Long-range Exploration of the Ridge Crests

An international workshop - InterRidge's Long-range Exploration Working Group

Workshop Report

National Oceanography Centre, Southampton, UK

28th to 30th June, 2010

Conveners:

Colin Devey, Chris German, Sidney Mello, Lucia Campos, Anton Le Roux, Cindy Van Dover, Gwyn Griffiths, Koichi Nakamura, Hidenori Kumagai, Jiabiao Li, Marcia Maia

Long-range Exploration of the Ridge Crest

Workshop Report

Conveners:

Colin Devey[1], Chris German[2], Sidney Mello[3], Lucia Campos[4], Anton Le Roex[5], Cindy Van Dover[6], Gwyn Griffiths[7], Koichi Nakamura[8], Hidenori Kumagai[9], Jiabiao Li[10], Marcia Maia[11]

[1]IFM-GEOMAR, Germany; [2] WHOI, USA; [3] Univ. Federal Fluminense, Brazil; [4] Univ. Federal do Rio de Janeiro, Brazil; [5] Univ. Capetown, South Africa; [6] Duke University, USA; [7]NOC, Southampton, UK; [8] AIST, Japan; [9] IFREE, JAMSTEC, Japan; [10] 2nd Inst. of Oceanography, China; [11] Univ. Brest, France

National Oceanographic Centre, Southampton, UK, 28-30 June 2010

Contents

Summary

The workshop had three main outcomes:

- **Segment Scale Studies (S3)**

  It quickly became clear that the technology (especially AUV) is now available to consider conducting total coverage studies of the seafloor at the first-order segment scale (length n x 100km). The science drivers for this type of study are very strong across a range of disciplines but the resources it will require are significant, confirming that there is a need for InterRidge involvement, coordinating the resources of more than one nation to conduct the work and meaning that the area to be studied needs to be picked with care. Because this is beyond the scope of the current "Long Range Exploration" working group we recommend to the InterRidge Office and Steering Committee that the possibility of establishing a new working group focussing on this problem and running a workshop specifically to address segment-scale studies (photographic mapping of axial valley and flanks) be investigated.

- **Global Exploration (GE)**: Main science drivers for global exploration are questions of vent biogeography, variations in fluid compositions in different or novel tectonic and geological situations and questions of tectonic evolution and functioning of the spreading axes. Our workshop identified 20 future targets for GE activities and prioritized the first 5 of these. These highest-priority targets have a global distribution and will attract multi-disciplinary scientific interest. It is clear that continuing international coordination will be required to bring the envisaged research to fruition.

- **Technological readiness:** A range of autonomous underwater vehicles is now available at academic institutions around the world - these vehicles will play a key role in many LRE endeavours. Other key equipment is also required, however, including ship-based multibeam mapping, CTD, ROV & HOV capabilities. The most technologically challenging aspect of the work, multi-AUV deployments, is judged to be possible and vehicle reliability, although still an issue, is no longer seen as an insurmountable barrier. We recommend that this technological issue be considered further at a forthcoming international AUV conference in September 2010 "Mapping The World Ocean".

Additionally it was noted that vast areas of the ridge remain unmapped even at ship-based multibeam resolution. InterRidge should therefore make every effort to utilize any opportunity to acquire additional data. One such opportunity is presented by the search for AF447 in the equatorial Atlantic - here side-scan data at <1m resolution and with 100% coverage is being acquired over a ridge-transform intersection at ca. 4°N. The IR Office should contact the authorities concerned to make this data available when possible for scientific research.

Introduction

Approximately thirty ocean scientists and engineers met in Southampton for three days in June 2010 to discuss how to make significant advances in ridge exploration in the near future. One initial driver for this was the recent advances that have been achieved in AUV technology and the extent to which these could enable new modes of ridge-crest exploration. A list of attendees is attached, as is the program. The meeting started with presentations on the state of knowledge in the various scientific and technological fields. This was followed by disciplinary breakout groups (Geology; Biology/Hydrothermal fluids/Oceanography; Geotectonics) to identify the most important science drivers. The definition of "long-range" was unclear - for questions of species genetics, for example, separations of 2-4 km might allow total genetic exchange and mixing while separations of 2500km lead to genetic isolation. Seafloor geology, on the other hand, sees length scales longer than a ROV dive as being essentially "long-range" and as yielding important new insights. The result of this mismatch in definitions led to a primary division in the workshop outcome - the seafloor geologists (with the support of a subset of biologists, hydrothermal fluid scientists and geophysicists) felt that the most compelling science could come from a comprehensive visual survey of a 1st order ridge segment. Another group concentrated on the more long-range exploration on a global scale.

Disciplinary science drivers and goals for LRE

Seafloor Geology

The seafloor geology group concentrated on intermediate and slow spreading areas as these were perceived to be the regions where most exploration was necessary. The most pressing scientific questions for spreading axis geology (petrology, hydrothermal mineralogy) are related to quantification of fluxes. They include:

- What is the eruption frequency on a single segment?
- Is volcanism concentrated at one part of the segment for a long period of time or does it occur essentially at random along the axis?
- What is the dimension of a magmatic plumbing system? Can we define a magmatic province to identify suites of magmas with common magmatic histories?
- How do volcanism and tectonism relate to the hydrothermal activity?
- Just where within the segment is hydrothermal activity (high and low temperature) taking place?
- How much energy is transported to the segment through volcanism and tectonic activity? Can we balance this against the total hydrothermal and conductive output of the segment? If not, how can we account for the discrepancy?

To answer these questions requires a clear understanding of both the geographical and age distribution of volcanic and tectonic activity within a segment, the determination of the size and duration of magmatic provinces and the size of individual eruptions. A pre-requisite for this is a geological map on which location and timing of events is clear. The ultimate goal is to quantify the energy being delivered to the seafloor in the form of hot rock by volcanic and tectonic processes and then to quantify the amount of energy being removed by hydrothermal and conductive release. The only way to achieve this goal would seem to be to visually map a whole segment. This will involve producing a high-resolution bathymetric map and complete photo-mosaicing on both horizontal and vertical surfaces using primarily AUVs. The length of time this takes is critically dependent on the height above the seafloor at which photographs can be taken - for a 200x50km box the amount of time saved by increasing height above seafloor by 1m can be measured in AUV-years! So camera technology is a key enabling feature.

Geotectonics

There are geotectonics science questions relevant to both the Global Exploration (GE) and Single Segment Studies (S3) scale.

At GE scale the questions are:

- What are the interactions between hotspots and mid-ocean ridges, and of these with mantle flow ?
- What is the relation between the nature of spreading centres and the underlying mantle structure and mantle temperature ?
- What controls the regional contrast between contrasting styles of crustal accretion ?
- What are the dynamics of major ridge-transform fault associations ?
- What controls back-arc extension ?
- How important are off-axis volcanism and tectonism to crustal construction ?

At the S3 scale many of the questions relate to the interplay between tectonics and magmatism. They include:

- What are the links between tectonic and magmatic activity within segments ?
- What are the limits on active detachment faulting of magma supply ?
- Is the smooth seafloor crustal style found on ultraslow ridges entirely amagmatic ?
- What controls the contrast in style of crustal accretion between adjacent segments ?
- What stabilises a style of crustal accretion in a given segment for millions of years ?
- What are the relations between transform faults and adjacent segments ?
- What is the nature of the interactions between ridges, volcanic arcs and subduction zones in a back-arc setting?

Physical oceanography

At the global scale, an enduring question is:

- How is the convective heat flux distributed along mid-ocean ridges?
- Specifically, what are the differences in partitioning of vent-fluxes, in terms of both fluid (volume/mass) and heat flux, between focused and diffuse sources along ridges of different spreading-rate?

At the inter-basin scale, an interesting question that may require intercomparison in a range of morphologies (due to different spreading rates, hence in different ocean basins) would be:

- How do differences in the topography and roughness of ridges - and particularly ridge flanks - influence vertical mixing locally? [Most current global circulation models ignore the bathymetry of Mid-Ocean Ridges].

Finally, at the scale of individual ridge segments and vent-sites:

- What is the impact of fine-scale turbulence on regional currents?
- What are the implications for:
  - export of hydrothermal "products" (chemical and biological) into the wider ocean
  - larval recruitment to any given vent-site?

Fluid and mineral geochemistry

- What is the impact of venting on global-scale ocean biogeochemistry?
- How many vents are there and where do they occur?
- Is there a fundamental difference in the partitioning/relative abundance of high temperature venting, rather than diffuse flow, along slow- vs fast-spreading ridges?
- Do the world's largest marine massive sulphide mineral deposits form in association with detachment surfaces?

In the North Atlantic (and in cursory plume studies completed on other slow or ultraslow ridges) we observe:

(i) evidence for one high-temperature source every ~100km along axis
(ii) evidence that 50% of such sites are hosted in association with long lived detachment surfaces (e.g. Rainbow, TAG, Logachev, Ashadze).

If these trends hold along all slow and ultra-slow ridges then much of the chemical flux from venting to the oceans may be released along the slow and ultra-slow ridges of the Arctic, Atlantic and SW Indian Oceans and hence, dominate the first 50% of the trajectory of deepwater circulation along the global thermohaline conveyor.

- Do these ridges also host the largest modern seafloor mineral deposits – both active and inactive?
- If we characterize both active and inactive sites, can we gain new insights into cumulative hydrothermal heat, as well as chemical, fluxes over more geologically relevant timescales?
- What other styles of hydrothermal venting remain to be discovered? Since the discovery of both "Rainbow" and "Lost City" vent-types had not been predicted in advance, what else might remain to be found?
- Does extremely high temperature (beyond critical point of seawater) venting occur at great depths along (e.g.) ultra-slow ridges and in fracture zones?
- Do hybrid "warm seeps" prevail in ridge-subduction intersections?
- What is the nature of hydrothermal activity in "Type 3/smooth terrain" seafloor as documented on the ultra-slow SWIR?
- What kind of cooling is happening on the Reykjanes Ridge?

Biogeography

A key driver for continued vent exploration is:

- to identify new biogeographic provinces and their boundaries with existing provinces, and to understand the processes that generate such patterns, such as connectivity of populations.
- We also need to understand the biogeographic context of assemblages at vents in "non-traditional" hydrothermal settings, such as further "Lost City" type systems, other novel (e.g. "off axis") systems, and possible vent systems in Fracture Zones.
- We also need to understand the potential role of hydrothermal settings in deep fracture zones with large offsets as habitat patches that facilitate linkages among populations on either side of such fracture zones.

Ecology

We need to understand, at the 1st and 2nd order segment scale, the relationships between local biodiversity and regional biodiversity as exhibited at individual vent sites.

- To what extent is the faunal assemblage at an individual site a subset of the regional species pool, and why (e.g. temporal controls)?
- How does this vary in different spreading-rate settings?
- We also need to characterize variations in larval distribution in space and time, and between taxa with contrasting modes of larval development.
- From a conservation science perspective, we need to identify scales of natural conservation units for vent species using genetic tools.
- We also wish to determine the full scope of biological adaptations to extreme conditions at mid-ocean ridge and other hydrothermal environments.

Physiology

Exploring larval physiology has potential as a tool towards understanding larval ecology, distribution and dispersal. We recommend continued exploration of the adaptations of vent species to different hydrothermal settings.

Microbiology

We need continued exploration of the diversity of settings and styles of venting that occur (e.g. "Lost City" type systems, and possible vents in Fracture Zones) and the diversity of energy sources that these provide.

- What are the consequences of different energy sources for the production of organics, and ultimately the structure and diversity of microbial assemblages?

Technological challenges

A review of available technologies and their relevance for global exploration showed that in terms of both vehicles and sensors most of the required hard- and software is available. Several long-range exploration goals can be met with traditional ship-based mapping and sampling - the workshop went on to identify the areas amenable to such an approach (see later). The newest technology is that of AUVs and discussions amongst the AUV experts present led to the conclusion that the technology already exists to achieve many of our proposed scientific goals. In view of the depth range of global ridge axes, combinations of AUVs with maximum depth ratings of between 3000 - 6500m could successfully carry out the surveys required. Both multi-vehicle, single ship and single vehicle, multi-ship operations appear possible. A common navigation base should be obtainable amongst participating national systems with some coordination effort to assure compatibility amongst, for example, LBL hardware and future USBL navigation. For surveys of areas larger than a single LBL region innovative USBL solutions (involving perhaps surface drones) appear interesting. All vehicles appear to have a similar and compatible set of base sensors (multibeam, magnetics, photography, oceanographic sensors) to accomplish the scientific goals.

For the most extreme studies proposed (see below) an extremely long-range AUV such as is currently already in development with the AUTOSUB group at the NOC, Southampton, UK or being investigated by engineers at JAMSTEC, Japan would only enhance our capability to extend explorations beyond our highest priorities to ever more global coverage. While we can continue to hone our methodologies using ship-supported AUVs in all of our highest-priority target areas for the LRE Working Group, it was recognized that the development of next generation long-range AUVs over the next ~5 years would provide an invaluable asset for exploration of ridge-crests in, for example, the remote southern ocean.

Proposed Experiments at GE scale

On the final day, the workshop participants met in plenary to reach a consensus on those areas of the global ridge-crest that should be rated as of highest priority, across multiple disciplines, for future GE exploration. From a list of 20 sites nominated by at least one disciplinary group a list of the top 5 sites was compiled. The matrix is shown below.

Table 1: Matrix of geographic areas of interest to 7 sub-disciplines represented among the workshop participants.

Areas of interest to any sub-discipline were first captured by ticks and each disciplinary group was then asked to assign highest prioritization to 5 key areas (yellow higher, pink lower). Double ticks were used by some disciplines to mark those areas which were also deemed highly interesting although not in that group's "Top 5".

* Deemed to require development of a long-range AUV for suitably detailed investigation in adverse sea-surface environment

	GeoTectonics	**Hydrothermal**	**Phys Oc**	**Biology**	**Geology**	**Astro bio.**	**Off-Áxis Volc.**	**Hits**
Gakkel Ridge			√	√		√		**2**
Knipovich Ridge	(√)	√	√	√				1
Reykjanes Ridge		√		√	(√)			
Chralie Gibbs FZ	√	√	√	√	√	√		1
MAR N.Az				√				
EqAtl Fracture Zones	√	√	√	√		√		**5**
Sth MAR 15-35S	√	√	√	√	√			**3**
Sth MAR 35-55S	√√	√	√	√	√			1
Oblique SWIR (0-10E)		√	√	√				1
SWIR (20-30E)	√	(√)	(√)	√	√			1
SWIR (60E)		√		√				1
Central Indian Ridge	√	√	√	√	√		√	**2**
Carlsberg Ridge		√	√	√				1
Red Sea		√	√	√		√		1
Andaman Sea	√	√		√√				1
SEIR (80-130E)			(√)	√				
AAD*	√	√		√√				2
Macquarie TJ*	√	√	√	√	√	√		1
Sth Marianas Trough	√ (S3)	√						
PacAntRidge (Nth of Polar Front)				√				
Pac-Ant Ridge (Sth of Polar Front)			√	√				
Southern EPR (14S and below)		√		(√)	√		√	1
Bransfield Strait	√ (S3)	√	√	√	√			
East Chile Rise	√ (S3)	√		√	√			**2**

Science Drivers for our Global Exploration priority targets

Two sites in the Atlantic (equatorial fracture zones and southern MAR between 15-35°S), the Central Indian Ridge, the Gakkel Ridge and the East Chile Rise were most consistently ranked highly. Reasons for this ranking were:

Equatorial Fracture Zones: The chances of finding novel settings for hydrothermal venting, the geotectonic information that a study of these fracture zones and their interactions with the spreading segments will yield, the biogeographic interest in animal dispersal (both within the fracture zone and across the Atlantic Equatorial Belt) and the physical oceanography of the fracture zone and its role in ocean mixing are all important drivers here.

Southern MAR 15-35°S: This area occupies a key position in terms of major questions of vent biogeography. Geotectonically, it is a region in which both plume-ridge interaction and relatively deep axial regions are juxtaposed leading to a variety of segmentation styles and presumably the mixing of hot and cold mantle. It is a type area to test the models of the partitioning of hydrothermal sites between volcanic and tectonic settings. In terms of physical oceanography, there is added value from studying the area due to the tie-in to the WOCE data sets. Much of the axis in this region is not mapped to any extent outside the axial valley, so extensive ship-based mapping work would lead to huge advances.

Central Indian Ridge: Although some national programs (notably from Japan, Korea and India) have begun some extensive work in this area, the need for exploration was stressed both by the biology group (the strong mining interest along these ridge sections raised conservation issues) and by the geologists who found the area ideal (both in terms of the splitting of the crust by the propagating SWIR near the triple junction and the reports of lava flows well off axis east of the triple junction) for off-axis studies of MOR processes. It may also provide a natural laboratory, at intermediate spreading rate, at which to test hypotheses arising from recent slow-spreading MAR studies.

Gakkel Ridge: The ice-covered nature of this ridge made it a natural target for astrobiology studies and for physical oceanography. It was also noted that, although extensive evidence for hydrothermal plumes had been found, no vent sites had been found on the seafloor, hence it remains a key target area for vent biogeography as well.

East Chile Rise: Although the large-scale mapping is done, many interesting tectonic questions remain here. The fluid chemistry of vents on a subducting ridge and the biogeography of hot vents near to whale falls, cold seeps etc. is seen as compelling. There is also scope for unusual rock petrology and petrogenesis so close to the subduction zone and incorporation of sedimentary components into hydrothermal fluid circulation pathways.

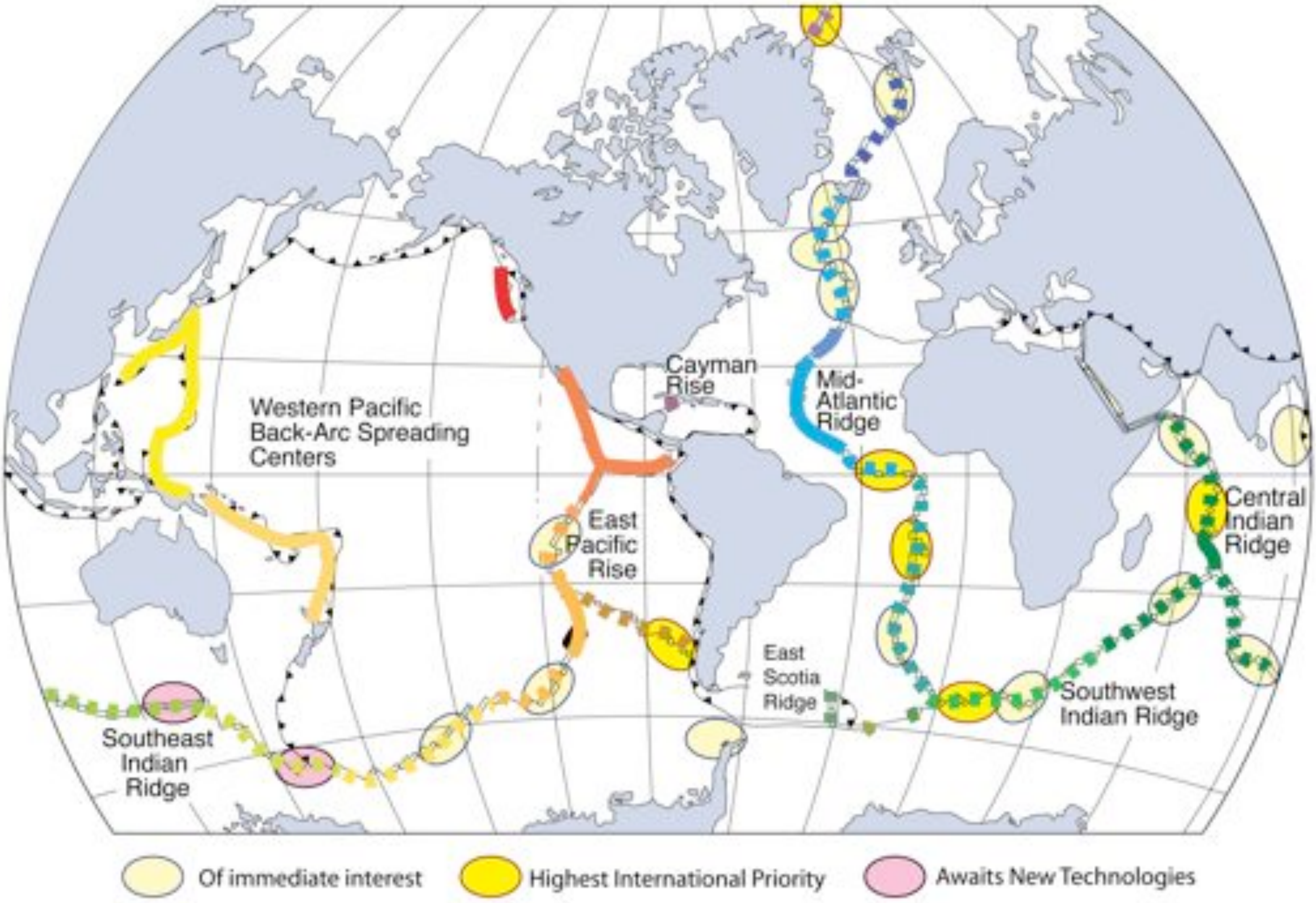

Fig 1. Figure modified from vent biogeography map of Van Dover (2010)

Recommended Global Exploration methodology

The experimental design for GE has been kept generic and can be applied to all priority areas with some modification to account for local conditions. The following components are deemed necessary:

- Ship-based multibeam bathymetric data need to be collected for at least a 50km-wide strip centred on the axis. Magnetic and gravity measurements should be co-registered where possible.
- Hydroacoustic and OBS arrays should be deployed in the area of interest to assess the levels of tectonic and volcanic activity.
- Determination and characterisation of hydrothermal sites along adjacent segments of contrasting geotectonic character. This will need to be repeated in each area, at different spreading rates, around the globe.
- A multi-national multi-cruise approach was discussed as appropriate for each area within such a global study, with initial ship-based multibeam mapping and transponder deployment, prior to investigation by multiple AUVs from different nations working together to survey vent sources. Such surveys could be tackled using existing technologies e.g. by AUVs within existing range limitations, and using largely existing sensors.

Tools required for Global Exploration

The following technological developments should be followed and where possible actively encouraged:

- Use of a new higher resolution satellite gravity system such as the ESA GOCE satellite needs our fullest support. (http://www.esa.int/esaLP/ESAYEK1VMOC_LPgoce_0.html) More detailed information on the gravity field will lead to better predicted bathymetry and so help focus the studies in poorly-mapped regions.
- Look at a more efficient way to map ridge axes (a dedicated research vessel may not always be needed). This could involve using a dedicated mapping vessel or vessels (such as have been developed for UNCLOS work by several nations) to cover the area needed.
- Develop a small, low power gravimeter for deployment on AUVs. To what extent the high-precision INS accelerometers installed on many modern AUV can be integrated into this effort needs to be investigated.
- Geoelectric surveys on the seafloor.
- For the S3 optical surveys the further development of long-range cameras for colour photography in up to 6000m of water is very important and every improvement will make the task of completing a photo-survey of a first-order segment more tractable. Initially, monchromatic laser line scanning may provide a way to image the seafloor at the required resolution and in a shorter time although the lack of colour information will hamper some studies
- For vent *detection* and *location*: CTD, ADCP, LSS, Eh were recognised as critical (and magnetics for inactive systems); a robust and cheap methane

sensor would be highly desirable, both to aid *in situ* exploration for low-temperature "Lost City" type vents and to enable in situ differentiation between ultramafic and mafic-hosted high-temperature systems.

- For *characterizing* vent systems: multibeam, sidescan and still photography were seen as critical, along with possible H sensor, mass spec and laser line scan capabilities.
- For characterizing larval distribution during AUV surveys, a CPR-type system, or flow cytometer, was identified as desirable.

Appendix I: Rationale for our choice of priority geographic areas for GE

All of the 20 areas listed in Table 1 were chosen by at least one disciplinary group as being of strong scientific interest for LRE. To give more information than can be captured in Table 1 here are the notes for each region highlighting its scientific merit:

East Chile Rise: Geotectonics mapping is done but other parameters (magnetics, gravity) remain? Hydrothermal studies would be interesting for fluid chemistry, but physical oceanography is seen as less globally interesting (teleconnections to Atlantic/Southern Ocean via flow through Drake Passage). Biogeography is of interest due to the close proximity to several other chemosynthetic environments – cold seeps, whale falls and oxygen minimum zone. Geology and petrology are also of interest in terms of magma generation and effects of plate bending on magma generation process.

Bransfield Strait: Geotectonics – rifted margin is interesting as it is the beginning of back-arc formation; hydrothermal fluid geochemical interest in the association of cold seep and hydrothermal environments and in the possibility of finding non-conventional sed.-hosted hydrothermal systems; phys oceanography is interesting; biogeography is important as it is an isolated back-arc basin.

Southern EPR: This may be the source of the extensive ^{3}He plume in southern ocean possibly also related to large off-axis lava fields which have been found here; for geology this could be an important area for large-scale off-axis studies due to low sedimentation rates and the presence of off-axis seamounts and lava flows. Biology interested in off-axis seamounts if shown to be hydrothermally active.

Pacific-Antarctic Ridge: Biogeographically and oceanographically important as it straddles the circum-polar front, a possible major barrier to faunal and water mass dispersal. From the tectonics and magmatic geology perspective this area has less pressing features, although the occurrence of evolved lavas on the ridge near the Foundation Hotspot may be interesting for hydrothermal fluid and vent ecology work.

Macquarie Triple Junction: Due to its extreme isolation this area has been poorly studied to date. It would be an ideal target for Long Range (1000+ km) AUV exploration due to limited weather windows and unpredictable sea states. It is certainly of longer-term interest for many disciplines including geotectonics, hydrothermal research and astrobiology.

S. Mariana back-arc: Geotectonics is the main driver for exploration here to understand the interactions between subduction and spreading. Hydrothermal exploration has been largely done by Japanese and Hawaiian research groups.

Australian-Antarctic Discordance: Geotectonics is of interest because of the change from magmatic to tectonically dominated spreading presumably associated with changes in mantle temperature or fertility. Need more extensive mapping, especially to E of AAD, hydrothermal exploration and biology like the deep axis, off-axis volcanism of interest for geol. This area, like Macquarie, may lend itself to future extremely long-range AUV development.

SEIR: A key area for biogeography, the main driver for exploration here. The geotectonic exploration is largely assessed as done at the exploration scale, the exploration drivers from hydrothermal chemistry are not compelling.

Andaman Sea: Geotectonics is interested due to the very oblique spreading, mineral deposits interest is very large as this is a sedimented back-arc spreading system. For physical oceanography and geology the interest is less as the ocean circulation is complicated and the rocks presumably largely inaccessible due to sediment covering.

Red Sea: Physical oceanography might be interested; microbiology has a strong interest as this is an extreme environment.

Carlsberg Ridge: Biogeography provides the main drivers for exploration here, although for hydrothermal research it is a place where event plumes have previously been recorded. For physical oceanography it is also a region with interesting features.

Central Indian Ridge: Has been explored for geotectonics, the hydrothermal circulation might be interesting, biogeography will not drive studies, if mining interest is present then biological studies relevant for conservation could be an issue.

SWIR 60E: This area of smooth seafloor, the only one known globally, has not been investigated in terms of its hydrothermal activity styles and what ecosystems it might support.

SWIR 20-30: Ultraslow area so interesting for geotectonics but not mapped yet. Biogeog is interesting here because of interaction with Circum-polar front. Sampling has been difficult here because of weather.

Oblique SWIR: Interests include petrology (extensive ultramafic outcropping); the potential for hydrothermal circulation to exist in a largely amagmatic section of ridge crest; and the biogeography of any such vents if they can be shown to exist and located.

Southern MAR : both areas host a variety of segmentation and hotspot-ridge interaction. Testing partitioning of hydrothermal sites between volcanic and tectonic settings could be done well here, oceanography is interested also tie-in to WOCE. Biogeography is strong driver, also in terms of straddling polar front. Mapping really needs doing before anything else can proceed.

Equatorial Atlantic: Major fracture zones are the aim of this. Tectonics, hydrothermalism, biogeography are all drivers here, as is physical oceanography. In view of the relative lack of geological FZ studies globally, the geological exploration of the FZ might also be interesting.

MAR N of Azores: Biogeography is the main driver, geotectonics not really interesting, hydrothermal chemistry not a prime driver.

Charlie Gibbs FZ: Leaky FZ for magmatic work? Biogeog would need something both N&S of FZ, is important for oceanography, geotectonics has been started, MPA aspect, search for deep FZ hydrothermal systems.

Reykjanes Ridge: The apparent absence (or our inability to detect) high-temperature hydrothermal systems on shallow ridges with thick crust is a major problem for any attempt to link magma input to hydrothermal output at a magmatic axis. Need to find hydrothermal systems here. Biology would also be interested in these systems as they are apparently anormal.

Knipovitch: Hydrothermal search not yet done totally, geotectonics might be interesting (mapping done, but not much else). Physical oceanography done for climate change. Biogeography would be interesting.

Gakkel: Astrobiology, biogeography, physical oceanography could be useful.

Appendix II: A Working Group proposal for photographic segment-scale study

There are many questions about the energy budgets of spreading systems, about their tectonic and volcanic styles, the nature of the magmatic plumbing system, and the nature and distribution of hydrothermal cooling which will only be answered by a thorough geological mapping of a first-order segment. This mapping would also provide a ground-truthing of the exploration techniques for finding vent systems - just how many vents are there in a segment and how many would we have found with traditional search techniques and protocols? Note that using photographic techniques circumvents all problems of aliasing that may arise with *in situ* vent-sensing - the visualization of vent ecosystems on the seafloor (which exploits a human´s best sensor - the eyes) will serve as a highly sensitive and vent-specific hydrothermal sensor. As an example of the efficacy of this approach, near-bottom (5m altitude) temperature sensing from ABE led to the discovery of the Golden Valley hydrothermal site, 5°S MAR, without down-looking photography working, whereas even this level of temperature measurement coverage did not detect the mussel patches only found through visual observation at the adjacent, and aptly named, "Clueless" vent-site.

This mapping will need to be at least visual, although in sedimented areas additional tools may be needed (e.g. sub-bottom profiling?). The map produced and the photo-mosaic on which it is based will be of interest and use to other communities such as macrobiologists for detailed small scale studies. Completing this map would seem to be only possible with international collaboration.

Questions which could be addressed at a Workshop might be:

- Which "ideal" segment should be studied? Is the amount of previous work important or the heterogeneity of spreading styles visible in multibeam maps the key factor? Operational accessibility (weather, ships, permission to work) may also be important factors.
- Ship or island? Is there an ideal segment close enough to an island to obviate the need for ship-based deployments?
- Deployment scheme? First make a detailed bathymetric map with the AUV and then do photo survey? Which AUVs to deploy, how many and from how many ships?
    - Data accessibility infrastructure? Based on mm-resolution of photos implies a total of 10^{16} pixels of images just on the horizontal surfaces. Including their colour information (total 3 bytes/pixel) means that data volumes of around 3000 Terabytes will be generated.

Appendix III – Workshop Agenda

Day 1 - 28 June 2010

Aim of the day: to establish common scientific and technological "State of the Art"

Series of 30-minute talks (20 min presentation + 10 min discussion)

Morning

9:00-9:05 Introduction & Welcome (Bram Murton, IR Chair)

9:05-9:15 Motivation, Goals (Colin Devey, WG Chair)

9:15-9:45 Geodynamics/Geophysics of Ridge-crests (Joe Cann)

9:45-10:15 Geology and Petrology of Ridge-Crests (Colin Devey)

10:15-11:00 Coffee

11:00-11:30 Hydrothermal Systems of the Global MOR (Chris German)
11:30-12:00 Vent Biology & Biogeography (Cindy Van Dover)

12:00-13:30 Lunch

Afternoon

13:30-14:00 Vehicles for Exploration & Their Capabilities (Gwyn Griffiths)
14:00-14:30 Sensors for Exploration - An Overview (Ko-ichi Nakamura)
14:30-15:00 Vehicle Navigation - Current State of the Art (Steve McPhail/James Kinsey)

15:00-15:30 Tea

15:30-17:00 POSTERS

Day 2 - 29 June 2010

Aim of the day: to converge on key future science drivers and set discipline-based geographical priorities for exploration (likely to be different targets, on a discipline-by-discipline basis but we may be pleasantly surprised)

Morning

09:00 – 12:00 Breakout Session 1 (Discipline by Discipline)

Disciplinary breakout sessions (Geophys., Petrol., Bio., Fluids, Technol.). The groups will be charged with identifying:

- Most pressing scientific questions needing LRE (for technology group - what are technologies which most need developing, where are the challenges)
- Most pressing sensor needs and how to prioritize them in terms of limited payload vehicles
- Looking at both along- and across-axis problems
- Identifying geographical areas which FOR THEIR DISCIPLINE are most relevant.

10:15-10:45 Coffee

12:00-13:30 Lunch

13:30-15:00 Plenary Session 1

Plenary session to report on morning breakout results. The round-up from this session should be to agree on a list of key science questions that IR seeks to address and a list of key geographical areas needing to be studied to address them. This session should also identify key platforms & sensors required and their current state of readiness.

Coffee

15:30-17:00 Breakout Session 2 (Along and across-axis issues)

Breakout transdisciplinary groups looking at along and across axis (these areas will have fundamentally different drivers and challenges which should be identified now). This will lead to…

17:00-18:00 Plenary Session 2

Plenary discussion to begin convergence on geographic priorities, to be debated further overnight!

18:30 Bus departs from NOC for…

19:30 Conference Dinner (courtesy of ChEss program, Census of Marine Life)

Day 3 - 30 June 2010

Aim of this day: to find the cross-disciplinary areas of most interest

09:00-12:00 Plenary Session 3

Start in Plenary and move to break out sessions, as required. Begin with a clear listing of science drivers, key geographical areas, key technologies available and in development. Then begin discussion on:

- Which science missions could cover the most scientific ground in the most interesting regions (i.e. identify scientific and geographical synergies). This should lead to a list of top projects, in different ocean basins around the world, with clear international community support for each.
- The structure within IR needed to ensure that LRE is coordinated internationally (suggestions include establishing WG web pages with information on key areas (maps, details of previous work with links to relevant web pages - input will be solicited at Workshop) and regular email updates via IR email news).

10:15-10:45 Coffee

12:00-12:30 Closing remarks (Colin Devey & Chris German, co-conveners)

12:30-13:30 Lunch

13:30-17:30 Writing of Workshop report (all rapporteurs and Workshop conveners)

15:00-15:30 Tea

This should present a clear plan to enable significant LRE to be achieved within the next five years.

Appendix IV: Participants

Name	Institution	Email
Miho Asada	JAMSTEC, Japan	asadam@jamstec.go.jp
Anne Briais	BGI-OMP, France	anne.briais@dtp.obs-mip.fr
Joe Cann	Univ. Leeds, UK	j.cann@see.leeds.ac.uk
Ana Colaco	Univ. Azores	acolaco@uac.pt
Doug Connelly	NOC, Southampton, UK	dpc@noc.soton.ac.uk
Jon Copley	NOC, Southampton, UK	jtc@noc.soton.ac.uk
Anne Deschamps	Univ. Brest, France	anne.deschamps@univ-brest.fr
Colin Devey	IFM-GEOMAR, Germany	cdevey@ifm-geomar.de
Nicole Dubilier	Max Planck Institute for Marine Microbiology, Germany	ndubilie@mpi-bremen.de
Chris German	WHOI, USA	cgerman@whoi.edu
Gwyn Griffiths	NOC, Southampton, UK	gxg@noc.soton.ac.uk
Jeff Hawkes	NOC, Southampton, UK	j.hawkes@noc.soton.ac.uk
Patrick Hickey	WHOI, USA	jhickey@whoi.edu
Se-Jong Ju	KORDI, Korea	sjju@kordi.re.kr
Hyun Sub Kim	KORDI, Korea	hyskim@kordi.re.kr
Jonguk Kim	KORDI, Korea	jukim@kordi.re.kr
Hide Kumagai	JAMSTEC, Japan	kumagai@jamstec.go.jp
Klas Lackschewitz	IFM-GEOMAR, Germany	klackschewitz@ifm-geomar.de
Marcia Maia	Univ. Brest, France	marcia.maia@univ-brest.fr
Steve McPhail	NOC, Southampton, UK	sdm@noc.soton.ac.uk
Sidney Mello	Univ. Federal Fluminense, Brazil	sidney@igeo.uff.br
Nélia Mestre	NOC, Southampton, UK	ncm1@noc.soton.ac.uk
Bramley Murton	NOC, Southampton, UK	bjm@noc.soton.ac.uk
Ko-ichi Nakamura	AIST, Japan	koichi.nakamura@aist.go.jp
Sang-Joon Pak	KORDI, Korea	electrum@kordi.re.kr
Stephen Roberts	NOC, Southampton, UK	sr1@noc.soton.ac.uk
Cindy Van Dover	Duke University, USA	clv3@duke.edu
Maren Walter	Univ. Bremen, Germany	mwalter@physik.uni-bremen.de
Fujio Yamamoto	JAMSTEC, Japan	yamamotof@jamstec.go.jp