Chapter

Perspective Chapter: Ostracoda

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Abstract

Ostracoda are small, bivalved crustaceans that have thrived on Earth for 500 million years. They inhabit marine and freshwater environments, and their well-preserved fossil record offers insights into past ecosystems and paleoenvironmental conditions. Ostracod shells, known as valves, are made of calcium carbonate or chitinous material, enclosing the body in two separate halves. The valves display diverse shapes and ornamentation, reflecting the wide variety of ostracod species. Internally, ostracods possess a developed musculature, antennae for sensing the environment and capturing food, mandibles for chewing, and maxillae for filtering food. Their body cavity houses the digestive, circulatory, and reproductive systems. Ostracod fossils are found in marine, lacustrine, and terrestrial deposits, providing opportunities to study their morphology, distribution, and evolution. Their rapid evolutionary rates and broad geographic distribution make ostracods valuable for biostratigraphy. By analyzing ostracod assemblages in fossil sediments, researchers can reconstruct ancient ecosystems and track environmental changes. Ostracods serve as indicators of environmental conditions such as water temperature, salinity, and oxygen levels. Studying ostracod fossils informs our understanding of past environments and climate change.

Keywords: ostracoda, morphology, ecology, fossils, biostratigraphy

1. Introduction

Freshwater and brackish water Ostracoda are small-sized crustaceans with a wide and large spread in all aquatic environments: streams, rivers, ponds, swamps, and shallow and deep ones. Despite that, it has received little attention from specialists because of its small size and the difficulty of dealing with the carapace [1]. Its importance, theoretically and practically, has not been evaluated so far, despite its role in the food chain. Ostracoda has enormous fossil records, which are important in geological studies [2].

The presence of Ostracoda is related to environmental factors and therefore related to the physical and chemical properties of the aquatic environment, so chemical and physical analyzes can determine the characteristics of these habitats [3]. The precise characteristics of the body and its appendages for classification are considered an impediment to environmental studies, as it is impossible to study any organism without classifying it to the species [4].

Ostracoda is small crustaceans mostly in length (5–0.3 mm), and the carapace completely covers their body. It is found mainly among plants and their remains, and appears at first sight as a small, kidney-shaped seed and can be easily distinguished by its carapace consisting of two shutters, which are closed by adductor muscles. It includes appendages inside, and the body does not contain any divisions [5–8]. The carapace surrounding it gives it a high specificity, as it resembles in its shape the bivalve mollusks; a number of them are plankton forms, but most of them live on the bottom where they are crawling or swimming near the surface of the water. Most of the carapaces carry their eggs in the brood pouch, which is the space between the dorsal carapace and the body.

Ostracoda is found all over the world and in both marine and non-marine environments and abound in all types of freshwater environments, whether permanent or temporary stagnant or running. It is considered one of the largest and most diverse groups of crustaceans and currently includes about 30,000–50,000 living species and 30,000 fossilized species [9, 10].

As for the fossilized ones, they are found near all geological layers. They predominated in the Silurian period and were found at a depth of 9 cm [11].

Many Ostracoda species are environmentally specialized and considered indicators of various environmental conditions, mainly temperature, depth, and salinity [12]. It is also considered an important part of the aquatic ecosystem and a unique part of the huge diversity of crustaceans. The small size of its crust and the difficulty of classifying and dealing with its crust reduce its popularity among naturalists [13].

The Limnocytheridae and Cypridacea families are the most common Ostracoda families in non-marine environments and are often considered to be of great interest and value in the knowledge of palaeoenvironment [14, 15].

Drakes prefer to live in clean, oxygenated water over polluted water, are more active in the evening, and do not prefer high light [16].

2. Classification of ostracoda

Phylum: Arthropoda, Subphylum: Crustacea, Class: Ostracoda, The issue of categorizing Ostracoda into Orders, Suborders, Superfamilies, and Families still needs more discussion among specialists.

Ostracoda is divided into four main orders:

Order: Paleocopida Henning, 1953. Fossilized species only.

Order: Myodocopida Sars, 1866. Marine species only.

Order: Platycopida Sars, 1866. Marine species and a few of them are marine and fresh species.

Order: Podocopida Sars, 1866. Brackish.

Podocopida and all types of freshwater dromedaries fall under the order Podocopida and are divided into three main families:

(Darwinulidae, Cyprididae, and Cytheridedae)

The three families can be distinguished by:

1. The similarity or lack of similarity of the three pairs of thoracopoda.

2. The number and order of muscle scars for each family.

3. The exopod of the second Antenna is modified into a scaly structure that carries a number of cilia or a long spiny structure (**Figure 1**) [17].

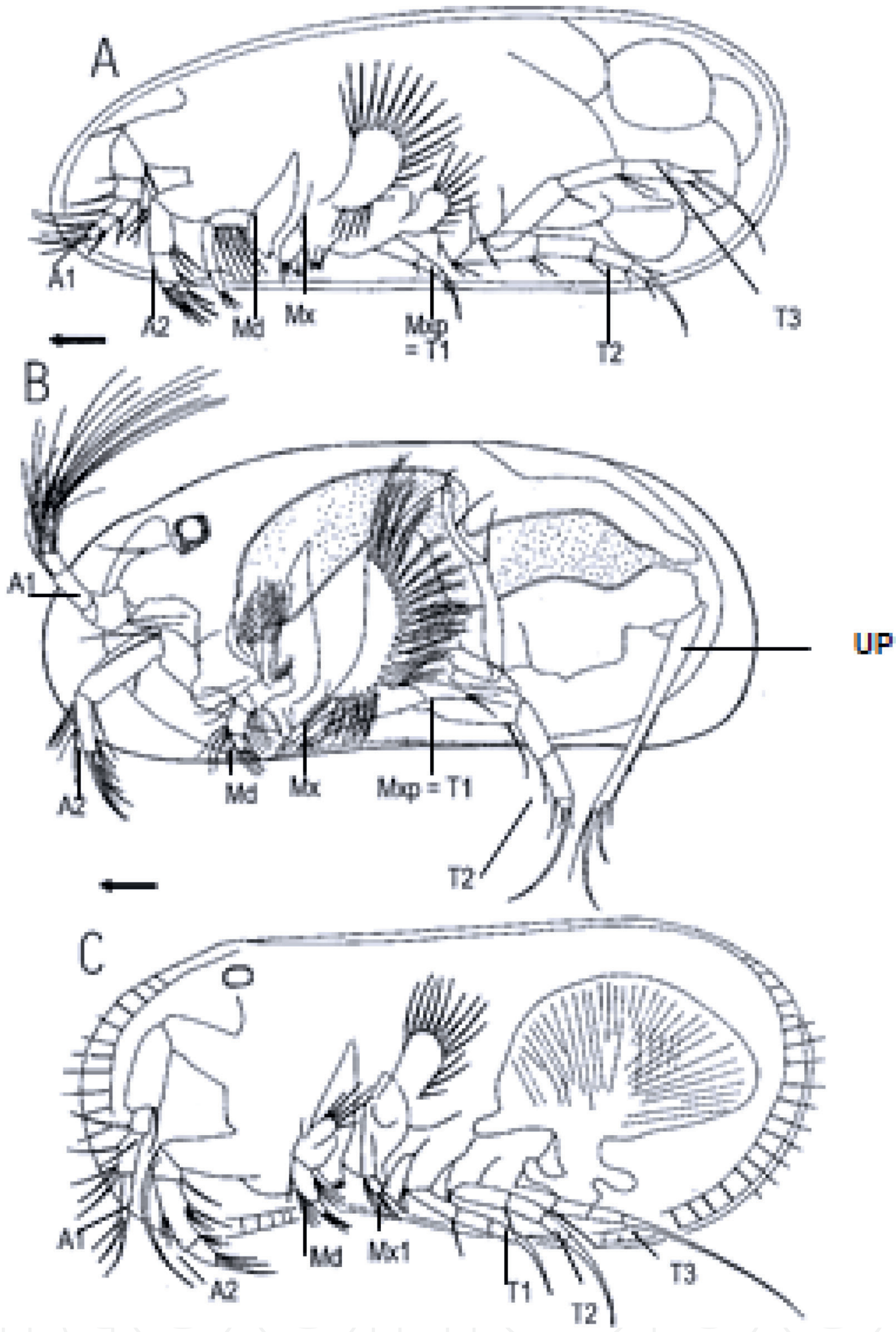

Figure 1.
Three Superfamilies: A—Darwinula strevensoni (Darwinuloidea), B—Heterocypric reptans (Cypridoidea), C—Limnocythere sanctipatricii (Cytheroidea). A&B. female, C. male [17].

3. General structure of ostracoda

3.1 Carapace

The carapace, consisting of two valves, covers the body of the Ostracoda completely, and the body consists of two regions: the head or cephalon and the thorax, separated by narrow partitions [18].

The two loose ends of the shutter snap together or overlap, creating a small loose end. A thick bundle of strong adductor muscles passes through the center of the body,

Figure 2.
Pattern of adductor muscle scar order: Podocopoda [20].

which contracts to close the two valves. The complete closure of the carapace provides the animal with a strong defense system against many types of predators and temporary drought conditions that occur in the habitat [19].

The two valves close by the adductor muscles (**Figure 2**) pass through the central part of the body and are attached to the inner surface of the calcified outer plates, where characteristic scars are formed. The adductor scar pattern is another important taxonomic feature in addition to the adductor scar pattern [20].

The valve consists of two double-folded excrescence of the body wall, which is two outer and inner lamellas, and there are in the space or space separating the two plates, perhaps reproductive organs or the alimentary canal, according to the orders and families [21].

The outer surfaces of the valves may be smooth, embossed with small pits, pitted, ornamented with reticulate ridges or spins [20]. The valves cover channels with radial or normal holes. The importance of the nature of the channels is in dividing species groups and as an idea for identifying and isolating species [22].

3.2 Appendages

The carapace appendages are specialized for locomotion, feeding, and reproduction. Appendages differ greatly in form and function, without a doubt, with different habitats, environments, and lifestyles. The number of Podomeres and Setae that make up the appendages is very important in the classification.

3.3 First antenna

Its function is sensory and kinetic, and it is uniramous and consists of (5–8) segments. The exopod is absent or reduced to a single inconspicuous palp. In swimming species, the palp is long, flexible, and thin, containing a number of natatory setae. As for crawling and climbing ones, they have short claw-like setae.

3.4 Second antenna

It is considered the main kinetic structure of walking and has great taxonomic importance in the Podocopida; the inner Endopod is well developed and consists of (3–4) articulated segments bearing a variety or group of setae with claw ends. As for the Exopod, it is reduced to a scale structure that usually bears three setae. The first segment of the Endopod of most of the family Cypridoidea bears (1–5) sensory setae.

3.5 Mandible

It contains a masticatory process with strong teeth and a textured attachment that usually bears a well-developed vibratory plate. Two digestive parts are attached to the lower lip and located in the oral cavity.

3.6 Maxilla

It consists of palp having two segments and three masticatory processes usually bearing a vibrating plate, which generates a continuous stream of water through the body for respiration. **Maxilla** are located directly behind **Mandible** and have two functions, respiratory and feeding.

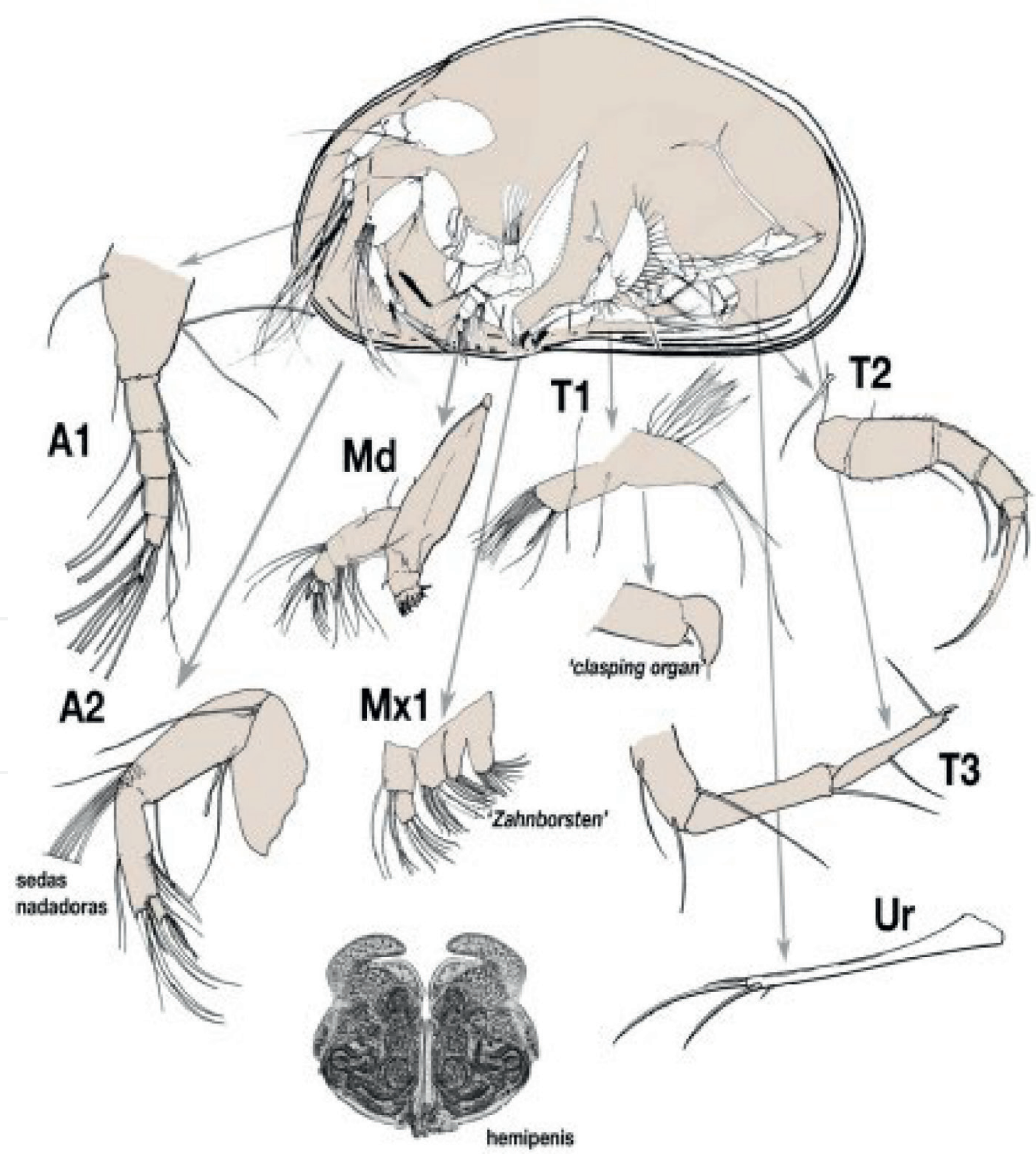

Figure 3.
Appendages of Podocopida [23].

3.7 First Thoracopod

It is a distinct structure in its form and function, as it works either as walking legs as in (Cytheroidea) or modified into a feeding organ as in (Darwinuloidea and Cypridoidea) and in males of the genus (Cypridoids) the Endopod modified into a clasping organ.

3.8 Second Thoracopod

It consists of all members of the Ostracoda of 4–5 segments, which usually bear a developing apical claw. It acts as a walking man.

3.9 Third Thoracopod

In superfamilies, Cytheroidea and Darwinuloidea, they are in the form of walking legs and resemble the **second Thoracopod.** In Cypridoidea, they are modified into cleaning legs that are curved or arched. In Candonidae, the distal end of the cleaning legs is slightly modified and bears 3 setae, and has taxonomic importance at the level of genera.

3.10 Uropod

Rod-shaped, flat-sided, undivided, bearing distal claws and two or more setae. In the family Cypridopsinae, it is partially reduced (flagelliform) in females, while males are completely reduced (**Figure 3**) [1, 17, 18].

4. Internal anatomy

Podocopida lack gills or any specialized respiratory organ, and gas exchange occurs by entering the body surface and the inner lamella, where gases are exchanged through the chitin layer of the inner surface of the valve [24]. Continuous ventilation of the respiratory plates equips the animal with oxygenated water and displaces carbon dioxide (CO_2) and the rest of the materials thrown through the valves. It also lacks the heart, as blood circulation occurs through muscle contraction in the body wall or the blood vessels themselves. As for the digestive system, it consists of the oral cavity, esophagus, anterior intestine, which can act as the stomach, posterior intestine, anus, which is located on the dorsal side of the uropod. In addition to the presence of the hepatopancreas, it collects the secretions of a pair of digestive glands and is located between the two plates of the valves. The alimentary canal or intestines may sometimes be visible through the carapace. The central nervous system comprises the cerebrum, the circum-esophageal collar of fused ganglia, and the ventral chain of ganglia. The brain supplies the nerves to each of the eyes, the lower layer of the valve, and the pairs of the first and second tentacles, and the rest of the appendages are supplied by the ventral chain of the ganglia. The eyes are above the base of the first Antenna and can be distinguished as a dark spot, usually in living animals. The eye includes three optical cups, which are usually fused. Ostracoda has two different visual systems, a single median eye and two pairs of compound eyes [4].

5. Reproductive system

The male reproductive system is distinguished in its complexity and size. It represents about a third or a quarter of the size of the body. It includes a pair of testes. Each testis consists of four long tubular branches between each valve's membrane, which unite to form the vas deferens, the seminal vesicle, and Zenker organ, which acts as a pump to push the sperm into the penis forcefully. In the female, the reproductive system occupies half the size of the body. It is simple in structure and includes a pair of tubular ovaries paired, oviduct, seminal receptacle, seminal receptacles, and genital opening.

5.1 Modes of reproduction

There are four modes of reproduction for Ostracoda groups depending on the presence or absence of males:

1. The first group: includes some species of both sexes, such as *Candona and Cypricercus*. Males are absent; the reproduction pattern is parthenogenesis.

2. The second group includes the genera *Cyprinotus, Candona*, *Darwinula, Ilyocypris*; males are rare, and the reproduction pattern here is also parthenogenesis.

3. The third group: includes the genera *Potamocypris, Darwinula, Cypridopsis, Cypricercus, Darwinula*, the presence of males here in small numbers, and the mode of reproduction here is sexual and pathogenic

4. The fourth group: includes the species of genera

5. *Cyclocypris, Cypria Candona Cypricercus. Cyprois, Limnocythere, Physocypria, Notodromas,* males are always present, and the reproductive pattern is sexual.

The eggs of the Ostracoda are spherical with a thin bilateral wall; their colors range from yellow, white, red, orange, and green. The eggs are transported by fish, birds, wind, or any other way [1, 17]. Podocopida lack the stage of the larval or coastal stage pelagic larval, so their migration or movement is determined by active motile elements and by the nature of the prevailing benthic current [25–28].

In environmental experiments, it was shown that the eggs of the Ostracoda retain their vitality even after being exposed to dry conditions at 20 and 40°C and after being exposed to freezing conditions at 18°C [28].

And the eggs of freshwater Ostracoda are highly resistant to the damage they are exposed to and can withstand harsh conditions [29].

And to reach the adult stage, the Ostracoda, like the rest of the crustaceans, suffer from molting several times (8 times) between their growth stages; immediately after that, the two valves harden in the form of new layers by taking compounds from the surrounding water [30].

Before molting occurs, the new epicuticle begins to harden, and during this process, trace elements merge and unite in the crust; and this phase is somewhat rapid, and these chemical elements, from which the crust is formed, can diagnose some phenomena in marine and fresh environments since the time the new crust was formed, such as pollution [31].

6. Feeding

The food of the Ostracoda consists mainly of bacteria, molds, algae, and fine detritus, and darts have several ways of feeding; most of them are filter feeding, as the beatings or movements generated by the cilia of mandibular palps, maxillary processes, and vibratory plate for the first thoracopod, a continuous stream of water is generated between the two valves, which enables it to catch the small particles with their Bristel appendages and deliver them to the mouth [1].

And some species of carnivores are predatory, Detritivorous herbitory, predaceous carnivore, or scavengers [32].

And species of them are parasitic on other crustaceans, polychaete worms, echinoderms, or sharks [18].

7. Ecology of ostracoda

In the eighteenth century, studies were largely focused on taxonomy, but the environmental sensitivity of Ostracoda was unknown among most environmentalists [33].

Ostracoda that live in continental waters are sensitive to various aquatic environments. Some species are found in springs, rivers, streams, ponds, or lakes, and others can be found in more or all environments and habitats, whether at the surface or depths, and they are endemic or alkaline [16, 34–36].

The presence of Ostracoda can be controlled by constant factors such as food availability, depth, pH, dissolved ions, oxygen concentration, temperature, concentrations of dissolved substances, salinity, electrical conductivity, ionic strength, and calcic saturation index [3, 7, 36–39].

The small size of the Ostracoda, its large numbers, and its sensitivity to environmental conditions make it ideal for determining the disturbance and change in lake environments since the non-marine dracaena is often used as an indicator of seasonal changes that occur in large lakes, as well as the dracaena is a source of information about past seasonal changes in the chemical and water temperature [40, 41].

The non-marine groups that live in freshwater are controlled by calcium ions Ca2+, calcium carbonate Hco3, and magnesium, Mg2+, to a typical extent, and cannot live in water dominated by sodium ions, Na+, chlorine, or other types of ions. These main ions play an important role in knowing the sensitivity of Ostracoda to dissolved compounds [42, 43].

The calcite crust of the Ostracoda is a source of data for stable and radiogenic elements and trace metals. These data test and refine the structure and organization of Ostracode paleohydrological [16, 44].

Species respond to temperature and other environmental changes, such as oxygen concentration and pH (pH, O_2), as they affect their succession and survival. When food is available, growth rates increase with increasing temperature. On the contrary, food rates that support growth at low temperatures may be insufficient or adequate at high temperatures [37, 41, 45].

The different species of Ostracoda require a difference in the environmental conditions, such as the change in temperature and oxygen, for the molting process to occur for growth. The temperature is very important for the stages of the life cycle of the Ostracoda (e.g., hatching, growth, and reproduction) [33, 46].

Salinity, ionic compounds, and water contents are important environmental factors and are considered the main dominant that affect the presence and distribution of marine and non-marine (brackish and fresh). They showed the importance of salinity in the life cycle of organisms such as Ostracoda. The external shape of the valve in the Ostracoda is in terms of thickness or decoration [47, 48].

Some species of Ostracoda may not be affected by the surrounding environmental conditions such as high salinity [49].

Oxygen is considered a catalyst that works for the survival of Ostracoda like other living organisms; some of them have no resistance to withstand the sudden lack of oxygen, most of the freshwater Cypridacea is abundant in stagnant water with little oxygen, and some of it is formed during harsh periods and long hot weather [50].

8. Fossil Ostracoda and paleoecology

Ostracoda that has a calcite valve easily turns into fossils in the sediments of lakes or wet places or any place where the animal resides or lives [21, 51].

The oldest rocks found in which ostracoda fossils date back to the Upper Cambrian period belong to the family Leperditidae of the order Leperditicopida [52].

Ostracoda considers at paleontologists, stratigraphies, and environmental indices important applications in oil and gas exploration and makes them an excellent subject in evolutionary studies [18].

In freshwater environments, ostracods are commonly found in lake and pond sediments and can provide insights into the changes in water chemistry, temperature, and sedimentation over time. The remains of ostracods, together with other microfossils, can help reconstruct past environments and climates, providing information on long-term environmental and biotic changes [53].

Important of Fossil ostracods are not only for their value in reconstructing past environmental conditions, but also for determining the relative ages of sedimentary rocks. Because ostracods have evolved so rapidly and their remains are abundant, they make excellent tools for biostratigraphy, allowing geologists to correlate rocks over large areas and between widely separated regions [54].

8.1 Stratigraphic significance and distribution

The morphological characteristics of fossil ostracods have significant implications for understanding the stratigraphic distribution of these creatures. Because ostracods have evolved rapidly and their morphology is sensitive to changes in environmental conditions, they make excellent tools for biostratigraphy, allowing geologists to correlate sedimentary rocks over large areas and between widely separated regions [55]. In addition, the variations in ostracod morphology over time can be used to trace the evolutionary history of these creatures and to infer patterns of diversification and extinction. For example, the rapid radiation of ostracods during the Paleozoic era can be linked to the onset of ecological and environmental changes during that time, including the evolution of new habitats and the rise of new predator-prey relationships. Fossil ostracoda have a widespread stratigraphic distribution, and their remains have been used as biostratigraphic markers to correlate sedimentary successions over broad spatial ranges. The key factors that influence the stratigraphic distribution of fossil ostracoda are their evolutionary history, ecological preferences, and environmental conditions. Ostracods have evolved rapidly, with many new species originating during the periods of ecological and environmental change. For example, the rapid radiation of ostracods during the Paleozoic era can be linked to the onset of ecological and environmental changes during that time, including the evolution of new habitats and the rise of new predator-prey relationships [56].

Ecological preferences of ostracod species can also affect their stratigraphic distribution. Ostracods that prefer freshwater environments are generally more abundant in freshwater sediments, while those that favor marine or deep-sea environments are more prevalent in marine sediments [54]. Environmental factors such as temperature, salinity, and pH can similarly shape ostracod distribution patterns. For instance, the presence of different ostracod species in marine environments can be used to infer salinity and temperature values of past seawater. The Mesozoic era is also famous for its diverse ostracod fauna, with many notable groups appearing during this time. For example, the Lower Jurassic period saw the appearance of the parasitic cypridinids, which were found in deep-sea sediments, while the Cretaceous period witnessed the rise of the suborder Podocopina, which includes many freshwater ostracods [57].

8.2 Global distribution of ostracodes

Ostracodes are aquatic and semiaquatic organisms, and their distribution varies widely based on ecological factors such as temperature, light levels, and water chemistry. These tiny crustaceans can be found in almost every aquatic environment, including lakes, streams, rivers, and oceans, and they are a key component of many food webs.

The distribution of ostracodes varies based on age and living stages. For example, ostracodes in their early developmental stages can be found in shallow areas with higher oxygen levels, while adults tend to inhabit deeper waters or even the benthic zone. Additionally, ostracodes are known to be sensitive to changes in water temperature and salinity, meaning their distribution can also be influenced by seasonal shifts or climate change.

In terms of geographic distribution, ostracodes are found in freshwater and marine environments all over the world, from the tropics to the poles. Some species are more abundant in certain regions, such as the Arctic and Antarctic, where they have adapted to extreme conditions. Researchers have also documented specific ostracode species associated with particular geological formations, which has implications for geochronology and stratigraphic studies [58, 59] (**Figure 4**).

8.3 Stratigraphic correlation

The stratigraphic correlation of fossil ostracoda is a crucial aspect of paleontological research, as it allows geologists to establish relative ages and correlations of sedimentary rocks over wide spatial areas. In this chapter, we explore the techniques used for stratigraphic correlation of fossil ostracoda, their applications, and their

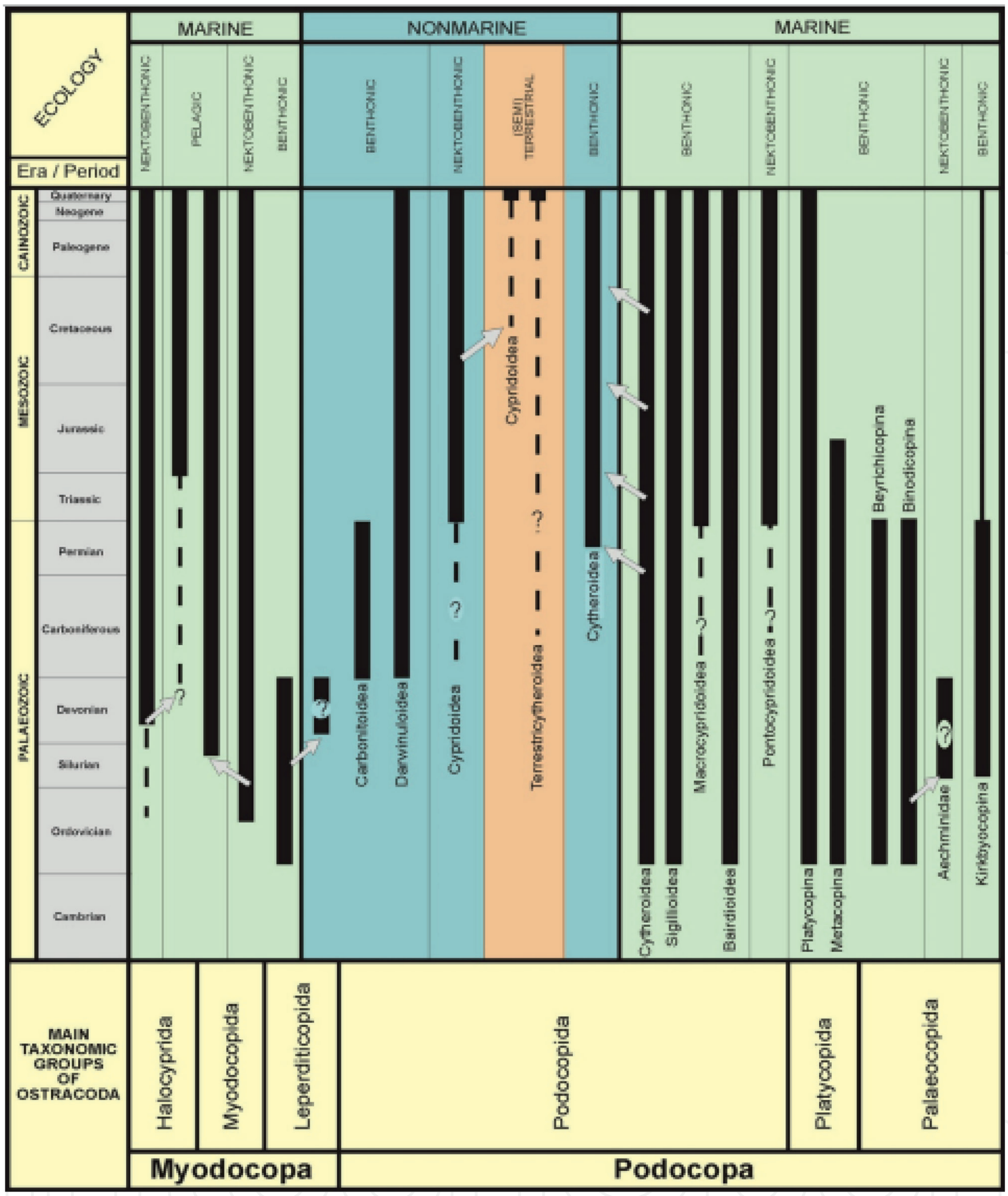

Figure 4.
Stratigraphical timelines of the major ecological radiations of the Ostracoda [60].

limitations.The primary techniques used for stratigraphic correlation of fossil ostracoda include biostratigraphy, lithostratigraphy, chronostratigraphy, and chemostratigraphy. Biostratigraphy is the most commonly used technique and relies on the identification and correlation of fossil assemblages. Lithostratigraphy involves the correlation of rocks based on their lithological characteristics, such as grain size and mineralogy. This technique is useful when fossils are absent or when other correlation methods are not applicable. Chronostratigraphy is the application of standardized geological time scales to establish the age and correlation of sedimentary rocks. This technique relies on the identification of stratigraphic boundaries and the allocation of rock units to different intervals of geological time.

Finally, chemostratigraphy involves the use of isotopic or geochemical signatures in sediments to establish relative ages and correlations. This technique works on the assumption that sedimentary rocks deposited at the same time and under the same environmental conditions should have similar isotopic or geochemical characteristics [54].

8.4 Fossil Ostracoda in biogeography

Ostracod fossils can also be used to investigate the biogeographic relationships between different regions. The distribution of ostracods is influenced by factors such as habitat availability and dispersal ability. Therefore, by comparing the ostracod faunas of different regions, scientists can test hypotheses about past biotic exchange and continental drift. **Case studies**: One example of a biogeographic study that used fossil ostracods is the investigation of the dispersal of freshwater taxa from the Paleogene of northern South America to southern Africa. This study found that ostracod faunas from these two regions were more similar during the early Eocene than during the late Eocene, suggesting that there was a period of enhanced biotic exchange between these regions during this time.

Another example is the use of ostracod fossils to investigate the biogeographic history of the Paratethys Sea, a large but shallow sea that existed during the Oligocene and Miocene (~30–5 million years ago) in the region of Central Europe. Using ostracod fossils from different parts of the Paratethys, scientists were able to reconstruct the changing biotic connectivity within the sea and the connections between the Paratethys and other seas and oceans at different times [61–64].

8.5 Role of ostracoda in earth crust formation

Ostracoda play a significant role in Earth's crust formation, despite their size, they contribute to important ecological processes, including sedimentation, mineralization, and biogeochemical cycling. Ostracods have a direct impact on sedimentation processes by producing and accumulating their shells in aquatic environments. These shells, composed mainly of calcium carbonate or silica, contribute to the formation of sediment layers over time. The accumulation of ostracod shells, along with other organic and inorganic particles, leads to the development of sedimentary rocks, such as limestone and shale. This process is crucial for the overall structure and composition of Earth's crust [18].

Ostracoda and Biomineralization: Ostracods have the unique ability to biomineralize their shells, a process that involves the deposition and organization of minerals within their exoskeletons. This biomineralization process contributes to the formation of hard structures that can withstand physical and chemical weathering, eventually becoming part of Earth's crust. The controlled precipitation of minerals within ostracod shells aids in stabilizing sediments and contributing to the development of calcareous and siliceous formations.

Ostracoda and biogeochemical cycling: Ostracods play an essential role in biogeochemical cycling by participating in nutrient cycling and remineralization processes. They contribute to the breakdown of organic matter and the recycling of nutrients in aquatic ecosystems. The activities of ostracods influence the availability and distribution of essential elements, such as carbon, nitrogen, and phosphorus, in the environment. These processes, in turn, impact the overall nutrient balance and the formation of sediments in Earth's crust [56].

9. Conclusions

1. The morphology of ostracoda, characterized by their bivalved shells and complex internal structures, is highly diverse and well-preserved in the fossil record. The varied shapes and ornamentation of their valves reflect the wide range of ostracod species. The detailed study of their morphology provides insights into their evolutionary history and adaptations to different environments.

2. Ostracods inhabit both marine and freshwater ecosystems, and their fossils provide valuable information about past environments and ecological conditions. Ostracods are highly sensitive to environmental parameters such as temperature, salinity, and oxygen levels. By analyzing ostracod assemblages in fossil sediments, researchers can reconstruct ancient ecosystems and track changes in environmental factors over time.

3. Fossils: Ostracod fossils are abundant and widely distributed in sedimentary deposits. Their excellent preservation in the fossil record allows for detailed examination of their morphology, providing valuable data for paleontologists. Ostracods have a rapid evolutionary rate and a wide geographic distribution, making them useful for biostratigraphy and dating sedimentary layers based on their fossil assemblages.

4. Paleoenvironmental Reconstruction: Ostracod fossils serve as important indicators of past environmental conditions. Changes in ostracod species composition and diversity can reveal fluctuations in water temperature, salinity, and other environmental parameters. By studying ostracod fossils, researchers can reconstruct past ecosystems, track climate change, and gain insights into the interactions between organisms and their environments throughout geological time.

5. Importance of Ostracod Fossils: Ostracod fossils play a significant role in paleontological research, contributing to our understanding of Earth's history and the evolution of aquatic ecosystems. Their widespread distribution, diverse morphology, and sensitivity to environmental changes make them valuable tools for paleoenvironmental reconstruction, biostratigraphy, and paleoecology studies.

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