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Editorial

Ecosystem revolution and evolution in the Early–Mid Paleozoic

The Early–Mid Paleozoic, spanning approximately 180 million years from the Cambrian to Devonian, was marked by several revolutionary events that re-shaped and defined global ecosystems; each event triggered a series of macroevolutionary processes and interactions in the biosphere. Following the rise and fall of the Ediacara Biota, a host for the precursory metazoan experimentation, the Cambrian Explosion saw the appearance of virtually all the phyla in the animal kingdom. In the past two decades, a rapid expansion of our knowledge about this key biodiversity explosion has been increased through innovative research on the Small Shelly Fauna that contained many stem groups for many major animal body plans in the early Cambrian Chengjiang and Sirius Passet biotas; these biotas demonstrate the early and largely simultaneous proliferation of a wide range of animal groups from protostome (e.g., worms, molluscs, arthropods) to deuterostome (e.g., echinoderms and chordates) animals (Chen, 2004). This drastic explosion of animal body plans continued into the well-known mid-Cambrian Burgess Shale Fauna, the Kaili Fauna, and others (Gould, 1989, 2001).

If the Cambrian Explosion established all the major branches in the tree of animal life, it was during the Great Ordovician Biodiversification Event (GOBE), which spanned some 40 million years, that these branches flourished into a full canopy, characterized by an exponential increase in the number of orders and families (Harper, 2006). The GOBE was highlighted by several diversity acmes, and established the basic framework of the Paleozoic Evolutionary Fauna (PEF) that dominated the marine ecosystem for more than 290 million years. This ecosystem revolution was accompanied also by a major diversification of phyto- and zooplankton (Servais et al., 2008), extending the complexity and robustness of marine food web. The end-Ordovician mass extinction was the first catastrophic event in life history, characterized by a substantial loss of total biodiversity, if not a severe collapse of ecosystem and paleocommunity structures (Sepkoski, 1993; Alroy et al., 2008; Alroy, 2011; McGhee et al., 2012, 2013; Harper et al., 2014). Throughout the Cambrian and Ordovician biotic radiations, the shallow-marine metazoan reef ecosystems also evolved rapidly, from mounds dominated in the early Cambrian by archaeocyathids, to the Early Ordovician sponge-dominated mounds, through the Mid-Ordovician bryozoan-dominated buildups, and finally to the complex coral-stromatoporoid-calcimicrobe reefs in the Late Ordovician, which expanded into the largest known reef complexes in Earth history by the Devonian. The Cambrian–Ordovician ecosystem transition was also marked by a marine substrate revolution, brought about by the expansion deep burrowing/tiering from shallow near-shore habitats to deeper, mid- to outer shelf settings, probably associated with a combination of increased oxygenation of the deeper water mass and increased complexity of the rapidly evolving animal body plans. This is reflected by the remarkable shift from the near-shore *Skolithos* ‘piperock’ and deeper shelf flat pebble conglomerate (FPC) facies in the Cambrian and Early Ordovician to the deeper shelf *Thalassinoides* facies by Mid–Late Ordovician time (Jin et al., 2012).

Global ecosystem underwent further revolution during the Silurian and Devonian, represented by the rise of fishes and land plants. These events resulted in a drastic change in the top predators in the aquatic food web from invertebrates (e.g., nautiloids and eurypterids) to vertebrates (jawed fish) (Zhao and Zhu, 2014), whereas spreading of land plants paved the way for major transitions towards the modern land ecosystem, and also altered the direction and nature of the pathways of numerous global cycles, such as the oxygen, carbon, and nitrogen cycles, as well as the nature of continental weathering and erosion. Most of the ecosystem revolutions and evolutions in the Early–Mid Paleozoic were intimately linked to global and regional tectonics and orogenic events, drastic swings from super greenhouse to icehouse episodes, and related sea-level fluctuations up to several hundred meters of amplitude, which are not known recorded in more modern geological history (Jablonski, 2003). To investigate these globally significant events in Earth history, geoscientists worldwide have cooperated over a number of years to conduct multidisciplinary research to help understand the processes and causes of such events. The current International Geoscience Program (IGCP) Project 591 is a continuation of two previous projects, IGCP 410 and 503, and is an important part of this international cooperation. It includes a wide range of studies, such as litho-, bio- and chronostratigraphy (including the revision of global stratotype sections and points in collaboration with the International Subcommissions

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on Cambrian, Ordovician, and Silurian stratigraphy), paleontology and global biodiversity change, paleoecology, geochemistry and tectonics. As part of the internationally coordinated study on Early–Mid Paleozoic revolutions, an IGCP Project 591 Field Workshop was held in Kunming in mid-August 2014 with 128 delegates from 18 countries, which was followed by a highly successful field excursion to northeastern and western Yunnan Province to investigate the Lower Paleozoic lithostratigraphic and biostratigraphic successions of the South China, Indo-China and Sibumasu paleoplates. The current proceedings volume was derived from those presentations during a two-day scientific program, and showcased some of the important recent advances and discoveries by Lower Paleozoic experts from many countries.

Among the 23 contributions included in this proceedings volume, seven are dealing with the Cambrian research, nine with the Ordovician, and seven with the Silurian, on topics ranging from paleontology, stratigraphy, and general geology. The international community of Cambrian researchers has been focusing on the establishment of a high-resolution chronostratigraphic framework for the system by refining and revising global stratotype sections and points (GSSPs), in addition to such ongoing research hotspots as the origin and early evolution of some key fossil groups (detailed systematic studies), the timings, processes, patterns, and causes of some major biotic events including the Cambrian Explosion and the later Cambrian extinctions. In this volume, many enigmatic organisms in the Chengjiang and Kaili biotas have received attention, such as the vetulicolians studied by Li et al. (2015), the sponges and sponge-like fossils by Chen and his international collaborators (2015), the puzzling *Tuzoia* by Wen et al. (2015). Other Cambrian studies involved more commonly known fossil groups, complementing our understanding of this early ecosystem, as exemplified by the unusual association of hyolithids with diverse ichnofossil assemblage in the Balang Biota of South China (Sun et al., 2015), and some strange forms of trilobites documented by Laibl et al. (2015) from Czech Republic. Li et al. (2015) break new ground in their work on early metazoan evolution through a comparative study of various types of Cambrian Lagerstätten, such as the Chengjiang and Guanshan biotas, which enabled them to recognize some unique morphotypes in the early evolution of these assemblages. Babcock et al. (2015) emphasized the critical importance of developing a high-resolution Cambrian chronostratigraphy as an intercontinental framework for correlating global geological and biotic events. To reach this goal, Cambrian experts are now conducting a synthetic stratigraphic investigation worldwide, using not only traditional paleontology and biostratigraphy, but also sedimentology and cyclostratigraphy. Babcock and his coauthors (2015) proposed that the climatic and sea level cycles may be closely related to the macroevolution of a series of Cambrian biotas. Põldsaar and Ainsaar (2015) suggested that soft-sediment deformation structures are good indicators of ancient environments, particularly depositional environments.

Ordovician research has been highlighted by two major biotic events during the past three decades, i.e., the Great Ordovician Biodiversification Event (GOBE) and the end-Ordovician mass extinction. Our synopsis (Harper et al., 2015) summarizes the GOBE, i.e., the Ordovician Radiation, emphasizing a few major characters including its duration, diversity pattern, and dynamics. To build sustainable development in this area, we highlight a series of promising research directions for future investigations on this critical interval in Earth history. Nevertheless, detailed systematic studies on fossil groups are one of the most important aspects of the essence of these major biotic events, providing new data to frame and test hypotheses. For example, Wang and Muir's (2015) report on the Early Ordovician graptolites from South China, Sproat and his collaborators' (2015) careful study of the Katian brachiopod genus *Parastrophina* from three major continents (North America, Kazakhstan, and Tarim), and Muir and Botting's (2015) synthetic analysis on the Welsh Ordovician Porifera, will be helpful in building a better understanding of the first and the third diversity acmes of the Ordovician Radiation, respectively.

Although all Ordovician GSSPs had been agreed by ISOS prior to 2007, there are still many unresolved problems associated with the high-resolution regional correlation of Ordovician successions (Bergström et al., 2009). Thus, Ordovician experts are applying multidisciplinary methods to reach a high-resolution correlation scheme, particularly using the combination of paleontology, sedimentology, and geochemistry. Wu and his international colleagues (2015), Ainsaar and his coauthors (2015), and Ma and her collaborators (2015) are all using chemostratigraphical methods to reach much more accurate local and regional correlation schemes. And Ma et al. (2015) recognized a regional hiatus between the Middle and Upper Ordovician in South China through their chemostratigraphical correlation that was thought, for several decades, to be a continuous sequence. Zhen and his colleagues (2015), and Wang and Muir (2015) are using refined biostratigraphical frameworks to achieve a better regional and global correlation for those key intervals during the Ordovician Period. Brett and his colleagues (2015) are using unique faunal epiboles to recognize a high-resolution Upper Ordovician sequence in the Cincinnati Arch (eastern North America) and a major regional unconformity, hence to achieve a much better and more reliable regional stratigraphical correlation. Potentially this innovative study may provide a practical way of recognizing unconformities in other regions and initiate a fruitful area for future studies. In Silurian studies, one of the current priorities is the revision of stage-level GSSPs, as some of the existing stage boundary GSSPs are inadequate for international correlation due to a general lack of diagnostic graptolite or conodont zonal fossils. Three working groups are currently active on the Rhuddanian/Aeronian, the Aeronian/Telychian, and the Telychian/Sheinwoodian boundary stratotypes, respectively. These GSSP studies constituted one of the main Silurian themes at the Kunming meeting. Melchin et al. (2015) emphasized that the reselection of any new potential GSSPs should be based on not only paleontological and biostratigraphical but also sedimentological and chemostratigraphical data, employing not only traditional methods but also numerical analyses based on Big Data, such as GBDB, PaleoDB, MacroStrat, GeoStrat, and other global databases. Melchin et al. (2015) also provided a case study they conducted in Nova Scotia, eastern Canada, showing

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