JJEES
Jordan Journal of Earth and Environmental Sciences

Volume 9, (Number 2), August, 2018
ISSN 1995-6681
Pages 89 - 101

A Comparative Study of Ringiculidae and Acteonidae (Architectibranchia, Gastropoda) from the Campanian Amman Silicified Limestone Formation and some Similar Species from the Fringing Reefs of the Gulf of Aqaba in Jordan

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Received 6 February, 2018; Accepted 27 May, 2018

Abstract

Two gastropod genera of Heterostropha and Architectibranchis were recorded from the Campanian Amman Silicified Limestone Formation. Representatives of these two gastropod genera are still living until now in the reef environment of the Gulf of Aqaba, and can be found near the Marine Biological Station of Jordan. An analytical comparison between the Campanian gastropods and the recent gastropods is attempted in the present study. The fossil shells have been transformed into silica and during this process of transformation from aragonite biocrystals of the crossed-lamellar structural type, they have retained the morphology of their micro-structure of crossed lamellae. The embryonic and larval shell of *Acteon* from the Cretaceous have the same size and morphology as that of the acteonid *Pupa* from Aqaba, and both also resemble each other regarding the adult shell morphology and ornament. The two genera of *Ringicula* recognized from Aqaba differ from each other predominantly regarding their size; one being larger than the other. They closely resemble the fossil *Ringicula* with some distinct characters of the inner lip of their aperture.

Keywords: Ringiculidae, Acteonidae, Cretaceous, Amman Silicified Limestone Formation, Marine Gastropods.

1. Introduction

An amazing continuity exists in regard to some species of gastropods which lived in the sea of the shallow Tethys Ocean that covered northern Jordan during the Campanian and those which now live in the Gulf of Aqaba in Jordan. For example, the species belonging to the families Ringiculidae and Acteonidae live in the sea at Aqaba and have been recovered from the Campanian rocks at Amman and Irbid. The Amman Silicified Limestone Formation of Jordan contains fossil-rich Upper Cretaceous deposits that have been studied for example in the general description of the oyster fauna of Amman Silicifed Limestone Formation as provided by Aqrabawi (1993). These form thick coquina beds covering most of Jordan, and reflecting local highs and sea-level lowstands. Fossilized microorganism assembleges and macrofauna including bivalve, gastropod, ammonite, and fish teeth fragments have been documented and studied (Farouk et al., 2016; Powell,1989)

In this article, the morphology, and environments of the studied species of the genera of Ringiculidae and Acteonidae (gastropods) from Amman Silicified Limestone Formation are described and compared with some similar species from the fringing reefs of the Gulf of Aqaba in Jordan.

2. Sample Collection and Treatment

The material described in this study were collected from Wadi Kafr, southeast of Kafr Yuba village (29°51’0” N, 35°30’0” E) in Irbid, about 63 Km northeast of Amman City (Fig.1a). The silicified fossils were found embedded in marls with a composition of calcium carbonate. They were carefully treated with a solution of hydrochloric acid to dissolve the carbonated matrix, and the rocks were then rinsed in water on a screen with a 0.5mm mesh. After a major cleaning, the dried fossils were studied under a binocular microscope, and were documented using the Scanning Electronic Microscope of the University of Jordan. The gastropods in the current study were described based on previous studies, and on new investigations. Regarding the recent gastropods, the samples were collected from the area next to the Marine Science Station along the marine reserve area (E34°58.210; N29°27.293) using a net with a 150 µm mesh width. The samples were collected in a plastic bucket, and were transferred to the laboratory. The gastropod specimens were deposited in the University of Jordan at the Department of Geology under collection numbers AM2033-2050.

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3. Geological Setting

During the upper Cretaceous time, the type of sedimentation within the Jordanian shelf sea of the Tethys Ocean switched from predominently benthic to predominantly pelagic source of material (Bandel and Salameh, 2013).Within the deposition of the sediments of the Belqa Group (Quennell and Burdon, 1959), that switch occurred at the base of the formations with the names Umm Ghudran = Ain Ghazal, (Amman, Al Hisa Phosphorit = Ruseifa, and the Muwaqqar throughout Jordan). The predominant type of rocks found in the Belqa Group consists of chalky limestones. Only close to the shore environments of the Tethys Ocean in the SE of Jordan, dolomites and sandstone are intercalted indicating the intermediate closeness of the shore of Gondwana Continent (Schandelmeier et al. 1997; Bandel and Kuss 1987; Bandel et al. 1987). Bandel and Mikbel (1985) confirmed the data of Bender (1968) according to whom, Amman Silicified Limestone Formation occured on a large scale in Jordan with its typical lithology (Fig. 1b). Only in the southeast of the country, it wedges out and is replaced by continental varicolored sandstone with plant fossil (Bender, 1974; Bender and Mädler 1969; Berndt, 2002). During its deposition mainly at Campanian times, the shore was laid in the far south of Jordan and on the other side of the Gulf of Suez (Bandel et al., 1987; Klitzsch, 1986). The sea had covered much of the northern Gondwana continent during the Coniacian, (withdrew during Santonian to flood and withdrew during the Campanian and flood far at Maastrichtian), but at the low stages of the sea level, continental sand reached the area from Gondwana, and a terrestrial flora was able to grow leaving traces in SE Jordan.

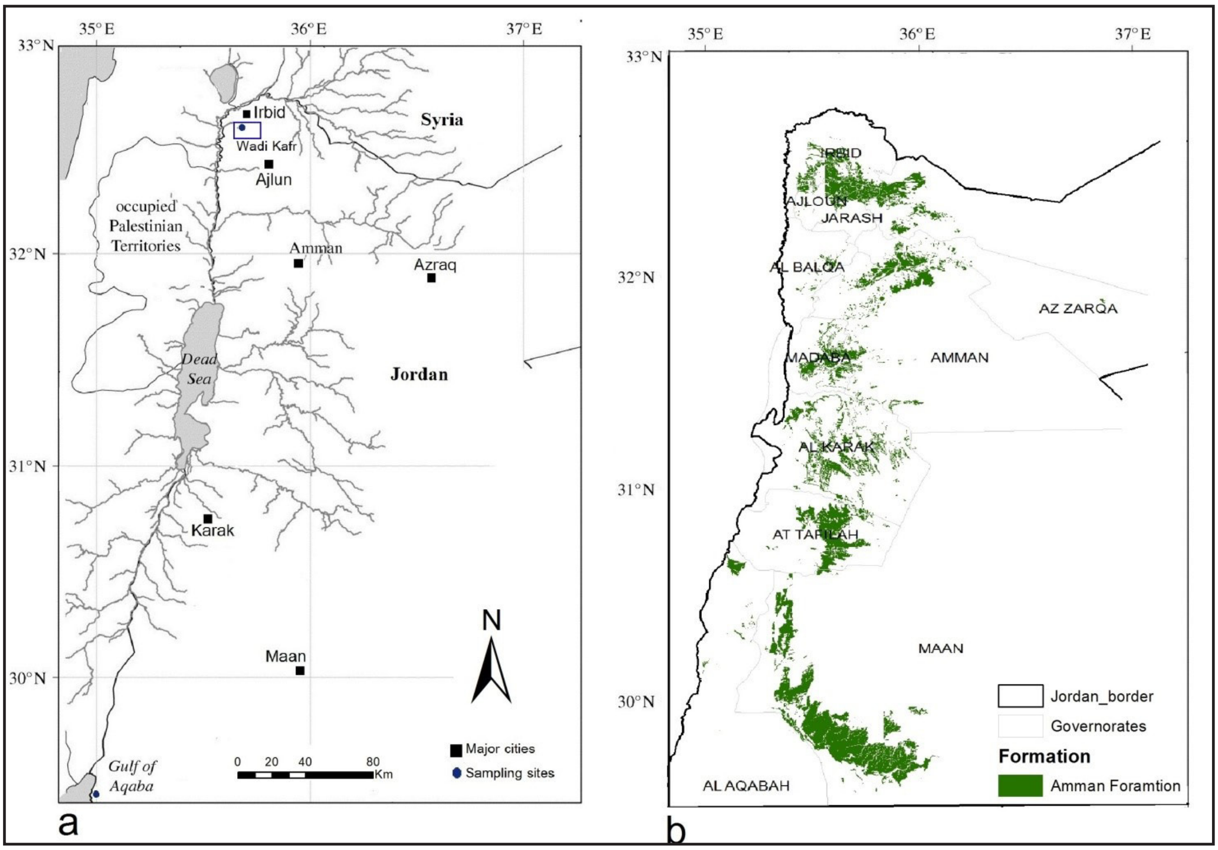

Figure 1. a. Map of sampling locations, **b**. Map showing distribution of Amman Silicified Limestone Formation deposits in Jordan.

During the upper Conician to upper Eocene Belqa Group, the deposition is dominated by the skeletal parts of pelagic organisms (predominantly coccoliths) (Bender, 1968). These deposits are widely distributed, and cover much of the Jordanian plateau extending from the Yarmouk River in the north to Ras En Naqab-Batn El Ghul escarpment in the south (Powell, 1989).

The Amman Silicified Limestone Formation disconformably overlies the Coniacian-Santonain Wadi Umm Ghudran Formation. The type section of Umm Ghudran is found in Wadi Umm Ghudran, which lies twelve km WSW of Irbid. The type for the Ain Ghazal Formation lies just to the southeast of central Amman within the city proper. The base of Umm Ghudran- Ain Ghazal Formations in both cases is well-defined by the last hard massive limestone bed of Wadi Sir Formation formed predominantly by skeletal products of benthic organisms. The top of the formation is recognized with the appearance of a thick chert bed of the base of the Amman Silicified Limestone Formation near Irbid and in the case of the sections within Amman also by a more or less silicified bed with an oyster coquina.

The Umm-Ghudran Formation was considerd to be Santonian in age (Bender, 1968; Parker, 1970; Quennell and Burdon, 1959; Wetzel and Morton, 1959) with the base inpart being Coniacian in age (Bandel and Geys, 1993). The Amman Silicified Limestone Formation has been determined to be Campanian in age based on occurrences of *Baculites cf. ovatu* fossils and micro planktonic assemblages (Haggart, 2000; Farouk et al., 2016; Wetzel and Morton's, 1959).

It is of variable thickness in different locations of Jordan.

Table 1. lithostratigraphic units of upper Cretaceous in Jordan (Masri, 1963; Farouk et al., 2016; Powell, 1989).

<table>
<tr><th colspan="2">Age</th><th>Group</th><th>Formation
Masri 1963</th><th>Formation
Powell 1989</th><th>Formation
Farouk et al. 2016</th><th>Lithology</th></tr>
<tr><td rowspan="2">Paleogene</td><td>Eocene</td><td rowspan="5">Belqa</td><td rowspan="3">Muwaqqar</td><td rowspan="2">Umm Rijam</td><td rowspan="3">Muwaqqar</td><td>Chert</td></tr>
<tr><td>Paleocene</td><td>Chalk</td></tr>
<tr><td rowspan="5">Upper Cretaceous</td><td>Maastrichtian</td><td>Muwaqqar</td><td>Phosphorite and oysters</td></tr>
<tr><td>Companian</td><td rowspan="2">Amman</td><td>Al Hisa Phosphorite
Amman Silicifed Limestone</td><td>Al Hisa Phosphorite
Amman Silicifed Limestone</td><td>Chert</td></tr>
<tr><td>Santonian</td><td>Ghudran</td><td>Umm Ghudran: Dhiban Chalk Member; Tafilah Member; Mujib Chalk Member / Alia Sandstone</td><td>Chalk</td></tr>
<tr><td>Coniacian</td><td rowspan="2">Ajlun</td><td>Ghudran</td><td rowspan="2">Wadi Sir Limestone | Sandy Phosphorite</td><td rowspan="2">Wadi Sir Limestone</td><td rowspan="2">Limestone</td></tr>
<tr><td>Turonian</td><td>Wadi Sir</td></tr>
</table>

It may have been totally eroded or is thicker than 100 m. In the area of Wadi Mujib, The Amman Silicified Limestone Formation is approximately 135 m thick (Bender, 1968; Powell, 1988; Powell and Mo'hd, 2011). The transition to Ruseifa Formation with beds of phosphate sand is here- not well-developed, while such deposits in the NNW of Jordan measure about 10 m, and about 25 m at Amman-Ruseifa, and even 40 m at Al Hisa (Beerbaum, 1977). In Wadi Mujib, the sediment formed continued from the base of Amman Silicified Limestone Formation to beyond the end of Ruseifa formation without any notable interruption. In the north and the south of the Mujib area, structural unrest resulted in the elevation of the sea floor to a level where it became eroded, and the sands winnowed from mud forming the phosphate deposits.

The studied outcrops exposed at Wadi Kaf*r* consist of alternating thick massive chert beds and limestone with silicified fossils (Figs. 2a-b). Well-preserved fossils with a thin limestone layer at the boundary to the chert bed are found and collected for the present study (Figs. 2c). Limestone beds with about 3m thickness consisting of fossil fragments were also noticed in the study area (Fig. 2d). The beds of chert are rich in silicified mollusk shells comprising cephalopods, gastropods and bivalves including species close to Nucula, Nuculana, *Barbatia*; others are present as well (Fig. 2e).

The calcareous composition of some specimens has been transformed into silica. The silicification during early diagenesis preserved the delicate shells of a fauna of which most animals had originally lived in, and on the muddy, aragonite-rich, predominantly calcareous sediment. Also, the remains of organisms which had lived in the water column, such as planktonic forminifera and ammonites formed part of the shell coquina. The silicified shells are connected in their origin to the formation of flint nodules and chert layers (Bandel et al., 2000). Chert formed due to the solution and redeposition of siliceous skeletal elements (sponge spicules, diatom and radiolarian sceletons) in the sediment (Bandel and Mikbel, 1985).

4. Overview of the Ringiculidae and Acteonidae Gastropods

Class Gastropoda holds the subclass Heterostropha with Acteon and Ringicula. Within the class, the Heterostropha (Fischer, 1885) (= Heterobranchia Gray, 1840) includes among others the orders Allogastropoda (Haszprunar, 1985) and Opisthobranchia (Milne Edwards, 1848). The members of the families Acteonidae (d'Orbigny, 1843), and Ringiculidae (Philippi, 1853) nowadays represent an exception among the Opisthobranchia since they have a solid well calcified shell (Wenz and Zilch, 1960). Most representatives of this larger group of Gastropoda have reduced their shells and many have even no shell when fully grown, because their earliest shells were lost during the early stages of life. The aperture of the shell of individuals belonging to Acteonidae and Ringiculidae is elongated and narrow, and in some species can be closed with an operculum; however, others do not have a lid. The thick shell is oviform with a short conical apex, and is usually ornamented with spiral groves or rows of pits. The elongated aperture is usually narrow with a posterior notch and enlarged base. The inner lip often has plaits.

Gastropods Ringiculidae and Acteonidae have quite a characteristic shell shape. Here the embryonic and larval shells are coiled to the left while the adult shell is dextrally coiled. The change in the coiling direction occurs within the larval shell where the orientation from the left is lost within the shell that has grown during the larval stage. The transition to the right of the shell of the adult occurs at the phase of the change from a free swimming larva to the benthic crawling young (protoconch to teleoconch transition). The protoconch is composed of one whorl of the embryonic shell with sinistral coiling mode and the shell grown by the larva. During the final growth of the larval shell, the change from the left coiling mode into the dextral coiling mode occurs (Bandel, 1982).

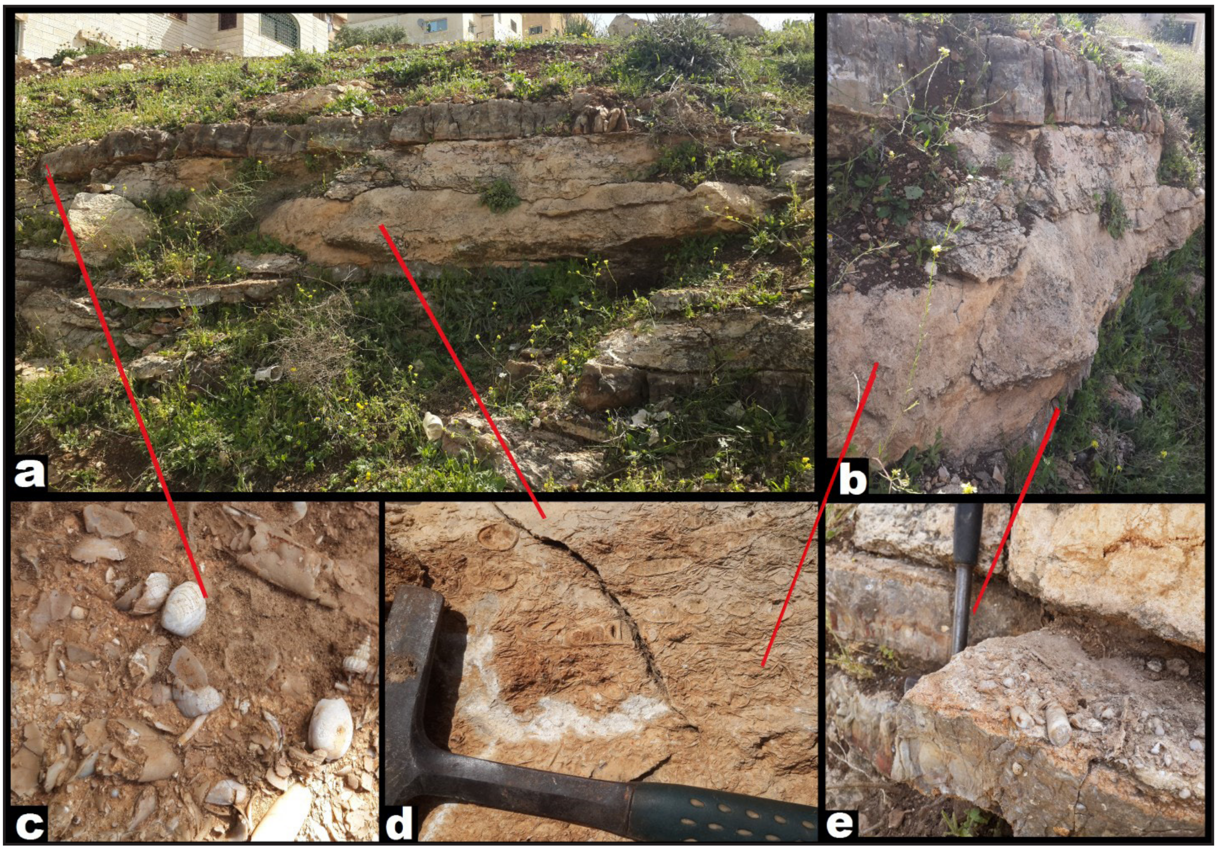

Figure 2. a. Field photograph showing the studied Amman Silicified Limestone Formation exposed at Wadi Kafr, Irbid; **b**. Filed photograph showing an alteration of chert and limestone beds; **c**. Close up of well preserved mollusk fossils such as bivalves, gastropods, and cephalopods from limestone layer at the boundary to the chert bed; **d**. Limestone with reworked mollusca fossils fragments, including turritella and baculites; **e**. Chert beds rich in silicifed fossils from the Amman Silicified Limestone Formation.

The embryonic shell grows during the development of the embryo within the egg, and the larval shell is secreted after hatching from the egg and during life as a free swimming larva. Before hatching, the shell and the soft body detach from each other, and both are connected to each other only by the muscle that is used to pull the soft body into the shell (retractor muscle) (Bandel, 1982; Bandel, 2017).

The change from the embryonic stage to the larval phase of life is also connected to a change in the source of food. The appearance of a first mineral shell here is composed throughout life by aragonite calcium carbonate. The embryo is nursed by the yolk that is contained within the egg, and the larva feeds on algal plankton. To be able to do so, a velum has grown on the embryo still within the egg (Bandel, 1982). The velum consists of two rows of cilia which propels the hatched larva through water and which collects algal cells that come into contact with them and transport them to the mouth. The animal growth now depends on the ingestion and digestion of external food. When the gastropod has concluded its larval life, it changes from a free swimming existence to life on the bottom of the sea (metamorphosis). Growth of the benthic snail is characterized by a shell of the animal after the metamorphosis from the larva (teleoconch) that has a dextral coiling mode (Bandel, 1982; Bandel, 2017).

The protoconch either rests on the teleoconch with angle or is included in its top with an opposite orientation to its columella (axis of coiling). The position of the protoconch depends on the exposure of the apex and the inclination of the shell spindle (columella) (*Acteon*, *Ringicula*) (Bandel 1979). As soon as benthic life is taken up, the mode of locomotion changes and also the mode of feeding. Plankton microorganisms as food are exchanged with feeding on benthic animals. Swimming by the beat of the cilia is changed to crawling with a foot on and in the bottom substrate. Food, thus is no longer collected by cilia, but hunted with the foot and by the mouth parts, and is eaten with the help of teeth present in the anterior part of the digestive tube (oesophagus). Teeth are attached to an elastic ribbon, the radula, which is moved in and out of the mouth and the anterior digestive tube. The teeth take hold of prey, and when the radula is pulled back into the mouth, it transports prey or parts of it into the gut (digestive system) (Bandel, 1990).

The mineral shell of *Ringicula* and *Acteon,* similar to that of most gastropods is composed of calcareous material, and here the modification of aragonite is organized in the bio-crystalline mode of crossed lamellae (Bandel,1979; Bandel, 1990). Gastropod shells are predominantly composed of a carbonate shell of the calcium carbonate in the crystalline modification of aragonite. The juvenile shells being delicate and thin are rarely well-preserved in the fossil record, but these differ from the gastropods found in Amman Silicified Limestone Formation (Bandel et al., 2000).

5. Fossil Record

Species with *Acteon*-like forms have been existent since the Triassic, and those with *Ringicula*-like shell shape have been known since the Jurassic (Bandel, 2017). Earliest species belonging to the subclass Heterostropha are documented from

Early Devonian (Fryda, 2001). Within the Heterostropha, all those species that change from sinistral to dextral coiling during their ontogeny, or those which have evolved from ancestors that had this development are included. Heterostropha hold the orders Allogastropoda and Euthyneura, the later with the suborders Opisthobranchia and Pulmonata.

Species with shell shape very close to that of modern *Acteon* and to *Ringicula* occur as early as Jurassic (Schröder, 1995; Bandel, 2017) and can be seen related to the Triassic Cylindrobullinidae that may represent the stem group to Acteonidae and Ringiculidae alike (Bandel, 1994). Many of the modern groups of the Opisthobranchia have reduced their shell, and when adult, they become naked. Some of them have only a shell during their embryonic stage, and may leave their shell when changing from larval life to the adult stage.

Hyman (1967) included within the Cephalspidea s.l. (=Tectibranchia) all opisthobranchs with a coiled external shell as is present in the members of the families Acteonidae, Ringiculidae, and several more including **also** the Bullidae, Atyidae, Retusidae, and Cylindrobullidae. The paleontological record allows to trace the general way to the different marine euthyneuran groups by comparing Triassic, Jurassic and Cretaceous species. Within the modern opisthobranch families Acteonidae and Ringiculidae species of the genus *Acteonina* or *Cylindrobullina* from the Triassic and Jurassic are very similar (Bandel, 1994; Bandel, 1996; Bandel, 2017).

One could place *Acteon* (Montfort, 1810) in the suborder Architectibranchia (Haszprunar, 1985), superfamily Acteonoidea (Orbigny, 1842), and could also include in this family *Pupa* (Röding, 1798) with *Pupa solidula* (Linnaeus, 1758).

Ringiculidae can be derived from the gastropods with a shell as found among the fossil Cylindrobullinidae of the Triassic (Bandel, 1984) parallel to the Acteonidae. The stem group to both Acteonoidea and Ringiculioidea alike can be suspected among the Cylindrobullinoidea or relatives of the Zardinellidae (Bandel,1984), both described from the Triassic St. Cassian fauna.

Burn and Thompson (1998) collected the data regarding modern representatives of the Ringiculoidea, and came to the conclusion that even though there are many species in the group, which live in shallow water to the great depth in all seas, very little is known about their anatomy and ecology. Even though young individuals are difficult to distinguish from young Acteonidae, the fully grown ones are quite distinctive from each other. The shape of the radula is quite different in both groups. While in the acteonids, there is a ribbon consisting of many subequal teeth which meet in the middle of the ribbon either having a central tooth between them or meeting without one as such,. In ringiculids, there are only a pair of lateral teeth in the row either with or without a central tooth between them (Bouchet, 1975). Regarding food requirements, it seems that ringiculids usually feed on Foraminifera (Fretter, 1960) or small endobenthic animals.

6. Taxonomic description

Class Gastropoda Cuvier, 1795
Superfamily Acteonoidea d'Orbigny, 1843
Family Acteonidae d'Orbigny, 1843
Genus Acteon Montfort, 1810

The family Acteonidae belongs to the superfamily Acteonoidea, which has recent representatives. Other families such as: Acteonellidae, Tubiferidae, Zardinellidae, are found only as fossils (Gofas, 2015).

Acteonoidea with the given genus name *Acteon* can be traced starting from the Middle Jurassic (Cossmann, 1895; Schröder, 1995; Gründel, 1997; Bandel, 2017) continually to the modern species. The group surrounding *Acteon* and *Bullina* appeared before the Cretaceous; Acteonoidea differ from Cylindobullinoidea in having a spiral ornament. They differ from Actaeonelloidea which also occured commonly in the Cretaceous of Jordan (Mustafa and Bandel 1992) by the same features, but may have folds on their inner lip like these. Ringiculoidea have a thickened margin of their aperture. The Bullinidae differ from the Cylindrobullinidae in the submerged protoconch and the spiral furrows as ornament on the teleoconch. Bullinidae differ from Acteonidae by the absence of folds on their inner lip. The oldest representatives of the Actaeonoidea were included in the family Sulcoactaeonidae (Gründel, 1997) which resemble Bullinidae that are still living in all the essential features especially their shell as described by Rudman (1972).

Most representatives of the Cephalaspidea have a functional shell with nearly cylindrical (subcylindrical) shape, and either an erect or a submerged spire, and are then considered to represent tectibranchiate opisthobranchs. The aperture of the shell is commonly narrow and high, and the inner lip of the aperture (columellar edge of the inner lip). may have folds. Water leaving the pallial cavity usually runs via a slit or sinus of the aperture that is next or near to the suture of the shell. In addition to the growth lines, the shell surface commonly has an ornament of fine spiral furrows and/ or rows of pits.

The shovel-shaped head has posterior extensions (cephalic shield) which cover the anterior shell and mantle opening in many Architectibranchia as was also observed in case of the individuals of *Pupa* from Aqaba. It is also known in *Akera* of the Anaspidea and *Cylindrobulla* of the Sacoglossa. Actaeonidae and Ringiculidae retain the streptoneurous nerve system, while in the other Cephalaspidea, it becomes simplified with the ganglia being concentrated in the head region (Mikkelsen, 1996; Ruthensteiner, 1997).

The Genus Named Acteon (Montfort, 1810)

The shell shape is ovate with a low to moderately elevated spire. The protoconch is heterostrophic, and often partly buried within the teleoconch. About four whorls of the teleoconch are present with the last whorl being very capacious. The sculpture consists of narrow spiral grooves and spiral rows of pits, typically with fine axial costae within the **grooves**. The aperture is large with the anterior end rounded and posterior end constricted. The columella is thick, subvertical, and has a single plait at its posterior end.

Genotype: Voluta tornatilis (Gmelin, 1788) from the North Sea (Thompson, 1988).

The shell of *Acteon* is rather characteristic having a large final whorl, smooth protoconch, an ornament of spiral furrows and one columellar fold. The columellar lip has only one fold compared to that of *Pupa* which has two folds, or that of *Triploca* which has three folds, or *Bullina* where there is no fold at all.

Remarks: Representatives of *Acteon* keep their operculum after metamorphosis. *Acteontornatilis* hatches from its egg mass with an embryonic shell measuring 0,12 mm and grows in the Plankton to a size of 0.32 to 0.35 mm (Thorson, 1946). Eggs are usually enclosed individually in a transparetn capsule. Each egg capsule is attached to the previous one and the next one by a thread (chalaza) of the capsule material. A string of capsules is usually twisted in a spiral coil within a jelly-like mucoid egg mass (Hurst, 1967; Bandel, 1976). Eggs are between 0,05 and 0,4 mm in size. Eggs below 0,17 mm in size usually develop into a planktotrophic veliger, and these of a larger size usually hatch from the egg mass as benthic crawlers.

Acteon hunts worms within the sandy or muddy bottom and sucks them empty. This has been observed in the case of *Pectinaria* by Hurst (1967).

Acteon tornatilis (Linne, 1758) has the oval-cylindrical shell with seven to eight whorls and a short spire measuring less than one third of the total height. Ornament can be seen through the punctate spiral furrows; the columellar portion of the inner lip has one twisted plication. The species lives carnivorously in the Atlantic and Mediterranean Sea (Thompson, 1988).

Species Actaeon cf gracilis Blankenhorn
Plate 1, figs. a-d

Material: Ten specimens from Amman Silicified Limestone Formation, Irbid, Jordan.

Measurements: 7 mm high and 5mm wide, last whorl up to 4 mm high, two folds on the inner lip, up to six whorl-ornament by the spiral lines.

Description: the shell is ovate and convoluted with elongate aperture. Late Cretaceous species from Ripley Formation Mississippi are *Acteon pistilliformis* (Sohl, 1964) with the shell being almost 5 mm high and ovate with a moderately high spire composing about 1/3 of the total shell height. The prococonch is sinistral and attached to the teleoconch with inclined axis. The teleococnh has a channeled suture and rounded whorls. The ornament of the incised spiral grooves with thin raised collabral elements crossing over is wider near the aperture than apically and there are four or five visible on the whorls of the spire. The raised interspaces are wider than the grooves. The aperture is elongate, narrowed posteriorly, and bears a strong oblique fold on the columellar lip. (Occurreence in Ripley Formation of Tennessee and Mississippi.) It resembles *Acteon cicatricosus* (Sohl, 1964) from the same locality that is a little smaller but quite simialar in shape and the ornament of spiral furrows with the interspaces being wider than the grooves. The aperture is elongate, narrowed, posteriorly and bears a strong oblique fold on the columellar lip. The outer lip is crenulated within (Sohl, 1964).

Acteo punctostriatus lives from Cape Cod to Argentina. It is 3-6 cm high, and has a rather high spire (Abbott, 1974). It is more common in shallow water. It resembles the Pacific species from Satonda, Indonesia with almost a 3 mm high ovate shell with a moderately high spire that composes less than one half of the total shell height. The protoconch forms a flattened apex consisting of one whorl in the teleoconch that has a channeled suture and rounded whorls. The ornament consists of incised spiral punctuate. The smooth interspaces of the ornament are wider than the grooves on the lower portion of the body whorl, where there are about eight to twelve spiral rows of pits with a decreasing distance from each other, and are sometimes very indistinctly developed. The aperture is elongate, narrowed in the posterior, and bears an oblique fold on the columellar lip. The outer lip is simple and thin.

Sulcoactaeon sp. from the Jurassic of Sakarahain Madagascar has a smooth protoconch that lies strongly inclined in the apex of the teleoconch forming an angle of about 90° between the axes of the coiling of the larval shell and that of the teleoconch (Plate 1, figs. e-f). Before meeting the teleoconch, the larval shell has turned from the left-handed coiling into dextral coiling. The ornament of the teleoconch consists of strong, about equally wide spiral ribs which are separated from each other by narrower grooves. The groove next to the suture and below it is wider than the following ones and forms a narrow ramp. The shell with two whorls of the teleoconch measures 1.2 mm in height and about 0.8 mm in width. About twenty broad, somewhat angular ribs separated by narrower, rounded grooves ornament the body whorl which occupies two thirds of the shell height. On the whorls of the spire, approximately ten ribs remain visible. The spiral ornament is transected by fine, axially arranged growth lines, best visible within the grooves. Here, they produce a regularly pitted appearance. The inner lip of the aperture is thickened by callus and is raised to cover a slit-like umbilicus. The inner lip is without folds, and is simple and smooth (Kiel, 2006).

The protoconch consists of almost two whorls and is approximately 0.2 mm wide and high. Its smooth whorls have left-handed coiling and a naticoid shape with a wide umbilicus. In the very last portion of the larval shell, the twist from the left into the right coil is apparent. The larval shell is well-distinguished from the teleoconch by an increment of growth as well as the first spiral sculpture of the teleoconch. The axis of coiling of the protoconch is at about a right angle with the spindle axis of the teleoconch.

Sulcoactaeon can be placed within the superfamily Acteonoidea (Orbigny, 1842) and here Acteonidae with *Acteon*-like shell shapes have as characteristic features including an ornament of spiral furrows with pitted appearance.

Remarks: Larva from the plankton at Aqaba are of a heterostrophic species such as Acteon or Pupa with a change in the coiling mode; the initial shell part up to the first growth line is usually with a little less than one whorl representing the embryonic shell and afterwards the sinistral larval shell continues (Plate 1, fig. g).

The Genus Named Pupa (Röding, 1798)

The shell is about 10 mm high consisting of about seven whorls of the teleoconch. It is solid and of oval to egg-shaped outline with short spire and is in general similar to *Acteon*. The aperture is high, with a narrow posterior and widened and rounded anterior. The outer lip is evenly convex, and the columella carries bifid plaits of which the one is continuous to the outer edge and the other is finer inside. *Acteon* has a simple and *Pupa* a bifid columellar plication. The columellar inner lip has two plications. Of the acteonid shells those of

Pupa have double columellar folds.

Genotype is *Pupa solidula* (Linnaeus, 1758) from the Pacific Ocean (Burn and Thompson 1998).

This Acteon occurs within the sea grass environment of the small fringing reef in Aqaba. In 2005 individuals were found at the end of their trail in sand just below the intertidal zone in the lagoon. The animal has an operculum that is elongate and narrow and makes use of it when the animal is withdrawn into its shell. The eggs are in a jelly- mass and are attached to hard substrates noted at the time of October. The animal is white and has a characteristic head with the foot, shovel-like anterior head lappets and lappets of similar shape behind these which cover the anterior portion of the shell when burrowing in the sand.

Living individuals were observed in the shallow sandy bay in front of the small mangrove forest on Lizard Island in the great Barrier Reef of Australia (1991) plowing through the sand and were totally covered by it during motion. The short foot bears a large chitinous operculum. When crawling through the substrate, the posterior lobes of the head-shield direct the substrate onto the shell. Undulatory motions of the margin of the shield push sand to the sides while the animal moves. There are no eyes visible on the head-shield. The exhalent siphon is formed both by an extension of the extreme right corner of the mantel floor and by a prolongation of the left edge of the mantel that covers the inner lip. This exhalent siphon directs fecal material out with the water current. The pallial cavity opens along the right side of the body. The water current entering the pallial cavity is channeled through a ciliated groove in the central line of the head-shield that continues into a cilated groove on the right shell margin.

Species Pupa solidula (Linnaeus, 1758)

Plate 1, figs. (h-j)

Material: Twelve specimens from the fringing reef in Aqaba, Jordan.

Measurements: The shell is 15 mm in length, and 7mm wide. The operculum is small and narrow; in the animals of about 1 cm long, there are seven whorls of the teleoconch.

Description: The shell is ovate and thick. The cephalic shield has two lobes and the posterior shield carries large rounded lobes that protect the neck and front part of the shell. These lobes are held on the anterior portion of the shell when the animal is moving, while the anterior lobes are utilized as burrowing structures on the animal when moving through the sand. Eyes are not seen. The animal is white and the animals collected in October 2005 produced large jelly spawns when held in a glass. The shell is characterized by spiral grooves with pits. The chitinous operculum is elongate and narrow, and serves as functional protection when the animal is withdrawn in its shell.

Differences: The Australian *Pupa nitidula* and *Pupa solidula* are characterized by bright pink or reddish quadrate spots (Burn and Thompson, 1998). Both characters are not present in the species from Aqaba. *Pupa* hunts polychaete worms which are taken hold of by their radula. In the species list from Eilat, a *Pupa* cf. solidula (Linné, 1758) is documented by Edelman-Furstenberg and Faershtein G (2010) with spiral dots.

Remarks: The animals were found in 2005 through the loose sand in the very shallow lagoon.

The Superfamily Ringiculoidea (Philippi, 1853)
Family Ringiculidae (Philippi, 1853)

Ringiculidae is a marine of heterobranch gastropods with a small group of described living species (Bouchet, 2010; Kano, 2016). Shells resemble miniature helmet shells (usually less than 10 mm long) like *Cassis* or *Phalium* and have folds (1-4) on the columellar lip. The whorls of the spire form no apical flattening or ramp, and the spire is small. The apertural margin of the fully-grown shell is strongly thickened and callus is covered in the columellar region. There may also be denticles on the inner side of the outer lip. Ornament consists of spiral incised furrows on a smooth surface or may be absent.

Remarks: The animal can retract fully into its shell, and there is no operculum (Fretter, 1960; Gosliner, 1968). In the active animal, the frontal portion of the shell is covered by the posterior margin of the cephalic shield which develops a siphonal tube at its dorso- medial part, Through it, water can be guided into the frontal mantle cavity that holds one gill. Ringiculids inhabit temperate to tropical seas from littoral zones to great depths. They live by hunting small prey.

Ringiculidae (Philippi, 1853) are represented by small sized species that live in sandy and muddy marine sediments usually on the shelf from just below intertidal areas to deeper water, hunting small animals. Their shell resembles that of a *Cassis* in shape with a strongly thickened outer lip and with folds on the inner lip, but is tiny (1-5 mm). Ornament usually consists of incised spiral grooves commonly crossed by fine axial ridges. The characteristic feature of its protoconch is its missing heterostrophy also in cases where a planktotrophic larva occurs during ontogeny. This character distinguishes them from the similar Acteon, where the heterostrophy in larval shells is always well- developed. This has been so since mid-Jurassic times.

The rounded conical shell is thickened and glossy. It is usually less than 10 mm long. The columellar lip bears one to four strong folds, and the outer lip of the adult is usually greatly thickened**.** Ornament usually consists of incised spiral lines. The spire is small and there is an anterior apertural sinus. There is no operculum in the metamorphosed animal. The protoconch distinguishes this group of the Heterobranchia (=Heterostropha) from the others by being dextral throughout with a plain embryonic whorl and smooth apertural edge.

The Genus Named Ringicula (Deshayes, 1838)

Plate 2, (figs. a-g)

Material: Seven specimens from Amman Silicified Limestone Formation, Irbid, Jordan. Measurements: Height 1.4-6.3 mm, 2.1mm thick folds of inner lip with two strong folds on the columellar part.

Description: The shells resemble miniature helmet shells like *Cassis* or *Phalium* with folds on the columellar lip. The whorls of the spira form no apical flattening or ramp. The apertural margin of the fully-grown shell is strongly-thickened and covered by callus in the columellar region. The columellar lip bears one or several folds, and there may also be denticles on the inner side of the outer lip. The small low spired globose to subglobose shell is either smooth or ornamented with incised spiral lines or furrows. The aperture is narrow with the outer lip being thick and smooth or dented within. The inner lip has a strong callus and three denticles, two strong folds on the columellar part and further up on the parietal portion a single denticle or fold. The type is *Ringicula ringens* (Lamarck, 1804) from the Eocene of the Paris Basin.

Remarks: *Ringicula* is known since the mid-Jurassic time (Gründel, 1997) and from the Early Cretaceous (Schröder, 1995), and more commonly in the late Cretaceous. It can be differentiated from other gastropods quite easily due to its characteristic shape which since Jurassic time has not changed. Today, the species that are similar in size and shape are found on soft bottom environments mostly in worm seas such as the Caribbean or the Indo-Pacific.

Ringicula buchholzi (Gründel, 1997) is the oldest representative of the genus *Ringicula* from the Callovian in Germany (Gründel, 1997, Pl. 9, figs. 8-12). The protoconch is coaxial consisting of 1,5 smooth whorls with 0,36 mm in diameter. Only the embryonic whorl is sinistrally coiled. The teleoconch consisting of four whorls is almost 4 mm high and 2,5 mm wide. The body whorl has a thickened margin of the outer lip which is thicker in the centre than at the margins, and there are two plicae on the clolumellar portion of the inner lip. Ornament consists of spiral furrows, 5 on the whorls of the spira, sixteen on the body whorl. A similar species, *Ringicula matura* (Schröder, 1995), from the Valendis of Poland differs from *R. buchholzi* by being broader, having a lower spira and on the aperture no inner thickening on the outer lip and only one plica on the columellar lip.

Ringicula from Aqaba appears to be very variable in ornament and shape of the folds on the inner lip of its aperture-so either there are several species, or it is quite a variability within one species.

Ringicula sp1

Plate 3, (figs. a-d)

Materials: twenty-five specimens from Aqaba, Jordan.

Measurements: Fully-grown individuals consisting of 3-3,5 whorls of the teleoconch and the protoconch consisting of 2,5 smooth whorls with only the embryonic one coiled to the left.

Description: The small ones are about 2.5 mm high. The subglobose shell is ornamented with narrow incised spiral furrows in a zigzag pattern and with pits or punctae separated from each other with broad, smooth interspaces. About twenty of these are on the body whorl and the interspaces are a bit narrower anteriorly. A few individuals have on the posterior part of the whorl wider zones without spiral furrows, mostly covering the whole whorl about equally. The aperture is narrow with the outer lip thick, thickened in its margin and crenulated, and often more well- developed in the anterior than in the posterior half, where it may even be smooth. The smoothness is a low central swelling on the central inner side of the outer lip a little anterior to the opposite folds and the swelling of the central inner lip. Thus, this posterior portion of the aperture is narrowed. The inner lip has a strong callus and about three similarly-wide folds. The anterior of these forms the columellar margin of the siphon and is inclined. The next posterior portion of it continues to the margin of the swelling and is oriented vertically to the shell axis. The third fold lies on the inner lip callus and ends on the central thickening formed by it. It is strong, and unites with the plate like the callus ridge forming an L-like shape with it and ending before reaching the posterior end of the outer lip. Thus, there is a furrow between the outer lip and the callus of the inner lip.

Discussion: Two species can be recognized from Aqaba, the second larger *Ringicula sp*2 (Plate 3, figs.e-h) with about 5.3 mm length and 2.9 mm width. It is very similar to *Ringicula sp*1 in shape, environment. Also both have a protoconch that reflects a lecithotrophic development with either a short period in the plankton or crawling young. In the list of species that had been documented by the Wikipedia from the sea near Eilat is the *Ringicula acuta* (Philippi, 1849) illustrated by Edelman & Faerstein, (2010) which most probably is one of the species also encountered in Aqaba (Fig.3a).

The small low globose to nearly globose shell with a low spire is either smooth or ornamented with incised spiral lines or furrows. The aperture is narrow with the outer lip being thick and smooth or dented within, and the inner lip having a strong callus and one to four folds on the columellar part, and further up on the parietal portion a single tooth or fold. This type is named *Ringicula ringens* (LAMARCK, 1804) from the Eocene of the Paris Basin. All its essential featuresresemble those of the species from Aqaba.

Ringicula semistriata (d'Orbigny, 1842) is larger than *Ringicula nitida* (VERRILL, 1873) (A. E. Verrill, 1872) which may be found in the same environment on the US shelf of the Atlantic Ocean. Also its protoconch is larger and it has no central thickening on the inner side of the outer lip. The species *Ringicula nitida (*VERRILL,1873) from the Atlantic Ocean has a small subglobose shell (about 2.5 mm high) that is ornamented with narrow incised spiral furrows with broad smooth interspaces, and consists of 3.5 whorls of the teleoconch. This ornament is quite variable and there may be quite few such furrows present. The aperture of the adult shell is narrow with the outer lip being thick, smooth and with a central inner thickening a little anterior to the opposite fold of the central inner lip. Thus, this posterior portion of the aperture is narrowed. The inner lip has a strong callus and three folds. The anterior of these forming the columellar margin of the siphon is just as strong as the next one posterior to it on the columellar lip; both have the same inclined orientation and a deep groove between each other. The third fold lies on the inner lip callus and ends on the central thickening formed by it. It is strong and unites with the plate like the callus ridge that ends before reaching the posterior end of the outer lip. Thus, there is a low furrow between the outer lip and the callus of the inner lip.

Ringicula nitida is smaller than *Ringicula semistriata* which may be found in the same environment on the Atlantic Shelf of the USA. Its protoconch is smaller but has more whorls. The central thickening on the inner side of the outer lip and the strong folds of the inner lip differ from those of *Ringicula semistriata*. A species of *Ringicula* from Satonda with up to a 2 mm-high shell consists of 4.5 whorls, and is ornamented with narrow incised spiral furrows with broad, smooth interspaces. This ornament is quite variable, and there may be six to ten such furrows present. The aperture is narrow with the outer lip being thick, and a central inner thickening a little anterior to the opposite folds of the central inner lip. These folds make the posterior portion of the aperture narrow. Two small knobs on the inner side of the outer lip are found between the central swelling and the rounded siphon. The inner lip extends in a callus and three folds. The anterior of these forms the inner margin of the siphon and has the same dimension **as** the posterior portion of it. The third fold lies on the inner lip callus and ends in the callus ridge. There is a broad furrow between the outer lip and the posterior folds on the inner lip. This *Ringicula* from the coast of the Indonesian Island of Satonda resembles *Ringicula nitida* from the Atlantic shelf of the USA, but is a little smaller. Here the central thickening on the inner side of the outer lip is accompanied by anterior denticles which are absent in *R. nitida*.

Difference: *Ringicula sp* is very similar to *Ringicula nitida* in size and shape, but has stronger and zigzaging spiral furrows and a crenulated outer lip margin.

Remarks: The two species from Aqaba live in the muddy sediment of the Gulf of Aqaba from just below the intertidal area in the lagoon of the top of the fringing reef down to depth at the base of the reef and below it.

A very similar shell is also found in the case of the genus *Triploca* that is based on the type *Triploca ligata* (Tate, 1894) from Eocene of Australia (Maxwell, 2009). Its ovate shell has the spire with a little more than half the total height. The protoconch is of about two smooth whorls; the initial whorl depressed. The last whorl is large, evenly convex with small pseudo-umbilicus. The spiral sculpture is of fine grooves with broad flat interspaces. Axial sculpture of fine growth lines is restricted to the grooves. The ovate aperture has the inner lip with three strong folds. The outer lip is thin with shallow spiral grooves within. *Triploca* has three folds on the inner lip instead of one as in *Acteon,* or two as in *Pupa* The genus was thought to represent a member of the Pyramidellidae Gray that is a family with a shell coiled in **a** heterostrophic mode (heterostrophically coiled shell) and that is convergent to, but not part of the Opisthobranchia (nnts). However it represents an independent group of the Heterobranchia. A bit more elongate shell could be placed with *Otopleura,* as is known from the tropical Pacific Ocean near the Philippines (Fig. 3b).

The Genus named Triploca (Tate, 1893)

Plate 3, (figs.i-k)

The species *Triploca sp* from Aqaba

Materials: six specimens from Aqaba, Jordan.

Measurements**: 6.5 mm high, 3.1 mm wide,** nine-whorl shell and a protoconch of about two smooth whorls with three folds on the inner lip.

Description: The shell is ovate. The operculum is thin and brownish and seals the aperture a bit behind the smooth outer and the keeled inner lip. The shell consists of about nie whorls with white protoconch and an axially-ribbed teleoconch, when the shell is fully grown. The ribs are white on a bluish white shell that may have yellowish brown dots. Between the larger axial ribs, there are fine spiral ribs. Only the first whorl of the teleoconch is white as the protoconch.

The species lives together with white “Olivella” and two species of *Nassarius*. The head has the eyes in the triangular tentacles forming sheets with two lobes which lie in the middle and extend over the wide spade-like foot. The color of the animal differs among individuals. *Triploca sp* of Aqaba may represent an *Otopleura* of the Pyramidellidae. *Triploca* is documented by Maxwell, P.A. (2009).

Remarks: The species was found alive in the sand of an intertidal pool as well as within the sea grass of the very shallow lagoon at Aqaba. The head is quite different from that of *Acteon* that is living in a similar environment and also next to *Triploca*. The shell was found in the sand of a tidal pool in the sandy intertidal region.

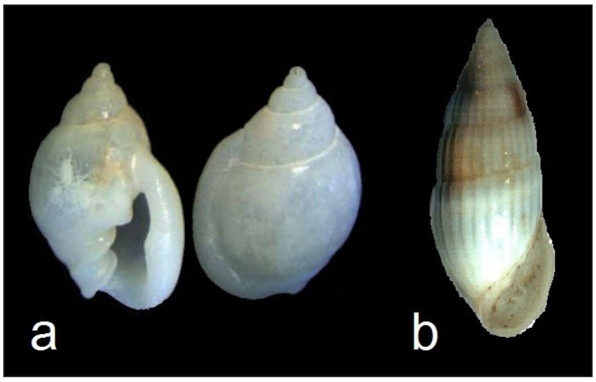

Figure 3. a. Ringicula acuta (Philippi 18490 from the Gulf of Aqaba on the eastern side (copy from Edelman-Furstenberg and Faershtein, G (2010), **b**. Otopleura nitida A. Adams 1854 from the Philippines Pyramidellidae (Gray, 1840) (Source: Wikipedia http://www.biolib.cz/en/image/id101181/?orderby=2&uid=3973)

Conclusion

The two gastropod species described from the Campanian of Jordan closely resemble species which are living near the shore at Aqaba. Even with a distance of approximately 85 Million years between their lifetimes and their existence in two different Oceans - their morphology has changed so little, that the Cretaceous species could be placed within the same genera. Recent comparisons with fossil species are possible, even though the shells of the species from Cretaceous Amman Formation have been transformed into silica. Chert formed due to the solution and redeposition of siliceous skeletal elements when beds were covered by several meters of sediment. The silicified shells are connected in their origin to the formation of flint nodules and chert layers. This change from aragonite to quartz was such that the original type of shell structure as well as the shape of the early ontogenetic shell has been preserved. In the case of *Acteon* and *Ringicula,* the crossed lamellar structure of the shell wall as well the shape of the embryonic and larval shell, and its ontogenetic change from left to right coiling mode were preserved. The amazing continuity of the species that lived in the shallow Tethys Ocean which used to cover northern Jordan during the Campanian and those which live in the Gulf of Aqaba now is quite exceptional. Most groups of gastropods have changed very much from Campanian to now. Relatives of *Acteon* and *Ringicula* have been recognized since the Mid-Jurassic. The larval shell of *Acteon* from Amman Silicified Limestone Formation has the same size and morphology as that of the acteonid *Pupa* from Aqaba, and both also resemble each other regarding the adult shell morphology and ornament. The two genera of *Ringicula* recognized from Aqaba differ from each other predominantly regarding their size; one is larger than the other. They closely resemble the fossil *Ringicula* with distinct characters of the inner lip of their aperture.

Acteon and *Ringicula* gastropods live in sandy and muddy marine sediments from just below the intertidal area to deeper water where they hunt small animals. The fauna was that of a fully-marine environment in the shallow sea with a soft bottom substrate that was in early deposits usually fully-aerated within the intertidal regime.

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Plate 1: SEM microphotographs of acteonid gastropods

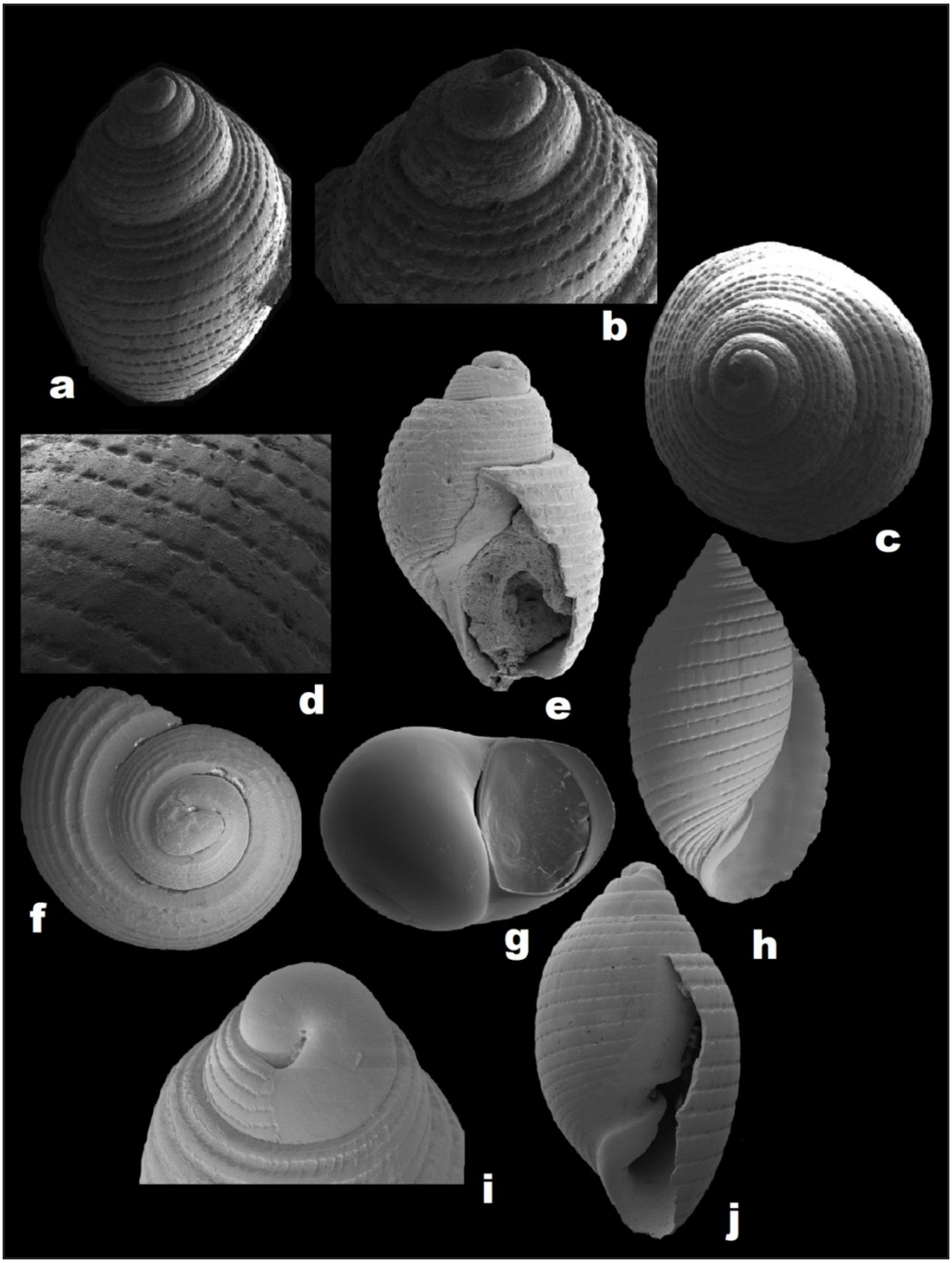

Figure a: Acteon sp from Amman Silicified Limestone Formation, Irbid, Jordan.
Figure b: Acteon with heterostrophic protoconch partly buried within the teleoconch, Amman Silicified Limestone Formation, Irbid, Jordan.
Figure c: Acteon has an ovate shape with four whorls of the teleoconch from Amman Silicified Limestone Formation, Irbid, Jordan.
Figure d: The same as in c showing sculpture of Acteon consisting of punctuated narrow spiral grooves and spiral rows of pits.
Figure e: Sulcoactaeon sp. from the Jurassic deposits, Sakaraha, Madagascar
Figure f: close- up of protoconch of Sulcoactaeon sp. from the Jurassic with a smooth protoconch of almost two whorls and is approximately 0.2 mm wide and high, Sakaraha, Madagascar
Figure g: Larval shell of heterostrophic species from the plankton at Aqaba of with change in coiling mode from right to sinistral larval shell.
Figure h: Acteon sp shell simillar to Pupa sp, Aqaba, Jordan.
Figure i: Protoconch, apical view, Pupa solida, Aqaba, Jordan.
Figure j: Pupa solida, not fully grown, Aqaba, Jordan

Plate 2: SEM microphotographs of Ringiculidae gastropods.

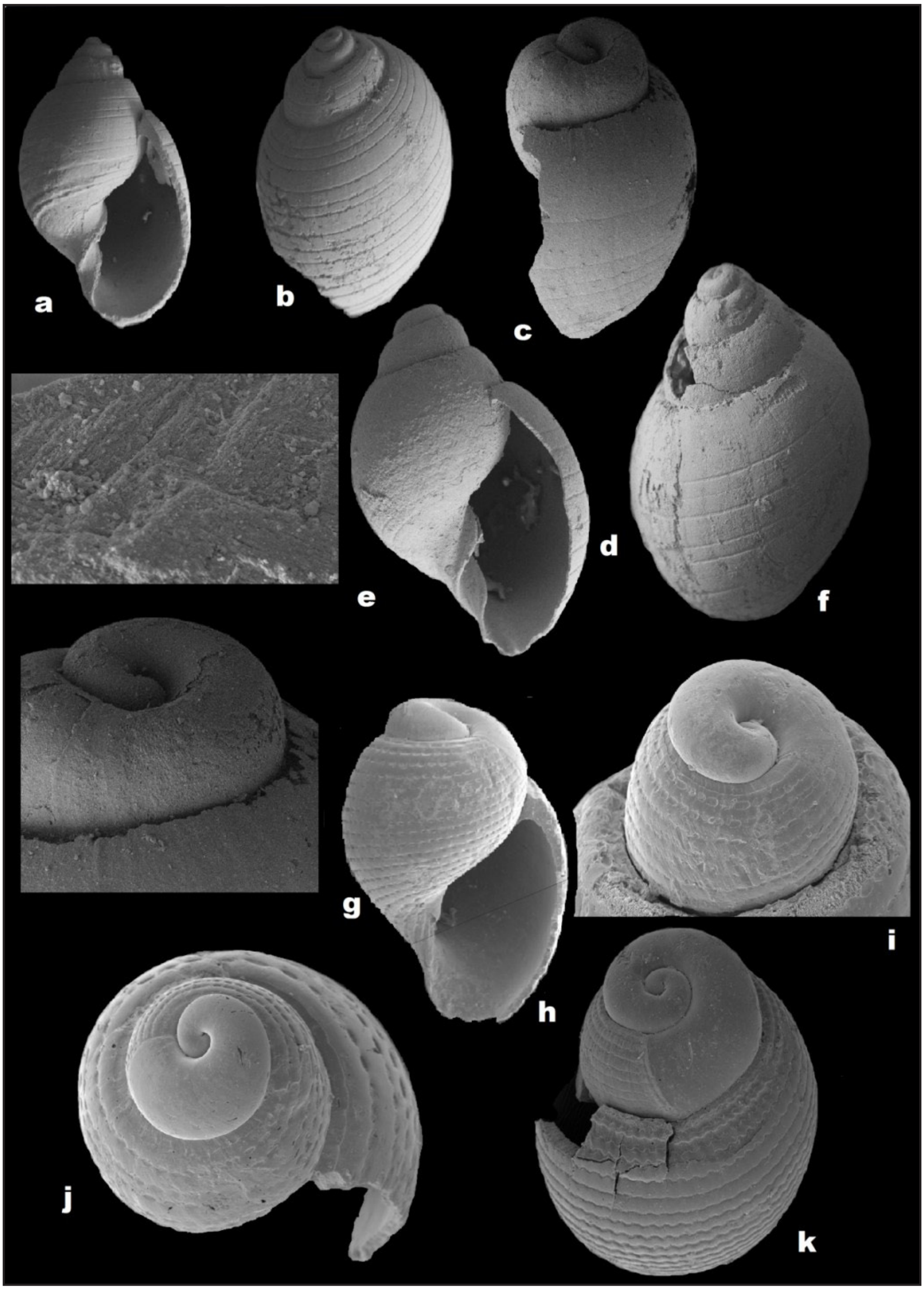

Figure a: Ringicula sp shell from Amman Silicified Limestone Formation at Irbid with narrow thick aperture.
Figure b: Ringicula sp shell from Amman Silicified Limestone Formation, Irbid, Ornament having spiral incised furrows on a smooth surface, Amman, Jordan
Figure c: Larval shell of Ringiculidae showing fold on the inner lip from Amman Silicified Limestone Formation, Irbid, Jordan
Figure d: Apertural view of Ringicula sp shell with two strong folds on the columellar part from Amman Silicified Limestone Formation, Irbid, Jordan
Figure e: Crossed lamellar sculpture structure preserved of Ringicula sp, Amman Silicified Limestone Formation, Irbid, Jordan
Figure f: Ringicula sp sculpture of incised spiral grooves from Amman Silicified Limestone Formation, Irbid ,Jordan.
Figure g: Shell apex, Ringicula sp having narrow protoconch with dome shaped and sculpture of incised spiral grooves from Amman Silicified Limestone Formation, Irbid, Jordan.
Figure h: Apertural view of Ringicula sp showing small low globose shell of the Jurassic from Madagaskar.
Figure i: Protoconch, apical view of Ringicula sp shell from the Cretaceous of Madagaskar
Figure j: Shell apex, punctuated spiral grooves on shell whorls from Mahajanga, Madagaskar
Figure k: shell of Ringicula sp from Eocene, Mississippi.

Plate 3: SEM microphotographs of Ringicula sp and Triploca sp, Aqaba, Jordan

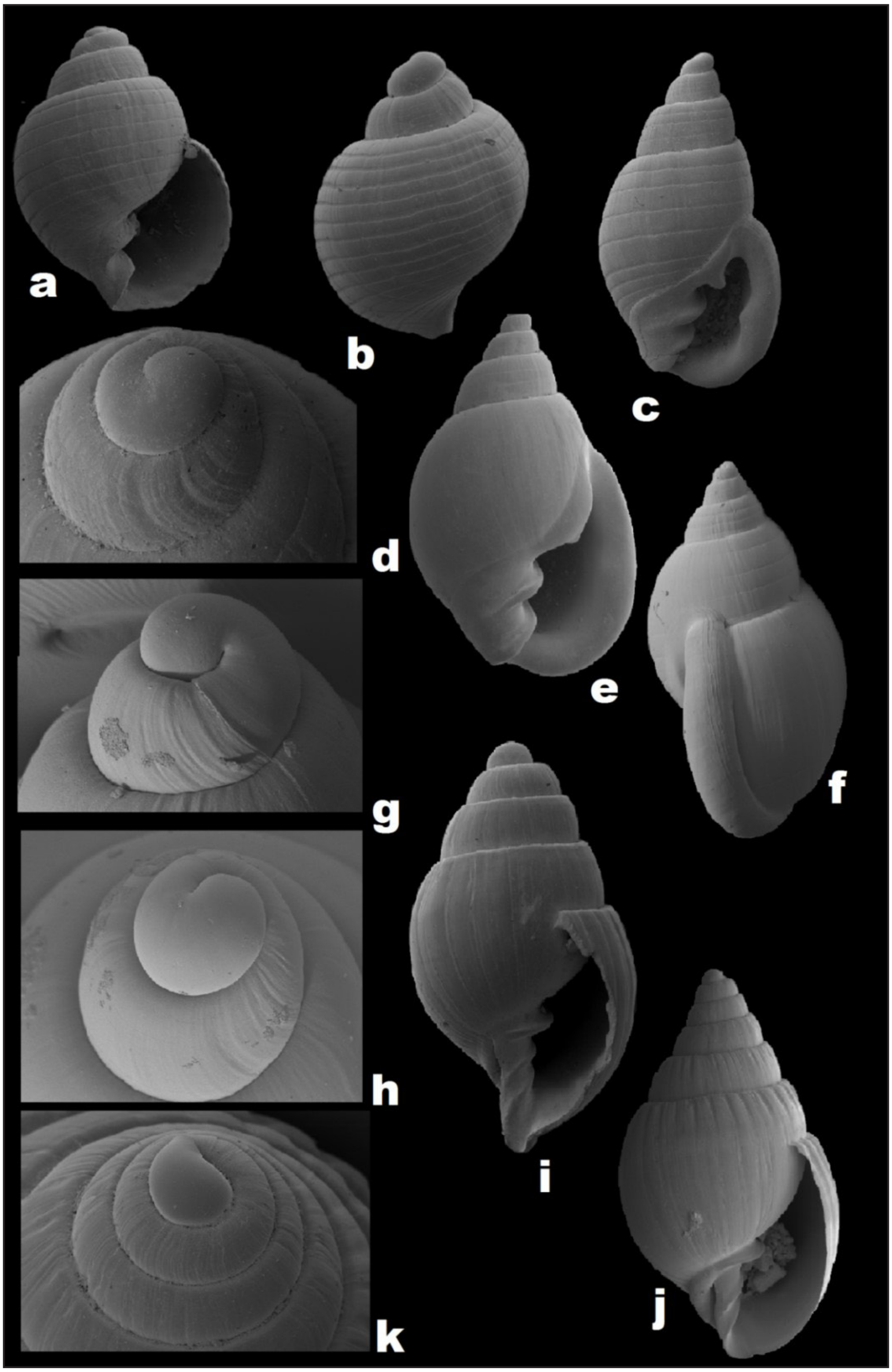

Figure a: Apertural view of Ringicula sp1, Aqaba. Jordan.
Figure b: Ringicula sp1 shell with narrow incised spiral furrows in zigzag pattern and with pits separated from each other with broad, smooth interspaces, Aqaba. Jordan.
Figure c: Ringicula sp1 shell has last whorl large, strongly convex and fold aperture, Aqaba. Jordan.
Figure d: close-up of protoconch, apical view of Ringicula sp1 shell, Aqaba. Jordan.
Figure e: Apertural view of Ringicula sp2, Aqaba. Jordan.
Figure f: Lateral view of Ringicula sp2, Aqaba. Jordan.
Figure g: Shell apex, of Ringicula sp2, Aqaba. Jordan.
Figure h: close- up protoconch, apical view of Ringicula sp2, Aqaba. Jordan.
Figure i: Apertural view of Triploca sp, shell from Aqaba, Jordan.
Figure j: Apertural view, fully grown Triploca sp with axially ribbed teleoconch, Aqaba. Jordan.
Figure k: Shell apex, Triploca sp juvenile, Aqaba. Jordan.