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The Current Status and Development of Research on Trace Fossil

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Abstract

In recent years, the progress of trace fossil is more and more remarkable. It is not only the evidence of biological activities and evolution on earth, but also the sedimentary structure that can be used to analyze the formation conditions of lithofacies and explain the sedimentary environment. Biological disturbance can not only reconstruct and break the sediments, but also reconstruct the sediments, which is an important part of sedimentology research. Nowadays, only the analysis and classification of the morphology and habits of vestige fossils cannot meet the requirements. Many scholars have begun to pursue a broader study of vestige fossils. For example, the birth of relic fabric has brought the study of relic fossils into a new world. In addition, the analysis and reconstruction of the paleoenvironment, paleowater depth, paleoclimate and paleotemperature by using the remains fossils are also the top priorities of current research.

Keywords

Trace fossils, Sedimentary, Evolution.

1. INTRODUCTION

Fossils, also known as trace fossils, are traces left by ancient organisms during various life activities in the lower layers or on the bottom surface. These traces are filled and buried by sediment and undergo later diagenesis to form fossils[1]. The ways in which ancient organisms leave traces of their life activities generally include 10 types: running, which can be further divided into running within layers and running on surfaces; walking; crawling, where organisms use their toes or appendages for crawling movements, often without body contact with the ground; undulating, where a part of the organism's body touches the ground; resting; foraging; feeding; dwelling; swimming; and flying[2]. Various types of trace fossils (ichnofossils) can be formed by these life activities on the bottom surface.

Trace fossils, which are preserved and buried together, are important for analyzing ancient environments. These trace fossil assemblages represent biotic communities that lived in situ, and the ancient environments they reflect are the original habitats of the trace-making organisms. Therefore, they serve as reliable index fossils for paleoenvironmental interpretations. Thus, trace fossils have become an important discriminant in the analysis of ancient environments[3].

The study of the relationship between trace fossils and sedimentary environments and sequence stratigraphy has described a large number of trace fossils and established various local trace fossil assemblages. Trace fossil

assemblages are not only a part of lithofacies paleogeography but also an important aspect of ichnology [4]. By investigating the formation mechanisms, preservation conditions and modes, as well as the spatial and temporal distribution patterns of biogenic structures, trace fossils can be used to explore and analyze ancient sedimentary environments. They have the

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advantages of being simple, reliable, and highly accurate in methodology, and have broad prospects for applications in geological exploration of oil, gas, and coal fields.

2. THE CURRENT STATUS OF RESEARCH ON TRACE FOSSILS

The scientific confirmation of trace fossils can be traced back to the early 20th century, but initially, it was limited to the description of some vertebrate footprints (such as dinosaurs) and carnivore bite marks. Many genuine trace fossils were classified as pseudofossils or dubious fossils. In the early decades of this century, German paleontologists Abel and Richter observed and studied biogenic structures in modern unconsolidated sediments, confirming that many similar structures in ancient rock formations were caused by biological activity. This greatly enhanced our understanding of trace fossils in geological history[5].

In the 1950s and 1960s, a series of works by German paleontologists Hantzschel and Seilacher established traceology as an independent discipline, which still influences the thinking of many contemporary researchers. Seilacher first proposed the environmental model for the depth distribution of marine trace fossils, which stimulated numerous productive research efforts. The study of trace fossils has various significances, and its interpretation of sedimentary environments is an important aspect. Except for coprolites (fossilized feces), trace fossils are preserved in situ. They not only reflect the behavior patterns of organisms but also provide insights into the substrates they relied on for survival. These aspects are directly influenced by environmental factors, making them closely related to sedimentation[6]. The environmental interpretation of trace fossils relies on the distribution patterns in known geological environments and studies of modern trace distributions. The combination of these two aspects provides a comprehensive set of traceological standards for evaluating environmental parameters. It is widely recognized that changes in trace fossil types or assemblages can reflect properties of the substrate, environmental energy, sedimentation rates and variations, bottom water chemistry, and water depth. Due to the unique advantages of trace fossils (ichnofacies) in environmental interpretation, their study has gained attention in the field of oil and gas exploration, and numerous research efforts are closely related to global oil and gas exploration. Seilacher's model has been tested, supplemented, and refined, leading to more comprehensive schemes today.

3. THE APPLICATION OF TRACE FOSSILS IN THE ANALYSIS OF SEDIMENTARY ENVIRONMENTS

The interpretation of sedimentary environments using trace fossils relies on the distribution patterns of known geological environments and research on the morphology, behavior, and distribution patterns of modern organisms. The types and variations of trace fossils can reflect certain properties and changes in sedimentation processes, such as sediment substrates, sedimentation rates, and environmental energy[7]. The appearance of trace fossil assemblages marks a new phase in the study of trace fossils, where scholars are no longer limited to analyzing the characteristics of individual trace fossils but are exploring various aspects by considering various biological activity structures, including bioturbation.

The significant importance of trace fossils in sequence stratigraphy has attracted widespread attention from experts both domestically and internationally. While there is a close relationship between the two, the integration of their research is still in the exploratory stage. Studies have shown that trace fossils exhibit sensitive indicators of environmental changes caused by dynamic sea-level fluctuations, known as "trace fossil events," providing important evidence for the delineation of sedimentary system tracts and the identification of depositional environments[8].

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Trace fossils are highly responsive to the environment, and under similar sedimentary conditions, similar combinations of trace fossils often occur. If influenced by periodic sedimentation processes, the same types of trace fossils can be repetitively observed in vertical sequences, indicating cyclic variations[9]. This characteristic aids in the analysis of stratigraphic cyclicity, particularly in high-frequency cyclicity studies. Additionally, as mentioned earlier, trace fossils provide sensitive indicators of substrate properties. By observing the vertical changes in trace fossil types, it is possible to indicate a series of changes in sediment substrates, such as from soft substrates to firm substrates to hard substrates. This can reveal sedimentary hiatuses, which are of significant importance in sequence analysis[10].

4. TRACE FOSSILS IN FLUVIAL-LACUSTRINE DEPOSITION

Non-marine trace fossils can be divided into two categories: terrestrial and underwater. Terrestrial trace fossils exhibit the following characteristics: (1) burrows often lack lining and have irregular boundaries, (2) burrow walls often show signs of erosion, scratching, or excavation, (3) open tunnels, (4) loose fillings without active filling features, (5) co-occurrence with terrestrial sedimentary features such as desiccation cracks and raindrop impressions, and (6) commonly preserved as surface or full traces. Trace fossils found in underwater environments are similar to marine subaqueous trace fossils, with differences in degree of differentiation and individual size. Apart from large perennial lakes, which may have depth zones similar to the marine environment, other sedimentary environments in terrestrial settings lack such conditions, making it difficult to define trace fossil zones based on water depth factors.

Since the early 1980s, research on fluvial sedimentary trace fossils has increased significantly. Trace fossils in fluvial sediments are considered non-diagnostic and unrelated to any specific environment. One characteristic of trace fossils in fluvial environments is that the depth of disturbance caused by trace-making organisms is generally greater compared to lacustrine environments, although the intensity of disturbance is generally lower. The trace-making organisms in fluvial and lacustrine environments mainly consist of insects and their larvae, as well as arthropods and their larvae[11]. The evolution of trace fossil assemblages in terrestrial environments complements and enhances the understanding of benthic organism ecology in terrestrial settings. The identification of prototype, repetitive, or Seilacherian trace fossil facies within continental settings has been a topic of substantial debate. By the 1990s, the recognition of prototype trace fossil facies of invertebrates in continental sediments had gained general acceptance in the scientific community.

Fossils identified in fluvial sediments mainly involve trace fossils of invertebrates and so-called prototype vertebrate fossils. Some recently proposed fossils lack progressive characteristics according to current definitions[12]. Lake environments are complex systems in which the distribution of flora and fauna is influenced by both abiotic factors (such as energy, light, oxygen, temperature, salinity, substrate, and nutrients) and biotic factors (such as competition, grazing, predation, and symbiosis). Lake systems differ from marine systems in several aspects, including the volume of sediment in lakes, the direct link between water levels and sediment supply, and the possibility of shoreline migration not solely due to regression.

5. PALEOCLIMATE AND PALEOSOL

Global climate change and its impact on biodiversity and ecosystems are forefront issues in 21st-century scientific debates and international governmental decisions[13]. Geological records provide the best archive of how life and ecosystems have responded to global cooling or warming, but much of the attention has been focused on the Cenozoic era. This is because ice

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cores, tree rings, corals, pollen, and other climate archives are best preserved and continuous in sedimentary records over the past million years or so.

However, deep-time paleoclimate records are also crucial as they provide a record of long-term climate change and the response of organisms and ecosystems to these perturbations. In general, paleobiological, lithological, and geochemical evidence serve as primary indicators of paleoclimate and global change. Fossils are the most direct and closest indicators of past climates, as they are used as sensitive proxies for paleoclimate through taxonomic, ecological, and paleobiogeographic concepts applied to continental trace fossils[14]. Understanding paleosols (ancient soils) is instrumental in interpreting paleoclimate records. However, continental trace fossils occurring in many paleosols have not been fully utilized in this regard. This is because these trace fossils have not been effectively linked to the sediments in which they are found, nor have they been considered as potential biological archives of paleoclimate data.

There is currently limited research on the relationship between soil trace fossil assemblages and paleoclimate. However, a hypothesis can be proposed that climate-sensitive soil trace fossil assemblages could serve as a catalyst for testing potential paleoclimate indicators. This also implies the need for research that integrates neoichnology (the study of modern trace fossils) with soil science and climatology to develop more temporally extensive climate proxies[15]. Continental trace fossils not only represent the diversity of organisms buried in situ but also record the interactions of sediments under the influence of past climatic conditions.

Fossil soils, also known as paleosols, are the products of natural landscapes during geological history. They record the influence of factors such as parent material, climate, biotic communities, topography (including drainage conditions), and time on surface materials during their formation period. Therefore, some consider paleosols as trace fossils of the ecosystems during geological periods and powerful tools for reconstructing ancient environments. Unlike sedimentary rocks, paleosols are the upper part of weathered crust that has undergone soil formation processes, exhibiting distinct soil horizons[16]. This unique horizon structure and formation process make paleosols contain geological information that is not easily obtained from typical sedimentary rocks, and it is this special geological information that has generated significant interest among geologists regarding paleosols. Over the years, paleosols have been widely applied in studies related to paleogeomorphology reconstruction, paleoclimate analysis, and the evolution of ancient plants. The value of paleosols in sequence stratigraphy, sedimentation rates, chronostratigraphy, and stratigraphic correlation analysis has also been recognized by geologists.

Although there has been an increased interest in paleosols over the past decade, there is currently no satisfactory classification method. The commonly used classification method utilizes soil formation characteristics with the highest preservation potential in the rock record. This classification is based on the relative prominence of six soil-forming features or processes: organic matter content, horizonation, redox conditions, in-situ mineral alteration, deposition of insoluble minerals or compounds, and accumulation of soluble minerals[17]. Four of these categories (organic soil, gleyed soil, oxidized soil, humus soil) are borrowed from soil classification, while the remaining five categories (calcic soil, gypsiferous soil, buried soil, argillic soil, and saprolite) are introduced for the first time. This classification method is suitable for easily accessible rock records and contributes to standardizing terminology. However, the current paleosol classification is integrated with modern soil research and may not adapt well to the inherent variations in rock formation processes. Therefore, it is necessary to re-evaluate the classification based on criteria more favorable for paleosol research, which will form the foundation for defining a more applicable classification method in the future.

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6. CONCLUSIONS

Fossilized traces, as unique materials reflecting biological and environmental events, play an important role in studying the development process and mechanisms of the environment. Although they may not serve as standard fossils like physical remains, they hold significant paleontological significance. Currently, fossilized traces not only have an impact on the study of ancient life forms and behaviors, but their application in research on paleoecology and paleoclimate has become a highly important field of work. By studying the diverse behaviors, burial mechanisms, and characteristics of ancient organisms, it is possible to establish a logical system for classification, which can be used to explain the interaction between ancient organisms and sediment, uncover the paleoecological and paleoclimatic characteristics of fossilized traces during their developmental stages, and ultimately build a bridge between paleontology, sedimentology, and sequence stratigraphy. Research on fossilized traces will certainly not stop here, and in the future, exploration will undoubtedly uncover even more aspects.

REFERENCES

[1] Yue, Y. D. Current Research Status and Future Development Trends of Sedimentary Geology. Heilongjiang Science, 2018, 9(01): 9-10.

[2] Zhang, J. P., Li, M. L. Current Research Status and Application Potential of Taphonomy in Sequence Stratigraphy. Acta Sedimentologica Sinica, 2000(03): 389-394.

[3] Bai, Z. K. Formation and Significance of Trace Fossils. China Mining News, 2018-11-09 (008).

[4] Bai, Z. K. Trace Fossil Assemblages. China Mining News, 2019-11-06 (007).

[5] Bai, Z. K. Historical Development of Taphonomy. China Mining News, 2018-11-02 (008).

[6] Yang, S. P. Paleotaphonomy. Beijing: Geological Publishing House, 1990.

[7] Yang, S. P. Trace Fossils and Their Significance in Paleoenvironmental Analysis. Acta Sedimentologica Sinica, 1984(04): 8-18+127-129.

[8] Shi, Z. S., Hu, B., Qi, Y. A., Zhang, G. C. Paleoenvironmental Significance of Macaronichnus Trace Fossil Assemblages. Journal of Jiaozuo Institute of Technology (Natural Science Edition), 2002(02): 98-100.

[9] Zhang, G. C. Trace Fossil Assemblages in the Upper Cretaceous River and Lake Sediments of the Xixia Basin, Henan Province. Henan Province, Henan Polytechnic University, 2009-01-01.

[10] Zhang, G. C., Li, J. L. Recent Advances in the Study of Continental Trace Fossil Assemblages. Geological Science and Technology Information, 1997(04): 50-55.

[11] Wang, D. S., Zhang, G. C. Paleosol Characteristics of the Middle Triassic Oilfanzhuang Formation in the Jiyuan Basin. Journal of Henan Polytechnic University (Natural Science Edition), 2005(04): 278-282.

[12] Qi, Y. A., Hu, B., Zhang, G. C., Gong, Y. M. Trace Fossil Assemblages and Their Environmental Interpretation in the Middle Triassic Oilfanzhuang Formation, Jiyuan Area, Western Henan. Acta Sedimentologica Sinica, 2007(03): 372-379.

[13] Xing, Z. F., Lin, J., Zhou, H., Li, D., Qi, Y. A., Zheng, W. Sedimentary Records of Late Permian-Late Early Triassic in Yiyang Area, Western Henan, and Their Response to Paleoclimate Change. Geological Journal of Universities, 2019, 25(03): 401-411.

[14] Hu, B., Zhang, G. C., Guo, W. X., Qi, Y. A., Zhang, L. W. Stipsellus Trace Fossil Assemblages in the Fluvial Sediments of the Tanchuang Formation, Jiyuan Area, Western Henan. Coal Geology & Exploration, 2004(03): 1-5.

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[15] Hu, B., Qi, Y. A., Zhang, G. C., Jiang, Z. X. Trace Fossil Communities in Terrestrial Sediments of China from the Mesozoic to the Cenozoic. Acta Sedimentologica Sinica, 2002(04): 574-581.

[16] Wu, X. T., Zhang, G. C., Lin, Y. L. Discovery of Plant Trace Fossils and Paleosols in the Lower Tertiary Shahejie Formation of the Dongpu Depression and Their Environmental Significance. Journal of Jiaozuo Institute of Technology, 1998(02): 3-5.

[17] Hu, B., Wang, Y. Y., Song, H. B. Trace Fossil Assemblages and Trace Fossil Associations in Terrestrial Sediments of China. In: Proceedings of the 1st International Symposium on Paleogeography. China University of Petroleum (Beijing): Stratigraphy and Paleogeography Professional Committee of China Mineralogy, Petrology, and Geochemistry Society, 2013: 3.

[18] J. A. Crame. Palaeoclimates and their modelling: With special reference to the Mesozoic ERA, J. R. L. Allen, B. J. Hoskins, B. W. Sellwood, R. A. Spicer & P. J. Valdes (eds). Chapman & Hall (London), 1994. No. of pages: ix + 140 pp. Price: £35.00. ISBN 0–41256–330–4[J]. J. A. Crame,1995,15(6).