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Evolution of marine and terrestrial geobiodiversity in the history of the earth

People have long been curious about the history of life on the earth—how many different species have existed, when they first occurred, how they evolved over geologic time, and how they reacted to major environmental crises. Although tremendous progresses have been made during the past decades, mysteries in evolution of life abound that remain to be deciphered. Millions of different types of organisms that inhabited the earth during the long geologic time have been recorded. Scientists have strived to develop the principles and theories in helping us understand how life has evolved in response to its living environment. Life on earth originated from organic structures more than three billion years ago and was first developed in the sea. All inferences of terrestrial ecosystem prior to the Middle Silurian come from indirect evidence. From the Middle Silurian onward, vascular plants began to develop on land. Since then, the marine and terrestrial ecosystems have become the two most important interplayed parts of the biosphere. The co-evolution of marine and terrestrial biodiversities as well as interactions with their living environments has become one of the most intriguing subjects for paleontologists, for it bears importantly on understanding current, and anticipating future, human-induced environmental changes.

During the past three decades, one major breakthrough in paleontology is the establishment of the database of the Phanerozoic marine fossil invertebrates by Jack Sepkoski. He and his colleagues recognized in 1980s that the stratigraphic distributions of biodiversity during the Phanerozoic is very uneven based on numbers of marine families within 91 metazoan classes known from the Phanerozoic fossil record. The geologic record displayed that geobiodiversity rapidly increased after the Snowball Earth in the Neoproterozoic. It was succeeded by an intriguing array of extinctions, biological radiations, and biogeographic shifts that have restructured ecosystems in the context of atmospheric chemistry, oceanic structures, land-sea configurations and changing climates. This kaleidoscopic history reflects the constant interaction between life and environment. Since then, study of the interplay between life and environment during the long history of the earth has been regarded as the key to unraveling the mechanism of biological evolution. It is also emerging as an especially important field in earth sciences.

Although major discoveries in paleontology have been made in China during the last three decades, progress has been slow in the area of macroevolution studies because of lack of integrated approaches. Thus, it is reasonably expected that the study of biodiversity evolution in the earth history would have progressed more rapidly and broadly if paleontologists with varied interests and expertise had worked together. Many major scientific problems that otherwise would have eluded a specialist on a narrow fossil group alone have recently become possible to tackle, thanks to the cooperation among paleontologists studying different fossil groups and the collaboration with experts in related fields such as geochemistry, plate tectonics, paleoclimatology and geochronology. The value of integrative research on the earth-life system is quite evident.

China is one of a few countries with the most complete geologic record containing the most abundant fossil resources. Previous studies of biodiversity patterns largely neglected the data from China. This is unfortunate, for regional studies certainly bring to light global phenomena because global patterns are pieced together through integration of regional studies. To investigate major biological evolutionary patterns in China, a first National Basic Research Program of China (973 Project) entitled “Origin, radiation, extinction and recovery of critical intervals during the geologic time” was funded by the Ministry of Science and Technology (MST) of China in 2000. This represents the first large national project on paleontology. More than 70 Chinese colleagues joined the project and focused their studies on paleontology based on geologic records in China. The project successfully achieved a number of breakthroughs and significant discoveries in the studies of the origin and radiation of life, the mass extinctions and their subsequent recoveries in the Phanerozoic. On the basis of the great success of the first 973 Program, the second 973

Program with the title "Evolution of marine and terrestrial geobiodiversity in the history of the earth" was approved by MST. The overarching strategy of the second 973 Program is to study multiple, interconnected components of the life system based on close collaborations among different researchers and to bring different expertise and resources in China together to focus on critical scientific issues in paleontological studies. In particular, it aims to organize a national research group to carry out further multidisciplinary integrative studies on some major macroevolutionary events in the earth history such as origin of early major fossil groups, the Cambrian explosive radiation, evolution of early vertebrates, mass extinctions, biological recoveries, the Jehol Biota, origin of modern humans, and co-evolution of marine and terrestrial ecosystems, etc.

Seventeen papers are included in this special issue. It represents some of the most recent advances produced by participants of this project during the past five years. The topics in this issue cover the geologic time ranging from the Proterozoic to Late Pleistocene. Origin of major fossil groups during the early geologic time has long been one of the hottest topics. Gong et al. studied abundant sphaeroidal acritarch from the Proterozoic Liulaobei Formation before the Snowball Earth event in Huainan, Anhui Province with TEM/SEM observation. They found that the Liulaobei leiosphaerids are of green microalgae based on the wall ultrastructures. Hua et al. described some vase-shaped microfossils in the Gaojiashan Member of the late Ediacaran Dengying Formation (~551–541 Ma) in southern Shaanxi Province. Two types of wall structures, i.e., calcareous and agglutinated, were identified in the vase-shaped microfossils, which are comparable to the wall structures of foraminifera. Therefore, they suggested that these vase-shaped microfossils might represent the earliest record of foraminifera. The Chengjiang Biota represents the first exceptional preservation of abundant soft-body fossils in the Cambrian. Nearly all animal phyla including many other unclassified fossil groups appeared in the fossil record for the first time. Ma et al. reviewed 45 Chengjiang vermiform animals discovered so far and discussed their phylogeny, systematic taxonomy and modes of life of the priapulid and lobopodian phyla. Hu et al. reviewed the fossil assemblage and taphonomy of the Guanshan Biota, which has become another important Burgess-Shale-type fossil Lagerstätte in eastern Yunnan, China, following the discovery of the Chengjiang and the Kaili biotas. On the basis of published data and field sampling data from the Chengjiang-Haikou-Anning area, Zhao and Zhu quantitatively analyzed the paleocommunity structure and the taxonomic composition of the Chengjiang Biota. They concluded that complex food web and high competition were already present in the early Cambrian communities.

The Ordovician Period featured an adaptive radiation characterized by a dramatic marine faunal increase at genus level, which was ended by the end-Ordovician mass extinction. Zhan et al. reconstructed the temporal and spatial distributions of the extremely important *Hirnantia* Fauna on the upper Yangtze Platform, South China. This fauna is a globally-represented, cool-water brachiopod fauna that flourished in shallow marine environments after the first episode of the end-Ordovician mass extinction, but became extinct in the second phase close to the Ordovician-Silurian boundary after the glaciation. Zhang et al. investigated the biodiversity and paleobiogeographical distributions of Ordovician graptolites in different environments from nearshore to deep basin. They concluded that the biodiversification and distributions of graptolites are closely related to the sea-level change and water depth.

The evolution of biodiversities of both terrestrial and marine ecosystems in response to environmental change is a theme of the second 973 Program. Wang et al. quantitatively analyzed the diversity pattern of land plant fossils from Silurian to Permian in South China. They revealed that vascular plant fossils experienced a steady increase stage in the Paleozoic in South China, but were seriously interrupted by the Frasnian/Famennian and the end-Permian mass extinctions. Qiao and Zhu analyzed the cranial morphological features of the Silurian stem-group sarcopterygian *Guiyu oneiros* Zhu et al., including the dermal bone pattern and anatomical details of the ethmosphenoid. Ma and Zong grouped five brachiopod biozones from the Devonian Givetian through the middle Famennian in Hunan Province. They concluded that eustatic fluctuation is the major factor in controlling the distribution of brachiopods in the Devonian in Hunan Province. Wang et al. specifically summarized the distribution of an important solitary coral fauna, the *Cyathaxonia* fauna, in the Carboniferous and Permian in China. This fauna was traditionally regarded as a typical fauna in the Gondwanan or peri-Gondwanan region, but was actually related to deep, mud-rich, quiet environment. Shen et al. provided a comparison for the recurrent biological, geological and geochemical events which occurred in the Neoproterozoic-Cambrian and Permian-Triassic transitions. They suggested that continental re-configuration and vast volcanism, triggered by internal mantle dynamics, caused the drastic environmental changes and major biological re-organization on the earth's surface in these two transitions. Large-scale glaciations were usually coupled with low biodiversity, but drove rapid increase of biodiversity during the subsequent transition into the greenhouse stage. Zhao and Tong analyzed the diversity of trace fossils across the Permian-Triassic transition at Meishan, Zhejiang. They recognized two episodes of intense changes of trace fossils in abundance and diversity, which coincide with the negative excursion of carbon isotope.

In the past two decades, the Late Mesozoic Jehol Biota of northeastern China has become the most spectacular lagerstätte of fossil birds, dinosaurs, pterosaurs, mammals, insects, and flowering plants in the world. Zhou and Wang presented a most updated summary of the vertebrate assemblage of the Jehol Biota. Their analysis showed that at least 121 genera and 142 species of vertebrates have been recorded. Those highly-diverse vertebrates played a critical role in the evolution of the Cretaceous terrestrial ecosystem. Zhang et al. did a quantitative analysis of insects of the Jehol Biota. Three different evolutionary stages are recognized based on the biodiversity patterns and community structures of insects.

In the aspects of Cenozoic mammals and origin of modern humans, Wang et al. recognized 12 different mammal-bearing horizons in the Paleogene strata in the Huheboerhe area, Erlian Basin, Inner Mongolia. They provided a basis to establish potential high-resolution mammal succession for Paleogene in that area. They concluded that the abrupt emergence of many modern mammalian orders at the beginning of the Eocene is probably related to the Paleocene-Eocene Thermal Maximum. Gao et al. made a comprehensive review on the history and current development on the issue of modern human origins. Based on hominid fossil evidence, associated faunal remains and artifacts collected in China, and genetic research results, they reassured that the evolution of ancient humans in China and East Asia is a process of continuity of local populations with occasional gene admixture with outside migrated groups (continuity with hybridization). They further proposed a regional diversity model for modern human evolutions in the Old World.

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