The Precambrian-Cambrian biosphere (r)evolution: Insights from the Chinese Yangtze Platform

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The PC-C boundary interval represents one of the critical phases in the evolution of life. Any outside observer considering the approximately 4500-million-year history of our planet would likely choose the 150 Ma time interval between 650 and 500 Ma as one of the most dramatic periods in Earth history. This period connects the Proterozoic and Phanerozoic Eons with its boundary at 542 Ma. It includes the Ediacaran (*ca* 630–542 Ma) and the Cambrian (542–493 Ma) periods. The Ediacaran, in particular, is characterized by concurrent profound changes in global tectonics, possibly the largest climatic deviation from the steady-state mean global temperature since the Archean (popularized by the "Snowball Earth" concept; Hoffman & Schrag 2000), the first evidence leading to the possibly "explosive" (on a geological scale) but indisputably largest evolutionary radiation event of the biosphere, and a significant increase of free atmospheric and oceanic oxygen. The subsequent Cambrian time interval largely records the gradual establishment of a newly acquired ecologic stability, the beginning of the metazoan conquest of Earth's surface environment, and a profound rearrangement in the chemical composition of Earth's atmosphere and oceans.

The South China Craton (Yangtze Craton) represents one of the smaller East Gonwanan palaeocontinents (Vaughan & Pankhurst 2008). It apparently formed part of the northern Rodinia margin in low southern latitudes and had largely been covered by a stable shallow-marine platform by *ca* 800 Ma (Powell & Pisarevsky 2002, Veevers 2003). Subsequent sedimentation was mostly counterbalanced by tectonic subsidence and thus preserves a sedimentary record ranging with only minor hiatuses from the Proterozoic into the Triassic. The succession includes a thick, well-exposed PC-C boundary interval. The Yangtze palaeocontinent rifted off Rodinia at approximately 750 Ma and became incorporated into southeastern Palaeo-Asia during the Early Triassic. Since then, it underwent only minor tectonic and thermal modification.

Although shallow-water sequences of the PC-C interval have been described from several other Precambrian cratons of West-Gondwana (*e.g.* Namibia), East-Gondwana (*e.g.* Antarctica, Australia) as well as Baltica and Siberia, the Yangtze Platform offers a unique opportunity for understanding the drivers and mechanisms of the PC-C biosphere (r)evolution for the following reasons:

(1) The sedimentary record covers the entire time interval from the Ediacaran to the middle Cambrian, whereas the records on comparable platforms such as North China, Australia, or Antarctica include larger stratigraphic hiatuses:

(3) The facies diversity is associated with a broad range of laterally time-equivalent lithologies, including carbonates, phosphorites, cherts, black shales, and minor tuffs.

(2) The region of platform sedimentation is large (*ca* 1.8 million km^2) and spans a wide facies spectrum, ranging from erosional and evaporitic regimes over widespread shallow-water marine environments to shelf-edge (Lu *et al*. 2012) and deep-water continental slope settings. Perhaps uniquely worldwide, these settings can still be related to each other in their original spatial context.

(4) Tectonic deformation and thermal overprinting have been minor, except at the platform margins, near fault and collisional zones.

(5) The strata are richly fossiliferous, highlighted by several exceptional fossil *Lagerstätten*. The fossil record of the basal Cambrian strata of the Yangtze Platform demonstrates the phenomenon of the Terreneuvian bio-radiation.

The fossil *Lagerstätten* include the still disputed occurrence of Ediacaran eggs and embryos from the Weng'an locality in Guizhou Province (*e.g.* Xiao *et al*. 1998, Yin *et al*. 2012; but see Huldtgren *et al*. 2011), diverse acritarch assemblages (Liu *et al*. 2012b), and the unique macro-fossils from the latest Ediacaran siliciclastic shelf deposits of Gaojiashan, southern Shaanxi Province (*e.g.* Hua *et al*. 2009).

The Cambrian strata of the Yangtze Platform include the famous Burgess Shale-type fossil associations of the Chengjiang fossil *Lagerstätte* with exceptional soft-bodied preservations (Cambrian Stage 3, *ca* 525 Ma: *e.g.* Hou *et al*. 2004, Forchielli *et al*. 2012), the Kaili region (Cambrian Stage 5, *ca* 510 Ma: Zhao *et al*. 1996), the newly discovered Guanshan fossil assemblage (Wulongqing Fm.; Cambrian Stage 4: *e.g.* Hu *et al.* 2010, 2012; Liu *et al*. 2012a; Steiner *et al*. 2012; Weber *et al*. 2012) and the roughly time-equivalent Balang fossil assemblage (Peng *et al*. 2012). Other types of exceptional basal Cambrian fossil *Lagerstätten* yielded phosphatized Orsten-type organisms

DOI 10.3140/bull.geosci.1346

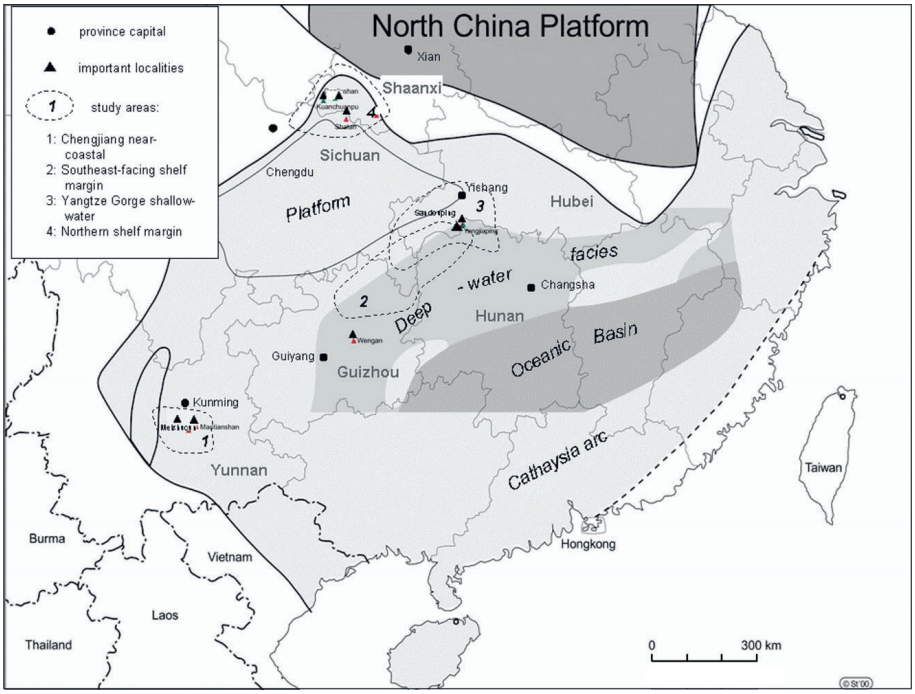

Figure 1. Geological overview map of South China, highlighting the study areas on the Yangtze Platform, most relevant locations, and principal facies belts (modified after Steiner *et al.* 2007).

(arthropods, eggs, embryos, cnidarians, algae, *etc.*, from several other localities), exceptional trilobite assemblages (Dai & Zhang 2012), and the rich small shelly fossil assemblages, widely distributed in the basal Cambrian of the entire Yangtze Platform (*ca* 540–520 Ma: *e.g.* Steiner *et al.* 2007, Li *et al.* 2012). Rencently, Sundberg *et al.* (2011) proposed the Wuliu-Zengjiayan section situated in the Guizhou Province as the GSSP for Cambrian Stage 5. The biostratigraphic zonation and chronostratigraphic subdivision of the Cambrian system in China and its correlation on a global scale are still disputed in many details (*e.g.* Peng & Babcock 2011).

In September 2000, a bilateral Sino-German research group was founded, and a first bundle of palaeobiological, geological and geochemical research projects with a multidisciplinary approach started to operate in August 2001 and lasted until summer 2004 to investigate the causes, dimensions, and sequence of the PC-C bio-radiation event. The results of this initial research group revealed the complexity of the paradox of an apparently sudden diversification of life. It became obvious that only a truly multidisciplinary research approach is able to tackle the various reasons for the largest increase in organismic disparity. Thus, a Sino-German Priority Research Project (DFG-Forschergruppe FOR 736) with 16 Chinese and German sub-projects covering geological, geochemical, and palaeobiological topics was designed and came into action in January 2008 for the duration of 6 years. The individual projects are bilaterally financed via different stages of research funding by NSFC (China) and DFG (Germany) and complemented by various scholarships from the DAAD, Chinese Scholarship Council, and Alexander von Humboldt Foundation. The FOR 736 summer school was established as an important instrument of scientific communication and study for the mostly young participants of international cooperation projects. Within the scope of this activity, the summer school studied the important and classical sedimentary successions of the Barrandian and Saxo-Thuringian micro-continents in June 2010 (Figure 2). Inspired by the achievements of geoscientists dealing with the early Palaeozoic of Bohemia, the research group decided to issue a volume in the *Bulletin of Geosciences* with contributions from the joint Sino-German Priority Project FOR 736.

In the present volume, a selection of 11 contributions by members of the research group with a focus on relevant sub-projects of FOR 736 is published, primarily illustrating palaeobiological research topics of the group.

One focus point of this special issue is the documentation of the diversity of the newly discovered Cambrian Stage 4 Guanshan fossil *Lagerstätte*, which is remarkable because it proves that soft-tissue preservation is possible in a rapid depositional environment with sufficient oxygenation and at a high bioturbation rate. The paper by Weber *et al.* (2012) describes and illustrates the diverse trace fossil communities of Guanshan Community, displaying different styles of sediment exploitation.

Hu *et al.* (2012) and Steiner *et al.* (2012) present new palaeontological data on the diversity of priapulid worms and lobopodians of this fauna. They describe three new taxa of palaeoscolecidans, one species of a corynetiid priapulid, and a new species of the enigmatic lobopodian *Hallucigenia*. This further illustrates that the diversity of

Figure 2. The members of the Sino-German research group during the summer school field trip to Bohemia in June 2010 in the entrance hall of the Chlupáč Museum of the Charles University in Prague.

ecdysozoan clades increased dramatically toward the end of the Cambrian bioradiation event.

Liu *et al*. (2012a) describe a new occurrence of the Guanshan fossil assemblage from the Huize County of eastern Yunnan, China. This new fossil occurrence indicates that soft-tissue preservation was distributed in a wide area of at least approximately 80 × 80 km during the Cambrian Stage 4 and it proves high potential for further explorations on fossil *Lagerstätten*.

Forchielli *et al*. (2012) also partially contribute to the study of the taphonomy of the Guanshan fossil *Lagerstätte*. They mostly discuss the preservational traits of sponges with originally siliceous spicules from both the similarly preserved Chengjiang and Guanshan fossil *Lagerstätten* to understand the timing and extent of iron mineral replacements of fossil occurrences with soft-tissue preservation.

Another article by Peng *et al*. (2012) describes the well-preserved new species *Naraoia taijiangensis* sp. nov. from the Balang Formation of Guizhou Province (China) that also contains the trilobite *Redlichia* and is roughly time-equivalent with the Wulongqing Fm. of Yunnan hosting the Guanshan Biota.

Dai & Zhang (2012) document the ontogeny of the trilobite *Estaingia sinensis* from the slightly older Shuijingtuo Fm. of Changyang County, Hubei Province (China). Besides including information on the ontogeny of the trilobite, this paper documents the similarity in redlichiid trilobite faunas of this period between South China and Australia.

Li *et al*. (2012) also describe skeletal remains of different ontogenetic stages of the eodiscoid trilobite *Hupeidiscus orientalis* from the Shuijingtuo Fm., but from a region in a marginal platform setting of southern Shaanxi Province (China). Structural data of the three-dimensionally preserved skeletal material prove that the form taxon *Mongolitubulus* is at least partially derived from eodiscoid trilobites such as *Hupeidiscus orientalis*.

Yin & Zhu (2012) discuss differently ornamented spheroidal microfossils of the Ediacaran Weng'an fossil *Lagerstätte* of the Doushantuo Fm. as egg stages and blastula stages of metazoans. Recent discussions on the origin and assignment of these spheroidal microfossils underline the importance of various fossil *Lagerstätten* of Doushantuo Fm. in South China. Therefore, a detailed discussion of the chronostratigraphical framework and the international correlation of this formation is greatly needed. Lu *et al*. (2012) present new carbon isotope and sequence stratigraphy data of the stratotype section of the Doushantuo Fm. supporting a more solid correlation of this rock unit.

In addition, Liu *et al*. (2012b) present new fossil data of well-preserved acritarch assemblages from the classical sections of the Doushantuo Fm. in the Yangtze Gorge region. They propose that the genus *Ceratosphaeridium*, which has already been reported from the Ediacaran of South Australia, may possibly support inter-continental correlation.

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