axis 3

Geobiological interactions in extreme environments

LabexMER Research project	**2016-2019 axis 3 roadmap**	**January 2016**

Geobiological interactions in extreme environments

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All of the above contributed at various stages to the redaction of this roadmap.

List of participating laboratories:

- LM2E – UMR 6197 (Laboratoire de Microbiologie des Environnements Extrêmes), UBO, CNRS, Ifremer
- LDO – UMR 6538 (Laboratoire Domaines Océaniques), UBO, CNRS
- LEP (Laboratoire Environnement Profond), Ifremer
- GM (Laboratoire de Géochimie et de Métallogénie), Ifremer
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1. Scientific context, scientific questions

Deep-sea environments, including seafloor and sub-seafloor environments, feature extreme variations in temperature, pH, pressure, salinity, and both inorganic and organic compounds, leading to a complex interplay between metabolic activity, biological diversity, and geochemical change. The objective of Axis 3 is to characterize and quantify — using the most efficient tools at sea and in the laboratory - fluid circulation and geobiological interactions in still-poorly understood deep-sea environments to evaluate their role on the dynamics and the functioning of deep-sea ecosystems as well as their contribution to global geochemical cycles.

The scope of this axis is inherently large, and also extends to include, for example, hydrothermal fluid dispersion, deep-sea volcanic and mantle processes, extreme ecosystems not directly influenced by hydrothermalism, and the sedimentary record of biogeochemical evolution. The 10-year vision for Axis 3 research initiatives is that they will contribute to a better management of activities that involve the exploration or exploitation of deep-sea biological, mineral, or energy resources, by providing the scientific arguments to best define the conservation strategy for these unique ecosystems that harbor major economic and societal interests. LabexMER Axis 3 activities are guided by three over-arching scientific questions:

- *What are the tectonic, magmatic, and sedimentary processes that control fluid circulation and its spatial and temporal variability?*
- *What are the environmental factors that control the dynamics of biological communities and functional diversity of deep-sea ecosystems?*
- *What impact does microbial community activity have on the environment and the major biogeochemical cycles?*

2. OBJECTIVES FOR THE NEXT FOUR YEARS AND SPECIFIC ACTIONS

2.1. SCIENTIFIC OBJECTIVES

The scientific objectives identified in phase one for Axis 3 are carried forward for phase 2, and center around the three over-arching scientific questions listed above. In more detail:

Question 1. What are the tectonic, magmatic and sedimentary processes that control fluid circulation and its spatial and temporal variability?

Fluid circulation and tectono-magmatic setting are the determining factors in the construction and spatio-temporal evolution of deep-sea/extreme ocean habitats. Understanding the relationship between faults, magmatic events and fluid circulation requires in-depth studies of diverse geological settings. With current methods for acquiring high-resolution bathymetry data in the deep sea, it is now possible to map the seafloor down to the level of faults and lava flows, at a scale similar to land-based surveys; high-resolution imaging of even deeper structures, necessary for the study of fluid circulation (plumbing), is still in its beginning stages with innovative instrument development in progress. Deep sea monitoring of active volcano-tectonic processes, informed by measurements of vertical or horizontal displacements, is also a key issue. Cutting-edge bathymetric tools deployed repetitively or continuously on selected sites will make it possible to address essential yet unresolved questions regarding fluid circulation. Questions include the depth of fluid penetration in the ocean lithosphere, how fluids and different types of substrata interact, the geometry of circulation, the relationship between deep fluid circulation and the deep biosphere, and the relationships between the development of faults and magmatism. This research is absolutely crucial for understanding chemical and heat exchanges between the earth's crust and the ocean, the origin and nature of the biosphere in these extreme environments as well as the energy sources and the mineral resources that are concentrated at the deep ocean-crust interface.

Question 2. What are the environmental factors that control the dynamics of biological and functional diversity of deep-sea ecosystems?

Chemosynthesis-based ecosystems thriving at ocean ridges (via hydrothermalism) and continental margins (via cold-seep fluids, reducing environments) constitute fragmented habitats that are difficult to access and remain poorly understood. They are under the influence of varied and extreme environmental parameters that structure the diversity of biological communities and control the functioning of these ecosystems. Understanding the interactions between the biological compartments and their environment in these complex ecosystems requires an interdisciplinary, multi-scale approach (from the ecosystem to the molecule) that is innovative in terms of sampling technology and data acquisition strategies. Assessing the connectivity among communities retrieved on different sites is also crucial for understanding their spatio-temporal dynamics. In addition to exploration at the regional scale it requires studies of reproduction, dispersal and gene flow, recruitment, succession, demographic dynamics, symbiotic associations and community evolution. We will therefore favour a temporal approach to the study of these ecosystems (in areas defined as 'worksites' or observatory sites) and a functional approach to the study of the biological components (activities, trophic networks, symbioses), along with the use of molecular tools (environmental genomics, high-throughput sequencing). We will also focus on technological developments

(sampling tools, tools for in situ chemical measurements and systems for culturing microorganisms) and the development of dedicated analytical and statistical tools.

Question 3. What impact does microbial community activity have on the environment and the major biogeochemical cycles?

It is now well known that submarine hydrothermal and cold-seep environments host very diverse microbial communities that are based on chemosynthesis, involving in particular CO2-fixing metabolisms and metabolisms based on the reduction-oxidation of locally available chemical species, such as hydrogen, sulphur, methane and iron. Moreover, the relatively recent demonstration that there exists a significant subsurface biosphere has led to profound paradigm shifts in the fields of biology and geosciences. These ecosystems in deep-sea environments are still poorly characterized and raise basic questions on the limits, evolution and global impact of life on the seafloor, whether in deep sediments, volcanic oceanic crust, mantle rocks or hydrothermal vents. Axis 3 also deals with the biogeochemical cycles of carbon, sulphur and certain metals (as electron acceptors/donors and as enzyme co-factors) in seafloor hydrothermal fields and ridge flank settings, which are accessible using multidisciplinary approaches to determine the relationships between microbial community structure and activity and the mineral, chemical and stable isotope characteristics (both light and heavy) of diverse extreme environments. Understanding the evolution of these biogeochemical cycles in deep geological time, when hydrothermalism was more important than at present, constitutes another important method for evaluating their organization and operation, and provides an alternative means of studying extreme conditions of biogeochemical cycling that may be difficult to observe in the modern. Finally, microbial communities attached on mineral surfaces are generally organized into biofilms; their structure, function, and communication networks (e.g. signalling molecules) are of particular interest is terms of their potential role for the concentration of metals.

2.2. INTERDISCIPLINARITY AND SYNERGIES BETWEEN TEAMS

Although there has been a strong tradition of multidisciplinary study of ocean ridges, continental margins, and submarine volcanoes between the LabexMER scientific teams, an immediate and central challenge is establishing even stronger links and interdisciplinary fertilization between Axis 3 themes. Phase 1 initiatives on the part of Axis 3, such as internal calls for team-spanning projects and the organization of scientific meetings, has greatly facilitated this synergy, and will be carried forward in phase 2. LDO (IUEM) and LGM (IFREMER) have both ample experience in the multidisciplinary study of ocean ridges, continental margins, and submarine volcanoes. The development of innovative instruments and methods for imaging the crust in deep-sea environments will continue to be supported in phase 2. IFREMER and IUEM share, through the Ocean Spectrometry Cluster (PSO), one of the most efficient analytical facilities in France for the analysis of major elements, trace elements, and their isotopes, and projects leveraging these shared facilities will also continue to benefit from Axis 3 support in phase 2. LM2E is the only French laboratory exclusively dedicated to study of deep-sea microbiology, and LEP, deep-sea animal ecology, including at high pressure/high temperature, while LBCM has expertise in culturing and monitoring biofilms and in the analysis of bacteria-bacteria communication molecules. The type of new synergy and collaborations that has developed naturally between these laboratories in phase 1 (e.g., Axis 3 funding of a PhD project in 2013: "Recognition system and cell-cell communication between

host and symbionts in extreme environments: the case of *Rimicaris exoculata*") will continue to be solicited by Axis 3 going into phase 2.

2.3. INTERNATIONAL VISIBILITY

Several actions will help ensure that Axis 3 projects enjoy the highest standing and international visibility. First, while significant consideration has and will always be given to the cost-effectiveness of proposed projects, no budgetary restrictions nor restrictions on the use of Axis 3 funds (whether for equipment, instrument time, travel, or personnel) will be imposed in exploratory project calls in phase 2. Each exploratory project is unique, and exploratory project calls should permit projects to be designed with excellence in science as first priority, rather than budgetary or operational pre-conceptions, continuing the "bottom-up" approach that was successful in phase 1. Second, a new program for funding PhD student participation in international meetings related to Axis 3 will be introduced. This program is not intended as a replacement for existing LabexMER support for student mobility, but rather as a complement to enable student participation in international conferences outside of Europe where participation costs (registration, airfare, lodging) range upwards of 1–2k€. This student–only action would engage PhD students working on Axis 3 related subjects and provide them important experience in raising their own funds for their scientific pursuits. A trip report would be expected following the conference, which would be posted on the Axe 3 website (see below).

2.4. LEVERAGING EFFECT

The strong emphasis that Axis 3 will continue to place on exploratory projects assures a healthy scientific leverage effect going forward. Axis 3 exploratory project calls, with their relatively favorable success rate as compared to national programs such those of ANR and CNRS, constitute a sort of thematic incubator, lowering financial barriers for researchers to explore the themes represented by Axis 3. Axis 3 exploratory projects generate publications, serve to gather preliminary data for larger proposals, and are often used as a source of co-funding to leverage other potential sources of funds (e.g. Institutional, Region of Brittany, ANR, etc). Axis 3 will thus continue to dedicate well over half its budget to exploratory projects in phase 2.

2.5. GOVERNANCE

In anticipation of phase 2, Axis 3 had already begun taking steps by mid-2014 to ensure a smooth transition in axis coordination. In phase 1, Axis 3 was coordinated by M. Maia (IUEM/LDO), O. Rouxel (IFREMER/REM/GM), and P.M. Sarradin (IFREMER/REM/EEP). These coordinators began involving junior colleagues who had demonstrated early interest in axis coordination activities, and by the time of the CSI at the end of phase 1, several junior colleagues had been identified as future Axis 3 coordinators, contributing to the phase 1 report, discussions of axis evolution, and events surrounding the CSI itself (presentation, workshop). New axis 3 coordinators going forward for phase 2 are: S. Lalonde (IUEM/LDO), J. Sarrazin (IFREMER/REM/EEP), J. Perrot (IUEM/LDO), and K. Alain (IUEM/LM2E). This ensemble of coordinators provides motivated junior colleagues the opportunity for leadership experience and at the same time ensures expertise across the diverse fields implicated in Axis 3 (microbiology, ecology, geology, and geochemistry). The phase 1 coordinators have all agreed

to remain available to share their experience and participate in axis administration activities where required.

3. ANSWERS TO CSI RECOMMANDATIONS

Axis 3 received a positive evaluation from the CSI for its phase 1 activities: *"The LabexMER International Council noticed overall excellent performance by Axis 3 during the LabexMER first phase … the strong integration between microbiology, plate tectonics, and hard rock geology/petrology documents a successful high internal inter-discipline approaches … The evaluation committee strongly encourages the axis members to continue their approach and objectives during its second phase".* Accordingly, Axis 3 plans to stick closely to the scientific themes and operational principles that brought its success in phase 1. These include a continued emphasis on exploratory research projects, a focus on inter-disciplinarity, and a "bottom up" approach to project calls that provides significant flexibility (both in project theme and structuration), whereby the best proposals are selected for their scientific excellence first and foremost.

In the perspectives presented by Axis 3 at the CSI meeting, and discussed in details with members of the CSI at the Axis 3 workshop, a need for reflection on the intersection of Axis 3 with Axis 1 (Ocean engine at very high resolution) and Axis 4 (Sediment transfer from coast to abyss) was identified. This was further reflected in the CSI report: *"Axis 3 should seek more opportunities for collaboration with axis 4 … either on extreme environments for deeper water corals at margins sites with high fluxes of terrigenous material and/or … investigation of cold seep ecosystems".* The CSI also suggested to Axis 4 to seek increased interaction with Axis 3 scientists. Similarly, the CSI suggested that *"[in collaboration with axis 1] the modeling of deeper ocean mixing could be another route to explore with more emphasis the role of fluid dynamics and dissolved element fluxes"*, a point that Axis 3 also noted both in its CSI presentation and workshop.

To specifically address these suggestions, and as a part of its natural evolution, Axis 3 will execute three actions going forward into phase 2:

1. Scientific objectives of the axis are evolving slightly in their wording to better reflect Axis 3 activities and to make it clear to potential participants that projects lying at the intersections with Axes 1 and 4 are welcome. Specifically, the following sentence has been added to the Axis 3 scientific objective statement (included in revised form at the beginning of this document): *The scope of this axis is inherently large, and also extends to include, for example, hydrothermal fluid dispersion, deep-sea volcanic and mantle processes, extreme ecosystems not directly influenced by hydrothermalism, and the sedimentary record of biogeochemical evolution.*
2. Increased interaction with Axis 1 and Axis 4 will be especially promoted in phase 2 through joint projects or project calls. With respect to collaboration with Axe 1 and the subject of deep ocean mixing of hydrothermal fluids, this is already underway. Thanks in part to LabexMER support in phase 1, Axes 1 and 3 researchers were recently successful in a joint project funded by the Agence Nationale de Recherche (ANR), *Lucky Scales* (2014–2019; 499k€). *Lucky Scales* will evaluate fluid and ecosystem dynamics at mid-ocean ridge hydrothermal vents, examining hydrothermal fluids with respect to their concentrated sub-surface end-members, their small-scale subseafloor circulation, and their ultimate dispersion into the water column. Axis 3 will continue to favor this kind of multi-

disciplinary interaction in their selection of internal projects and other funded initiatives funded by Axis 3. With respect to increased interaction with Axis 4, an agreement between Axes coordinators has been reached for an envelope to be set aside by each Axis in phase 2 to fund at least one inter-axis project, and indeed, the first Axis 3 internal project call (Oct 2015) specifically highlighted the need for increased Axis 3-4 interaction and the fact that prioritized funds have been set aside for such collaborative projects. These actions directly address the CSI suggestion of fostering new collaboration with these axes, and will be a priority of Axis 3 going forward.

3. Several small actions will be pursued to increase the dynamicity and visibility of Axe 3. These include: a new Axis 3 program for funding PhD students to attend major international conferences for which current student mobility programs do not come close in terms of covering cost; an active mailing list to which interested researchers can subscribe to follow the latest Axis 3 activities; an Axis 3 blog page where news, institutional happenings, and researcher accomplishments may be broadcast in a more accessible way; and a yearly social event, such as a Café of Science lecture or Geobiology quiz game, to help Axis 3 researchers meet, network, and exchange. These are detailed below in the Strategy section.

4. IMPLEMENTATION PLAN AND RESOURCES

In accordance with positive feedback received from the CSI, Axis 3 will continue to place a strong emphasis on exploratory projects, dedicating 60% of the budget to this action. Considering the difficulty in soliciting, selecting, funding, and executing projects over periods of less than a year, all exploratory project funds will be awarded through three calls of 40k€ each that will occur in Spring 2016, 2017, and 2018. No exploratory project call will occur in 2019, although multi-year projects funded in 2017–2018 will have until 2019 to conclude their activity. This project-funding schedule will ensure a timely liquidation of phase 2 funds, and full maturity of Axis 3 exploratory project outcomes, for the end of the LabexMER program in 2019. As it did in phase 1, axis 3 will co-fund a new Axis-specific PhD project beginning in 2016. A call for Axis 3 PhD project proposals will be launched in Fall 2015, from which one will be selected on the basis of scientific excellence. Co-funding of the second Axis 3 PhD project will constitute 27% of the budget (18k€/year for 3 years).

Finally, the remaining 13% of the budget will be dedicated to (in order of decreasing cost): (1) axis 3 operational costs (2.5k€ / year), (2) the invited speaker program (2k€ / year), (3) a student mobility fellowship for international conference attendance (1k€ / year), and (4) a social event (Café of Science or geobiology quiz game, 500€ / year).

To elaborate on the latter two actions, Axis 3 plans to establish a science-social event that would occur off-site, such as an evening activity in the form of a Café of Science or Geobiology quiz game, to bring together scientists at all career stages (PhD, postdoc, junior and senior permanent personnel) to network, exchange, and build camaraderie. The inherent inter-disciplinarity of Axis 3 means that potential participants are spread out across multiple laboratories at IFREMER and IUEM, and may rarely meet face to face. Holding at least one yearly, Axis 3 meeting in a highly socialized setting (e.g., equivalent to a conference icebreaker event) should help overcome the physical and social barriers between laboratories and foster a greater awareness amongst participants of Axis 3-related research that is occurring in these physically separate locales.