InterRidge – The Next Decade

A science and structure plan for ridge research

2004 – 2013

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Mission Statement

InterRidge was created in 1992 with the express objective of supporting and developing important international programmes which could not have been realized by researchers in individual countries alone. This philosophy remains at the core of InterRidge for the Next Decade (IRND). The first 10 years have produced a united, coordinated international ridge community in many of the industrialised nations and lead to vastly improved contacts amongst ridge researchers in all parts of the world. These developments mean that InterRidge´s primary objectives can now evolve in two directions: (1) the fostering of contacts within the active community with a strong emphasis on integrating scientists from countries not yet fully integrated into InterRidge and (2) placing a stronger emphasis on the achievement of major, long-term scientific goals.

The revised mission statement for InterRidge in the next decade could be put like this:

"InterRidge promotes interdisciplinary, international studies of oceanic spreading centres through scientific exchange among researchers in all countries. InterRidge promotes the sharing of technologies and facilities and it especially encourages the integration of additional countries into the study, use and protection of spreading centres. InterRidge promotes the sharing of knowledge among the public, scientists and governments."

InterRidge – The first ten years

When InterRidge began, ridge research was conducted primarily by national groups working alone or in limited collaborations. The first ten years of InterRidge have seen the transformation of these diverse groups into a strong, coordinated and informed community consisting of over 2700 active researchers from 47 countries. Notable successes of InterRidge and its member researchers in the first decade include:

- **Exploration and study of the South-West Indian Ridge (SWIR):** At the inception of InterRidge the SWIR was almost completely unknown due to its geographical remoteness, nevertheless it was identified as one of the most interesting ridge targets due to its slow and highly oblique spreading. The efforts of the InterRidge SWIR Working Group have led to 16 cruises to this region in the last decade, making the SWIR now one of the best studied slow-spreading ridges of the world.
- **The first mapping and sampling of the Arctic Gakkel Ridge:** One of the few unknown areas of the global ridge system was, until recently, the arctic Gakkel Ridge. Through the activities of its Arctic Ridge working group and the organization of two workshops (1994 and 1998) to formulate a plans for mapping and sampling this ridge, InterRidge provided essential support leading to the first two-ship international cruise to the Gakkel ridge in 2001. The results of this cruise have shown the Gakkel ridge to be spreading in ways never previously recognised on Earth. Amagmatic spreading has been seen along some of the ridge, direct evidence for the theoretically proposed strong melt-focussing at these ultra-slow spreading rates was also found.
- **Workshops on many aspects of ridge science:** InterRidge has convened and coordinated 21 workshops with publication of white papers in 8 countries during the last decade. A total of 1300 attendees from 36 countries shows the international significance of this effort.
- **The generation of an international ridge scientific community:** There are over 2700 ridge researchers registered in the InterRidge directory. The biannual InterRidge News, containing information on Working Group activities, upcoming cruises and reports of cruise results is circulated to over 3000 addresses. The InterRidge web site receives over 10.000 page requests per month from people requiring ridge information. All of these features are clear indicators of the sense of community that InterRidge has fostered in its first decade.
- **Liaison to other international programmes:** Collaborations with other international programs, SCOR, ODP, IAVCEI, have been pursued through the joint coordination of working groups and workshops. Many of the members of these international programmes are also active members of InterRidge.
- **Providing a voice for ridge researchers:** With the advent of deep-sea tourism and resource assessment and extraction at sensitive mid-ocean ridge hydrothermal vent sites, ridge scientists have been challenged to formulate standpoints and principles for wise use of the deep ocean. InterRidge has attempted to provide a central forum for outreach and communication for ridge scientists so that their expertise can guide those involved in the designation of Marine Protected Areas and advise the International Seafloor Authority.
- **The global sampling of the ridges:** Prior to the inception of InterRidge many areas of the world's ridge system were unsampled or only poorly sampled. Concerted efforts by InterRidge scientists using both targeted cruises and cruises of opportunity has greatly improved this situation.

Horizon – The next decade

The sense of community and the maturity of the scientific aims achieved by InterRidge in the first decade mean that the programme is ideally placed to play a leading role in facilitating major advances in ridge science in the future. InterRidge will progress in the future towards more in-depth studies of the ridges, involving actively supporting the development of advanced technologies to aid in the enormous task of studying the ridges both in time and space.

Principal Themes for InterRidge Next Decade (IRND)

Although InterRidge is committed to encouraging the study of all ridges, some areas or aspects of global ridge research are recognised as needing a concerted and coordinated research effort. The following themes (each represented by a working group, the workhorses of InterRidge) will therefore constitute the core of the IRND efforts:

1. Ultraslow-spreading Ridges
2. Ridge-Hotspot interaction
3. Back-arc Spreading Systems/ Back-arc Basins
4. Mid-oceanic ridge Ecosystems
5. Monitoring and Observatories
6. Deep Earth Sampling
7. Global Exploration

The scientific questions which InterRidge Next Decade intends to focus efforts upon and the way InterRidge will participate in solving these questions are outlined below.

1. Ultraslow Ridges

The Southwest Indian Ridge (SWIR) and Arctic Ridges working groups have been some of the most successful programs in InterRidge thus far. The members of these groups have reached a general consensus that the two share a common objective - Ultraslow spreading - that should be given a common focus in the future. Therefore we recommend the establishment of a new working group based on the scientific theme of ultraslow spreading (1/2 rate < 1cm/yr) that will combine both of these previously geographically based groups. Themes which this Working Group should work on in the next decade include:

1.1 Lithosphere/Asthenosphere interaction

The primary characteristic that differentiates ultraslow ridges from others is the thermal/rheological structure, characterized by a significantly thicker lithosphere. Determining the topology of the lithosphere is an important part of the characterization of such ridges that needs to be accomplished. This influences magma plumbing systems and melt focusing in a significant way, and has a strong influence on the dynamics of extreme lithospheric extension and ridge/hotspot interaction. Approaching this question requires extensive new geophysical investigations.

1.2 Magma genesis and mantle composition

The ultraslow spreading ridges are unique among the major ocean ridges in the abundance of the mantle rocks exposed along their length. This, along with the very low magma budgets, indicate that this is a unique place to look for primary mantle heterogeneity. Initial work at the SWIR and Gakkel ridges suggests that these exist. Ultraslow spreading ridges provide the opportunity to examine the effects of mantle source composition on basalts more directly than at other ridges, due to the small size of magma batches. This requires a much closer sample spacing than is typically required on faster ridges in order to understand both the distribution of magmatism and its origin. Episodic magmatism at ultraslow spreading ridges results in the emplacement of the mantle magmatic plumbing system of the ridge to the sea floor where it can be directly examined. This is thus a critical region for the study of mantle magmatic transport, including focussing mechanisms.

1.3 Hydrosphere/Lithosphere interaction

The abundance of ultramafic rocks close to the seafloor on ultraslow spreading ridges, combined with extraordinarily long-lived faults, provides a unique hydrothermal environment. The exploration of the Gakkel and the SW Indian Ridges during the first InterRidge decade have provided evidence of extensive hydrothermal activity over a broad range of temperature and substrate types.

While the heat source for magmatically robust spreading centres is known to be a magma chamber or crystal mush zone, the heat source at ultra slow ridges is presently unclear. Due to the extreme reactivity of ultramafic rocks exposed on the sea floor, the heat released by serpentinization (approximately 300 KJ/Kg) may play a significant role.

This type of hydrothermal activity may thus play a more important role in the overall geochemical budget of the oceans than the known outcrop of peridotite on the ocean floor might suggest. It is important that a mass balance approach to examining the chemical fluxes at ultraslow ridges is developed, since ultramafic and mixed mafic/ultramafic hydrothermal systems are more common than black smoker systems in this environment. It is necessary to study fluids, hydrothermal deposits, and their recharge zones in the ultraslow spreading environment to accomplish this.

1.4 Biogenesis

The interaction of ultramafic minerals and water provides a unique substrate for life in ultramafic–hosted hydrothermal systems. Serpentinization results in the production of large amounts of abiogenic CH_4 and H_2 that can be used as energy sources by chemoautotrophic microorganisms. Recent work has also shown that specific products of seawater/peridotite interaction (*e.g.*, Fe-Ni alloys) may catalyse the reaction between H_2 and CO_2 to form a variety of abiogenic hydrocarbons. It is a therefore possible that ultramafic-hosted hydrothermal systems play an important role in microbial ecology and the carbon cycling in the deep sea.

1.5 Biogeography

Both ultraslow ridges which have been studied up to present lie in key biogeographic areas. The biogeography of the SWIR is unique in that it acts as a link between the distinct faunal provinces in the Atlantic and Pacific oceans. The Arctic basin is even more intriguing, as it has been relatively cut off from the remainder of the world hydrothermal systems throughout geologic time, and may provide a unique set of macro and microfaunal assemblages.

1.6 Implementation

Icebreaking resources – Healy, Polarstern
Drilling: Aurora Borealis

1.7 Links to other programs

Integrated Ocean Drilling Project (IODP)

2. Ridge-Hotspot Interaction

The structural, geophysical, petrological and geochemical characteristics of mid-ocean ridges are drastically affected by the presence of a hotspot in the vicinity, such as in the case of Iceland, Azores, Reunion, Galapagos and more than a dozen other near-ridge hotspots. A large part of the global mid-ocean ridge system is or has been affected by the interaction of a ridge with a hotspot, and most of the islands located near mid ocean ridges result from such an interaction. Among the scientific questions raised by ridge-hotspot interaction are (1) the mantle dynamics associated with the interaction, (2) the structure of crustal features resulting from the interaction, and (3) the thermal, hydrothermal and magmatic consequences of the interaction.

2.1 Mantle dynamics of ridge-hotspot interaction

Many seamount alignments and elongated highs related to ridge-hotspot interaction display marked geochemical trends between isotopic and trace element characters of the hotspot and the nearby spreading centre. Such topographic features and geochemical trends are believed to reflect the flow of contaminated mantle away from the hotspot and its mixing with "normal" oceanic lithosphere material, although it may also result from the initial contamination of a large area of sub-lithospheric mantle by the wide plume head and the subsequent sampling of this mantle to build volcanic features on weakness zones. A direct flow connection between a mantle plume and a spreading centre separated by several hundred kilometres has never been observed, although seismological and electromagnetic techniques have proven adequate to address such a question (for instance during the MELT experiment on the EPR). Imaging the mantle beneath areas of ridge-hotspot interaction is therefore an important challenge, which can only be achieved through international collaboration.

Conversely, individual efforts should be encouraged to describe different zones of interaction in terms of scale, morphology, geochemistry as it is clear that parameters such as the distance separating the ridge and the hotspot, the "strength" of the hotspot (whatever parameter is used to define this "strength"), the type of spreading centre and its geometry including the presence of large offsets, the relative motion of the ridge and the hotspot, among others, affect the area influenced by the interaction.

The interaction of a ridge with a hotspot should be seen in the context of its evolution, with a ridge approaching a hotspot, remaining over this hotspot for some time, and finally drifting away. The different stages of this evolution should be described and understood. Moreover, it has been suggested that ridges tend to be "attracted" by the hotspots and remain over these hotspots, mostly through asymmetric spreading. The mechanisms of such interaction are still poorly understood.

2.2 Crustal structure

Various types of crustal features are associated with ridge-hotspot interaction, including seamount alignments, linear volcanic ridges, and volcanic plateaus. They likely correspond to various stages of the interaction, with seamounts and volcanic ridges being associated with hotspots relatively distant from the ridges whereas a plateau is created when a ridge is located over a hotspot. Again, the variability of such features should be addressed for different cases of interaction (*e.g*. "close" versus "distant" hotspot, "strong" versus "weak" hotspot, ridge approaching versus moving away from the hotspot), hence providing constraints to thermal models of the interaction.

The origin of linear volcanic ridges observed in the case of distant ridge-hotspot interactions should also be investigated. Because these features may represent tension-crack analogs, particular attention should be given to the stress budget in the zone of interaction, through detailed morphological analysis and the determination of focal mechanism of microseisms in the interaction zone.

The depth, size and persistence of the magma lens at the ridge axis is strongly influenced by the presence of hotspots, as is the petrologic stratigraphy of the crust. The factors controlling these influences are still only poorly understood.

2.3 Thermal and magmatic consequences

Beyond the intrinsic interest of ridge-hotspot interaction, the perturbation induced by the presence of the hotspot to a mid-ocean ridge may also represent a way to test our understanding of how ridges work. Ridge segmentation, thermal structure and melting systematic are clearly affected by a nearby hotspot. Its effects should be described and modelled using the present paradigm on mid-ocean ridges. Questions such as the restriction (or not) of silicic lavas to ridge hotspot interactions may be resolved in this way.

The consequences of ridge-hotspot interaction on the hydrothermal activity should also be evaluated. Are the hydrothermal products in regions of ridge-hotspot interaction geochemically or mineralogically different from those on "normal" mid ocean ridges (*e.g*., due to different thermal regimes, host rocks, magmatic fluids, and/or longevity of the hydrothermal activity)? Is the 3D structure of hydrothermal systems in an area of ridge-hotspot interaction different from "normal" ridges, and is there a relationship with the peculiar structures observed at such zones of interaction? How is the permeability of the crust affected as a result of ridge-hotspot interaction? Because the best known hydrothermal sites on slow spreading centres are located in the interaction area of the Mid-Atlantic Ridge and the Azores hotspot, such questions have to be addressed.

2.4 Implementation

Researchers in several counties are actively working on the problems of ridge-hotspot interaction. In the coming years, the InterRidge working group on Ridge-Hotspot Interaction can play an active role in promoting unique experiments that can address some key questions about plume-ridge interactions but that can not be done alone by single nations. Examples include, but are not limited to, (1) large-scale seismic/EM experiments to image the crustal and mantle structure in the interaction zones between plumes and ridges; and (2) establishment of one or two ridge-hotspot systems as integrated study sites, where enhanced research activities (including long-term seafloor observatories) can be conducted by multiple nations. It is recommended that the Ridge-Hotspot Interaction working group continues to play an active role in promoting timely exchange of the latest data/cruise results through organizing special sessions at international meetings (*e.g*., AGU, EGU) and to consider organizing more focused InterRidge symposiums on plume-ridge interactions.

2.5 Links

The research activities of plume-ridge interactions are strongly linked to other programs, especially the following programs:

- ODP/IODP
- International Association of Volcanology and Chemistry of the Earth´s Interior (IAVCEI)
- IAVCEI Large Igneous Provinces (LIPS) group
- Monitoring the Mid Atlantic Ridge (MoMAR)
- Mantle Dynamics (NSF)

3. Back-arc Spreading systems

Back-arc basins (BABs) contain divergent plate boundaries situated behind subduction systems. Many important geological aspects of normal spreading axes can be found in BABs as well, including seafloor spreading, hydrothermal activity, associated vent fauna communities. However, BABs differ from mid-ocean ridges in several aspects. Due to their location close to convergent plate boundaries, they represent a non-steady state system which undergoes complex change over a relatively short period of time. They are influenced by the kinetics of a subducting slab and melting processes which generate arc magma. Their geometry is strongly affected by the interplay among plate tectonic forces and as a result complexity and spatial heterogeneity are common features of BAB. Continental run off and sedimentation strongly affect the mass accumulation in the basin. BABs are an integral part of the arc-backarc systems. The following fields will be the focus of InterRidge studies in the next decade:

3.1 Complexity of tectonics

BABs exhibit wide range of tectonic features as they evolve in time from initial rifting to seafloor spreading and eventually cessation of spreading. Because BABs lie at the convergent boundary between major plates, they are affected by even small changes in plate motions and frictional forces. The interplay between magmatism and tectonism is an important factor in BABs. The evolution of a back arc basin is closely linked to the subducting process. In-depth investigations of different evolutionary stages and combining results from various BABs studies are necessary in order to identify the parameters controlling the generation and evolution of BABs. Many BABs are thought to have initiated when there was a major change in plate motion – the tectonics of such situations are however so complex that very little is understood about how this might work. Because BABs change significantly over a short period of time, there is a strong chance that important new discoveries will be made by studying not only close to the spreading centres but also off-axis. Specific questions related to BAB tectonics which InterRidge should attempt to foster in the next decade are:

- What are the interactions between magmatism and tectonism in BABs ?
- How do geological parameters contribute to rapid temporal changes in BABs ?
- Are the initiation of subduction and BAB formation caused by changes in major plate motion ?
- What factor controls the oblique spreading and the segmentation of BABs ?

3.2 Diversity of magmatism

The endogenetic processes taking place in BABs derive their energy from upwelling magma which themselves provide heat for hydrothermal circulation and water-rock interactions. Since BABs lie close to convergent margins, they are inevitably influenced by arc volcanism and melting of the subducting slab. Their range of volcanic products is much more diverse than at mid-ocean ridges; for example bi-modal volcanism is commonly observed in BABs. Volatile content and fluid from the subducting slab also increase the complexity of chemical compositions of the rocks. Degassing processes from the crystallizing magma at relatively shallow depth is thought to have strong influence on the volatile budget of circulating hydrothermal fluids. Another point is that felsic melts are generally richer in fluids than mafic melts. The following questions appear most crucial for InterRidge attention:

- How can the development of bi-modal volcanism in BABs be explained?
- How can we define the deep mantle influence and sedimentary input on the composition of volcanic rocks in BABs ?

3.3 Mineralization and role of fluids

Hydrothermal fluids generated in BABs display a great variety in metal composition, volatile content, and salinity, because of their interaction with very different types of rocks (felsic, mafic, and sedimentary rocks). In particular, the higher volatile content due to magmatic degassing controls fluid chemistry. Because of the shallower depth range of fluid discharge, the fluids are often subject to phase separation, which will have a strong influence on fractionation processes and mineral precipitation. Due to this complexity, the related mineral deposits show a great variety in metal composition, including remarkable gold and silver enrichment. Since many on-land volcanogenic massive sulphide deposits are thought to have been formed by submarine hydrothermal activity in BABs, the investigation of modern hydrothermal systems offers an opportunity to understand the formation processes of these metal-rich deposits ranging from massive sulphides to epithermal occurrences. Due to the multi-stage evolution of these mineral deposits, re-equilibration and replacement processes are very common. Thus, the mineral assemblages in BABs are ideal targets to study these dynamics in terms of energy and material fluxes. The assemblage and compositions of minerals in hydrothermal deposits reflect basic aspects of the physical and chemical conditions at the time of formation, and can be used to comprehend these conditions, therefore these types of studies are an important field where progress can be achieved. Other questions for the next decade are:

- How do different source rocks, including sediments, affect the composition and volatile budget of BAB hydrothermal fluids ?
- How do different water depths affect the degassing process ?
- How does subcritical and supercritical phase separation control fractionation of the volatiles and metals in fluids and mineralization ?
- What are the compositional consequences of re-equilibration and replacement processes on the mineralizations ?
- Do we understand how sulphide mineral deposits produced in BAB systems end up on land ?

3.4 Biogeography

BABs are disconnected from major mid-ocean ridge systems, therefore it is possible that the local eco-system have evolved differently. There is a large gap in our understanding of the global distribution of hydrothermal vent communities, especially along back-arc spreading systems. One important aspect is that BABs eco-systems often develop in a boundary situation between the deep-sea and the continental controlled environment. The influence of environmental factors on eco-system changes is not well understood at present at BAB sites. The following are some of the important questions:

- How do eco-systems in BABs relate to global bio-distribution ?
- How well do we understand endemisms in BAB eco-systems ?

3.5 Implementation

InterRidge has to intensify its work to promote interactions among members of the Backarc Basin Working Group. Investigations of BABs often require building of long-term relationship with coastal states, helping them to increase their research capacity and with the dissemination of knowledge to the public.

One activity which InterRidge should become involved in the next decade to further these goals is to organise BAB workshops in such countries to increase awareness of the scientific and societal problems associated with the back-arc spreading systems and to help local scientists participate more fully in InterRidge work. A start to this will be made with an InterRidge Theoretical Institute in Korea in mid-2004.

3.6 Links

The BAB Working Group has strong links and common interests with the following international programs:

- MARGINS
- IODP
- SOuth Pacific Applied geosciences Commission (SOPAC)

4. Mid-ocean ridge ecosystems

In the last decade the exploration of mid oceanic ridges (MOR) has revealed new hydrothermal ecosystems with highly specialized and endemic micro- and macrofauna. The functioning of these chemo-autotrophic based ecosystems is not yet fully understood and further, more detailed, investigations are required which should also focus on the interactions of vent systems with the surrounding, photosynthetic ridge ecosystems. Vent fields represent a minor fraction of the ridge area and the influence of the chemosynthetic production on the overall biological production along the ridges is unclear but probably small. There has been relatively little focus on the productivity and biodiversity of the ridge fauna not associated with vents.

In terms of scientific research, the main tasks should continue to be the acquisition of basic knowledge on structure and function of the diverse mid oceanic ridge ecosystems and a more detailed investigation of the living communities that are characteristic of both vent and non-vent sites. There is however also an urgent need to improve the techniques for monitoring and sampling the living communities. Specific research themes may be the following:

4.1. Patterns and processes of the ecosystems of mid-oceanic ridges

IR should endorse the development of interdisciplinary research programmes which will focus on the least well-known areas and habitats of the ridges. The overriding aim would be to describe and understand the patterns of distribution, abundance and trophic relationships of the organisms inhabiting these areas, and furthermore identify and model the ecological processes that cause variability in these patterns. Studies should consider all trophic levels including the role of endo- and exo-symbionts, aspects of parasitism and, in particular the biogeography of keystone micro- and macro-organisms. A further task should be to measure productivity in chemosynthetic and photosynthetic driven ecosystems for creating essential input to models that provide estimates of expected productivity.

4.2 Population structure of organisms associated with ridges

The ridges may have isolated populations of some species, but very probably the rule is that dispersion rates are significant and advection essential for sustaining populations. Many ridge species have immense areas of distribution, but dispersion patterns are virtually unknown. The information on population identity and the extent of migrations and exchange of early life stages between assumed population units is often lacking or insufficient. Knowledge on population discrimination is essential for both assessing and describing the biogeography of selected species, and studies using novel methods covering a wide range from molecular techniques (DNA sensors) to tagging methods and studies on the dispersion of early life history stages should be encouraged by the IR community. Further studies should address systematic work on dominating species to develop morphological descriptions. These should be used to produce and update illustrative keys of the ridge micro- and macrofauna.

4.3 Validation and calibration of age determination methods for keystone species

It is often assumed that many deep oceanic species as they occur at the ridges grow slowly, have long life-spans, high ages at maturation, low fecundity and limited mobility. Major efforts should be made to test these assumptions through new investigation of growth and life history traits and systematic comparison of the diversity of these traits with related taxa from different habitats (the better known fauna of the continental slope). To study life history processes of the ridge fauna, age estimations of dominating taxa are essential. Deep-water species have been aged using skeletal structures such as otoliths in which growth increments similar to annuli in shelf species have been found. Information on age of ridge fauna taxa such as crustaceans and molluscs is not available. Hence, it will be a major challenge to develop and apply techniques to age invertebrate organisms of the ridge fauna in order to obtain information on their growth patterns and how that is related to physiological characteristics.

4.4 Investigations on sub-surface communities

Scientific studies should focus also on biologically mediated processes below the seafloor, where oxygen is not available. Other characteristic features are sharp pH, temperature, and chemical gradients. Organisms living in such an environment had to develop adaptation strategies including a specialized metabolism. Therefore, a high diversity of various micro-organisms of metabolically different pathways can be expected. Many specialized anaerobic micro-organisms will use reduced components for growth and substantially modify the composition of the hydrothermal fluid. A fundamental understanding of the composition and function of these microbial communities is required and will contribute to the understanding of the whole hydrothermal system.

4.5 Scientific experiments on conservation aspects

IR has put considerable emphasis on management and conservation aspects of mid oceanic ridge systems (see Report of the IR Workshop on Management and Conservation of Hydrothermal Vent Ecosystems, Sidney, Canada, 28 – 30 September 2000). The protection of marine areas has become a major concern in environmental issues.

Scientific investigations of the fate of debris left on the seafloor could be a major contribution to determine which environmental effects are caused by equipment lost during scientific field work at ridge ecosystems. Long term imaging of batteries, mooring and/or submersible weights left on the seafloor could be a valuable contribution to investigate environmental impact of these objects in areas with repeated submersible/ROV visits.

4.6 Implementation

Studies of deep-water macrofauna and their distribution have mainly relied on capture-based assessments of numbers or biomass. Most gears are selective, and their behaviour on the bottom at great depths is often unclear. Alternative strategies both for observation and quantification should be explored and developed. Furthermore, aquaria with the ability to simulate real habitat pressure should be developed for physiological and life cycle investigations in the laboratory. Hydroacoustics and optics, as well as manned and unmanned vehicles etc. should be further developed to gain more direct observations of deep-water organisms and communities.

Studies should be systems-orientated. This will require close cooperation between biologists spanning a range of fields, geologist, physical oceanographers, and technologists. A pre-requisite for all planned investigations will be a detailed knowledge of the abiotic factors of the surrounding environment. IR should provide a platform for data, image and specimen exchange which have been collected at ridge ecosystems.

4.7 Links

- MAR-ECO (see *www.mar-eco.no*)
- Census of Marine Life (CoML) and its component Chemosynthetic Ecosystems (ChEss)
- DFG-Schwerpunktprogramm1144: “From the mantle to the ocean: Material, energy and life cycles on spreading axes”

5. Monitoring and Observatories

Understanding the dynamic processes of ridge systems and the complex interaction of the various components of these systems requires sustained time-series observations using a multidisciplinary suite of tools. The development of a seafloor observatory at a designated mid-ocean ridge site where infrastructure can support the installation, maintenance, and data telemetry for a broad spectrum of seafloor instruments led to the concept of MoMAR, or Monitoring of the Mid-Atlantic Ridge. At the first planning workshop held in Lisbon, Portugal in 1998, an initial science plan was created and a site selected at Lucky Strike, about 150 km south of the Azores on the Mid-Atlantic Ridge. The site is relatively well studied and is located within range of Azores-based vessels making response to seafloor events possible. A few studies have already begun at the site, including the development of long-range acoustic monitoring of the site. A second planning workshop was held in Horta, Faiel in June 2002. The following are the major scientific questions for which InterRidge intends to have made major advances in answering in the next decade:

5.1 What are the interdependencies between the various components of the geological, chemical and biological systems of an active hydrothermal site?

How do changes in the magmatic and crustal properties affect the hydrothermal circulation and composition? How do these changes in the hydrothermal system affect the associated biological systems? How does the biological system affect the hydrothermal circulation and chemistry?

5.2 What is the evolution and temporal variability of a seafloor hydrothermal system?

How does the hydrothermal system respond to environmental forcing? What is the immediate impact and recovery response of hydrothermal ecosystems to magmatic or seismic disturbance? What is the susceptibility and response of the system to cyclical environmental forcing (*e.g*. tides)? In the absence of forcing by seismic or changes in magmatic activity, how do the hydrothermal, chemical and biological systems evolve toward a steady-state ecosystem?

5.3 How do ridge crest hydrothermal systems impact the environment of the ridge?

How do the conditions change as one moves from close proximity to an active hydrothermal system into a non-hydrothermal ridge crest environment? What are the spatial gradients in chemistry, mineralogy, biology, etc.?

5.4 How are the heat and mass originating from hydrothermal discharge dispersed into the ocean?

What are the interrelationships among ocean currents, dispersal, productivity, and mass/thermal flux? How does this dispersal behave at various time/space scales, under different background environmental conditions (*e.g*. tidal states, surface productivity), and in response to changes in the originating hydrothermal system?

5.5 How can a deep-sea observatory be best used to conduct controlled experiments outside of the laboratory?

How are mineral compositions affected by multiple hydrothermal overprinting? How is barren substrate colonized by vent organisms?

5.6 Implementation

Understanding the complex interaction of geological, hydrothermal and biological components of the ridge crest ecosystem requires the measurement of a wide range of environmental parameters, collected simultaneously at a common location. Determination of spatial gradients in chemical and physical parameters are particularly critical for understanding geochemical reactions and biological systems. The sustained measurement of geophysical, hydrothermal, chemical, and biological parameters in the deep ocean requires the development of new technologies. In some cases, instruments already exist or can be deployed with only minor modification; in other cases, entirely new technologies or extensive modification of existing technologies is required. For example, there is a critical need for new chemical sensors; both existing and new sensors must be capable of long-term deployment on the seafloor. The following is a non-exclusive list of variables that it would be desirable to measure:

<u>Environment:</u>
- Temperature
- Pressure
- pH
- Eh
- Turbidity
- Currents
- Geodesy
- Seismicity
- Magnetics
- Gravity
- Particles/precipitates/Particle size distribution
- Heat and mass flux (plume integration and flow measurements)
- Acoustic plume imaging
- High-resolution imaging
- Seafloor Video

<u>Chemistry:</u>
- Gas (H_2S, CH_4, H_2, total CO_2, CO, NH_3, $^4He/^3He$)
- Salinity/chlorinity
- *In situ* mineral alteration
- Stable isotopes
- Dissolved constituents (Mn, Fe, Zn, Cu, REE, Pb, S, Mg, Ca, Si, Po4, NO3/NO2)

<u>Sampling:</u>
- Biological sampling
  - Mark/resample
  - Collection (net sampling, slurp gun, etc.)
  - Video imaging
  - Microbiological sampling
  - Substrate experiments
- Sediment cores

Routine access to the seafloor is also critical, whether from a surface ship or deep submergence assets. Telemetry can produce massive volumes of data and the management and dissemination of this information presents an additional technical challenge. Real-time data telemetry is of value when a rapid response to events at the monitoring site is required. The location of the MOMAR site near the Azores offers the potential to respond to events on the seafloor. Potential technologies for real-time telemetry include deep- sea cables, large scale buoys, small scale buoys, or pop-up messenger buoys (either routine or triggered). These real-time technologies can be quite expensive and will only be undertaken after a more complete understanding of the MoMAR site is obtained and a commitment to event response is made. Also, due to the real-time, interdisciplinary nature of the monitoring effort, data must be readily available to all investigators. In many cases, the data will need to be extensively processed before being of use to other investigators. Resources and technologies must be provided to individual investigators to make this data management model a reality. Finally, the success of any complex monitoring/observatory effort depends on the creation of an effective coordination system. This Monitoring and Observatories working group will provide the coordination necessary during the next decade to ensure the success of the MoMAR project.

5.7 Links

There are several seafloor monitoring projects being formulated around the globe from various organizations. InterRidge/MoMAR is the only seafloor observatory targeted to the slow spreading Mid-Atlantic Ridge. The following initiatives are also involved in similar projects:

- RIDGE2000 (Integrated study sites)
- Achaean Park
- ODP/IODP
- International Ocean Network (ION)
- CoML component project "Patterns and Processes of ecosystems in the northern Mid-Atlantic" (MAR-ECO)
- NE Pacific Time-series Undersea Network (NEPTUNE), Victoria Experimental Network Under the Sea (VENUS), Monterey Accelerated Research System) MARS
- Hawaii Undersea Geo-Observatory (HUGO)
- New Millenium Observatory (NeMO)
- Hawaii-2 Observatory (H2O)
- Long-term Ecosystem Observatory (LEO15)
- Ocean Observation Initiative (OOI)

6. Deep Earth Sampling

InterRidge should seek to promote interdisciplinary investigations of the 4-D architecture of the ancient and modern ocean crust and shallow mantle at all scales, and explore the extent and diversity of the sub surface biosphere of the oceanic lithosphere. This would be best achieved by the formation of an InterRidge Working Group with a focus on promoting the development and use of different drilling platforms ranging from over-the-side rock drills to riser drilling, and land-based platforms. It would be instrumental in formulating a new international drilling project that will seek to achieve total penetrations of *in situ* ocean crust in the Atlantic and Pacific within 20 years, and partial sections of crust and mantle in different tectonic settings. Drilling of active hydrothermal systems and young ocean crust and mantle at the ridge axis and in tectonic windows would be a high priority for the working group. These holes should also be used as laboratories in themselves allowing, for example, experiments with, and long term monitoring of, hydrologic systems within the crust. Recognising the value of ophiolite studies to understand the ocean lithosphere, the working group should promote on-land drilling to acquire long sections of the ocean crust and shallow mantle in well understood ophiolite complexes thought to represent key end-members for mid-ocean and arc environments. The following points give more details on possible activities for the next decade:

6.1 Drilling of Active Hydrothermal Systems

Sea floor hydrothermal systems provide modern analogues to on-land ore deposits and may constitute an important economic resource in their own right. They occur in a wide range of lithologies and tectonic settings that require careful evaluation before the impact of their exploitation can be assessed. The hydrothermal systems also harbour a diversity of key ecologies both where they vent on the seafloor and in the sub-surface. Study of these hydrothermal systems in their entirety is critical to understanding the elemental fluxes from the Earth's crust and mantle to the oceans. Drilling these complexes is required in order to understand how they develop in three dimensions as well as their temporal evolution.

Following the successful TAG model, InterRidge can promote interdisciplinary projects within IODP to drill active hydrothermal systems in various oceanic settings, including both ultramafic and basalt hosted systems. Drilling should include zones of focused and diffuse upwellings, and different temperatures of flow. The group can also encourage the development of new drilling technologies including over –the-side rock drills and diamond coring.

6.2 Zero-age Ocean Crust and Axial Mantle

Evaluation of the physical properties of young ocean crust is a required starting point for understanding the evolution of this crust through time. Drill holes in young ocean crust are also required for instrumentation of sea floor observatories for long term monitoring of seismicity, fluid fluxes, bottom currents and hydrothermal vents. In the case of ultramafic exposures at the axis, drilling is the only method of obtaining much critical information. For example, locating the source of heat driving ultramafic-hosted hydrothermal deposits requires drilling to measure heat flow. Drilling is also necessary to obtain samples of fresh peridotite suitable for many geochemical studies at zero-age. Even in the case of low recovery from drill holes in young crust (both basaltic and ultramafic), geophysical logging of these holes can yield extremely valuable information about the properties of new crust, and can be used for active experiments to measure permeability and fluid flow.

6.3 The Deep Biosphere

The discovery of the deep biosphere has changed our perception both of the distribution of biomass on Earth and of the interaction between the biosphere and the geosphere.

Living organisms have been identified to several hundred meters depth in the upper crust. The spatial distribution of the deep biosphere is still unknown, and its relation to thermal gradient, crustal age and lithology is unconstrained. The importance of biodissolution and biomineralisation in low-temperature alteration needs to be further explored. The microbial interactions with ultramafic rocks and its possible relation with the formation of methane need to be investigated. The subsurface biomass needs also to be considered as a potentially important carbon sink.

As a microbial habitat, the oceanic lithosphere spans the entire temperature and pressure range that can accommodate living organisms and harbours various chemical gradients. This environment can thus be expected to select for a variety of organisms including extremely thermophilic, psycrophilic and barophilic organisms (extremophiles). This provides for a large microbial diversity, but the microbes involved are presently largely unknown. These highly important and novel questions can only be addressed by drilling, and InterRidge can provide the expertise to select suitable sites and design experiments.

6.4 Drilling in Ophiolites

Continuous core and logs have proved invaluable in understanding the stratigraphy and evolution of the ocean crust and provide unique information not obtainable by surficial studies even on land. Comparison of long sections of core from ophiolites and ocean crust may be the only way to fully evaluate ophiolites as analogues for different ocean crust environments. Drill holes in intact well-preserved ophiolites , for example in the Urals, are unique in terms of the ease with which the bore-hole observations can be seen in a three-dimensional setting. Ophiolites also offer the unique opportunity of precisely positioning drill holes to examine specific features of interest within the stratigraphy that would be difficult if not impossible to locate in an ocean floor setting.

6.5 Implementation

- Use and development of existing rock-drill technology
- Nuturing of IODP proposals
- InterRidge-IODP workshop
- An official IODP liaison

6.6 An International Crustal Penetration Drilling Project

Understanding global geochemical fluxes from the Earth's interior to the crust, oceans and atmosphere, the relationship between the seismic structure of the ocean crust and its stratigraphy, as well as the economic potential of the oceans requires a full knowledge of the composition and structure of the ocean crust and shallow mantle. This goal can only be achieved by drilling representative end-member crustal types formed in a variety of tectonic settings. Drilling in one ocean basin or one type of ocean crust alone cannot achieve this objective. This drilling must include total penetrations into the mantle at both fast and slow-spreading ridges, as well as drilling long partial sections in tectonic windows representing the diversity of oceanic environments. This, then, rather than a single deep drill hole is the goal of an International Crustal Penetration drilling project that the working group will promote through IODP.

Deep holes in the ocean crust and mantle require proper engineering and planning, staged developments, clear intermediate milestones, and a good long-term scientific plan. This is a Complex Drilling Program ("CDP" - as outlined by the IODP planning structure) that will need a working group with the best experience available in ocean lithosphere drilling, insight and knowledge of the ocean crust for planning.

The working group, through international meetings and planning sessions will develop a long term plan for the drilling, and will organise the preparation of specific drilling proposals for submission to the ocean drilling program, monitor the progress of the program, and identify and encourage key groups of proponents.

7. Global Exploration

The following are important areas of global exploration which should be addressed by InterRidge in the next decade:

7.1 Global bathymetry and tectonics

There are still large sections of the global mid-ocean ridge system that have not yet been explored with even the most rudimentary single-swath multibeam map. Given the fact that at any one time, most of the global spreading segments are quiescent, we need to better determine the proportion of the spreading centre that is most active, and whether there is a true ´cycle´ of volcano-tectonic activity (a largely untested paradigm – logical but unproven).

7.2 Global distribution of hydrothermal activity and global vent biogeography

Our knowledge of the biodiversity of the spreading centres is also strongly limited by the fact that well over 80% of the global ridge system has not been surveyed in enough detail to be able to find present hydrothermal activity, should it exist. Moreover, existing surveys have been concentrated along eastern Pacific ridges and the northern Mid-Atlantic Ridge. Except for a few sites clustered near the Indian Ocean triple junction, a 30,000 km stretch of mid-ocean ridge that includes the southern MAR,

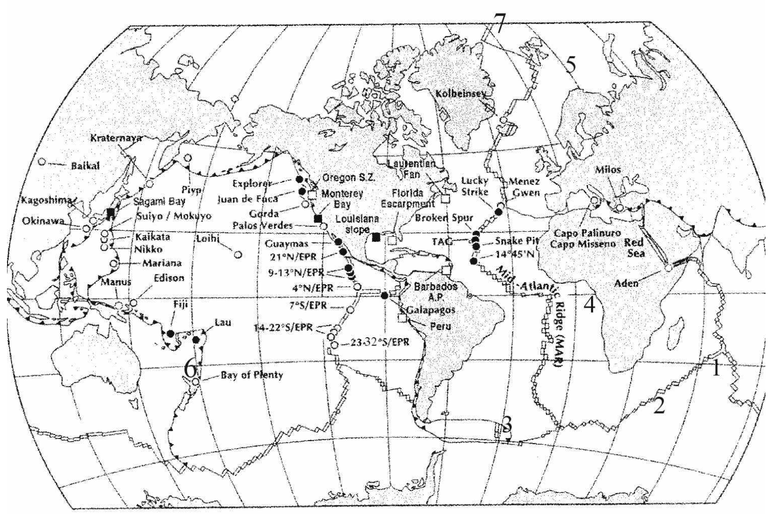

Fig.1 Distribution of confirmed hydrothermal vents (circles) and cold seeps (squares) in the world oceans. Recent discoveries include Kairei and Edmonds vents (1), plumes along the SW Indian Ridge (2) and the Scotia Arc (3) and cold seeps off Angola (4), the Hakon-Mosby Mud volcano (5), volcanoes in the southern Harve Trough (6), and plumes on the Gakkel Ridge (7). Closed symbols represent sites from which there are reproductive and dispersal data (Tyler & Young 1999).

all the Indian Ocean ridges, and the EPR south of 38°S is unsampled for hydrothermal biology or fluids. Future progress in understanding global trends in biogeography or hydrothermal chemistry will require a comprehensive catalogue of the distribution of active hydrothermal systems along the global spreading system. A priority is the development of tools and exploration strategies to gather this necessary information as part of `routine´ marine ship operations. For example, the most effective surveying strategy appears to be routine mapping of the ridge water column, either as dedicated studies or as ancillary data gathering in conjunction with other geological or geophysical operations. A new autonomous deep-float sensor system that could be deployed by ships of opportunity would be very useful. A previous InterRidge Working Group, "Global Distribution of Hydrothermal Activity," made significant inroads into the problems of global vent biogeography. This work will continue under the auspices of the Census of Marine Life and the subproject ChEss (Chemosynthetic Ecosystem Studies). The work is aided by the technological developments in the areas of long-term monitoring, remote observation and sampling (ROV etc.) and hydrothermal sniffers. The state of play in terms of known vents is shown in Figure 1.

7.3 Acoustic remote sensing

We need to strongly encourage the development of acoustic remote sensing techniques to determine noisy volcano-tectonic activity along the entire spreading system. A particular priority is to instrument the Indian Ocean (building upon existing test-ban monitoring stations)

7.4 Global fluxes

Many fundamental flux budget questions (*e.g*. mid-ocean ridge release of He, S, methane,…) require accurate estimation of currently emitted fluxes (and recent paleo-fluxes) from the entire mid-ocean ridge system, yet many basic measurements have been well-made in only a few locations. For example, if ridge degassing occurs to any significant degree by 'explosive' volcanism, then current quiet degassing estimates may be off by a large degree (and too low). At least a factor of two accuracy is needed in global inventories to address flux budget questions; this demands more basic exploration/mapping coverage of the system.

7.5 Off-axis volcanism and extinct spreading centres

Once we move away from the most active part of the neovolcanic zone, we know almost nothing about the volcanic and hydrothermal activity or tectonic evolution of the ridge axes. InterRidge needs to encourage exploration of off-axis regions, of the evolution of ridge segmentation, of the cessation of seafloor magmatism (on a normal spreading segment, and dying propagating/ridge-jump segments). All of these studies will provide glimpses into the workings of the spreading centre which are not available from a robust, neovolcanic zone.

7.6 Implementation

All global exploration strategies would greatly benefit from the development of effective tools that make this information gathering a more routine task that does not require dedicated cruise(s). For example, development of an AUV system that can be deployed during oceanographic/biological cruises to collect hi-resolution bathymetry/gravity/magnetics information (of opportunity) and likewise, routine deployment of a hydrothermal AUV detecting system during geological/geophysical cruises should be encouraged. The development and increased deployment of seafloor drilling capability is also an aim that InterRidge should actively pursue. All of these developments will however have only limited effectiveness in the absence of standards allowing the easy deployment of equipment form a variety of ships furnished by a variety of nations. These standards cover such diverse areas as cable connectors, voltages, acoustic transmission protocols, service connections for containers.

Organizational Structure of InterRidge in the Next Decade

Introduction

The present structure is very effective and will in general be continued. Some changes in the nature of the working groups is needed to focus them more towards long-term science planning, as their initial mandate of fostering of contacts is already well advanced. The rotation of InterRidge Office amongst the member nations was seen by all as a good thing. In the next decade InterRidge must redouble its efforts in strengthening contacts to the less industrialised or non-coastal nations, heightening the appreciation that the world's oceans are relevant to the lives of all the peoples on Earth.

Working Groups

These are the real success story of InterRidge up to present. They have proved very effective at both fostering international collaboration and, through the organisation of workshops, in defining clear program plans for the attainment of new ridge research objectives. Without InterRidge it is clear that many of these projects would not have been achieved. A new structure using Theoretical Institutes to assess the state of research in a particular area and to raise the international awareness of this research area is a further tool which will become important in the next decade.

Databases

InterRidge presently maintains databases on research vessels and vehicles, research cruises, location and general information on known hydrothermal vent areas, vent biological data, and ridge related references, all of which are of immense importance to the international ridge community. Particular additional activities which will become important in the next decade are the creation of a cruise report databank for ridge cruises and the identification of the scattered national databases in a coherent structure. To increase the scope of the InterRidge-hosted databases significantly is certainly beyond the limits of most projections of the InterRidge budget. We envisage NDIR database activities consisting of:

- Automating the input, modification and access processes for the presently-existing databases as much as possible or integrate their content into existing external databases as appropriate.
- Creation of a portal to other databases with ridge-related content consisting of brief descriptions and direct links.

Finances

The present funding structure of InterRidge, with the membership categories Principle (US$20.000, two steering committee members, able to bid for hosting IR office), Associate (US$5.000, one steering committee member) and Corresponding (no financial contribution, receive IR information) does not at present cover the running costs of InterRidge, the Office host has had to be inventive in providing additional funds. In the future, to enable InterRidge to achieve one of its main goals for the next decade of increasing and assisting the participation of developing countries, it will be necessary to increase the amount of money available to support delegates from these countries at Working Group meetings and Workshops. To achieve this goal InterRidge will have to solicit much more actively than at present support from both intergovernmental agencies and the private sector.

Outreach

InterRidge has a major role to play in the education of the public and governments about the global significance of ridges. Thus, the outreach activities are of high priority both for contacting the public and also for informing and involving governments in all parts of the world. Particular resources which InterRidge will provide are web-based presentations on InterRidge itself and on what a ridge is and why it is important. Press releases and scientific resources (suggested codes of conduct, policy for ridge environmental protection etc.) will be provided on the InterRidge server. All InterRidge scientists should be provided with the material necessary to act as ambassadors for InterRidge in any country in which they should find themselves.