ECORD/ICDP MagellanPlus Workshop Series

MAREXKUS:

MAntle Remelting and hydrothermal chemical Exchange at Knipovich Ultraslow Spreading ridge

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Rome – Italy

REPORT

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ECORD newsletter

Tectonic spreading at ultra-slow spreading ridges leads to the exposure of deep lithospheric levels - the Earth's mantle - on the seafloor. While the interplay between tectonic extension and magmatic processes are still to be fully constrained, the exposure of mantle on the seafloor further allows for the interaction between these ultramafic lithologies and seawater, through fluid-rock interaction and weathering processes. Notably, these widespread hydrothermal processes and related chemical exchanges between the exhumed mantle and seawater need to be considered within assessments of the global chemical budget of the oceans. Furthermore, hydrothermal fluids can provide the necessary elements and energy to sustain the development of life in extreme, deep anoxic environments. These themes were the basis for the organisation of a MagellanPlus workshop, with a focus on a specific geological object: Knipovich ridge.

Knipovich ridge is a one-of-a-kind ultraslow-spreading ridge in the Arctic ocean; it shows widespread exhumation of mantle lithologies, active hydrothermal vents recently discovered along the ridge axis, and its vicinity to the Norwegian continental margin translates into a high sediment discharge into the actively spreading rift valley. Hence, the element exchange at Knipovich is controlled to some extent by the presence of sediments, yet this process is poorly understood. Given its unique character, Knipovich ridge is a compelling target for a drilling proposal that integrates several aspects of the 2050 Science Framework, including the formation of the oceanic lithosphere, mantle alteration and global geochemical cycles.

The MAREXKUS MagellanPlus workshop was held in Rome in March 2023, and gathered a working group of scientists from different disciplines spanning from seismic, igneous petrology, rock alteration, sedimentary geology, magnetics and microbiology. The workshop was highly multidisciplinary and international, with the attendance of 38 scientists from 8 ECORD countries and 2 from Japan on site, and 42 participants online. Ten on-site participants were early career scientists, including PhD students and postdocs. The first day was focused on defining the state-of-the-art knowledge on the area of interest and considered research topics. The second day was aimed at creating working groups on specific topics, with the task of defining precise objectives and hypotheses to be tested by drilling at Knipovich ridge. The third day provided an overview of the conclusions reached by the different working groups, discussion regarding possible locations for drilling and existing data. The participants identified three specific scientific objectives to be implemented in a future IODP proposal such as: (*i)* defining the link between magmatism and composition of the mantle at spreading ridges; (*ii)* characterizing chemical fluxes during fluid-rock interaction processes at a sedimented ridge axis; (*iii)* constraining hydrothermally-sustained development of biological communities and the limiting conditions for the occurrence of life. Moreover, discussion with leaders of existing proposals in the region allowed the identification of potential drill sites, and discussion on drilling strategies and technologies. Based on existing data, we verified the existence and availability of geophysical and site survey data and samples, and started to establish future connections with other entities interested in developing a drilling proposal in the region.

1. Scientific Rationale

The oceanic lithosphere is the fundamental zone for thermal and mass exchanges between Earth's deep interior and the surface, via a direct interplay between mantle, crust, and ocean. At mid-ocean ridges (MOR) mantle melting depletes the upper mantle in incompatible elements, creating an oceanic crust prone to water-rock reaction. Over the last ~20 years, a major change in our understanding of the ocean crust occurred, with the discovery that oceanic lithosphere at ultraslow spreading ridges is extremely diverse, and that limited magmatic production may lead to large areas of the oceans floored by mantle and lower crustal rocks. Hence, elemental exchanges at ultraslow spreading ridges will differ fundamentally from those at a traditional basaltic seafloor formed at faster-spreading ridges. Hydrothermal exchange at ultraslow-spreading ridges is therefore likely to play an important, yet hitherto unaccounted for, role in controlling ocean chemistry. Given the heterogeneity in magmatism, hydrothermal alteration, mantle composition and thermal structure of the global MOR, the ocean lithosphere needs to be thoroughly characterised across the range of spreading rates. To date, ocean drilling programs have targeted the East Pacific Rise, Central Mid-Atlantic Ridge and Southwest Indian Ridge, while the ocean lithosphere formed at the ultraslow spreading ridges in the Arctic Ocean has not been drilled.

Knipovich is an almost 500 km-long ultra-slow Arctic spreading ridge (14-17 mm/yr full spreading) characterized by a high obliquity (35°-50° between spreading direction and ridge axis) and consisting of a series of pull apart basins with sparse magmatic activity (*Okino et al, 2002*). This long ridge section, free of transform faults, is bound to the north by the Molloy transform fault and bends to the south into the Mohns Ridge. Basalts, recovered from volcanic centres, have distinctly high Hf isotope ratios, not mirrored by comparatively high Nd and low Sr and Pb isotope ratios (*Blichert-Toft et al., 2005*). This suggests anomalously high proportions of ancient, highly depleted mantle in their asthenospheric source (*Sanfilippo et al., 2021*), caused either by multiple melting events in an asymmetric melting region or by the occurrence of subcontinental mantle stripes. Notably, ridge morphology, magnetic and gravity data (*Okino et al., 2002*) indicate that these volcanic centres are separated by 60–110 km-long amagmatic segments characterized by aseismic deformation (*Meier et al., 2021*). Mantle and lower crustal rocks have been recovered at oceanic core complexes at the connection between Knipovich and Mohns Ridge (*Pedersen et al., 2007; Bruvoll et al., 2009*), whereas the origin of the basement in the amagmatic segments remains unresolved (*Kvarven et al., 2014*). Another unique aspect of Knipovich Ridge is its vicinity to the Norwegian continental margin. The proximity of the oceanic spreading ridge to a glacial margin with high sedimentation rates causes high sediment discharge into the rift axis. Hence, the element exchange at Knipovich is controlled to some extent by the presence of sediments, yet this process is poorly understood.

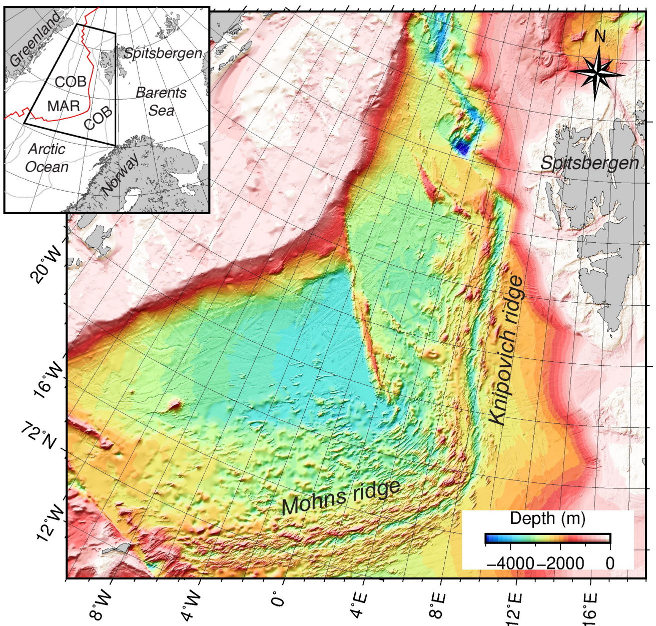

Figure 1. Location of the Mohns and Knipovich ridge segments in the Arctic Ocean. In the upper-left inset, the solid grey lines are the Continent-Ocean Boundaries (COB), and the solid red line is the Mid Atlantic Ridge

In summary, Knipovich Ridge provides a unique opportunity to study the interplay between mantle alteration, volcanism and sedimentation. This makes it a compelling target for a drilling proposal that integrates several aspects of the 2050 Science Framework, including the formation of the oceanic lithosphere, mantle alteration and global geochemical cycles.

2. Workshop goals

The proposed workshop aimed at creating a working group of scientists from different disciplines who are now in the process of developing an MSP-type drilling proposal at Knipovich Ridge. During the workshop, the participants identified specific scientific themes for each Strategic Objective as outlined in the 2050 Science Framework. In this setting, participants discussed drilling strategies and technologies available to an MSP expedition. Several scientific topics have been defined, *(i)* defining the role of prior mantle depletion in the formation of oceanic lithosphere; *(ii)* understanding relationships between spreading asymmetry and mantle melting; *(iii)* exploring mechanisms of tectonic exposure of basement rocks at ultraslow spreading ridges; *(iv)* defining the extent of chemical exchange between peridotites, sediments and seawater, *(v)* exploring the impact of mantle serpentinization and hydrothermalism on microbial activity, *(vi)* defining the interplay between mantle-seawater exchange and the evolution of the sedimentary cover. In addition, the workshop allowed to discuss with scientists involved in IODP 985-Full2: Eastern Fram Strait Paleo Archive-FRAME (R. Lucchi; S. Buenz). The latter is aimed at retrieving sedimentary records along the eastern side of the Fram Strait to establish the past and present connections between the Northern North Atlantic and Arctic regions and their links with global climate. Importantly, the workshop served as a chance to re-discuss the science of proposals 934 and 944, previously submitted to IODP and now deactivated. The proponents of these two proposals are now involved in the development of the MSP-type drilling proposal at the Knipovich Ridge and will share science and objectives of their research to develop synergy between the different projects into a future, common IODP proposal.

3. Programme

February, 28th

17:00	Registration and Ice Breaker party

March, 1st

Session 1 - Moderator: Alessio Sanfilippo

08:45-09:15	Alessio Sanfilippo: Welcome, Introduction and Workshop Goals
09:15-09:40	Angelo Camerlenghi: MSP concept and IODP beyond 2024
09:40-10:05	Kyoko Okino: Seafloor accretionary style at Ultraslow Spreading Ridge
10:05-10:30	Renata Giulia Lucchi: IODP 985-Full2: Eastern Fram Strait Paleo Archive-FRAME
10:30-11:00	Coffee Break

Session 2 - Moderator: Marco Cuffaro

11:00-11:25	Gerhard Bohrmann: Hydrothermal vents at Knipovich Ridge - the Jøtul Field and other recent discoveries of R/V Maria S. Merian cruise MSM109
11:25-11:50	Michaela Meier: Microseismicity at Knipovich Ridge
11:50-12:15	Matthias Pilot: Oceanic Detachment Faulting at the Mohns-Knipovich Ridge Bend: Results from a 12 Month Microseismicity Study
12:15-13:30	Lunch

Session 3 - Moderator: Valentin Basch

13:30-13:55	Stefan Buenz: Buried detachment, fluid flow and gas hydrate systems in northern Knipovich
13:55-14:20	Sebastian Tappe: Cenozoic tectonomagmatic evolution of the northernmost Atlantic and its margins
14:20-14:45	Andreas Stracke: Melt-depleted nature of the Arctic mantle
14:45-15:10	Antony Morris: Magnetic properties at oceanic core complexes
15:10-15:40	Coffee Break, “Sala Laguna” room

Session 4 - Moderator: Johan Lissenberg

15:40-16:05	Muriel Andreani: Mantle serpentinization at (ultra)slow spreading ridges
16:05-16:30	William Orsi: Endolithic microbial life in subseafloor ultramafic rocks
16:30-16:55	Javier Escartin: Global distribution and mode of development of OCC at (ultra)slow spreading ridge
16:55-17:20	Andrew McCaig: IOPD Exp 399: building blocks of life

March, 2nd

09:00-10:00	Moderator: Johan Lissenberg - Thematic Working Group assignment
10:00-11:00	Divided in specific working groups to define objectives
11:00-11:30	Coffee Break, "Sala Laguna" room
11:30-12:30	Divided in specific working groups to define objectives
12:30-14:00	Lunch
14:00-15:00	Divided in specific working groups to define objectives
15:00-16:00	Group leader report building
20:00	Social dinner Sponsored by IODP-Italia

March, 3rd

09:00-11:00	Moderator: Marco Cuffaro - Working group leader reports
11:00-11:30	Coffee Break
11:30-12:30	Moderator: Valentin Basch - Discussion & Wrap-up - Towards an MSP drilling proposal
12:30-14:00	Lunch
14:00-15:30	Scientific Drilling report writing (organizing committee)

4. Workshop outcomes and future plans

Thirty-eight in-person participants from 8 ECORD countries, plus two Japanese colleagues took part in the workshop, almost entirely covered economically by ESSAC; in addition, 42 researchers attended online during Day 1. The dedicated effort of this large group of people allowed to define the state-of-the-art of the petrological and geodynamic-structural settings of Knipovich ridge. As reported in the programme, keynote talks covered many scientific topics, ranging from geodynamics, igneous petrology, geochemistry, mantle alteration, microbiology, seismic and sedimentary processes. Specific talks were also provided by the proponent of other active IODP proposals, or proposal deactivated but still of potential interest. Discussions were mainly focussed on the definition of open questions and hypotheses possibly tested at Knipovich ridge, also taking into consideration the record of past IODP expeditions. In detail, the main outcomes of the workshop can the synthetized as follows:

1- Identification of 3 main scientific objectives, spanning from evolution of the Earth's mantle, alteration of oceanic basement and serpentinization, geochemical cycles, tectonics and microbiology, following the strategic objectives of IODP Science Framework 2050 #1. Habitability and life on Earth; #2. The oceanic life cycles of tectonic plates; #6. Global cycles of energy and matter.

Objective 1. Defining the link between mantle heterogeneity and magma production at present-day mid-ocean ridges

Basalt chemistry and peridotite data reveal a unique geochemical character of the mantle source and peridotites recovered at Knipovich Ridge; it appears to retain evidence for ancient events of melt depletion. Competing hypotheses can be tested by drilling:

a. The Knipovich mantle includes large proportions of ancient subcontinental mantle that has been dragged from the continents (*Blichert-Toft et al., 2005; Bjerga et al., 2022*);

b. The mantle is highly depleted and has a geochemical affinity similar to that of the 'Iceland' plume (*Stracke et al., 2022*);
c. The depleted character is caused by the peculiar geodynamic environment, where magma is produced in an unusual melting regime or by processes of re-melting due to ridge jumps (*Sanfilippo et al., 2021*)

Objective 2. Constraining chemical fluxes and rheological feedbacks during fluid-rock interaction processes involved with tectonic exposure of basement rocks at highly sedimented ultraslow-spreading ridges

Knipovich Ridge provides a unique setting in which high sedimentation rates from the Bear Island Fan system (~10 cm/Kyr) interact directly with the nearby ridge axis and the related hydrothermal circulation of the oceanic lithosphere (e.g., Loki's Castle hydrothermal field). Knipovich Ridge therefore represents an endmember setting of oceanic alteration whose geochemical and volatile budget is very poorly constrained compared to that of (i) sediment-poor, hydrothermally active mid-ocean ridge settings and (ii) sediment-rich but hydrothermally inactive passive margins. The following hypotheses can be tested by drilling:

a. The thick sedimentary cover provides an archive of hydrogen/methane time-integrated fluxes related to alteration of the underlying ultramafic mantle and prolongs hydrothermal exchange between basement, sediments and seawater.
b. Fluid-rock interaction of altered ultramafic basement by sediment-modulated hydrothermal fluid follows reaction paths and produces alteration assemblages that are distinct from direct seawater-basement interaction.
c. The volatile budget and rheological behaviour of sediment-covered altered ultraslow oceanic crust upon eventual subduction is markedly different from common oceanic crust.

Objective 3. Constraining biological and geochemical interactions at sediment – basement interfaces in an active ultraslow ridge

The serpentinization of large-scale exposures of mantle ultramafic rocks leads to the formation of abiotic H_2 and to the development of microbial communities that are adapted to utilizing abiotic H_2 as a source of energy. However, it remains unknown whether this abiotic geochemical process can provide sufficient energy to sustain life in deep subseafloor anoxic sediment that is persisting at, or close to, the energetic limit to life. The unique sediment-basement setting at the ultraslow spreading Knipovich Ridge provides a one-of-a-kind opportunity to test the hypothesis that serpentinization from ultramafic ocean crust can provide the necessary energy to sustain life living at energetic limits in deep anoxic subseafloor sediment. The following hypotheses will be tested during MSP drilling at Knipovich Ridge.

a. The abiotic H_2 produced by serpentinization in the basement diffusing upwards to the peridotite-sediment interface provides sufficient energy to sustain microbial life that is living close to energetic limits in the deep anoxic subseafloor sediment.
b. At the interface between basement and sediment, the abiotic H_2 gas from serpentinization diffusing upwards from the underlying oceanic core complex allows some microbes within deep sub-seafloor sedimentary communities to proliferate beyond energy-limiting conditions.

2- Identification of potential drill sites and discussion on drilling strategies and technologies. Based on existing data, two potential drill site target areas were defined; they are located at the connection between Knipovich Ridge and Mohns Ridge (74°N), and close to a black smoker hydrothermal field (Loki's Castle; *Pedersen et al., 2010*) and axial volcanic ridge. For this location, discussions focused on the verification of the existence and availability of geophysical and site survey data and samples. The need to establishing future collaborations and connections with Norwegian Petroleum Directorate

(NPD) has been defined, in order to get access to the compiled maps of existing sampling, bathymetry and geophysical data.

3- Production of a roadmap for the implementation of a future IODP proposal, to be tentatively submitted to IODP[3] in October 2024. In particular, the need to create connection and synergy with lead proponents of IODP proposals 935 and 994 has been emphasized. Future drilling strategies have to be thoroughly discussed in the framework of the development of the MSP proposal.

5. List of on site participants

Muriel Andreani	*LGL - Université Lyon 1*
Valentin Basch	*CNR-IGG*
Christoph Beier	*University of Helsinki*
Thomas Belgrano	*University of Southampton*
Manon Bickert	*Geo-Ocean*
Gerhard Bohrmann	*MARUM - Research faculty, University of Bremen*
Giulio Borghini	*Università di Milano*
Daniele Brunelli	*Università di Modena e Reggio Emilia*
Stefan Bünz	*UiT The Arctic University of Norway*
Angelo Camerlenghi	*National Institute of Oceanography and Applied Geophysics OGS*
Nishant Chauhan	*University of Oxford*
Alessia Conti	*CNR-IGAG*
Marco Cuffaro	*CNR-IGAG*
Eemu J. Ranta	*University of Helsinki*
Javier Escartin	*CNRS/ENS*
Carlotta Ferrando	*DISTAV Università degli Studi di Genova*
Eleonora Ficini	*CNR-IGAG*
Yumiko Harigane	*Geological Survey of Japan, AIST*
John Hopper	*Geological Survey of Denmark and Greenland*
Annalisa Iadanza	*CNR*
Benoit Ildefonse	*CNRS & University of Montpellier (Geosciences Montpellier)*
Johan Lissenberg	*Cardiff University*
Renata Giulia Lucchi	*Istituto Nazionale di Oceanografia e di Geofisica Sperimentale*
Andrew McCaig	*University of Leeds*
Michaela Meier	*Alfred Wegener Institute (now at Technical University Munich)*
Manuel Menzel	*Instituto Andaluz de Ciencias de la Tierra (CSIC-IACT), Spain*
Mateusz Michailow	*Università di Modena e Reggio Emilia*
Alessandra Montanini	*Università of Parma*
Anthony Morris.	*University of Plymouth*
Kyoko Okino	*Atmosphere and Ocean Research Institute, The University of Tokyo*
William Orsi	*LMU Munich*
Lara Perez	*Geological Survey of Denmark and Greenland*
Lorenzo Petracchini	*CNR-IGAG*
Matthias Pilot	*Alfred-Wegener-Institut*
Claudio Robustelli Test	*Università degli Studi di Torino*
Alessio Sanfilippo	*Università di Pavia*
Camilla Sani	*Università di Pavia*
Arianna Secchiari	*Università di Milano*
Andreas Stracke	*WWU Münster*

Sebastian Tappe *UiT The Arctic University of Norway*

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