IODP³ INTERNATIONAL OCEAN DRILLING PROGRAMME

PROPOSAL 1117-S

Chemical and energy exchanges between the mantle, magma and seawater: assessing how melt-driven heterogeneities influence exhumation and alteration processes at slow-spreading ridges

IODP^3 Proposal Cover Sheet

Proposal Title:

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Project Abstract

Formation, aging and recycling of oceanic lithosphere is a fundamental part of plate tectonics, which drives global cycles of energy and matter on Earth. Mid-ocean ridges are dynamic environments in which magmatic processes, tectonic deformation and hydrothermal circulation are tightly intertwined. These processes result in the largest fluxes of energy and matter from the deep Earth to the surface, with volcanism along ▪ 60000 km of oceanic ridges representing their most evident manifestation. While high- to low-temperature processes driving the formation and evolution of oceanic lithosphere are often approached as separate entities, the lithological, geochemical and rheological heterogeneities formed during mantle melting and magmatic activities strongly influence deformation patterns, which in turn have drastic control on melt focusing and hydrothermal fluid circulation within the oceanic lithosphere. This project aims to bridge the gap between these processes, by constraining the impact of magmatic processes on hydrothermal fluxes and the formation of secondary mineral assemblages, and assessing the role of deformation in focusing melt and fluid circulation.

While robust magmatism at fast-spreading ocean ridges produces a continuous magmatic crust and impedes large-scale lithospheric deformation, crustal accretion at slow-spreading ocean ridges can result from an interplay between magmatic intrusions within the lithospheric mantle and tectonic processes involving deformation and exhumation. Such ubiquitously deformed horizons enhance seawater circulation deep into the oceanic lithosphere, driving a complex system of hydrothermal alteration and venting. Slow-spreading ridges are therefore essential in constraining the interplay and feedbacks between *i)* magmatic processes related to melt percolation and intrusion, *ii)* deformation patterns of the oceanic lithosphere, and *iii)* low-temperature hydrothermal fluid circulation. This SPARC project will be developed using complementary ODP and IODP assets drilled along the Mid-Atlantic Ridge, namely at the Atlantis Massif, the Kane Fracture Zone and the Fifteen-Twenty Fracture Zone. Together, these legacy cores are representative of the strong heterogeneity of slow-spread oceanic lithosphere, with variable magma budget, deformation and hydrothermal alteration. The cores record interactions between partially refertilized mantle portions and gabbroic bodies, thereby providing insights into melt migration and reactive crystallization within the oceanic lithosphere, and the role of initial mantle heterogeneities on those processes. Extensive hydrothermal alteration allows to constrain how preexisting lithological and mechanical heterogeneities control fluid flow, redox conditions and the chemical and energy exchanges between basement rocks and seawater. Numerous deformed horizons further offer the opportunity to investigate the relationships and feedbacks between lithosphere deformation, melt percolation, and fluid circulation.

Scientific Objectives

This SPARC research project aims at constraining the nature and origin of lithological and geochemical heterogeneities characterising the slow-spreading oceanic lithosphere, which result from complex feedbacks between magmatic, deformation, and fluid-rock interaction processes. It will address four main objectives. ***Objective 1 -*** **Constraining the heterogeneity of the mantle and its modification during reactive melt percolation and refertilization** will test *Hypothesis 1*) Geochemical heterogeneity of the lithospheric mantle reflects inherited variability, further amplified by compositional modifications caused by invading melts. ***Objective 2*** – **Assessing the evolution of crustal mush processes through time and constraining the architecture and thermal evolution of igneous reservoirs** will address *Hypothesis 2*) Melt migration and melt-rock interaction processes strongly influence the thermal regime, composition and chemical budget of the oceanic lithosphere. ***Objective 3 -*** **Defining the relationship between deformation, melt injection and fluid-driven alteration within the oceanic lithosphere** will assess *Hypothesis 3)* Positive feedbacks between deformation and magma percolation drive the development of melt extraction pathways at depth, and *Hypothesis 4)* Rheological contrasts at intrusive contacts can induce high fluid/rock ratios and rock alteration, thereby enhancing mechanical weakening and tectonic exhumation from deep to shallow levels. ***Objective 4 -*** **Assessing the dependence of alteration style and redox budgets on the compositional heterogeneity of the oceanic lithosphere** will test *Hypothesis 5);* Lithological heterogeneities and temperature conditions drastically control chemical exchanges between basement rocks and seawater, and *Hypothesis 6);* Melt addition and lithospheric deformation impact fluxes of bio-available energy sources that hydrothermal fluids carry from depth to the seafloor.

Science Communication Plain Language Summary

Earth’s tectonic cycles drive constant formation of oceanic lithosphere at mid-ocean ridges and its recycling at subduction zones. These large-scale cycles are the expression of Earth’s cooling and represent the largest exchanges of matter and energy from the Earth’s interior outwards. The formation of new oceanic lithosphere involves high-temperature processes of melt migration and crystallization, widespread deformation of mantle and magmatic rocks, and circulation of hydrothermal fluids leading to partial alteration of the basement rocks. While these complex processes are strongly intertwined in space and time, they are mainly investigated as separate entities, and a profound understanding of the relationship and feedback between these fundamental building blocks of the oceanic lithosphere is still needed. Namely, the lithological and geochemical heterogeneities formed during magmatic processes influence deformation and the focusing of melt and hydrothermal fluid circulation. The aim of this research proposal is to constrain primary mantle heterogeneities, magmatic processes, and their impact on hydrothermal fluxes and secondary products, and to assess the role of deformation in focusing melt and fluid circulation.

The architecture of the oceanic lithosphere is not uniform along the ▪ 60000 km of mid-ocean ridges; it is dependent on the spreading velocity and magmatic budget. Fast-spreading ridges drive the formation of a continuous magmatic crust, in which deformation is sparse. Conversely, the oceanic lithosphere formed at slow-spreading ridges (< 50 mm/yr) is characterized by strong lithological heterogeneities with magmatic bodies embedded within mantle rocks, which can be brought to the seafloor through distributed and localized deformation. Deformed horizons facilitate deep seawater circulation and enhance hydrothermal alteration. Slow-spreading ocean ridges are therefore essential in understanding the interplay and feedback mechanisms between *i)* high-temperature processes of melt migration and crystallization, *ii)* deformation mechanisms within the oceanic lithosphere, and *iii)* hydrothermal fluid circulation. This SPARC research project will be developed using ODP and IODP cores drilled along the slow-spreading Mid-Atlantic Ridge. The targeted cores include the ideal and complementary material to address the scientific questions raised by this proposal. Ubiquitous magmatic intrusions within mantle lithologies will allow us to assess the impact of melt addition on geochemical and lithological heterogeneity. Quantification of the alteration style and the secondary mineralogical assemblages will reveal how the primary lithological and rheological heterogeneities in mantle and igneous rocks control deep hydrothermal processes. Numerous deformed horizons further offer the opportunity to explore the relationship and feedback between lithospheric deformation, melt migration and fluid circulation.