High-precision U-Pb temporal constraints on the early Cambrian diversification of animal life from eastern Yunnan, China

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The Terreneuvian Epoch at the onset of the Cambrian marks the time of major biotic radiations and marine geochemical changes on the global scale. In order to understand the tempo of emergence of complex animal life as well as its interrelationships to the geologic environment, a robust correlation of the Terreneuvian intercontinental stratigraphic records is necessary. This correlation has been aided by long recognized patterns of perturbation in the ocean carbon cycle of presumed global extent. Here we report new high-precision U-Pb zircon geochronology (CA-ID-TIMS method) from interbedded volcanic ash beds in key stratigraphic sections of the eastern Yunnan Province in South China in order to calibrate the interval spanning the latest Ediacaran to the terminal Terreneuvian.

Samples from the top of the Ediacaran Dengying Formation and the base of the Cambrian Daibu Member of the Zhujiaqing Formation in the chemostratigraphically constrained Xiaotan section provide the best estimate for the age of the basal Cambrian negative carbon isotopic excursion (BACE), as well as the Ediacaran-Cambrian boundary. The new U-Pb age constraints for the boundary are on the order of 2 myr younger than the currently accepted age. Preliminary analyses of previously dated boundary ash beds from Oman and Namibia appear to support a revision of the boundary age, pending more comprehensive examination of the corresponding successions.

Further up stratigraphically, new high-precision age results from the base of Dahai Member of the Zhujiaqing Formation and the base of the Shiyantou Formation constrain the interval of the largest and most widely recognized positive carbon isotope excursion of the Terreneuvian, generally known as ZHUCE, to have occurred between ca. 527 Ma and ca. 526 Ma. Our new age results from the uppermost Dahai Member and basal Shiyantou Formation together constrain the beginning of the important negative carbon isotopic excursion known as SHICE. The latter also places maximum age limits on the first known appearance of trilobites and Chengjiang fauna. Our new calibration of the basal Cambrian biostratigraphy in South China places the base of Zone II (*Siphogonuchites triangularis- Paragloborilus subglobosus* Assemblage) and Zone III (*Heraultipegma yunnanensis* Assemblage) of the small shelly fossils at ca. 533 Ma and ca. 527 Ma, respectively, whereas the top of Zone III is constrained at ca. 526 Ma.

Keywords: U-Pb geochronology, Cambrian, Small shelly fossils, Biostratigraphy, Ediacaran-Cambrian boundary

寒冷化を伴う大量絶滅イベント：同位体比組成からの制約-オルドビス紀末イベントを典型例として

Mass extinctions related to global cooling: A case study of the late Ordovician mass extinction using a multi isotope approach

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Except for the most severe mass extinctions, such as the Permian-Triassic (PT) and Cretaceous-Paleogene (K-Pg) boundary events, most moderate- to minor-class mass extinctions were related to global cooling rather than global warming [1]. The elevated extinction rates for the cooling-related mass extinctions were generally accompanied by a positive carbon isotope excursion, implying that major perturbations of the global carbon cycle might be involved. As it is very difficult to draw conclusions from carbon data alone, a multi-isotope approach is necessary to understanding the paleoenvironmental perturbations in such mass extinctions. Although there are some common characteristics for cooling-related mass extinctions, it is still unclear whether or not all of them were induced by a common trigger event, such as volcanic activity, meteorite impacts, or nearby supernova explosions. In this study, we discuss the environmental perturbations at the late Ordovician mass extinction as an example of a cooling-related mass extinction. Although the late Ordovician mass extinction was one of the "Big Five" mass extinction events in the Phanerozoic, the rate of species extinction was lower than those of the P-T and K-Pg boundary events [2]. The decline of biodiversity coincided with the onset of the Hirnantian glaciation, the inducing mechanisms for which are still unclear. In this study, isotopic ratios and concentrations of carbon and sulfur were analyzed in the Upper Ordovician to Lower Silurian shales from the Langkawi Islands in Malaysia. The results revealed that the weight ratios of organic carbon and pyritic sulfur (C/S) varied periodically from <1 to ˜30. These periodic variations were interrupted by the position of the positive d[13] C excursion. The excursion was accompanied by C/S ratios <0.1, lower than the minimum values during the periodical variations. Although the C/S ratios varied periodically, the minimum values for each C/S variation cycle gradually increased. This implies that the environmental perturbation recorded as very low C/S ratios repeated high and low intensities, but its fluctuation was attenuated overall.

[1] Stanley (2010) PNAS 107, 19185-19189.
[2] McGhee et al. (2011) Geology. 40 (2): 147–150.

キーワード：オルドビス紀-シルル紀境界、安定同位体、寒冷化
Keywords: Ordovician-Silurian boundary, Stable isotopes, Global cooling

The redox history and nitrogen cycle in the pelagic Panthalassic deep ocean during the double-phased extinction interval across the Paleozoic-Mesozoic transition

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The end-Permian mass extinction, the largest catastrophic perturbation in the Phanerozoic life history, comprises two distinct extinctions; the first one across the Guadalupian-Lopingian (G-L) boundary and the second one across the Permian- Triassic (P-Tr) boundary. The appearance of prolonged global-scale anoxia during this interval was likely unfavorable for most animals and marine ecosystems. In order to constrain oceanic redox conditions and biological activity, carbon isotope ratios and redox proxies were measured in many sections; however, most of these studies have been undertaken on the sections from the Tethys Ocean, a region covered only 10-15% of the area of the global-ocean, and ignored the larger part of central Panthalassa, comprising 85-90% of the area of the Permian to Triassic global-ocean. The Permo-Triassic deep-sea pelagic cherts preserved in the on-land exposed Jurassic accretionary complex in Japan are ideal material for paleoenvironmental studies; however, the linkage between marine redox history and biological activity in the mid-Panthalassic deep ocean has not been well understood owing to limited data-set. We collected shales partings of bedded cherts of the Guadalupian to earliest Induan ages exposed at the Gujo-Hachiman section in central Japan. We determined the organic carbon ($\delta^{13}C_{org}$) and nitrogen ($\delta^{15}N_{TN}$) isotopic ratios, and major, trace and rare earth element abundances of the shales, in order to clarify changes in the redox history and nitrogen cycle in mid-Panthalassa for the double-phased mass extinction across the Paleozoic-Mesozoic transition.

Little enrichments of Mo, V, U, and TOC were detected from the Guadalupian to Lopingian shales, suggesting that the mid-Panthalassic deep ocean was dominated by an oxic-suboxic condition across the G-L transitional zone. In addition, the $\delta^{13}C_{org}$ and $\delta^{15}N_{TN}$ values across the G-L transitional zone exhibit little fluctuation, and the former is almost the same as those obtained from adjacent bedded cherts. In contrast, a negative $\delta^{15}N_{TN}$ shift and the extensive ocean euxinia are recognized in the Tethyan shallow marine strata. These lines of evidences indicate that the development of euxinia and nitrogen-limited conditions were limited only to shallow shelf domains of the Tethyan Ocean and had little influence to the mid-Panthalassic deep ocean across the G-L boundary.

High abundances of U, V, and Mo in the Induan black mudstones indicate the appearance of anoxic conditions in mid-Panthalassa. The $\delta^{13}C_{org}$ values during the Induan show a similar pattern to that reported in other deep-sea sites. On the other hand, the $\delta^{15}N_{TN}$ values in the Induan mudstones range from -2.0 to 0.7‰. These low $\delta^{15}N_{TN}$ values together with the emergence of anoxic condition suggest that a relative predominance of nitrogen fixation, which in turn means a nitrogen-limited condition in the mid-Panthalassa. Our $\delta^{15}N_{TN}$ profiles are similar to those reported from other P-Tr boundary sections, such as eastern Panthalassic and Tethyan Oceans. Therefore low $\delta^{15}N_{TN}$ values during the Induan was likely a global signature, and we concluded that the protracted oceanic nitrogen depletion during the Induan would have acted as an environmental stress on shallow and deep-sea biota.

キーワード：大量絶滅、パンサラッサ海、有機炭素同位体、窒素同位体、酸化還元鋭敏元素
Keywords: mass extinction, Panthalassa, organic carbon isotopes, nitrogen isotopes, redox-sensitive elements

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小惑星ー彗星衝突と大規模火山活動による大量絶滅時の気候変動
Climate changes during mass extinctions by asteroid-comet impacts and large volcanic eruptions

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Cooling and associated drought induce mass extinctions. Warming is difficult to cause mass extinctions, because high latitude areas are good condition for life during hot surface of the Earth. Causes of cooling are soot and sulfate aerosols to cut sunshine. These aerosols in the troposphere fall out soon with rain, which do not cause global cooling, but stratospheric aerosols can live long to cause the global cooling and drought. Energy is needed to carry burned hydrocarbon and sulfur to the stratosphere. The energy can be provided by asteroid-comet impacts and large volcanic eruptions. Soot aerosols and sulfate aerosols are main causes of mass extinctions by the impacts and volcanic eruptions. Cooling on land reaches 1 month after the ejection on soot aerosol case, but one year after the ejection on sulfate aerosol case, followed by gradual recovery in 10 years on both cases. Warming subsequently occurred by CO_2 ejection by the impacts and volcanic eruptions in 10 to 1000 years after the events. The amount of CO_2 is usually smaller on the impact case than on the volcanic eruption case, resulting in no significant warming by the former, but significant warming may occur by the latter. Mass extinctions by the volcanic eruptions can be emphasized by subsequent warming events, resulting in stepwise extinctions.

キーワード：小惑星ー彗星衝突、大規模火山活動、気候変動、大量絶滅
Keywords: asteroid-comet impacts, large volcanic eruptions, climate changes, mass extinctions

Land ecosystem collapse followed by marine environmental stress spanning the Permian-Triassic mass extinction

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Abstract

The Permian–Triassic mass extinction was the most devastating extinction in the Phanerozoic Era. We investigated the biomarkers from the Shangsi section, South China, to identify changes in the biosphere and marine environments. We show that the collapse of land vegetation occurred before the latest Permian marine extinction at the Shangsi section. The stressful environmental conditions were persisted during the earliest Triassic rather than the latest Permian marine extinction. The second phase of stressful environmental conditions occurred in the late Griesbachian.

Keywords: Permian-Triassic, Mass extinction, Land plant, Environmental stress, Shangsi, Organic geochemistry

生物進化と多様性の中立的確率モデル：系統樹の位相的性質からの考察
Neutral stochastic model of evolution and biodiversity: topological approach to phylogenetic tree

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　生物進化と多様性の構造は、地球史における短期的な大規模環境変化の結果を反映している。 このような生物多様性と安定性の解析については、群集生態学も重要な役割を果たして来た。特に近年、中立的群集生態学が、生物の種多様性を統一的に考察するための理論として注目されている（e.g., Hubbell, 2001; Etirnne, 2005）。これは、集団遺伝学における分子進化の中立説（Kimura, 1968）と同質の考え方を、生物群集に適用した中立モデルであり、例えば遺伝的浮動には生態学的浮動という概念が対応する（e.g., Alonso et al., 2006）。この中立的群集生態学により、生物進化と多様性に関する構造が、従来のような多様な種間相互作用やニッチ構造を仮定しなくても説明可能となった（e.g., Tilman, 2004; Suzuki and Chiba 2016）。したがって、地球史規模の生物進化と多様性の構造に関しても、中立モデルの概念は有効なのではないだろうか。本研究はその基礎研究の一つとして、系統樹（生物進化と多様性のパターンを視覚的に表現したグラフ）の位相的性質を、実際の遺伝データと中立的確率過程のシミュレーションに基づき考察するものである。

　実際の系統樹と確率シミュレーションとの比較に関しては様々な研究が為されてきたが、必ずしも中立的モデルではなく、また両者の比較は系統数の時間変化に着目しているため、 系統樹の位相的情報を十分に反映していない（e.g., Levinton, 1979; Harvey and Nee1994; Nee et al., 1995; Lieberman, 2011）。そこで、まず系統樹の位相的情報の定量化を試みる。系統樹は”遺伝子の川”(Dawkins, 1995)と形容されるが、 地形学の分野では河川の形態についてHortonの法則が成立することが知られている（Horton, 1945）。これは分岐形としての河川の水路に適当な方法で次数付けをおこなったことで見出された法則である。Hortonの法則のうち、水路数の法則(Hortonの第一法則)は河川以外の分岐形一般にも適用が可能な法則である。また、Hortonの第一法則が成立しているかを判定する"Horton解析"をおこなうことで、分岐形の位相的性質を定量化することが可能になる。

　本研究で解析する系統樹は分子系統樹であり、対象生物は以下の脊椎動物でる：魚類（Near et al., 2013）、両生類（Frost et al., 2006）、カメ類（Grawford et al., 2015）、ヘビ・トカゲ類（Pyron et al., 2013）、鳥類（Burleigh et al., 2015）、哺乳類（Murphy et al., 2001）。これら6種類についてHorton解析をおこない、全ての系統樹でHortonの第一法則が成立していることが判明した。また、末端種数や系統樹が包括している分類階層のレベルによらず、分岐比の値は6種類の系統樹の分岐比の平均値3.18に近い値となった。これは脊椎動物の種分化現象は、系統樹全体として分岐比が平均3.18になる機構を有していることを示唆している。

　この平均値3.18は従来のHorton解析における中立的確率モデルにおける理論値：約4(e.g., Leopold and Langbein, 1962; Shreve, 1967)より低い値である。その原因としては，（1)実際の分子系統樹の分岐比は、特定の大きさを持つ絶滅イベントや環境変化などの効果を含んでいる非中立的値であるため，あるいは（2）従来の解析は合流モデルなので分岐現象とは異なるため，などが考えられる。

　そこで、分岐率と時間という最小限のパラメタセットしかない単純な分岐モデルの確率シミュレーションを行った。これは、特定の大きさを持つ絶滅イベントや環境変化および種分化率変化を考えない、という意味において中立的確率モデルである。その結果，生成された分岐形にもHortonの法則が成立することが分かった。また、分岐比の平均は2.96になった。これは、上記の分子系統樹の平均値3.18と近い値である。 さらに確率過程で生成された分岐形の特徴と脊椎動物の系統樹の分岐形としての特徴を比較したところ、両者は同様の特徴を示していた。 以上の結果は、脊椎動物の種分化過程は中立的な確率過程によって説明可能である

ことを示す。すなわち、生物分類や生物種ごとの種分化率の違い、特定の大きさを持った絶滅や環境変化による種分化率の変化の効果を考慮しなくても、実際の系統樹の位相的性質を説明できることを示唆する。

キーワード：分子系統樹、位相的性質、Horton解析、分岐比、中立的確率モデル、多様性
Keywords: molecular phylogenetic tree, topological property, Horton analysis, bifurcation ratio, Neutral stochastic model, biodiversity