酸素発生型光合成の痕跡は３２億年前のフィグツリー層群に記録されているか？
Early oxygenic photosynthesis in 3.2 Ga Fig Tree Group, Barberton Greenstone Belt?

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Reconstructing Archean ecosystem is important to constrain the evolution of early life. Less metamorphosed sedimentary rocks in ca. 3.2 Ga Fig Tree Group gives us an opportunity to examine where and how the early life habituated. Here I report results of geological and geochemical studies on Fig Tree Group, in particular for Jesefsdal (southern section) and Waggon Road Mine (northern section) areas. For both areas, clastic sedimentary rocks were dominant at the base. Northern section is more dominated by fine-grained black shales rich in various sulfides. Southern section is more dominated by conglomerate. Such horizontal change and mineral characteristic suggest that northern section deposited in deep basin where submarine hydrothermal activities were taking place, and southern section deposited shallow and high energy sedimentation environments. Most of these sedimentary rocks are rich in Cr (up to 900 ppm in black shale). Chromite is often found under microscope. Such finding suggests significantly high flux of clastic materials from ultramafic rocks in ca. 3.4 Ga Onverwacht Group to sedimentary basin of early Fig Tree Group. Some chromite crystals in examined samples have distinct chemistry (very low Mg#) compared to detrital chromite (high Mg #). This suggests that a part of chromite were chemically precipitated from 3.2 Ga ocean water. This further implies the presence of oxidized Cr species (e.g., Cr6+) in 3.2 Ga shallow ocean water. Those clastic sedimentary rocks are overlain by banded iron formations. In particular, silica-rich band in banded iron formation in northern section contain appreciable amounts of organic carbon (up to 0.2 wt %). Surprisingly carbon isotope compositions are constant (at around -25 per mil) from early clastic sedimentary rocks to banded iron formations, although their sedimentary environments and ages were different. Such homogheneous carbon isotope compositions require single and high productive primary producer, which maybe lived in photic zone, through sedimentation of Fig Tree Group. Presence of oxygenic photosynthesis in 3.2 Ga oceans well explains oxidation of Cr (and also Fe2+) and high primary production.

キーワード：シアノバクテリア、南アフリカ、フィグツリー
Keywords: cyanobacteria, South Africa, Fig Tree

西グリーンランドの太古代かんらん岩体から何がわかるか？
What can we learn from ultramafic rocks in Mesoarchaean orthogneisses in the Fiskefjord region of southern West Greenland?

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Ultramafic rocks occur sporadically as variably sized, lens-shaped bodies (e.g., Seqi, Miaggoq and Ulamertoq) within Mesoarchaean (ca. 3000 Ma) amphibolite- to granulite-facies orthogneisses in the Akia terrane of southern West Greenland (Garde, 1997 Geol. Greenland Surv, Bull.; Szilas et al., 2015a GeoResJ). Two contrasting models can be proposed for the origin of peridotite bodies in the studied area and other Archaean belts in Greenland: (1) residual mantle peridotite after partial melting, and (2) ultramafic cumulates (Friend & Nutman, 2011 Geology; Szilas et al, 2015a, 2015b Gondowana Res.). In either case, these ultramafic bodies would provide new insights into the links between magmatic-metasomatic processes and crust-continent formation during the Archaean. The Ulamertoq body is a relatively large ultramafic body, 1 x 1.5 km in size. Here we document its field occurrence and petrological characteristics as an example of the ultramafic bodies in the studied area in the context of magmatic and metasomatic processes during the Archaean age. The Ulamertoq peridotite body and also other ultramafic bodies are crosscut by granitic rocks at ca. 3000 Ma (U-Pb zircon; Szilas et al., 2016 AGU abstract). The Ulamertoq peridotite body suffered extensive metasomatism of hydrous silica-rich metasomatic fluids/melts and provides evidence for subduction-like metatomatism during the Archaean. Consequently, although it is difficult to find primary igneous features in peridotite bodies from Archaean belts, our field observations and geochemical data from these peridotite bodies support their cumulate origin (Szilas et al., 2015a, b).

キーワード：30億年かんらん岩体の産状、30億年前の島弧交代作用、30億年前のかんらん岩集積岩
Keywords: Occurrence of Mesoarchaean peridotite body, Mesoarchaean Subduction-related metasomatism, Archaean ultramafic cumulate

The Hadean environment inferred from mineral inclusions within the oldest terrestrial zircons

The Hadean environment inferred from mineral inclusions within the oldest terrestrial zircons

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Terrestrial rock records during Hadean era (> 4.0 Ga) are scarcely preserved due to surface erosion, subduction, and intense meteorite bombardment. Clues about conditions during this time can be deduced from detrital zircon and its mineral inclusions as old as 4.4 Ga recovered from metasedimentary rocks at Jack Hills in the Narryer Gneiss Complex, Western Australia [1-2]. Hadean zircons from Jack Hills contain various mineral inclusions such as muscovite, quartz, plagioclase, biotite, hornblende, apatite, magnetite, and biogenic carbon (graphite). Investigations of these mineral inclusions have suggested the emergence of a hydrosphere, granitic continental crust, sedimentary cycling, geo-magnetic field, and biosphere in Hadean earth [3-6]. Especially, chemistry of apatite inclusions in zircon reflects the compositions of whole rocks, thus can characterize the host magma [7]. However, the percentage of Hadean zircons to detrital zircons in Jack Hills was as small as 5% [8]. Moreover, skepticism about the preservation of such inclusions have recently raised because of secondary metamorphic overprint [9]. Owing to these reasons, large number of age analysis for zircon grains and precise identification of primary mineral inclusions must be operated to derive reliable information for Hadean earth environment. To overcome this, we have developed rapid and precise dating technique using laser ablation ICP-mass spectrometer (LA-ICP-MS). Mineral inclusions in the zircons were investigated using laser Raman microspectroscopy, equipped with high-speed Raman mapping system. Our preliminary results show that primary apatite and melt inclusions are successfully recovered from zircons of over 4.0 Ga out of 3000 checked grains. The chemistry of apatite and melt inclusions are commonly utilized to characterize host rock, missing Hadean crust. Combination of rapid U-Pb dating with LA-ICP-MS and mineral identification with laser Raman leads us to trace a missing Hadean environment from the oldest zircon of the Earth.

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キーワード：Hadean、zircon、mineral inclusion
Keywords: Hadean, zircon, mineral inclusion

Geology of the Eoarchean Nuvvuagittuq supracrustal belt: Constraints on the geochemical signatures of ^{142}Nd anomaly and a geochemical variation of volcanic rocks.

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The Nuvvuagittuq supracrustal belt is one of the oldest supracrustal belts so that the geology, geochemistry and geobiology provide important insights into the early evolution of the earth. The minimum age (*ca.* 3.8 Ga) of the supracrustal rocks are provided by U-Pb dating of zircons from surrounding granitic gneisses and thin felsic intrusions into the supracrustal belt. Besides, the mafic and ultramafic rocks were suggested to be formed in the Hadean as old as 4.2 Ga based on a pseudo-isochron of ^{147}Sm/^{144}Nd–^{142}Nd/^{144}Nd. However, the interpretation of the pseudo-isochron of ^{147}Sm/^{144}Nd–^{142}Nd/^{144}Nd is highly controversial; the apparent good correlation between them is also regarded as mixing between chondritic ^{142}Nd/^{144}Nd and low ^{142}Nd/^{144}Nd sources. The geological interpretation of the felsic intrusions is also on debate, and felsic volcaniclastic sediments intercalated with the supracrustal rocks are also proposed for the protoliths. In this case, the age of zircons from the rocks is interpreted as a depositional age of the sediments, namely the age of the supracrustal belt.
The Nuvvuagittuq supracrustal belt (NSB) is located on the eastern coast of Hudson Bay, in the Inukjuak Block of the Hudson Bay Terrane of the Northeastern Superior Province of Canada, and contains ultramafic rocks, mafic rocks, banded iron formation (BIF), chert, conglomerate, gabbroic and felsic intrusions. The belt forms an arcuate structure with moderately dipping and NW-plunging hinge line. In addition, the belt was also tightly to isoclinally folded before the folding to form a syncline structure. Previous work suggested three groups of mafic-ultramafic suites with different chemical compositions such as TiO_2 contents and REE patterns: High-Ti, depleted Low-Ti and enriched Low-Ti Ujaraaluk units in ascending order, respectively, and considered the ultramafic rocks as sills.
We made a detailed geological map of the southwestern part of the NSB at a 1:5000 scale, and found many geologic differences from the previous works. The belt comprises ultramafic volcanic rocks, mafic volcanic rocks, mafic intrusions, BIF, chert, “carbonate rocks”, “putative” conglomerates and fine-grained felsic intrusions, and pegmatitic intrusions.
The previous work suggested that the southwestern part forms the synclinal structure, but our geologic reappraisal shows that the volcanosedimentary sequences of ultramafic and mafic volcanic units overlain by the BIF and chert mostly strike NS and dip to the east. The stratigraphy that ultramafic rocks are overlain by the BIF layers indicates that they are not sills but flows under the water. Although there are some coarse-grained amphibolites, possibly originating from gabbroic intrusions, many NS-trending structures are not due to the gabbroic intrusions but due to the felsic intrusions. Many of the gabbroic intrusions, interpreted by previous works, are not intrusions, but they originate from mafic volcanic rocks and apparently form linear structures due to felsic intrusions on both sides. It is because there are no chilled margins along the rims and the grain sizes are varied within the linear structures. Although a banding structure occurs along the boundary with mafic rocks in some places, a large chert layer (silica formation) should be referred as a pegmatitic intrusion, which is one of many large pegmatite intrusions in the belt. Two types of felsic intrusions are ubiquitously distributed over the belt: pegmatite and fine-grained felsic intrusions. The felsic intrusions are quite enigmatic; the felsic intrusions fade away into

conglomerate-like structures in some places and form many linear structures within the mafic rock units. We, preliminarily, consider that the felsic intrusions account for the conglomerates and three geochemical groups of basaltic volcanics due to assimilation of the felsic rocks into the mafic rocks as well as a pseudo-isochron of $^{147}Sm/^{144}Nd$-$^{142}Nd/^{144}Nd$.

キーワード：142Nd同位体異常、初期分化、初期太古代
Keywords: 142Nd isotope anomaly, Early differentiation, Eoarchean

ジルコンから読み解く大陸地殻進化
Zircon perspectives on the evolution of the continental crust

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One of the Earth’s unique features among the known terrestrial planets is the presence of a chemically evolved massive crust –the continental crust. It is generally accepted that the modern continental crust has an andesitic bulk composition and is vertically stratified in terms of lithological and chemical compositions–from lower portions dominated by mafic rocks to upper portions dominated by granitoids. Yet there is considerable debate as to when and how the continental crust has evolved to its present form. In this presentation, we explore perspectives on the evolution of the continental crust emerged from the zircon U–Pb age and Hf isotope data with supplementary zircon O isotope data.
Zircon, a common accessory phase in granitoids, can be precisely dated by the U-Pb system. Zircon Hf isotopic composition is a function of crustal residence time of the magmatic protolith, whereas the O isotopic composition is a sensitive record of reworking of mature sediments such as pelite. An integration of U-Pb, Lu-Hf and O isotopic data for detrital zircons from modern large rivers indicates that: (1) granitoid magmatism has played a significant role in the crustal differentiation and crustal reworking over geologic history, (2) the supercontinent cycle has controlled the evolution of the continental crust by regulating the rates of crustal generation and intra-crustal reworking processes and the preservation potential of granitoid crust, and (3) ~25% and ~80% of the preserved continental crust would be formed by 2.5 Ga and 1.0 Ga, respectively. Given that the continental growth is a combined result of the addition of new continental crust and recycling of continental crust into the mantle, the actual net growth of continental crust could be remarkably earlier than this. Taking into account the crustal residence times of continental crust recycled back into the mantle, we propose a continental growth model that stable continental crust was firstly established in the Paleo- and Mesoarchean and significantly grew in the Paleoproterozoic.

キーワード：大陸地殻、ジルコン、同位体
Keywords: continental crust, zircon, isotope

U-Pb zircon geochronology of the North Pole Dome adamellite in the eastern Pilbara Craton

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Supracrustal rocks around the North Pole Dome area, Western Australia, provide valuable information regarding early records of crustal growth, surface environments and biosphere. Owing to the occurrence of the oldest known microfossils, the North Pole Dome area has attracted interests from many researchers. The Paleoarchean successions (Warrawoona Group) in this area mainly comprise mafic-ultramafic greenstones with intercalated cherts and felsic lavas. Previous age constraints on the succession have been mainly based on zircon U-Pb geochronology of felsic rocks (e.g., adamellite, rhyolite and tuff). However, most zircon grains have suffered from metamictization and contain anomalously high contents of common Pb, which makes interpretation of the U-Pb data complicated. Actually, previous zircon U-Pb data were highly scattered even plotted on Concordia curve within their analytical errors. In order to provide more convincing chronological constraints, we attempted to acquire U-Pb Concordia ages, which had been widely accepted as the best estimate of U-Pb age with the smallest uncertainties.
The North Pole Dome adamellite intrudes into the bottom of the Warrawoona Group, and most zircons separated from the adamellites (95NP207 and 96NP208) suffered from severe metamictization. We selected less metamictized domains using a pre-ablation technique in conjunction with elemental mapping and then conducted *in situ* U-Pb isotopic analyses with a laser ablation inductively coupled plasma mass spectrometry. Most analyzed domains contain certain amounts of common Pb ($^{204}Pb/^{206}Pb > 0.0001$), whereas we have obtained three and five concordant data points with less common Pb ($^{204}Pb/^{206}Pb < 0.0001$). These concordant data-sets yield Concordia ages of 3445 ±23 and 3454 ±17 Ma, respectively. Although these ages are almost similar to those from previous reports, the new ages are based on more reliable data with the smaller errors owing to avoidance of metamictized domains. These ages constrain the intrusive age of the North Pole Dome adamellite and the minimum depositional age of the Warrawoona Group and indicates that the microfossils discovered in this area had appeared by *ca.* 3454 Ma. In addition, a single xenocrystic zircon grain with less common Pb ($^{204}Pb/^{206}Pb < 0.0001$) shows a $^{207}Pb/^{206}Pb$ age of *ca.* 3545 Ma, supporting the idea that the sialic basement of the Pilbara Craton existed prior to 3500 Ma.
In general, old zircon grains often suffer from metamictization and contain detectable level of common Pb, which are unsuitable to constrain precise igneous ages of the host rocks. In contrast, the *in situ* U-Pb zircon dating combined with the pre-ablation technique can obviate to measure such metamictized domains, and has the potential for yielding precise and accurate geochronological data even from metamict zircons.

キーワード：ノースポール地域、ジルコンU-Pb年代学、メタミクト化、初期鉛、U-Pbコンコーディア年代
Keywords: North Pole Dome, U-Pb zircon geochronology, Metamict, Common Pb, U-Pb Concordia age

太古代大気組成解明に向けた高波長分解能4種硫黄同位体SO2吸収断面積測定

High-resolution 32/33/34/36SO2 absorption cross-section measurements for revealing Archean atmospheric composition

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Many geological and geochemical records suggest a reducing Archean atmosphere. Revealing Archean atmospheric composition is important proxy for the understanding of the origin and evolution of life. The discovery and explanation of sulfur mass-independent fractionation (S-MIF) signatures in Archean sedimentary rocks possess as a key to unravel Archean atmospheric composition. Our SO_2 photochemical experiments generated large S-MIF ($\Delta^{33}S > +5‰$) and reproduced basic character of the Archean S-MIF signature ($\Delta^{36}S/\Delta^{33}S = -1$) under a specific condition for the first time (Endo et al. 2016). Self-shielding of SO_2 photodissociation and intersystem crossing (ISC) form singlet SO_2 to triplet SO_2 are shown as key mechanisms. Next, we simulated large S-MIF signature ($\Delta^{33}S > +5‰$) in our box numerical model, and we showed that Archean S-MIF trend ($\Delta^{36}S/\Delta^{33}S = -1$) can be explained when there are several ppm level of SO_2 (like the plume of volcanic gas) and 2% (2 kPa) CO or 3% (3 kPa) CH_4 in the atmosphere. But box model’s calculation is not completely correct because photochemical reaction rate and fractionation factor (such as self-shielding) strongly depends on the altitude. Then we need to develop 1-D atmospheric model.
Our group's new 1-D model which focuses on UV spectra because reactions and fractionation factor (such as self-shielding) change delicately as a function of irradiative photon flux. Fractionation factor of photodissociation can be calculated by isotopologue cross-section and irradiative photon flux. Then in order to develop 1-D atmospheric model including sulfur isotopes, SO_2 isotopologue cross-sections ($^{32/33/34/36}SO_2$) are necessary. Although SO_2 isotopologue cross-section have been measured, they are too low-resolution to estimate self-shielding (Danielache et al. 2008, Endo et al. 2015). Here, we report preliminary results of high resolution (~1cm^{-1}) $^{32/33/34/36}SO_2$ absorption cross-sections and estimation of fractionation factor including self-shielding effect.

Referces: Endo et al. (2016), EPSL, Danielache et al. (2008), JGR Atmospheres, Endo et al. (2015), JGR Atmospheres

キーワード：太古代大気、硫黄同位体、光化学
Keywords: Archean atmosphere, Sulfur isotope, Photochemistry

西オーストラリア・ピルバラ地域デキソンアイランド層における32億年前の重晶石および黄鉄鉱硫黄同位体不均質
3.2 Ga sulfur isotopic heterogeneity of barite and pyrite microcrystals in Dixon Island Formation, Pilbara, Western Australia.

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中期太古代(32~28億年前)は還元的大気海洋環境の遷移的酸化を示す大規模縞状鉄鉱層の形成(Windley, 1995)など多くの地球史上重要なイベントがあった時代として知られている。当時の硫黄サイクルや酸化還元環境を知る上で硫黄の安定同位体比($\delta^{34}S$(‰)=(($^{34}S/^{32}S)_{sample}$/ ($^{34}S/^{32}S)_{standard}$-1)×1000)は重要なプロキシである。各硫黄化学種の$\delta^{34}S$はマントルや海洋などのリザーバーごとに大局的な平衡状態にある。しかし局所的にそれらが混合することや酸化還元反応により化学種が変わることで値は大きく変化し、とくに還元性物質である硫化鉱物および酸化性物質である硫酸塩鉱物の$\delta^{34}S$変動は酸素濃度上昇や硫酸還元菌の活動活発化と密接に関わっていると考えられる。近年の微小領域高精度の分析法の向上により詳細な変化を識別できるようになったことから、本研究では32億年前の堆積物に注目し、西オーストラリア州ピルバラ地域のデキソンアイランド層中にわずかに残存する重晶石および黄鉄鉱について高空間分解能二次イオン質量分析計(NanoSIMS)による$\delta^{34}S$微小領域分析を行った。

デキソンアイランド層は下位からコマチアイト-流紋岩質凝灰岩部層、黒色チャート部層、多色チャート部層からなる。多色チャート部層中の黄鉄鉱試料について、DXCL掘削により得られた未風化黄鉄鉱試料は数mmから1mm以下の非常に細かなラミナを成し、$\delta^{34}S$値は-10.1~+26.8‰(n=143; Avg. = +8.9‰)(坂本, 2010MS)、初期にできた微小球殻状黄鉄鉱内でも10μmで5~10‰の同位体変化が見られる(三木, 2015MS)。

また、重晶石層はデキソンアイランド層黒色チャート部層の下部に5~8層残っているが全体に珪化しており、珪化を免れた重晶石が200μm以下の結晶としてごくわずかに保存されている。また重晶石が結晶形を保って珪化した偽晶は非常に細粒の黄鉄鉱を含む。この地層から3層準を選んで岩石試料を採取し、粒界粉砕により重晶石29粒および付随する黄鉄鉱19粒を取り出してNanoSIMS分析を行った。その結果、重晶石からは-7.1±1.0~+18.7±0.9‰ (Avg. = +0.4±1.3‰) という値が得られた。一方、共出した黄鉄鉱は+2.1 ±2.0 ～ +22.3 ±5.9 (Avg. = +11.4 ±2.8‰)であった。

堆積物中で硫酸還元菌が関与した場合，最終生成物である黄鉄鉱のδ34Sは負の値を取ることで知られているが、本研究ではほとんど差がなく、むしろ黄鉄鉱が重い値を持った。最近の研究では32億年前の硫黄同位体の値は高い値をとっており、硫酸還元菌が関与しない反応経路もしくは火山活動などの外からの流入が考えられる。またレイリー分別により正にシフトすることはラグーンや全球凍結等硫酸供給が閉じた環境を意味するため、$\delta^{34}S$値が高くなる原因を識別することが重要になる。

キーワード：太古代、硫黄同位体、黄鉄鉱、重晶石
Keywords: Archean, sulfur isotope, pyrite, barite

古原生代Transvaal超層群Hotazel層の縞状鉄鉱層およびMn堆積物の地質学・地球化学的研究：希土類元素組成から示唆される堆積環境の酸化還元と熱水の影響の変化

The petrographical and geochemical characteristics of the BIFs in the Hotazel Formation from Transvaal Supergroup: Implications for redox and hydrothermal contributions in their depositional environments.

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The surface environments on the earth have evolved from anoxic to oxic. The oxidation has occurred discontinuously mainly at two times throughout the earth history: the Neoarchean to the Paleoproterozoic and the Neoproterozoic. The first oxidation event is known as “the Great Oxidation Event (GOE)”. In the Paleoproterozoic Hotazel Formation of the Transvaal Supergroup, South Africa, there are the manganese ores hosted by the banded iron formations at the three stratigraphic horizons, which is one of the most conspicuous evidences for GOE.
Previous studies in the Hotazel Formation have focused only on their metallogenic studies of the Mn ores such as post-depositional alterations (e.g. Gutzmer and Beukes, 1997). On the other hand, their sedimentary environment changes responsible for depositions of the manganese rocks and the BIFs have not been constrained fully. In this study, we tried to estimate redox and hydrothermal contributions in the sedimentary environments from the lowermost BIFs to the lowest Mn-rock layer based on stratigraphic variations of some geochemical proxies (some major element contents such as Mn, Ca and Fe, and REE + Y patterns).
In the studied strata, the Mn/Fe ratios and Ca/Fe ratios from the lowermost BIFs to the lowest Mn rocks show increasing trends, suggesting that precipitations of Mn-oxide minerals and Ca-carbonate minerals were becoming prevailed relative to that of Fe-oxide minerals in the sedimentary environments. These trends suggest that the sedimentary environments were becoming more oxic and shallower.
Whole-rock REE + Y contents in the BIFs show weakly positive correlations with Fe contents and strongly positive correlations with phosphorus (P) contents. Moreover, micro-scale elemental imaging in the lowermost BIFs shows that apatite occur as spots in the Fe-oxide bands, and REE + Y is concentrated in those spots. Those REE + Y distributions in the BIFs suggest that REE + Y might have been primarily derived from adsorbents on Fe oxyhydroxide and secondarily moved into phosphorous minerals at the diagenesis. On the other hand, REE + Y in the lowest Mn-rock layer is positively correlated with Mn contents, suggesting that those elements might have been derived from adsorbents on Mn oxyhydroxide. However, secondarily movement of REE + Y associated with the diagenesis forming apatite might be less influential on REE + Y patterns because anomalous behaviors of Eu and Ce are seen regardless of P contents. PAAS-normalized REE + Y patterns show that the lowermost BIFs overlying the Ongeluk

Formation show positive Eu anomalies characteristics of high-temperature hydrothermal fluids (e.g. Bau and Dulski, 1999). On the other hand, the Mn rocks show negative Ce anomalies similar to modern oxic seawater (e.g. Alibo and Nozaki, 1999).
Above stratigraphic variations of Mn/Fe, Ca/Fe ratios and REE + Y patterns in the analyzed strata suggest that the Paleoproterozoic ocean was composed of double-layered structure. The deep ocean was anoxic and subject to contributions of hydrothermal fluids, resulting in precipitations of Fe-oxide minerals (the BIFs). On the other hand, the shallow ocean was oxic with active primary productions, resulting in Mn-oxide and Ca-carbonate minerals.

キーワード：縞状鉄鉱層、Mn堆積物、希土類元素組成
Keywords: Banded Iron Formations, Manganese rocks, Rare Earth Elements

カナダ/古原生代トランスハドソン変動帯に残された堆積盆の層序復元: Reconstruction Paleoproterozoic sedimentary basin stratigraphy in Trans Hadoson Orogeny, Canada

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古原生代は，大気中の酸素濃度上昇事件（Grate Oxidation Event）や，真核生物の台頭が始まり，大陸集合・分裂イベントを伴って地球表層が大きく変化したと言われる (e.g. Holland, 1994, Condie 1997, Kopp et al, 2005)．表層の急激な酸化作用から，海底は極度の還元環境に陥り，硫化物に富むユーキシニック海洋が広がるとされている（Lyons et al., 2014）．しかし，大陸が安定化するこの時代の深海底の地質学的証拠は原生代の深海底の地層は付加や衝突帯に巻き込まれており，その復元は詳細な地質調査による層序復元が重要になる．我々は古原生代における比較的深い海底の環境変遷を明らかにするために，カナダ・スペリオルクラトンの北縁にあたるトランスハドソン造山帯中に残されるフリンフロン帯およびケープスミス帯に注目した．特に黒色頁岩を含む地層に注目し，地質調査および鉱山が取得する掘削コア記載・サンプリングにより，比較的深い海洋環境における海底状態の復元を試みている．

フリンフロン帯（Trout Lake (Embury lake) Formationトロウトレイク層）：島弧火山活動によって形成されている火山岩帯に沿って分布する砂岩・泥岩からなるタービダイト層からなる。露頭では造山運動の影響により千枚岩化しており、タイト褶曲が面構造に沿って見られる。Hadbay社の掘削コアより、400ｍの連続試料について現地にて記載し、黒色頁岩部分を中心に200個におよび試料を取得している。褶曲解析により約150ｍの連続層序が復元できた。薄片観察にて、これらの地層は石英粒子に乏しい火山岩起源の砂岩と泥岩の互層であり、島弧起源から供給された比較的深い堆積盆でできた地層と思われる。現在、砂岩および石英斑岩の年代測定、炭素同位体測定を行っている。

ケープスミス帯（Nuvilik Formation, Povungnituk Group：ヌービリック層，ブブンマタク層群）

ケープスミス帯は19億年前のシート岩脈をもつオフィオライトからなるWatts層群、構造的下位の玄武岩およびコマチアイト溶岩を主体とするChukotat層群、Watts層群の下位に整合的関係で分布する大陸棚起源堆積岩（黒色頁岩）のPovungituk層群からなる。Chukotat層群の最下部に位置するコマチアイト溶岩はサーマルエロージョンによる侵食ｗ起こしており、溶岩最下部はNi-Cu硫化物鉱物鉱床（Relgan鉱山）を形成する(Lesher 2017)。我々はコマチアイト溶岩直下に分布する黒色頁岩（千枚岩）からなるNuvilik層（Povungituk層群）について、Relgan鉱山の許可を得て露頭調査を行なった。また、2箇所のコアKikialik siteにおいて鉱山内から掘削した300mコア（468069 core）と Katinniq siteのzone 5-8 地域での表層から800mパイロットコア(718-3485 core)について、詳細な層序記載および試料採取を行った。薄片観察では、黒色頁岩には石英粒子をおよび有機物に富む特徴を持つ。スペリオルクラトンの北縁部にあたる2地域での比較的深い海底堆積物について，層序復元を陸上調査および掘削コア記載を行った。

キーワード：古原生代、トランスハドソン造山運動、有機物深海堆積物
Keywords: Paleoproterozoic, Trans Hudson Orogeny, rganic rich deep sea sediment

Lithology and Depositional Age of Paleoproterozoic Volcaniclastic Sequence from Ashanti Belt of Birimian Supergroup, Southwest Ghana

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Paleoproterozoic Birimian volcaniclastic successions occur along the coast near Cape Three Points, in Ashanti belt, southwest Ghana. In this study, the depositional environments and bioactivities recorded in the c.a. 2.3 Ga rocks were investigated. We reporrt the structure and stratigraphy in the area, improved depositional age of the sediments by zircon U-Pb dating and C isotope features of the bioactivities in the paleo-ocean.
The Ashanti belt, generally showing NE-SW strike, composed mainly of andesitic basalts, volcaniclastic rocks and belt type granitoids (Perrouty et al., 2012). The greenstone is uncomformably overlain by Tarkwaian conglomerates and metasedimentary rocks. The maximum depositional age of the overlying metasedimentary rocks and the oldest age of the intruded rock into Birimian volcanics in the Sekondi region is 2154±2 Ma and 2174±2 Ma, respectively (U-Pb zircon: Oberthür et al., 1998).
Detailed field investigations were performed to reconstruct about 1000m out of over 2000m thick stratigraphy of the volcaniclastic sequence in the Cape Three Points area. The rocks, affected by greenschist-facies metamorphism, generally strike N-S, mainly dip 60-80º to the east and show fining upward stratigraphy. Using a west vergent thrust fault which occurs in the central part of the area, we sub-divided the area into two, a western zone and an eastern zone. The eastern zone consists of approximately 800 m thick fining upwards sequence which appears to have been repeated two times within the sequence. Thick basaltic lava in the lowermost part of the sequence is replaced by or changes into sediments produced by gravity flows. The uppermost part of the sequence reveals thick basaltic andesite and/or pyroclastic layers which then changes to fine altered volcaniclastics containing organic material. The western zone has not yet been reconstructed the stratigraphy.
TiO_2/Al_2O_3 ratios from EPMA analyses of chromite in basaltic rocks suggest that these rocks originated in a volcanic arc system. Whole-rock trace element compositions tend to show low concentrations of Nb and high LREEs, which also supports derivation from volcanic arc.
A foliated porphyritic dyke which occurs in the Cape Three Points area was dated by SHRIMP at the National Institute of Polar Research. Zircon grains in the dyke yielded a weighted mean ^{204}Pb-corrected ^{207}Pb ^{206}Pb age of 2265.6±4.6 Ma (95% confidence), which suggests that the volcaniclastic sequence was deposited before 2265.6±4.6 Ma and was deformed afterwards. This age is the oldest in the Ghanaian greenstone terrane (Loh and Hirdes, 1999). It would seem, therefore, that rocks in the Cape Three Points area record the history of early volcanic activity in the Birimian greenstone terrain.
We measured organic carbon isotope ratio of some black shale samples. The TOC varies from 0.02 %- 0.3 % and the $\delta^{13}C$ values are -35 ‰- -15 ‰(N=5). These low concentrations of the organic matter suggest dilution by the continual influx of volcanogenic clastics.
The thick finning-upward volcaniclastic sequence and chemical compositions may suggest the Cape

Three Points Formation was deposited on mid-deep sea floor beside an oceanic volcanic arc. The deposition may have occurred before 2265.6±4.6 Ma suggesting these sediments record oceanic environmental changes from Makganyene glaciation toward Lomagundi Event (2.3 Ga -2.06 Ga, Bekker and Holland, 2012 and Kopp et al., 2005).

キーワード：ガーナ・ビリミアン超層群、古原生代
Keywords: Birimian Supergroup, Ghana, Paleoproterozoic

東エジプトEl Dabbah地域の層序と堆積場の復元：新原生代の縞状鉄鉱層
Reconstruction of stratigraphy and tectonic setting in El Dabbah, Eastern Egypt: Neoproterozoic banded iron formations

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In the Eastern Desert of Egypt, Neoproterozoic Banded Iron Formations (BIFs) are reported within Nubia greenstone belt whose geological structure and stratigraphy are not well understood. In this study, the geological structure was established to reconstruct the stratigraphy including Iron formations (IFs) in El Dabbah in the middle of the Eastern Desert.
Greenstone sequence in El Dabbah area, strike-slip basin on Nubia shield during pan African orogeny, is covered by Hammamat Group. The greenstone sequence preserved the thick volcano-sedimentary rocks with gabbro, coarse-grained volcaniclastics rocks, pillow lavas, black shales, and BIFs. Reconstruction of stratigraphy in this greenstone sequence, which is 4000m in total thickness, composes Basal, Lower, Middle, and Upper members. There are 13 iron sections within this greenstone sequence.
Especially, BIFs sequence preserved within Lower and Upper members. BIFs sequences are well preserved within massive - pillow lavas sections and it contain laminated greenish - black shales. BIFs are composed of magnetite and/or hematite. Magnetite are oxidized from rims and become hematite.
We have determined major and trace element compositions of whole rock of volcanics and BIFs by using XRF and ICP-MS analysis. Trace elements compositions indicate that the volcanics are arc origin in term of a Nb-Zr-Y discrimination diagram and a MORB normalized spider diagram. Major elements in BIFs in this area are characterized by their higher content of Al_2O_3 than the other Archean BIFs. In addition, REE in BIFs show pattern of light REE enrichment and negative Eu anomalies.
This Volcaniclastic sedimentary sequence would be related at island arc sedimentary sequence with volcanic activity.

キーワード：縞状鉄鉱層、新原生代
Keywords: banded iron formation, Neoproterozoic

Toward a better understanding of trace element availability in Paleo-proterozoic seawater

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One of the large gaps between prokaryotic and eukaryotic lives lies in the utilization of trace elements in seawater. Eukaryotes have higher Cu and Zn requirements than prokaryotes; for example all eukaryotes have Cu-Zn-SOD (Superoxide Dismutase), whereas prokaryotes have Fe-Mn-SOD. Phylogenomic reconstruction suggested that above-mentioned protein structures evolved either concurrent with or after the emergence of the Eukaryotic domain. Therefore Cu and Zn would be two of the most likely trace metals to provide a geochemical barrier specific to eukaryotic evolution, and deficits of Cu and Zn in seawater have been hypothesized as one of the explanations for the delayed diversification of eukaryotes.

Previous works have tried to decipher a secular variation of marine Zn inventory based mainly on Zn concentrations in ancient sediments. They suggested that the amount of bio-available Zn remained relatively unchanged through time (Robbins et al., 2013; Scott et al., 2013), but stoichiometric assessment concerning removal process of elements during sedimentation still remains difficult. In order to quantitatively track secular variations of Cu and Zn availabilities in seawater, we adopted Cu and Zn isotopes of carbonate rocks and black shales, because these isotopes are expected to reflect marine inventories of each element.

Francevillian Group in Gabonese Republic was recently established as a typical sedimentary sequence for the Paleoproterozoic, and it contains macroscopic structures interpreted as colonial eukaryotic organisms. We hypothesize that these organisms might have evolved in concert with the oxidation of the atmosphere-ocean system and increases of marine Cu and Zn inventories at that time. Although Chi Fru et al. (2016) recently reported eight Cu isotopic ratios from sediments in the Francevillian Group, sequences round macroscopic structures have never been investigated. We collected some carbonate rocks and black shales from the Francevillian Group, and made thin sections from them. SEM-EDS analysis demonstrated that Cu and Zn are enriched in pyrite grains. Powdery samples were prepared by micro-drilling, and acid digestion was performed with aqua regia at 150 Celsius degrees for 48 hours. For isotopic analysis, Cu and Zn were purified using anion exchange on AG-MP-1M resin column. Bulk Cu and Zn isotopic ratio were obtained with a multi collector inductively coupled plasma mass spectrometry (NEPTUNE) at UC Davis. We will report the preliminary results in this presentation.

キーワード：銅同位体比、亜鉛同位体比、ガボン、前期原生代
Keywords: Cu isotope ratio, Zn isotope ratio, Gabon, The Paleo-proterozoic

ガボン・前期原生代フランスヴィル層群における生物多様性
Biodiversity in the Paleoproterozoic Francevillian Group, Gabon

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The Paleoproterozoic (~2.2 Ga) macrofossils are discovered one after another from the sedimentary sequence of the Francevillian Group in Gabon; pyritized macrofossils from Socoba section in Franceville Basin (Albani et al., 2010, Nature; 2014, PLOS ONE) and nodular fossils from Akou section in Okondja Basin (Moussavou et al., 2015, J Geol Geosci; Edou-Minko et al., 2017, J Geol Geosci). These fossils are interpreted as microbial colony or colonial eukaryotic organisms on the basis of their complex structures and macro sizes. They are reported from the black shales of the FB Unit; however, the fossil horizons are not correlated precisely because of the poor stratigraphic correlation between the basins. In order to clarify the interbasinal appearance of the fossils and the corresponding environmental changes, we conducted a geological fieldwork and investigated the litho-, bio- and chemo-stratigraphy in the Franceville, Lastoursville, and Okondja Basins. These intracratonic rift basins on the Archean basement rocks were filled up with the Paleoproterozoic Francevillian Group; i.e., FA (fluvial sandstones with uranium ore at the top, including the well-known Oklo nuclear reactors), FB (black shales and carbonates, containing manganese-rich carbonates and the fossil horizon at the upper part), FC (cherts), FD (black shales), and FE (sandstones). We will report the preliminary stratigraphic correlations between the Franceville, Lastoursville, and Okondja Basins, especially on the fossiliferous FB Unit.

キーワード：前期原生代、大型化石、微化石、ガボン
Keywords: Paleoproterozoic, macrofossil, microfossil, Gabon

エディアカラ紀海洋の硫酸濃度上昇イベント
Oceanic sulfate increase events in the Ediacaran ocean

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It is thought that the development of life was closely linked to seawater chemistry, especially redox conditions. Since metazoans diversified in the Ediacaran, revealing redox condition in Ediacaran ocean is crucial for evolution of life. Recent sulfur isotopic values ($\delta^{34}S$) of carbonate associated sulfate (CAS) and chromium reducible sulfur (CRS) of Ediacaran sediments indicate that the ocean-atmosphere system was progressively oxidized during the Neoproterozoic. Those data further suggest that sulfur cycle was closely related to Shuram excursion, the largest carbon isotope anomaly in the Ediacaran. Ediacaran sediments in South China are ideal to unravel possible linkages between oceanic redox conditions and biological activity, because various proxies have been provided by a number of works. A previous work reported both $\delta^{34}S_{CAS}$ and $\delta^{34}S_{CRS}$ from Ediacaran Doushantuo Formation at Three Gorges, South China. Their $\delta^{34}S_{CAS}$ data were highly scattered, and this is possibly attributed to contamination from CRS during separation processes. Therefore stratigraphic profile of the $\delta^{34}S_{CAS}$ has not been fully determined, which leaves ambiguity in reconstruction of the oceanic redox nature.
We carried out sulfur isotope analyses of CAS and CRS of Ediacaran drill core samples collected from the Three Gorges. To reduce contamination from CRS fraction into CAS fraction, we employed an improved method to extract the pure CAS. The newly obtained $\delta^{34}S_{CAS}$ values display a smooth curve above the lower part of Member 2 of the Doushantuo Formation and range from +18.7‰ to +46.4‰, except for a datum of -3.7‰. The $\delta^{34}S_{CRS}$ values also display a smooth curve, and range from -18.6 to +42.8‰. The differences between $\delta^{34}S_{CAS}$ and $\delta^{34}S_{CRS}$ values are negatively correlated with $\delta^{34}S_{CRS}$ values, suggesting that the $\delta^{34}S_{CRS}$ values likely reflect degree of isotopic fractionation during sulfate reduction. The $\delta^{34}S_{CAS}$ data in sediments deposited before Shuram excursion are unsynchronized among South China, USA, Mexico, and Oman. The heterogeneous $\delta^{34}S_{CAS}$ data possibly arose from low oceanic sulfate concentration, because residence time of oceanic sulfate fell below a mixing time of the various ocean basins when sulfate concentration was low.
The stratigraphic profile of $\delta^{34}S_{CRS}$ exhibits two negative excursions, and we firstly found that the both excursions coincide with the positive excursions of the $^{87}Sr/^{86}Sr$ ratio and the negative excursions of the $\delta^{13}C$ value of the carbonate ($\delta^{13}C_{carb}$). These correlations indicate that enhanced oxidative weathering increased oceanic sulfate concentration and accelerated release of isotopically light carbon through sulfate reduction of organic matter. Furthermore, the $\delta^{34}S_{CAS}$ decreases from +23.5‰ to +18.7‰ parallel with the Shuram excursion. This decreasing trend during the Shuram excursion is comparable to those in Mexico, USA, and Oman. Therefore decrease of $\delta^{34}S_{CAS}$ concomitant with the Shuram excursion was a global trend, and this fact further suggests increase of oceanic sulfate concentration during this period. During the Shuram excursion, $\delta^{13}C_{carb}$ values started to co-vary with $\delta^{13}C$ values of the organic carbon, which indicates that a large oceanic organic carbon pool was exhausted owing to elevated oceanic sulfate level and extensive sulfate reduction. Our new results indicate that enhanced oxidative weathering supplied sulfate into ocean and induced high oceanic sulfate level and subsequent Shuram excursion

during the late Ediacaran.

小惑星ー彗星衝突による寒冷化ー大量絶滅事件の頻度

Frequency of significant cooling and subsequent mass extinctions by asteroid-comet impacts

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For decades, rule of asteroid-comet impacts for climate changes and extinctions of biota has been a subject of debate. A consistent impact rate since the end of the late heavy bombardment and vulnerability of comet suggests approximately 70 and 10 significant Cooling Events enough to cause Mass Extinctions (CEME) after the late heavy bombardment 3.8 Ga and in the Phanerozoic after diversification of multicellular animals, respectively. Many scientists have sought evidence of impact for all mass extinctions. However, only one mass extinction likely occurred by asteroid impact in the Phanerozoic. Here I show that approximately 20 and a few CEME caused by asteroid impacts are possible after 3.8 Ga and in the Phanerozoic, respectively. High concentration of hydrocarbon in target rocks is essential to cause CEME, as an impact burned hydrocarbon in the target rocks forming stratospheric soot, which caused extreme global cooling and draught. The high content areas enough for CEME occupy 13–15% and 40% of the Earth surface for 9–15 km and 20–30 km asteroid impacts, resulting in the decrease of possible number of CEME.

キーワード：大量絶滅、小惑星ー彗星衝突、地球寒冷化
Keywords: mass extinctions, asteroid-comet impacts, global cooling

白亜紀セノマニアン／チューロニアン境界のOAE2に対する南半球高緯度の反応

Response to Cretaceous Cenomanian/Turonian OAE2 in souothern high latitude

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白亜紀セノマニアン／チューロニアン(C/T)期境界では，短期間に大量の有機物が広範囲の海底に堆積する「海洋無酸素事件（OAE）2」と呼ばれるイベントが生じたことが知られている．このイベントは顕生代において重要な炭素循環の攪乱イベントと考えられ，テチス域および大西洋域の大陸海を中心に多くの研究がなされてきた．このOAE2期に相当する層位範囲では有機物および炭酸塩の炭素同位体比に特徴的な正のエクスカーション(CIE)がみられることが知られており，炭素同位体比層序による国際対比がなされてきた．しかしながら白亜紀当時の海洋の大半を占めていた太平洋域がOAE2にどのように反応したのかについての知識は乏しい．

本研究では南太平洋高緯度域の海域・陸域にその炭素循環の攪乱の影響がいかに現れるかを理解するため，C/T階境界上下の堆積岩から得られた抽出性有機物に関する総括的な研究を行った．試料を採集した露頭はニュージーランド南島のマルボロ地区である．

バイオマーカー分析から明らかになったホモホパンインデックス(HHI)は世界の他地域のOAE2相当層準付近には知られていない周期的な増減変動を示し，この堆積場の酸化還元環境が周期的に富酸素ー貧酸素環境を繰り返していたことを示唆する．OAE2の最初期段階では強い酸素欠乏が生じ，その後急速に酸化的環境に移行した．ステラン／ホパン(S/H)比はこれとほぼ同期して大きく低下したが，HHIの低下（海底の富酸素化）より約10万年程度遅れて生じた．この真核生物由来バイオマーカーの減少は海洋有機物の海底への輸送量の低下，すなわち生物生産の減少を示唆している．海底に到達する有機物が減少することが海底の酸素消費量を減らすことに連動して貧酸素環境から富酸素環境へのシフトを誘導したという考察は，酸化的環境に移行するタイミングが生物生産減少に先行していることを説明できない．酸素に富む水塊の流入が海洋の富酸素化を誘導したという解釈が，上述のOAE2層準のバイオマーカー変動を最も良く説明できるようだ．

OAE2層準における陸域由来の多環芳香族分布は，高緯度南太平洋域において，OAE2直前まで徐々に自然火災を引き起こしやすい気候が卓越していくことを示していた．その後CIEの開始と共にその自然火災頻度は減少し，OAE2期全般に渡ってその頻度は低かったと解釈される．球果植物由来のジテルペノイドと多様な植物に由来するカダレンを用いた高等植物指標はOAE2前後の層準を含めて全体として低下していく傾向を示したが，特にOAE2層準では低い値を示した．このことはOAE2層準では植物群集の中で球果植物が減退していたことを示唆する．

海洋と陸域の環境を示唆するバイオマーカー指標等から，南半球高緯度太平洋域において海洋，陸域の双方で深刻な生息環境の変化が示唆された．この地のOAE2期における環境変化はテチス域およびその他の地域のそれとはどことも似ておらず，OAE2のメカニズムが従来考えられていたよりも複雑であることを示している．

キーワード：白亜紀、セノマニアン、チューロニアン、OAE

Keywords: Cretaceous, Cenomanian, Turonian, OAE

古生代末の二段階の絶滅：四川省・朝天セクションにおける層序学的研究
The double extinction at the end-Paleozoic: Stratigraphy at Chaotian, Sichuan, China

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約2億5000万年前の古生代末では、顕生代最大の大量絶滅事件がおきた。この事件は、ペルム紀中-後期（G-L）境界およびペルム-トリアス紀（P-T）境界における、二段階の絶滅からなる。発表者らはこれまで、南中国・四川省の朝天セクションにおいて、G-L境界層およびP-T境界層の層序学的研究を行ってきた。本発表では、これまでに得られた成果について報告する。

キーワード：大量絶滅、朝天、環境変動
Keywords: mass extinction, Chaotian, environmental changes

The latest research on REY-rich mud in the Pacific Ocean

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Deep-sea mud enriched in rare-earth elements and yttrium (REY), termed as REY-rich mud, has been expected as a novel mineral resource for the critical elements. A recent discovery of the extremely REY-rich mud with the maximum total REY content of ~8,000 ppm in the Japanese Exclusive Economic Zone (EEZ) around Minamitorishima Island makes it realistic to economically develop the highly promising deep-sea mineral resource.
In the presentation, we report the progress of our researches on the REY-rich mud within the Minamitorishima EEZ towards the world’s first development of deep-sea mineral resources. Moreover, we also introduce our latest findings including the basin-wide spatial distribution of the muds with a high resource potential and various genetic components identified in the western North and central to eastern South Pacific REY-rich muds. Our accumulation and integration of the scientific knowledge about deep-sea sediments including REY-rich mud strongly suggest an intrinsic linkage between the formation of deep-sea mineral resources and Earth system dynamics such as climate change, geochemical cycles, and plate tectonics, which can offer new insights into resource geology, oceanography, paleoclimatology, and solid earth science.

キーワード：海底鉱物資源、レアアース泥、南鳥島、北西太平洋、南太平洋
Keywords: deep-sea mineral resource, REY-rich mud, Minamitorishima Island, western North Pacific, South Pacific

南鳥島南方海域における超高濃度レアアース泥層の側方分布
Lateral distribution of extremely REY-rich mud layer in the southern part of the Minamitorishima EEZ

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Recently, we discovered deep-sea sediment containing ~7,000 ppm of total rare-earth elements and yttrium (REY), which was termed ‘extremely REY-rich mud’ (Iijima et al., 2016), within the Japanese exclusive economic zone (EEZ) around Minamitorishima island. To clarify the mineralogical/chemical characteristics and distribution of REY-rich mud in the Minamitorishima EEZ, we conducted eight research cruises over the four years. In the MR15-02 cruise by R/V Mirai from June 22 to July 17, 2015, we focused on investigating the lateral continuity of the extremely REY-rich mud layer in the southern part of the Minamitorishima EEZ. During the cruise, we collected 16 sediment cores by piston coring from the southwestern to southeastern areas of the Minamitorishima EEZ. Here we report visual core descriptions and bulk chemical compositions of the deep-sea sediment core samples, and discuss the extent of a highly promising area for future development of REY-rich mud in the Minamitorishima EEZ.

キーワード：レアアース、レアアース泥、南鳥島、海底鉱物資源
Keywords: rare earth elements and yttrium (REY), REY-rich mud, Minamitorishima Island, deep-sea mineral resource

Origin of deep-sea sediments within the Minamitorishima EEZ based on downhole variation of bulk chemical composition and neodymium isotopic ratios

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In 2011, the deep-sea sediments containing a high concentration of rare-earth elements and yttrium (REY) were discovered in the Pacific Ocean [1]. Moreover, the presence of "highly/extremely REY-rich mud" was confirmed within the Japanese exclusive economic zone (EEZ) surrounding Minamitorishima Island in 2013 [2].
On the basis of geochemical characteristics in major- and trace-elemental composition, it was reported that the deep-sea sediment layers within the Minamitorishima EEZ can be classified into several distinct groups including the highly/extremely REY-rich mud, although they are apparently very similar pelagic brown clay [3]. However, the origin and formation mechanism of the highly/extremely REY-rich mud has not been completely unraveled yet.
To elucidate the origin of deep-sea sediment including REY-rich mud within the Minamitorishima EEZ, isotopic composition of neodymium (one of the rare-earth elements), together with major and trace element compositions, can provide an important constraint. We aim to decipher geochemical end-members characterized by distinctive chemical compositions and isotopic ratios that enable us to specify their sources, fluxes and processes of supply [4, 5]. Here, we investigated (1) bulk chemical compositions by XRF and ICP-MS analyses and (2) bulk Nd isotopic ratios using Thermal Ionization Mass Spectrometry (TIMS) throughout a piston core, KR13-02 PC05 of 11.45 m in length, which contains the Extremely REY-rich mud and the other several characteristic layers. We report the downhole variations of bulk chemical composition and neodymium isotopic ratios, and discuss the origin of the highly/extremely REY-rich mud on the basis of their geochemical features.

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キーワード：Nd同位体、化学層序、深海堆積物、南鳥島EEZ、レアアース泥
Keywords: Nd isotopes, Chemostratigraphy, Deep-sea Sediments, Minamitorishima EEZ, REY-rich mud

全岩化学組成に基づく北太平洋の遠洋性深海堆積物層序

A chemostratigraphic correlation of deep-sea pelagic clays in the North Pacific Ocean: Insights from the ODP Sites 1149 and 1179

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Pelagic clay, referred to as red clay, is one of the common types of seafloor sediment, especially in the Pacific Ocean floor [1]. It is known that the pelagic clay deposits at remote areas in the ocean with considerably slow sedimentation rates of only 0.1-0.5 cm/kyr. Recently, this type of sediment is also recognized as a new deep-sea mineral resource. In 2011, Kato et al. [2] reported that some parts of the deep-sea pelagic clay in the Pacific Ocean contain high concentrations of rare-earth elements and yttrium (REY). They defined the pelagic clay containing more than 400 ppm of total REY as “REY-rich mud” and concluded that this sediment could be a prospective resource for the critical elements.
Pelagic clay is, however, not so well studied as other types of sediments, such as carbonate and neritic sediments, probably due to the lack of visible features and little availability of microfossils to determine its depositional age. Therefore, detailed stratigraphy of the pelagic clay layers including REY-rich mud is not well understood, although it deposited throughout the Cenozoic era [3]. To clarify the stratigraphy of the pelagic clay layers including REY-rich mud, analyses of long and fully recovered deep-sea sediment cores are needed. Here we focused on the ODP Sites 1149 and 1179 in the North Pacific Ocean, both of which were recovered continuously from seafloor to basement rock.
In this study, we provide the results of bulk chemical analyses of sediment samples from the ODP cores. By comparing the multi-elemental compositions of these cores and those of GPC3-LL44 [4], we constructed a general chemostratigraphy of pelagic clay layers in the North Pacific Ocean. We also quantified the relative contributions of each geochemical end-member causing the chemostratigraphic variations of the pelagic clay layers. Based on the results, we discuss the deposition processes of pelagic clays including REY-rich mud in the North Pacific Ocean.

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キーワード：遠洋性粘土、化学層序、レアアース泥、北太平洋、ODP Site 1149、ODP Site 1179
Keywords: pelagic clay, chemostratigraphy, REY-rich mud, North Pacific Ocean, ODP Site 1149, ODP Site 1179

南太平洋におけるレアアース泥の分布と成因の解明
Genesis and distribution of rare-earth elements and yttrium-rich mud in the South Pacific Ocean

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In 2011, Kato et al. [1] reported the potential of deep-sea sediment containing high concentrations of rare-earth elements and yttrium (REY-rich mud) in the Pacific Ocean as a new source for REY. It has been demonstrated that the REY-rich mud are distributed mainly in two regions: the eastern South Pacific and central North Pacific. In the North Pacific Ocean, REY-rich mud has also been discovered within the Japanese exclusive economic zone (EEZ) around Minamitorishima island [2]. Subsequently, detailed geochemical study on the REY-rich mud in the North Pacific Ocean proceeded rapidly, clarifying its distribution, stratigraphic position, and structural components including the host phases of REY [3, 4].
In striking contrast to the substantial progress in the North Pacific Ocean, REY-rich muds in the South Pacific Ocean has still not been well understood, even though their high ΣREY concentrations (> 2000 ppm) [1]. This is, at least in part, due to the lack of sediment cores recovered from the South Pacific Ocean (especially southern part of the South Pacific Ocean). IODP cores recovered by Exp. 329 [5] can provide a unique opportunity to elucidate genesis and distribution of REY-rich mud in the South Pacific Ocean.
In this study, we present the results of geochemical analysis of sediment samples obtained from the IODP Exp. 329 cores and discuss the distribution, stratigraphic position, and constituting components of the South Pacific Ocean REY-rich mud. We also compare our results with those in the North Pacific Ocean.

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キーワード：レアアース泥、海底鉱物資源、IODP Exp. 329、全岩化学組成、南太平洋
Keywords: REY-rich mud, deep-sea mineral resources, IODP Exp. 329, bulk chemical composition, South Pacific Ocean

前期始新世「超温暖期」のインド洋深海堆積物から統計的に抽出された地球システムのフィードバック機構

Earth system feedbacks statistically extracted from the Indian Ocean deep-sea sediments during the early Eocene hyperthermals

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The most prominent global warming event in the Cenozoic era was the Paleocene-Eocene Thermal Maximum (PETM) at ~56 Ma, which is characterized by a rapid global warming by 5 to 8°C, severe ocean acidification, and a distinct negative carbon isotope ($\delta^{13}C$) excursion both in the marine and terrestrial realm. These features suggest a massive injection of ^{13}C-depleted greenhouse gas to the ocean-atmosphere system. Moreover, multiple PETM-like global warming episodes termed 'hyperthermals' during the early Eocene period (56~52 Ma), accompanying rapid and pronounced negative excursions in $\delta^{13}C$, have also been recognized over the past dozen years. Geologic records of the hyperthermals have so far been reported from around the globe (e.g., the Pacific, Atlantic, and Arctic Oceans, Europe and North America). However, albeit the third largest ocean on the planet, the Indian Ocean is almost a blank area where only a few published data of the hyperthermals are available.
Here we have constructed a comprehensive geochemical data set including major- and trace-element contents, $\delta^{13}C$, and $CaCO_3$ contents of 250 bulk sediment samples taken from ODP Sites 752 and 738, located in the southeastern Indian Ocean and the Indian sector of the Southern Ocean, respectively. The analytical results show that the sediments of these cores record multiple carbon isotope excursions and reductions of carbonate contents, probably corresponding to the PETM and the early Eocene hyperthermals including the Eocene Thermal Maximum 2 (ETM2), H2 and I1/I2 events, and ETM3. We applied Independent Component Analysis to the high-dimensional compositional data matrix, and extracted four geochemical independent components that collectively account for 85.6% of the total sample variance. One of the components involving Ba content and $\delta^{13}C$ indicates a signature of a negative feedback in Earth system that efficiently sequestered the excess carbon in recovery phases of the hyperthermals.

キーワード：深海堆積物、インド洋、気候変動、前期始新世超温暖期、独立成分分析、多変量解析
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