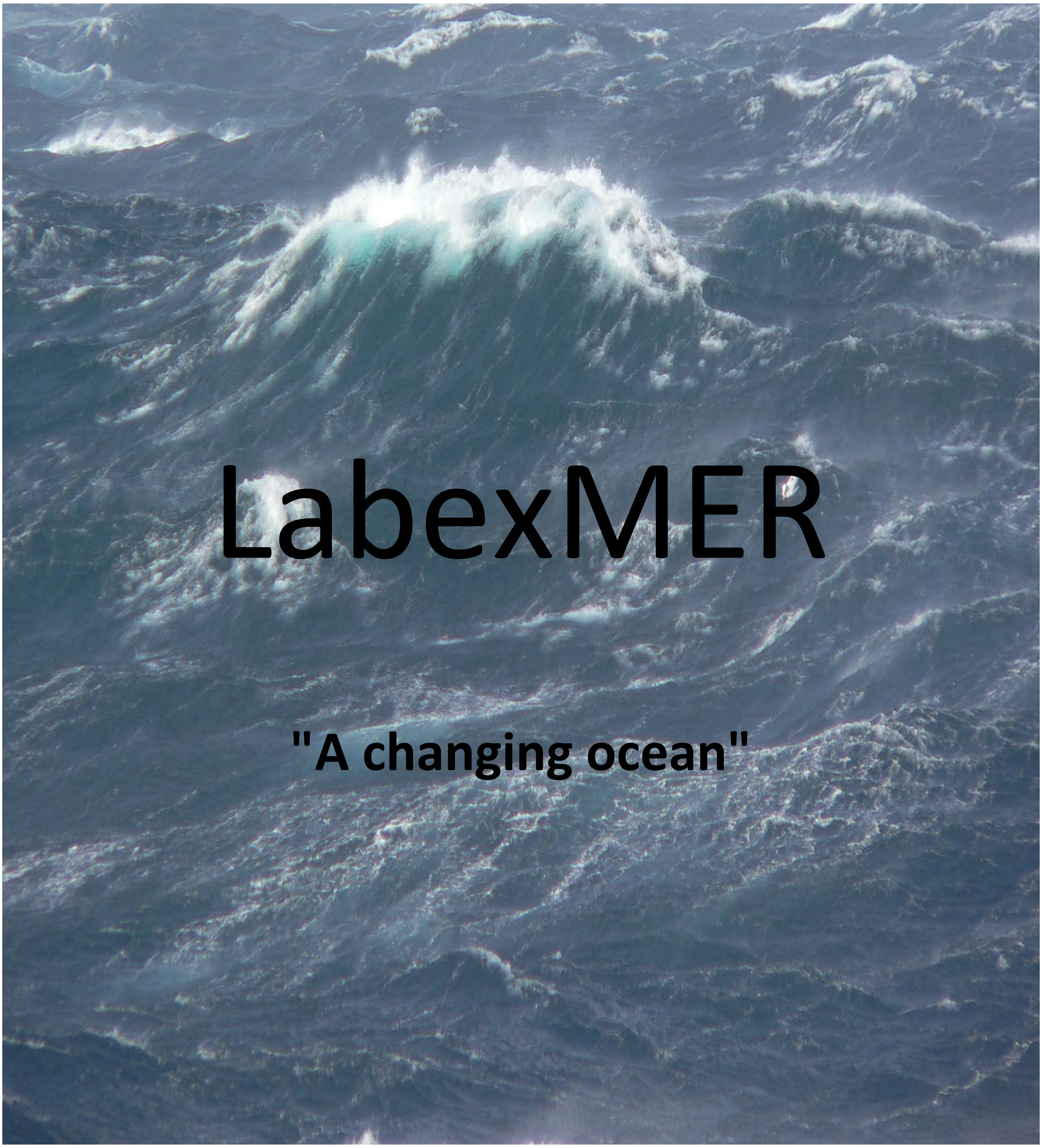

LabexMER

"A changing ocean"

LabexMER - Axis 3	**Research project 2012-2014**	**16/02/2012**

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1. AXIS 3 : GEOBIOLOGICAL INTERACTIONS IN EXTREME ENVIRONMENTS

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List of participating laboratories:

Laboratoire Microbiologie des Environnements Extrêmes (LM2E, Ifremer, UBO, CNRS/INEE)
Laboratoire Domaines Océaniques (LDO UMR6538, UBO, CNRS/INSU)
*Laboratoire « Environnement Profond » (*Unité Etude des écosystèmes Profonds Profonds, Ifremer)
Laboratoire « Géochimie & Métallogénie » (Unité Géosciences Marines, Ifremer)
Laboratoire Biotechnologie et Chimie Marines (LBCM), EA 3884, Université de Bretagne-Sud

1.1. SCIENTIFIC CONTEXT, SCIENTIFIC QUESTIONS, 10-YEARS VISION

Deep sea environments, including seafloor and subseafloor environments feature extreme variations in temperature, pH, pressure, salinity, and both inorganic and organic compounds leading to a complex interplay between metabolic activity and diversity, and geochemical changes. The objective if this Axis is to characterize and quantify — using the most efficient tools at sea and in the laboratory — fluid circulation and geobiological interactions in the 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. This research will lead 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.

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 to understand 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 favor 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 CO_2-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. We therefore propose to study 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 by using a multidisciplinary approach to determine the relationships between microbial community structure and activity and the mineral, chemical and stable isotope characteristics (both light and heavy) of diverse environments. Microbial communities attached on mineral surfaces are generally organized into biofilms; their structure and function will be examined through the use of sophisticated bioreactors (operating in continuous culture). In addition, we will screen for communication molecules which have been implicated in the regulation and the formation of biofilms. Screening for these molecules is a particularly novel line of research with regards to extremophile prokaryotes (archaea and bacteria), as the nature of their chemical signalling network is completely unknown. One important point concerns the role of microorganisms both for the formation and destruction of minerals in different types of rocks. Of particular interest is the role of microorganisms for the concentration of metals.

The deep-sea environments involved in this project are those where contrasting geobiological interactions occur: mid-ocean ridges, in particular in the Atlantic Ocean (e.g. south Azores, MoMAR observatory site; ridge flans, IODP North Pond), the Pacific Ocean (e.g. East Pacific Rise, Guaymas basin) and the Indian Ocean; submarine volcanoes (active sites and inactive areas); certain areas of the abyssal plains (e.g. FeMn nodule-rich areas,); continental margins (cold seeps, methane hydrate formation, cold-water corals), in particular the Mediterranean Sea and the equatorial Atlantic Ocean. Unique opportunities also exist within the French EEZ, including the Polynesian seamounts, St Paul and Amsterdam Islands on the south-west Indian ridges and continental margin off French Guiana. Most of these sites need a strong effort for exploration at regional and local scales.

Technological and methodological challenges: The exploration effort and the acquisition of data in these environments is tightly linked to technological progress in mapping, acoustic imagery, sampling, monitoring and analysis. Even if repetitive operations over time are required, the temporally-dynamic nature of deep-sea extreme environments makes it essential to develop permanent, continuous acquisition systems capable of monitoring a wide variety of parameters such as hydroacoustics through autonomous hydrophones, geophysics, geodesy, geochemistry, visual and microbiological imaging. It is also essential to develop high-resolution 3D geophysical approaches for characterizing the subsurface compartment (geophysics: gravimetry/gradiometry, electrical measurements). Joint projects, coupling molecular, cultural and geochemical approaches have already been initiated between the LDO, GM and LM2E groups for investigating water-rock-microorganism interaction in hydrothermal systems. As part of the 'Mer' LabEx project, this approach will be reinforced by the creation of an *ad hoc* research group in 'geobiology. It is also expected that the Labex will positively impact and bolster several on-going projects such as the implementation of new culture techniques (high output automated culture facility, Cocagne/CPER), new analytical techniques (e.g. femtosecond laser ablation MC-ICP-MS and gas-source mass spectrometry) at the PSO facility, automated processing of video images, environmental metagenomics and new field techniques (*in situ* incubators).

Societal and economic challenges: Anthropogenic pressure on deep-sea environments is ever increasing (fishing activities, exploration for oil and mineral resources, and even pollution and global change). Some deep-sea areas have been incorporated into projects for establishing protected marine areas, while others are now areas where exploration is authorized for metal-rich hydrothermal sulphide deposits, manganese nodules and manganese crusts. For the most part, the societal and economic challenges involve the following: exploration to locate potential resources and specific biological "hotspots", dissemination of scientific and technical information to the industrial sector and to the general public, characterisation of potential mineral resources (sulphides, manganese deposits) and energy resources (gas hydrates, hydrogen), providing expertise and impact studies of industrial activities in the deep sea, conservation of deep-sea ecosystems, and screening for molecules with high added potential.

Multidisciplinary nature of and synergy between research groups: LDO has ample experience in the multidisciplinary study of ocean ridges, continental margins and submarine volcanoes. It is actively developing innovative instruments and methods for imaging the crust in deep-sea environments. LGM is one of the world leaders in the study of hydrothermalism associated with mid-ocean ridges and back arc basins. Its expertise lies in the geology and geochemistry of fluids, rocks and sediments associated with hydrothermal vents, in slow and fast accretionary settings. LGM is also very active in the study of cold seeps, carbonates crusts and gas hydrates in the margins environments. It is also the French leader for the exploration and scientific study of deep sea potential mineral resources and of metals cycles. LEP and LM2E groups are the only French laboratories that dedicate their activity exclusively to deep-sea ecosystems. LM2E has equipment dedicated to culturing microorganisms from extreme environments (high pressure/high temperature) and two major development projects: a high-throughput culture facility and the creation of an Ecotron-type tool called the Bathytron, designed to culture organisms under pressure. LEP is the driving force — in collaboration with the RDT department — behind the development and utilisation of deep-sea observatories (e.g. MoMAR, Neptune CA). IFREMER and IUEM share, through the Ocean Spectrometry Cluster (PSO), one of the most efficient analytical facilities in France for analysing major, trace and isotopic elements. IFREMER and IUEM are also actively involved in the technological development of instruments for studying deep-sea environments. LBCM has expertise in culturing and monitoring biofilms (confocal laser-scanning microscopy) and in the analysis of bacteria-bacteria communication molecules.

1.2. OBJECTIVES FOR THE NEXT THREE YEARS AND SPECIFIC ACTIONS

Objectives center on producing important and novel results of international visibility in the "Frontier" thematics defined in the deposed proposal. Of specific consideration are multidisciplinary questions that would be unapproachable by any single laboratory alone or through traditional funding streams. Accordingly, a complimentary objective is to form and develop inter-organization synergy, both between laboratories and between research organisms (IUEM and IFREMER), and to provide state-of-the-art training for young researchers at this exciting interface. This approach is envisioned in the long term to augment research capabilities, facilitate growth with respect to new positions and analytical means, and ultimately raise the status of the participating institutes and laboratories.

The structuration of Axis 3 and the priority classification of its scientific projects are in their initial stages. Although there has been a strong tradition of multidisciplinary study of ocean ridges, continental margins and submarine volcanoes between the Labex scientific teams, an immediate and central challenge is establishing even stronger links and interdisciplinary fertilization between Axis 3 themes. Current initiatives such as internal calls for team-spanning projects and organization of scientific reunions should facilitate this synergy.

1.2.1. PRIORITY ACTIONS

(1) Technological development for the study of extreme environments

This action emphasizes technological expansion of the Axis' capabilities in exploration, observation, and comprehension of active processes in deep sea environments. New discoveries on geodynamic, geochemical and biological processes in extreme environments, including mid-oceanic ridges, margin and abyssal seafloor are strongly related to technological progress and the development of specific tools that permit new insight at a variety of spatial and temporal scales. Progress in high-resolution bathymetry now permits study of the seafloor at scales comparable to what is possible on land. However, methods permitting high-resolution imaging of the structure of the crust subsurface (e.g., high-resolution seismic survey; ocean bottom gravimetry) and movement of the deep ocean floor (e.g., seafloor geodesy) remain poorly developed. Active technology development groups at WHOI and JAMSTEC are currently investigating advanced exploration techniques. The positioning of a French group among the international leaders of new submarine exploration technologies would be not only academically advantageous, but also potentially interesting for submarine exploration companies that are routinely chartered by petroleum, mineral, and geotechnical sectors.

This action equally implicates the development of physico-chemical sensors to detect fluid emission and revealing in new detail the dynamic mixing zone that occurs at – or below - the seafloor. The continued development of long term observation systems, « environmental metagenomic » molecular biology tools, and high pressure experimentations will ensure observations that are state of the art. To complement technological development, special consideration is placed on integration of data across multiple scales and between teams, to both enhance synergy and improve breadth of understanding in ecosystem functioning.

(2) Biogeochemical processes at the biological-mineral interface

Biofilms are communities of organisms adhering to each other and to a biotic or abiotic surface. Biofilms present complex gradients of environmental conditions that can be exploited by microorganisms leading to a wide range of biogeochemical reactions with key roles in the cycling of organic matter, CO_2, many macro- and micro-nutrients, and even in detoxification processes. Biofilms on biotic surfaces also constitute biological filters which may affect the passage of matter and signals through this interface and contribute substantially to metabolic processes, health and communication with the host species. The ecological and evolutionary role of these associations is huge but also largely unexplored. Although the ability of microorganisms to exploit mineral-seawater reactions energetically has been indicated by abundant growth and high diversity on rocks exposed at the seafloor, the importance of biofilms in affecting rock alteration processes remains unknown. Understanding the role of detoxification processes in metal accumulation at the seafloor will also require new scientific and technological approaches. In addition, although biofilms have been increasingly studied since 1983 (this is now considered as the predominant bacterial lifestyle), only very few publications have focused so far on biofilms of extremophile prokaryotes. This field is thus wide open to exploration and new discovery. We intend to address such problems by applying comprehensive and detailed geochemical, isotopic, and mineralogical/spectroscopical studies combined with a geomicrobiological assessment of microbial activity, physiology, and phylogeny using a range of techniques and experimental set-ups.

(3) Deep-sea drilling program and the deep subsurface biosphere

The recent recognition of the importance of the deep subsurface biosphere – Earth's "intraterrestrial life" is now leading to paradigm shifts in the biosciences and geosciences. It has been argued that the biomass in the deep subsurface biosphere, including marine sediments and crustal rocks, may rival the total biomass found in surface-terrestrial and oceanic ecosystems. The largest potential subsurface biome is also the least accessible – the deep ocean subsurface. It also has the greatest potential for influencing global-scale biogeochemical processes, including carbon, energy and nutrient cycles. Numerous phylogenetic lineages of archaea, bacteria, and unicellular eukaryotes have been detected and most of them are novel, some are endemic, and most are uncultured. Today, only a few microbial strains have been isolated from deep marine sediments. Subseafloor basalt also represents the largest habitable zone by volume on Earth. Seafloor oceanic basalts are exposed to seawater for millions of years, become colonized by dense microbial communities and undergo radical chemical and mineralogical transformations. Chemical reactions of basalt with seawater flowing through veins release energy that can potentially support chemosynthetic communities. These communities are likely to play a critical role in determining seawater chemistry.

Fundamental questions that have far reaching consequences for life on Earth and beyond include, what are the nature and extent of life on Earth? What are the physico-chemical limits of life on Earth? How metabolically active is the deep biosphere, and what are the most important redox processes? How are microbes dispersed in the deep sub-seafloor biosphere? We propose to address these questions within the Labex Mer by developing stronger international interactions with DEBI (Dark Energy Biosphere Institute) and IODP (Integrated Oceanic Drilling Program) and bolstering synergy between current deep biosphere projects undertaken by LM2E, LDO and LGM laboratories (e.g. North Pond, New Jersey and Canterbury basins). In order to accomplish our goals, a joint call of internal proposals between DEBI and Labex scientists are currently being discussed and promise to lead to new research opportunities, additional funding and stronger international collaborations.

(4) Temporal and spatial dynamics of hydrothermal systems

Hydrothermal system functioning is directly related to tectonic and magmatic activity inherent to subduction zones and spreading centers. Seismicity, ruptures, eruptions, and faulting all effect fluid circulation at the surface and at depth, and in turn control longevity of any given hydrothermal site. While it is known that hydrothermal sites on fast-spreading ridges are more ephemeral than slow on spreading ridges, there exists very little information about the variability of processes mentioned above that effect fluid circulation. While studies surveying sites geographically along a ridge may reveal spatial heterogeneity in chemistry, communities, and connectivity, the temporal study of targeted sites enables time-resolved observation of active processes (tectonic, volcanic, and hydrothermal), and are therefore essential for understanding dynamic controls on the operation and longevity of hydrothermal sites.

Hydrothermal site assemblages are distributed in a patchwork mosaic that is strongly influenced by physical, geological, and chemical processes operating at different scales in time and space. Few time-series studies are available that reveal the variability of hydrothermal systems in terms of geological and environmental parameters and the biological communities associated with them. Recent efforts in the field have focused largely on recolonization on rapid spreading ridges and have relied on a strategy of frequent return sampling rather than continuous monitoring. The systematic acquisition of imagery, over several years and with the aid of submersibles, has revealed shifts microbial and faunal distributions with the evolution of vent edifices, response in biological assemblages to changing environmental parameters, and even catastrophic events at certain sites. A sub-annual tempo of observation is thus essential for understanding biological and geochemical dynamics at hydrothermal sites and gauging their response to site-impacting geological events and changing environmental parameters.

Studies combining multiple, carefully targeted hydrothermal zones, concurrently with a high-temporal-resolution data acquisition approach, will enable unprecedented combined observation of temporal, spatial, and biological hydrothermal site dynamics. The envisioned results will certainly serve to inform decisions pertaining to the management, protection and conservation of hydrothermal sites, as well as mineral resource (e.g., polymetallic sulphide) exploration activities that seek to exploit them.

1.2.2. THREE YEAR OBJECTIVES

(1) Development of dynamism in interdiscplinary research within the axis

An ad-hoc working group has been assembled to actively contribute to the scientific animation, efficiently diffuse of all information regarding Labex, and to maintain close contact between teams, temporary employees, and technicians in terms of project initiatives, funding calls, and internal evaluation. With the Axis coordinators, the working group also ensures training and outreach activities related to Labex, such as the production of articles for scientific and general audiences, organization of themed sessions at international congresses, and management and participation in targeted workshops and short courses.

Axis coordinators: O. Rouxel ; M. Maia ; PM Sarradin

Theme 1 : Geodynamics and Hydrothermalism.

Members : Y. Fouquet, A. Deschamps, J-Y. Royer, L. Geoffroy

Theme 2 : Ecosystems and Habitats

Members : J. Sarrazin, MA. Cambon, M. Waeles

Theme 3 : Geomicrobiology and Biogeochemistry

Members : A. Godfroy/M. Jebbar, K. Alain, A. Dufour

Objectives for 3 months: Review project initiatives within the Axis and organization of a day-long Labex scientific panel for refinement of scientific goals, review of current field sites, and team building.

Objectives for 6 months: Diffusion of an internal project call to prioritize initial-stage and innovative projects, to promote project development across teams and themes, and identify potential international collaborations and co-financing opportunities.

Objectives for 1 year: Establishment of flagship projects that are competitive for additional EU or ANR support in year 2.

Objectives for 2 years: Identification of study suites (e.g., mid-Atlantic ridge and French EEZ sites) for proposal of a Axis-themed scientific cruise to be submitted in year 3. In this period, terrestrial field sites (e.g., emergent ridges) will also be considered with the goal of complementing existing team field efforts, already underway at onshore hydrothermal analogue sites (e.g., Iceland, Djibouti), with an Axis 3 multi-disciplinary approach.

(2) Reinforcing international visibility

The operating budget of Axis 3 will permit the invitation of established researchers to give guest seminars and to interact with Axis 3 research scientists and engineers. In addition to traditional actions such as congresses, project collaborations, Axis 3 participation in scientific campaigns, and the hosting of sabbatical scientists, the targeted invitation and hosting of preeminent international researchers will further distinguish the Axis.

Objectives for 6 months: The finalization of an agenda for a “deep-sea” lecture series to correspond with the invitation of field-leading researchers for public seminars and Axis 3 meetings.

Objectives for 1 year: Organization of a summer school and scientific workshop on geodynamic and geobiologic processes at mid-ocean ridges (“school GEOCEAN).

Objectives for 3 years: Organization of a deep biosphere workshop co-organized with DEBI (Dark Energy Biosphere Institute).

(3) Training of highly qualified personnel and young researchers and reinforcing the international competitiveness of our students

Objectives for 6 months: Co-financing of a thesis (year 1) in one of the themes of the axis with preference for projects with inter-team and international collaboration.

Objectives for 1 year: Obtain external funding (outside of axis) for a complete thesis to begin in year 2, specifically labeled and submitted to funding bodies as an Axis 3 thesis project.

Objectives for 2 years: Initiation of a third co-funded thesis in year 3.