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科学研究費助成事業　　研究成果報告書

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研究課題名（和文）Understanding magnetic mineral diagenesis in the methane-rich sediments from Nankai Trough

研究課題名（英文）Understanding magnetic mineral diagenesis in the methane-rich sediments from Nankai Trough

研究代表者
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研究成果の概要（和文）：科研費　基盤研究（C）によって資金提供された研究により、オープンアクセスの国際ジャーナルに2つの主要な論文が発表されました。 データは無料のオンラインデータリポジトリで入手できます。 国際会議および国内会議での多数の科学的コミュニケーションが、PIおよび共同研究者によって行われました。
追加のデータは、オンラインで利用可能なデータレポートで公開されます（オープンアクセス）

研究成果の学術的意義や社会的意義
この研究は、鉄と硫黄の循環に新しい洞察をもたらします。 特に鉄の循環は微生物の生命（活動）にとって非常に重要です。 調査されたサイトは、生命の温度限界に近い、高温環境の地下生物圏を対象としていました。 公開された論文は、エネルギーが制限された環境での微生物の活動と、炭素循環（炭素の放出と貯蔵）におけるその役割に関する知識のマイルストーンです。

研究成果の概要（英文）：The research funded by a Scientific Research (C) has led to the publications of two major papers in international journals in open access. Data are available on free online data repository. Numerous scientific communications in international and domestic conferences were given by the PI and co-investigators.
Additional data are going to be published in data report, available online (open access)

研究分野：environmental magnetism

キーワード：magnetic diagenesis　iron cycle　microbial activity

１．研究開始当初の背景 Background at the beginning of research

Diagenesis is an important process which occurs in marine sediments as soon as they are deposited on the seafloor. Physical and geochemical mechanisms, as well as microbial activity, impact the rock magnetic properties and paleomagnetic record by changing the magnetic mineralogy in the sediment. Magnetic minerals are destroyed, transformed, and formed in situ depending on the environmental conditions. In sulfidic environment at the sulfate-methane transition zone (SMTZ) dissolved hydrogen sulfide reacts with dissolved iron or directly with iron oxides to form iron sulfides which pyrite is the end member (Berner, *J. Sediment. Petrol.* 1981; Berner, *Geochim. Cosmochim. Acta* 1984; Roberts and Weaver*, Earth Planet. Sci. Lett.* 2005). The mechanism(s) responsible for the formation and preservation/transformation of iron sulfides in the methanic zone underneath the SMTZ are poorly understood. Their formation at a later diagenetic stage and thousands of years after the deposition of the host sediment (e.g., Larrasoaña et al., *Earth Planet. Sci. Lett.* 2007; Kars and Kodama, *Geoch. Geoph. Geosyst.* 2015) is strongly debated and many formation pathways have been proposed (e.g., Jiang et al., *Earth Planet. Sci. Lett.* 2001; Roberts and Weaver, *Earth Planet. Sci. Lett.* 2005; Roberts, *Earth Sci. Rev.* 2015). Little is known about the respective contribution of biotic and abiotic mechanisms responsible for such mineralogical transformations in high temperature and deeply buried sediments and competing hypotheses disagree on the role of sulfate and of microbes.

２．研究の目的 Purpose of research

This research project aims to understand the biotic and abiotic diagenetic processes in methane-rich marine sediments which presently are at a temperature close to the temperature limit of life. A deep SMTZ with downward increase of sulfate and deep methane occurrence have been identified in the central Nankai Trough, off Cape Muroto, Shikoku Island, Japan, which is the study area of this project.
The findings from the investigated sites would help to understand the formation of magnetic minerals in high temperature methane-rich sediments. The integration of both rock magnetism and geochemistry results would bring insight on biotic and abiotic processes responsible for magnetic mineral diagenesis in deep methanic zones. Different hypotheses which have been proposed so far are tested: 1) redox process via the degradation of organic matter, 2) sulfate-dependent microbial reaction such as anaerobic oxidation of methane (AOM), 3) sulfate independent AOM coupled with iron reduction.
Understanding these mechanisms is of great importance as this phenomenon heavily impacts iron mineral-based rock magnetic properties and the paleomagnetic record in the sediments, as well as the iron elemental cycle necessary to sustain microbial activity. Investigating the distribution of iron sulfides could be another way to help reconstructing methane-rich environments and potentially methane flux in the past that impacts global climate.

３．研究の方法 Research method

The main targeted materials are sediments from IODP (International Ocean Discovery Program) Expedition 370, Site C0023. Nearby sites (ODP Leg 131 Site 808 and ODP Leg 190 Site 1174) are also investigated as they present similar rock magnetic properties with a different geothermal gradient.
The combination and integration of rock magnetism and geochemistry are needed to solve competing hypotheses regarding the magnetic mineral diagenesis in methanic zones, and to identify which mechanisms are responsible for the mineralogical observations. A detailed rock magnetic study in sediments from the three sites mentioned above was conducted by using recent techniques and cutting-edge instruments to document the magnetic properties and mineralogy of the sediments with a particular focus on the deep SMTZ characterized by high burial temperature. Remanence analysis and magnetic properties study at high, room and low temperatures were used to identify and characterize the magnetic mineral assemblages in terms of abundance, grain size and composition. Complementary inorganic

and organic geochemical analyses, and sulfur isotope data on iron sulfides, performed by Research Collaborators in Germany were combined with rock magnetism for the determination of the iron- and sulfur-bearing phases. Finally scanning electron microscope observations completed the study.

４．研究成果 Research results

All three investigated sites show similar rock magnetic properties and mineral assemblages which define four main diagenetic zones. Each zone is characterized by a magnetic mineral assemblage which is the result of one or more diagenetic processes.
At Site C0023, rapid burial resulting from a high sedimentation rate enables the preservation of ferrimagnetic iron sulfides in the top sediments. Deeper sediments are characterized by coarse-grained (titano-)magnetite that survived diagenetic dissolution and is a remnant of a more complex mineral assemblage which was altered diagenetically a few million years after deposition. Around the decollement zone, fluid circulation through faults in the accretionary prism is likely responsible for the formation of new magnetic phases.
Varying sediment supply and organic matter input through time, burial temperature, and tectonic fluid circulation are the primary drivers of magnetic mineral assemblage variations in the studied sediments of the Nankai Trough. Catagenesis, fluid circulation, ash alteration, and microbial iron reduction all affect magnetic mineral assemblages at Site C0023 to varying degrees. Processes such as catagenesis and elevated interstitial silica due to ash alteration would lead to magnetic mineral dissolution, whereas fluid circulation could be responsible for mineral authigenesis. Microbial iron reduction is versatile and can contribute to both magnetic mineral formation and reduction. Assessing the types and extent of non-steady state diagenetic alteration and its impact on magnetic mineralogy is important in marine sediments to assess the reliability of paleomagnetic records, including possible remagnetizations, and for redox paleo-reconstructions to determine the relative sequence of biogeochemical conditions in the geologic record.
Our findings and data are available online in open access research papers and data repository.

５．主な発表論文等

〔雑誌論文〕　計2件（うち査読付論文　2件／うち国際共著　2件／うちオープンアクセス　2件）

１．著者名 Kars M., M. Koester, S. Henkel, R. Stein, F. Schubotz, X. Zhao, S. A. Bowden, A. P. Roberts, K. Kodama	４．巻 22
２．論文標題 Influence of Early Low-Temperature and Later High-Temperature Diagenesis on Magnetic Mineral Assemblages in Marine Sediments from the Nankai Trough	５．発行年 2021年
３．雑誌名 Geochemistry, Geophysics, Geosystems	６．最初と最後の頁 e2021GC010133
掲載論文のDOI（デジタルオブジェクト識別子） 10.1029/2021GC010133	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 該当する

１．著者名 Koester, M., M. Kars, F. Schubotz, M-Y. Tsang, M. Maisch, A. Kappler, Y. Morono, F. Inagaki, V. B. Heuer, S. Kasten, and S. Henkel	４．巻 22
２．論文標題 Evolution of (Bio-)geochemical Processes and Diagenetic Alteration of Sediments Along the Tectonic Migration of Ocean Floor in the Shikoku Basin off Japan	５．発行年 2021年
３．雑誌名 Geochemistry, Geophysics, Geosystems	６．最初と最後の頁 e2020GC009585
掲載論文のDOI（デジタルオブジェクト識別子） 10.1029/2020GC009585	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 該当する

〔学会発表〕　計6件（うち招待講演　1件／うち国際学会　0件）

１．発表者名 Myriam Kars, Tetsuya Fukuta, Carina Becker
２．発表標題 Paleomagnetic and rock magnetic investigation in marine sediments, Nankai Trough, offshore Cape Muroto
３．学会等名 EGU General Assembly 2020
４．発表年 2020年

１．発表者名 Myriam Kars, Andrew P. Roberts, Xiang Zhao
２．発表標題 Characterization of complex magnetic mineral assemblages in Nankai Trough sediments, off Japan (IODP Expedition 370)
３．学会等名 AGU Fall Meeting 2018
４．発表年 2018年

１．発表者名
Myriam Kars, Susann Henkel, Natsumi Okutsu, IODP Expedition 370 Scientists

２．発表標題
Investigating the effects of high temperature and a deep SMTZ on rock magnetic properties at Site C0023, IODP Expedition 370

３．学会等名
Goldschmidt Conference 2017

４．発表年
2017年

１．発表者名
Myriam Kars, Susann Henkel, IODP Expedition 370 Scientists

２．発表標題
Investigating the effects of high temperature and a deep SMTZ at Site C0023, IODP Expedition 370

３．学会等名
AGU Fall meeting 2017

４．発表年
2017年

１．発表者名
Koester, M., M. Kars, F. Schubotz, M-Y. Tsang, Y. Morono, F. Inagaki, V.B. Heuer, S. Kasten, and S. Henkel

２．発表標題
The influence of tectonic migration of ocean floor on (bio-)geochemical and diagenetic processes in subseafloor sediments from the Nankai Trough off Japan

３．学会等名
EGU General Assembly 2021

４．発表年
2021年

１．発表者名
Kars, M., M. Koester, S. Henkel, S. A. Bowden, X. Zhao, and A. P. Roberts

２．発表標題
Early low-temperature and later high-temperature diagenetic processes and their influence on magnetic mineral assemblages in marine sediments from IODP Site C0023, Nankai Trough, Northwestern Pacific Ocean

３．学会等名
Joint Scientific Assembly IAGA-IASPEI 2021（招待講演）

４．発表年
2021年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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6．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考
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研究協力者	なし　なし (Henkel Susan)	Senior Scientist	
研究協力者	なし　なし (Schubotz Florence)		

7．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

8．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関