Gondwana Research 25 (2014) 881–883

Contents lists available at ScienceDirect

Gondwana Research

journal homepage: www.elsevier.com/locate/gr

Editorial

Beyond the Cambrian Explosion: From galaxy to genome

1. Introduction

Some may say that discussion of "Cambrian Explosion" started in 1996 when this unique biological event was the cover story, titled "Evolution's Big Bang," of the American news magazine *Time*. Actually, however, discussion of the Cambrian Explosion dates back to the mid-19th century when Charles Darwin realized this conundrum of sudden appearance of animals without ancestors. *Time's* story probably reflected the worldwide influence of the best seller "*Wonderful Life*" (1989) by the late S.J. Gould. Shortly after *Time's* cover story, another appealing concept, the Neoproterozoic "snowball Earth" concept was proposed Hoffman et al., 1998). The synergetic effect of these two hot topics had a great impact on the earth science community, and many projects were carried out through the world on these issues, leading to numerous scientific articles and books. Geological, paleontological, geochemical, and genomic phylogenetical approaches were pursued, and the results led to further discussions on possible causes and processes. Despite the vast amount of data that have been amassed, the ultimate cause and processes of the Cambrian Explosion have not yet been fully resolved.

On the other hand, the finding of nearly 1000 exoplanets, including many Earth-like ones, outside our solar system (e.g., Howard, 2013; Seager, 2013), has expanded our curiosity regarding extra-solar life. In this context, the history of the Cambrian Explosion on our planet is important in understanding the critical conditions for large animal evolution and diversification on other Earth-like planets.

2. Context of this special issue

Near 6 years after the publication of the special issue of *Gondwana Research* entitled "Snowball Earth to Cambrian Explosion" in 2008 (vol. 14, p. 1–286; edited by S. Maruyama and M. Santosh), here we assemble the latest perspectives of the biggest biological innovation at the start of the Phanerozoic ca. 540 million years ago. The objective of this special issue is to report new data mostly from the Ediacaran to Lower Cambrian strata/fossils in South China and to address the cutting-edge scenarios of the Cambrian Explosion, including even some *avant-garde* ideas. We hope that the papers in this special issue would stimulate Earth and Planetary Science communities to pursue further research on evolution studies and astrobiology.

This special issue is composed of four parts: 4 general review articles about the Cambrian Explosion, followed by two parts with reports on new discoveries from paleontological studies (7 articles) and geological/geochemical investigations (8 articles), and concluding with one article that proposes a united view of the snowball Earth and Cambrian Explosion. Following the summary by Shu (2008) in the previous GR special issue, the latest paleontological findings make the Cambrian biological world look much more similar to the modern and thus more realistic. The isotope-based chemostratigraphical correlation documents much higher-resolution secular changes in the late Ediacaran–Cambrian shallow seas where the life explosion started. These approaches are important to decipher the place, time, and conditions of animal diversification. For explaining all these phenomena, a new interpretation is given in the final part in terms of the interaction between the Cambrian biosphere and solid Earth, and also that between the Earth system and outer galaxies from much broader time-space viewpoint.

The first two review articles summarize the current status and perspectives of the Cambrian explosion on the basis of the latest paleontological/genome phylogenetical dataset, and re-emphasize the significance of the greatest biological innovation at the start of the Phanerozoic. Shu et al. (2014–in this issue) note that even with taphonomic bias, the Cambrian Explosion *sensu stricto* was the rapid bilaterian phenotype diversification, which occurred in the first 20 million years of the Early Cambrian, and peaked in the Cambrian Stage 3. This clearly postdates the animal diversification on genome level. In the second paper, Zhang et al. (2014–in this issue) review the latest knowledge of phylogenetic tree of animals (TOA) and speculate the possible triggers for this unique episode.

The scenario for the Neoproterozoic snowball Earth to Cambrian Explosion was proposed earlier by Maruyama and Santosh (2008) is integrated into a much wider canvas by Maruyama et al. (2014–in this issue) who propose that the Cambrian Explosion was triggered by the initiation of return-flow of voluminous seawater into mantle. The lowering of the temperature in upper mantle around subduction zones, below the critical point of 600 °C at depth ca. 30 km, over the geologic time is identified as the principal cause. The subduction of large volumes of hydrous minerals (= water) into the deep mantle likely caused a significant sea level drop and the extensive exposure of landmass to provide abundant nutrients for the Cambrian Explosion. This scenario is correlated with the geochemical evidence from newly gathered data on the 25 drill core samples mentioned above. In contrast, collision-related mountain-building such as the Trans-Gondwana Mozambique belt has been previously proposed for explaining nutrient sources. In a different model, Santosh et al. (2014–in this issue) propose that the rift-related regional dome-up of Gondwana as a whole was a more efficient process for weathering and nutrient supply than localized mountain-building.

Although many of the new interpretations/proposals wait testing by further studies, the contributions assembled in this special issue illustrate the need for multidisciplinary approach and synthesis from broader viewpoints when addressing the complexities of life evolution. Most of the articles in this issue are the outcome of the China-Japan Co-operative Project between Northwest University (Xi'an) and Tokyo Institute of Technology since 2004, with some additional contributions from outside groups.

http://dx.doi.org/10.1016/j.gr.2014.01.001

3. New fossils of early animals

In the second part, 7 articles related to paleontological studies in South China report new findings of interesting fossils. Four of these report new contributions from the Chengjiang biota in Yunnan province. Lei et al. (2014–in this issue) document "anchoring nail" of anthozoan-like animals in the Cambrian Stage 3, which is explained as a new adaptive life style on soft substrate in response to the appearance of pelagic larvae and SSF-animals. Fu and Zhang (214–in this issue) demonstrate the ontogenetic development of the unique bivalved arthropod fossil *Isoxys* with venomous gland. Duan et al. (2014–in this issue) describe another arthropod fossil *Kummingella* that performed "spawning egg" just like modern analogs. These additional fossil data illustrate that the Early Cambrian shallow marine environments were already occupied by various animals with similar life fashion. Dai et al. (2014–in this issue) present pristine example of detailed ontogenetic development of early trilobite *Hunnanocephalus*, in particular the unique pattern in segment addition that is markedly different from modern arthropods.

From the Three Gorges area in Hubei province, Guo et al. (2014–in this issue) report the occurrence of 3 Terreneuvian SSF zones in sequence within the Yanjiahe Formation that allows fair correlation with the Lower Cambrian in Yunnan. From the Ningqiang area in Shaanxi province, Cai et al. (2014–in this issue) newly recognize a mat-related lifestyle of *Cloudina*, one of the oldest skeletonized fossils, from the upper Ediacaran. From the Weng'an area in Guizhou province, Yin et al. (2014–in this issue) present synchrotron X-ray microtomographic and SEM images of the Ediacaran "embryos of certain animals", emphasizing their possible cytokinesis-related structure.

4. Drill core, high-resolution chemostratigraphy, and field data

In the third part, 8 articles report the latest results of geological and geochemical analyses for the Ediacaran and Lower Cambrian strata in Hubei and Yunnan provinces, South China. Okada et al. (2014–in this issue) obtained new Early Cambrian U-Pb zircon ages from the Three Gorges area in Hubei province and the Chengjiang area in Yunnan province to constrain the timings of early animal diversification episodes during the Cambrian Epoch 2.

The following 5 articles display chemostratigraphy of the drilled core samples from the Three Gorges area. As reported in part by Ishikawa et al. (2008, 2013), Ohno et al. (2008), and Sawaki et al. (2008, 2010), the China-Japan Joint Research project conducted deep drillings in the Three Gorges area in Hubei province during 2004–2010, with 25 drill cores at 6 sites on the southern side of the Yangtze river near Zigui, for collecting unweathered core samples for better-quality geochemical analyses. The stratigraphic thickness of the Ediacaran to Lower Cambrian beds penetrated by drilling is just over 700 m; however, the same intervals of different lithofacies were multiply recovered. Ishikawa et al. (2014–in this issue) document stable carbon isotope chemostratigraphy of the Lower Cambrian, providing a basis for global correlation particularly for the Cambrian Stages 3 and 4. Kikumoto et al. (2014–in this issue) report carbon and nitrogen isotopic stratigraphy of the Ediacaran and Lower Cambrian rocks, and speculate that oceans fluctuated between N-limited and N-enriched conditions under the existence of large organic carbon pool. Sawaki et al. (2014–in this issue) present the first dataset of secular change in Ca isotope ratio of the Ediacaran-Cambrian seawater, and discuss the possible background conditions and mechanism for the change. Also using the same core samples, Shimura et al. (2014–in this issue) provide the first estimate on phosphate concentration in the Ediacaran-Cambrian seawater, and discuss its link to the animal diversification. Likewise Yamada et al. (2014–in this issue) identify biomarker molecules of n-alkane from the core samples around the Ediacaran-Cambrian boundary, and discuss the redox change in seawater based on the ratio between longer and shorter chains of those molecules. Igisu et al. (2014–in this issue) detected some cell structures with unique fabrics by utilizing the FTIR technique, and suggested the so-called "embryo" fossils from Weng'an in Guizhou province may contain both algae and possible embryo of animals of uncertain kinds.

Sato et al. (2014–in this issue) present the results from a detailed field geological study. They examined the sedimentological aspects of the Lower Cambrian phosphorite in Yunnan and based on the results, they challenge the conventional "upwelling shelf margin" model for the SSF-rich phosphorite deposition by proposing a contrasting setting of extremely shallow-water "restricted embayments" unique to the continental rift zone in western South China. Localized unusual seawater chemistry might trigger the diversification of SSFs first in Yunnan.

5. Model

Closing this special issue, the last article evaluates Cambrian Explosion in a broad perspective, linking with tectonic processes in our planet. The role of the Neoproterozoic snowball Earth for the Cambrian Explosion has remained enigmatic. Nonetheless, it is apparent that the main trigger of snowball glaciation cannot be explained by any of the greenhouse gas effects. A working hypothesis at present is the GCR (galactic cosmic radiation)-Cloud link induced by the starburst in far-away galaxies in the Neoproterozoic, as discussed by Kataoka et al. (2014–in this issue). These authors put forward a model for the snowball Earth event from theoretical grounds, speculating that the rare glaciation was likely caused by the burst-driven increase in galactic cosmic radiation to the Earth's atmosphere and the resultant cloud development for limiting the insolation, and that the post-snowball rapid speciation was likely caused by the extremely high mutation rate on genome level owing to the radiation.

We thank all the authors for their scholarly contributions to this special issue. We also thank all the referees who spared their valuable time and efforts to provide insightful peer-reviews. We hope that the papers assembled in this special issue will be well-received and that these works would enthuse further research on the intricacies of life evolution on our planet, as well as the quest for life in Earth-like planets in the Universe.

References

Cai, Y.P., Hua, H., Schiffbauer, J.D., Yuan, X.L., 2014. Tube growth patterns and microbial mat-related lifestyles in the Ediacaran fossil *Cloudina*, Gaojiashan Lagerstätte, South China. Gondwana Research 25 (3), 1008–1018 (in this issue).

Dai, T., Zhang, X.L., Peng, S.C., 2014. Morphology and ontogeny of *Hunanocephalus ovalis* (trilobite) from the Cambrian of South China. Gondwana Research 25 (3), 991–998 (in this issue).

Duan, Y.H., Han, J., Fu, D.J., Zhang, X.L., Yang, X.G., Komiya, T., Shu, D.G., 2014. Reproductive strategy of bradoriid arthropod *Kummingella douvillei* from the Lower Cambrian Chengjiang Lagesttaete, South China. Gondwana Research 25 (3), 983–990 (in this issue).

Fu, D.J., Zhang, X.L., 2014. Ontogeny and dimorphism of *Isoxys auritus* (Arthropoda) from the Early Cambrian Chengjiang biota, South China. Gondwana Research 25 (3), 975–982 (in this issue).

Gould, S.J., 1989. Wonderful life: The Burgess Shale and the nature of history. Norton, New York (347 pp.).

Guo, J.F., Li, Y., Li, G.X., 2014. Small shelly fossils from the Early Cambrian Yanjiahe Formation, Yichang, Hubei, China. Gondwana Research 25 (3), 999–1007 (in this issue).

Hoffman, P.F., Kaufman, A.J., Halverson, G.P., Shrag, D.P., 1998. A Neoproterozoic Snowball Earth. Science 281, 1342–1346.

Howard, A.W., 2013. Observed properties of extrasolar planets. Science 340, 572–577.

Igisu, M., Komiya, T., Kawashima, M., Nakashima, S., Ueno, Y., Han, J., Shu, D.G., Li, Y., Guo, J.F., Maruyama, S., Takai, K., 2014. FTIR microspectroscopy of Ediacaran phosphatized microfossils from the Doushantuo Formation, Weng'an, South China. Gondwana Research 25 (3), 1120–1138 (in this issue).

Ishikawa, T., Ueno, Y., Komiya, T., Sawaki, Y., Han, J., Shu, D., Li, Y., Maruyama, S., Yoshida, N., 2008. Carbon isotope chemostratigraphy of a Precambrian/Cambrian boundary section in the Three Gorge area, South China: Prominent global-scale isotope excursions just before the Cambrian Explosion. Gondwana Research 14, 193–208.

Ishikawa, T., Ueno, Y., Shu, D., Li, Y., Han, J., Guo, J., Yoshida, N., Komiya, T., 2013. Irreversible change of the oceanic carbon cycle in the earliest Cambrian: high-resolution organic and inorganic carbon chemostratigraphy in the Three Gorges area, South China. Precambrian Research 225, 190–208.

Ishikawa, T., Ueno, Y., Shu, D.G., Li, Y., Han, J., Guo, J.F., Yoshida, N., Maruyama, S., Komiya, T., 2014. The δ13C excursions spanning the Cambrian explosion to the Canglangpuian

mass extinction in the Three Gorges area, South China. Gondwana Research 25 (3), 1045–1056 (in this issue).
Kataoka, R., Ebisuzaki, T., Miyahara, H., Nimura, T., Tomida, T., Sato, T., Maruyama, S., 2014. The Nebula Winter: The united view of the snowball Earth, mass extinctions, and explosive evolution in the late Neoproterozoic and Cambrian periods. Gondwana Research 25 (3), 1153–1163 (in this issue).
Kikumoto, R., Tahata, M., Nishizawa, M., Sawaki, Y., Maruyama, S., Shi, D.G., Han, J., Komiya, T., Takai, K., Ueno, Y., 2014. Nitrogen isotope chemostratigraphy of the Ediacaran and Early Cambrian platform sequence at Three Gorges, South China. Gondwana Research 25 (3), 1057–1069 (in this issue).
Lei, Q.P., Han, J., Ou, Q., Wan, X.Q., 2014. Sedentary habits of anthozoa-like animals in the Chengjiang Lagerstaetten: adaptive strategies for Phanerozoic-style soft substrates. Gondwana Research 25 (3), 966–974 (in this issue).
Maruyama, S., Santosh, M., 2008. Models on snowball Earth and Cambrian explosion: a synopsis. Gondwana Research 14, 22–32.
Maruyama, S., Sawaki, Y., Ebisuzaki, T., Ikoma, M., Omori, S., Komabayashi, T., 2014. Initiation of leaking Earth: an ultimate trigger of the Cambrian explosion. Gondwana Research 25 (3), 910–944 (in this issue).
Ohno, T., Komiya, T., Ueno, Y., Hirata, T., Maruyama, S., 2008. Determination of 88Sr/86Sr mass-dependent isotopic fractionation and radiogenic isotope variation of 87Sr/86Sr in the Neoproterozoic Doushantuo Formation. Gondwana Research 14, 126–133.
Okada, Y., Sawaki, Y., Komiya, T., Hirata, T., Takahata, N., Sano, Y., Han, J., Maruyama, S., 2014. New chronological constraints for Cryogenian to Cambrian rocks in the Three Gorges, Weng'an and Chengjiang areas, South China. Gondwana Research 25 (3), 1027–1044 (in this issue).
Santosh, M., Maruyama, S., Sawaki, Y., Meert, J.G., 2014. The Cambrian explosion: Plume-driven birth of the second ecosystem on Earth. Gondwana Research 25 (3), 945–965 (in this issue).
Sato, T., Isozaki, Y., Hitachi, T., Shu, D.G., 2014. A unique condition for early diversification of small shelly fossils in the lowermost Cambrian in Chengjiang, South China: Enrichment of phosphorus in restricted embayments. Gondwana Research 25 (3), 1139–1152 (in this issue).
Sawaki, Y., Ohno, T., Fukushi, Y., Komiya, T., Ishikawa, T., Hirata, T., Maruyama, S., 2008. Sr isotope excursion across the Precambrian–Cambrian boundary in the Three Gorges area, South China. Gondwana Research 14, 134–147.
Sawaki, Y., Ohno, T., Tahata, M., Komiya, T., Hirata, T., Maruyama, S., Windley, B.F., Han, J., Shu, D., Li, Y., 2010. The Ediacaran radiogenic Sr isotope excursion in the Doushantuo Formation in the Three Gorges area, South China. Precambrian Research 176, 46–64.
Sawaki, Y., Tahata, M., Ohno, T., Komiya, T., Hirata, T., Maruyama, S., Han, J., Shu, D.G., 2014. The anomalous Ca cycle in the Ediacaran ocean: Evidence from Ca isotopes preserved in carbonates in the Three Gorges area, South China. Gondwana Research 25 (3), 1070–1089 (in this issue).
Seager, S., 2013. Exoplanet habitability. Science 340, 577–581.
Shimura, T., Kon, Y., Sawaki, Y., Hirata, T., Han, J., Shu, D.G., Komiya, T., 2014. In-situ analyses of phosphorus contents of carbonate minerals: Reconstruction of phosphorus contents of seawater from the Ediacaran to early Cambrian. Gondwana Research 25 (3), 1090–1107 (in this issue).
Shu, D., 2008. Cambrian explosion: Birth of tree of animals. Gondwana Research 14, 219–240.
Shu, D.G., Isozaki, Y., Zgang, X.L., Han, J., Maruyama, S., 2014. Birth and early evolution of metazoans. Gondwana Research 25 (3), 884–895 (in this issue).
Yamada, Kn, Ueno, Y., Yamada, Kt, Komiya, T., Han, J., Shu, D.G., Yoshida, N., Maruyama, S., 2014. Molecular fossils extracted from the Early Cambrian section in the Three Gorges area, South China. Gondwana Research 25 (3), 1108–1119 (in this issue).
Yin, Z.J., Liu, P.J., Li, G., Tafforeau, P., Zhu, M.Y., 2014. Biological and taphonomic implications of Ediacaran fossil embryos undergoing cytokinesis. Gondwana Research 25 (3), 1019–1026 (in this issue).
Zhang, X.L., Shu, D.G., Han, J., Zhang, Z.F., Liu, J.N., Fu, D.J., 2014. Triggers for the Cambrian explosion: Hypotheses and problems. Gondwana Research 25 (3), 896–909 (in this issue).

Yukio Isozaki
Guest editor
Department of Earth Science and Astronomy, The University of Tokyo, 1-3-8 Komaba, Meguro, Tokyo 153-8902, Japan
Corresponding author.
E-mail address: isozaki@ea.c.u-tokyo.ac.jp.

Degan Shu
Guest editor
Early Life Institute, Northwest University, Xi'an 710069, PR China
State Key Laboratory of Continental Dynamics, Northwest University, Xi'an 710069, PR China

Shigenori Maruyama
Guest editor
Earth Life Science Institute, 2-12-1 O-okayama, Meguro, Tokyo 152-8551, Japan
Tokyo Institute of Technology, 2-12-1 O-okayama, Meguro, Tokyo 152-8551, Japan

M. Santosh
Guest editor
School of Earth Science and Resources, China University of Geosciences Beijing, 29 Xueyuan Road, Beijing 100083, PR China