# InterRidge Program Plan
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Revised 1994

# InterRidge Program Plan

## Summary

Mid-ocean ridges, including those in marginal basins, are the primary sites of volcanic activity on the earth and the primary sites of creation of new crust. In addition to exerting a major influence on the evolution of the solid earth, they affect the chemistry of the ocean and support unique forms of life. Nonetheless, because they lie beneath the sea, ridges remain poorly understood. We know less about volcanic activity on the seafloor than we do for many other planetary bodies in the solar system.

**InterRidge is an international and interdisciplinary initiative concerned with all aspects of ridges. It is designed to encourage scientific and logistical co-ordination, with particular focus on problems that cannot be addressed as efficiently by nations acting alone or in limited partnerships.**

The existence and functioning of mid-ocean ridges depend upon intra-planetary (mantle) processes, as opposed to processes driven by external (solar) energy. The scientific purpose of the InterRidge initiative is to discover the inter-relationships among the diverse manifestations of the ridge system and to integrate growing understanding of ridge dynamics with knowledge about the functioning of the earth as a whole. Achieving these objectives concerns many subjects, from seismology to bacteriology, and a variety of approaches at many different scales.

This report presents an initial research plan consistent with current national priorities and strategies and with present-day perceptions of the most important scientific problems at hand. The plan recognizes that these problems can change rapidly and is correspondingly flexible.

Principal InterRidge activities are grouped under three major themes, or Integrated Projects, the objectives of which are to:

- Acquire a balanced set of global-scale data on the entire mid-ocean ridge system, which implies notably a concerted effort of exploration in high latitudes where data are extremely sparse.
- Observe, measure and monitor active processes at individual ridge sites in order to begin to quantify the fluxes of mass and energy involved and their biological consequences.
- Investigate the interplay of mantle processes at temporal and spatial scales that bridge the gap between the global perspective and fine-scale studies of active processes. These "meso-scale" studies focus on magmatic and tectonic patterns as well as on fluxes, and include a specific effort on ridges in marginal (back-arc) basins.
- Understand the evolution, reproduction strategies and dispersion paths of hydrothermal vent biota and determine their relevance to and interaction with physical, chemical, and geological processes at the ridge-crest.

InterRidge is defined as a decadal program divided into three phases:

- Phase 1 (1992-1994), devoted to improving co-ordination of on-going independent national and international (principally bi- and tri-lateral) activities, encouraging exchange and communication through the facilitation of international symposia and workshops, and to planning specific future InterRidge actions;
- Phase 2 (1995-1997), involving in-depth studies of temporal variability and broadened spatial characterization, in the form of major interdisciplinary field efforts conceived and co-ordinated by InterRidge, and development of a database information catalogue accessible to the international ridge sciences community via the Internet;
- Phase 3 (1997-2003), including continued mapping and sampling coverage of the global ridge system, intensive development and deployment of seafloor instrumentation, and an international symposium to consider progress and future directions.

There will be a mid-term review of the program in 1997-98.

# InterRidge Program Plan

## I. OVERVIEW

## 1. INTRODUCTION

### *1.1 Context of InterRidge*

#### *1.1.1* New perceptions of the Mid-Ocean Ridge

The mid-ocean ridge is now fully recognized as an extensive province of focused mass and energy exchange that affects the entire earth. The 50,000-km-long mid-ocean ridge dominates the Earth's volcanic flux and creates an average of 20 $km^3$ of new oceanic crust every year. The processes of generation and cooling of oceanic lithosphere contribute two-thirds of the heat lost from the Earth's interior. One third of the heat flux in oceanic lithosphere is carried by the circulation of seawater through fractures in hot oceanic crust. This hydrothermal circulation causes important chemical exchanges between seawater and oceanic crustal rocks, and ultimately with the atmosphere, and acts as an important regulator of the chemistry of the oceans and of the volatile content of the Earth's interior.

Recent discoveries show that not only many fundamental geological and chemical processes, but also biological processes, are concentrated within a relatively narrow band centered on these zones of crustal divergence at the ridge crest. For instance, biological communities associated with hydrothermal vents flourish in a highly unstable, nutrient-rich environment, in sharp contrast to the previously well-established precept that deep-sea benthic communities are the product of stable, relatively nutrient-poor environments. The study of bacterial and animal populations associated with hydrothermal activity has generated fundamental questions about physiology and ecology, and concerns basic aspects of molecular biology and the origin of life on earth.

Challenging new hypotheses have been generated by the recent period of discovery and analysis. Topics of particular interest include the following.

- Submarine heat and mass fluxes may significantly influence the chemistry of the planetary ocean, and may affect its circulation.
- Ridges may have served as refuges for—or even sources of—early life forms.
- Processes of metal deposition may be studied *in situ* at ridge crests.
- The structure and geochemistry of ridges offers still unexplored access into mantle dynamics.
- The biology of unique deep-sea communities is supported by chemical energy released from hydrothermal vents.

In general, the mid-ocean ridge provides a unique opportunity and a unifying theme to address a fundamental scientific problem: the mechanisms by which mantle processes find expression in the geology and biology of the planetary surface. Whereas on the continents these expressions are typically indirect and complicated by interaction with other continent-forming processes, in the oceans they are direct and dominant. Yet even in the oceans, we are remarkably ignorant of the details of how mantle processes operate. For instance, the discovery of structural and petrological features of the ridge not intrinsic to the plate tectonics model has demonstrated that there are serious gaps in our understanding of the formation of crust associated with the growth of ocean ridges. Volcanoes at the ridge are expressions of the predominant type of volcanic activity on the planet, and have quite different structural and petrological manifestations than volcanoes that erupt on land, which are much better studied. Undersea volcanoes are a vast, unexplored frontier.

At still another scale, analysis of measurements from satellites and recent advances in seismic tomography have served to emphasize the full scale of ultimate objectives in ridge research, which are concerned with the role the mid-ocean ridge plays as an integral part of the dynamic Earth.

### 1.1.2 Technological developments

Technological progress provides strong support for the scientific impulse to pursue investigations of the ridge. We can now plan ambitious sea-going investigations previously impossible or logistically unrealistic. In the early nineteen-seventies, at the time of the French-American project called FAMOUS, no civilian ships were equipped with swath bathymetric systems. Today's seafloor mapping systems make it possible to cover about 200 $km^2$ of seafloor per hour for typical mid-ocean ridge depths, opening the way to effective global mapping coverage of the ridge crest. The Global Positioning System came into routine use in the 1980s. Powerful seismic imaging systems have only in the last few years been used to explore subseafloor structure of the ridge. Deep diving submersibles, which had hardly been used for scientific exploration before the 1970s, are now operated routinely by four countries engaged in ridge research. Deep operating instrument packages have evolved considerably. Hard-rock drilling capabilities can be expected to mature significantly in the coming years. High-performance computers have radically improved possibilities for digital data manipulation, imaging and theoretical modelling.

### 1.1.3 Role of InterRidge

The opportunity for scientists and engineers of different countries to advance co-operation in ridge research is timely from several perspectives. Major new directions for development are now available as a result of convergence between current insights and rapidly developing technology. The ridge is a complex network of interlinked physical, chemical and biological processes that has given rise to an extended family of interdisciplinary problems at a range of spatial scales from microns to thousands of kilometers, and temporal scales of seconds to millions of years. Solutions to many of these problems require a level of commitment, a breadth and depth of scientific expertise, and a technological framework that no one country can offer.

Furthermore, the capabilities and motivation of nations taking an active interest in mid-oceanic ridge exploration have grown rapidly in recent years; the total number of scientists involved and the number of at-sea operations have also increased. One outcome of these developments is that most researchers and agencies can no longer even keep informed about where and when new cruises are scheduled to enable more effective program planning.

The convergence of scientific motivation, technological progress, and the increased complexity and cost of addressing ridge problems invites the dispersed global community of ridge researchers to reach beyond the limits of its usual investigative boundaries and to create stronger international linkages. InterRidge is designed as a decadal program to improve co-ordination at the international level and facilitate the pursuit of stimulating new ideas and projects. Each country brings to InterRidge its particular investigative emphasis, which reflects the interests of its scientific community and which is used in defining priorities at a national level in that country.

### 1.1.4 Development of InterRidge

Ridge-crest research was pursued actively and successfully by several nations from the early 1970s into the 1980s. In France, the creation of the Programme National de l'Étude de l'Hydrothermalisme Océanique (PNEHO) represented a recognition of the importance of the subject. A 1985 report by the U.S. Bureau of Science and Technology policy, "Earth Sciences Research in the Civil Space Program," led to the creation of the National Academy of Sciences (NAS) Committee of Earth Sciences (CES) and the Committee for the Study of Global Change Research Issues. CES was to examine the possibility of broadening the focus of Global Change issues to include efforts other than climatic change. The U.S. RIDGE Initiative took form in 1987 with *The Mid-Oceanic Ridge: A Dynamic Global System,* an NAS-sponsored, interdisciplinary workshop held at Salishan, Oregon, USA. The U.S. program RIDGE is now a formal part of the U.S. National Science Foundation's Global Change Research Program.

Following the recommendation made at the Salishan workshop that RIDGE be international in scope, scientists from eight nations gathered in July 1989 at the NAS in Washington, D.C. They agreed that the concept of an international initiative should be further developed, and identified four general areas for initial efforts: fostering communication among scientists of member nations, co-ordinating survey work, encouraging international research co-operation, and data exchange. National correspondents were designated, and *In-*

*terRidge* was adopted as the name for this effort.

The first formal InterRidge meeting was held at Ifremer in Brest, France in June 1990, and was attended by scientists from eleven countries. Participants considered various possible objectives of and approaches to an international initiative. An interim steering group was created to help advance the project in the immediate future and to help prepare a second international meeting. Based on the conclusions of the Brest meeting, the steering group prepared a draft program plan to be considered at the second international meeting, which was held in York, UK, in March 1992. The draft plan was examined and endorsed with various modifications, which were incorporated in this Program Plan.

The British ridge-studies consortium BRIDGE was initiated in 1987 to help national co-ordination of ridge research. Since the Brest meeting in 1989, French scientists have created a "Comité Dorsales" to strengthen research efforts on mid-ocean ridges not covered by the PNEHO, and Japan has moved to identify ridge research activities under its "InterRidge-Japan" working group, which consists of scientists from universities and research institutes. More recently DeRidge has come into being in Germany and CANRIDGE in Canada.

InterRidge is now endorsed by fifteen countries, which were invited in the summer of 1992 to become founding members of the initiative.

In October of 1993, the members of the Steering Committee agreed that an updated version of the program plan be drafted incorporating development of InterRidge during the 18 months since the York Meeting. It was decided that an overview of InterRidge Science and Organisation appear as the main body of the document and that the evolution of the program be chronicled in a series of yearly addenda.

## *1.2* ***Overall program design***

### *1.2.1* *Major research foci*

The outstanding opportunity available to InterRidge is to use the collective intellectual and technological resources of member countries to address major scientific research problems that would not be dealt with as effectively by countries acting in isolation or in limited partnerships. At the same time, it is neither feasible nor necessarily desirable for InterRidge to attempt to be involved equally in all actions relevant to ridge-crest research. A multi-component approach is proposed, with principal initial emphasis on three major themes, or Integrated Projects, and on improving co-ordination of existing research efforts. The aim of this approach is to accomplish selected compelling scientific objectives that could not be achieved without well-co-ordinated international efforts.

Objectives chosen for InterRidge Integrated Projects should be:

- of major scientific interest;
- unlikely to be developed without international planning and co-ordination;
- interdisciplinary;
- globally or thematically defined, rather than regionally-based;
- relevant to active on-going efforts of participating countries.

It was recognised at the outset that new projects would undoubtedly emerge and be refined as the program proceeds. Three specific study areas were originally retained as the major near-term emphases of InterRidge

***I. Patterns of global variation: Global ridge systematics.*** The objectives of global reconnaissance studies are: (a) to define the general (large-scale) spatial characteristics of the global ridge system, and (b) to understand the origin and evolution of the patterns of variation, to determine how the patterns of structure, rock composition, volcanism, hydrothermalism, and biological activity are interrelated. This work requires, in particular, a sea-going effort in high latitudes where there are few data compared with most other areas of the ridge.

***II. Meso-scale ridge processes.*** To understand first-order aspects of the crustal accretion process and its related fluxes, a wide range of interdisciplinary investigations must be carried out on a scale encompassing along-axis distances ranging from a single segment to several hundred kilometers, and extending tens to hundreds of kilometers off-axis. Many relevant investigations are currently being conducted by InterRidge member countries. InterRidge seeks to develop and, as the program progresses, to co-ordinate investigations concerning three key aspects of meso-scale ridge dynamics:

- Segment-scale variations in fluxes;
- Crustal accretion in back-arc settings;
- The interplay between tectonic and magmatic processes and the relationship of this to ridge segmentation.

To increase the efficiency of these studies, InterRidge will offer co-ordination and encourage co-operative efforts, such as those involving series of cruises concentrated in already well-studied parts of the ridge crest.

***III. Observing active ridge processes.*** The objective of observational efforts is to understand the interactive roles and temporal variability of diverse ridge-crest processes operating on time scales of a decade or less, with extension to longer time intervals. Investigations will address physical, chemical, and biological patterns and pathways of mass and energy transfer through the ridge system. Specific approaches to this objective include (1) development of ridge observing capability, including long-term observatories, and (2) detection and response to transient ridge-crest seismic, volcanic, and hydrothermal events.

***Ridge-related research.*** In addition to its major themes, appropriate attention should be given by InterRidge to research in fields in which the ridge community does not act as the driving force, but that are of vital interest to the development of ridge science—such as whole-mantle seismic tomography, satellite altimetry, and certain theoretical and experimental studies.

### *1.2.2 Implementation and mechanisms for co-operation*

*Phased approach*

Although InterRidge is envisaged as a research effort that should be continued over decades in order to answer many of the scientific problems discussed, for realistic planning purposes the program is presented as a plan of approximately 12 years. Activities are proposed to take place in three phases (Section 6). This sequenced approach is intended to support an evolving program and corresponding commitments of support by participating nations, who would agree in principle to the decadal effort and to more specific engagements phase by phase.

*Program structure*

Program administration and organization (Section 7) is kept as trim as possible, but requires an adequate supporting structure. Two levels of InterRidge membership are proposed to take into account the varying degrees of activity of different nations, and where possible to encourage ridge-related research in countries without active sea-going programs (7.1).

Co-ordination and planning efforts take place at a variety of levels. For instance, bilateral co-operative agreements have often been used successfully to promote international collaborative research efforts. Although such two-partner programs are relatively simple to organize, they often have wide implications, particularly where other countries are working in the same area at the same time. Providing encouragement for and guidance in constructing agreements among member countries will be one of InterRidge's primary mechanisms for promoting ridge research. In other cases, InterRidge may take a more prominent part in furthering ridge investigations.

InterRidge administration requires an Office, a Steering Committee and currently 3 working groups (7.2-7.6). Among other tasks, facilitating the exchange of information about the location and nature of on-going research in participating countries is an obvious and fundamental role of InterRidge. Use of such information can allow more effective use of ship time and equipment, diminish duplication of efforts, and foster co-operative programs that utilize international scientific expertise. Some mechanisms for this information exchange are outlined in Section 7.7, and questions of data management are briefly addressed in Section 7.8.

*Program resources*

Principal resources, at least in the first phase of the program, will include primarily the sum of intellectual and technological investments, and of sea-going facilities, allotted to ridge research by participating nations in pursuit of their own efforts. These efforts may be conducted individually or as part of agreements with other countries (Sections 8.1 and 8.2). However, some joint funding activities will also be essential for co-ordination and program development as indicated in Section III of this program plan.

*Interactions with other programs*

It is important that InterRidge not only avoids duplication of activities more suited to national levels, but acts in concert with other relevant international efforts. The International Council of Scientific Unions (ICSU) is a natural parent body for InterRidge. A request for a working group under the Scientific Committee on Ocean Research (SCOR), a commission under ICSU, was made by Marin Sinha (Section 9), and approved by SCOR as Working Group 99 at its September 1992 General Meeting. This Working Group is entitled

"Linked Mass and Energy Fluxes at Mid-Ocean Ridges". In addition, a close relationship with ODP appears essential for the intelli gent pursuit of the InterRidge effort, in particular concerning research that depends on the successful development of seafloor instrumentation systems (10).

# II. SCIENTIFIC ACTIVITIES

The greatest challenge in ridge studies is to understand the relationships among processes at many different spatial and temporal scales. Meeting this challenge requires a wide variety of methodological and technological approaches. Some of these approaches need only to be applied, others must be designed and developed.

Over the next several years, InterRidge will provide co-ordination for multidisciplinary studies at a global scale (Section 2), for meso-scale studies of interrelated magmatic, tectonic, and hydrothermal processes, (Section 3) for studies of temporal variations at ridges on a local scale, including the development of observatory capabilities (Section 4).

Disciplines not directly involved with the acquisition of data at sea - for example numerical modelling of melt production, migration and emplacement; experimental petrology; satellite geology and global seismic tomography - are of great importance to the overall progress of ridge science, and InterRidge will seek to foster links with groups conducting research in these areas (Section 5). InterRidge is also developing an effective working relationship with the Ocean Drilling Program.

## 2. GLOBAL RIDGE SYSTEMATICS

### *2.1 Rationale and objectives*

The purpose of a global program is the characterization of mid-ocean ridges necessary to investigate broad-scale aspects of geologic, hydrothermal, geodynamic, petrologic and biologic processes active near spreading centers. There are two major scientific aspects of ridges that require data from a global spectrum of locations. First, ocean crust formation is a multi-dimensional problem, as is clear from the variations that occur even at constant spreading rate. Second, there are problems that are global in scale, and have wavelengths longer than any regional study can encompass. There are too few of these long-wavelength features to be investigated statistically. Their description alone requires surveys of large portions of the ridge system. In addition, there is inherent value in the exploration of unknown terrain. Every ridge that has been investigated thus far has yielded surprises that did not conform to our preconceptions. Until we begin to see broad-scale duplication of ridge properties, exploration remains necessary simply to know the variability and the global systematics that must be explained by quantitative models.

In terms of logistics and level of effort, the work required for global investigations cannot be accomplished by a single country. At the same time, there is a cohesiveness of approach and necessary technology that makes it desirable for the work to proceed in a co-ordinated way rather than randomly.

There are many practical reasons for individual countries to take part in a co-ordinated effort. A few examples are:

- The UK has the world's most rapid reconnaissance-mapping sonar (GLOIA) yet has difficulty deploying its ships outside the North Atlantic of Mediterranean.
- The US has historically had difficulty maintaining a scientific presence in the Indian Ocean, and has no civilian submersible that can go deeper than 4000 meters.
- Germany has no submersible capability, but a strong mapping and sampling fleet.
- Japan has a developing expertise in seagoing instrumentation, but its ships are usually distant from the eastern Pacific, Atlantic, and Indian Ocean ridges.

In all these examples, one nation can provide the capability lacking in another. Collaboration among nations is thus both desirable and frequently necessary to accomplish the diverse scientific aims of a program of first-order definition of the global ridge system.

Another critical aspect of global cooperation is the development of a consistent, integrated database for the entire ridge system on a broad scale. Such a data base will be an invaluable resource for a variety of research fields and a host of scientific problems. One of the objectives of the co-ordinated effort should be the production of an InterRidge Atlas of the

Global Spreading System. Such a document, together with supporting data, will provide a necessary background for ridge science that will be invaluable well into the 21st century.

### *2.2 Approach*

#### 2.2.1 General requirements

The strategy with which to carry out the global program must include consideration of the interdisciplinary nature of the problem, which includes tectonic, petrologic, geochemical, hydrothermal and biologic objectives. Accomplishment of all of these objectives to the full satisfaction of all the individual fields would make a global program prohibitively large. Therefore there must be compromises in each of the scientific disciplines. Insistence on a full bathymetric swath that goes out to 20 Ma., or a rock sample every 5 km, simply makes the acquisition of a global perspective unrealistic within a reasonable number of years. A strategy must be developed that can best accomplish the largest number of goals and surmount the difficulty that the problems for each discipline are on different scales.

Two general requirements are that (1) the approach should lead to a significantly improved global knowledge of the ridge crest over the next decade; and (2) the approach must address the interdisciplinary aspects of the problem, including bathymetry, tectonics, geophysics, hydrothermal activity, and biology. The overall methods are clear: swath mapping, underway geophysics, petrological and hydrothermal sampling, and bottom photography for the first-order characterization of biological communities. Details of these methods will depend on specific areas and investigators, and will evolve throughout the program with the evolution of technology.

Also clear is which portions of the ridge are least well characterized. These occur primarily in the high latitudes, and particularly in the southern oceans. Relatively unknown areas can be divided into "super-segments" bounded by natural morphological discontinuities of the ridge system. These super-segments are:

- Chile Rise;
- Pacific-Antarctic Ridge from the Chile Triple Junction to the major south-easterly-stepping transform system at 179°W;
- Southeast Indian Ridge from this large transform system to the Australian-Antarctic Discordance;
- Southeast Indian Ridge from the Australian-Antarctic Discordance to the Indian Ocean Triple Junction;
- Southwest Indian Ridge;
- Southernmost Mid-Atlantic Ridge;
- The mid-ocean ridge system north of Iceland, including the Arctic.

Several of the super-segments are extensive and would require numerous cruises for full coverage. It is therefore proposed that each super-segment be addressed as a series of investigative units. Such units may necessarily span the boundaries of two adjacent super-segments: for example, in the case of studies of the Australian/Antarctic Discordance. The investigative unit of ridge that can reasonably be evaluated in a multi-disciplinary fashion by a series of three to four cruises is about 2000 kilometers. The unknown sections of ridge comprise about 12 investigative units. If one unit is studied per year, the global knowledge of the ridge system would be achieved in the twelve-year time span currently envisaged for InterRidge. Thus one of the major accomplishments of InterRidge would be the global definition of the ridge system: an accomplishment of historical significance. The total level of effort is 40-50 cruises (about 3-4 cruises per investigative unit) with 20 days on station. This level of effort would be impossible for an individual nation, but is possible for the international community as a whole.

#### 2.2.2 Cruise sequencing

An ideal series of cruises designed to achieve the InterRidge objective of ridge characterization would include studies of morphology and geophysics, rock chemistry/ petrology, physico-chemical properties of the water column, and biological diversity. A logical first step is the production of a base map to define the segmentation characteristics of the investigative units. Subsequent evaluation of petrology and water chemistry would follow, and the results of these cruises would enable the appropriate strategy to be developed for biological studies. A number of possible approaches to optimizing progress towards the InterRidge goal are presented below as a guide. In each is assumed an average of 20 days of survey/station work within a 30 day leg; where appropriate, the first three disciplines could be combined within a single cruise program.

*Swath mapping:* Using a standard multibeam swath mapping system, generating twice-water-depth coverage at 8 knots, and assuming an average water depth of 3 kilometers, approximately 2000 square kilometers of ridge axis can be mapped each day. In a 20-day program, a 20-km-wide swath could be achieved over a 2000 km investigative unit. The final coverage would of course depend on the system in use. State-of-the-art mapping systems now offer swath widths at greater multiples of water depth (up to 5X), and such systems are likely to become more generally available.

*Petrological sampling:* In any 2000 km investigative unit of ridge it is likely that an average of perhaps 40 second-order segments would be identified. Each of these segments would require as a minimum one successful dredge haul. In addition, two selected segments would be sampled at about tweleve sites. Transit time along the 2000 km segment would take up to about eight days, leaving nine days for dredging and three days for coring.

*Hydrothermal sampling:* Continuous water sampling could be carried out using recent developed, deep-towed instrument packages. This continous record could be punctuated by water column sampling stations at a minimum spacing of 20 km. If each station took an average of three hours to run, it would be possible to complete 96 stations in 12 days: the necessary coverage for a 2000 km length of investigative unit. Eight days' transit would be required along the ridge.

*Biological reconnaissance:* The minimum spacing required for species evaluation and diversity characterization will be controlled largely by the results of earlier field programs. In some cases these parts of the global ridge effort could be incorporated into either or both of the sampling programs indicated above. Where this is not logistically possible, then cruises devoted to photo reconnaissance, deep tow video and possibly ROV studies would need to be developed.

Of course, the cruise strategy for the station work in all of the above disciplines may have to evolve depending, for example, on real-time results. This could, for instance, involve denser sampling while maintaining the overall minimum requirements of ridge characterization of the investigative unit.

# 3. MESO-SCALE RIDGE PROCESSES

## *3.1 Rationale and objectives*

Primary program goals involve characterization of roles of key variables that affect crustal accretion processes and related magmatic, hydrothermal, and biological activity. Examples of such variables are spreading rate, magma source characteristics, mantle temperature, tectonic setting, and spreading history. This characterization must be addressed through wide ranges of highly specialized and/or interdisciplinary investigations focused particularly at the "meso-scale"; that is, the scale of one to three single spreading ridge segments (tens to a hundred or more kilometers of ridge length). Constituent studies should include the following:

- Mapping and sampling to characterize the morphologic, structural, and compositional variability of the ridge;
- Geophysical studies to constrain crustal and upper-mantle structure;
- Geochemical and geological observations to estimate hydrothermal fluxes at the segment scale;
- Biological studies of vent populations, species replacement and genetic exchange.

Meso-scale studies will provide a critical link between efforts to understand crustal accretion processes on a global scale and highly site-specific studies such as those involved in monitoring temporal variability. Some principal topics relevant to regional and intermediate-scale sea-going research are developed briefly in this section.

## *3.2 Principal themes*

Three principal themes have been outlined as appropriate for a program involving significant international co-ordination at different levels: from co-ordination of a broad effort on a large segment of ridge to concentrated multi-disciplinary actions in specific areas. These themes are as follows.

- Interplay between tectonics and magmatism in segmentation.
- Crustal accretion in back-arc basins;
- Segment-scale variation in fluxes

### *3.2.1 <u>Interplay between tectonics and magmatism in segmentation</u>*

Recent detailed geologic and geophysical observations have shown that ridge crest structure, topography, and petrology vary along axis, defining discrete accretionary segments. These segments are bounded by a hierarchy of discontinuities, ranging from major stable offsets (transform offsets) to unstable discontinuities such as propagating ridges, overlapping spreading centers, and small non-overlapping offsets. These boundaries separate spatially distinct segments of variable lengths (a few tens to hundreds of kilometers) often with different morphologies and petrologic signatures. Off-axis investigations show that the length and character of these segments vary with time, indicating that spreading is not a steady-state process. The spacing and nature of ridge segmentation, the morphology of the ridge axis, and petrologic character of the crust that is created appear to depend on a number of factors, including spreading rate, magma supply, and proximity to hot spots.

These observations indicate that spreading is a truly three-dimensional process. However, the origin of this fundamental segmentation is still poorly understood. It appears to arise from the complex interplay between magmatism and tectonism, which may be related to the pattern of mantle upwelling beneath the ridge axis. In order to quantify the factors that control ridge segmentation, it will be necessary to determine the variation in morphology, crustal structure and petrology along axis at the scale of several hundred kilometers (~4-5 segments) and off-axis out to crust of several million years age at a variety of ridges with different spreading rates, magma supply histories, segmentation geometries and proximity to hotspots. These observations will need to be closely integrated with detailed three-dimensional thermo-mechanical and petrologic modelling of the spreading process. Because this problem is best approached by integrating the results from detailed geological and geophysical studies of a number of different sections of the ridge system, it is a particularly appropriate focus for InterRidge Meso-Scale studies, which can combine the resources and research interests of many different nations.

*Implementation*

In Phase 1 of the InterRidge program, we can envision two primary activities for InterRidge in segmentation studies. InterRidge can play an important role in the co-ordination and facilitation of the various on-going national research programs focused on this problem. These activities may include, but are not limited to, distribution of information on cruise schedules and plans, early dissemination of cruise results, data exchange, sharing of equipment or facilities (including ships), and participation of guest investigators on cruises of another nation. [A symposium and workshops on "The Processes that Control Ridge Segmentation" were recommended in the InterRidge Initial Program Plan and held in 1993.]

### *3.2.2* *Crustal accretion in back-arc basins*

The presence of a subducted slab beneath back-arc spreading centers affects the mantle circulation and thermal flux, introduces volatile and other elements into the mantle source, and sometimes adds deeply-sourced arc magmas to the shallow mantle decompression melts. The geographic isolation of back-arc basins from mid-ocean ridges is an important variable in biological evolution, diversity, and ecology. The arc ridges that bound back-arc basins provide covering sediments and physical barriers that modify fluid circulation in the crust and ocean. The different composition of back-arc versus mid-ocean ridge crust and sediments profoundly affects all aspects of the hydrothermal systems: depth and temperature of the magma chamber, fluid and precipitate geochemistry, rock physical properties, and hence fluid-rock interactions. Most ophiolites and volcanogenic massive sulfide (VMS) deposits have geochemical signatures different from crust and hydrothermal deposits formed at mid-ocean ridges, but similar to those formed in back-arc basins. Given the economic importance of VMS deposits and the use of ophiolites as field models of ridge-crest geology, it is important to understand the different processes involved in back-arc versus mid-ocean ridge accretion. Many back-arc basins vary along strike from intra-arc rifts to mature spreading centers, which allows various stages of their evolution, from initiation to maturity, to be investigated in a small area. Indeed, the size of back-arc basins makes them ideal for meso-scale ridge studies, but their complexity requires internationally co-ordinated future work.

*Implementation*

Given the strength of several on-going national and multi-national programs in back-arc basin research, the first phase (1992-1994) of an InterRidge back-arc spreading studies program should facilitate information and equipment exchange and encourage piggy-back and tandem field experiments. [A workshop recommended in the InterRidge Initial Program Plan was held in 1993.]

### *3.2.3* *Segment-scale variation in fluxes*

The goal of this topic is to quantify the magnitudes and spatial variability of all of the fluxes — magmatic, hydrothermal (heat, water, and chemicals), and biological — occurring within a volume extending for one to a few segments along strike; a few tens of kilometers across strike; and from the uppermost mantle to a height in the water column above the influence of hydrothermal plumes. This project will involve major, co-ordinated, international focusing of effort on a small number of study areas, which will be selected following or during work on the first two themes of the Meso-Scale Project to reflect contrasts in spreading style. These could include slow or fast spreading, high or low levels of magmatic activity, maturity of hydrothermal systems, proximity to hot spots, or major basin/back-arc basin spreading systems. It will be beneficial if, where possible, the selected study areas include sites of detailed observations and monitoring carried out under the temporal variability project.

Experimental work to be carried out under this theme could include:

- A major three-dimensional seismic experiment using large numbers of OBSs to determine variations in crustal thickness and lithospheric structure, and hence time-integrated magmatic flux.
- Collection and analysis of dredge and drill samples of crustal rocks for petrological/geochemical analysis to provide further information on magmatic fluxes and magmatic history. A link with the Ocean Drilling Program would be highly desirable for this part of the experimental work.
- A detailed hydrographic survey of water-column structure and water transport to evaluate the flux of water, heat and associated chemicals from both low- and high-temperature venting systems.
- Measurements of heat flow through the ocean floor, and analyses of altered basalts and hydrothermal sedimentary deposits to provide a longer-term record of hydrothermal fluxes. Again, a link to the Ocean Drilling Program would be a desirable component of this part of the experiment.

- Associated biological studies of the export of chemosynthetically-produced carbon to the oceans, and the controls on vent populations, species replacement, and genetic exchange.

*Implementation*

The scientific objectives of this theme of the InterRidge Meso-Scale Project will require a large, co-ordinated, international sea-going effort. It is envisaged that this should take place beginning late in Phase II of InterRidge, possibly continuing into Phase III. Sea-going work would not commence until sufficient work had been undertaken under other parts of InterRidge and national/bilateral programs to allow a clear choice of site(s) to be made. There will, however, be important work preparatory to this to be undertaken during Phase I and early Phase II.

*Phase I actions*

Firstly, co-ordination of existing work on fluxes can be improved, for example by InterRidge activities such as dissemination of information about current, proposed, and programmed experiments. Secondly, additional work could be undertaken, for example by ensuring that opportunities for piggy-back measurements being made on repeated visits by ships of different nations to particular locations are taken up. Thirdly, it may be necessary to broaden the community involved in ridge studies for this experiment. One example of this is the need to include physical oceanographers in the water-column experiments proposed for the co-ordinated experimental phase. Forthly, essential technological developments need to be identified and set in motion. [A workshop specifically proposed in the InterRidge Initial Program Plan was held in 1993.]

## 3.3 *Some components of thematic studies*

The following sections describe some of the components that will contribute to these major themes.

### 3.3.1 *Hydrothermal studies, metallogenesis and the sediment record*

Some of the main preoccupations of the InterRidge research community for the next several years are likely to concern investigations of hydrothermal activity, metallogenesis and the associated sediment record at scales between global and very local.

The first discovery of active hydrothermal deposits in the oceans in the late 1970's opened a new field of research in metallogenesis. The results of subsequent investigations have been important both for the reconnaissance of deep-ocean resources and for knowledge of active metallogenic processes (with their application to deposits found on land). The study of active submarine systems can lead to a great advance in the knowledge of ancient ore-forming processes.

Deep-sea sulfide deposits are now known in a wide variety of geodynamic contexts: slow- and fast-spreading ridges, seamounts, young and mature back-arc spreading centers. In addition, the variable character of the deposits results from the interaction of fluids with rocks and derivatives of different types (basaltic crust, continental crust, andesites and rhyolites, for example) and from the presence or absence of sediments. The range of possible combinations of particular volcano-tectonic environments with different types of seafloor (rock composition, sediments) produces a considerable variety of contrasted ore deposits.

Most of the deposits so far found in the oceans have their fossil equivalents on land, and the size of the largest known oceanic deposits is now close to that of the biggest comparable fossil deposits.

Principal objectives in the study of hydrothermal and metallogenic processes for the coming years are to:

- Continue investigations of hydrothermal activity and the formation of sulfide bodies in different geological environments of spreading centers and associated volcanoes, in order to be able to improve prediction about the nature and composition of deposits according to a given set of variables (tectonic context, rock composition);
- Investigate the links between the degree of hydrothermal activity, hydrothermal fluid composition and different geological settings of the ridge, including young and mature back-arc basins, in order to characterize the physico-chemical conditions for the formation of large sulfide deposits;
- Understand and begin to quantify interactions between seawater and oceanic lithosphere;
- Quantify hydrothermal fluxes (particles, water, energy) in selected areas with a view to improving first-order generalizations for the ridge as a whole;

- Study the physical processes related to hydrothermal circulation both in the field and in the laboratory (modelling water circulation in the crust, modelling plumes);
- Study interactions among fluids, sulfides, and biological activity.

Sediment studies will be concerned with intermediate-scale variations of hydrothemal activity. Monitoring active processes and episodicity of venting over time-scales of years and decades can provide only partial insight into how activity has varied over time scales of centuries to thousands and millions of years and how this variability relates to interlinked tectonic and volcanic changes for a given portion of ridge crest. This is a new field of research involving both fundamental chemistry (tracers, residence-times) and appropriate methodology.

### 3.3.2 Crust and upper-mantle structure; gravitational and magnetic fields

As the surface structure and composition of the ocean floor become increasingly accessible to high-resolution mapping and sampling over dramatically increasing areas due to new acoustic and other types of tools, so the gap is widening between our knowledge of these parameters and our understanding of the processes that give rise to the observed features. Without evidence of deep structure of the axial zone of the ridge and of the plates off-axis, it is difficult to see how mechanical and petrological models for the creation and early evolution of new crust can be complete, or can be tested. Developing and applying techniques that will enable us to image or characterize subsurface structures in the crust and upper mantle with comparably improved resolution is a necessary step towards closing this gap. Taking such a step implies a major emphasis on geophysical techniques at spatial scales of a few kilometers to tens and hundreds of kilometers.

Structural sections through the crust and uppermost mantle are essential for understanding the processes of melt migration and emplacement that give rise to the formation of oceanic crust and the morphology of ridge crests, as well as their along-strike and temporal patterns of variability. Various indirect methods can be applied — for instance, the measurement of physical fields (e.g., gravity and magnetic anomalies) — can help to place constraints on models of the physical and petrological characteristics of crust, although solutions are inherently non-unique. Heat flow measurements can help to identify thermal anomalies including, for example, zones of magmatic upwelling; but there are important practical limitations.

Direct techniques that can address the deeper structure include deep drilling and borehole logging; wide-angle, normal-incidence and natural-source seismics; and artificial and natural-source electrical and electromagnetic sounding methods. Many of these techniques, applied on the scale of experiments covering a few kilometers to a few tens of kilometers, are at present most likely to be applied through collaboration among groups of scientists, rather than through an organized international program. However, their application and development towards attaining resolution of sub-surface structure appropriate for correlating deep structure with surface expression of deep-seated processes can only benefit from greater concentrations and must be a principal long-term aim for the next stages of InterRidge.

Fine-scale seismic and other studies aimed at three-dimensional exploration of the oceanic crust, particularly in ridge-crest areas, must be conducted in appropriate relation to submersible observations.

### 3.3.3 Morphological and compositional variability

A number of important research objectives require characterization (mapping and sampling) of the mid-ocean ridge at scales smaller than global. The study of ridge-crest processes and their variation over time scales of millions of years will involve mapping of selected, representative areas on scales of hundreds of km along and across strike.

The mapping involved should include the following.

(a) *Bathymetric total coverage of extensive off-axis areas, with magnetics age control, conducted as a complement to, or adjunct part of, the global mapping project.* The purpose of this effort includes establishing how crust evolves and recognizing meaningful periodicities in structural patterns with wavelengths of one to several million years. For example, we still have a very imperfect understanding of the relationship of present to past segmentation and the extent to which such relationships reflect temporal variations (and/or spatial migration) of active magma supply systems. The work would be conducted in some cases with single-channel seismic reflection profiling (to get basement depths) and would include gravity and magnetics mapping to help to show up magmatic segmentation patterns and variations in deep structure.

(b) *Finer-scale investigations using closer line spacing for surface ship data acquisition, deep-towed instruments and submersibles.* This work would be addressed to questions of volcanic and tectonic structures at the scale of segments and offsets of different types and in different geodynamic settings to acquire knowledge about processes that can be extrapolated to infer the dynamics of long portions (provinces) of the ridge crest. Resolution of mid-scale subsurface features may be achieved through high-resolution potential field mapping, using towed and autonomous vehicles and gradiometer instrument.

(c) *Sampling to investigate variations in composition of oceanic crust at scales of resolution that are not part of the global mapping and sampling project.* The purpose of on-axis work will be to test meaningful levels of variation of mantle and magmatic signatures with a view to generalizing results for given provinces of ridge crest. Topographic and gravity signatures, for example, can be used as references. A second objective for finer-scale crustal sampling, which is likely to become increasingly important, is the mapping of crustal composition for isochrons other than those of zero and youthful ages. The evolution of this work will ultimately be linked to Ocean Drilling Program policies and to the maturation of other techniques and projects for penetrating sediment cover to reach and sample hard rock.

### *3.3.4* Biological studies

Biology is an essential component of any ridge program, especially when hydrothermal systems are being studied. Fundamental objectives of biological research on hydrothermal systems include:

- Understanding the importance of hydrothermal environments in the origin and evolution of life;
- Assessing the role of hydrothermal processes in the productivity of the deep sea; identify and describe main biological production pathways;
- Identifying structures and processes adapted to survive in extreme conditions and unstable environments (nutrition, detoxification, reproduction);
- Characterizing new species, including those with potential biotechnological value for production of thermostable macromolecules and enzymes.

The primary aims of biological research on hydrothermal systems can be grouped into five main topics.

*1. Composition of ecosystems, biogeography and evolution of species.* Improving our knowledge of spatial variation of populations and species should lead to a better understanding of the history of life in the oceans and of systematic relationships between species; such data should also be of interest concerning the origin of life. These studies will include the latest techniques of molecular biology.

*2. Functional aspects of the ecosystems and species adaptation to environmental conditions.* This topic includes studies on microdistribution relative to chemical and physical parameters, determination of nutritional and reproductive strategies, morphological and physiological adaptations of biological functions (respiration, nutrition, reproduction), specificities of the environment (thermophily, bioaccumulation and detoxification of heavy metals) and adaptation of interfaces (membranes, teguments). Such studies are the essential first step towards quantifying the role of living organisms in hydrothermal fluxes.

*3. Long-term evolution of hydrothermal vent ecosystems and influence of variations in venting patterns.* Vent populations are strictly dependent on hydrothermal fluids, which are discontinuous in space and time. Both short- and long-term aspects must be studied to understand the biology of vents and their chemical importance in the world ocean. Problems of dispersion and growth patterns of species, as well as colonization and regression of the sites in relation to the evolution of physical and chemical characteristics of the environment, suggest the value of "working sites" with instrumented stations of emplaced "observatories" to be visited repeatedly.

*4. Fluxes associated with hydrothermal systems and their importance at the oceanic scale.* An ultimate aim of studies of function of hydrothermal systems is to quantify transfers of carbon and energy through the biological compartments and identify their role in global organic and inorganic fluxes. Since chemical fluxes may stimulate production outside the venting areas, it is important to quantify export of elements and compounds.

*5. Possible applications of species living in hydrothermal ecosystems.* Thermophilic bacteria have great industrial potential. This field of work deals with specific questions about biochemistry (study and use of thermostable enzymes, molecular basis of thermostability), genetics (e.g., research on plasmids), technology, etc.

#### *3.3.5* *Other comments*

InterRidge could be an important framework in which to formalize and extend existing and necessary international cooperation. Exchange of biological data could also be an important InterRidge function; for example, explored sites, site maps, future cruises, types of samples collected and their present locations, research teams involved. This exchange of data requires a coordinating office.

InterRidge biological sampling would benefit from a recommended protocol of handling, preservation and storage of biological materials. We recommend that at least one biologist be invited to participate in any cruise where seafloor geological sampling is proposed.

# 4. TEMPORAL VARIABILITY: OBSERVING AND MONITORING ACTIVE RIDGE PROCESSES

## 4.1 *Rationale and objectives*

The global oceanic ridge system is the locus of massive energy flux from the interior of the planet to its near-surface environment. Identifying the geophysical, geochemical and biological consequences of this energy output is a major focus of modern ridge-crest research efforts. Temporal patterns and energy pathways within any portion of the system are of major interest in defining the interplay among the myriad processes operative along the planetary rift system. Temporal scales of important activity range from seconds to millions of years, and spatial scales from microns to global in size. Large and small submarine volcanic eruptions, massive and microearthquake activity, extended and local hydrothermal exchange between oceanic crust and seawater, and all levels of chemosynthetically-based life processes are integral components of ridge-crest systematics.

As in all volcanic systems, ridge-crest activity is episodic on time and spatial scales that are not readily observable. A major problem to be addressed by InterRidge is the issue of the balance between highly transient and more steady-state processes at the ridge crest.

Central to the objective of quantifying active physical, chemical and biological processes is the aim of establishing long-term seafloor monitoring systems (Section 4.2). An essential prerequisite for any system is the development of testable models and their refinement by iteration with field observations. Observing and measuring various phenomena when the ridge is most active (Section 4.3) is an associated aspect of the overall task, as is the approach of revisiting parts of the ridge to test for recent changes.

## 4.2 *Monitoring decade-scale ridge processes through seafloor instrumentation*

### 4.2.1 Current scientific problems

Answers to several critical scientific questions rely on an integrated approach to studies of geochemical, biological, geophysical, and geological investigations of temporal patterns of ridge processes. Many of these can be addressed through extended real-time observation of ridge-crest processes.

- What are the rates of arrival of basaltic magma at the base of the oceanic crust? Do the partial melts from the mantle enter a subaxial magma chamber episodicly or continuously?
- Is plate divergence along spreading centers episodic or continuous? On what time scale? On what spatial scale?
- Under what conditions and at what rates does the zone of brittle failure (cracking front) encroach on a solidifying magma chamber? How does the heat-source geometry evolve?
- What is the duration, extent, and character of hydrothermal activity at any given site, on any given segment?
- On what time scales and for what reasons do the vent-related biological communities grow? Recruit? Reproduce? Die?
- What are the rates of biological activity?
- How does the process of oceanic crustal accretion affect the overlying water column in the short term? In the long term?
- What are the episodicities of, and feedback mechanisms linking, magmatic, tectonic, hydrothermal, and biological activity at a mid-ocean ridge?
- How much organic matter is produced and exported from a vent system during its life cycle?
- Is the chemical environment of a hydrothermal vent a viable candidate setting for the origin of life?
- What is the diversity of organisms and how do they evolve?

Development of seafloor laboratories for conducting on-going observations and long-term experiments related to temporal variability is a major objective of InterRidge. Seafloor observatory projects are ideally suited for international co-operative efforts because of the inherently interdisciplinary nature of observatory-based studies, the location of most ridges outside the territorial purview of any single nation, and the range of expertise available from different countries.

### 4.2.2 Issues in observatory development

A fundamental distinction should be made from the start between: (1) an *instrument station* : i.e., instrument package made up of several sensors with their data organization and transmission systems, and (2) a full-sized *observatory* spread over a ridge segment (meso-scale), made up of a network of several stations along with ancillary geophysical devices (e.g., OBS's, hydrophone antennae, tiltmeters, etc.) or oceanographic devices (e.g., moored arrays of nephelometers and sediment traps).

Design, construction, testing, and emplacement of essential instrumentation represent particularly complex aspects of observatory development, in part because of timing requirements: certain technologies must be in place earlier in the program to conduct baseline measurements that allow development and refinement of other required instrumentation. Successful execution of this complex sequence of developments will require close co-ordination of efforts among all participants.

Technology development is a promising avenue for international co-operation also because of the range of expertise among the InterRidge countries. For example, Japan and Iceland have been conducting intensive volcano monitoring on land for many years, as has the US. Hydrothermal monitoring has been executed on the Juan de Fuca Ridge through co-operative efforts of US and Canadian scientists. Interaction among involved scientists from these and other interested countries, such as that initiated through the European project for ocean-bottom observatory studies, is likely to enhance the international community's capability to monitor volcanic processes on the seafloor.

Types of technology that are particularly critical for observing and monitoring studies include the following:

- Sensing devices for long-term monitoring of change and covariation of physical, chemical, and biological processes in active seafloor volcano-hydrothermal systems. Examples of such devices are:
  - chemical sensors for achieving hydrothermal and biological objectives;
  - seafloor geodetic instrumentation;
  - technology to deploy arrays of stable benchmarks;
  - development of video imaging systems;
- Seafloor work systems (tethered and untethered, manned and unmanned) to install delicate and heavy equipment precisely with respect to benchmarks or geological features, to take rock, water, and biological samples, and to service permanent installations and arrays of instruments.
- Seafloor experimental devices to study *in vivo* biology.

Studies of the temporal variability of biological processes require both repeated cruises and also long-term observatories in order to obtain information between cruises. Videographic and photographic documentation is needed in addition to physical and chemical data.

### 4.2.3 Recommendations for InterRidge actions

The major activities in observing active ridge processes should include time series observations and the development of instrumentation for the creation of seafloor observatories.

The role of InterRidge should be to co-ordinate such studies and to provide avenues for communication and collaboration among the community. The first step should be aimed at opening communication channels immediately, and co-ordinating the development of instruments to ensure compatibility among modules developed by different groups. Several mechanisms may contribute to this first step:

- The InterRidge office will publish a newsletter twice a year to provide information on the on-going activities in the member countries.
- To reduce duplication and ensure that gaps are filled, InterRidge will establish a standing working group to co-ordinate international efforts in development of instrument packages. This co-ordination may include definition of international standards in power supply, information protocols and mechanical structures to allow compatible use of components from many countries in a single observatory.
- Communication and collaboration between communities with experience in time-series observations and those developing instruments for observatories. The objectives of this collaboration will be to review the scientific targets appropriate for seafloor observatories, to discuss new approaches to time-series observations and to co-ordinate instrumental developments to ensure compatibility. Workshops will act as a forum for generating collaborative international proposals for new research

Initial instrument deployments have already taken place successfully. Time-series images have been collected, and in one experiment have been transmitted back to the surface by acoustic link. Time-series measurements have been made of temperature, flow rate, current velocity, seismicity and many other physical variables. A three-phase approach to observatory development is proposed.

*Phase A:* During the first three-year period (1992-1996), several national (e.g., US, Japan) or international pilot projects (EEC) will be tested.

*Phase B:* In 1996, a decision should be made about the first truly integrated InterRidge interdisciplinary program: a joint international effort to deploy an observatory at one hydrothermal site.

*Phase C:* Two or three other observatories may be simultaneously operated for five years.

## 4.3 *Event detection and response*

### 4.3.1 Introduction

Hydrothermal and volcanic events may frequently be associated with detectable earthquake swarms, lasting from a few days to a few weeks; the longer events are relatively rare. The nature and longevity of an event cannot at present be predicted from its early stages. The earthquakes of some of these events can be detected teleseismically, and may also give detectable acoustic signals. Acoustic monitoring may also detect other events that do not register teleseismically.

Once an event is detected, its volcanic or hydrothermal nature can only be determined by much closer inspection. While it continues, observation must be made of near-source seismic activity, the nature of any submarine eruption, changes in physics and chemistry of the water column resulting from volcanism or hydrothermal activity, and other relevant changes.

Since events can be so brief, a very rapid response is necessary if an event is to be studied while it is in progress. Such a rapid response can be achieved most effectively through international collaborative efforts. A number of specific recommendations were made at the June 1990 InterRidge meeting in Brest, France. An outline of these is presented in Table 1; more detail may be found in the Brest meeting report.

To develop a full-fledged program for mid-ocean ridge event detection and response requires a major co-ordinated international effort over several years. During that time useful responses may be possible, but these are likely to lack important components.

In the early stages of the program, the alerting network must be established and tested to ensure that alerts can be given smoothly and reliably. At the same time detection procedures must be evolved, using seismic and acoustic means, so that alerts can be triggered. Access to acoustic signals will require negotiation with defence authorities, and will then depend on the development of computer codes for recognizing events and producing a trigger.

Seismic triggering is likely to be more easily available, though again development of event recognition algorithms may be necessary. Development of local seismic networks will require data telemetry. It may be possible to utilize redundant submarine telephone cables; however, the issue of telemetry is likely to prove a complex one.

Another early activity must be the compilation of available data about segments for which a marine response is possible, including multi-beam maps of topography, maps of fractures, faults and seamounts based on side-scan imagery and maps showing location and types of hydrothermal vent fields and their related biological communities. Funding must be sought to fill gaps in this information.

For biological research, two types of events are visualized. The opening of a new vent field is seen as the start of a time series, with less need for a rapid response by biologists. A collapse of an existing vent field with rich fauna needs more immediate response.

Rapid Response Instrument Packages (RRIP; see Table 1) must be the focus of further effort. Part of this effort will involve simply defining needs and the extent to which these can be supplied by some sort of informal agreement. Beyond this, a specific goal must be set to obtain funding for critical components of the response package, as identified by working groups of those involved. Contingency funds must be acquired to enable a response to get underway smoothly and swiftly.

In the medium term, higher-quality seismic data for event detection is desirable. Digital local seismic networks should be installed at appropriate sites and special effort should be directed to precise location of earthquakes with these systems.

Advances will be necessary in acoustic location techniques, especially on mid-ocean ridges that do not produce teleseismic signals. Little baseline information is currently available about acoustic manifestations of ridge-crest events. To obtain that information, we require both access to acoustic data and ground-truthing of the nature of the event causing the signals. International co-ordination will be necessary in all of this work. Especially important will be collaboration in alerting, and in making ships available for event responses. Military/civilian co-ordination will be necessary for best use of acoustic data and also for effective aerial response. Teams of scientists must be trained in the use of RRIP instruments. Training exercises will be a necessary part of international collaboration.

Finally, arrangements must be made for analysis of data and for extended post-event monitoring of active segments

**Table 1.** Components of InterRidge event detection and response activities.

| | |
|---|---|
| Detection of events | Teleseisms<br>Local seismic networks<br>Acoustic signals<br>Visual observations<br>Satellite observations |
| Alerting | Report to cental office<br>Determine ship availability, RRIP status; organise scope and nature of response activities.<br>Set up network of contacts and organise formal alerting system. |
| Response to events | Aerial response<br>Ships of opportunity<br>Planned marine response<br>Geographic areas |
| Rapid Response Instrument Package (RRIP) | High quality mulit-beam maps<br>Seismic equipment (sonobuoys/OBS/OBH)<br>Hydrocast instruments<br>Bathythermographs, chemical analytical instruments<br>Magnetometer<br>Dredge/other rock sampling equipment |
| Preparation and follow-up science | Encourage extended post-event observations and monitoring of active segments. |

## 5. RIDGE-RELATED RESEARCH

### *5.1 Satellite altimetry, global seismic tomography*

Understanding the dynamics of a small portion of the ridge from detailed studies can be extrapolated by means of large-scale work to the scale of ridge provinces and ultimately to the scale of oceans and the planet. The global-scale picture can provide a context for studies at all other scales; the ability to recognize the variety of geodynamic responses of the ridge in different settings is a prerequisite for constructing models of ridge behavior.

What are the large-scale controls on the geometry of plate separation? How do ridges respond through time to deep convection patterns? How do geochemical signatures relate to deeper mantle circulation that is not directly related to plate separation? New geophysical techniques – for example, whole mantle seismic tomography and satellite altimetry and magnetometry – are starting to provide three-dimensional views of aspects of the planet as a whole.

Seismic tomography, by indicating the amplitude and patterns of variation in seismic velocities, provides an insight into the thermal structure and hence large-scale circulation of the mantle. The availability of such information raises the possibility of understanding how, and to what extent, this circulation affects the chemistry and magmatic processes at ridges.

At long wavelengths, satellite altimetry provides additional constraints on mantle circulation. At shorter wavelengths, it can provide invaluable information to guide bathymetric surveys at global scales as well as providing information about underlying structure both from spatial and wavenumber domain. A further advantage of satellite data is that it allows information obtained by ship-based studies at all scales on the ridge crest to be correlated with off-axis structures, showing its setting within a global geodynamic framework.

The collection and interpretation of data at a truly global scale will have a funda mental and probably increasing influence on advances in ridge science.

### 5.2 *Theoretical and experimental foci*

Some work of direct relevance to InterRidge scientific objectives does not require sea-going facilities or data collection. Examples include numerical modelling of melt generation and migration and of magma chamber processes; and experimental petrology, both to study chemical processes and to measure physical parameters that can be measured *in situ* by geophysical techniques. Another example os the study of related phenomene in non-marine or non-ridge environments. Two examples of these related fields are the studies of continental rifting and ophiolites. InterRidge will encourage interaction among all communities involved.

# III. PROGRAM STRUCTURE

## 6. PROGRAM SCHEDULE

### 6.1 *Phase 1 (approximately 1992-1994)*

#### *6.1.1 Phase 1 aims*

The aims of the first phase of InterRidge are to:

- Facilitate increasing harmonization and co-ordination of independent existing or projected national and international (bi-lateral or tri-lateral) programs;
- Carry out detailed consultation and planning in preparation for new InterRidge projects to be carried out during Phases 2 and 3.

#### *6.1.2 InterRidge co-ordination*

In Phase 1, the principal co-ordinating role of InterRidge is to interact with the independent national and international efforts in the following manner:

- The InterRidge Office may act as an international clearinghouse for information related to ridge research, including both sea-going and land-based efforts. In particular, the InterRidge Office will collect information on cruise tracklines and station locations.
- The InterRidge Steering Committee should act to encourage work in certain areas and themes required to fulfil the goals of the program.

Most ridge-crest research is presently conducted either on a national basis by scientists from one or more research laboratories, or in a frame of agreements between two or perhaps three countries. There have been few multinational efforts involving more than three countries. Some specific InterRidge actions, particularly involving several nations, will be proposed for Phases 2 and 3.

#### *6.1.3 Design of major InterRidge projects for Phase 2*

The series of concentrated programs at sea described in Sections 2 to 4 will require detailed planning before the submission of proposals to national agencies, and continuing co-ordination throughout their planning and execution phases. During Phase 1, InterRidge will promote, co-ordinate, and prepare these programs and implement the minimum necessary organizational structures for facilitating and integrating the independent nationally- (or bi-laterally-) based constituents of these programs.

#### *6.1.4 Other activities*

The other principal activities of InterRidge during Phase 1 will occur in the context of developing the appropriate support structures for carrying out the program: InterRidge Office, Committees, working groups, data management, and so forth (see Section 7, Program Administration).

### 6.2 *Phase 2 (approximately 1995-1996)*

Phase 2 will focus on a major multi-disciplinary program addressing both spatial characterization and temporal variability. This phase will constitute the first active field phase of the InterRidge program, and will involve some level of direct planning and co-ordination to address the objectives of the four program components outlined in previous sections.

#### *6.2.1 Bilateral-type agreements*

The first approach to structuring InterRidge co-ordination will be through integration of projects under bi-lateral (or tri-lateral) agreements among participating countries. Countries interested in studying a particular part of the ridge system could collaborate through joint national agreements under the ægis of InterRidge. The particular configuration of those agreements would vary with the countries involved. Development of the InterRidge program as a whole would be co-ordinated by the Steering Committee; each National Correspondent would be responsible for monitoring the progress of agreements executed by his/her country, and reporting on the projects' status to the group as a whole. In this scenario, "InterRidge cruises" would, by agreement, be those conducted under the auspices of the bilateral agreements, or agreements among a small number of countries such as may occur, for example, in the context of European co-operation. Primary support for InterRidge cruises would be derived from the countries involved.

Each InterRidge country would be encouraged to enter into co-operative agreements with other members. Countries not entering into such agreements could still make important contributions to InterRidge through sharing of scientific expertise and information related to their ridge-crest cruises, and perhaps through participation of their scientific representatives in InterRidge-designated cruises.

### 6.2.2 *InterRidge co-ordinated projects*

It is envisaged that Phase 2 would see concerted international actions at sea, co-ordinated by InterRidge over a period of two or more years. This action would bring the ships and technology of different nations together in major multi-disciplinary experiments focused on InterRidge thematic goals.

### 6.2.3 *Approaches to InterRidge cruise augmentation*

Increasing subscription to the program permitting, it may become appropriate for InterRidge to fund limited augmentation of cruises and other research with potential for particularly significant contributions to InterRidge goals. Augmentation may be requested by proposal to InterRidge by countries for adding projects, scientists, or equipment onto an existing cruise to allow it to make a greater contribution to InterRidge goals.

Selected proposals that have received primary funding within the host country would be submitted by the Co-Chief Scientists to an InterRidge review panel. Evaluations could be based on a summary of the original proposal, a statement of the purposes for which InterRidge augmentation support is requested, and a budget for its use. The review panel could examine proposals for overall relevance to the InterRidge program, for appropriateness of timing, and for utility of the proposed augmentation.

### 6.2.4 *Preliminary scientific planning schedule*

The Initial Program Plan envisaged that a general schedule for Phase 2 activities would be prepared during thematic workshops to be held in the second half of 1992 and in 1993.

## 6.3 *Phase 3*

It is envisaged that Phase 3 will see continuing sea-going InterRidge activity along the lines indicated for Phase 2, with an increment of real, pooled international funds. Phase 3 would culminate in a major ridge-dedicated international symposium to evaluate progress in internationally co-ordinated ridge research and to consider the most exciting and challenging research programs for focused efforts in the future.

A Phase 3 is included in the Program Plan because of the very long lead time necessary for the preparation of certain projects and because some proposed projects already defined (e.g., global reconnaissance mapping, seafloor instrumentation for studying temporal variability) require a decadal frame for logical development. The context of Phase 3 will be developed during Phases 1 and 2 and will be confirmed during the InterRidge mid-term review.

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# 7. PROGRAM ADMINISTRATION

## *7.1 Membership*

Two types of membership in InterRidge are proposed, as follows:

- Principal Member: Guaranteed membership of Steering Committee for two voting representatives; responsibility and opportunity to host the InterRidge Office during the coming years; guaranteed membership on all working groups, voting and proportional representation at all general InterRidge meetings; and entitlement to receive all information, newsletters and data catalogues.
- Associate Member: Guaranteed membership of Steering Committee for one non-voting representative; guaranteed membership on at least one working group, with total representation approximately in same proportion as Steering Committee membership; entitlement to representation at all general InterRidge meetings; and entitlement to receive all information and newsletters and data catalogues.
- Corresponding Member: Entitlement to receive information, newsletters and data catalogues, on request.

"Principal" membership requires a higher level of support of InterRidge running costs than "Associate" membership. Each country will be asked to propose its own affiliation. Countries may combine into consortia who would constitute a Principal Member.

### *7.2 InterRidge Office*

The functions of the InterRidge Office include preparing and publishing program documents; coordinating InterRidge planning activities, including meeting support; managing the program budget; and providing other support as required. Such an office would comprise several components: routine office operations, technical support, coordination of event detection and response, production of a newsletter (see Section 7.7), and an executive administrator and a program assistant. The InterRidge Office will normally be sited at the institution of the Chairman of the Steering Committee, who will have day-to-day responsibility for running the Office, subject to the overall approval of the Steering Committee.

*Routine office operations:*

- Limited meeting support (documents and on-site co-ordination), with increased support in subsequent years
- Communications (telephone, fax, telemail, mailings)
- Document production (meeting reports, program plans, newsletters)

*Technical support:*

- Development of database of cruise track-lines and station positions
- Creation of international directory of addresses and specialities of ridge researchers

*Co-ordination of event detection and response:*

- Co-ordination of fast-response procedures: potential participants, paths of authority, equipment locations, ship locations
- Co-ordination of computerized response package
- Co-ordination of RRIP development (see Section 4.3)

*Personnel:*

- Executive administrator (Co-Ordinator)
- Program assistant

*Rotation:*

The InterRidge Office and Chairman shall normally rotate every three years. The Steering Committee shall choose the next host country and Steering Committee Chairman on the basis of bids, including a projected budget, which they will invite from Principal Members

### *7.3 Steering Committee*

The InterRidge Steering Committee will co-ordinate and promote InterRidge activities. It will:

- define and from time to time update the Program Plan;
- propose and oversee specific InterRidge projects;
- consider and prioritise proposals for new program elements, workshops and other appropriate activities;
- liaise with the leaders of national ridge research programs;
- determine the membership of InterRidge and its working groups and committees;
- approve the InterRidge budget and oversee the operation of the InterRidge Office;
- select the InterRidge Chairman and the host country for the InterRidge Office.

Membership of the Steering Committee will be determined annually, as follows:

- Each paid-up Principal Member nation will be entitled to two positions on the Steering Committee, of which one may be nominated by the member country, and the other will be chosen by agreement between the member country and the Steering Committee. It is desirable that the nominee be the head of the national program or be official representative of that program. These representatives will usually also act as the National Correspondent and his/her alternate (see 7.4). Either position may be temporarily taken by a replacement if the nominated member is unable to attend. In the case of the Member hosting the InterRidge Office, one of the Steering Committee positions shall go to the Chairman and the other will normally be the National Correspondent.
- Each paid-up Associate Member nation will be entitled to one non-voting position on the Steering Committee, to be nominated by the Member and agreed by the Steering Committee. This person will usually also act as the National Correspondent (see 7.4). This position may be temporarily taken by a replacement if the nominated member is unable to attend.
- Additional members may be from time to time co-opted on the basis of their scientific expertise, affiliation to other international programmes, etc., to provide appropriate balance and coverage. Such members

should total no more than four, or one third of the total Steering Committee, whichever is smaller.

No individual member, whether a National Correspondent or otherwise, may serve more than four consecutive years. Normally members will be expected to serve at least two years.

The Steering Committee will normally work by consensus. However, in the event of a vote, each principal member of the Steering Committee shall have one vote, except that in the case of a tie the Chairman shall have an additional, casting vote.

In the absence of the designated Chairman, the Committee shall elect a temporary chairman from its members.

The InterRidge Co-Ordinator shall normally act as secretary to the steering committee, but shall not have a vote.

Chairmen of the InterRidge Working Groups will normally be invited to attend meetings of the Steering Committee, but will have no vote. Each working group chairman, if unable to attend, may be temporarily replaced by another member of his or her working group.

In the case of a vote in the course of a Steering Committee meeting at which only one of a principal member's representatives is present, only the representative present may vote.

### *7.4 National Correspondents*

Each member country of InterRidge should name one National Correspondent and one Alternate to serve in place of the National Correspondent when necessary. Normally for Principal Members the National Correspondent and Alternate will be the Steering Committee members as indicated in 7.3. For Associate Members, the Steering Committee member will normally act as the National Correspondent, but the Alternate will not be a member of the Steering Committee. In order to maximise the dissemination of information, InterRidge will recognise National Correspondents even for countries that are not yet paying members, although such countries and Correspondents will not be able to influence InterRidge policy.

National Correspondents are a vital component of InterRidge, representing the main nodes of communication between InterRidge and participating countries They are expected to maintain appropriate formal relationships with agencies and individual researchers in their countries through whatever mechanisms are determined at a national level.

### *7.5 Ad hoc Committees*

Ad hoc committees may be established where appropriate. Possible ad hoc committees that may be constituted during InterRidge's development include:

- Biological Studies
- Cruise review committee (synthesis of geographical and thematic efforts, and recommendations where appropriate)
- Information and data standards committee
- Technology review committee
- Theory review committee

Each InterRidge ad hoc committee would be composed of members from at least four InterRidge nations, including at least one Associate country, where possible. Membership in the committees should be established by the Steering Committee and would normally rotate every two years. Members of ad hoc committees should not normally serve for more than four consecutive years.

### *7.6 Working groups*

Working groups will be established by the Steering Committee to oversee development and execution of various aspects of the InterRidge program. Initial Working Groups recommended at the York general meeting in March 1992, are as follows:

- Global-scale studies
- Meso-scale characterization: mid-ocean ridges at regional scales
- Temporal variability (Active Processes): (a) event detection and response; (b) mid-ocean ridge observatories

Working groups may also be convened around other InterRidge research priorities as appropriate. Members of Working Groups should not normally serve for more than four consecutive years.

### *7.7 Information dissemination*

An InterRidge newsletter will be produced on a semiannual basis by the InterRidge Office. Included in the newsletter will be international cruise schedules, articles on ridge research topics of interest, programmatic updates and deadlines, information about other international programs, and other items of interest.

Notices will be sent to National Correspondents and other InterRidge participants as required, to promote broad communication among the international community interested in ridge-crest research.

### 7.8 *Data management*

In the first phase of InterRidge, information concerning cruise tracklines and station coordinates will be requested from member countries. The InterRidge Office will keep a record of this information, and will make the data available to the community.

All InterRidge program components will benefit greatly from the development, in later phases of InterRidge, of standardized databases comprising geophysical, geochemical, bathymetric, and biological data. Current technology allows such databases to be distributed across the Internet.

An Ad hoc Committee will be established including a representative from each of the Principal Member nations. Each member of the ad hoc committee will be responsible for encouraging the development of banks of relevant ridge data in his or her country in a common format accessible via the Internet. Participating scientists will be expected to bid for funds from their national funding agencies to support this work. The InterRidge Office will co-ordinate the efforts of the committee members and will make the data available to the community through the World Wide Web.

A first step in this direction has already been taken by researchers at Lamont-Doherty Earth Observatory funded by the US RIDGE program. To avoid duplication of effort, the InterRidge Office will work closely with the developer of the LDEO database as well as with committee members from other nations.

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## 8. PROGRAM RESOURCES

### 8.1 *National facilities of InterRidge countries*

Information concerning national sea-going facilities and technological resources potentially available for ridge-crest research will be gathered by InterRidge through the InterRidge National Correspondents. This information will be made available to the ridge-crest research community upon request.

### 8.2 *Operating costs for InterRidge planning*

In Phase 1, the cost of operating an InterRidge Office will be the primary expense associated with early InterRidge activities (see Sections 6 and 7), together with national support for necessary meetings; the latter could be derived from identified national funds. It is anticipated that contributions from InterRidge countries would be made in proportion to their overall levels of sea-going activities and other resource contributions to research.

Planning, development and management of a database of information derived from InterRidge-related cruises would be appropriate activities for more mature phases of the InterRidge program. Other activities that may be supported in later phases of the program could include theoretical research and cruise augmentation (see Section 6.2.3 above).

An approximate estimate of total yearly funds required to support an InterRidge Office for the first year of Phase 1 is on the order of US$100,000 - $120,000. Travel funds (other than for two people; see Section 7.2), to be identified or pooled, are not included in this figure, nor are any other funds to support InterRidge development (data synthesis, cruise augmentation).

# IV. RELATIONS WITH OTHER INTERNATIONAL PROGRAMS AND ORGANIZATIONS

## 9. SCOR

The Scientific Committee on Ocean Research (SCOR), a committee of the International Congress of Scientific Unions (ICSU), has the purpose of furthering international scientific activity in all branches of oceanic research. Discussions have been initiated with SCOR representatives concerning establishment of a SCOR InterRidge Working Group. Formation of such a body would mean that SCOR would provide some financial and organizational support for meetings and publications. Initial terms of reference for a SCOR Working Group were proposed as follows.

- To assess which portions of the global ridge system are particularly well-suited for in-depth studies, through a review of information on both well-known portions of the ridge and areas that are less well known but appear to have potential for future multi-disciplinary work.
- To identify the approaches required to address quantitatively the interplay among the important variables involved in oceanic crustal accretion.
- To assess possible water-column investigations aimed at evaluating the consequences of hydrothermal venting on ocean physics and chemistry.
- To consider the scientific and pragmatic foundation necessary to accomplish the goals set out in the first three terms of this list.
- To prepare a report to SCOR on the scientific prospects for a long-term program leading to the quantification and modelling of the global spreading-center system.
- To prepare and convene a SCOR symposium to present the working group's results and current research in the field.

## 10. OCEAN DRILLING PROGRAM

Since its inception, InterRidge has been in close communication with representatives of the Ocean Drilling Program (ODP). An InterRidge Liaison will insure the flow of communication between InterRidge and ODP. Of particular interest in the near term to InterRidge members are two technologies currently being developed with ODP support: a Diamond Coring System (DCS) for hard-rock drilling, and high-temperature logging tools for deep crustal drilling.

## 11. OTHER PROGRAMS

InterRidge has a liaison with the International Lithosphere Program (J. Mutter, Lamont-Doherty Geological Observatory) and will interact with any existing international ridge-research efforts where appropriate.

Discussions are underway to establish liaison activities with other international programs.