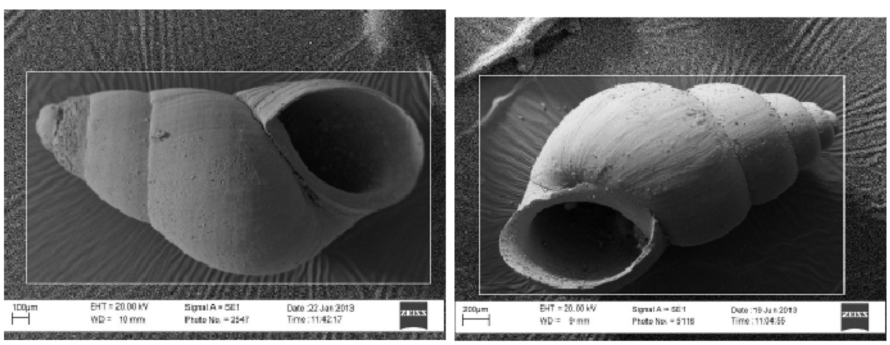
Reproduction of *Theodoxus* is distinct and egg cases are quite conspicuous. Often the presence of *Theodoxus* in a stream can be recognized by the presence of the egg capsules which are attached to hard substrates, stones as well as the shells of other gastropods, including *Theodoxus*. Within these capsules the young develop as has been described in case of *Theodoxus fluviatilis* by BLOCHMANN (1882), assembled and completed regarding the formation of the shape of the early shell by BANDEL (1982, 2001). Food for intra-capsular development to miniature juvenile stems from nurse eggs and is reflected in the minute shape of the protoconch (BANDEL 1982; RIEDEL 1993). The young within such a capsule may survive pollution events that may occur in a spring portion of a creek and which kill all adult specimens. Thus, sometimes as was observed in the Wadi Hisban, only tiny juveniles are found, that had hatched after such a pollution event.

The food of *Theodoxus* consists of algal covers on hard substrates and the snails are very efficient in scraping the rock surfaces. Their many radula teeth used by this process are well equipped for scraping since they are continuously replaced by new ones and some of them in each row are composed in part of iron-oxide and thus harder than the others. Theodoxus can be so efficient that Melanopsis that normally occurs alongside is found only at the margins of the creek, where softer plant material and sediment is found, while on the stones only Theodoxus is feeding. In springs with stony substrate a different faunal composition with more Melanopsis present is indicative of some small degrees of pollustion.

Family Hydrobiidae,

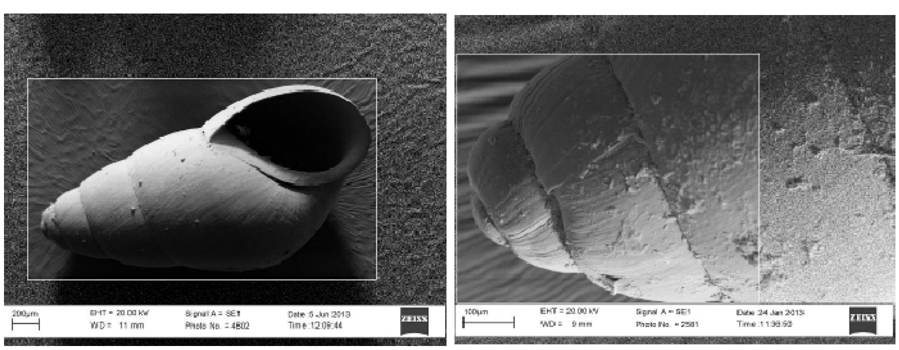
The *Hydrobia* relation belongs to the Caenogastropoda and within that order to the rissoidean group which is considered to have had representatives from the begin of the Mesozoic time (WENZ, 1938; BANDEL, 1996). In it most species live in the sea, but within the family Hydrobiidae there are also many species which live on land in fresh water as well as brackish water.

Genus *Hydrobia* HARTMANN, 1821, A species that is close or the same as *Hydrobia acuta* or *Semisalsa contempta* occurs together with *Pseudamnicola* in brackish water creeks near the Dead Sea ad also occasionally in different springs with more or less pure fresh water in Jordan (Figs 8.8 &8.9). It differs from *Pseudamnicola* by having a larger and higher shell with more whorls when fully grown. The shell is about 3.3 mm high and 2 mm wide, consists of about 5 whorls, is ovoid elongated, smooth with slightly convex whorls, weakly excavated sutures and has no umbilicus. A rather indistinct ornament of spiral grooves and ridges may be seen, but may also be less evident. The spire is conical and higher than the last whorl. The aperture is of oval shape with an upper corner and continuous simple margin that is thickened along the inner lip. The operculum consists of few whorls with eccentric nucleus. The embryonic shell consists of a little more than one whorl and was connected to a young leaving the egg case crawling on its foot. Along with shells of all stages of growth also the minute shells of freshly hatched young have been washed from the sediment of a small creek with brackish water. This documents that cf *Hydrobia acuta* was breeding here with the young hatching from the numerous small hemispherical egg capsules which are attached to hard substrates in the water. The gastropod feeds from growths present on stones much of which consists of diatoms.



(The scale bar is 100µm) (The scale bar is 200µm)

Figure 6.8: Semisalsa contempta, from creek at Dead Sea, Wadi Atun.



(The scale bar is 200µm) (The scale bar is 100µm)

Figure 6.9: Creek Northeast of Dead Sea, Wadi Atun, with juvenile part of the shell.

Remarks: cf. *Hydrobia acuta* DRAPARNAUD, 1805 was called *Semisalsa contempta* by SCHUETT (1983, FIG 3) and was considered a member of the genus *Semisalsa* RADOMAN, 1974. Another species of *Hydrobia* called *Semisalsa musaensis* by SCHUETT (1983, Fig 4) was collected from a clean spring near Wadi Sir (1978). According to TCHERNOV (1975, Pl.1, Fig.5) *Hydrobia acuta* had also been determined as *Hydrobia fraasi* BLANCKENHORN, 1897 and it has been widely distributed since the Neogene in the Mediterranean region of Europe and in Mesopotamia. He interpreted it to have became extinct in Syria and Israel towards the end of this period. The species still lives in Iran, as it lived in the Erk el- Ahmar Lake with about 7 mm in length and 5 mm in width. A *Hydrobia ventrosa* was mentioned by NELSON (1973) to live in the Druze and Shishan pools at Azraq oasis, and it may also be the same species. We noted it from Wadis Hisban spring-creek. *Hydrobia (Semisalsa) contempta* (DAUTZENBERG, 1894). The taxon *Bithinella* is a nomen nudum (SCHUETT, 1991). *Bythinella* MOQUIN-TANDON, 1856 is a hydobiid with a blunt and more flattened protoconch, living in southern Europe and Anatolia.

Since *Hydrobia* has been used to describe many gastropods with a similar shell as that documented here and since it has been documented among others by WILKE (1970) that quite a number of different snails may have a shell as that of *Hydrobia* the species here documented to occur in Jordan may be one or, as is assumed the likely case at least two species, one living in the brackish water and the other living in clean water spring- but it different from each other both are rare and would need to be studied when provided with the soft body animal.

A *Hydrobia* (*Semisalsa) galilaea* (PRESTON, 1913) (Hydrobia stagnalis) has been described from the catchment area of the Jordan, differing from *S. contempta* by having a longer spire and more rounded whorls, but less rounded and less long spire than *Semisalsa longiscata*. SCHUETT (1991) reports them from brackish water springs at the shore of Lake Kinneret and from the Hula region. Thus is probably what SCHUETT (1978) called *Hydrobia (Semisalsa) musaensis* FRAUENFELD 1855 found in the Azraq pond and the Rumeimin spring in the side creeks of River Zarqa (SCHUETT, 1983, FIG.4).

Hydrobia (*Semisalsa) longiscata* (BOURGUIGNAT, 1856) occurs in Turkey according to SCHUETT (1991) and also along the coast in Israel and within the Orontes area. According to HOROWITZ (1979) as species of modern Lake Hula but not in the Ubeydiya Formation and below.

Genus *Pseudamnicola* PAULUCCI, 1878, has a circum-Mediterranean distribution, while the known species diversity increases from East to West. The species of this genus are well investigated from Tunisia (BOETERS, 1976), Spain (BOETERS, 1988), Balearics (BECKMANN, 2007), Malta (GUISTI ET AL 1995) and Algeria/Tunesia (GLOER et al 2010). Especially in the later study it was obvious that the species in the genus *Pseudamnicola* are difficult to distinguish by shell features alone and their anatomy needs to be known as well. A number of species of Pseudamnicola was described by GLÖER, BOUZID & BOETERS (2010) from different localities in North Africa. Species differ only slightly regarding their shell shape and can be distinguished from each other only by anatomical characters. This is probably a different one than the small species from Wad Atun (Fig 6.10).

The genus contains small brackish water snails. The about one mm high shell consists of about 3.5 whorls. The aperture is rounded and there is a small umbilicus. The modern *Pseudoamnicola solitaria* TCHERNOV, 1971 occurs in the springs on the Dead Sea (TCHERNOV 1971; SCHUETT, 1983). It was found in the spring at the NE end of the Dead Sea, but also in the spring near the Amman-Jerash road (mineral water, old roman ruin) and Zarqa Ma'in springs.

Pseudamnicola is small with more than 2 mm high hydrobiid shell and has only about 4 whorls and the last one increases in size rapidly. It composes more than two thirds of shell height. The apertural margin in the fully grown shell is thickened and continuous. There is only a columellar slit. The species is fairly common.

Species *Pseudamnicola solitaria* TCHERNOV, 1971, A shell with about 1mm in height consists of about 3.5 whorls. The aperture is rounded and there is a small umbilicus, but also in the spring near the Amman-Jerash road (mineral water, old Roman ruin) and Zarqa Ma'in springs (SCHUETT, 1983, FIG.5). The shell is sperical with brown surface that may be glossy in places at other places densely settled by diatoms. The apex is low and blunt and succeded by 4-5 whorls with a cleas suture. The umbilicus is slit like. The spire height is about xxx and the aperture is oval with a sharp outer lip (peristome). Shell height is 2-2.5 mm and width approximately 2 mm.

The egg capsules are produced in large numbers as was observed in Wadi Atun. They consist of small cupula-like structures which are white at first but rapidly become settled by cyanobacteria coloring them greenish. From the egg capsules the young hatching have a little more than one whorl of the shell.

Pseudamnicola solitaria occurs in the springs on the Dead Sea according to TCHERNOV (1971, 1975), SCHUETT (1983), and HELLER (1997). It was found in the spring at the NE end of the Dead Sea (1978) (Fig 6.11).

This or a very similar species from Wadi Atun has its shell smaller than 1 mm and has an open umbilicus (Fig 6.11). Its protoconch differs from that of the *Pseudamnicola* found in the brackish creek at the northern end of the Dead Sea. The difference between these two species needs to be resolved.

Remarks: According to SCHUETT (1983) this species is common in Jordan. The shell is shorter than that of *S. galilaea*. The species occurs in the brackish springs at the Dead Sea (SCHUETT, 1991, 1983).

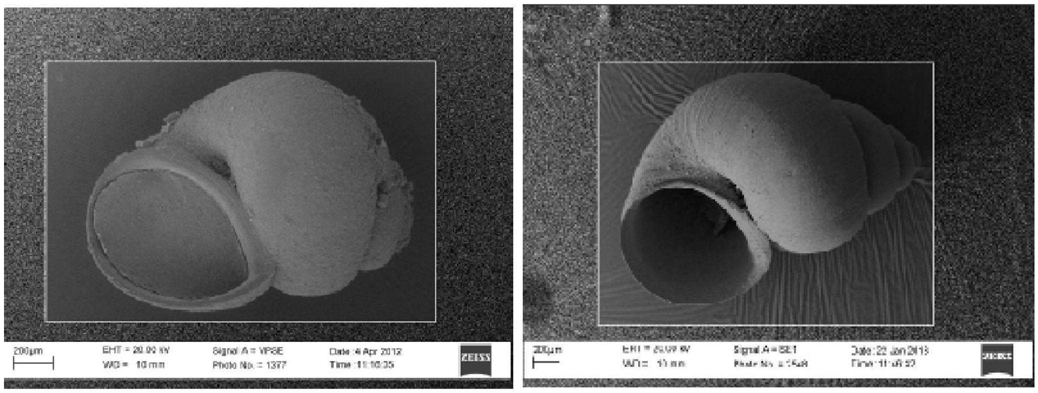


Figure 6.10: Showing *Pseudamnicola solitaria* in Jordan creek 2012, from Wadi Atun , from creek at NE Dead Sea (1978), the scale bars are 200μm.

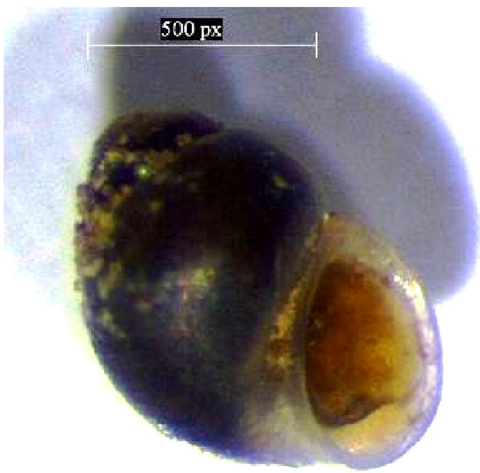


Figure 6.11: Pseudamnicola from the creek at Wadi Atun next to the Dead Sea as in the field.

Genus Falsipyrgula RADOMAN, 1973, Species Falsipyrgula barroisi (DAUTZENBERG, 1894) has its shell with 2.5-3 mm high and around 1.3 mm wide with 32°-34° apical angle (Fig 6.12). The embryonic whorl is rounded and 0.3 mm wide and a little more than one whorl with rough rounded wrinkle surface and evenly rounded apex. It ends with the insertion of the first clear growth lines and rounded aperture. The first whorl of the teleoconch is rounded, on the second a keel appears in the lower shoulder, which is of different strength in different individuals. With the fourth whorl or a little more the teleoconch the shell is fully grown. The last whorl may have the keel or it may be rounded. The outer lip of the aperture is sharp or rarely may be thickened. The shape of the aperture is drop-like and the inner lip often a little thickened by callus and is extended to form a narrow umbilicus. The aperture is around 1mm high and the total shell measures around 3 mm in height. The growth of the end of shell is clearly indicated by growth line concentration and grooves. Due to different strength width of the shell keel as well as its width and continuation onto or disappearance before the last whorl the species is quite variable.

Remarks: BLANCKENHORN (1918) described the shell as consisting of 4.5 whorls and being 2.25 mm high and 1.3 mm wide with an apical angle of 34°. He noted that the two first whorls are rounded and the following whorls are flattened with a keel in supra-sutural position. The suture is deep and its flank forms a sharp corner with the keel. The body whorl measures about 1 mm in height and ends with an oval aperture. This description can be confirmed with small corrections regarding the firs, embryonic whorl and regarding variability of the presence of the keel. BLANCKENHORN distinguished a variety of this species that is smaller with 4.5 whorls than that originally described forms from Lake Tiberias with 7 whorls by DAUTZENBERG (1894). The individuals illustrated by RITTNER (2010, INTERNET) are as described by Dautzenberg, and those illustrated by Tchernov (1975, Figs 5-6) from Lake Tiberias are intermediate with 5.5 whorls. Falsipyrgula barroisi was found to be common in the KAC west of Abu Habil in spring 2001 (Fig 6.13). MIENIS & MIENIS (2008) considered the species to be endemic to Israel and Lake Tiberias. The individuals from KAC are all with less whorls than these. This can most probably be explained as reaction to the environment, which in the water of the KAC resulted in a more rapid adulthood and fully grown shells with one to several whorls less than those in Lake Tiberias.

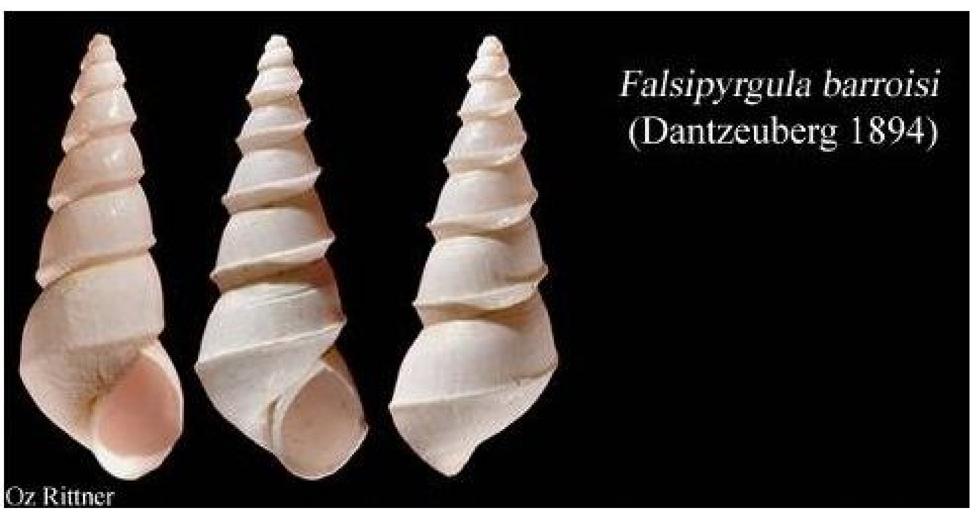
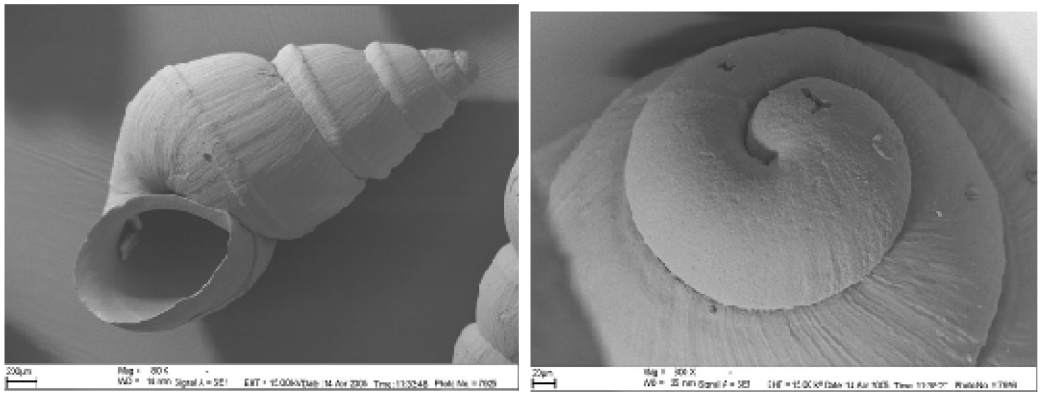


Figure 6.12: Falsipyrgula barroisi without exact locality and they appear to be longer than the individuals from KAC. (Source from Oz Rittner “Inland water molluscs of Israel”).



(The scale bar is 100μm) (The scale bar is 20μm).

Figure 6.13: Shells of *Falsipyrgula barroisi* from KAC.

BLANCKENHORN (1918, Pl.8, Fig.24) described this species, but with fewer whorls than the living one from Lake Tiberias from Pleistocene deposits in the Orontes Valley. HOROWITZ (1979) suggested that this species from Lake Tiberias has also been reported from the Erk el- Ahmar of the early Pleistocene. Very similar but slightly broader shells have been placed in Falsipyrgula rabensis (BLANKENHORN, 1897) by SCHUETT (1988, Pl. 3, Figs 32-33) and were considered to be of Pliocene age in the Orontes Valley in Syria. F. barroisi lives also in the region of Antakia and a variety with a second keel was named *Falsipyrgula* ghabensis SCHUETT, 1988.

Falsipyrgula barroisi was considered as endangered and only known from Lake Tiberias and its tributaries (extent of occurrence = 166 km²) and so it is present in a single location. There are several major threats to the lake. The primary current threat comes from decreasing lake levels due to overpumping and increased eutrophication as a consequence of heavy agriculture around the lake. The recently discovered invasive species, a tropical snail *Thiara scabra* (MUELLER, 1774) has been reported from the Lake Tiberias and considered as a potential competitor for food (MIENIS& MIENIS 2008). Monitoring is recommended in the future to follow future changes in its population and habitat status.

TCHERNOV (1973, 1979) suggested that typical Sarmatian (Paratethys) elements are Hydrobia longiscata, Falsipyrgula, Melanopsis and Melanoides didianus. Melanoides tuberculatus is considered to represent the oldest element of all by TCHERNOV (1979) with Melanoides jordanicus representing an endemic species that became extinct.

The subgenus Pyrgula (Falsipyrgula) RADOMAN, 1973 is represented by Pyrgula barroisi DAUTZENBERG, 1894 (=Falsipyrgula) according to HOROWITZ (1979) from the Lake Tiberias and has been also reported from the Erk el- Ahmar of early Pleistocene deposits close to the lake (TCHERNOV, 1975b, Pl.1, Fig.6). A species with very similar but slightly broader shell has been placed in *Falsipyrgula rabensis* (BLANKENHORN, 1897) by SCHUETT (1988, Pl. 3, Figs.32-33). *Pyrgula barroisi* is a rather variable species.

TCHERNOV (1975a, Figs. 5-6, 9) illustrates two morphs of this species which could also be interpreted as representing two distinct species. Some morphs have a keel and others are smooth, some are slender, others short. *Falsipyrgula barroisi* lives also in the KAC, which receives part of its water from Lake Tiberias.

Falsipyrgula barroisi from the KAC (Pl.1, Figs. 1-5) closely resemble as fossil species that has been placed with Iralimelania or Marticia from the deposits of the Pliocene Lake at Kos (Pl. 1, Figs. 6, 7).

Family Thiaridae ,Genus Melanoides Olivier, 1804, The elongate shell is up to 5 cm long with high and slender spire and up to 15 whorls. Often even juvenile shells are decollated. Transverse and spiral ribs are generally present, commonly forming tubercles with each other. The type is Nerita tuberculata MUELLER, 1774 from the Coromandel Coast of southern India.

Melanoides tuberculata (MUELLER, 1774) in Jordan was found to live in pools in Azraq (now extinct here), near Hemma at the Yarmouk and from here along the Jordan to the Dead Sea and to its southernmost creeks including the old Roman Reservoir at the extreme south end (Fig 6.15- 8.17). It lived in Karama Reservoir Lake when water was still less salty (Fig 6.18) and it can be found in pools next to Al Hasa River- and probably anywhere in Jordan at places with muddy ground covered by clean fresh to slightly brackish water. In the sub recent lake of the Azraq oasis it grew to such a large size that is no longer found in Jordan, but as known from some African Lakes. Melanoides lives in the creek that flows through the village Hemma into the Yarmouk, occurs along the Jordan River to the Dead Sea on muddy grounds as well as in a similar environment along the lower Mujib River. It also lived in the Pliocene lake; Ubeidiya Formation.

Melanoides tuberculata has its protoconch characterized by the relatively large diameter of 0.30 to 0.35 mm, compared to other members of the Cerithioidea with usually about 0.1 mm of the first, initial whorl. The initial 1.5 to 1.7 whorls show an irregularly wrinkled shell, a sculptural pattern, which formed due to retarded calcification during early ontogeny (BANDEL & KOWALKE, 1997). The wrinkled shell does not demarcate the actual protoconch as the embryonic shell (formed until the embryo hatches) and is confined to the initial 2/3 to 3/4 whorls (RIEDEL, 1993). On subsequent whorls ornament appears and the young hatch with about five whorls present.

Melanoides tuberculata can be found worldwide in tropical and warm regions in running and standing fresh water. It prefers soft bottom in slow moving rivers and creeks and standing water near the shore of lakes. Its success in rapidly settling all available fresh water substrates in ponds, lakes and channels is connected to its parthenogenetic mode of reproduction. Melanoides has a rather special mode of life by its populations consisting of only females but males occurring only as an exception. With only one individual a whole populationcan be started. The young are brooded in a pouch behind the head.

Thus, when beginning their live outside of the shelter of this pouch four of five whorls of the shell are completed and well calcified. The youngs released to the environment are thus well protected from attacks.

Among the individuals of the *Melanoides tuberculata* population of Israel now and then males appear (LIVSHITS & FISHELSON, 1983). But it is not known how many generations may follow each other without males being present. According to MORRISON (1954) males are unknown or very rare among the representatives of the Thiaridae in general.

Thus a single individual can start a whole new population of many individuals. The female broods its young in a special pouch and releases juveniles provided with a shell of several whorls. This tiny juvenile can easily be transported on the feet or on feathers of water birds and can thus be spread easily over long distances. Melanoides nowadays lives in Jordan also when water is a little brackish as it was in Karama Dam Reservoir, but water salinity has increased here and Melanoides became extinct in the lake.

Remarks: According to BROWN (1980) there are about 30 species of Melanoides recognized in Africa, with all species except M. tuberculata in Lake Malawi and the Zaire basin. The anatomy was analysed by STARMUEHLNER (1969). The epithelium of the brood pouch secretes amoeboid cells which are ingested by the embroys. GLAUBRECHT (1994) found 0.06 mm large eggs surrounded by a membrane. These embryos grow to form a foot, visceral mass and shell (RIEDEL, 1993). The early feeding embryo has a velum. In Europe it has been living in the Pliocene of Hungary.

According to SCHUETT (1983) this species has its northern margin of occurrence in the area of the Orontes (STARMUEHLNER, 1976). From Lake Tiberias TCHERNOV (1975 Fig. 10-11) documented the species.

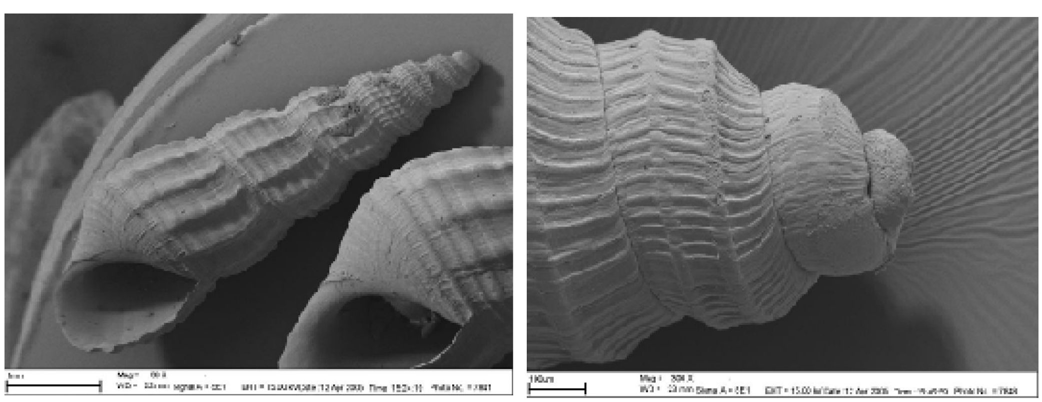


Figure 6.14: Melanoides tuberculata from KAC (2012), the scale bar is 1μm.

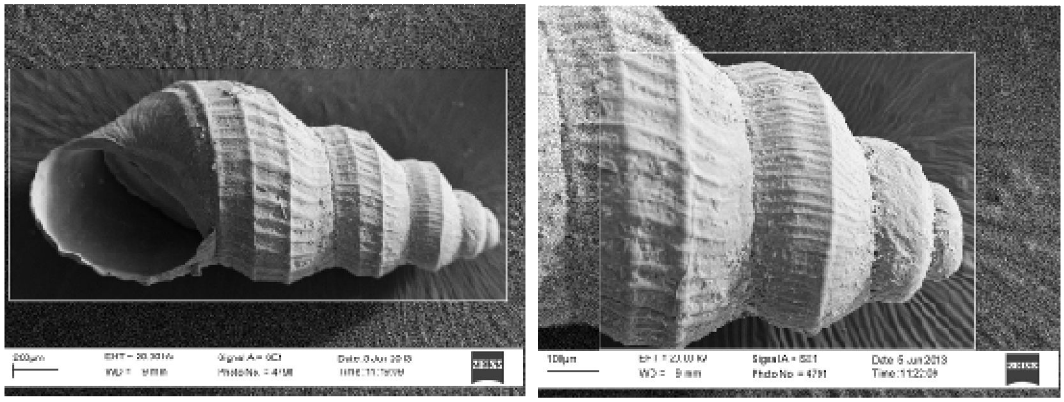


Figure 6.15: a. Melanoides tuberculat from the salty creek at the NE end of the Dead Sea, the scale bar is 200µm, b. juvenile shell that formed in the brood pouch of the female and documents, with changes in sculpture, the mode of growth, the scale bar is 100µm.

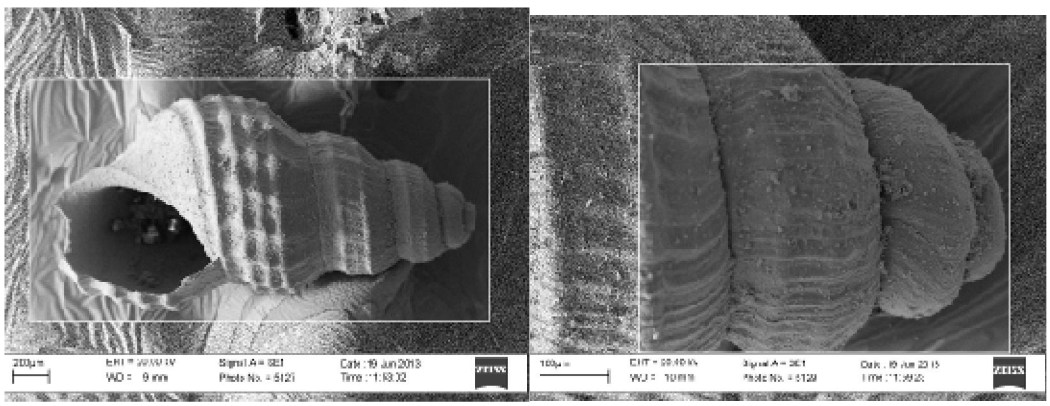


Figure 6.16: a. Embryonic portion with change from larval stage to postlarval within the brood pouch is documented by change in growth lines from sinuous to straight, the scale bar is 200µm. (Individuals from an ancient Roman water basin SE of the Dead Sea), the scale bar is 100µm.

Figure 6.17: Melanoides tuberculata from Karama Lake.

Family Melanopsidae

BANDEL (2000) distinguished among species of Melanopis living in Jordan:
Melanopsis buccinoides (Figs 20-24).
Melanopsis doriae (Figs 25-29)
Melanopsis sharhabili (Figs 119-123)
Melanopsis costata (Figs 72-75)
Melanopsis saulcyi (Figs 78-79)
Melanopsis bandeli (Figs 80-83, 85-93, 95)
Melanopsis ammonis (Figs 113-118).

Melanopsis is an early inhabitant of the Levant, and is known from several Pliocene deposits of Israel (TCHERNOV, 1979), who also noted it is presence in the Miocene of the region (has not be confirmed). According to this author an extensive faunal exchange took place during the early Pleistocene through the Jordan-Orontes-Mesopotamia water systems. He also assumed that during post-Pliocene time a new wave of fauna invaded the Jordan Valley, consisting of *Unio semirugatus*, *Unio terminalis*, *Corbicula fluminalis*, *Acroloxus lacustris* (probably Ancylus), and *Planorbarius planorbis*.

Genus Melanopsis FÉRUSSAC, 1807

The shell has a cyrtoconoid outline with the body whorl more or less inflated and whorls of the spire hardly rounded and smooth or ornamented by axial and/or spiral ribs. The size ranges from about 1 to 4 cm in shell height. The aperture is depressed egg-shaped with a regularly rounded outer lip, anterior channel, smooth inner lip which is usually thickened by a posterior callus pad. There is no umbilicus. The protoconch is simple, not clearly demarcated from the teleoconch, and about 0.2-0.4 mm across.

The type of the genus is Buccinum praemorsum Linné, 1758 from freshwater rivers and springs in southern Spain, and the Maghreb (AZPEITIA MOROS, 1929).

Melanopsis is common in fresh water in Jordan such as Wadi Hisan and Mujib (Fig 6.19 & 8.20).

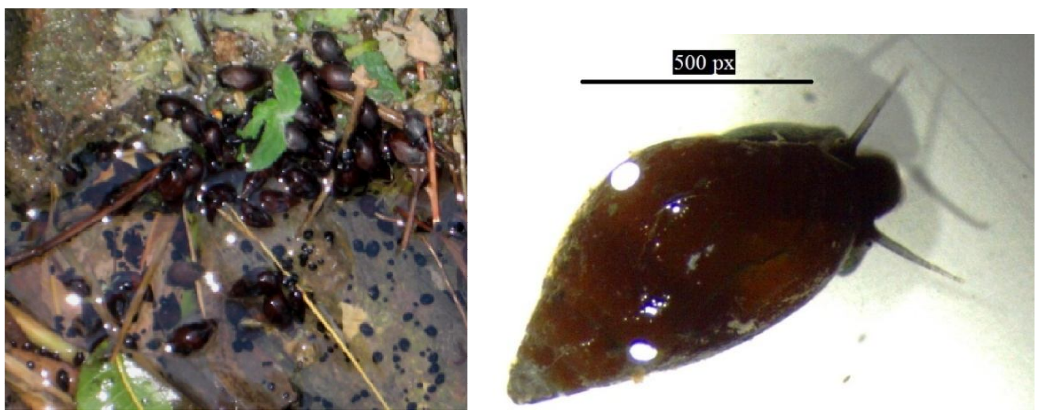


Figure 6.18: Melanopsis from Wadi Hisban.

Species *Melanopsis buccinoidea* Férussac, 1823 differs from the type species of the genus Melanopsis praemorsa by a more rounded cylindrical shape (BANDEL, 2000). Individuals of Melanopsis buccinoidea like those which lived in the spring and creek at Pella in Jordan can be taken as an example. They are smooth, consist of 8 to 9.5 whorls and usually reach a height of around 25 mm and width about 12 mm. The spire is pointed and the growth of whorls occurs with regular increases in width. The body whorl is evenly rounded with the aperture taking about half of shell height. Its posterior portion is a narrow slit formed between the thickened callus pad of the inner lip and the evenly curving outer lip. Between these a deep and narrow slit is present that is closed further within the shell lumen. The anterior portion of the aperture is drop-like in shape and ends in a narrow short and distinct siphon notch.

The protoconch has three quarters of a whorl without growth lines and from there on growth lines up to the hatching point, which occur with about 1.5 whorls (RIEDEL, 1993).

Coloration is dark brown to light reddish brown and arranged in bands. One spiral reddish brown band lies right anterior of the suture, followed by a dark brown ribbon that extends to the base, while the base is reddish brown again. Exceptionally large shells of members of this species from Jordan measure 32 mm in height and 15 mm in width.
The species occurred in the area of the Jordan Valley since the existence of the Erk el-Ahmar lake and Ubeidiya lake and lived also in the Al-Qarn lake and thus for more than 1 million years, basically unchanged. HELLER et al. (1999), BANDEL (2000), HELLER & SIVAN (2002, Fig.3A), BANDEL et al. (2007).

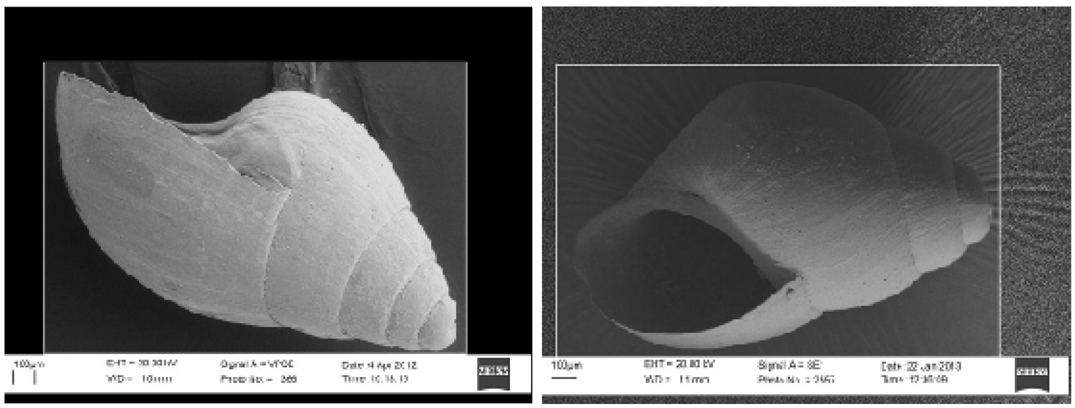


Figure 6.19: a. Juvenile shell of Melanopsis buccinoidea from Wadi Hisban spring, b. juvenile shell of Melanopsis buccinoidea from Wadi Mukheiris, the scale bars are 100µm.

Species *Melanopsis costata* OLIVIER, 1804 has a slender fusiform shell with up to ten whorls and reaches a size of up to 3.3 cm in height. Shell shape is that of a slender *Melanopsis* buccinoidea, with which it probably forms hybrids. But ribbed individuals of this species are by far the more common ones in the population of Azraq Druz pond 1995, and now extinct (BANDEL, 2000, Figs 72-75). The ornament consists of 12 to 15 rounded ribs which are continuous across the whorl forming an even curve pointing forwards in the rounded transition of the whorl sides into the base. Ribs are usually continuous onto the base but may become less distinct here. Transitional individuals to M. buccinoidea have weak ribs which are present only in the juvenile shell or irregular ribbing up to the end whorl.
Difference: The spire of *Melanopsis saulcyi* is shorter, the ribbing in Melanopsis noetlingi is more pronounced, and the stair-like whorl shape from the fifth whorl onwards distinguishes *Melanopsis blanckenhorni*. According to BANDEL (2000, Figs 72-75) and to HELLER et al (1999, Fig.4B) the main feature of Melanopsis jordanica is the presence of an ornament of 9-14 axial ribs on each flattened whorl and an usually slender relatively large shell (around 2.5-3 cm high) with rounded upper whorl side(Fig

6.21).More than 9 whorls compose the shell and the straight ribs are usually continuous onto the base and may have a weak posterior swelling on their subsutural portion that may be accompanied by a shallow furrow on the whorl side anterior of it. BLANCKENHORN (1897) discovered that the type locality of the species is the middle Orontes region in Syria and was here collected in a canal for irrigation. The shape of the shell is taken as that illustrated by HELLER et al. (1999) without stair-like spire.

Figure 6.20: Melanopsis jordanica (source from Oz Rittner "Inland water molluscs of Israel").

The species that lives next to Lake Tiberias and in the Jordan north of it closely resembles the species that lived up to 1995 in the ponds of Azraq oasis in Jordan, and is here described as Melanopsis costata. It can be collected from the beginning of KAC near the connection to the Yarmouk River.

Species *Melanopsis saulcyi* BOURGUIGNAT, 1853 has in addition to axial ribs also some spiral elements its whorls. The species is smaller (about 15 mm high) than *Melanopsis costata* and its spire is shorter. The type locality is Tartus in Anatolia (SCHUETT, 1983). BANDEL (2000, Figs 76-79) noted that the shell of this species has a more or less well developed corner of the posterior shoulder on the whorls of the spire with the axial ribs inserting with a spiral row of tubercules. This row is accompanied by a depression anterior to it. Also present are spiral elements. *Melanopsis saulcyi* BOURGUIGNAT, 1853 was determined by HELLER & SIVAN (2002, Fig. 3C) from Erk el- Ahmar Formation.

Melanopsis saulcyi has the shorter spire and a well developed row of nodes below the shoulder, contrating to *Melanopsis costata* with high spire and less nodular ribs. Compared with Melanopsis bandeli it has a shorter spire and fewer spiral ornamental elements. In regard to Melanopsis blanckenhorni the spire is less stair-like. HELLER et al (1999, Fig.4 F,G) placed with *Melanopsis saulcyi* two distinctly different forms which can be determined as *Melanopsis saulcyi* and *Melanopsis bandeli*. This difference is probably real since in Jordan they occur in several independent populations which have many individuals and are geographically isolated from each other.

Species *Melanopsis doriae* ISSEL, 1866 has conical shape and flat sides. The species is recognized in the hydrogensulfide rich water of Hemma spring next to the Yarmouk River. It is characteristically more conical and less rounded than *Melanopsis buccinoidea* (BANDEL 2000, Figs. 25-29). *Melanopsis doriae* does not occur in the populations encountered in the rivers and creeks near Amman.

Species *Melanopsis sharhabili* BANDEL 2000 is characterized by five to six first whorls that are like those of Melanopsis buccinoidea, and in the next whorl the shell becomes wider and an ornament of distinct spiral lines is developed (BANDEL 2000, Figs 119-123). The fully grown shell consists of 9 whorls and is up to 18 mm high and 9 mm wide. The first five to six whorls are of a fusiform shell with conical spire and regular increase in shell width. In the next whorl the shell widens more rapidly, whorl height in relation to shell height increases, so that it is two thirds of total shell height. With increasing diameter of the whorls an ornament of somewhat irregular spiral lines appears, which is either not present before or only indistinctly developed. The inner lip of the aperture has curving outline with a rather thick posterior callus pad.

Melanopsis sharhabili has allometric growth with more rapid increase on shell width from the fifth whorl onwards, which differs from the other species noted in Jordan and which are known from the area of the Orontes and Jordan River catchments.

Species *Melanopsis cerithiopsis* BOURGUIGNAT, 1884 (Fig 6.22) was interpreted to represent the subspecies Melanopsis praemorsa ferussaci by SCHUETT (1984). *Melanopsis praemorsa* and *Melanopsis costata* according to HOROWITZ (1979) live in modern Lake Kinneret and according to his interpretation they lived throughout Pleistocene time in the Jordan Valley. *Melanopsis bandeli* (Figs 81-96) is similar but more slender.

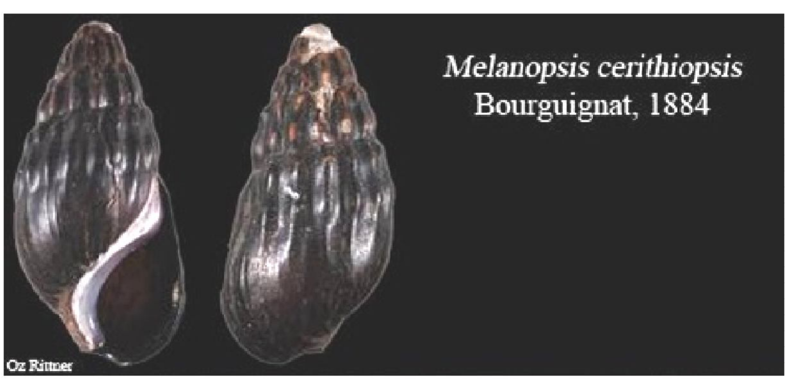


Figure 6.21: Melanopsis cerithiopsis (sources From Oz Rittner “Inland water molluscs of Israel”).

Species *Melanopsis bandeli* (SCHUETT, 1988) according to SCHUETT (1988, Pl.1, Fig 7) has the shell slender and tightly axially ribbed of about 20 mm in height and 8 mm in width with an about 10 mm high aperture. Ribs cover the shell only above the periphery. The shell consists of 9 whorls separated from each other by a shallow suture. Ornament inserts with the fifth whorl while the first whorls are smooth and form a spire of conical shape with flattened sides. Ornament consists of about 15 ribs on each whorl which are crossed by more or less well developed spiral lines and one more or less distinct spiral thickening just below the suture. The shell is dark with three light spiral color bands of which the upper one is broader than the other two. The aperture is characteristically narrow and it is closed by an operculum with characteristic excentric nucleus that lies close to the inner lip (BANDEL, 2000, Figs 80-96). The individuals encountered in small springs in the Zarqa Valley, a few km downstream from Suckhna, probably belong to this variety or species of Melanopsis.

Melanopsis ammonis is close to *Melanopsis bandeli* regarding the similarly slender shell shape but the indistinct ribs of the former differ. The fossil *Melanopsis turriformis* PICARD, 1934 from the Ubeidiya Formation resembles in shape and also has many ribs, but differs by having no spiral ornament and its more pronounced axial ribs continue onto the base. SCHUETT (1988) interpreted *Melanopis bandeli* to represent a subspecies of *Melanopsis praemorsa* and to intermediate between *Melanopsis costata* and *Melanopsis obsoleta* (also considering both as subspecies to *Melanopsis praemorsa*) (SCHUETT, 1983, Pl.3, Fig.57). *Melanopsis obsoleta* is a species from the Palmyra Oasis in Syria (SCHUETT, 1987). According to SCHUETT there is another subspecies *Melanopsis praemorsa ferussaci* ROTH, 1839 that lives along the coast of Lebanon and Syria. This species has also received the name *Melanopsis buccinoides* living in coastal rivers which drain into the Mediterranean Sea and not the Orontes catchment by KINZELBACH (1987). There are three more subspecies mentioned by SCHUETT (1988), among them *Melanopsis praemorsa olivieri* BOURGUIGNAT, 1884 in Syria (Basin of Aleppo) and the mountains of Lebanon. The population that used to live in Azraq oasis and has since 1995 been exterminated was cosidered an independent subspecies close to *Melanopsis costata* (SCHUETT, 1988).

Species *Melanopsis ammonis* TRISTRAM, 1865 has the slender shell delicately ornamented by low axial ribs which are discontinuous and do not reach the base (BANDEL 2000, Figs 113-118). The shell of about 17 mm in height and 7 mm in width has a 7 mm high aperture. It consists of a little more than 9 whorls separated from each other by a shallow suture. Ornament inserts within the fifth or sixth whorl and there is usually also a more or less well developed spiral lines. The shell is dark brown sometimes with one or two indistinct light spirals. The aperture is elongate and provided with a distinct callus pad of the inner lip. Melanopsis ammonis resembles in shape and ornament *Melanopsis bandeli* but has a weaker ornament. The species has been noted from creeks in Ajlun and south of it to the Mujib River. According to SCHUETT (1983) the type of *Melanopsis ammonis* was collected in Wadi Hisban and Wadi Ammon, which could be in theZarqa near Amman, where it has not survived.

Melanopsis ammonis was collected 2000, and 2001 in the spring and the creek near Hashemiye in Ajlun, where it occurs in pure form in a great number (many thousands) of individuals of the same shell character. While at the base of Wadi Mujib Melanopsis ammonis appears to grade into rather slender types of *Melanopsis buccinoidea,* near the end of the river near the Dead Sea, which is no longer preserved. These, sometimes, resemble Melanopsis doriae as found in the thermal spring in Hemma next to the Yarmouk. In Wadi Mukheiris just east of the northern Dead Sea end, thus, close to the type locality Wadi Hisban, the species also occurs together with Melanopsis buccinoidea.

Melanopsis jordanica (ROTH, 1839) (Fig 6.22) from the Pleistocene below the Lisan Marl in the Zhor area west of Abu Habil (BANDEL, 2000 Figs.127-128). It is very close to the species determined as *Melanopsis lampra* that can be considered of the same shape.

Figure 6.22: Melanopsis jordanica (sources From Oz Rittner “Inland water molluscs of Israel”).

Melanopsis alba sp new species (Fig 6.23)

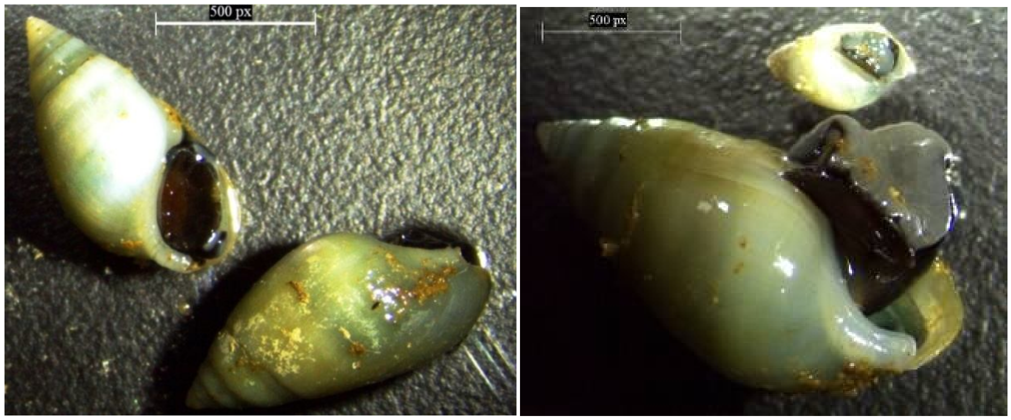


Figure 6.23: Melanopsis Alba sp, white Melanopsis, small and large individuals from Wadi Atun (2012).

Localities of occurrence of Melanopsis in Jordan:

Melanopsis had been collected in the year 2000 (March and begin of April) at the localities mentined below: 16 separated faunas of Melanopsis were sampled of which the northern-most consists of three faunas connected to the Yarmouk River of which one is surviving in a sulfur spring. The faunas of the all Valleys ending in the Dead Sea are similar to each other with the exception of that of Wadi Mujib.

1. Hemma at the Yarmouk with two different localities. One is at the creek that comes down the mountains and ends in the Yarmouk about 1 km east of Hemma town. This fauna ends with the begin of the hot spring entering into the creek from time to time. The second is from the creek of the hot spring water. Here a smaller Melanopsis, but also Theodoxus and Melanoides are found. The later two are present in Hemma town, the first also in the canal besides the road in warm water, but this canal is dry from time to time. The spring water has a good percentage of H_2S in it, which results in a strong smell.

2. Spring Ain Turab on the wadi that runs in the same direction towards the Yarmouk River. Here Melanopsis is found only near the small canal that issues from the mountain side representing the lower spring, while the upper one is water that has no longer a Melanopsis population. This population is clearly discontinuous, but may connect to the Yarmouk when water is high. The probability of settlement in the Yarmouk is very low. The fauna is represented by a smooth form.

3. Spring and creek at Pella (Ain al Jirm). Here two species occur, but the spring and creek are now badly damaged due to water works. They live together with Theodoxus in the spring area. Further down the smooth Melanopsis prevails. The ancient spring has since been destroyed due to the construction of the pumping station.

4. Pond in the Jordan Valley near Mashara and just west of its northerly part Al Himma with a rich fauna on mud and in the canal connecting two ponds containing a slender ribbed form.

5. Wadi Ziglab contains above its end lake a rich fauna of the smooth Melanopsis living on the rocks of the clean creek that also contains fish.

6. At the end of Wadi Rayyan near the mosque of Shar-habil a spring issues from the Jordan Valley base flat that contains a rich fauna of two types of Melanopsis along with Melanoides and Theodoxus. This fauna is now discontinuous, but it could very well connect up with the Jordan in times of high water. The fauna was sampled in 2001 again at the type locality to Melanopsis sharhabili.

7. Into the wadi next (south of) Wadi Ziglab a spring issues that is called the White spring (Beida). In it a smooth form of Melanopsis live that resembles that of Wadi Ziglab. Both Wadis only join in the Jordan River, and not before.

8. Near Hashemya in Ajlun (actually town to the northeast of Istafayna) a spring with it is concrete canal contain fauna of a smooth slender variety of Melanopsis. This form could well connect with Jordan forms in times of much water, but most probably could not crawl up the hill to the spring. The same locality was sampled again 2001.

9. The small creek with the Tertiary rocks exposed just southwest of Abu Habil and west of the Ghor Canal contains a few specimen of ribbed and smooth Melanopsis. This is continuous upstream into Wadi Siyale.

10. The spring of Rumeimin that discharges into the Zarqa river and now sends King Talal revervoir, contains a thriving fauna of a smooth Melanopsis. The fauna now appears to be quite isolated.

11). On the southern slope below the road in Um ed Dananir a small spring is collected in an artifical pond to water plants. The spring has a fauna of Theodoxus as well as the smooth Melanopsis buccinoides. This occurrence is quite isolated since the creek downstream is strongly polluted.

12. Small springs issue from the Valley base a few km downstream of Sukhna in Zarqa Valley, and here a slender and ribbed Melanopsis occurs as well as Bulinus, none of them enters the Zarqa River, due to its pollution and they remain close to the springs.

13. The creek in Wadi Mukheiris that ends in the Dead Sea has a littel fauna in its lower part, that can be connected to the fauna of the springs further upstream, which were not sampled in 2000.

14. Wadi Dardur (the next south of Wadi Mukheiris) contains a rich fauna with large specimen with a nice colored pattern of light colors in the spindle portion of the shell. All are of the smooth type. This wadi ends in the Dead Sea.

15. One wadi further south of Wadi Dardur (Himara) ending also in the Dead Sea with a fauna of smooth forms which are very similar to those further norths.

16. The mouth of Wadi Mujib contains rich fauna of slender form that differs from the other wadis in the north discharching into the Dead Sea.

17. The Wadi Khanzira (little pig) ending in the southern end of the Dead Sea, contains water only upstream of the concrete pool has a fauna of smooth Melanopsis. Above, at

the wadi fills a wide swamp of large grass forming a dense growth, and the wadi continues to the east, but without fauna. They may very well exist in the spring water.

18. Wadi Atun (2011) with occasionally also white specimens of Melanopsis alba resembling otherwise Melanopsis buccinoides. Here the smooth Melanopsis is together with small, short hydrobiid Prosostenia, with springs partly discharching mineral water and partly fresh water- in the latter with Melanopsis.

19. Wadi Al-Hasa (2012) in its lower part Wadi Al-Hasa has many Melanopsis buccinoides and few Melanoides in small muddy side pools.

In 2001 four more localities were discovered to contain Melanopsis; these are:

20. Next to the Jordan River in North Shuna in a spring and creek, where ribbed slender Melanopsis is common.

21. The spring of Wadi Rayan where normal smooth Melanopsis together with Theodoxus are found.

22. Just opposite to Kufranja on the small road down the northern slope of Wadi Kufranja a spring in a small cave contain the normal smooth Melanopsis along with Theodoxus. The same is noted in clean water that issues into Wadi Kufranja, but the creek in this wadi is too dirty to still support snails.

23. From dredgings in the Ghor Canal near Abu Habil many shells of well ornamented Melanopsis saulcyi were found dumped on the road next to the canal together with Theodoxus jordani of the variable type that is described from Lake Tiberias. Similar individuals of Melanopsis are seen in the begin of the canal close to the Yarmouk River. The species comes from the Yarmouk and was noted in large numbers on the canal walls at the begin of KAC in the northern area of North Shuna (2011).

24. Karama dam (2011) still with a lot of Melanoides and 2012 salinity rose and no snails were still living in it.

In 2012 four more localities were found:

25. A small spring near to Sukhna in Zarqa Valley Melanopsis together with Theodoxus.

26. Khresan spring in Zarqa Valley only Melanopsis buccinoides.

27. Sarah spring and creek in Karak, a large number of Melanopsis and Theodoxus.

28. From Wadi Wala downstream Melanopsis and Theodoxus.

Melanopsis produces single eggs; each surrounded by a gluy gelatinous cover, and lays them onto the ground. They are thus difficult to spot since they are usually coated by sediment particles. From them a minute crawling young hatches with a shell consisting of little more than one whorl. In places in which Melanopsis thrives well individuals of all age groups are found, larger more grown individuals can tolerate some polution for a limited time and survive, but the young ones tolerate it in a lesser degree.

Species belongs to Heterostropha, Allogastropoda, and Superfamily Valvatoidea

Genus Valvata O.F. MUELLER, 1774

The type to the genus is Valvata cristata O.F. MUELLER from central Europe. The embryonic shell was described by HADZISCE et al (1976) and RIEDEL (1993). The shell is usually small and lowly trochospirally or almost planispirally coiled with rounded whorls and wide umbilicus. The aperture is round and oblique. Typical features of the body as seen from the outside are the gill that is commonly extended beyond the pallial cavity, the pallial tentacle that is held to the side toward the apex of the shell, and the operculum bearing foot with rounded end. The characteristic embryonic shell of the modern forms of Valvata consists of one planispiral whorl (RIEDEL, 1993).

Species *Valvata* (Cincinna) *saulcyi* BOURGUIGNAT, 1853

The trochiform shell consists of three whorls with a little more than 2 mm in diameter (Fig 6.24). Living *Valvata saulcyi* BOURGUIGNAT, 1853 was encountered in 1978 a spring in Wadi Rum in Disi area and in the Roman bath-pond in Jerash. It was also collected from the southern pool in Azraq oasis 30 years ago, but was not noted to occur in any place at which fauna was collected in the present study. The modern individuals live in springs in Jordan (SCHUETT, 1983). TCHERNOV (1975: pl. 1, Fig. 4) suggested that *Valvata saulcyi* represents the only species that lived throughout the Neogene and Pleistocene of the Levant. The species is encountered in the deposits of the late Pliocene lake of the Al Qarn Formation (BANDEL, 2010, Figs. 52–53).

Figure 6.24: Valvata saulcyi From Oz Rittner “Inland water molluscs of Israel”

Heterostropha, Basommatophora, Suborder Archaepulmonata

Family Ellobiidae H. & A. Adams in PFEIFFER 1854

These marine pulmonates have an ovoid shell usually with large last whorl and short spire and with an usually narrow elongate aperture with one or more columellar folds on the inner lip and sometimes additional plicae further posterior to them and commonly teeth, plicae or thickenings within the outer lip of the aperture. The ornament consists of incised spiral lirae that may be very indistinct to absent and in some cases also short axial ribs are stronger collabral elements. The animals are small to large and live mostly amphibious in marine and brackish habitats, inhabiting the upper and supralittoral zones of the mangroves of the tropical regions and salt marshes of temporal regions, as well as rocky coasts. The family is based on the genus Ellobium including its relation.

Genus Ovatella BIVONA 1832

The elongate oval conical shell is smooth and not umbilicate. The aperture is a little widened and is lirate on the inner outer lip that bears two to five folds and has one columellar fold.

Ovatella (Myosotella) myosotis (DRAPARNAUD, 1805) is a common Mediterranean and east Atlantic species that lives in salt marshes (Fig 6.25). It also occures in Bermuda and the Azores as well as the Baltic Sea, and even New in Zealand. The shell may consist of up to eight whorls, is up to 7.5 mm high and ornament consists of flattened and wide spiral gooves of which 5.6 are visible above the suture. The aperture has no strong varix. The first whorl of the teleoconch has only wavy spiral ornament and on the second whorl the groove ornament begins, including periostracal spines.

Figure 6.25: Ovatella myosotis, from Oz Rittner “Inland water molluscs of Israel”.

This species was found alive in 1978 at the NE end of the Dead Sea in a small creek below a brackish water spring (Fig 6.26). In 2002 it was collected next to the branch off of the road to Madaba from the main road along the Dead Sea and described by SCHUETT (1983 Fig.9). Individuals of Ovatella myosotis lived in great numbers on the wet zone of a small creek originating from the little spring. In the begin of this creek, that issues from a spring with brackish water Ovatella it not present, while only some ten meters below they settle the narrow wet creek sides. Here moist sand, Salicornia plants and their roots, stones and plastic and wood remains are settled by numerous individuals of all sizes.

The accompanying fauna consists of Hydrobia and Pseudamnicola found under water on hard substrates and Melanoides in all sizes. In 2012 the spring was destroyed due to construction of appartment blocks- and only dead shells of Ovatella were noted near a creek formed partly by irrigation and by spring water further north of the houses.

HELLER (1993, p.211) noted the occurrence of *Ovatella myosotis* on the western side of the Dead Sea and from the lower Jordan Valley under similar environments.

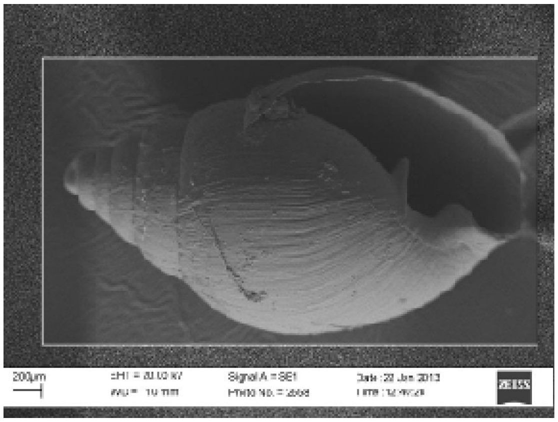


Figure 6.26: *Ovatella myosotis* from the salt creek near the NE end of Dead Sea, the scale bar is 200µm.

Laemodonta PHILIPPI, 1846 resembles Ovatella and is the only archaeopulmonate species found among the pebbles along the shore of Aqaba (Fig 6.27). It has a small shell growing to 4-9 mm in height. It is of ovoid shape with conical spire. The spire is a little higher than the final whorls of the fully grown. Ornament consists of spiral furrows and ribs with pits in the furrows. The aperture is narrow has a fold on the columella, two folds on the inner lip, and one ridge on the inner side of the outer lip (HARBECK 1996, Figs.121-130). *Laemodonta octanfracta* (JONAS, 1845) has coarser ornament than Ovatella. It differs also by having a larval shell that is sinistrally coiled and inserted in the teleoconch in inclined position with its apex pointing into the later and larval umbilicus exposed. The margin of the larval shell is sinuous and transition from smooth larval whorl to ornamented teleoconch drastic. Ovatella lives on the coasts of the Northsee and Baltic See as well as in creeks of brackish water that form between springs and die in the salty Dead See. It resorbs the inner walls totally and reduced the osphradium. Typically, it lives on muddy bottom in the uppermost region of estuaries where adults feed on diatom crusts and deposit their spawn on wet mud, commonly below the surface. Ovatella myosotis was in an aqarium over several years and here produced during spring and summer-time spawn at irregular intervalls. The operculum is cast serval days after hatching from the egg mass as crawling young. Ovatella myosotis completes its embryonic and larval developent within the shelter of its egg mass.

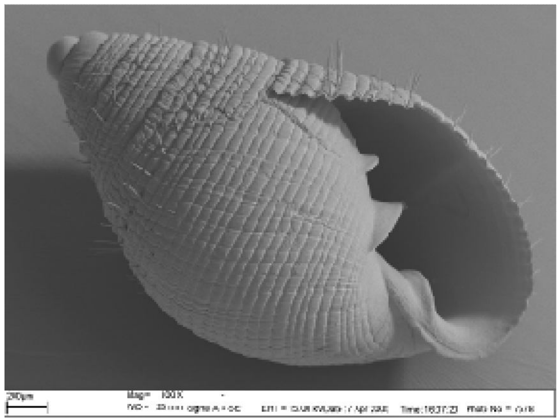


Figure 6.27: *Ovatella myosotis* from the Gulf of Aqaba, the scale bar is 200µm.

The Basommatophora are shell bearing pulmonates of fresh water without operculum and with one pair of tentacles on their head which bear eyes near their base. The early ontogenetic shell is of simple shape and ornament since there exists no planktrotophic stage in the develepment and a miniature adult ususally leaves the egg capsule after embryological development. That portion of embryological development during which the shell and mantle are in close connection to each other and the shell is attached to the shell secreting epithelium is only short and ends with the formation of a shallow initial shell disk.

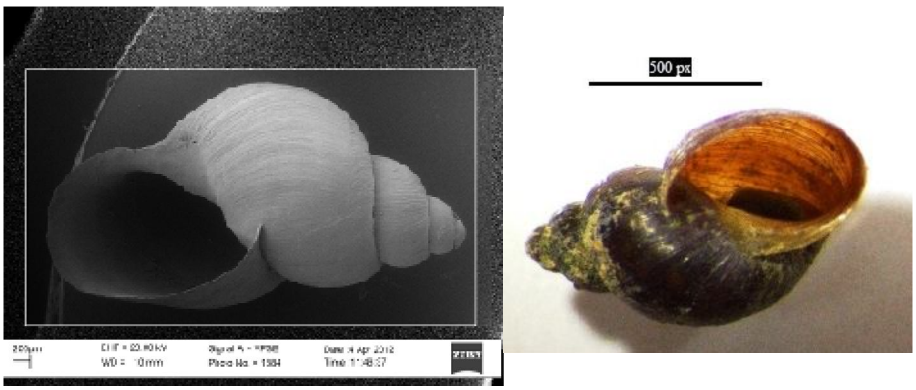
Superfamily Lymnaeoidea

Family Lymnaeidae RAFINESQUE, 1815

The shell spirally coiled, and the head tentacles are flat and of triangular shape. Physidae and Lymnaeidae have no gill but transport a bubble in their pallial cavity. They can thus also utilize badly oygenated water by taking their oxygen with them. The bubble is actively sucked into the cavity guided by the muscular opening, the pneumostom and it is also expelled that way by being pressed out due to muscular contraction of the walls of the lung. Oxygen bubbles can also be collected from plants or cyanobacterial growth, where they are continuously produced when sun light is available.

Genus Galba SCHRANK 1804, has small shell with pointed spire is conical and the sutures between whorls are deep. The shell resembles that of Stagnicola. The type *Galba truncatula* (O.F. MUELLER) (Buccinum) = *Galba pusilla Schrank* is from central Europe. Species occur in Europe as well as South America and Hubendick considrs known it a subgenus of Lymnaea.

Species *Lymnaea* (Galba) *truncatula* (O.F. MUELLER, 1774), has small shell with pointed spire is conical and the sutures between whorls are deep. The shell resembles that of Stagnicola. The type *Galba truncatula* (O.F. MUELLER) (Buccinum) = *Galba pusilla Schrank* is known from central Europe. Species occur in Europe as well as Africa and can or cannot be considered as a subgenus of Lymnaea. The shell is up to 10 mm high and 5 mm wide. In our collections in Jordan Galba truncata was found near the springs of Hisban and Wadi Shita in small canals leading to fields (Fig 6.28). It was collected from Wadi Musa (Petra) 1978 and described by SCHUETT (1984, Fig. 11). It was also found in a creek that issues into the ZarqaRiver just downsream of Zarqa Bridge on the road Amman-Jerash (SCHUETT, 1983, Fig.11). HOROWITZ (1979) described it as Lymnaea lagotis of Lake Hula and as a fossil from the Ubeidiya and Erk el- Ahmar Formations. A Lymnaea auriculata was mentioned to occur in Druze and Shishan marshes of Azraq Oasis by NELSON (1973).



(The scale bar is 200µm)   (The scale bar is 500 px)

Figure 6.28: *Galba truncatula* from Wadi Hisban (2012) scanned and as in the field.

Subfamily Bulininae
Genus Bulinus MUELLER, 1781
This branch of the planorbids may have a sinistral shell resembling that of Physa. The outer shell shape resembles that of the Physidae in being sinistral coiled. There are about 30 species in Africa and among them also Bulinus truncatus (BROWN 1980, FIG 108).

Species *Bulinus truncatus* (AUDOUIN, 1827)
The shell is sinistral and consists of rounded whorls with the aperure wide and higher than the spire. Growth can be strong and a fine spiral pattern of lines may lay on the gray periostracum (Fig 6.29). The living animals appear grey while the similar Physa is brown. When crawling the mantle is not expanded across shell margin, as is the case in Physa. This species is found in Africa from the Nile to Lake Tanganyika and also occurs in southern Europe and the Middle East. BROWN (1980) noted that the species lives in a variety of water bodies. Bulinus truncatus is a transmitter of Schistosoma, but occurs

only rarely in Jordan. Bulinus truncatus was found living in the pool formed by the ancient water collecting basin bulit by the Romans at Jerash. The individuals from this Roman Bath at Jerash 1978 were described by SCHUETT (1983, Fig. 12), and before by SALIBA et al. (1976) from near Deit Alla. Bulinus was also discovered in springs and puddles formed next to them close to Zarqa River 2013 and here together with Melanopsis (Fig 6.30). Bulinus entered pools with mixed water of springs and Zarqa River which were not entered by Melanopsis living in a clear small creek from the spring, and both do not enter Zarqa River proper, but disapear before contact to the actual river, its water obviously not healthy to them.

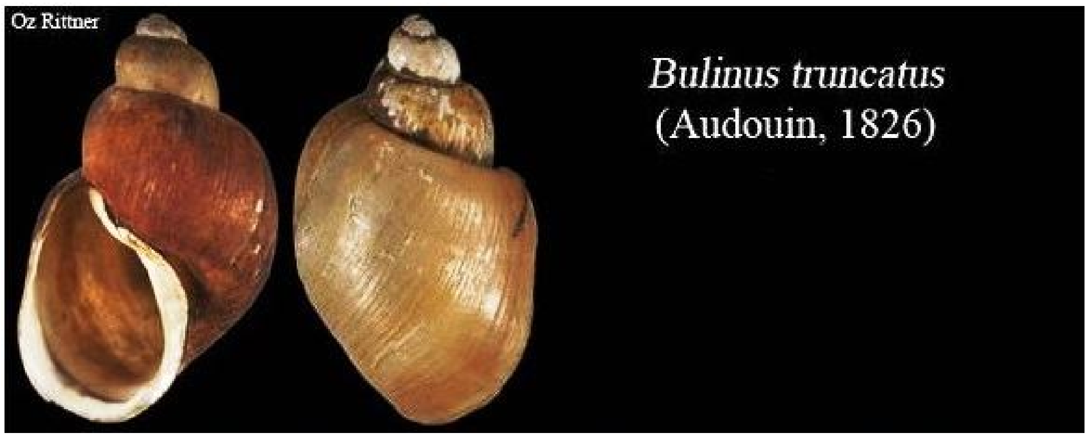


Figure 6.29: Bulinus truncatus by Oz Rittner “Inland water molluscs of Israel.

Figure 6.30: Bulinus from small spring lake in the upper ZarqaValley, March 2013.

Physidae, the smooth, sinistral shell resembles that of Bulinus. On the living animal finger like appendages of the mantle margin extend onto the outer shell. Physa is found in Europe (Holarctic) but has also spread to South America and all parts of the world including New Zealand. It is possible that Prophysa BANDEL, 1991 as sinistral fossil species is related to Physa DRAPARNAUD, 1801. But this Late Jurassic (Purbeckian) gastropod that could belong here or next to the other sinistral forms as found in the genus Bulinus O.F. MUELLER, 1781.

Genus Physa DRAPARNAUD, 1801,

The type is Physa fontinalis Linnaeus, and in Jordan Physa acuta DRAPARNAUD, 1805 is common. The Middle East species has spread into similarly warm water bodies in Egypt as well as other regions in the world. In 1978 it was found only in a ditch near Deir Alla, but since then it has become one of the most common gastropods living in waters of Jordan. This species occurs in all Mediterranean areas and in all rivers and lakes in Syria (SCHUETT, 1983, Fig.10) (Fig 6.31). The shell resembles that of Bulinus but has a more pointed apex and a shinier smooth surface of it periostracum. Living individuals appear more reddish brown with the soft body of the snail seen through the semi-transparent shell. *Physa acuta* is now (2011-2013) present in weakly polluted creeks and in clean rivers such as Mujib, in Shueib above and below the treatment plant and even in theZarqaRiver shortly below the wastewater treatment plant of Amman (2013) while in fall 2011 it was only found in the lower Zarqa River below King Talal Revervoir (Fig 6.32).

Figure 6.31: Physa acuta from internet (Oz Rittner “Inland water molluscs of Israel).

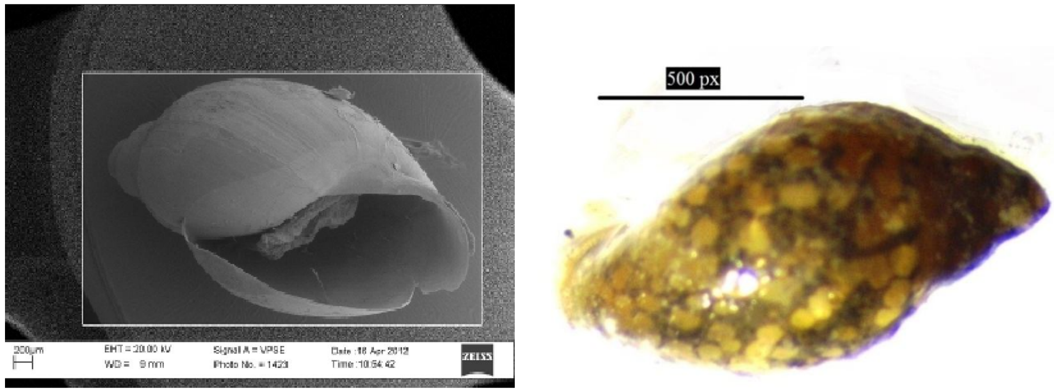


Figure 6.32: a. Physa acuta from Jordan collected in 2012 documented by the Scan (The scale bar is 200µm), b. Physa acuta Physa acuta from Zarqa River (The scale bar is 500 px).

Physa acuta has developed into a character species to moderately polluted water in Jordan. It represents the fresh water gastropod in Jordan that can tolerate more pollution than all species but does not survive increasing water salinity.

Superfamily Planorboidea, family Planorbidae RAFINESQUE, 1815
Genus Planorbis MUELLER1774 (GEOFFROY, 1767)
The type is Helix planorbis LINNAEUS, 1758 from Europe with the flatly coiled shell having a size of 10-20 mm and outer whorl with keel. Whorls are bluntly angular or carinate. The shell is mostly coiled in planispiral mode. Development of the eggs continues in the spawn until crawling young hatch with a shell of little more than one whorl. Usually the protoconch is coiled in a plane, but sometimes a slight sinistral twist is preserved. Ornament of the embryonic shell usually consists of spiral striation (BANDEL, 2010).
Planorbis planorbis was collected alive from from Azraq Druze pool in 1978 and described by SCHUETT (1983 Fig. 13) as Planorbis planorbis antiochianus LOCARD, 1883. BANDEL (2010, Pl. 14/168–171) documents the shell of the species. Planorbis planorbis has its whorls plane on the apical side, convex at the wide umbilicus, with keel near to the lower side. The shell consists of up to 6 whorls and is up to 18 mm wide. The suture is deeper on the lower side than on the upper side. Collabral growth lines form a regular pattern. RIEDEL (1993) described the development of the embryo. Its shell when hatching after about 9 days of development is 0.6 mm in diameter and consists of 1.3 whorls. The rounded initial part of the embryonic shell is about 0.1 mm wide and commonly covered by irregular folds. In most cases transition from the protoconch to the teleoconch is gradational because protoconch ornament ceases earlier or continues onto the teleoconch. The dextrally coiled shell has a more rapid increase in whorl width more ornament of growth lines and a more flattened whorl flank.

This species that lived both Azraq ponds (1978), according to HOROWITZ (1979) was also a species of Lake Hula. NELSON (1973) reported a Planorbis planorbis philippi from Shishan pools and the marsh and salt flats next to it in Azraq, which is probably the same species as described by SCHUETT (1983). The dextrally coiled shell has a more rapid increase in whorl width, more ornament of growth lines and a more flattened whorl flank. MEIER-BROOK (1983, 1984) reviewed the genus Gyraulus in which all species have a small planispiral shell that has a flattened apical side and convex umbilical side. Its whorls are rounded (Fig 6.33). The type species is Gyraulus albus (O.F. MUELLER, 1776) from Europe with the shell of 4-7 mm maximum diameter and 1.2 to 1.8 mm height with 4 to 4.5 whorls, which rapidly increase in width. The planispirally coiled shell consists of 3 whorls with inclination of the aperture indicating dextral coiling mode. The shell of Gyraulus usually has a more rapid increase in shell width than found in Planorbis. Species are found worldwide and occur in any kind of fresh water environment with normal chemistry. The protoconch of Gyraulus resembles that of Valvata in shape and ornament. In contrast to Valvata its margin is not straight but inclined, and increase in shell diameter is more rapid (BANDEL, 2010, Figs. 177, 179, 187). *Gyraulus piscinarum* (BOURGIUGNAT, 1852) with small planispiral shell and flattened apical side and the umbilical side concave with rounded whorls was determined from Jordan (Fig 6.34). It was collected in 1978 from a small spring and pool at Disi in Wadi Rum and described by SCHUETT (1983 Fig.14). He determined it as Gyraulus piscinarium homensis (DAUTZENBERG, 1894).

Figure 6.33: Genus Gyraulus CHARPENTIER, 1837 (source from Oz Rittner “Inland water molluscs of Israel).

Figure 6.34: The small planispiral shell has a flattened apical side and the umbilical side is concave with rounded whorls. (Source from Oz Rittner “Inland water molluscs of Israel).

Figure 6.35: Genus Gyraulus, living in fresh water in Israel according to Oz Rittner “Inland water molluscs of Israel.

Remarks: The genus Anisus Studer, 1820 with the shell very low and lower side almost straight and plane with 5-8 whorls, reaches a size of 10 mm. In Europe there are 5 species. Anisus lives in Europe, Palaearctis (Sibiria) and Algeria. It is penis is like that of Gyraulus. The type to the genus is Anisus vortex Linnaeus 1758 with upper shell side cup like, 9-10 mm wide with basal keel. Anisus spirobis was found, according to HOROWITZ (1979), together with Segmentina nitida (Fig 6.35) in the deposits of the early middle Pleistocene in the northern Jordan Valley.

Species Ancylus fluviatilis MUELLER, 1774, (Fig 6.36)
In Jordan Ancylus O.F. MUELLER, 1774 was only found as fossil in Al-Qarn Formation, while BLANCKENHORN & OPPENHEIM (1927) report Ancylus lacustris in gravel deposits of Yarmouk River as described by NÖTLING (1886 Pl.23, Fig.14). HOROWITZ (1979)

called it *Acroloxus lacustris* (found ar Lake Hula). According to SCHUETT (1983, FIG.12) this species lives on Bulinus truncatus shells feeding on algal covers.

Figure 6.36: Ancylus fluviatilis From Israel by Oz Ritter "Inland water molluscs of Israel.

The limpets of the planorboid stock like Ancylus have an early ontogeny which is characterized by dealing with much yolk. Yolk is taken from the albuminous liquid of the egg in such quantities that the shell calcification is retarded until the limpet shape of the adult shell is reached. When the shell is solidified by aragonitic material a coiled shell is no longer present at all and the torsion of the visceral mass is not reflected in the shape of the shell at all (BANDEL, 1982). According to RIEDEL (1993) one to three eggs of about 0,1 mm in diameter are found in an egg mass of a round cupola. They hatch with about 1 mm large cap-like shell. These small gastropods live submerged and attached to hard substrates that their wide open pallial cavity serves in the exchange of gases between water and blood and there is no lung and no gill. Ancylus lives in running water of streams and creeks in Europe and in the Near East, and according to SCHUETT (1983) are unknown from Jordan.

Gastropods as indicators of environmental conditions in Jordan.

Among the species Theodoxus stands for clean fresh water and is found in Jordan where water is not polluted. This does not indicate that there may not be plenty of planktonic organisms in the water, as is the case in localities at the northern KAC with water coming from the Yarmouk River and in the water of the Mujib River after biological cleaning by the reservoir behind Mujib Dam. Theodoxus is also found in locally very restricted places, such as around very small springs, as for example in a spring in the Wadi Um ed Dananir, several small springs at Wadi Sir, one spring at Wadi Shueib, but it may also appear in a river after water improved in quality as in Wadi Mujib.

Melanopsis prefers running water of springs, creeks and streams and is less delicate regarding water purity. It reacts very sensitively to chemical pollution, for example by sewage or traces of oil. Slightly raised salinity can be tolerated to a lesser degree as is the case in Melanoides. Several groups of morphologically different species of Melanopsis are recognized with slightly different ecologic preferences but unclear relation to each other. Melanopsis stands in competion for food with Theodoxus and may be out-competed by Theodoxus on stony ground in spring water as well as the concrete bed of KAC.

Melanoides in contrast to Melanopsis prefers muddy ground and also standing water. It may tolerate an increase in salinity, but no longer that of Karama reservoir. Here it had lived in huge number a few years ago, but now has disappeard due to raised content of salt in the lake. Melanoides tolerates higher salinity than is the case in any of the varieties of Melanopsis. A similar water quality may be also accepted by Hydrobia but the species of this genus occurs only sporadically in Jordanian water and it thus, is not very useful as indicator species. It apparently, prefers flowing water with a lot of vegetation in it.

Special conditions are required in case of the bivalve, with Unio and Corbicula which prefer continuously flowing water and together with Corbicula such water that contains much phytoplankton, and on the mud next to them Falsipyrgula is common. But these are only found in KAC and no other one of the studied water courses in Jordan.

The bivalves Pisidium and Sphaerium occur only rarely in Jordanian waters and can not be used for pollution assessment. Regarding the water salinity, the gastropods Semisalsa and Pseudamnicola prefer creeks with brackish water and even in case when the salinity reaches almost that of the sea Ovatella and can be present near the Dead Sea (Fig 6.37). While the first two remain in the streaming water of the creek, Ovatella moves on the wet mud next to it. The Pseudamnicola from Wadi Atun may represent a different species from the one found in a creek formed by a spring with salty water near the Dead Sea since it is characteristic to the mineral water of that special isolated creek.

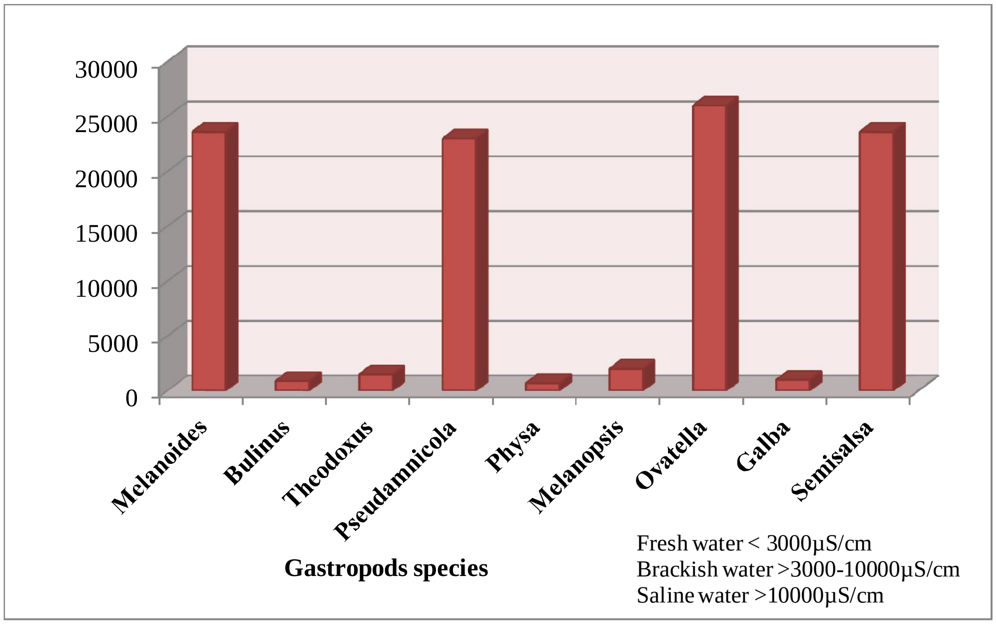


Figure 6.37: The relative occurances of gastropod species in fresh, brackish, and saline water in the study area.

Among the pulmonate gastropods especially Physa is a good indicator species for moderately polluted water. Physa tolerates some degree of house sewage added to streams. Additions of chemical pollutants as for example some oil kills it. The similar Bulinus which also has a shell that is coiled to the left prefers pond water and slow flowing creeks but not up to the degree of pollution as is tolerated by Physa. Galba occurs in running and almost quite water with much vegetation, is rather rare in Jordanian creeks and thus not useful for classification of water quality, but probably prefers clean water. Valvata, Planorbis, Gyraulus and Ancylus species occur occasionally in clean vegetated spring environments but are rare in Jordan, so none of them are useful indicators in Jordan. Thus we have Theodoxus for water of high quality. Melanopsis of water with slight pollution, Melanoides as an indicator of quiet water and tolerance to some increased salinity, Physa as a good indicator for moderately to quite strongly polluted water, Pseudamnicola for mineral water influence and Ovatella for not polluted but salty water that approaches the salinity of the sea.

6.2.2 Other bioindicator groups

Among the Arthropoda many species of insects spend part of their life in water in water. Often eggs are placed in or near water and larvae hatch from them and grow here until they metamorphose into the adult that lives on land. This larval development can be carried out in quite a wide variety of aquatic environments. The location in which the young of a distinct insect species can grow and develop may be quite different among species even of the same group. Some need running water, others quiet water, some tolerate no pollution, others some pollution, and a few even strong pollution and some have their larval life only in fresh water, while others prefer brackish or even salty water for early development. Especially larvae of the mayflies belonging to the order Ephemeroptera, Caddisflies of the order Trichoptera, and true flies of the order Diptera can be encountered in Jordanian waters.

Of these insects the mayflies represent an ancient group which had ancestors that have been recognized as fossils already from the Paleozoic period and have living representatives which are globally distributed, with the highest diversity in tropical areas. According to BARBER - JAMES et al. (2008) worldwide more than 3000 species are known and there may be more that have not been described. The larvae of many species which have been studied in this respect represent very useful indicators of water quality as has been documented for example by BAUERNFEIND & MOOG (2000).

The fauna of mayflies present on the Arabian Peninsula has been the subject of some studies. They document that here as in Jordan live representatives of at least ten families of the mayflies including members of the Baetidae, Caenidae, Ephemerellidae, Heptageniidae, Leptophlebiidae, Oligoneuriidae, Palingeniidae, Potamanthidae and Prosopistomatidae, as is documented by SAMOCHA (1972), DEMOULIN (1973), KOCH (1988), SARTOR (1992), MARIE et al. (2000, 2001) and BARBER - JAMES et al. (2008).

Two studies dealing with mayflies from Jordan were carried out by MALZACHER (1992) and GATTOLLIAT et al. (2012). Of these MALZACHER (1992) predominantly described species from Israel, but also a few from Jordan. But in the more recent work of GATTOLLIAT, VUATAZ &SARTORI (2012) the identification and describtion of the mayflies from Jordan was begun in more detail. They identified and described different species belonging to Baetidae and Caenidae which were collected from the central parts of Jordan. But the taxonomy of mayflies from Jordan is still in progress and numerous still unknown species and genera await description.

Among the mayflies from Jordan determination of species and description of their cycle of life from egg to adult is difficult since larvae change their skeleton during growht and that may happen up to 20 times only during growth of the larva in the water. These larvae may differ not only in size, but also in shape from each other during growth and at different growht stages. It is thus quite difficult to distinguish different species from each other based on different growth stages. The larvae here described were determined to species level by GATTOLLIAT (2013). The aquatic larvae of mayflies were sampled both in freshwater as well as in brackish water habitats from all our locations of study.

The most commonly occurring species of larvae are members of the family Baetidae and four species of that group could be recognized. In Wadi Hisban, Wadi Mujib, and Wadi Shita, in the creeks with freshwater the lavae of *Baetis monnerati* were determined (Fig 6.38 a). Here they are indicators for quite clean water that contains a lot of oxygen. Larvae of another species of *Baetis* were recognized from Wadi Hisban. It can be distinguished from *Baetis monnerati* and all other species of mayflies by the two long caudal filaments without terminal filament (Fig 6.38 b).

This *Baetis Sp* with the distinct two tails is confined to clean spring water as only found in Wadi Hisban spring. Larvae determined to belong to *Nigrobaetis vuatazi* were observed in the creek of Wadi Atun (Fig 6.38 c) and *Cloeon gr simile* was found in the salty water of a small creek that issues into Karama reservoir in the Jordan Valley (Fig 6.38 d). The larvae of three more species of Caenidae were encountered which may belong to the genus *Caenis* (Fig 6.38 e). Among them *Caenis antoninae* occurs in Wadi Hisban and was encountered there in spring 2013. *Caenis antoninae* inhabits very clean water and the presence of the larvae of this species can be used as indicator of high water quality in the freshwater environments (Fig 6.38 f).

A large number of larvae of different species of the Caenidae was encountered in the stream of Wadi Shueib upstream of the Salt treatment plant, Here they tolerate some degree of household sewage that has been added to the water which is still of relatively good quality, but polluted to such a degree that *Theodoxus* is missing and *Melanopsis* has problems of suvival. The mayflie larvae in Jordan in general may tolerate moderate pollution but are absent from heavily polluted water as is found in large parts of Zarqa River, the lower part of Wadi Shueib and large parts of the creek in Wadi Sir, and here especially downstream of treatment plants.

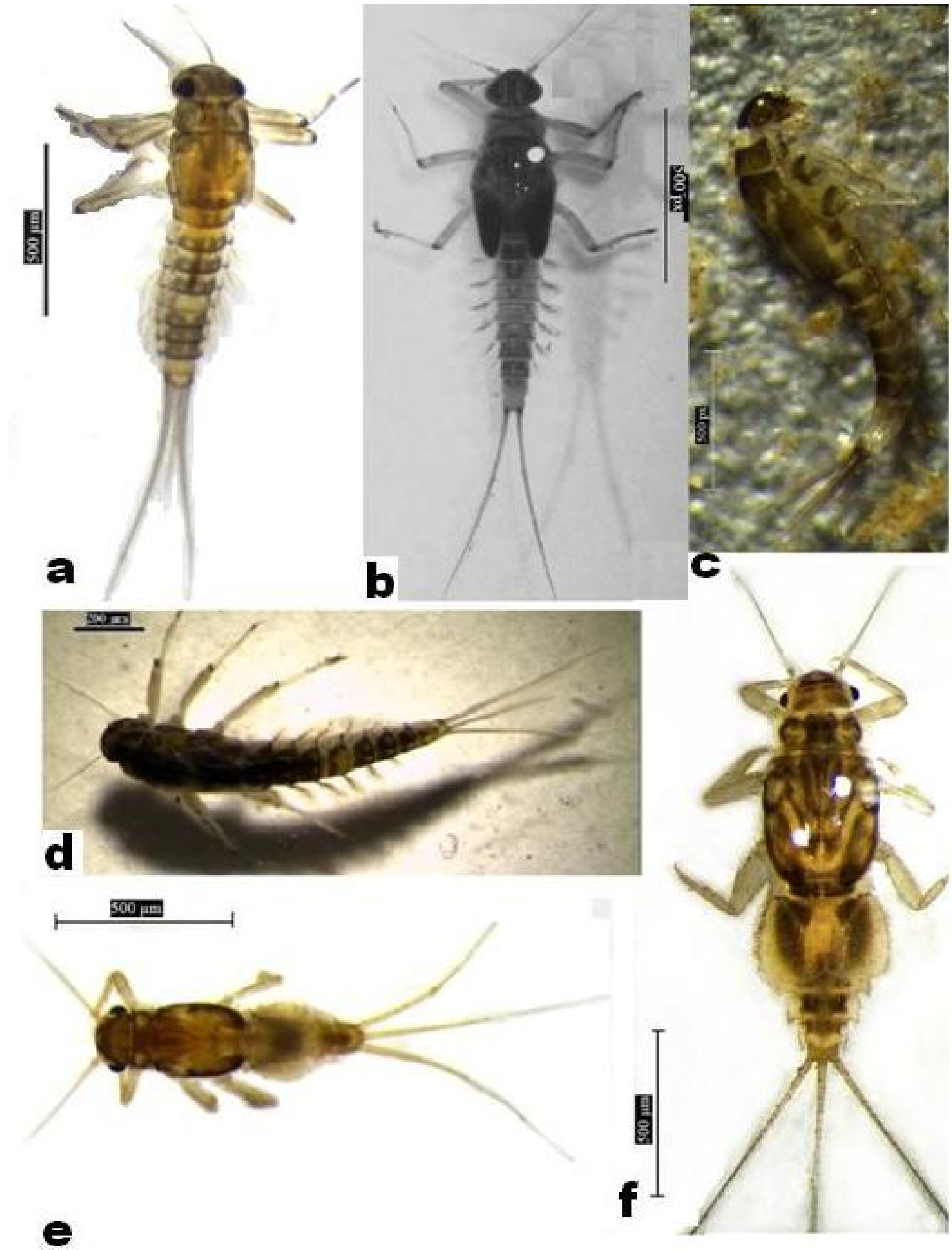


Figure 6.38: showing different larvae of mayflies from Jordan: a. Species 1 (*Baetis monnerati)* from Wadi Hisban spring, b. Species 2 (*Baetis Sp)* the larva has two long caudal filament without terminal filament (Hisban spring), c. Speices 3 (*Nigrobaetis vuatazi*), the larva highly streamlined, (Wadi Atun), d. Species 4 *Cloeon gr simile* from Karama area, e. Species 5 *Caenis antonina* appear with flattened shape, long three tails and square plate like gills shaped (Hisban spring), f. Species 6 (*Caenis Sp)* from Wadi Shueib.

The Trichoptera (caddisflies) represent a quite diverse group of insect, which are interpreted to have over 10,000 species and according to MORSE (2013) an occurrence worldwide with possible exception of Antarctica. Generally, Caddisfly larvae are characterized by building shelters during their larval stage or within a pupa stage, and these cases often have a characteristic shape and construction that characterizes a species or a group of species. The shape and construction of the larval shelter can be used for species of group determination (ROLDAN, 1988).

In Jordan three types of caddisfly larvae are recognized to represent different distinct species or species groups which are present in freshwater habitats as well as in those with brackish water. We collected and distinguished these three types of caddisfly cases and determined two species of caddisfly larvae. Since the taxonomy of caddisfies in Jordan is only poorly known the encountered species were identified only to family or genus level. The "Atlas of central European Trichoptera larvae" by WARINGER & CRAFT (2011) and the study of Morse and HOLZENTHAL (1984) were helpful here for the indentification of the caddisefly larvae, but identification is difficult due to the difference in geographic region.

The first type of caddisflies belongs to the Hydroptilidae, which represents a family with its larvae attached to stones in running fresh water. Their laterally flattened, often purse shaped case is made of silk to which sand grains are attached (Fig 6.39). The case is small in size with a length of 1-2 mm and its color is brown. Cases are common in the creek at Wadi Hisban and the river in Wadi Mujib. Those of Wadi Mujib are darker in color and smaller in size and have a more laterally compressed than those from Hisban. Members of the Hydroptilidae have free-living larvae which construct the cases only in the stage in which they get ready to pupate. According WARINGER & CRAFT (2011) the flattened case covered by sand particles is produced belong by members of the genus *Hydroptila*.

A second type is represented by tubular cases as present in the creek at Wadi Atun that has sources among others stemming from warm mineral springs. Here the case is constructed by grains of sand agglutinated to each other with silk and its shape is that of an elongated and slightly curved tube. According to WARINGER & CRAFT (2011) such tubular cases are constructed by species of the Limnephiloidea. Some other similar but not the same caddifly tubes were noted from the lowest part of Zarqa River at its end near Deir Alla. The larvae were encountered only at one visit- in fall 2012 and at the same locality later no more, since insect life had profoundly deteriorated by than.

The caddisfly larva from Wadi Atun that produced a cylindrical shaped slightly curved case of approximately 5 mm in length (Fig. 8.40 A) can also be characterized by the animal inside. Its head is rounded with tiny antennae and small eyes at its sides. Fine long and black hair covers the top part of the head and sclerotized appendages are present (Fig 6.40 B). The body is white to yellow in general appearance with yellow head, dark eyes, and white thorax. Three yellow sclerotized plates on all three thoracic segments have dark lines along plate margins. The gills are branched many times and white and the abdomen is whitish. The claws of frontal legs differ from the claws of the middle legs and hind-legs which are similar to each other. The anal claws are hook-shaped and carry a brush of hair (Fig 6.40C). The shape of this larva resembles that of the species of members of the Hydropsychidae.

A third distinctive group, and very common on rocks in running water, belongs to the Glossosomatidae. They make their rounded humped cases of coarse sand grains.

Plenty of Caddisefly cases are present in the Wadi Shita stream. Here a cylindrical slightly curved shape is found (Fig 6.41). The head is prognathous that means it is orientated horizontally, and the mouth parts point forward. The eyes are small and lie at margins of the head covered with black hair. Only the pronotum is sclerotized. The posterior edge of the pronotum, has a black band. General coloration is yellowish to brown with dark brown head. The thorax is brown while the margins are yellow. Abdominal is yellow to brown pigmented and their legs have yellow color. They are characterized by the presence of a dorsal sclerite on the ninth abdominal segment. Their abdominal segments are deeply incised. Claws on anal prologs are large with the terminal abdominal prolegs free of one another. The shape of this larva resembles that species of the Rhyacophiloidea family (FLINT, 1962). Regarding habitat, Rhyacophiloidea larvae are preferring limestone and tufa formation (variety of limestone, formed by the precipitation of carbonate mineral from ambient temperature water bodies) (HAASE, 1999).

Figure 6.39: Jordanian caddisfly cases belonging to the Hydroptila genus, a. purse-shaped case made mainly of silk and covered with fine sand grains found in Mujib and Hisban locations, b. tube case shaped belonging to the Limnephiloidea family, the case built from fine sand grains (Wadi Atun).

Figure 6.40: Atun caddisfly larva resembles that species of *Cheumatopsyche lepida species, a*. Hydroptilidae family, long bristles on the head and pronotum, and the seven abdominal segments with gills present, well developed sclerotized plate on all three thoracic segments, b. Legs with basal spur of tarsal claw much shorter than tarsal and forked fore trachantin is present (F: forked fore trachantin, T: tarsal claw, S: Basal spur of tarsal claw), c. Close-up of the anal claws hooks shaped brush of hair at the end (Ac: Anal claws).

Figure 6.41: Free-living caddisfly larva resembles Rhyacophiloidea, found in Wadi Shita location.

Larvae of caddisflies are in general useful as biological indicator organisms for assessing water quality and are generally intolerant to pollution. They prefer clean and well oxygenated water conditions (WARD, 1992). In relating to our field work it is clearly seen that very polluted water such as that of Zarqa River has caddisflies only in areas where water pollution decreases as a result of self-purification enhanced by ample sun-light and water aeration. Caddisfly larvae are found in clean water, mineral water as in Wadi Atun and slightly salty water also. The species determines as *Cheumatopsyche lepida* from Jordan at Wadi Atun creek prefers fast flowing water although with 2000 μS/cm, Sr 37.4 ppm , and Br 10.41 mg/l concentration. This species may be an indicator for slight tolerace to salt water and it can survive with a characteristic concentration of trace elements.

Thus of the caddis-flies the three behavioral groups of larvae are persent, the case-making caddis-flies with case attached (third type here), the free-living caddis-flies that make cases only to pupate (first type here) and the tube constructing species which move around with the tube as shelter (second case here). Those that build retreats build a net or retreat from silk and other materials and use it to catch food items such as algae, aquatic invertebrates and zooplankton from the flowing stream. Case-making caddis-flies make portable cases using silk along with substrate materials such as small fragments of rock, sand, small pieces of twig, aquatic plants, or sometimes silk alone. Free-living caddis-flies do not build retreats or carry portable cases until they are ready to pupate. In general these insects are easy to detect in a stream since they have relatively large constructions usually found in the shelter of stones and attached to them. Members of the genus Hydroptila (Hydroptilidae) among them, apparently, live mostly in clean and unpolluted water, near springs as in Wadia Hisban or after self-purification of the river water as in River Mujib, and they can be considered as indicator for good water quality. The nymphs of species of the Rhyacophilidae can be used as an indicator for clean, fresh water, since they are only found with high water quality. And in the Zarqa River at its end near Deir Alla tubular cases of the Glossosomatidae are present and these species live in somewhat polluted water conditions but not in heavy polluted water such as the Zarqa River near Jaresh bridge location.

The adult stage of caddis-flies, in most cases, is very short-lived, usually less than 1–2 weeks, but can in some cases last more than a month. Even though most adults are non-feeding and are equipped mainly to mate, they can fly large distances and thus reach all open water available in Jordan readily. Once mated, the female caddis-fly will lay eggs often enclosed in a gelatinous mass by attaching them above or below the water surface. Eggs hatch with the time of several days and thus larvae will be present rapidly in any water with a quality fit for survival. Since their food consists of minute autotrophic organisms it is usually available in profusion. The life cycle of many caddis flies is one year, from creeks in Jordan that time of development is not known, but it may be more rapid than that observed from European waters.

Among the Diptera of the insects the most secies rich groups are found with around 200,000 species, worldwide (WILLIAMS & FELTMATE, 1992). The earliest fossil flies are known from the Triassic of the Mesozoic geological period, some 225 million years ago (EVENHUIS, 1995). In the presented study only such Diptera with an aquatic larva have been considered and these only on the larger taxonomic level and determination of the species is out of scope. Among the members of the Diptera of which larvae were collected from water in Jordan are the non-biting midges or bloodworms (Chironomidae), the black flies (Simulidae), and the brine flies or shore flies (Ephydridae). Field and laboratory observations are discussed separately below.

Chironomidae also called non-biting midges and bloodworms represents the most abundant insects living in freshwater with over 5000 species occurring (PINDER, 1983, ARMITAGE et al. 1995). The oldest known Chironomid is *Aenne triassica* and it has been found in sedimentary rocks of Upper Triassic age in the United Kingdom (KRZEMINSKI & JARZEMBOWSKI, 1999). Their determination to the species is difficult and only few specialists are able to determine the species, and non of such specialist have dealt with the larvae of midges of Jordan. Mostly larva, pupa and imago are needed for a safe determination of a species. Data regarding the biology of the Chironomidae is taken from MAILL (1895), OLIVER & ROUSSEL (1983), ARMITAGE et al. (1995), COFFMAN & FERRINGTON (1996) and JOHNSON & KRIEGER (2005).

Larvae of the chironomids usually have a delicate, long and worm-like body shape with well defined sclerotized head capsule. The pro-legs are paired, one pair lies just behind the head on firstthoracic segment (pro-thorax) and the other pair has its position on the last abdominal segment.

They may be pigmented in yellow, white, green, and red. The chironomids with red colored resulting from the presence of hemoglobin respiratory pigment inside their body, for this reason they are usually called bloodworms as was discussed by OLIVER & ROUSSEL (1983). Hemoglobin allows the larva to obtain oxygen from low oxygen environmental conditions and to inhabit and settle in such environments but they must rise to water surface occasionally to renew their supply of oxygen.

In most studies dealing with chironomids regarding water quality assessment they have been considered as the most useful bioindicators. They are good indicators due to their high diversity with estimated 15000 species globally and they occur not only widespread but also very abundantly near various aquatic environments as has been discussed by many authors, among others by KOLKWITZ & MARSSON, (1908, 1909), CHUTTER (1972), WIEDERHOLM (1990), and ARMITAGE et al. (1995) stated that certain species of this group are capable of surviving and thriving under and extreme conditions such as low dissolved oxygen or highly turbid conditions and that they are tolerating some organic substances and trace metals load in the sediments. Thus their existence in an environment usually indicates some environmental stress as noted by PLAFKIN et al. (1989).

Bloodworms therefor represent good bioindicators also for the recognition of water quality in Jordan, and they are locally abundant, widely distributed and easy to recognize. Their red worm-like bodies can be seen in the field often connected to black sediments which they carried to the surface when constructing their tube in the mud. When such fine muddy sediment is washed through a screen with a mesh sized of 0.5 mm diameter a large number of the red larvae is usually present. They are usually found with many individuals together in large clusters in or on the substrate (usually mud) on the bottom of shallow ponds, drainage canals or other waterways with slow-moving water.

Different species among these larvae present in Jordan have not been distinguished since determination of species is difficult and out of scope. Thus species belonging to different groups of chironomids were distinguished from each other by the color of the larvae.

Chironomid larvae were encountered in large numbers especially in relatively polluted water such as that of large portions of Zarqa River, within Wadi Mujib reservoir lake, and in the Wadi Shueib. Here especially the red type of larva is found concentrated in puddles with organic mud, but also the white and yellow types of larvae are also present. Chironomid larvae are present also in springs, creeks and rivers with good quality of water, such as the spring of Wadi Shita (Fig 6.42a).

Bloodworms settle in mud that is rich with organic material as early settlers in the muddy sediment that is formed by bacterial crusts as in the first portion of Zarqa River. These blood worms are indicators of relatively poor water qualities (e.g., eutrophication), thus document the impact of organic load resulting from sewage and agriculture runoff. They live in tubes in the mud which commonly reach into oxygen free environment. They are here associated with low biodiversity ecosystems, often associated with the worm Tubifex and the gastropod Physa. Such localities were noted in the Zarqa River (Fig 6.42b)., in the creek below Shueib treatment plant (Fig 6.42c) and puddles and pools in Mujib River just below Wadi Mujib Lake-dam (Fig 6.42d). Chironomid tubes may sometimes be confused with the larval shelters of caddisflies and the mucus tubes of Tubifex, which are of about the same size, shape.

In the small reservoir dam of Wadi Shueib blood worms and their eggs represented the only obvious animals living in that water during spring 2012 (Fig 6.42e). The eggs are delicate, of orange-brown color, and imbedded in a gelatinous substance that forms a long cylindrical tube-like shape . Eggs within the tubular mucus mass are numerous and arranged in a regular spiral.

The egg mass collected from this location are preserved in the field by adding 70% alcohol to be subsequently studied in the laboratory at the University of Jordan. They remained alive and after three days even hatched as tiny orange chironomid larvae with small head. This observation documents that the eggs of some chironomid are highly tolerant to pollution- even the addition of alcohol, where they successfully completed their development to hatch als larvae.

Other species of chironomids can be used as indicators of salty water. Chironomid larvae obviously belong to quite a number of different species in Jordan and they document quite different behavior. They may be free-living and a yellow variety as was encountered together with mayfly larvae in the brackish pool and creek near Karama Reservoir-Lake. In the same shallow small stream of brackish water chironomid larvae forming mud composed tubes live together with mats of filamentous algae and next to cyano-bacterial crust and mats (Fig 6.42f). Their cylindrical mud shelters are attached to rocks and the stems of plants in the creek and their bodies have a yellow pigment. The Karama individuals of chironomid larvae occur with a salinity of about 16120 μS/cm. They live in small creeks entering the lake and in ponds formed by them before they are connected to the lake of the reservoir. In the lake proper they have totally disappeared since in the reservoir formed by Karama Dam the salinity level has risen and reached a salinity of high 23600 μS/cm.

Similar individuals as seen near Karama reservoir were encountered in the creek of Wadi Atun, and here together with black fly larvae (Simuliidae). In that creek fed by springs of warm mineral water they live in somewhat salty water and tolerate a relatively high concentration of Sr (37.41 pmm), Br (10.39 pmm) and slightly raised salinity of (2040 μS/cm).

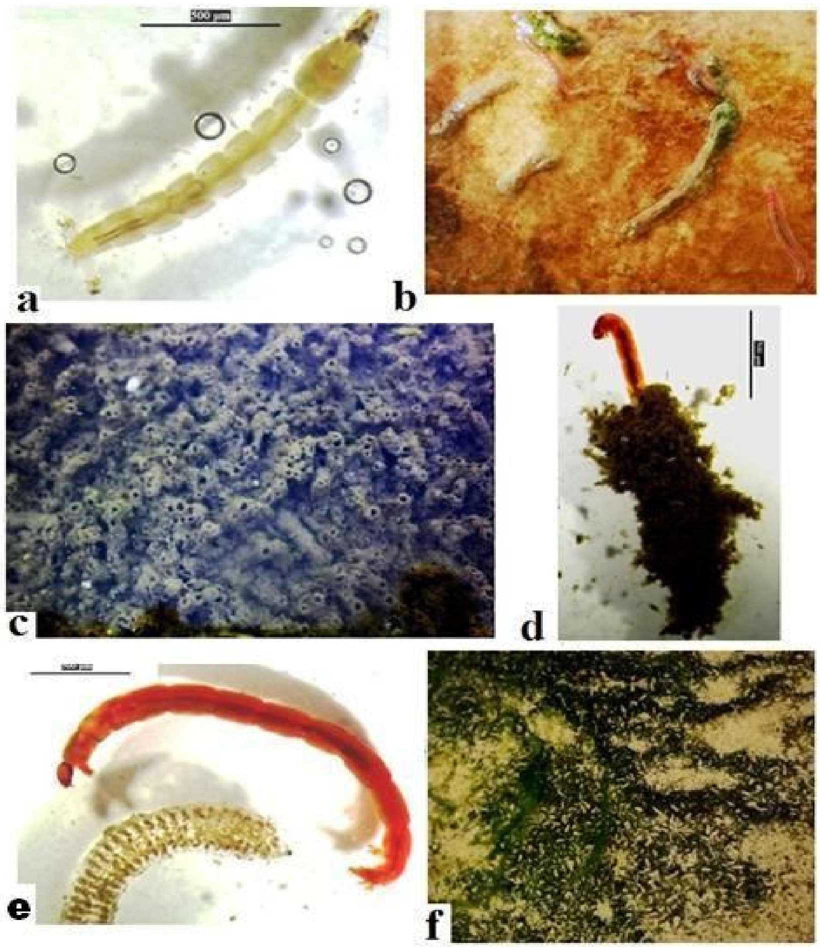


Figure 6.42: a. Whitish chironomid larva collected from Wadi Shita spring, b. Bloodworms with and without their cylindrical tubes which attached to a stone in Zarqa River, c. Dense settlement of red chironomid larvae which transformed the mud do a dense pattern of living tubes in the eutrophic stream downstream of the wastewater treatment plant in Wadi Shueib, d. Bloodworm halve exposed from its shelter of agglutinated pellets of its shelter from a pond just downstream of Wadi Mujib Lake-dam, e. Fully grown bloodworm and it is eggs, f. Large number of tubes of Chironomid larvae attached to filamentous algae and crusts formed by cyanobacteria on the mud in a brackish water pond near Karama reservoir lake.

The Simuliids or black flies are also member of the Diptera and hold more than 1800 species worldwide. Black flies larvae was studied and described for example by (MIALL, 1922), WILLIAMS & FELTMATE (1992) and LECHTHALER (2005) and that descriptions is consulted here. The larval stage of Simuliidae in water is represented by a smooth, worm- like larva that is distinctly swollen towards the lower part of its abdomen. The head is well defined and sclerotized and completely separated from the thorax. Simuliid larvae live almost exclusively in running water. Here they attach with short hook-like spines on their abdominal end supported by an adhesive disc to a substrate, such as a rock or plant. On the mouth of the larva the upper lip carries two pairs of fans of comb-like composition, which together form a sort of basket that is used in filtering algal cells from the water that passes by. Cylindrical antennae are located near the base of each head fan. Characteristics to the black fly larvae are the extendable feet with hooks at the anterior part of the body and the ring of hooks at the posterior part of the body.

Black fly larvae breathe through the skin and thus oxygen is taken directly from the water. That does explain occurrence of the black fly larvae only in well-aerated flowing water. Within the pupa stage, the larva breaths through a branched filament close behind their heads, which extends outside their cocoon. The mature larvae have dark gill spots on the side of the thorax, which represent developing gills or respiratory filaments as preparation to molt into a pupa.

Simuliid larvae inhabit water of different degrees of pollution raging from clean to polluted. Most authors have recorded the Simuliidae as a family with larvae which can tolerate organic pollution and used them as indicators of water degradation (HILSENHOFF, 1988; BOHLMAN et al., 2009). MIALL (1922) stated that the number of black fly larvae increases in water with poor quality due to the contamination by sewage effluent. In addition swift currents provide even more favorable habitat conditions for black fly larvae. Simuliid larvae may occur in large numbers together attached close to each other on rocks and aquatic vegetation.

In Wadi Atun and Wadi Shueib, simuliid larvae associated with chironomidae larvae occur in great numbers and they may be confused with each other when they occur together at the same habitat. The larvae share the presence of a prothorax with pro-legs, but in simuliid larvae there is only a single pro-leg pair on the thorax, while chironomidae larvae have a pair on the thorax and on the abdomen. Furthermore simuliid larvae have no hemoglobin and thus no red pigment and they avoid standing water. But both of these larvae have a high tolerance to organic pollution and also to some raised saltinity of the water. Here simuliid larvae have not been identified to the species and the difference between species was only depending on their color, with those from Wadi Atun and Wadi Shueib. Wadi Atun simuliid have bright yellow color while the Wadi Shueib species have gray to brown pigments.

In Jordanian streams black fly larvae can be distinguished from other animals living together with them by the following combination of characters: The body has worm- like shape (Fig 6.43a) and is approximately 3 mm in length. Head is oriented horizontally and has a more or less elliptical shaped, is separated from thorax, bears two pairs of small eyes and its mouth part include a pair of mandibles and filamentous fans (Fig 6.43b). Antennae are slender and located near the fans. The larva generally has a transparent yellow color with gray spots on the abdomen and the anterior region of the head is of brown color. In the fully grown larvae two large dark spots of developing gills are distinguishing feature for last instar nymphs and are carried on the thorax, near to anterior legs (Fig 6.43c).While a single pair of prolegs characterizes the pro-thorax (first segment of thorax), the abdomen is swollen in its posterior part and ends in a ring shaped hook.

Pupae of black flies were found in the creek at Wadi Atun as well as that of Wadi Shueib with well developed filamentous cephalic respiratory appendages and slipper- shaped cocoons. The species occurring Wadi Atun can survive and grow under slightly salty water and relatively high ratio of Sr (37.41 pmm) and Br (10.39 pmm). Other species are tolerant to relatively organic water pollution which heavily occurs attached to rocks in the Wadi Shueib stream. But black flies are absent from Zarqa and Mujib Rivers. Clean water species are less common in Jordan and they are represented only in one spring at Wadi Hisban with low population.

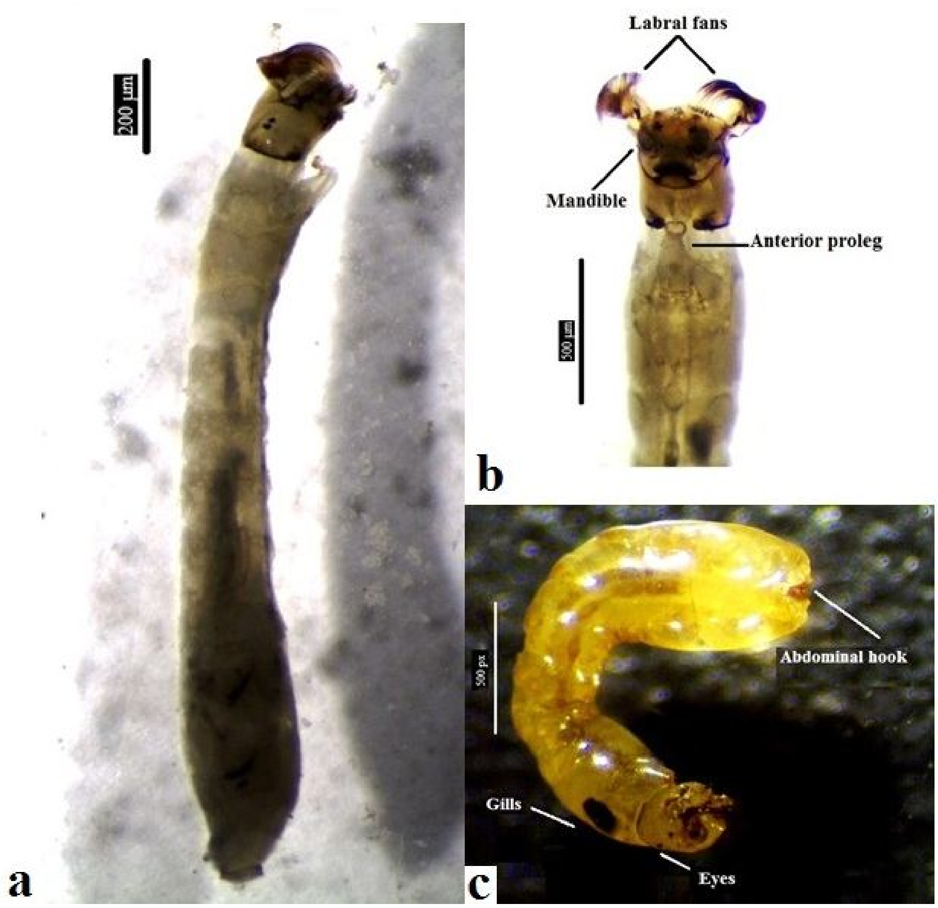


Figure 6.43: The main characteristic features of black fly species in Jordan, a Larva of black fly with worm-like shape (Wadi Shueib), b. Magnified ventral side of black fly larva showing their morphological features (Wadi Shueib), c. Mature larva with two large dark spots of developing gills and two pairs of small dark eyes (Wadi Atun).

Another group of tiny insects which belong to the Diperta is represented by the Ephydridae, shore lies or brine flies. This family consists of about 1,500 species which have been described worldwide. Shore fly larvae are recognized by having well-developed 8 pairs of ventral pro-legs present in rows with hooks or spines. The larvae use their hooks to hold on to the benthic substrate or to move with them. Their locomotion is slow and along the bottom substrate, but they may also swim by bending the body sideways back and forth. The head is reduced or absent and typically retractile into thorax. The antennae are small or absent. They feed on small particles filtered through the mandible that is moving vertically. Food consists of small organisms such as cyanobacteria, algae, and also organic detritus, some are leaf miners, and some even predators of other small insect larvae.

Terminal abdominals are supported by breathing tubes with two dark openings, the spiracles. The respiratory tube may split (spine-like) or be branched.

Aquatic Ephydrids are among the less common true flies in Jordanian waters and were noted only from brackish water. Here they settle puddles, ponds and creeks while other aquatic organisms are absent. Large numbers of shore flies larvae occur on rocks and salt-encrusted sandy shore in the saline lake at Karama dam where the salinity range about 20500 μS/cm. Here large numbers of Ephydrids pupae and empty pupa cases coated by salt crust ad have a dome like appearance (Fig 6.44). Some pupae are found submerged while others stay above the water surface. The shore flies in Jordan can be considered as indicator to salty environment.

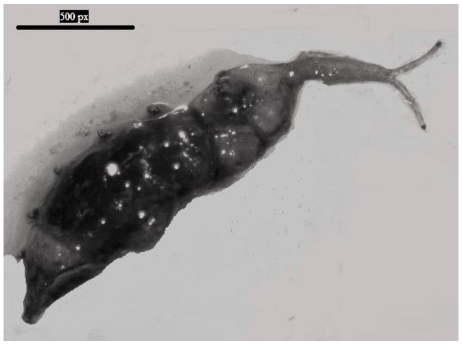


Figure 6.44: a. Shore flies larvae from Karama Lake, b. Shore fly pupae covered by salt crust, occurring on submerged rocks and sandy shore of the Karama reservoir lake.

Aquatic worms represent a diverse group of animals that can commonly be found both in running and standing waters. While many species live in the sediments, others are closely associated with aquatic plants. In this study only flatworms (Platyhelminthes) and segmented worms (Annelida) of the Oligochaeta and Hirudinea are considered.

Plathyhelminthes (flatworms) of the free living Turbellaria type are characterized by their horizontally flattened body. Most turbellarians are detritivores, feeding on dead particulate organic material, or zoophagous, feeding on small living or moribund invertebrates (MACKIE, 2001). In Jordan they have been encountered as benthic dwellers in under rocks and between plants in shaded and protected areas and only in the very clean and well oxygenated water of springs.

As is stated among others by PENNAK (1989) Turbellaria-like worms have no lungs and the respiration process occurs by diffusion through the moist surface of the body. DE LANGE (1994) and PECKARSKY et al. (1990) noted that free living turbellarian worms can be considered to represent very good bioindicators of hight water quality because they are intolerant to organic pollution and need well-oxygenated water. Freshwater turbellaria as water quality bioindicators have been noted at many places in the whole world and especially in studies carried out in Europe (METCALFE, 1989; MANENT, 2010). Turbellaria worms are difficult to identify because the preservation methods with alcohol make them unrecognizable and the microscope pictures that were taken from the collected individuals do not show much detail. The two different species recognized from the springs at Wadi Hisban and from Shita live in shallow, cold and well oxygenated water that issues from carbonate rocks. A third locality with turbellarian worms was noted in a spring at the base of Wadi Mukheiris, a Valley that issues directly ito the Dead Sea with the spring in an altitude spring well below Sea level.

The lack of circulatory and respiratory organs limits platyhelminths to small sizes and a body shapes that enables oxygen to enter their bodies by simple diffusion, as well as CO2 to leave the body the same way. They therefore have small and have flat ribbon-like shapes. Their guts have many branches, so that nutrients can diffuse to all parts of the body. They thus have a mouth, and the food is delivered to all part of the body through the gut and digested substance goes back the same way, they thus have no anus. Respiration through the whole surface of the body restricts them in Jordan to live in springs. In general Jordanian turbellarian worms are confined to cold, shallow, and slow moving fresh water, containing a high content of dissoved calcium carbonate. This group of worms can be considered as indicators of very good quaity of water.

In Jordan these organisms have received little attention. Among the two types of flatworm individuals which resembles *Dugesia tigrina* and has brownish color, a distinct anterior with triangular shape with a pair of lateral projections known as auricles (Fig

6.45a). Such species have been discribed by NOLAND (1979) characterized by the well defined eyes spots situated between these auricles. It resembles the turbellarian worm found ar Wadi Shita. Here the head has triangular shape with ear- like structures (auricles). Dark eye spots are located close to each together on the head. They are large enough to be easily seen. The shape of the body is regular long elongated with about 4 mm in length. In the area of the spring at Wadi Hisban, the turbellarian worms encountered have dark brown (Fig 6.45b) and black body colors (Fig 6.45c) with large light spot on the middle of their worm body which characterize them when seen in the field. The general shape of the body oval seen from above flat seen from the side with approximately 0.5 mm high and 10 mm in long. The head is rounded and not much differentiated from the rest of the body and two eyes are seen as closely spaced spots on the head and there is a sharp long line across the body. The flat worm *Polycelis* that is common in Europe and does not has the two eye spots like the species from Jordan but has many small eye-spots on the margin of the anterior end.

Annelids are segmented worms and their internal organs, unlike those of the Platyhelminthes, are organized to have a digestive system with separate mouth and anus and a body cavity that is a true coelom, often divided by internal septa. Annelida are divided into three classes, Oligochaeta (earthworms), Polychaeta, and Hirudinea (leeches) of which only members of the Oligochaeta and Hirudinea will be discussed here since some of their representatives occur in larger number and characteristic shape in Jordanian running water. Tubificid worms of the Oligochaeta are commonly known as sewage worms or sludge worms. Their narrow and elongate body is segmented, and of cylindrical shape. They live in soft sediments which have much organic matter and are often present in very large numbers. They can not easily leave their living environment to swim away and to escape stress as would be contamination of the sediments used as food and home. For this reason the occurrence of this worm on the bottom of a stream represent an excellent indication of a distinct type of organic contamination of the water (BRINKHURST, 1966; LANG, 1984; FARARA& BURT, 1993). THOMAS (1972) discovered that the presence or absence of tubifex worms can be used as useful bioindicators to assess the functional efficiency of water treatment plants. In Jordan, tubifex worms occur in still water puddles as well as in slow moving streams with muddy bottom substrates. They have been encountered in such environments just below the dam in River Mujib and in the muddy margins of the reservoir formed by the dam in the Wadi Shueib and also along soft bottom environments in the creek here below the Salt treatment plant. Tubifex worms at both sites form similar populations close to each other in mud tubes and worms of reddish appearance of the same shape at both sites (Wadi Mujib Lake and Wadi Shueib). Below the Salt treatment plant in Wadi Shueib tubifex worms occur commonly at locations in the stream with slow flowing water with low content of dissolved oxygen, much suspended organic material and brownish color (Fig 6.45 d).

The tubifex worms here live very close to each other in dense settlements and have a body lengthe of approximately 6 mm. The sewage worms at this locality are associated with blood worms, which at fisrt sight are similar due to the red color of their elongate body and the similar behaviour by constructing vertical burrows in the mud. In the settlements of tubifex worms in Mujib River below the dam and close to the lake large parts of the river bed contain slow moving water with a bottom consisting of fine mud that is rich with organic material. Here the worms occur together with large amount of aquatic plants and algae, and a joined by many other animals (for exampe frogs and fish). Tubifex worms dwell in the bottom of the muddy ponds inside their tube like burrows held stable by mucus agglutinating clay particle (Fig 6.45 e). In these tubes the head of the worm is buried in mud and the undulating tail extends in the water (Fig 6.45 f). Huge numbers of these worms were observed living close to each other with their size less than 5mm in lenght. Tubificid worms and chironomid larvae are among the most abundant animals seen in eutrophied creeks and rivers in Jordan. Population densities can be very high. Tubificid worms feed primarily in the top 2 to 8 cm of sediment and their activity is seen by the presence of dark black feacal pellets on the gray muddy surface. The worms feed on bacteria in the oxygen depleted zone that is black. Tubificid worms are thus functioning as conveyor belt by living and feeding head down in the sediment. Some portion of the posterior of the worms projects above the sediment-water interface since they breath with the posterior part of their digestive system. The consolidate the muddy substrate to a certain dgree by forming mucus coated tubes. Fecal pellets are deposited at the sediment-water interface, where they may form a pelletized layer at the sediment surface. Tubifex worms in such dense settlements with many individuals next to each other represents a bioindicator for strong pollution with organic material with the water above their settlement containig just sufficient oxygen for their needs and beeing eutophicated so much that bacterial growhts supply plenty of food.

Leeches or Hirudinea are specialized annelid worms with parsitic mode of life. They have a fixed number of segments composing their body that differs among the members of their orders (Branchiobdellida 15, Acanthobdellida 29, and Euhirudinea 33) (SAWYER, 1986). The leeches are characterized by having elongated flatted body shape without any bristle-like setae. They usually show black to brown color and sometimes appear bright brown. Their body usually tapers towards the head.

The last segment has a sucking device that forms when the animal is fully grown. These sucking segments form by several fused segments. Leeches have a good bioindicator value and most of their species are classified as inhabitants of eutrophic, polysaprobic, moderately and highly stressed freshwater environments (LENAT, 1993). Leeches occur in practically all creeks and ponds in Jordan which are not strongly polluted. Their occurrence in a locality is rapidly recognized by their egg cases, which have a characteristic shape. In all places with leeches present or having been present a short time ago the cupola-like organic capsules are attached to hard substrates, preferably the lower side of stones. When fresh, the egg cases are transparent and when older they turn brown. Jordanian leeches were noted to parasitize fish, frogs and invertebrates such as snails. Clearly different species of leeches occur, but it was not undertaken to distinguish them from each other.

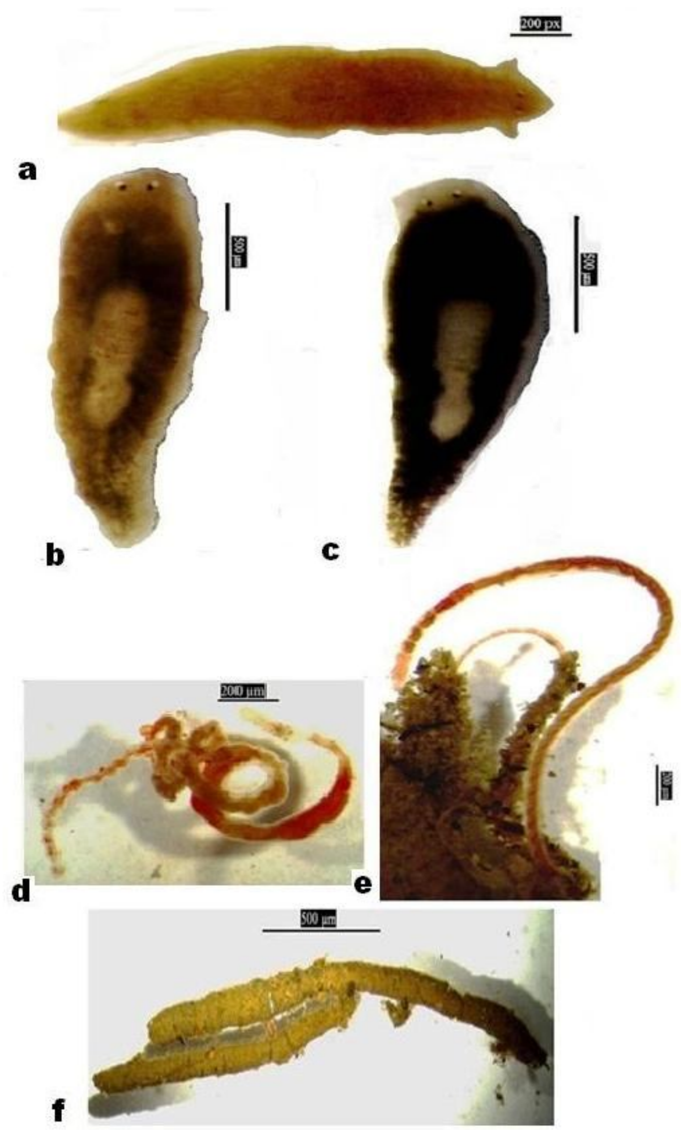


Figure 6.45: Aquatic worms were collected from Jordanian water bodies, a. Wadi Shita flat worm species has a light brown color with head end showing the characteristic triangular shape and ear- like structure, b. Dark brownish species of turbellira from Wadi Hisban, c. Black turbellira worm with rounded head shaped (Wadi Hisban), d. Wadi Shueib Tubifex worm, e. Tubifex worms dwelling in muddy substrate (Wadi Mujib), f. Tubifex worms hidden inside muddy coated tubes from Wadi Mujib.

Last group of Jordanaian bioindicators is Crustacea and spider group. Crustacea represent a large and diverse group among the invertebrates of the phylum Arthropoda which consist of over 30 000 species (BURSCA & BURSCA, 1990). Creeks rivers and ponds with freshwaters in Jordan are usually have a population of crustaceans which belong to copepods, cladocerans, ostracods, amphipods, isopods and decapods some of which can be used as bioindicators. In our samples ostracods are smallest crustaceans, their size ranges from about 0.05 to 2mm in length. The largest crustaceans are represented by crabs with a range in size below 10 centimeters.

Amphipodas are commonly known as scuds or side-swimmers due to their swimming behavior (swim sideways). Amphipoda differ from other crustacea by their curved laterally compressed body with shrimp-like appearance. Their body usually consists of 13 distinctive segments including the cephalothorax (Pereon) and the abdomen (Pleon). The head jointed to the thorax and some species the first and second thoracic segments are fused to head. The compound eyes may be on a stalk. On their head they carry a pair of chitin mandibles, two pairs of maxillae and two pairs of antennae. The thorax carries seven pairs of legs the first two serving as food collectors, the next five for crawling and swimming. The abdomen carries six segments divided equally into pleosome used for swimming and urosomes as tail appendages. The descriptions were adopted from GROSSE & PAULEY (1986) and BARNARD & KARAMAN (1991). The most common genus of freshwater amphipod encountered belongs or is close to *Gammarus*. Amphipods of the *Gammarus* type are found in large numbers hidden under rocks, plant fragments and among the aquatic vegetations in freshwater throughout Jordan when the water is clean and well oxygenated. They are of white to brown color, but usually yellowish light brown, and range in length from 1 to 5 mm. They prefer cold water and spring environments such as that of Wadi Shita spring, Wadi Hisban springs, and Wadi Shueib spring (Jadoor). In Wadi Hisban amphipods are very abundant and easily seen in the field (Fig 6.46, a). Amphipods commonly occur together with the gastropods *Theodoxus* and *Melanopsis*, often also with turbellarian worms and always mayfly larvae are present as well. They do not occur when water is brackish or salty as for example near the Karama reservoir, even in clean springs. They are sensitive to any kind of pollution and are absent from the Zarqa River, most of the creek in Wadi Shueib and in the Mujib river above the reservoir. They also do not occur in mineral water such as that of Wadi Atun and in warm water such as Zara spring. Amphipods in Jordan are good indicators for clean, cold, calcareous non saline freshwater springs and streams.

Isopods are small crustacean also known as water slaters or sow bugs. Within the order Isopoda more than 10,300 species are contained and they occur in nearly every aquatic habitat from fresh to marine water and have even become adapted to terrestrial environments. The isopods of fresh water contain around 942 described species, with the largest number of species in the family Asellidae, as has been worked out by WILSON (2007). Members of the fresh water Isopoda can usually easily be distinguished from those of the amphipods by the shape of their bodies which are dorso-ventrally flattened. Isopods have a one pair of tail appendages (uropods), and seven pairs of legs, which more or less are similar to each other. Their compound eyes are dorsally attached to the head without a stalk. The gills are attached to the abdominal segments. They may differ in regard to their tolerance of pollutants among species, and have been used as water quality indicators for example by LORRAINE MALTBY (1991). In Jordan, isopods are less commonly encountered than amphipods, but are usually found at places with relatively clean water but much organic bottom substrate. Such parts in the creek at Wadi Hisban contain many individuals, and they are also present in the upper portions of the small creek below the spring that issues from the rocks below Salt and issues with the creek in Wadi Shueib. A different smaller species was found clinging to algae in Suneh spring in Wadi Hisban (Fig 6.46 b, c). Jordanian isopods inhabit clean and relatively cool freshwater, and can be used as an indicator of unpolluted water with much vegetation.

The decapod *Potamon* of the Potamidae, is member of a class Malacostraca, order Decapoda. In Jordan *Potamon* is a commonly occuring freshwater-water crab and represents a relatively large benthic crustacean. It has dorsoventrally flattened body and consists of the cephalothorax and the abdomen (Fig 6.46 d). The cephalothorax is usually covered by carapace. The abdomen is small and recurved under the Cephalothorax. The abdomen shape can be used to distinguish between male and female; the female has a U-shaped abdomen, and the male has a V-shaped abdomen) (Fig 6.46 f, g). They are benthic and their legs adapted mainly for walking. The crab feeds on different food resources such as dead plants or animals, and algae, others are predatory. In Jordan, it constructs burrows which found on the creek or river margins with their entrances on land but continuation into a burrow that reaches water (Fig 6.46 h). The crab can obviously resist much pollution and is found along Zarqa River almost from its “spring” at the treatment plant to its end near Deir Alla. But the crab is also found in clean water, such as River Mujib or River Hasa. It is thus not useful as bioindicator, but appears to be absent when water turns salty. It was not found near Karama Revervoir. It occurrence in the highlands as well as near the level of the Dead Sea indicats that it does not depend to the altitude and also not to the climate, but only to the presence of running water nearby.

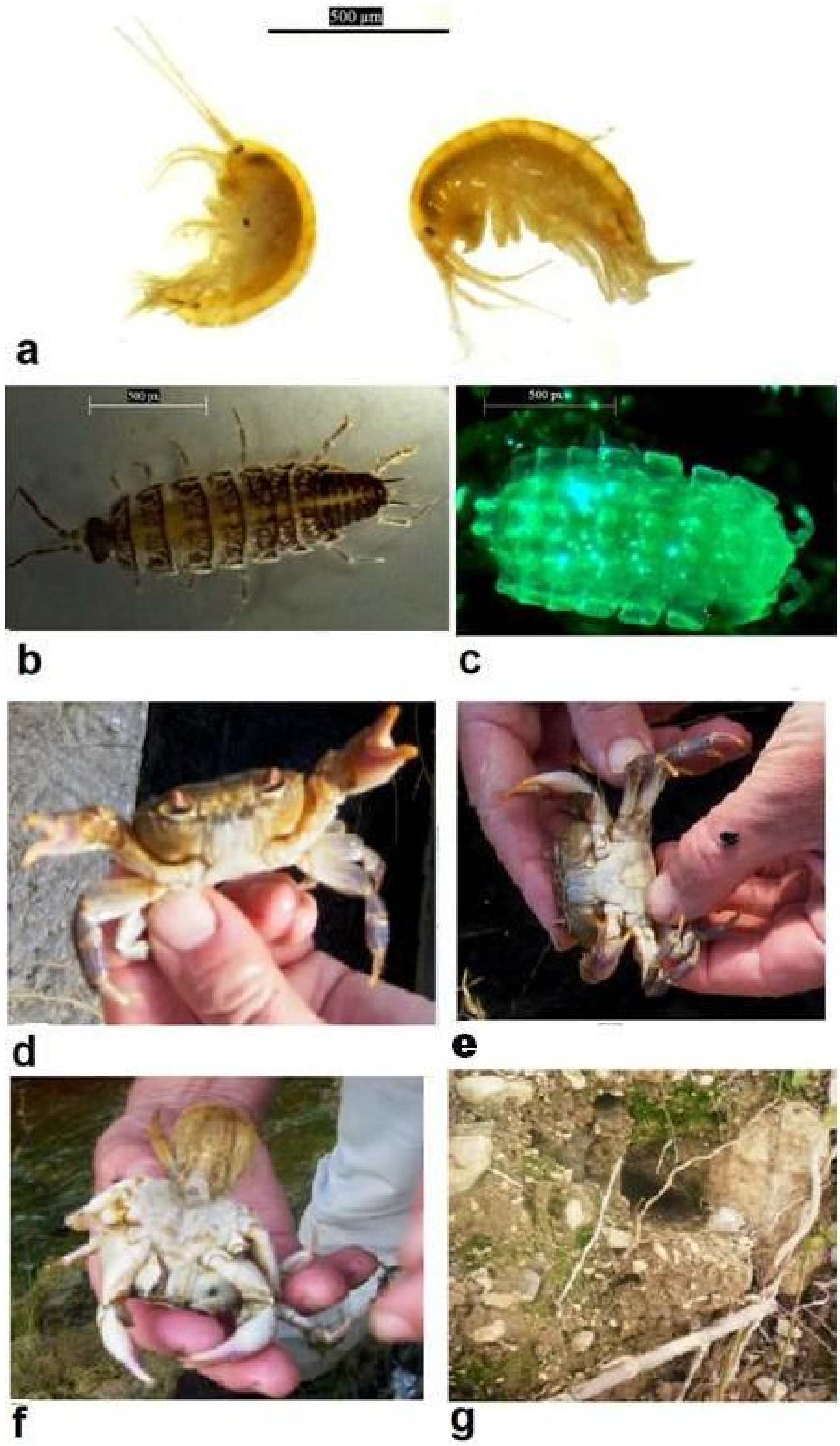


Figure 6.46: Crustacea group in Jordan, a. Yellowish amphipod collected from Wadi Hisban spring (Suneh spring), b. Isopod fauna clinging to algae in Wadi Hisban spring, c. Isopod from Wadi Hisban (Artifical canal),d. Crabs from Wadi Hisban, e. Ventral view of Crab from Wadi Hisban, f. Crab with ventral brood chamber from Wadi Shueib, g. Crab burrow with balcony- like near Zarqa River.

Ostracods are also known as seed shrimp, they are small crustacean which usually occur in huge numbers in Jordanian waters, both in freshwater and in salty water. They can easily be distinguished by having bivalved carapace with ovate or bean-shaped. The body is of bilateral symmetry and horizontally compressed shaped. The soft body can be divided into two main parts the head (cephalon) separated by the thorax (between the head and abdomen) by a slight constriction. They may be of a somewhat orange color but many species has brown, yellowish and white in appearance. Living Ostracods are often used as bioindicators of their environments and also when they fossiliz are important for paleoenvironments studies. In Jordan they inhabit almost all water bodies under different environmental conditions. The determination of ostracod samples was done by Mischke (2013).Different species belonging to this group of crustacean are common in Jordan in freshwater to slightly brackish water bodies including *Heterocgpris reptans, Cypridopsis vidua*, *Humphcypris* subterranea, and *Ilyocypris sp*. Other species of ostracods which have a high tolerance to salt in water are represented by *Heterocypris salina, Heterocypris reptan,* and *Cyprideis torosa* (Fig 6.47). But *Heterocypris salina* species can be also found in freshwater (e.g., Wadi Sir, Wadi Shueib, and in the downstream area of Zarqa River), and also in thermal mineral water (e.g., Hemmet Thableah in Wadi Hemmah). By contrast *Heterocypris reptans* and *Cyprideis torosa* only occur in salty water, hence their usefulness as indicators of salt water. Ostracods are also present in freshwater sediments such as Heterocypris salina and Ilyocypris sp at pre Lisan sediments. Ostracods are opportunistic and can settle any aquatic environment rapidly due to the almost omnipresence of their eggs and their being transported by water birds attached on mud glued to their feet or by even their attachment to their beaks and feathers. Thus they will fill any body of water rapidly and can disappear rapidly again after that water has dried up. Species can also react to the change in water quality, either by being tolerant to such changes and surviving or be being replaced by other species as salinity changes and that can happen in the time range of weeks only.

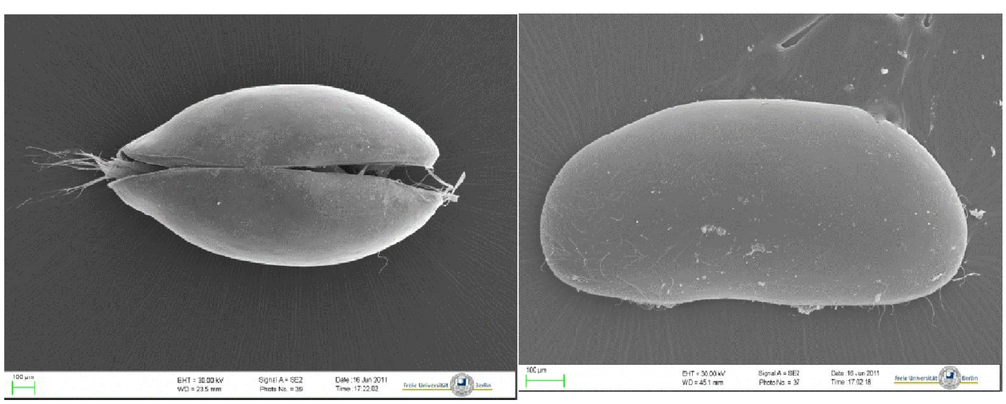


Figure 6.47: a. *Heterocypris reptans* carapace (Salt water tolerant species of ostracods), b. *Humphcypris* subterranea is common fresh water species.

Other group of crustacean which have been observed in creeks in Jordan are Copepoda (subclass Copepoda), and daphnids (Suborder Cladocera). Copepods are tiny animals that can be found planktonik or benthic. The body has two parts, the cephalothorax and the abdomen and there are distinct long antennae. The abdomen is terminated by a caudal furca. Copepods are periodically abundant in the downstream area of Wadi Shueib. Copepoda are absent in polluted and salty water habitats in Jordan.

Species of the suborder Cladocera, order Diplostraca (water fleas), and family Daphniida were only found in a pool near to Wadi Shueib dam. Daphnids are small crustaceans and with their whole body except for part of the head enclosed in a bivalved carapace. Their presence was noted only in puddles at the margin of the Shueib reservoir and they occur only sporadically after rainy periods. Since they produce hardy eggs which can survive harsh time to hatch when conditions are favourable to water fleas and since once hatched individuals are females that produce numerous offsprings by parthogenesis, they may be abundant rapidly in periodical good environments. Thus this fauna is only found in still freshwater environments.

Mites are small very fast moving fresh water Arachnida (spiders) and are common in practically any water with a rich fauna, such as Wadi Shueib, Wadi Hisban or Wadi Mujib. The body of water mites has rounded shape in which the cephalothorax and the abdomens are fused to each other. They have a pair of small eyes and commonly appear with bright orange color. They have strong claws and crawl and clamber rather than swim. Mites prefer sheltered, shallow vegetated areas of standing and sluggish flowing waters, even in pools of temporary streams. They may also enter the bottom substratum and are found amongst the submerged vegetation. In Jordan, water mites are found in freshwater and also live in slightly salty water as is found in the creek at Wadi Atun (Fig 6.48). They are not present in water of higher salinity as in the small creek and pond near Karama Reservoir or in the even saltier Karama Lake and they also avoid the polluted water as present in Zarqa River.

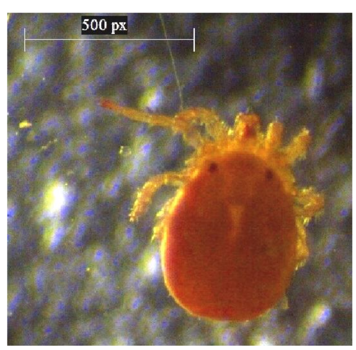


Figure 6.48: Mites from Wadi Atun creek.

6.2.3 A biotic and biotic components of the aquatic ecosystems

The types of organisms present in water bodies vary greatly from one aquatic ecosystem to another. These organisms live in the water for all or part of their life, so their survival is related to the water quality. Biological communities are constantly influenced by variations in the chemical, physical and biological characteristics of environments. Most of them grow and adapted to specific ecological conditions while others may occupy a wider range of habitats. These organisms which are restricted to specific habitat can provide information about the quality of the water bodies. It is worth mentioning here that water quality degradation and fluctuation of biological life in water results, not only from human activities, but also from natural stress such as competition, predation and season variations (e.g., increased turbidity during floods).

Water quality can be described here as physical, chemical and biological parameters present in a certain water body. The following physical and chemical variables were used to define the water quality in the study area are: water temperature (ºC), acidity (pH), Electric conductivity (EC) all of which were measured directly in the field while biochemical oxygen demand (BOD5), chemical oxygen demand (COD) and ionic composition (e.g., Ca, Mg, Na, K, Cl, SO4, PO_4, HCO_3, NO_3, Br, Sr, etc..) were determined in the laboratory. Determination of these factors can provide correct and accurate water quality analyses. Biological parameters such as aquatic organisms (fauna and flora) are very useful for the interpretation of water composition and quality since they react to different ecological conditions. Many factors may be important in explaining patterns of abundance and diversity which reflect in the organisms life conditions such as water temperatures, light, habitat, pollution, salinity, ionic compositions,and dissolved oxygen. Each of these factors is discussed separately, below.

Factors that affect the quality of surface water in Jordan:

- Temperatures

The water surface temperature is influenced by several factors including; geographic position, altitude, season, time of day, air circulation, cloud cover, and the depth of the water body (CHAPMAN &KIMSTACH, 1996).

Life of organisms in water depends on it is temperature which has influence on the presence or absence of organisms, length of their life cycles, time of their reproduction, mode of growth etc. This influence is seen very drastically, when life in hot springs as that of Zara is compared with the fauna and flora noted in springs of clean water with normal temperature as for example that of Hisban stream. While life in the hot water is restricted to a few species, which are adapted to these conditions. Springs with clean water and normal temperature provide the place for the highest diversity of life that is observed in the studied area.

Oxygen concentration is high in normal spring water which has its reflection in the animals that may live here, such as flat worms (Turbellarians) or gastropods such as Theodoxus. The first of these also prefers cold water, while the second has a wider tolerance regarding water temperature. In warm water springs usually not only the oxygen content is lower, but usually also other gases such as CO2 and also some H2S may be dissolved, which are not tolerated by many higher organisms, besides the negative effects of higher temperature of the water.

Running water in Jordan has temperatures usually ranging from 17 to 22 °C between January and March and with these temperatures a high diversity and abundance of aquatic organisms has been noted in the clean parts of Wadi Hisban, Wadi Shita and Wadi Mujib. Warm water as that from Zara thermal springs has fewer organisms living in it with decreasing diversity towards their source with temperatures of around 60 °C. Here bioproduction may be very high but is predominated by bacterial growth (cyanobacteria). Degraded water quality is predominantly due to human influence and to the addition to more or less strongly polluted water to the springs and streams. Eutrophication results in strong growth of organisms in the water, which in turn increases the warming of the water due to sunlight capturing especially in the summer months.

- Light

Sunlight in Jordan is available in abundance throughout the year, more so in the summer than in the winter, but always during most hours of the day. It provides the energy for all autotrophic organisms using chlorophyll for the synthesis of their organic body materials. The intensity of sun light in Jordan differs strongly with altitude, which near Amman is up to 1000 m in height and near the Dead Sea is 400 m below sea level. Thus high energy ultra-violet components influence the higher regions and spring waters while it is largely absorbed by the thick atmosphere over the Jordan Valley. This influences the growth of autotrophic organisms in the water as does the composition of the water regarding dissolved or suspended particles in it. Higher organisms also react to the intensity of light in the water, as was for example noted in case of egg-laying process in blackflies (GOLINI & .DAVIES, 1975; SALAMEH et al., 2013).

Environmental conditions such as; watercolor, the depth of water bodies, sediment load (turbidity) affect the amount of light absorbed by water or organisms in aquatic ecosystems. Light intensity and influence of the heat of the sun depends much on the vegetation present along creeks. The number of organisms of Plankton and other organisms in the water also increases absorption of light in it and thus its temperature

Different organism's species have different tolerance degrees to light. Species of organisms are sensitive to prolonged periods of high light intensities. For instance flat worms prefer shaded environments which were often found resting under the rocks at daylight and are active at night. Jordan is defined as a semi desert area with arid to semi arid climate (SALAMEH& BANNAYAN, 1993) shows plenty of organisms species adapted with different life conditions but not all organisms are responding positively to strong sunlight that can lead to declining growth rate or even killing of organisms. A recent example of sun radiations as the control factor of aquatic organism growth (Algae) and eutrophication process were described by SALAMEH, HARAHSEH S, TARAWNEH A. 2013, UV radiation and Bromide as control factors in eutrophication process that the strong UV radiation with high sun illumination in arid and semiarid climates can limit algal growth. Because of the relatively high UV during daylight make algae inactive and hides underwater surface to protect them-self from the sunlight stress.

- Habitat

The environment in which organisms live is their habitat and it has to provide all essential requirements for their survival. Shelter and food, and, for higher organisms, supply of oxygen for breathing are required for life, growth and reproduction. The substrate on or in which they live has to provide certain characters which differ for specific organisms. Some attach to stones such as some caddis-fly larvae, others live on their underside such as many insect larvae, or on plants moving around and others buried in the soft sediment as is the case with worms and worm-like insect larvae or move on its surface as is the case among crabs, and others again swim in the water as fish or tadpoles. Contamination impacts differ due to habitat types, at standing water conditions for instance aquatic organisms have higher pollution stress than running water because moving water in general has lower temperature than still water and higher dissolved oxygen level. Low dissolved oxygen concentration also leads to lower diversity and less abundance of aquatic fauna and flora. The ground substrates type (e.g., fine sediments or hard ground) of water bodies is also affected by the water quality. Furthermore, fast flowing water flushes away pollutants while in standing water the pollutants accumulate for example along the Wadi Mujib, the change from eutrophic water near the Dam area to clean clear water conditions downstream. Here, aquatic organisms composition shifted dramatically from eutrophic species (*Physa*, *Tubificds* and *Chironomidae*) to intolerant organisms (Theodoxus, and *Melanopsis*) in the downstream area. In this case natural purification by aeration process was found to be responsible for water quality improvement.

- Pollutants

Water pollutants can threaten human health and also have a significant impact on the abundance and diversity of aquatic organisms. As stated by FRIEDRICH, CHAPMAN & BEIM (1996) the reaction of aquatic organisms mainly depends on the concentration of natural substances and pollutants in their habitats, and the time required for these substances to affect the internal systems of the organisms. According to SALAMEH & BANNAYAN (1993) and SALAMEH (1996), the major contaminant sources in Jordan are inefficient wastewater treatment plants (WWTP), cesspools, industrial wastewater, irrigation return flows, and solid waste disposal. Water pollutants generally result from anthropogenic or natural stress (SALAMEH, 1996). An example the inefficient Wadi Sir Wastewater treatment plant and domestic waste water are the main resources of pollutants in Wadi Sir Steam which caused to killed fish in Kafrein Dam. Pollutants have direct and indirect negative influences on aquatic organisms by introducing an organic and inorganic substance. These products can change the chemical, physical and biological characteristics of water, e.g., decline dissolved oxygen, increased water turbidity, temperature variation, acidity change, nutrient enrichment and produce poisonous compounds. Aquatic organisms have variable tolerance to pollution, some group of them are generally sensitive to even minor increase in pollution while others are somewhat tolerant or completely tolerant to increasing pollution loads. KOLKWITZ & MARSSON, 1908, BRINKHURST, 1966, ARTS 2002, and NUMINEN 2003. reported that some species of aquatic organisms can act as pollution indicator such as tubificds, chironomids and algae because they respond to specific changes in the water conditions. Eutrophication has been identified as one of Jordanian most serious water pollution issues, mainly caused by human activities (SALAMEH, 1985). In Jordan the main occurring eutrophication problems can be summarized as follows; High temperature, sunlight, slow water movement, High NO3, PO4, K and other micronutrients (e.g., Zn, Fe, Cu, etc.) (AL-KHOURY, 2005; AL-HARAHSHEH & SALAMEH, 2010; SALAMEH et al., 2013). In general eutrophic aquatic system, receiving high inputs of nutrient level or organic load from agriculture source (e.g., fertilizers and pesticides) and waste water effluents (domestic and industrial), lead to activate excessive algal growth (algal blooms). The death and decomposition of these algae can consume the dissolved oxygen and produce toxic substances which tend cause low diversity of intolerant organisms and an increase in tolerant species. The additional nutrients may cause the water color to become darker green rather than the normal water color. The most polluted area covered in the present study is Zarqa River. According to SALAMEH (1996) the causes of water quality degradation in this river had mostly resulted from human activites such as inefficient waste water treatment plants, leaching of solid waste disposal, domestic and industrial waste water. All these pollutants reflect on the biological communities in the Zarqa River, causing a damage of aquatic life and lower of biodiversity. On the other hand, increasing sediment load can be a serious problem with a great impact on water quality and living organisms. For example spongs community requires clear water because sediments clog their pores, reduce gas exchanges and feed efficiency and will eventually cause death. Other organisms are capable of surviving with high sediment loads. Species such as burrowing mayfly larva (Caenidae) has square gills which cover and protect the other delicate gills from sediment that would block their gills and make it difficult for them to breathe. These were observed in Wadi Shueib. In addition, high sediments reduce light penetration through the water column and are responsible for degraded water quality and they kill most benthic species specially submerged plants that need light for photosynthesis process. Extremely in high suspended load water body, sediment tolerant organisms such as oligochaetes worms and lunged snails are common. In contrast the sensitive organisms are eliminated (e.g., Stonefly larvae, *Theodoxus* and Spongs). Many of Jordanian aquatic bodies have naturally high concentrations of suspended loads which mainly result from weathering products. In Jordan, aquatic fauna have different levels of tolerance to pollution and generally fall into two categories; Pollution tolerant organisms (including: tubifex, chironomids, and Physa) (Fig 6.49)and pollution intolerant organisms: they are only observed in unpolluted water systems in Jordan such as *Turbellarian*, *Theodoxus*, *Melanopsis*, *Galba***,** *Amphipoda***,** *Isopoda* and Mayfly larvae.

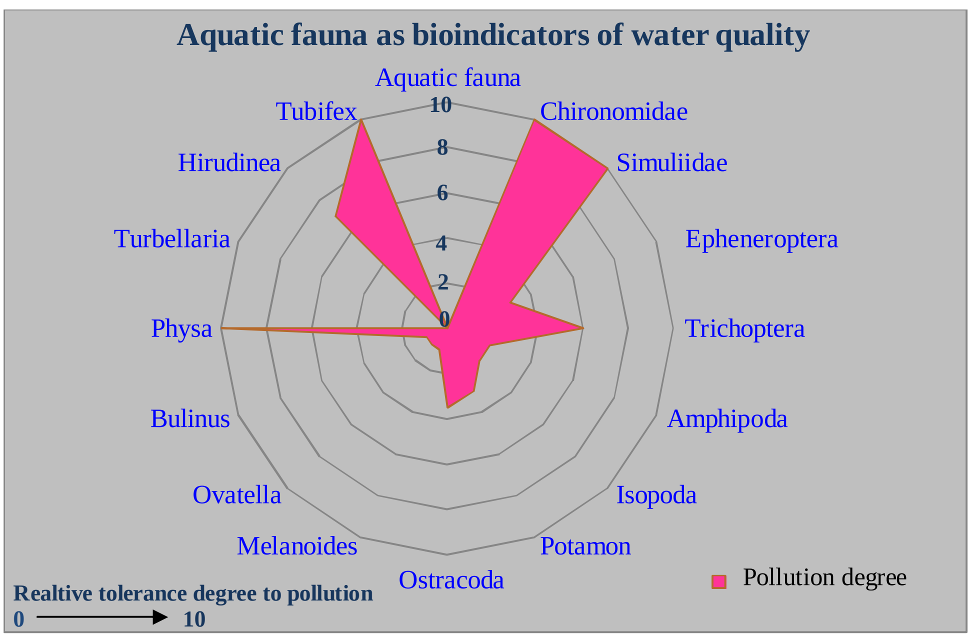


Figure 6.49: Biological indicators of water quality in Jordan.

- Salinity

Increasing salinity levels in water bodies are one of the most challenging environmental problems in the world. High salt content is more likely to occur in semiarid and arid region where evaporation exceeds precipitation. Like many other countries which have arid climate, Jordanian water bodies (surface water and ground water) are facing salinity problem too, according to SALAMEH (1996) that the major factors contributing to rapid degradation of the quality of fresh water are salinisation and pollution impacts. SALAMEH (1996 & 2001) reported also in other studies that the main sources quality degradation are treated and untreated wastewater, flood flows, rock weathering (e.g., dissolution of evaporates from rock formation such as Lisan Formation), industrial activities, irrigation return flow, high salt content in precipitation water and arid climate with insufficient precipitation and high evaporation.

The salt level in aquatic systems was measured here in electronic conductivity unit (EC) in micro Siemens per cm (µS/cm) in the field, using electronic probe (WTW equipment). The salinity was measured to range from 567 to 26100 µS/cm during late winter to early spring season. The highest EC value was found close to the Dead Sea in regions such as Karama Dam area. In Jordan freshwater bodies have usually less than 2000 µS/cm conductivity. Some slightly salty water ranges from around 2000 to 3000 µS/cm and brackish water could range from 4000 to 10000 µS/cm, and saline water have conductivities of more than 10000 µS/cm.

Salinity fluctuations affect on organisms distribution and abundance. Salt in water is the basic element for some group of animal such as salt loving insects which need sodium for their nervous system. Most plants are particularly affected by rising salinity more than animals because plants often do not require so much Sodium for their growth and, the water becomes unusable for irrigation, and salt encrustations problem arise which may cause major crop losses.

Each species of organism has its own optimum or preferred salinity level and have a different requirement on salinity. The relative upper limit tolerance to salinity in aquatic organisms was observed and discussed in the study are shown in figure 6.50. This figure indicates that's *Theodoxus and Melanopsis* gastropods are very vulnerable to salinity and are restricted to freshwater only. The richness was greater in cool running freshwater bodies with salinity ranged between 685-1395 µS/cm. Aquatic worms such as leeches and flatworms are examples of intolerant salinity fauna. Group of aquatic insect such as Dragonflies are highly sensitive to increases in salt content in water bodies but some others of Mayflies found in freshwater, slightly salt water and brackish water. Amphipods are particularly sensitive to salt as they are completely absent from slightly salty water, brackish and saline water. Ephydridae (brine flies) prefer high salt content habitats reach to 26100 µS/cm (Karama lake).

There are clear relation between salinity fluctuations, season variation, and living organisms. As an example, Karama Dam, during the winter season 2010 has an average salinity of around 23600 µS/cm but in early spring 2011, the decline of rainfall has resulted in decreasing water amount entering the dam and raising the salinity to 26100 µS/cm, so that large numbers of fish and gastropods *(Melanoides)* could be died or moved elsewhere.

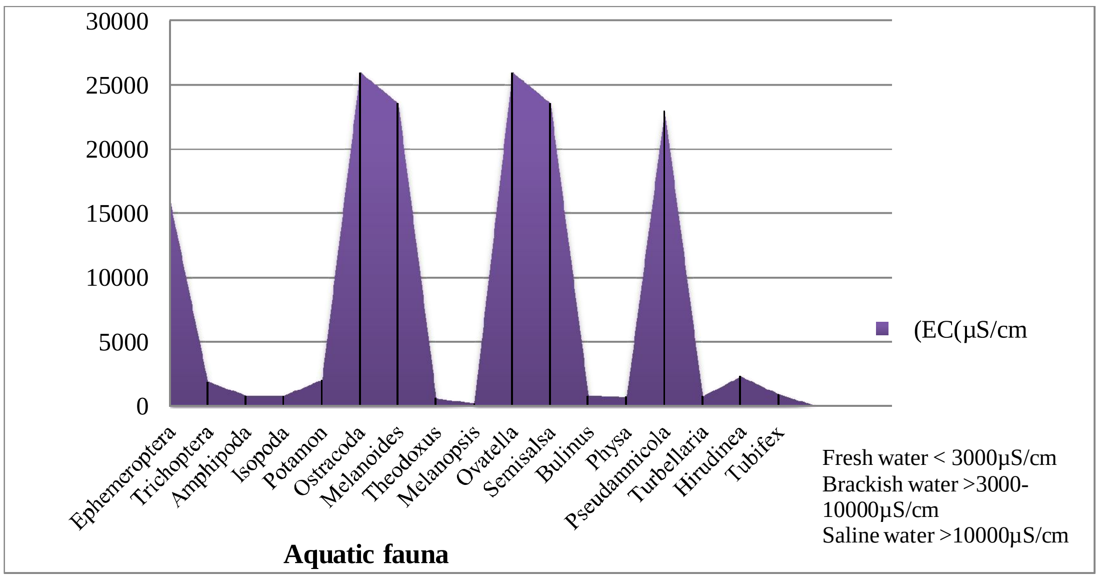


Figure 6.50: Showing the upper limit of aquatic fauna salinity tolerance in the study area.

- Compositions of the studied water bodies,

  Nearly all water has a certain quality of dissolved ions which is an important characteristic to define the water chemistry. The ionic composition is influenced by water source, local geology, precipitation water quality, physicochemical features (temperature and pH), human activities, and biological components. Most of the Jordanian surface water generally are found in rivers (Jordan River, Zarqa River and Yarmouk River) and wadis throughout the country such as; Mujib, Hisban, and Hasa. Flood flows also represent sources of surface water, originating from recharge of rain water, waste water treatment plant effluent and irrigation return flow.

In present study concentrations of major anions and cations were analyed for each site, including anions: Sulfate, chloride, bicarbonate and carbonate), cations: Calcium, magnesium, sodium, and potassium, and nutrients: Phosphate and nitrate) (Table 6.1-6.3). Trace elements metals: Copper, iron, lead, zinc, molybdenum, manganese, strontium, barium, bromine and fluorine (Table 6.3). Generally, the major common components are calcium and magnesium which dissolve through weathering processes of carbonate rocks. Gypsum rocks introduce calcium and sulfate compound. Carbonate occurs naturally in most of Jordanian surface water, with higher levels common in carbonate spring. Salty water is dominated by sodium chloride with different quantities. The higher Sr and Br concentration than other Jordanian water bodies are found in Wadi Atun stream with around 37.42 ppm of Sr and Br concentration of 10.41 mg/L which result of weathering processes. Heavy metals are naturally present with a low concentration (e.g., copper, zinc, and lead). Pb and Mo concentrations were measured in all water samples to be less than 0.01ppm. In general Cu and Ba have concentration less than 0.01ppm except in hot springs (e.g, Zara where they reach to 0.192 ppm and 0.699 ppm respectively. Zinc concentration usually is less than 0.01ppm and 0.02 ppm in the water samples. Fluorined concentration varied from 0.06 to 1.254 ppm.

Ionic composition of each location is discussed in details further in chapter five. Agriculture related input of phosphorus and nitrogen, or to nutrient- limited waters promote aquatic plant growth.

The aquatic organisms distribution and diversity is affected by ionic content of the water. For instance: Characeae prefers alkaline condition and can be used as a good indicator of calcium rich environment (BELLINGER & SIGEE, 2010). Diatoms and Spongs have a fundamental growth requirement for silicate in order to build their skeleton or shell. Also calcareous water is an important environment for snails and crustacean fauna because they need the calcium ions to reconstruct their shells.

The macronutrients; nitrogen and phosphorous are necessary for the survival and growth of aquatic organism's life especially algae. Natural phosphorus in water is generally low and usually the product of weathering of rocks but the sources of high concentration of phosphorus result from human activities, including; wastewater treatment plants, septic tank, animal wastes , industrial and municipal discharges. Trace metals in water or sediment have their impact on aquatic organisms. Bromide for example as by SALAMEH et al. (2013) stated that the relatively increased bromide concentration in the surface water (e.g., KAC) is a factor restricting the algae growth in the Jordan Valley area due its toxicity to algae life. Lower aquatic organisms (plants and animal) occur in some water with high trace element concentration such as those associated with the thermal spring. Hence, high bromide and sulfate with release of H_2S gas in thermal water can explain the absence of aquatic animals can indicate the toxic condition in the Dead Sea area.

- Oxygen content

Oxygen content plays an important role in the growth, development and survival of aquatic organisms. Dissolved oxygen is derived from the atmosphere and it is also produced by photosynthesis. Measure of the amount of oxygen required for decomposing organic matter biologically Biological Oxygen Demand (BOD5) and inorganic matter chemical oxygen demand COD under aerobic conditions within five days. The amount of oxygen needed to chemically oxidize organic water pollutants to inorganic product by using strong oxidant (e.g. potassium dichromate and potassium permanganate) under acidic conditions is called COD. The BOD and COD values are inversely proportional to the dissolved oxygen level. The measured COD value in the examined surface water ranged from 4.1 to 69.05 mg/L and the BOD from 0 to 37. 24 mg/L.

As stated by CHAPMAN &KIMSTACH (1996) dissolved oxygen level of natural waters varies with temperatures, salinity, turbulence, the photosynthetic activity of algae and atmospheric pressure. They are also noted that the amount of oxygen in water bodies can be used as an indicator of the degree of pollution by organic matter, the destruction of organic substances and the level of self purification. According to FRIEDRICH, CHAPMAN & BEIM (1996) the ability of organisms to survive different levels of oxygen depletion in water forms the basis of some biotic indices and water quality assessment methods.Simply, health of aquatic ecosystem relies on oxygen content. That means the decrease in the oxygen supply in the water for example, in polluted water, has often a negative effect on aquatic life and commonly the environment tends to have relatively low diversity and abundance of organisms and that indicates that the water quality is degraded. Each of the aquatic animals in the study breathes somewhat more or less differently. They can take oxygen directly from the water or other equipped to obtain oxygen from the atmospheric air by different respiration techiqnices such as Culicidae larvae (mosquitoes) breathe atmospheric air through open spiracles, but they must come to the water surface periodically (BOUCHARD, 2004).
In our field observations, examples of aquatic organisms are found in very good water quality in oxygen rich water such as: *Turbellarians* worms and *Theodoxus* while other found species like chironomids, and tubifex occur in black muddy substrate depleted of oxygen such as in Mujib Lake.

- pH value

pH is a measure of the acidity of the water and commonly used to express the concentration of hydrogens ions in water . pH values have range from 0 to 14, classified into basic (pH > 7), neutral (pH = 7), and acidic (pH< 7). As defined by EBBING, 1990 an acid is a substance that, when dissolved in water, increases the concentration of the hydrogen ion (H+) while a base is any substance that, when dissolved in water, increases the concentration of the hydroxide ion (OH-) and H+ decreases . A neutral solution has same number of hydrogen and hydroxide ions. Most pH values in high water flow periods were between 6.0 and 8.5 which is within the range of the most natural water. Lower values of pH occur in dilute waters high in organic content and high values were found in eutophic water (CHAPMAN & KIMSTACH, 1996). Field measurements, ranged from 6.01 to 10.02, with most waters having a normal pH near neutral (6.5–7.5) to slightly basic (7.5–8.5) with different physical, chemical and biological features. The change of PH in the water is mainly due to the biological activity especially of non-air breathing microbs. It has to do with H2S and CO2 production from organic mud. Acid rain plays no part in that in Jordan as stated by SALAMEH (1996) the pH value of precipitation water is more than 5.6 and generally more than 7.0.

Most aquatic organisms have adaptations to water with a specific pH and they respond to changes in the pH values. They may die or move to another environment. For this reason pH measurements are important in the monitoring of water quality and it has a great impact on, chemical reactions, ionic composition, and living organisms. The pH value of a water body can be affected by pollutants, photosynthesis process and other chemical reactions. The abundance and toxicity of a number of metals is greatly based on the pH value of the water. For examples, some ions such as iron naturally exist in very low concentration in water bodies because iron is insoluble under oxidizing conditions. Change in pH may increase the solubility of certain elements in water bodies which are important for their growth. An elevation in the pH value can significantly increase nutrients (nitrogen and phosphorous) solubility and creating favorable habitat for eutropfichication organisms (e.g., Algae, plant and tubifex worm). Aquatic environments with high or low pH conditions have low biodiversity and occurrence of organisms. In an old spring near Zarqa River the water has relatively high pH value reach 10.22 (Basic), and macro organisms were not present in it.

7 DISCUSSION

This study deals on one side with the predominantly Pleistocene macrofauna of deposits from a variety of sites in Jordan, and on the other side the usefulness of many of the encountered genera from fresh water also for the evaluation of quality of the now existing running water. These later data regarding living molluscs and crustaceans are substituted by observations dealing with the aquatic fauna. The data on fossil occurrences have been enlarges to also hold observations on former brackish lakes in the SE desert and on the deposits left by former shores at the Gulf of Aqaba. A review of the history of the Jordan Rift Valley is included to also document the great gaps which are still present in the relatively recent part of the geological history of Jordan. Of the localities with a fauna of fresh water studied the oldest site is that of the Al Qarn Formation in the Jordan Valley from a lacustrine environment that existed there at Pliocene- Pleistocene time.

In the general area of the Jordan Valley fossils of animals which lived in a spring pond forming the limestone of Aramshi Formation and the proper of Jordan River at Pre-Lisan time are dealt with. Pleistocene coral reefs with their lagoons and beaches as they occur near Aqaba are discussed. Fossils found in deposits of Lisan- Lake Formation and some of its tributaries and on the beaches of the former lake are presented. The fauna of the Late Pleistocene brackish Halat Ammar Lake (Mudawwara Lake) in the SE of Jordan are discussed, and the deposits of ancient Azraq Lake, Hasa Lake and Jafr Lake are compared. The sediments formed under the influence of freshwater holds a rich molluscs fauna of which the fossilized gastropods are represented by 16 species which belong to genera such as *Theodoxus*, *Melanopsis*, *Melanoides*, *Bithynia*, *Hydrobia*, *Ancylus*, *Gyraulus*, *Galba*, and *Valvata*, most of which still have living relatives in Jordanian fresh water creeks and ponds. Only *Bithynia* and *Ancylus* are no longer found, and *Valvata* is extremely rare in extant streams, springs and ponds, while species belonging to them were very common in the ancient lake and creek of Al Qarn. Especially representatives of *Melanopsis* and *Theodoxus* occur commonly in the freshwater deposits of Al Qarn Formation, Aramshi Formation, pre Lisan deposits of the Paleo- Jordan River sediments and the Lisan shore deposit (at Hammeh) and they still represents the most remarkable gastropod found in clean and shallow fresh-water in Jordan.

Two new species of gastropods were recognized including a *Planorbis* sp and *Melanopsis* sp from Al Qarn Formation. Representatives of five genera of bivalves such as belonging to *Unio*, *Corbicula*, *Cardium* (*Cerastoderma*), *Brachidontes* and *Pisidium* are documented in different deposits and they are extremely rare in modern streams and creeks, some are only more common in King Abdulla Canal. Two species of *Pisidium* are well preserved in Al Qarn Formation while *Unio* was found only in the form of brittle fragments at the same formation which it has same or very similar to the two species of *Unio* as found in the fossil Jordan River deposits and as living in King Abdulla Canal. Ostracods are also present in freshwater sediments such as *Heterocypris salina* and *Ilyocypris* sp at pre Lisan sediments. Remains of crab claws of *Potamon* are also documented from Al Qarn formation which is only occur in freshwater. The historical geological data of Cenozoic Era during the time from the early Miocene, as found in Waqqas range from the time with normal sea water present to such when environment became salty (BANDEL & SHINAQ, 2003) until fresh water deposits such as those of localities like Ubeidiya, Erk el- Ahmar or Gesher formed. But relations of these to each other are insecure regarding their time of formation. Jordan was differentiated into a highland bordered in the West by a rift-graben.

That rift was a deep structure around 5 Million years ago when during the Messinian Stage the Mediterranean Sea dried up, and it probably connected by a deep canyon with that huge Mediterranean basin with exit near modern Haifa (BANDEL & SHINAQ, 2003). When the Mediterranean Sea filled the basin again with water that had come from the Atlantic Ocean the sea-water also entered the Dead Sea-Jordan Rift and here evaporated, but that is assumption and the age of the salt, at least in part, may also be older than Messinian. Facts are that a lot of salt was left behind from the evaporating sea water which formed hundreds and even thousands of meters of salt deposits below that region where now Lake Tiberias is and below the Dead Sea, as was documented by drill holes in these areas (NIMROD, 2012).

This salt has formed salt domes, and most probably there is also a salt dome below the Karama area, since here Lisan deposits have been pushed up to form hills rising from the Valley floor and salty springs issue into the lake. The youngest epoch of geological history began around 1.4 Million years ago when the Tertiary Period ended according to differing sources. The earth cooled and advancing Glaciers covered periodically more or less large parts of the Southern and Northern Hemisphere. The older of these cold phases and advances of ice are badly known predominantly by the reason that their deposits have largely been destroyed by the younger advances. The ice formed on the continents fixed much water, so that in each cold spell the surface of the world oceans was lowered.

Jordan was affected by these climatic changes due to changes in the amount of rain that fell here and had impact on erosion and vegetation. Data for age determination of deposits formed during these times come from several sources. A good source could be those extracted from basaltic eruptions that occurred along the rift and behind it on the eastern highlands. A problem with these data lies in the circumstance that they need to be correlated with the sediments that have been deposited prior to their eruption and those deposited just above them. These studies still need to be carried out, and there are numerous outcrops along Yarmouk, Zarqa, Mujib and Hasa river Valleys, where this could be done.

A good date line is formed by the lake deposits of Lake Lisan. It existed between at least 50.000 to 15.000 years ago (NEEF & EMERY, 1967; BEGIN et al., 1974; HOROWITZ, 2001). The history of the Jordan Valley before Lake Lisan formed and after the sea around 15 Million years ago had filled its depression probably coming from the east, is thus still quite unresolved. The holes drilled into the Rift Valley ground near Lake Tiberias and the Dead Sea penetrated predominantly salt and the basalts found here often are intrusions. The times of the rising eastern margin of the rift, as well as the shape of the eastern lands behind that margin are also still largely unresolved. Here interrelation between volcanic flows and terrestrial sedimentation can resolve questions, for example of the interesting history of Zarqa Valley. For the time between Messinian and Lisan Formation we have fossils such as those from Al Qarn Formation, and the much younger fluviale beds of the pre-Lisan Jordan River but no good time indicators. It is very evident though that a former Jordan River and its alluvial plain was flooded by Lake Lisan when it first formed. Thus the gastropods from these deposits are older than those which lived in springs along the shores of Lake Lisan and the margins and swamps formed by its tributaries. Since Al Qarn Formation had already been deformed before Lisan and also before that ancient Jordan River was flowing, the snails in it are much older. It seems that around and age of 1 Million years can be possiblity, but the Al Qarn deposits may be much less old.

Aramshi Formation is also older than Lisan Formation, but what age relation exists to from Aramshi to Al Qarn is unknown. The eastern margin of the Jordan Rift was affected by much structural unrest and such movements of the Rift margin are still going on which results in insecure time relations. Humans came into the area perhaps 1 Million years ago, hunted big game and left tools mostly made of flint, which during the so called Paleolithic period are so similar to each other that they allow no age determination (MACUMBER, 2008; OLSZEWSKI, 2008) and cannot even help in determination of the species involved- *Homo sapiens* or *Homo erectus*. Both had similar life behaviouer, they hunted big and produced similar meat cutting tools, mainly made from flint. This behavior changed only when people began with agriculture less than 10.000 years ago and these people definitely were *Homo sapiens*- who had come to the region around 50.000 years ago.

Regarding remains of animals in freshwater deposits, they consist predominantly of shells of molluscs and ostracods, and in Jordan they allow no age determination. This is so even when they differ in details from their modern relatives, since the modern fauna for example in case of Melanopsis has many local variants. They allow the interpretation of their living environment, but cannot be used for age dating. Due to the change in the original mineralogy of the shells- as occurred in the deposits of the former salty lake at Ammar Halat and those of the former coral reefs near Aqaba, also the isotopic composition of the shell cannot be used for determination of the time of its production. Dating of post-Lisan sediments in Jordan is becoming more precise when products of human occupation are included, since the country was well settled since the begin of agriculture about 10.000 years ago, also in the region of Amman (ROLLEFSON, 2008), and with rise of the Egyptian and Mesopotamian cultures even the type of people living in Jordan come into focus.

The fossil terraces found on the coastal slope south of Aqaba represents evidence for a shore environment with pebbles, beach rock, shallow lagoon with calcareous sand and single coral heads, and fringing coral reef with corals connected to each other in dense growth. And they also provide an evidence for structural unrest that strongly affected the northern side of the Gulf of Aqaba along the Jordanian coast.

The raised coral reefs in Aqaba include pectinids (*Pecten* and *Spondylus*), *Lima*, oysters, and among the recognizabls echinoids remains of *Clypeaster*, *Diadema*, *Echinometra*, *Tripneustes*, *Heterocentrotus*, *Eucidaris* irregular forms resembling *Lovenia*. Also some recognizable gastropods of large shell size such as members of the Trochidae, Strombidae and Muricidae have survived diagenetic dissolution. All the mentioned animals still have their relatives living in the Gulf of Aqaba and here within the environment of the fringing reefs. Their place in the ecology of the reefs and their associated deposits is easily determined by comparing with that of their living relatives. But the age of the fossil reefs at the coast of the Gulf of Aqaba in Jordan is also not known, as there are still many questions open to the geological history of the Gulf of Aqaba ad their relations to the Red Sea.

The fossil reefs have formed on a fan of detritus that has it's origin in the North and the highland there. This fan nowadays increases no longer in dimension, since it has been cut off from its source. It nowadays changes in morphology only by erosion and some re-sedimentation within itself. The coastal sediments formed on that fan only locally, as can be observed along the modern shore.

Modern erosion within the fan cuts through former reef terraces and thus these ancient reef terraces cannot be traced for a long way parallel to the shore. Also water level relative to the fan had to be higher than now since they occur up to 70 m above it. They occur so far above modern level of the Gulf of Aqaba that not even the highest water stands that may have existed in the last 500.000 years could have reached them and thus formed them. Their reconstruction as such is made easy by coastal reefs and lagoons which are growing now and have the same structure and shape as the fossil ones. But the time of formation of the fossil reefs-lagoons-and beaches is difficult to reconstruct since the coast including the fan onto which the terraces are placed have changed due to structural unrest, as is the case along the whole of the eastern margin of the big rift system of the Gulf of Aqaba, the Wadi Araba, the Dead Sea and the Jordan Valley. The fossils preserved in the ancient beach and reef deposits cannot help, since they belong to the same or very similar species as live in the Red Sea now. Also changes in the mineralogy of the rocks involved have resulted in the dissolution of most original aragonitic shells, which compose most of the fauna. Larger aragonitic skeletal parts, as those of corals have been recrystallized to quite some degree.

In the deposits of Halat Ammar Formation also changes in shell composition have occurred. The brackish Lake Halat Ammar existed during or before the last ice age in Europe in its position crossing the desert boundary to Saudi Arabia along the old Hejas Railway. Here shells of the bivalves *Cardium* (*Cerastoderma*) and *Brachidontes* are common and form much of the calcareous part of the sediment. Both have the same or a very similar species living in the Gulf of Aqaba.

Regarding to the Crustacea, several species of ostracods lived in Lake Halat Ammar such as *Cyprideis torosa* and *Candona* sp and they still have relatives in present fresh and brackish water occurrences in Jordan. The ostracods are often preserved with both valves still connected to each other that indicate they were obviously killed before reaching full age due to fluctuating water level and thus without valves detached from each other after death. Here shells of molluscs have changed their mineralogy so much that age determination with them will present data which have nothing to do with their time of secretion from the living animal. Thus interpretation of that lake as equivalent to the Eemian Interglacial is a suggestion only without reliable data.

In Jordan, molluscs group can be considered as very good indicator candidates for paleoenvironmental reconstructions during the Pliocene- Pleistocene time (Fig 7.1). They are also very useful indicator species for the recognition of the modern environmental conditions, since they occur widespread and at their living places are abundant. Each species lives in a specific habitat and their presence or absence in time and place reflects the change in the ecological conditions. They are relatively well preserved within sediments due to the hard shell. In addition, the fossil molluscs and their modern relatives are very close to each other where they have same or similar species are still occurring and live under the same environmental conditions. *Melanopsis* for example, has modern varieties or subspecies which are in part like those from the past and in part differ from them. *Melanoides* has not changed shape during the Pliocene as well as the two species of *Unio*. It was determined that *Melanoides* disappeared from the shallow water in Karama Reservoir lake when the salinity of the water increased and had reached 26100 µS/cm. This observation confirmed that Lisan Lake was deposited under hypersaline condition as suggested by ABED and YAGHAN (2000) since here *Melanoides* fossils are absent. Thus the salinity of the Lisan Lake was as high or higher than 26100 µS/cm.

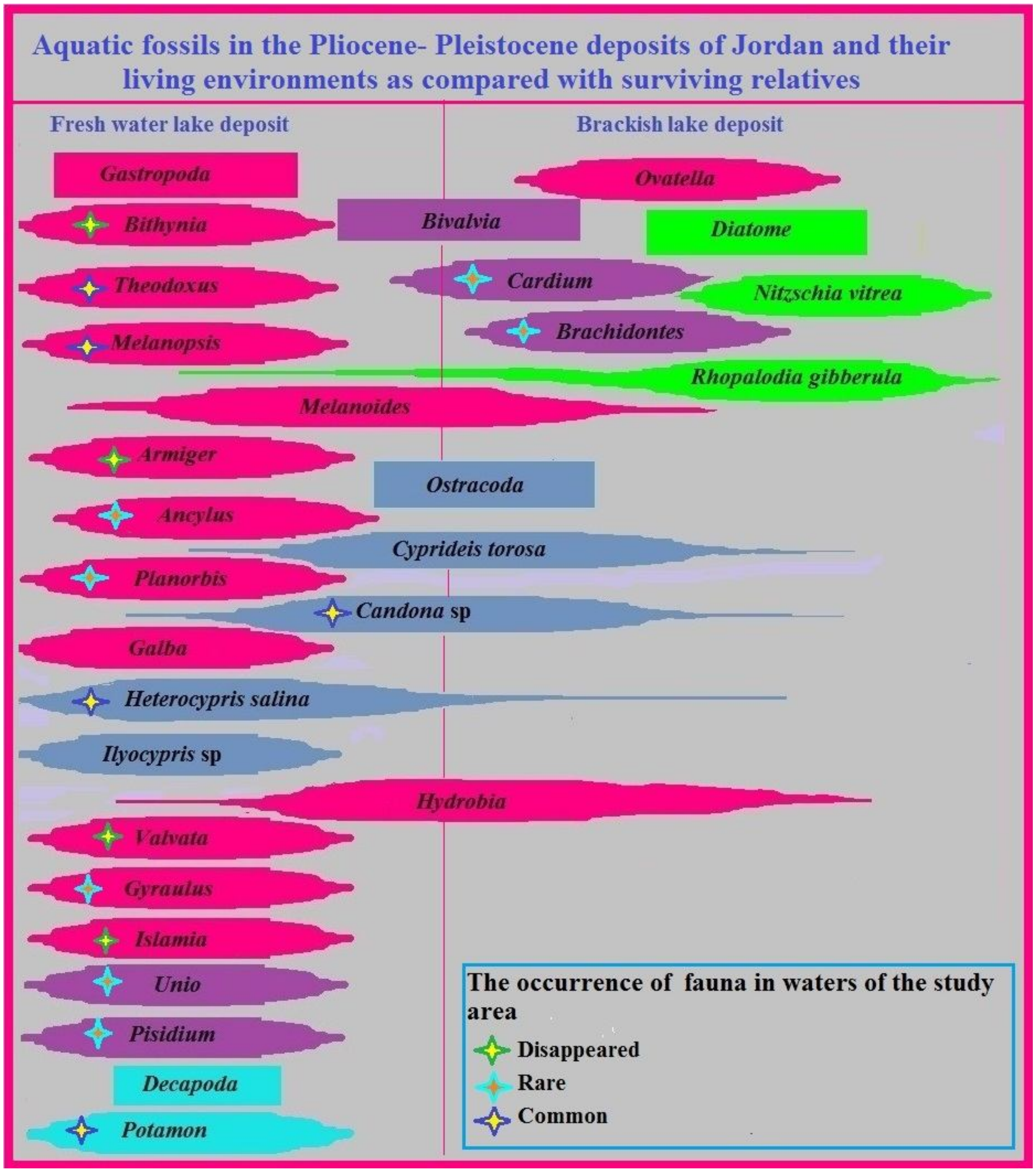


Figure 7.1: Aquatic fauna fossils as indicators of the Pliocene-Pleistocene environments as compared with modern fauna of Jordan.

The interpretation of molluscs as indicator species of the paleo-environment can be connected with data extracted from the character of the sediment, such as travertine with encrusted reeds and the presence of beach rocks on a terrace of Lake Lisan. Both are evidence for the presence of fresh water springs in former times. Paleoenvironment reconstruction is also made possible by considering remains of other organisms, such as the crab claws in the Al Qarn Formation indicating a freshwater deposit, the ostracods species from Halat Ammar Lake indicating salt tolerance and diatoms in the Lisan Formation giving evidens for brackish water with seasonal changes in salinity. While these fossils can help in the interpretation of the former environment they are not useful for the determination of the age in which they were formed. Their occurrence helps in the reconstruction of bio-physical- chemical parameters and in their use as bioindicators for existing conditions in Jordan, an example the occurrence of the *Theodoxus* without *Melanopsis* at Wadi Hisban and locally on the concrete wall of King Abdullah Canal is related to the availability of food. Both gastropods compete for food mainly consisting of the dense growth of algae growing on the well illuminated hard substrate. *Theodoxus* has partly mineralized teeth of its radula and is thus better equipped to scrape off algae from stony surface, thus leaving not sufficient food for *Melanopsis*. When water is more polluted than is good for *Theodoxus* but still tolerated by *Melanopsis* and when substrate on which the snails search for food is softer, *Melanopsis* will be more common or be exclusively present. Also a factor is presence of the calcareous operculum of *Theodoxus* that can seal the aperture tightly and protects the snail from attacks of crabs while the organic operculum of *Melanopsis* can not prevent the crab *Potamon* to use it as food. Successful attacks of *Potamon* especially on still growing *Melanopsis* with still thin shell margins were observed in Mujib River. Living gastropods respond rapidly to environmental changes from clean to polluted water as shown in Table 7.1. Furthermore, the reason for using molluscs as bioindicator, that they can easily be recognized and collected from the field by usually having a size that makes them visible in a creek. Also they are well known and can be determined to species level in this study, and this also while still in the field. Additional to gastropod which represent the frame bioindicators in the present work, other animals were chosen for the analysis predominantly flat worms (Turbellaria), annelid worms with well recognize ones in case of *Tubifex* and the Hirudinea, larvae of insects (e.g., mayflies, caddisflies, black flies, shore flies and chironomids) and crustaceans (ostracods, amphipods, isopods and the decapod *Potamon*) (Fig 7.2).

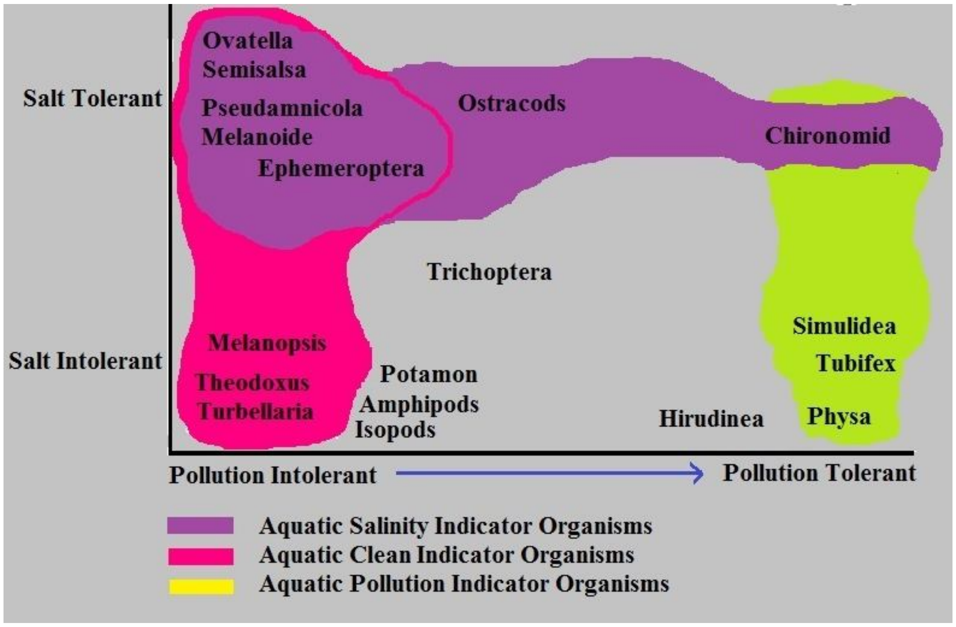


Figure 7.2: Aquatic indicator organisms of salinity and the ecosystem health of Jordan.

The creek in Wadi Shueib below Salt can exemplify the pollution history with transition from clean water spring water to polluted water and transition from water flowing reatively high up in the country into a reservoir at the margin of the Jordan Valley within the course of a single creek (Fig 7.3). Here also the changes which occur between slow runoff during the dry months and rapid flood flow in the rainy season was documented. Four sites were chosen along Shueib creek, the first at the Jadoor spring site, the second is creek near Alfrkhah and Deak spring, third site after the Salt sewage treatment plant and final site is represent pond located near Shueib dam. Jadoor spring just at the western margin of Salt is clean and has the clean water signal with the gastropods *Theodoxus*, and *Melanopsis* and the crustaceans *Gammarus* and *Asellus.* This signal falls out and disappears when pollution increases along Wadi Shueib due to added household sewage. Even further downstream the efflunents of the Salt treatment plant are added to it which has strong impact on the type of insect larvae present in the creek. When Shueib creek mixes with the effluents the sewage treatment plant and further flows over stony beds bordered by *Nerium oleander* bushes towards the Jordan Valley the only gastropod present is *Physa*. Elevated phosphorus and nitrate concentrations in this creek due to the added treated waste water is reflected in a strong growth of cyanobacteria on surfaces and in the water as phytoplankton, supporting reproduction and growth of the sewage worm *Tubifex* and the similarly red larvae of Chironomidae which settle in the organic sludge. These two organisms are good indicators for the water quality that has been degraded by sewage and both organisms can tolerate water with depleted content of dissolved oxygen. Floods caused by winter rains may flush out all muddy bottom sediments and with it the substrate for occurrence of *Tubifex*, but with the return of more moderate flow conditions, the sludge is rapidly produced again as well as red worm and red larvae colonies in it. The amount of winter floods determines the living conditions in Shueib reservoir at the end of the Valley and water there can be polluted up to different degrees. In 2012 pollution was strong and dipteran larvae settled near shore puddles and in 2013 pollution were more moderate and a large population of *Daphnia* had developed in the shallow parts of the lake.

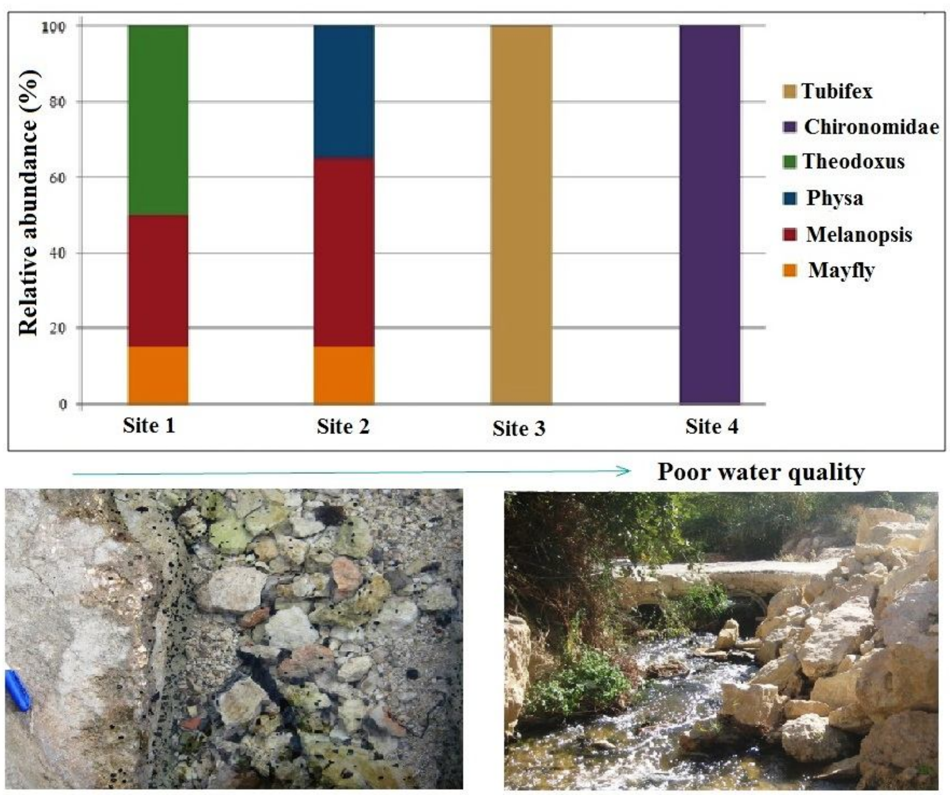


Figure 7.3: In Wadi Shueib stream, aquatic macrobioindicators document a shift in community composition related to human activity (Site 1: Jadoor spring; Site 2: creek near Alfrkhah and Deak spring; Site 3: creek after the Salt sewage treatment plant; Site 4; pond located near Shueib dam).

In case of Wadi Mujib below the dam site a change to much better water quality from that of the lake and also from some of its tributary streams was observed. Here initially nutrient tolerant species (e.g., *chironomids*, *Tubifex* and *Physa*) are associated to a high nutrient production by strong growth of algae and phytoplankton. Here also content of dissolved oxygen is relatively low. But still close to the dam *Melanopsis* appears, fish and frogs are common and within a short distance of about 2 km downriver the biological communities change completely documenting a rapid improvement of water quality also due to the turbulent flow of the river across many rapids in the stream bed. The river bed is stony and air mixes with the river water, and pollution-tolerant organisms such as Tubifex and red chironomid larvae are replaced by the pollution-intolerant organisms such as *Theodoxus*, and *Melanopsis* (Fig 7.4). In general the river is cleaned by a self purification process, but there are still many nutrients in the water which support the growth of a rich phytoplankton and the mud that may settle in quiet puddles on the side turns black just below the surface, and the lower sides of stones is black. The high quality water containing many planktonic organisms here even enables the growth of fresh water sponges covering rocks in the river rapids.

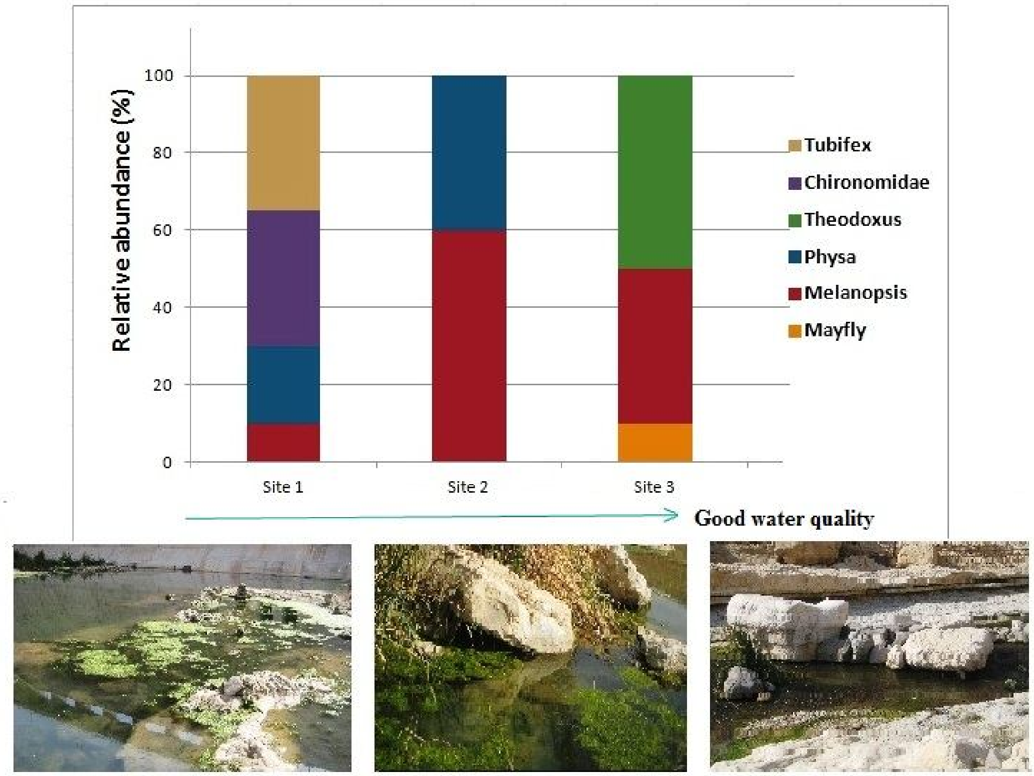


Figure 7.4: The occurrences of bioindicators along the Wadi Mujib (Site 1: lake below the dam; Site 2: creek in Wadi Mujib about 1 km from site 1; Site 3: creek about 2 km down stream of Wadi Mujib).

It was possible to classify the quality of running and standing water in Jordan by using biological indicators species. It provides a basic frame by which easily and rapidly the status of water quality and pollution is recognized in the field. It is based strongly on the gastropods which can usually be detected on stones and determined in the field and is improved and enlarged with other invertebrates, especially the aquatic worms and insect larvae. They have been selected according to their common presence and their characters which can usually also be rapidly determined in the field and thus they can serve as bioindicators. The results of the present study suggest a "Jordanian Biomonitor System for Watercourses (JBSW)" which classifies water qualities of 12 categories as shown in Table 7.1.

Table 7.1: Jordanian Biomonitor System for Watercourses (JBSW), categories, organisms, tolerance degree, water body type, Chemical indicators and some example locations for the bio indicators of water quality in Jordan.

Category	Water quality	Aquatic organisms bioindicators	Tolerance degree	Environments description including; Substrates, water body type, and color.	Chemical indicator	Locations (examples)
1	High water quality (very clean/ non-polluted)	Theodoxus, Turbellarian (flat worm), and Mayfly larvae *(Caenis antoninae)*	Organisms highly sensitive to pollution	Rocks and gravels, clear shallow water from still to slow running water	Low COD and BOD values and main ions Ca^{2+} and Mg^{2+}	Hisban, and Shita Spring.
2	Very good water quality by self purification	No Turbellarian (flat worm). Theodoxus, Melanopsis, Mayfly larvae, (*Baetis monnerati*), and sponges.	Organisms highly sensitive pollution and not sensitive to strong growth of phytoplankton (no nitrate)	Exposed riverbed rocks but with darker mud deposits than normal due to additional nitrate. Shallow water from moderate to swift current.	COD value is around 15 mg/L and BOD 0 mg/L. High occurrence values of SO4 (>7 meq/l), NO3 (about 0.2 meq/l) , and Na (5 meq/l)	Mujib River a few km below dam site and KACduring spring 2013.
3	Good water quality	Gastropods (Melanopsis, Galba and Bulinus). Crustacea (Amphipoda) and mayfly larvae such as *Baetis monnerati*	Organisms sensitive to pollution, clean water to slightly polluted water.	Gravel bottom stream with moderate running water and springs issuing from carbonate rocks.	Normal freshwater chemistry but small increase in NO3 and PO4 values	W. Hisban below spring area, Wadi Sir, small spring creek in upper Wadi Zarqa.
4	Fairly good water quality	Melanopsis coming from continuous sources, Physa, Mayfly larvae (Caenis sp), and leeches.	Semi tolerant organisms that tolerate some degree of house sewage added to streams.	Rock and gravel, less sand occurs in the relatively turbid running water from moderate to swift current with high occurrences of aquatic vegetation.	NO_3 concentration up to 1.0 meq/l and low concentration of Na dissolved ions	W. Shueib and Wadi Sir upstream of the treatment plant.
5	Moderate	Chironomidae (blood worms), Physa, Mayfly larvae, and Caddisflies larvae.	Tolerant organisms which survive with moderately polluted water	Bottom surface between stones with organic mud and sand below surface black.	COD value reach to 50 mg/L and BOD 22mg/L. The concentration of SO_4^{2-} around 6meq/l, NO_3^- 1.5 meq/l , and PO4 0.3 mg/l.	Periodically in lower Zarqa River
6	Slightly bad	Low densities of Physa and leeches or disappearance and well present Simulidae (Black fly larvae) and tube- building	Pollution tolerant organisms but still with well aerated water	Rocks with muddy organic rich deposits in interspaces. Brown, turbid water with moderate to swift	Relatively high values of COD with 60 mg/L and BOD reach 35 mg/L. concentration of SO_4^{2-} about 1,5	Wadi Shueib downstream of the treatment plant and periodically parts of Zarqa

		animals such as Chironomid (blood worms), and Tubifex (Sludge worms)		current.	meq/l, NO_3^- 1.0 meq/l , and PO4 1.0 mg/l	River
7	Bad (Eutrophic)	High occurrence of Chironomidae (blood worms), Tubifex and Physa with their eggs.	Tolerant to eutrophication organisms.	Fine sediment below surface and lower side of rocks black with still greenish turbid water and high growth of algae and Cyanobacteria.	The value of COD is 35.0 mg/L and BOD is measured 5.0 mg/L. characteristic compounds including SO_4^{2-} (4.5 meq/l) , NO_3^- (0.20 meq/l), and PO4 (0.30 mg/l)	Wadi Mujib Lake directly below dam
8	Very bad water quality	Red Chironomid worms, frogs and fish.	Organisms not sensitive to pollution.	Muddy sediment between rocks, black below surface, rocks covered with bacterial slime.	COD has high value of >70 mg/L and BOD >10 mg/L. Main ionic compounds such as NO_3^- (1.50meq/l) , PO4 (0.30 mg/l), HCO_3^- (8.0 meq/l), and CL (11.98 meq/l)	Periodically Zarqa River especially upstream of King Talal Reservoir.
9	Poor water quality (Heavily polluted water) (smelly and colored water.	No insect larvae only bacterial slimes. In Kafrain lake fish periodically killed.	Organisms highly tolerant to pollution.	Muddy with high sludge content. Turbid - gray color in creeks brown in lake.	COD value reaches to 83.0 mg/L and BOD 40.0 mg/L. high concentration of PO4 and NO3	Wadi Sir after and below treatment plant and lake of Kafrain dam
10	Mineral water	Large numbers of Pseudamicola (snail), Simulidae (Black fly larvae) and Chironomid worms. Larvae of mayflies such as *Nigrobaetis vuatazi* and caddisflies are present here. Springs with mosses and ferns	Organisms tolerant to mineral water and slightly salty water.	Springs with Gravel and silty ground in creeks.	Relatively high concentrations of Sr (reaches 37.0 mg/L*)* Br 10.0 mg/L, and *Z*n 0.02 mg/L	Wadi Atun stream
11	Warm water	No macroaquatic animals only dense crust of Cyanobacteria and springs with reeds (Phragmites)	Organisms are able to survive high temperatures.	Warm springs issuing from basalt and sandstone as warm as 60°C.	Relatively high concentration of trace elements such as Mn 5.0 mg/L, Cu 0.2 mg/L, Ba 700mg/L	Zara and ZarqaMa'in springs

12	Brackish water	Class 1	Pseudamnicola(snail), Ostracods (e.g., *Heterocypris salina*, *Cyprideis torosa* , and *Heterocypris reptans*) and Insect larvae such as Ephydridae (shore fly), Chironomidae, mayfly (*Cloeon sp*).	Salt tolerant organisms which survive with salinity of 16000 - 21000 µS/cm	Creek on gravel with algae and aquatic plants and pools surrounded by salt tolerant plants with ostracodes may be included in one	Relatively high concentrations of dissolved salts such as sodium chloride. Br and Sr concentrations are high	Karama area
		Class 2	Periodically with ostracods (e.g., *Heterocypris reptans* and *Cyprideis torosa*) up to 2011 with Melanoides but from 2012 including 2013 without Melanoides- surrounded by salt tolerant plants	Up to 2011 with salinity about 23600 µS/cm. In 2012 and 2013 the salinity level reaches to 26100 µS/cm	Standing water with muddy ground	Higher salt concentrations and Br concentration reachs to 16 mg/L and Sr with 50 mg/L.	Karama Reservoir lake.

8 CONCLUSIONS

The fossils of animals that lived in rivers and lakes during the Pliocene to Pleistocene times in Jordan have provided clues to the interpretation of these historical environments. They can also provide information about the changes that have occurred during the last million of years and to a better understanding of the history of their relatives which are this found living in the waters of Jordan and can help in the evalution of the development and also deterioration of water quality that has occurred in modern times by comparing with surviving relatives. These fossils document the amazing stability of fresh water fauna throughout history of human habitation within the area until dramatic changes within the last decades changed the environment.For examples, species of gastropods which belong to the genera *Theodoxus*, and *Melanopsis* are common fossils in the Al Qarn Lake and creek, Aramshi spring and lake, and pre lisan deposits of the ancient Jordan River and they still live under the same conditions in the area in shallow freshwater environments when not polluted. On the other hand *Melanoides* still prefers more muddy environments and more standing water in fresh and also brackish environments.

Fresh water gastropods include species of *Theodoxus*, *Melanopsis*, *Melanoides*, *Bithynia*, *Hydrobia*, *Ferrissia*, *Islamia Armiger*, *Planorbis*, *Ancylus*, *Gyraulus*, *Galba*, and *Valvata*.

Many gastropods from the Pliocene- Pleistocene Formations still have living relatives in Jordanian fresh water creeks and ponds, with the exception of those of the genera *Islamia*, *Bithynia* and *Ferrissia*. In case of *Melanopsis* two species from Al Qarn Formation are so similar to forms now living in Jordan that they can not be distinguished from them- the other three differ little and only *Melanopsis tchernovi* has no counterpart among the living but a certain resemblence with *Melanopsis sharhabili* form Jordan Valley. They are evidence for shallow beach environment in case of *Melanopsis*, and vegetated pond environment in case of *Valvata*. Also present is a *Theodoxus* that closely resembles the species still living in Jordan also next to the outcrop in King Abdulla Canal. The ornament of the early ontogentic shell of *Melanoides* from Al Qarn Formation indicates that it is not the same species of the genus that is common in Jordan nowadays. *Valvata cristata* and *Valvata saulcyi* may still live in the region around the Jordan Valley but have not been encounterd by us as living here now.

Galba and *Gyraulus* from Al Qarn Formation closely resemble those living now. The bivalves *Unio* as well as *Pisidium* lived in the Al Qarn waters, and may be the same species as occur in case of *Unio* in the canal near the outcrop and in case of *Pisidium* in clean water of ponds in Jordan.

Also the large crustacean Potamon has been present in the oldest fresh water deposits known from Jordan- in the Al Qarn Formation as they are now along rivers and creeks in Jordan, representing animals which also fed on Melanopsis. Potamon claws collected from Al Qarn Formation an amazing stability of shallow freshwater environment from the ancient Jordan Valley to the modern one and its presence gives evidence for similar conditions of predating behavior and water salinity throughout the last few hundred thousand years in this area. The phosphatic-calcitic carapace of ostracods can also be valuable indicators for both past and present environments.

The species *Cyprideis torosa* for example occurred in the shell debris of Halat Ammar formation and nowadays occurs in great abundance in brackish water ponds such as that sampled that is formed by a creek of a brackish spring near Karama dam reservoir in the Jordan Valley. Other ostracods from that Halat Ammar Lake can belong to a species of *Candona* which has a wider tolerance and occur commonly in water with low and high salinity.

The tiny silicious tests of diatoms can also provide information about the quality of the water in which their producers grew. They live and lived in fresh and salty water with preference to one or the other by a certain number of species, and when preserved, as is the case some deposits of the ancient Lisan Lake they can be used as bioindicator for the reconstruction of the paleoenvironments and the periodic seasonal changes in the lake during a year and the history of the lake during the time of its existence. Different species of diatoms may also help in the interpretation of water quality in other types of water than those of the ancient salty Lisan Lake, as is documented by some samples from Jordanian creeks with differences in their salinity.

Macro fossils of aquatic animals allow the interpretation of their living environment but they are not useful for age dating due to changes in mineralogy composition of the shells during the diagness or transformation process by replacement or recrystallizetion of the original composition, as is documented her in case of the fossil corals found in the ancient raised reefs near Aqaba and fossil bivalves that lived in the lake that produced the Halat Ammar Formation. In Jordan the fossilized invertebrate fauna from the beds formed within the last 1 Million years belongs to the same or very similar species as are still living in the area and they cannot be used as index fossils for specific time. In the case of Aqaba raised coral reefs, the fossil fauna and beach deposits can also be used as indicators of tectonic movements that affected the Gulf of Aqaba during the last few tens of thoushand of years.

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10 APPENDICES

Table 6.1: Chemical and physical analyses of surface water samples from selected area.

Sample	Location	EC (µS/cm)	Temp (°C)	pH	COD (mg/L)	BOD (mg/L)
1	W. Hisban 1(main spring)	805	18.5	6.92	16.79	15
2	W. Hisban 3(Romany spring)	743	19.2	7.04	1.39	0
3	W. Hisban 4 (souneh spring)	630	91.9	7.54	1.04	0
4	W. Al Mujib Lake (Site 1)	925	17.3	7.71	35.2	5
5	W. Al Mujib creek (Site 2)	950	17.3	7.73	27.65	15
6	W. Al Mujib downstream (Site 3)	1395	17.3	7.9	15.9	0
7	W. Shita 1(main spring)	630	17.3	7.49	8.3	0
8	W. Shita 2(channal)	685	18.2	8.03	44.07	35
9	W. Shita 3(Bahath)	567	19.1	8.51	10.05	5.01
10	W. Shita 4 (bahriya)	1120	18.6	8.01	72.05	37.24
11	W. Shueib 1(Site 1: Jadoor up)	835	18.5	7.63	21.05	20
12	W. Shueib 2 (Site 2: creek)	685	18.6	7.47	25.96	5
13	W. Shueib 3(after Salt WWTP)	775	18	8.45	60	35
14	W. Shueib 4(Site 4: next to dam)	680	17.3	8.43	30.56	20
15	W. Atun upstream	2040	18	6.72	5	34.86
16	W. Atun downstream	1896	17.48	6.59	4.1	27.8
17	Abu Thabelh spring	1920	36.6	6.9	15.8	0
18	Abu Ziegan stream	2380	21	8.4	45.83	21.63
19	Karama 1(stream)	15630	21.9	8.03	41.2	36
20	Karama 2(Small pond)	16120	21.8	8.02	27.8	15
21	Karama 3(large lake)	20500	22.2	8.15	20.65	10
22	Karama 4(dam)	26100	22.3	8.15	35.7	25

23	Zarqa River 1(Jaresh bridge)	2300	17.3	7.86	72	9
24	Zarqa River 2(Nimra)	2000	18.2	7.3	10.04	0
25	Zarqa River 3(mixing)	2200	18.9	7.52	60.09	25
26	Zarqa River old Romany spring	2910	18.3	8.36	5	0
27	Zarqa, near Jaresh bridge	2350	17.3	7.86	72	9
28	Zara spring	1702	50.31	6.01	4.79	0.019

Table 6.2: Chemical measurements of surface water of study area (for locations refer to Table 6.1)

Sample	Ca^{2+} meq/l	Mg^{2+} meq/l	Na^{+} meq/l	K^{+} meq/l	HCO_3^{-} meq/l	Cl^{-} meq/l	SO_4^{2-} meq/l	NO_3^{-} meq/l	PO_4^{3-} mg/l
1	4.527	1.751	1.188	0.0991	4.09	1.321	1.061	0.711	0.215
2	4.315	2.12	1.01	0.092	4.71	0.891	0.722	0.677	0.182
3	3.246	2.045	0.932	0.0741	4.57	0.81	0.489	0.561	0.091
4	3.73	2.351	2.963	0.247	1.57	2.856	4.387	0.15	0.313
5	3.81	2.69	3.244	0.2	1.57	3.102	4.61	0.1	0.123
6	5.182	3.83	4.789	0.19	1.57	4.766	7.259	0.116	0.0132
7	4.432	1.059	0.899	0.044	3.98	0.819	0.649	0.78	0.036
8	3.637	1.206	0.991	0.248	3.95	1.001	0.857	0.584	0.103
9	3.7	1.54	0.62	0.031	3.87	0.17	0.953	0.51	0.107
10	3.7	4.8	3.1	0.115	5.41	3.5	2.03	0.515	0.049
11	4.627	1.655	2.13	0.366	4.01	1.189	1.202	1.397	1.025
12	3.95	1.53	0.55	0.1	4.9	0.77	0.32	0.31	0.057
13	3.987	1.479	1.979	0.197	2.59	1.2	1.456	0.775	1.005
14	3.337	1.747	1.532	0.199	2.49	1.001	1.75	0.662	0.085
15	5.92	2.918	10.633	0.689	3.8	7.45	8.451	0.83	0.165
16	5.26	2.75	10.31	0.654	3.4	6.59	8.343	0.693	0.03
17	7.2	4.7	8.719	0.46	7.13	9.34	3.31	0.0789	0.208
18	5.97	6.42	10.31	0.855	2.98	12.01	5.62	1.3	0.26
29	37.399	56.36	60.651	5.118	4.69	58.32	87.65	5.015	0.115
20	40.01	58.2	63.11	5.511	5.91	58.45	89.05	5.876	0.165
21	41.927	67.939	96.356	6.232	3.1	83.8	111.07	6.483	0.187
22	54.879	86.071	120.62	8.338	3.15	110	153.9	0.0032	0.189
23	6.18	5.69	11.057	0.841	8.3	11.98	1.55	1.412	0.354
24	5.8	5.8	7.4	0.1	4.86	11.86	1.53	1.042	0.3

25	6.08	5.72	10.07	0.974	6.53	11.9	1.541	1.238	0.333
26	10.22	9.3	9.1	1.16	4.8	14	10.81	0.19	0.171
27	6.18	5.69	11.057	0.841	8.3	11.98	1.55	1.512	0.333
28	5.03	1.55	8.79	0.31	3.26	10.19	2.1	0.02	0.049

Table .3: Chemical analysis of trace elements from study area for locations refer to Table 6.1)

Sample	Fe^{2+} ppm	Pb^{2+} ppm	Zn^{2+} ppm	Mo^{2+} ppm	Cu^{+} ppm	Mn^{2+} ppm	Sr^{2+} ppm	Ba^{2+} ppm	Br^{-} mg/l	F^{-} mg/l
1	0.021	<0.01	<0.01	<0.01	<0.01	<0.01	0.35	<0.01	0.286	0.519
2	0.022	<0.01	<0.01	<0.01	<0.01	0.11	2.1	<0.01	0.128	0.409
3	0.022	<0.01	<0.01	<0.01	<0.01	0.12	2.19	<0.01	0.659	0.162
4	0.021	<0.01	<0.01	<0.01	<0.01	0.044	11.36	<0.01	1.506	0.691
5	0.024	<0.01	0.02	<0.01	<0.01	0.025	37.42	<0.01	0.264	0.24
6	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	1.99	<0.01	0.355	0.635
7	0.016	<0.01	<0.01	<0.01	<0.01	<0.01	0.43	<0.01	0.275	0.703
8	0.018	<0.01	<0.01	<0.01	<0.01	<0.01	0.45	<0.01	0.289	0.842
9	0.021	<0.01	<0.01	<0.01	<0.01	<0.01	1.219	<0.01	0.365	0.882
10	0.022	<0.01	<0.01	<0.01	<0.01	<0.01	1.231	<0.01	0.39	0.867
11	0.021	<0.01	<0.01	<0.01	<0.01	0.109	0.503	<0.01	0.293	0.24
12	0.017	<0.01	0.03	<0.01	<0.01	<0.01	0.59	<0.01	0.205	0.244
13	0.022	<0.01	0.043	<0.01	<0.01	<0.01	1.085	<0.01	0.448	0.19
14	0.041	<0.01	0.05	<0.01	<0.01	<0.01	1.041	<0.01	0.373	0.373
15	0.024	<0.01	0.02	<0.01	<0.01	0.025	37.42	<0.01	10.4	0.893
16	0.023	<0.01	0.02	<0.01	<0.01	0.025	37.39	<0.01	10.41	0.892
17	0.019	<0.01	0.02	<0.01	<0.01	0.029	6.283	<0.01	1.947	0.035
18	0.021	<0.01	<0.01	<0.01	<0.01	<0.01	2.918	<0.01	0.8	0.543
19	0.017	<0.01	<0.01	<0.01	<0.01	0.1	32.82	<0.01	6.421	0.975
20	0.016	<0.01	<0.01	<0.01	<0.01	0.101	31.62	<0.01	6.795	1.254
21	0.015	<0.01	<0.01	<0.01	<0.01	0.102	6.36	<0.01	0.864	0.417
22	0.021	<0.01	<0.01	<0.01	<0.01	0.108	50.21	<0.01	15.72	0.967
23	0.014	<0.01	<0.01	<0.01	<0.01	<0.01	3.014	<0.01	0.606	0.44

24	0.014	<0.01	<0.01	<0.01	<0.01	0.05	4.49	<0.01	1.038	0.352
25	0.017	<0.01	<0.01	<0.01	<0.01	0.112	1.567	<0.01	0.634	0.421
26	0.016	<0.01	<0.01	<0.01	<0.01	<0.01	11.61	<0.01	0.71	0.408
27	0.01	<0.01	<0.01	<0.01	<0.01	0.152	2.85	<0.01	0.629	0.451
28	<0.01	<0.01	<0.01	<0.01	0.192	5.36	<0.01	0.699	0.509	0.409