Evolutionary Characteristics and Controlling Factors of the Fossil Thalassinoides in the Cambrian Deposits: A Case Study from the Southern Margin of the North China Craton

Chenxiang Peng

Henan Polytechnic University, Jiaozuo 454002, China

Abstract

Thalassinoides is a type of unlined, open, branching, three-dimensional burrow system that serves as both a dwelling and foraging structure. It has a long geological history, with reported occurrences from the Cambrian to the Cretaceous. Its continuous and widespread distribution provides reliable conditions for studying the evolutionary response of organisms to their environment. In the Henan Cambrian deposits, Thalassinoides exhibits a high diversity and abundance, yet there is a lack of systematic research on the evolution of Thalassinoides in this region. Our aim is to investigate the morphological and sedimentological aspects of Cambrian Thalassinoides in order to identify the controlling factors of their evolution.

Keywords

Cambrian; Evolutionary; Thalassinoides.

1. Introduction

Thalassinoides is a type of unlined, open, branching, three-dimensional burrow system that serves as both a dwelling and foraging structure[1][2][3]. It exhibits a diverse range of sizes and morphologies, with lengths varying from a few centimeters to several meters[4]. It is commonly found in sedimentary rocks such as mudstone, muddy sandstone, and sandy mudstone[5]. Thalassinoides has a long geological history, with reported occurrences from the Cambrian to the Cretaceous [6][7][8][9][10][11][12][13]. Its continuous and widespread distribution provides reliable conditions for studying the evolutionary response of organisms to their environment. Thalassinoides can survive in various environments, including intertidal flats[14], shorelines[15], continental shelves[16], and even deep-sea environments[17]. This wide distribution makes it more challenging to accurately reconstruct the evolutionary changes of ancient environments, while playing a significant role in deepening our understanding of the evolution of life and ecosystem changes in Earth's history[18].

Throughout the 3.8 billion years of Earth's evolutionary history, the Cambrian explosion undoubtedly stands out as a remarkable event of evolutionary innovation[19]. As the first period of the Phanerozoic Eon, the Cambrian marks the beginning of biodiversity and preserves a rich fossil record. These fossil records can help us gain a deeper understanding of early life evolution and the interaction between life and the Earth's environment, greatly advancing our knowledge of geology and paleontology.Based on current research, the Cambrian deposits in Henan exhibit a high diversity and abundance of Thalassinoides. Previous studies on Cambrian Thalassinoides in Henan mainly focused on morphological classification, reconstructing paleoenvironments through studying their distribution and characteristics in the stratigraphic record, as well as analyzing the ecological structure of the region's ecosystem through the study of Thalassinoides in combination with other fossil assemblages[20][21][22][23][24]. However, there is a lack of systematic research on the evolution of Thalassinoides in this region. Therefore, we aim to investigate the morphological and

ISSN: 2414-1895 DOI: 10.6919/ICJE.202308_9(8).0010

sedimentological aspects of Cambrian Thalassinoides in order to identify the controlling factors of their evolution.

2. Geological Background

The North China Craton is one of the oldest cratons in the world, preserving basement rocks dating back approximately 3.8 billion years. Through multiple tectonic events spanning 2.5 billion and 1.8 billion years, it eventually amalgamated into a unified and stable continental craton, becoming part of the Columbia supercontinent around 1.8 billion years ago. Specifically, the boundaries of the North China Craton are mainly located in the northern part of China, including regions such as Beijing, Tianjin, Hebei, Shanxi, and Inner Mongolia[25].During the Cambrian period, the North China Craton was a relatively stable ancient craton primarily composed of crustal rocks, including basalt, granite, gneiss, and metamorphic rocks[26]. In the eastern and southern parts of the North China region, there are ancient plateaus such as the Taihang Mountains, the Jilu-Yu Plateau, and the Southern Anhui-Jiangxi Block[27]. There are also ancient fault zones, such as the southern boundary fault zone and the northern boundary fault zone of the North China Craton.

Unlike the structural changes, the sedimentary environment of the North China Craton during the same period was very diverse[28]. It included marine sedimentation, continental sedimentation, aeolian deposition, and volcanic eruption deposits. In the Jilu-Yu Plateau and the Southern Anhui-Jiangxi Block in southern North China, there are ancient marine sedimentary rocks, including limestone and shale, which preserve abundant biological fossils. In the northern part of the North China region, such as Shanxi and Hebei, there are ancient continental sedimentary rocks, mainly including sandstone, mudstone, and coal seams, reflecting the terrestrial environment at that time.

In addition, the Lower Cambrian series (lower part of the Lower Cambrian) is an important stratigraphic unit where atmospheric deposition, volcanic ash, and detrital materials form a distinctive sedimentary environment. Overall, these diverse sedimentary environments provide important information for studying the geological and biological evolution of the North China region.

Henan Province is located in one of the important Cambrian stratigraphic regions in China, at the junction of the southern part of the North China Craton and the Qinling Fold Belt. The western part of Henan is situated on the southern margin of the North China Craton and was part of the North China landmass during the Cambrian period. It exhibits typical characteristics of a continental shelf basin in terms of sedimentation. The Cambrian strata in Henan are predominantly composed of marine sediments, including mudstone, sandstone, and limestone.Specifically, the Runan Group consists of marine limestone and dolomite, with thickness ranging from several hundred meters to over a thousand meters. The Luoyang Group, on the other hand, is primarily composed of marine sandstone and mudstone, but its distribution is relatively narrow. Furthermore, the Cambrian strata in Henan exhibit a north-south inclination and have formed a "basin-mountain-basin" topographic structure[29]. The mountainous areas are mainly karst mountains, while the basins are mostly carbonate basins.Lastly, there are significant regional variations in the Cambrian strata of Henan. The southern region is dominated by shallow-marine limestone and marine mudstone, the central region is characterized by deep-sea limestone and marine mudstone, and the northern region is primarily composed of carbonate rocks. These variations reflect the complex geological evolution that Henan underwent during the Cambrian period.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202308_9(8).0010

3. Analysis and Results

3.1 T.suevicus

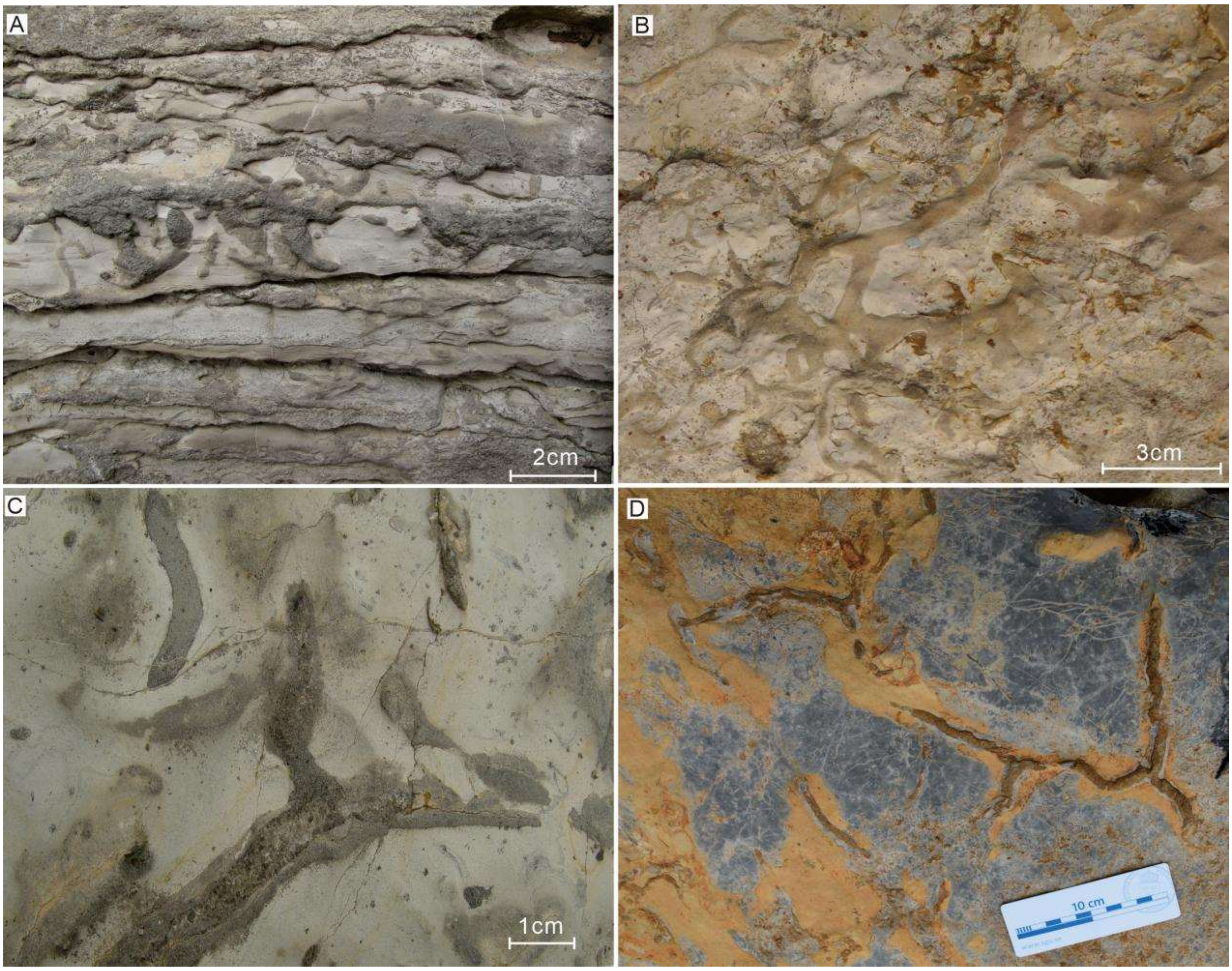

Fig.1 Henan Cambrian T.suevicus Macroscopic Field Photographs in Different Regions

A.T.suevicus in the Longmen area on the profile section. B. Multiple intersections and distinct branches of T.suevicus in the Longmen area on the stratigraphic level. C, D. T.suevicus on the stratigraphic level in the Mianchi area.

T.suevicus in the Zhangxia Formation is predominantly developed at the bottom, forming mostly horizontal reticulate burrow systems with noticeable Y-shaped branches (Fig. 1B-D). The burrows have sizes ranging from approximately 10-20cm in length with diameters between 1-3cm. The angles and lengths of the branches vary, exhibiting inclined structures. In the vicinity of T.suevicus branches, there are evident swellings that take on a semi-circular or conical shape (Fig. 1C). On the cross-section, the burrow surfaces appear nearly circular or irregular, which is related to the morphology of the exposed branches (Fig. 1A). There are significant differences between the bedrock and fillings in the Longmen and Mianchi areas. The burrow walls in the Longmen area are relatively smooth, while the burrows in the Mianchi area exhibit distinct burrow walls. The varying degrees of weathering contribute to different exposures.Origin and stratigraphic position: Bottom of the Zhangxia Formation in the Longmen area and Mianchi area.

ISSN: 2414-1895
DOI: 10.6919/ICJE.202308_9(8).0010

3.2 T.horizontals

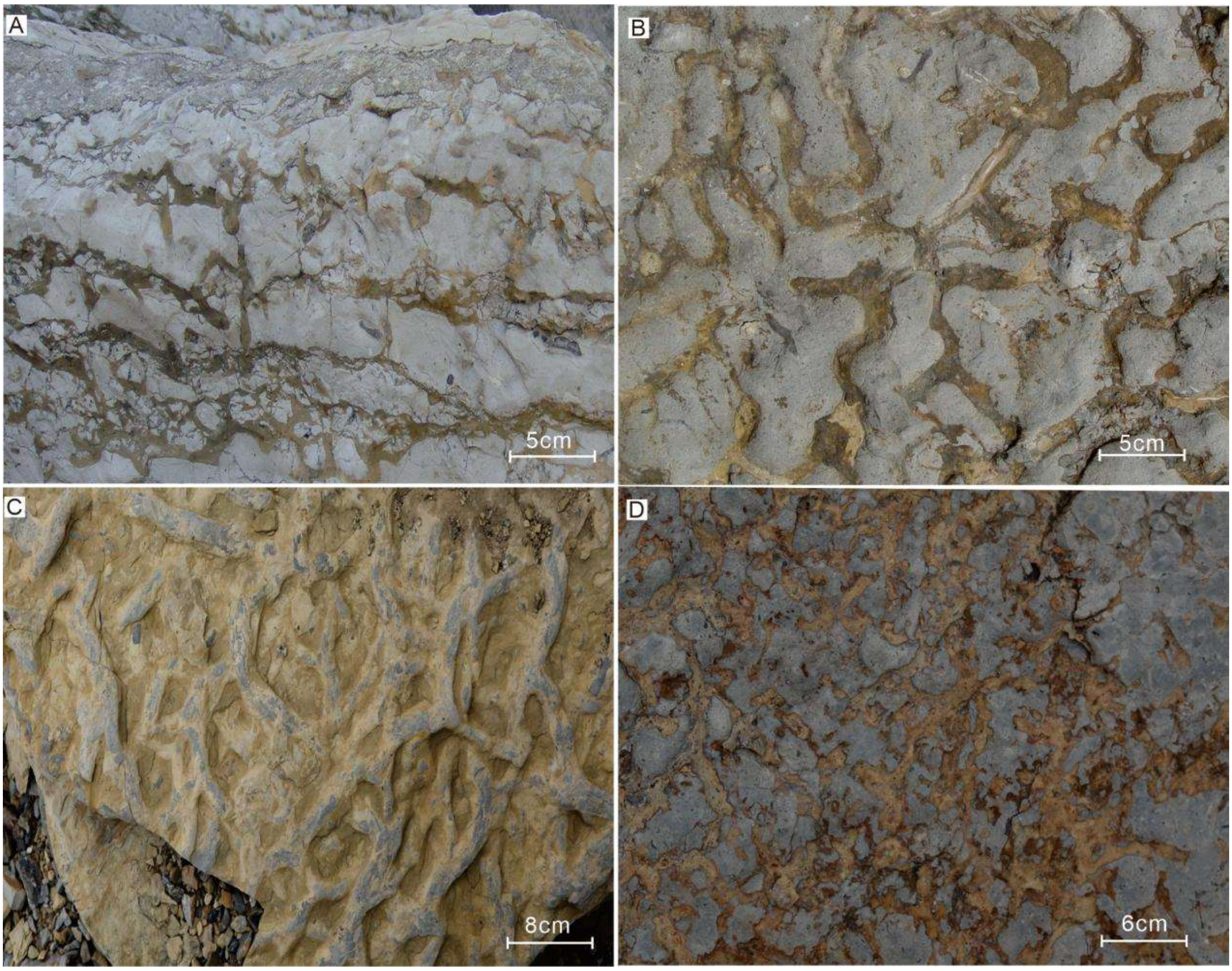

Fig.2 Macroscopic field photographs of T.horizontals in different regions of the Henan Cambrian Formation.

A.T.horizontals on the profile section in the Longmen area. B. T.horizontals on the stratigraphic level in the Longmen area. C, D. T.horizontals on the stratigraphic level in the Mianchi area.

T.horizontals in the lower part of the Zhangxia Formation form a three-dimensional burrow system with smooth linings. They exhibit a polygonal, grid-like pattern with horizontal branching. The distance between branching points varies, and there are Y-shaped or J-shaped branches (Fig. 2B, C). There is a slight expansion or enlargement at the junctions of the burrow tubes or in other areas. The diameter of the burrow interior is approximately 3-6mm, and there is little overall diameter variation. The spacing between branches is relatively uniform. On the cross-section, the burrows display irregular morphological changes and lack vertical structures.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202308_9(8).0010

3.3 T.beace

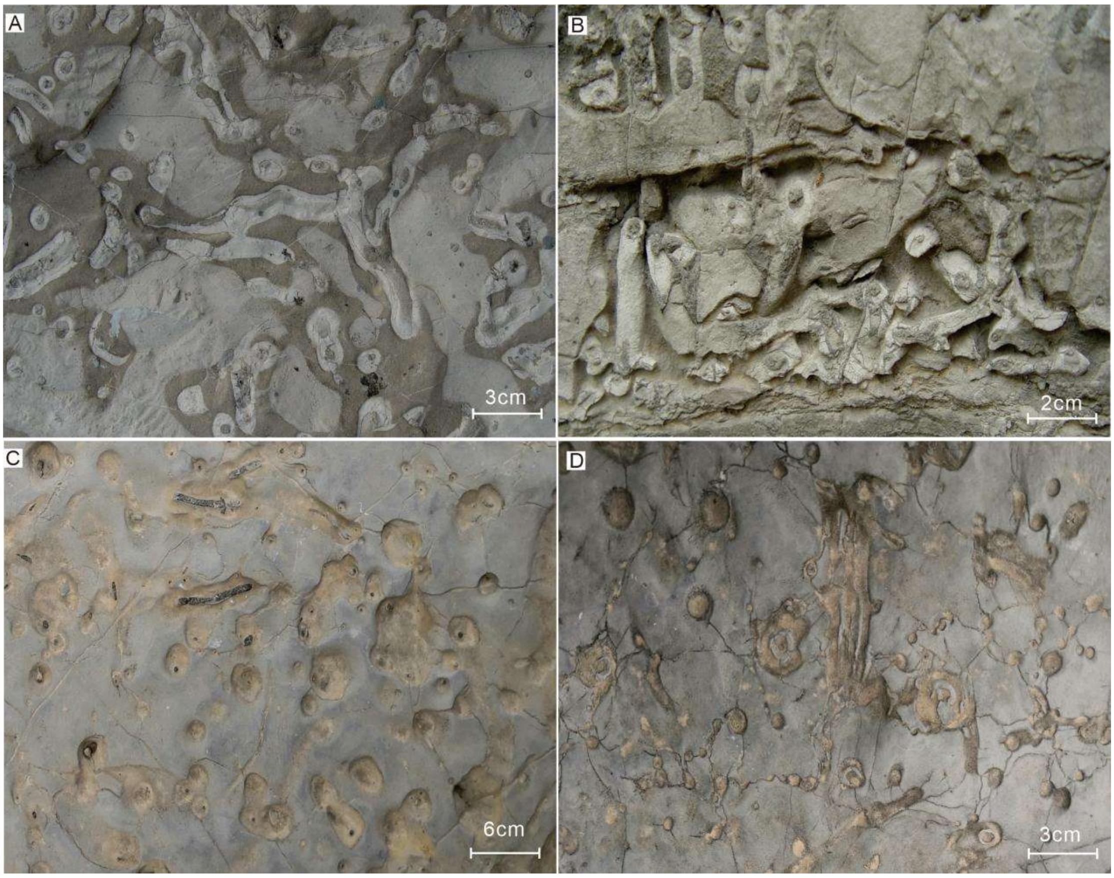

Fig.3 Macroscopic field photographs of T.beace in different regions of the Henan Cambrian Formation.

A. Cross-overlapping of T.beace on the stratigraphic level in the Longmen area. B. Vertical structures are clearly present in the T.beace on the profile section in the Longmen area. C. Point-like distribution of T.beace on the stratigraphic level in the Weihui area, with visible connections between horizontal and vertical tubes. D. Partial point-like distribution of T.beace on the stratigraphic level in the Weihui area, with multiple branching of burrows in a linear pattern.

T.beace in the middle part of the Zhangxia Formation and the Gu Mountain Formation is mostly characterized by a point-like distribution on the stratigraphic level. The burrow walls are smooth and exhibit T-shaped branching points. The diameter of the burrow tubes ranges from 4-6mm, and some show multiple branching phenomena (Fig. 3D). The distance between branching points is highly variable, and the burrow tubes can be straight or curved. There are connections between nearly vertical burrow tubes and horizontal burrow tubes (Fig. 3A-C). Openings of the vertical tubes are visible on the stratigraphic level, with individual vertical tubes ranging from 3-6cm in length. Overall, T.beace exhibits a maze-like structure composed of multiple vertical and horizontal tubes. Vertical structures are clearly visible on the cross-section.

4. Conclusion

In the early Cambrian, Thalassinoides exhibited primarily straight, short forms with few branches and a diameter of a few millimeters. In the middle Cambrian and beyond, Thalassinoides gradually developed into irregular forms with branching patterns such as Y-shaped, U-shaped, and V-shaped. They featured a main channel connected to several branching channels, resulting in complex morphologies and sometimes multiple layers and branching pathways. In the late Cambrian, Thalassinoides commonly displayed V-shaped or Y-shaped forms with multiple branches, reaching

ISSN: 2414-1895 DOI: 10.6919/ICJE.202308_9(8).0010

lengths of several tens of centimeters. The size of Thalassinoides also varied over time, with smaller sizes in the early Cambrian with diameters of a few millimeters. As time progressed, Thalassinoides evolved into larger forms with diameters ranging from several tens of millimeters to centimeters.

The evolution of Thalassinoides occurred in conjunction with geological changes. Initially, Thalassinoides were predominantly found in shallow marine environments but later became widely distributed fossils in various marine settings. Thalassinoides can also be found in sedimentary rocks such as sandstone and mudstone. The population structure of Thalassinoides changed over time, with early forms existing as solitary or scattered individuals that eventually developed into aggregations or colonies.

The functionality of Thalassinoides also underwent evolution. In the early Cambrian, Thalassinoides primarily represented trace fossils formed by burrowing marine organisms, but they later diversified into various types of trace fossils, including meandering traces and probing traces. The systematic evolution of Thalassinoides in the Cambrian can be observed from the appearance of Thalassinoides-like forms in the early period to the emergence of Thalassinoides in the middle period, and finally the occurrence of large Thalassinoides species such as T. suevicus in the late period. These changes reflect the phylogenetic evolution of Thalassinoides. Additionally, the distribution of Thalassinoides was influenced by factors such as marine environments, water depth, and hydrodynamics. Different water depths and environmental conditions resulted in variations in the morphology and size of Thalassinoides. Thalassinoides were more commonly found in shallow marine environments during the Cambrian, while being rare in deep-sea environments. Furthermore, physical and chemical factors in the marine environment, including water temperature, hydrodynamics, salinity, and pH, may have influenced the growth and morphological evolution of Thalassinoides.

Thalassinoides' evolution is also related to the evolution of the contemporaneous biotic communities. In the early stages, trace-making organisms coexisted primarily with algae, sponges, and other lower organisms. In later stages, they lived in association with higher organisms such as trilobites and brachiopods. The interactions between these organisms would have influenced the growth and morphological evolution of Thalassinoides.

During the Cambrian, significant geological events occurred, including glaciations, changes in sea level, and variations in seawater chemistry. These events had important impacts on the evolution and distribution of Thalassinoides. Changes in sea level could have altered the growth environment and ecological niche of Thalassinoides, thereby influencing their morphological evolution. Climate changes during the Cambrian may have also affected the evolution and distribution of Thalassinoides. Temperature fluctuations could have caused changes in their morphology and size, while variations in oxygen levels may have influenced their growth rates and branching patterns.

The controlling factors are complex, and different factors may interact with one another. The relationship between biological behavior and environmental factors may be closely intertwined, and the evolution of biotic communities and geological events can also influence each other. Additionally, the evolution and distribution of Thalassinoides may be influenced by genetic factors, leading to genetic variations among Thalassinoides in different geographic regions. The evolution of Thalassinoides in the Cambrian may also be related to geological structures and changes in sea level. Seismic activities could cause changes in the seafloor environment, thereby affecting the distribution and evolution of Thalassinoides. Variations in sea level could also impact their evolution. In the early Cambrian, global sea levels were relatively low, but as time progressed, they gradually rose, resulting in changes in the distribution and evolution of Thalassinoides during the Cambrian.

In addition to the aforementioned factors, chemical environments and nutrient conditions could also have an impact. In the early Cambrian, seawater had lower oxygen content, and organic-rich sediments were less abundant, potentially limiting the distribution and evolution of Thalassinoides. Furthermore, changes in seawater temperature could have influenced them. During the late Cambrian, global climate gradually cooled, which may have caused changes in the distribution and evolution of Thalassinoides during that time. Earth's physical factors could also affect the evolution of Cambrian

Thalassinoides, including changes in the Earth's magnetic field and plate tectonics, which could result in changes in marine environments and subsequently impact the distribution and evolution of Thalassinoides. Additionally, geological events such as seismic activities and volcanic eruptions in ancient marine environments may also have influenced them.

In conclusion, the evolution of Thalassinoides, a trace fossil from the Cambrian period, is influenced by various factors. These factors include biological behavior, habitat, biological community evolution, geological events, climate change, chemical environment, nutrient conditions, and geophysical factors. In future research, it is necessary to further investigate the interactions and mechanisms of these factors to better understand the history of Cambrian marine ecological environments and biological evolution.

References

[1] Bromley R G, Frey R W. Redescription of the trace fossil Gyrolithes and taxonomic evaluation of Thalassinoides, Ophiomorpha and Spongeliomorpha[J]. Bulletin of the Geological Society of Denmark, 1974, 23(3-4): 311-335.

[2] Sheehan P M, Schiefelbein D R J. The trace fossil Thalassinoides from the Upper Ordovician of the eastern Great Basin: deep burrowing in the early Paleozoic[J]. Journal of Paleontology, 1984: 440-447.

[3] Shipu Yang Fossil Remains in China.[M]. Beijing: Science Press, 2004: 1-417.

[4] Kainan Li. Thalassinoides bacae in the Zhangxia Formation of the Miaolingian Series in western Henan Province and its ecological significance [D]. Henan Polytechnic University, 2019. DOI: 10.27116/d.cnki.gjzgc.2019.000040.

[5] Watkins R , Coorough P J . Silurian Thalassinoides in an offshore carbonate community, Wisconsin, USA[J]. Palaeogeography Palaeoclimatology Palaeoecology, 1997, 129(1):109-117.

[6] Tang R , Zhang J , Yao D U , et al. Thalassinoides Ichnofabrics of Lower Cambrian Longwangmiao Formation(Stage 4,Toyonian)on the Yangtze Platform,South China:Improving Paleoenvironmental Interpretations[J]. 2023, 97(1):13.

[7] Ekdale A A , Bromley R G . Paleoethologic interpretation of complex Thalassinoides in shallow-marine limestones, Lower Ordovician, southern Sweden[J]. Palaeogeography Palaeoclimatology Palaeoecology, 2003, 192(1-4):221-227.

[8] Rodney, Watkins, and, et al. Silurian Thalassinoides in an offshore carbonate community, Wisconsin, USA[J]. Palaeogeography Palaeoclimatology Palaeoecology, 1997.

[9] Judge S A , Richardson J G , Babcock L E . Depositional environments and paleontology of the Bellepoint Member of the Columbus Limestone (Devonian: Emsian-Eifelian) of central Ohio. 2004.

[10] Hu B , Song H , Liu S , et al. Sedimentary facies, ichnofossils and storm deposits in the Lower Permian Taiyuan Formation, Jiaozuo city, Henan Province, central China[J]. Acta Geologica Polonica, 2010, 60(1):45-52.

[11] Robert N , Mariusz S . Triassic crinoids from the Tatra Mountains and their stratigraphic significance (Poland)[J]. Geologica Carpathica, 2016, 57(2).

[12] FT Fürsich. A revision of the trace fossils Spongeliomorpha, Ophiomorpha and Thalassinoides. 1973.

[13] Wiest L A , Buynevich I V . Recent Overprinting of Cretaceous–Paleogene Thalassinoides Framework. 2015.

[14] Curran H A , Frey R W . Pleistocene trace fossils from North Carolina (U.S.A.), and their Holocene analogues. 1977.

[15] Kamola D L . Trace Fossils and Paleoenvironments: Marine Carbonate, Marginal Marine Terrigenous and Continental Terrigenous Settings || Trace Fossils from Marginal-Marine Facies of the Spring Canyon Member, Blackhawk Formation (Upper Cretaceous), East-Central Utah[J]. Journal of Paleontology, 1984, 58(2):529-541.

[16] Bromley R G,Ekdale A A. Chondrites: A Trace Fossil Indicator of Anoxia in Sediments[J]. Science (New York, N.Y.),1984,224(4651).

[17] Crimes T P . ?Late Precambrian-low Lower Cambrian trace fossils from Spain[J]. Trace Fossils Geo Jour, 1977, 9.

[18] Wang Yue, Wang Lian, Shi Xiaoying. "Pioneer Organisms after the Late Devonian F-F Extinction Event in the Dushan Area of Guizhou Province and Their Significance in Ecosystem Reconstruction" [J]. Science in China Series D: Earth Sciences, 2006, 36(4): 11.

[19] Yin Zongjun, Zhao Fangchen. "The Origin of Animals and the Cambrian Explosion - Preface" [J]. Acta Palaeontologica Sinica, 2021, 60(01): 1-9. DOI: 10.19800/j.cnki.aps.2021022.

[20] Fan Yuchao. "Biogenic Structures and Sedimentary Substrate Evolution of the Second Member of the Cambrian Zhu Shadong Formation in Henan" [D]. Henan Polytechnic University, 2021. DOI: 10.27116/d.cnki.gjzgc.2021.000064.

[21] Guo Wenfei. "Architecture and Geological Significance of the Second Interval Balanoglossites Trace Fossils in the Cambrian Miaoling Formation, Western Henan" [D]. Henan Polytechnic University, 2021. DOI: 10.27116/d.cnki.gjzgc.2021.000231.

[22] Di Tong. "Study on Trace Fossils of the Second and Third Members of the Cambrian Mantou Formation in Lushan, Henan" [D]. Northwest University, 2020. DOI: 10.27405/d.cnki.gxbdu.2020.001787.

[23] Liu Bingchen. "Benthic Ecosystem Engineers after the Cambrian Biological Explosion" [D]. Henan Polytechnic University, 2020. DOI: 10.27116/d.cnki.gjzgc.2020.000133.

[24] Zhang Xiyang, Qi Yong'an, Dai Mingyue, Chai Shu. "Coupling Variations of Nucleiforms and Trace Fossils in the Cambrian Zhangxia Formation, Dengfeng, Henan Province" [J]. Journal of Micropalaeontology, 2015, 32(02): 184-193. DOI: 10.16087/j.cnki.1000-0674.2015.02.007.

[25] Yu Hezhong, Han Shouhua, Xie Jinlong, et al. "Prototype Sedimentary Basin Types and Tectonic Evolution in the Southeastern Margin of the North China Plate" [J]. Petroleum and Natural Gas Geology, 2006, 27(2): 244-252.

[26] Liu Yican, Wang Chengcheng, Zhang Pingang, et al. "Crustal Growth and Metamorphic Evolution of the Lower Precambrian in the Southeastern Margin of the North China Craton" [J]. Acta Petrologica Sinica, 2015, 10.

[27] Cheng Shixiu, Li Sanzhong, Xu Liqing, et al. "Intracontinental Deformation and Transition Mechanism in the Taihangshan-Qinling Belt during the Cenozoic" [J]. Geological Review, 2014, 60(6): 1245-1258.

[28] Chen Xiaowei, Mou Chuanlong, Ge Xiangying, et al. "Distribution Characteristics and Controlling Factors of the Cambrian Third Member of the Nodular Shoal in North China" [J]. Journal of Oil and Gas Technology, 2012, 34(11): 8-14.

[29] Liu Yinhuan, Wang Jianping. "Division and Significance of Cambrian Biota in Henan Province" [J]. Sedimentary and Tethyan Geology, 1990, 2.