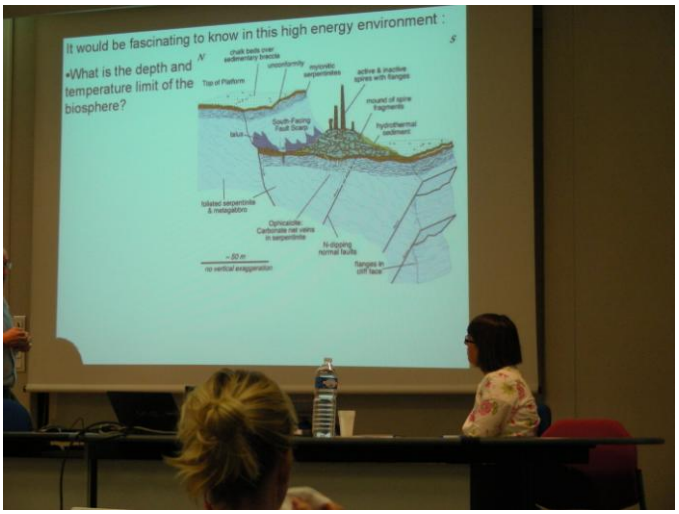
Lithospheric heterogeneities, hydrothermal regimes, and links between abiotic and biotic processes at slow spreading ridges

International Workshop on Marine Research Drilling in the Atlantic
(Magellan Workshop Series)
10-12 September 2008, Montpellier (France)



Lithospheric heterogeneities, hydrothermal regimes, and links between abiotic and biotic processes at slow spreading ridges

International Workshop on Marine Research Drilling in the Atlantic
(Magellan Workshop Series)
10-12 September 2008, Montpellier (France)

Conveners: Marguerite Godard (Université Montpellier 2), Gretchen Früh-Green (ETH Zurich), and Christopher MacLeod (Cardiff University)

Summary

The workshop "Lithospheric heterogeneities, hydrothermal regimes, and links between abiotic and biotic processes at slow spreading ridges" was held in Montpellier (France) between 10th and 12th September 2008. It brought together specialists in marine geology and geochemistry, oceanography, biology and petrology; its aim was to develop an European-initiated, mission-specific platform (MSP) Integrated Ocean Drilling Program (IODP) drilling proposal to investigate the geological, physical and chemical evolution of the accretion system at slow spreading ridges and the life it sustains. The workshop was supported by ESF (Magellan Workshop Series), UKIODP and InterRidge. A total of twenty-three participants from twelve research institutions from six European countries, together with four participants from the United States (three institutions) attended.

The workshop commenced with a series of presentations that provided an updated view of tectono-magmatic processes at magma-poor slow-spreading ridges, the associated development of H_2-generating, serpentinite-hosted hydrothermal fields and on related microbial communities. This was followed by an introduction to robotic seabed rock drill technologies, principally those developed and applied by the British Geological Survey (BGS) and the University of Bremen (MeBo), and a review of the use of such devices on previous scientific expeditions. Discussions focused on: *(i)* the development of novel uses of seabed drills as MSPs within IODP; *(ii)* how such tools might be utilised to explore hard-rock scientific themes within the IODP Initial Science Plan, and specifically those centred around mid-ocean ridge processes; leading ultimately to *(iii)* how to design a drilling experiment to address the major questions and rationale that drive interest in scientific ocean drilling at slow spreading ridges today. The Atlantis Massif oceanic core complex (Mid-Atlantic Ridge, 30°N) was chosen as a target area because: *(i)* the processes by which it exposes mantle peridotites (with associated gabbroic intrusions) on the seafloor by detachment faulting are now believed to be representative of processes at up to half of all slow-spreading ridges; *(ii)* it hosts a H_2-generating hydrothermal system (Lost City Hydrothermal Field); *(iii)* abundant geophysical and geological data are available at this site, including prior IODP drilling (Expeditions 304-305); and *(iv)* it is shallow enough and the seafloor is locally smooth enough for a seabed drilling programme to be feasible with relatively low operational risk.

Substantial discussion was directed at defining the detailed objectives, and work plan, with the intention of submitting an MSP proposal to IODP in April 2009, under the coordination of Gretchen Früh-Green. It is planned that the proposal will be focused on the exploration and characterisation of interactions between faulting, serpentinisation, fluid flow and microbial activity in the shallow ultramafic seafloor.

Scientific Rationale & Workshop Goals

Recent discoveries of low-temperature hydrothermal vents specific to mantle exhumation areas and of abiotic synthesis of hydrocarbons directly associated with these vents highlight the exciting possibility that strong links exist between the structural and petrological heterogeneities of the lithosphere formed at slow spreading ridges and the development of conditions favourable to life in extreme environments.

The formation of the oceanic lithosphere and its subsequent interaction with the hydrosphere are fundamental processes that play a central role in the chemical and physical evolution of our planet. However, in the nearly 40-year history of the scientific ocean drilling programs only a very limited number of sites have been drilled into oceanic basement: two so far to depths >1000m in lower crustal sequences, and none deeper than ~150m or so into mantle lithologies. In conjunction with other, coordinated geological and geophysical studies this previous drilling has nevertheless given us a radically different view of mid-ocean ridge processes and, in particular, the recognition that fundamental differences exist in crustal accretion and alteration processes with spreading rate. In contrast to the apparently more layered and spatially homogeneous oceanic lithosphere at fast-spreading ridges, slow- and ultra-slow spreading centres are markedly heterogeneous on a variety of scales as a result of profound variations in magmatic and tectonic activity along- and across-isochrons.

At many sites on the Mid-Atlantic Ridge (MAR) it has been documented that the magmatic layer is discontinuous, with mantle lithologies exposed at or near the seafloor at oceanic core complexes (OCCs): the exposed footwalls of long-lived low-angle detachment faults. The length scale of this variability, the implications for fluid flow paths and fluxes, and the life these systems sustain are, however, almost completely unconstrained. Previous expeditions and drilling in the Atlantic and Indian oceans (e.g., ODP Legs 153, 176, 179, 209 and IODP Expeditions 304/305) have concentrated upon a few, relatively deep holes, thereby providing minimal information about the extent or scale of lateral heterogeneity. These studies have nevertheless highlighted complex *vertical* heterogeneities in composition, deformation, and hydrothermal alteration. That IODP Hole U1309D on the Atlantis Massif (AM) on the MAR unexpectedly yielded 1400m of gabbro adjacent to where peridotite had previously been recovered, and close to the peridotite-hosted Lost City vent field, is testament to how laterally variable magmatic accretion processes must be.

The long-term scientific goal of the workshop "Lithospheric heterogeneities, hydrothermal regimes, and links between abiotic and biotic processes at slow spreading ridges" was to explore the inter-relationship of these processes, emphasising a key parameter previously neglected in most studies of the slow spread lithosphere, namely the length scale of heterogeneity, particularly in the horizontal dimension. It aimed to achieve these goals by developing at least one European-initiated IODP mission-specific platform drilling proposal

that will employ seabed rock drills to investigate these processes at the Atlantis Massif on the Mid-Atlantic Ridge.

Workshop: participants, program & discussions

The workshop brought together twenty-three researchers (including four early career scientists and three PhD students) with a strong interest in understanding the linkages among the geological, physical and chemical evolution of the lithosphere at slow spreading ridges, interaction with fluids and their impact upon life. The workshop participants came from sixteen research institutions from France, Switzerland, Germany, Sweden, Italy, United Kingdom and United States (see List of participants). The workshop was supported primarily by ESF (Magellan Workshop Series); complementary funding was provided by UKIODP and InterRidge.

The workshop took place from September 10th to 12th at the University of Montpellier, France. The first day was dedicated to a series of keynote talks on the main topics of the workshop and a poster session with the aim to stimulate synergies among the different disciplines. First, Mathilde Cannat (IPGP France), Gretchen Früh-Green (ETHZ Switzerland) and John Parkes (Cardiff University UK) provided an updated view of tectonic and magmatic, hydrothermal and biological processes at slow spreading ridges; then, Barbara John (University of Wyoming USA) and Donna Blackman (Scripps Institution San Diego USA) presented the most recent results of geophysical and drilling studies of the Atlantis Massif. A poster session followed, during which each participant presented his/her most recent works of relevance to the goals of the workshop.

During the second day, keynote talks and follow-up discussions were directed at the exploration of novel uses of mission-specific platforms to investigate ridges processes and possible new options to design a drilling experiment on a mantle-dominated lithosphere at a slow spreading centre. Dave Smith (BGS UK) gave an introduction to British Geological Survey (BGS) seabed rock drills; Tim Freudenthal (MARUM Germany) presented the MeBo seabed rock drill and the result of recent experiments carried out with this tool; and Chris MacLeod (Cardiff University UK) initiated the follow-up discussion with a presentation of the scientific potential and practical considerations learned from previous seabed rock drilling cruises.

Consensus was rapidly reached that an IODP MSP expedition that employs seabed drills offers an exciting and innovative opportunity to explore the lateral heterogeneities of the shallow subseafloor in slow spread mantle-dominated lithosphere, with the potential to advance significantly our understanding of the closely interdependent tectonic, hydrogeological, geochemical and biological processes that control the development of these systems. Atlantis Massif (Mid-Atlantic Ridge, 30°N) was chosen as a target area because *(i)* the processes by which it exposes mantle peridotites (with associated gabbroic intrusions) on

the seafloor by detachment faulting are now believed to be representative of processes at up to half of all slow-spreading ridges; *(ii)* it hosts a H_2-generating hydrothermal system (Lost City Hydrothermal Field); *(iii)* abundant geophysical and geological data are available at this site, including prior IODP drilling (Expeditions 304-305); and *(iv)* it is shallow enough and the seafloor is locally smooth enough for a seabed drilling programme to be feasible with relatively low operational risk. The latter point is particularly important when considering the use of the presently available robotic seabed drills: MeBo (Bremen), the only drill available today that can core the 30-50m sub-seafloor that we consider optimal, cannot be used in water depths greater than 2000m. Fortunately all targets on the Atlantis Massif are within this depth range.

The third day of the workshop was dedicated to discussions. We focused ondefining more clearly the major questions and rationale that drive interest in scientific ocean drilling at Atlantis Massif, identifying possible drilling targets on Atlantis Massif, and organising writing groups and choosing a coordinator to prepare a future drilling proposal. This we intend to submit to IODP for the 1st April 2009 deadline.

The future Atlantis Massif IODP MSP proposal will focus on the exploration/characterisation of the lateral variations of the geological and hydrogeological heterogeneities in the shallowest parts of Atlantis Massif and the links between abiotic and biotic processes. It is based on the simple premise that mantle lithosphere is a highly reactive chemical and thermal magmatic system, in which hydrothermal processes have a major control on cooling, water-rock chemical interactions and associated mineralogical changes, with important feed-back effects on the rheological and physical properties of the system; and the composition of fluids sampled at ultramafic-hosted hydrothermal vents bears the signature of extensive interaction with mantle and/or mafic rocks (e.g., high H_2 and/or CH_4 and other long-chain hydrocarbons) and favours the development of chemolithoautotrophic microbial communities. Yet little is known about the extent of these hydrogeological systems at slow spreading ridges, the driving forces and localisation of hydrothermal fluids in amagmatic/off-axis systems, their role in the ocean/lithosphere mass balance (and thermal) budgets, and their possible impact on life in these extreme environments (and possible feedback effects).

The scientific objectives to be addressed by IODP MSP drilling are essentially twofold, and investigate:

(1) *Consequences of Serpentinisation Processes on Global Geochemical Cycles and an H_2-based Deep Biosphere.* This part of the proposal integrates Theme 1 of the IODP Initial Science Plan "The Deep Biosphere and the Subseafloor Ocean". Its goal is to investigate (active) hydrothermalism and (palaeo-) hydrogeology in an exhumed mantle-dominated lithosphere in order to better quantify the extent and pathways of low temperature ultramafic-hosted hydrothermal systems, their role in the development of biomass and possible feedbacks on fluid chemistry, and as well as their contribution to global geochemical fluxes (e.g., natural carbonation, cycling of carbon, sulfur and boron).

(2) *Geodynamics, Faults and Fluids.* This part of the proposal addresses issues outlined in Theme 3 "Solid Earth Cycles and Geodynamics" in the IODP Initial Science Plan. It aims at characterising the evolution of asymmetric extension at slow spreading ridges and dating detachment faulting, and at exploring the feedback effects between the focusing of fluids into faulted areas and localisation of deformation in altered areas within the exhumed mantle-dominated lithosphere.

We envisaged drilling a series of ~30-50 m deep boreholes along two profiles: *(i)* an 10 km long E-W section centred on a site as close as possible to the Lost City Hydrothermal Field, and *(ii)* a 5 km long S-N section from the Lost City Hydrothermal Field to IODP Site U1309.

G. Früh-Green has accepted the proposition that she lead the proposal-writing process, aided by a team consisting of a sub-set of workshop participants and several external scientists. The Magellan participants (as well as some scientists that had been contacted but couldn't come) have shown strong interest in contributing to the IODP proposal; however, we are still encouraging a broader community to become involved in the process, especially outside of Europe. In addition, because the proposal is focused in part on links between biotic and abiotic processes, microbiology specialists should represent an important part of the writing group.

Milestones have been set for the writing of the proposal in order to meet the IODP Spring 2009 deadline. The first follow-up meeting will be at the 2008 Fall AGU meeting and will bring together many of the workshop participants. This meeting will allow for discussion of a first draft/outline of the proposal, agree on the preferred locations of drill holes, and finalise the list of proponents. The proponents will meet for the second follow-up meeting in February/March (location to be determined); the outline and writing of the proposal will be carried out during this meeting and through email exchange.

Assessment of the results and impact of the event on the future direction of the field

The major result of the workshop is the consensus that was rapidly reached amongst the workshop participants to: *(i)* submit an IODP proposal aiming at better understanding crustal ageing processes and the role of serpentinisation in deformation, in the generation of volatile-rich fluids, and in supporting biological communities in a heterogeneous lithosphere; *(ii)* write an MSP proposal; and *(iii)* consider that the Atlantis Massif may serve as a natural laboratory for such an interdisciplinary study. We need now to build up a writing group for the future Atlantis Massif IODP MSP proposal that would be more representative of the IODP community. For future success at the proposal-writing stage, we intend to reach a broader community, and will encourage early career scientists to become active proponents.

In recent years it has become increasingly apparent that geochemical and geological processes of mid-ocean ridge systems are intimately linked with microbial activity and biological diversity. With the recognition that olivine-rich gabbros and mantle peridotites are

common constituents of the lithosphere at slow- and ultra-slow spreading ridges, there is a clear need for multidisciplinary studies to better understand crustal ageing processes and the role of serpentinisation of olivine in deformation processes, in the generation of volatile-rich hydrothermal fluids, and in the biological communities that may be supported in ridge environments dominated by a heterogeneous lithosphere. By defining the Atlantis Massif as an important natural laboratory, we can build on previous geophysical, geological, and geochemical studies and focus on outstanding questions to better understand these processes at slow-spreading ridge environments in general. We also foresee that a successful use of seabed rock drilling within a MSP drilling expedition context will serve to stimulate further proposals with ocean crust and deep biosphere objectives.

List of participants (23)

Dr. Muriel Andreani **	Université Lyon 1 (FR)	
Ms Tamara Baumberger *	ETH Zürich (CH)	
Dr. Donna Blackman	Scripps Institution of Oceanography, La Jolla (US)	Speaker
Dr. Chiara Boschi **	IGG-CNR, Pisa (IT)	
Dr. Mathilde Cannat	IPG Paris (FR)	Speaker
Dr. Mike Cheadle	University of Wyoming, Laramie (US)	
Dr. Adélie Delacour **	IPG Paris (FR)	
Ms Marion Drouin *	Université Montpellier 2 (FR)	
Dr. Tim Freudenthal	MARUM Bremen (DE)	Speaker
Dr. Gretchen Früh-Green	ETH Zürich, (CH)	Convenor
Dr. Marguerite Godard	Université Montpellier 2 (FR)	Convenor
Dr. Philippe Gouze	Université Montpellier 2 (FR)	
Dr. Magnus Ivarsson **	Stockholm University (SE)	
Dr. Barbara John	University of Wyoming, Laramie (US)	Speaker
Dr. Yves Lagabrielle	Université Montpellier 2 (FR)	
Dr. Marvin Lilley	University of Washington, Seattle (US)	
Dr. Christopher MacLeod	Cardiff University (UK)	Convenor
Dr. Andrew McCaig	University of Leeds (UK)	
Dr. Antony Morris	University of Plymouth (UK)	
Prof. John Parkes	Cardiff University (UK)	Speaker
Ms Esther Schwarzenbach *	ETH Zürich (CH)	
Prof. Roger Searle	Durham University (UK)	
Mr. Dave Smith	British Geological Survey, Edinburgh (UK)	Speaker

* PhD student

** Early career scientist

Workshop Program

WEDS 10TH SEPT (MORNING):

- Introduction talk: Background/Goals of workshop (Chris MacLeod, Cardiff University UK)
- Keynote talk 1: Tectono-magmatic processes controlling lithological heterogeneities at slow spreading ridges (Mathilde Cannat, IPGP France)
- Keynote talk 2: Fluid-rock interaction and hydrothermal systems: linking abiotic and biotic processes (Gretchen Frueh-Green, ETHZ Switzerland)
- Keynote talk 3: The prokaryotes and their activities in H_2 generating geological settings (John Parkes, Cardiff University UK)

(AFTERNOON):

- Keynote talk 4 & 5: Atlantis Massif & IODP Expeditions 304/305: Recent results. (Barbara John, University of Wyoming USA, & Donna Blackman, Scripps Institution of Oceanography USA)-

POSTER SESSION

THURS 11TH SEPT (MORNING):

- Keynote talk 6: British Geological Survey seabed rock drills (Dave Smith, BGS UK)
- Keynote talk 7: MeBo seabed rock drill (Tim Freudenthal, MARUM Germany)
- Keynote talk 8: Previous scientific seabed rock drill cruises: successes, failures and opportunities (Chris MacLeod, Cardiff University UK)

(AFTERNOON):

- Plenary session: reflection on science questions and options for design of a drilling experiment, with separate thematic sessions as necessary to formulate detailed ideas/testable hypotheses for drilling proposal

FRI 12TH SEPT

- Summary of the previous day talks, discussion/choice of proposed drill sites
- Review plans, then definition of writing groups and start on proposal text