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InterRidge: Near-Term and Long-Term

J.R. Delaney and H.D. Needham, InterRidge Co-Chairs

The fifteen months since the York InterRidge meeting in March 1992 have seen some significant progress as we move from the planning to the implementation phase. National agencies have committed their support. The United States, France, the United Kingdom, Japan, and Spain have agreed to become Principal Members of InterRidge this year. Germany has indicated that it hopes to do so. Portugal, Iceland, Canada and Australia plan to join as Associate Members in 1993 and 1994. Discussions about membership are ongoing in other countries. The executive committee of SCOR has accepted the InterRidge proposition to create a Working Group on linked mass and energy fluxes at mid-oceanic ridges (SCOR WG 99). It appears that a substantial part of the scientific community concerned has gathered around the idea of a cooperative international impetus to mid-oceanic ridge research.

The York agreement that InterRidge should be a three-theme program has led to the constitution of corresponding Working Groups and the preparation of several workshops [see pages 26 and 27, this issue]. A workshop on global studies was held in Paris in April of this year. The Meso-Scale Working Group has organized a symposium on Ridge Segmentation with accompanying workshops in Durham in September and a workshop on Marginal Basin Accretion to be held in Seattle in October. An Active Processes Working Group is preparing a workshop to be announced later in the year.

The workshops will translate the general scientific objectives of InterRidge, now endorsed by the community, into more specific plans, and will consider practical ways of running projects on a routine basis. Since there is no similar international deep-seafloor research program that can be referred to as a model, some of the rules for InterRidge management must be worked out by trial and error. In particular, the right balance must be struck between too many and too few guidelines for the purposes of the program. To benefit the science, InterRidge must be intellectually flexible and attractive to imaginative scientists. In our efforts to understand the mid-oceanic ridge as a single system, we must be concerned with all aspects of ridge research, especially the interaction of the physical, chemical, and biological processes associated with accretion. An important guideline should be selection of activities that particularly benefit from or require international cooperation.

In the few years since its inception, InterRidge has been configured to improve the flow of information within the ridge research community. One important part of that effort is the exchange of information and ideas for planning purposes. Another

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aspect, which should begin to mature in the next few years, will involve building readily accessible data bases for community use. We are confident that the scientific community will benefit from more efficient information transfer, and will treat that sharing with the respect and care that it deserves. It is up to InterRidge to find appropriate mechanisms to put these aims into practice.

Although InterRidge has made an effective beginning, we must now move rapidly on consolidating the effort. Yet in doing so, we need also to look beyond immediate tasks and bear in mind the question of what oceanographic and seafloor research is likely to be in 10 to 20 years. In envisioning the nature of InterRidge's potential contributions to the community's overall goals, we must think creatively about cooperative new approaches to ridge research. To retain its vitality, the program must be able to evolve and be progressively redesigned over several-year periods as scientific emphasis shifts. At the same time, some projects involving complex technological efforts and the design of future ships and other facilities require long lead times and long-term commitment of funds.

With the rapidly expanding international fleet of ships equipped with multibeam echosounders, particularly the new generation of very broad-swath systems such as Simrad EM 12 Dual, SeaBeam 2000, and also the latest GLORIA towed vehicle, much of the ocean floor could be mapped within a few decades. The InterRidge Global Studies project, whose goal is to survey and sample, within ten years, the least-known areas of the ridge crest, is clearly attainable, but will require both logistical and scientific cooperation to ensure that suitable vessels are in high latitudes and remote areas.

As larger and larger areas of the ocean floor are increasingly revealed through high-resolution surface-ship echo-sounders, the gap between this information and knowledge about the origin of the surface features of the ridge is actually widening. The Meso-Scale investigations targeted by InterRidge must bring to bear new sampling and observational devices and to define 3D oceanic crustal structure and other geophysical objectives required to test and guide theoretical models of ridge structure and processes. In this effort, InterRidge can play a crucial role in focusing multidisciplinary studies on specific areas or themes over limited periods of time.

The Active Processes theme of InterRidge is a primary area for growth and future collaborative research. The Event Detection and Response part of this theme is perhaps the most original component of InterRidge, and one truly requiring a new mode of international cooperation. Adequate response to ridge-crest seismic, hydrothermal, or volcanic events requires rapid mobilization of resources, including information, personnel, ships, equipment, and funds, from many countries. The feasibility and scientific value of this approach has been partially demonstrated through international responses to events on the Reykjanes Ridge in 1989 and 1990, and on the East Pacific Rise (9°50'N) in 1991. Yet, because of the inertia of normal ship scheduling, and the long lead times in developing the technical and logistical capacity for full event detection and response, the community is not now adequately configured to accomplish such goals routinely.

The larger objective of measuring change and covariation in major seafloor processes within a three-dimensional framework over extended periods of time will require even more innovation. One intriguing 20- to 30-year scenario for monitoring active processes throughout the ocean basins is that we will be increasingly dependent on three-dimensional networks of sensors that return data directly to our laboratories at regular intervals or in real time. Ships are liable to operate more as shuttles for transporting instrument arrays to and from selected experimental sites or for allowing *in situ* servicing or data retrieval. Rapid convergence of developments in microelectronics, increasingly efficient power cells, new flexible optical fiber networks and improved satellite telecommunications will allow deployment of hundreds of different kinds of long-life modular sensor packages in specially-designed nodal nets that are multiply linked to high-capacity communications networks. These systems could provide a wide spectrum of high-quality, spatially-indexed environmental information in a predetermined time domain, for comparison with next-generation models of the interactive processes involved.

Development of a highly flexible and sophisticated "sensornet" capability with real-time data transmission is not a short-term project. On a five-year time scale, costs would be prohibitive, results would be limited, designs would be incompletely developed or proven. Working sensornet systems will require routine real-time communication links, computers capable of handling vast amounts of complex time-space data, reasonably-priced appropriate optical fiber, and major emphasis on sensor development and miniaturization. A long-range, well-designed, internationally-cooperative plan to develop a new and highly flexible sensornet capability could benefit many aspects of oceanographic research. InterRidge could be one effective forum for developing ideas of this type within our extended community.

For example, ocean drilling will continue to return samples to bring ground truth to less direct geophysical measurements, but a parallel and highly important return will be a growing number of instrumentable holes. Drilling strategies are already beginning to shift, in part because of InterRidge efforts, to include the positional value of the borehole for instrumentation such as simple temperature and pressure monitors, hole-to-hole experiments, or subseafloor seismic stations. InterRidge must work closely with the Ocean Drilling Program to implement these and other critical development projects.

The next six months will see the successful consolidation of this first phase of InterRidge. Looking beyond, in the first of an anticipated series of rotations, plans are now advancing to move the InterRidge Office from the University of Washington in Seattle, where it has been since the inception of the program, to the University of Durham in the UK by the start of 1994. The next general meeting is planned for early 1994. Ultimately, the definition, utility, and effectiveness of the program will depend on the efforts of those individuals and nations who choose to be involved.

Ridge Research Around the World

Diving on the obliquely spreading Reykjanes Ridge in the North Atlantic around 59°50'N

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Introduction

During June 1992 a scientific team of five US and 10 Russian scientists used the twin deep-diving, Russian submersibles, the MIRs, and their support ship, the R/V *Academic Mstislav Keldysh* (Cruise 28), to study the spreading axis of the Reykjanes Ridge around 59°50'N in the North Atlantic.

The Reykjanes Ridge is anomalously shallow, and is oriented oblique to the inferred spreading-normal direction (Talwani et al., 1971; Vogt and Avery, 1974). En echelon, overlapping axial volcanic ridges (AVRs) form the spreading axis. Axial faults are oriented roughly normal to the spreading direction and off-axis faults trend parallel to the ridge axis. Along-strike axial morphology changes from a median valley in the south to a central high in the north (Laughton et al., 1979; Searle and Laughton, 1980). The anomalous morphology of the Reykjanes Ridge along with its unusual geochemical and petrological signature (Schilling, 1973) have been attributed to the regional influence of the near-by Iceland hot spot.

Goals of the Diving

Our four primary goals were: (1) to investigate a recently (1989) seismically active area, interpreted to be the site of recent volcanism; (2) to study the volcano-tectonic processes along and between AVRs to determine how the en-echelon ridges initiate and evolve; (3) to study the faulting patterns and relative ages of the seafloor for comparison with SeaMARC II sidescan images; and (4) to obtain a densely spaced set of lava samples for studying the geochemical diversity of the mantle beneath the en-echelon ridges and to study crustal-level effects on the magmas erupted in this segmented region.

During over 50 hours of on-bottom time (6 dives) we took 45 hours of video, over 500 still photographs, 18 hours of CTD data and two heat flow measurements. We collected 36 igneous rock samples, nine water samples, seven sediment cores and numerous biological samples (Fig. 1). From the Keldysh we took 52 CTD casts, 23 volcanic glass samples from outside the diving area, five sediment cores, two rosette water sampling runs and we completed a 19-hour magnetic survey.

Selection of the Dive Area

The dive area was centered around 59°50'N and included two AVRs: a large double-limbed ridge to the south-west (AVR-SW) and a smaller single ridge to the northeast (AVR-NE) (Fig. 1), as well as the overlap basin between the two ridges. Our MIR submersible work is part of a chain of studies intended to support the InterRidge initiative in studying, in a timely manner, geological and geophysical events on the world's mid-ocean ridges. A major teleseismic earthquake swarm was detected on land in Iceland and localized using aircraft-deployed sonobuoys in June 1989 [SEAN-Bulletin, 1989; Nishimura et al., 1989; Nishimura and Vogt, 1991]. These seismic events signalled that extensional faulting and/or magmatic activity were occurring on the ridge. In July of 1990, a sidescan sonar (SeaMARC II) and swath bathymetry (Hydrosweep) survey of this region revealed several robust AVRs as well as faults, fissures, and at least three large fields of high acoustic backscatter, tentatively interpreted as recent lava flows [Shor et al., 1990; Appelgate and Shor, 1991]. Our MIR dives specifically targeted one of the high-backscatter patches located just east of the ridge axis but within the possible epicentral region of the teleseismic events (Crane et al., 1992) (Fig. 1).

The Dives

The MIR submersibles dive together and are capable of submerging to a depth of 6 km. The shallow depths of the Reykjanes Ridge (600-1100 m) allowed between 5 and 11 hours of on-bottom time per dive. Both submersibles are equipped with video cameras for continuous recording and an externally mounted Hassalbad 70 mm camera for still photographs. Both cameras can be hydraulically positioned to provide full coverage of the area in front of the submersible. Navigation was accomplished with 6 bottom mounted transponders; however, extensive local bathymetric relief (several hundred meters) made three-transponder fixes difficult. MIR-I is capable of making CTD measurements, and a 1 m heat-flow probe was attached to MIR-II and used to take heat-flow measurements in sediment ponds on the flanks and between ridges.

Three sets of approximately parallel dive tracks (Fig. 1) were selected for the MIRs. One set concentrated on the crest of the eastern arm of AVR-SW and the high backscatter region. A second set was on the crest of the western arm of AVR-SW and a third set, trending W-E, was located on the northern tip of AVR-SW, the southern tip of AVR-NE, and the overlap basin in between (Fig. 1).

Abundant particulate matter in the water column ("marine snow"), sessile marine life on the rocks and benthic fishes are present in all three areas surveyed. Up to 60% of the surface of some rocks is covered by sessile organisms such as en-

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crusting sponges, sponges, corals, barnacles and clams. An unusual colony of barnacles (Balanomorpha) and Lima (bivalvia) was discovered at about 850 m depth on both of the limbs of the large AVR. These were interpreted to be methane-eating organisms, but no hydrothermal vents or temperature anomalies were discovered in the vicinity. With only one exception, sediment cover ranged from 1-2 cm along ridge tops, with small ponds of 15-30 cm between pillows, to greater than 1 meter in the overlap basin between the two AVRs. The high-backscatter region proved to be a flat, featureless, plain with 20-40 cm of sediment cover. Fresh lava was found at only one location near the southern end of AVR-NE (59°52.4'N, 29°38.8'W) on the flanks of a small volcano at a depth of about 1100 m. This flow lacks sediment and biological cover and exhibits minimal alteration of the glassy rind. No other young lavas or evidence of recent volcanic or hydrothermal activity were discovered (Johnson, 1992).

Pillow lavas are common in the axial region and are typically lobate, 1-3 m in diameter, but can be elongate (1-2 m by 4-6 m) on slopes. Many of the pillows exhibit striations or "toothpaste" structures on their surfaces. Sheet flows are sparse, but may be preferentially covered by sediment due to their low relief. Rubble covered slopes and talus piles at the base of sharp flow fronts and faults are common. Rocks are all fine grained, vesicular (2-10 %) and slightly plagioclase-phyric (1-5 %).

Sediment cores were taken slightly off axis and in interaxial lows. All sediment cores recovered, submersibles and shipboard, were primarily brown mud with ash layers (up to 2 cm thick) and abundant sponge spicules.

On the basis of sediment cover across fault scarps and cracks in sedimented areas, it appears there has been recent tectonic movement within the dive area. Recent faults are especially common in the overlap region and along the eastern side of the large AVR near the high-backscatter region. Fault trends and relative sizes agree well with interpretation of SeaMARC II side-scan and usually trend approximately parallel to the general trend of the ridge. On the basis of biological colonization and sediment cover, the western limb of the bifurcated ridge appears to be younger than the eastern limb; however, neither limb exhibited fresh lavas.

Preliminary interpretation of CTD data collected suggests that colder water on the western side of the ridge (potential temperature 4.2 degrees) flows eastward through the basins between AVRs and interfingers with warmer water to the east (4.4 degrees), making it is very difficult to distinguish hydrothermal phenomena whose signatures are more commonly in the 0.02 degrees range. No hydrothermal sediments or temperature/salinity anomalies were found.

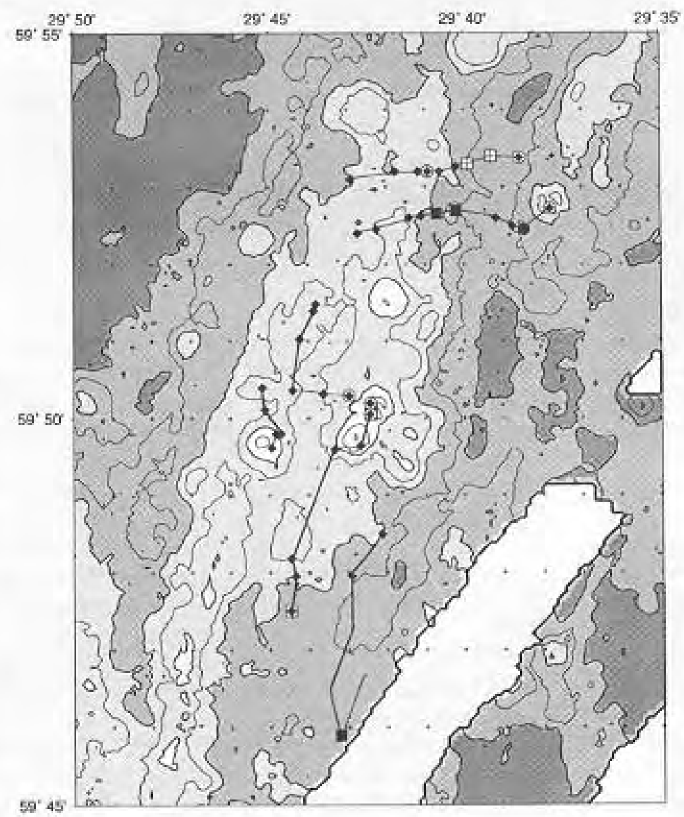

Figure 1. *Location of dives on the Reykjanes Ridge. Dark stippling is 1300-1500 m, moderate: 1100-1300 m, light: 900-1100 m and no stippling: 700-900 m. Symbols indicate type of sample recovered at that site. Diamond: rock sample; square: sediment sample; circle: water sample; cross: heat flow measurement; solid lines: dive tracks.*

Significant Findings and Preliminary Conclusions

(1) The only young lavas discovered were the unsedimented, glassy flow encountered on the flanks of a small volcano at the southern end of AVR-NE (Johnson, 1992). At an average sedimentation rate of 3 mm/1000 yr we would expect only about 0.1 mm of sediment cover on a three-year-old flow (the age of a flow related to the 1989 seismic activity). No evidence for ongoing or recent hydrothermal venting was found in the study area.

(2) The high backscatter region (imaged by SeaMARC II) is a smooth, sedimented plain colonized by round spiny sponges. Thus the acoustic energy which revealed the high backscatter area must have easily penetrated 20-40 cm of sediment, revealing an older lava flow beneath its surface. This shows quite clearly that SeaMARC II's side-looking sonars can penetrate one to two wavelengths of the sonar frequency (11-12 kHz) of sediment and reveal the hard seafloor below. These findings led us to conclude that the teleseismic swarm likely was caused by faulting or perhaps intrusive, not extrusive, activity further to the east along the ridge crest.

(3) Faults and fissures mapped from the submersibles correlate well with those interpreted from SeaMARC II images.

(4) In general, it appears that the

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smaller northern AVR (NE) is more active than the larger AVR (SW) and that the large size and rifted nature of AVR-SW suggests it is in the latter stages of its evolution as proposed by Murton and Parson (1991). Thus we speculate that the large, rifted AVR is no longer active, eruptions have ceased and the magma supply at this location along the Reykjanes Ridge will soon be taken over along strike by the smaller AVR on either end.

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Marine Geophysical and Geological Investigations of Macquarie Ridge, Macquarie Island and the Macquarie Triple Junction

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Introduction

Despite accelerating focus on the Mid-Atlantic and East Pacific Rise spreading center systems, the Southern Ocean remains poorly studied, and few future programs are currently in place to amend this situation. Eastward along the Southeast Indian Ridge from the Australian - Antarctic Discordance, past the Macquarie Triple Junction, and along the southern end of the Pacific - Antarctic Ridge, more than a 10,000km length of spreading centres is essentially unsampled and unstudied since the pioneering work using R/V *Eltanin* more than 25 years ago (Hayes and Talwani, 1972). Here, we provide some background to several new marine geophysical research programs in the vicinity of the Macquarie Ridge and the Macquarie Triple Junction, as well as for on-going geological-geochemical studies on Macquarie Island, itself an in situ ophiolite.

The Macquarie Ridge System - Structure and Tectonics

At the Macquarie Triple Junction, the Macquarie Ridge intersects the main global spreading ridge system approximately 1000km south of New Zealand, at the boundary between the Antarctic, Pacific and India-Australia plates (Fig. 1). Macquarie Ridge itself is a ~ 2000km-long complex feature consisting of a broadly continuous series of bathymetric highs with troughs that occur on alternate sides of the ridge; bathymetric data defining the ridge area are relatively sparse, and the detailed structure of the ridge is poorly known. Macquarie Ridge has been proposed to be the site of incipient subduction. Of particular importance in the context of InterRidge is Macquarie Island, politically a part of the Australian state of Tasmania, and perhaps the least ambiguous and best exposed ophiolite on Earth.

The regional pattern of seafloor magnetic anomalies is summarized schematically in Figure 1. West of the Macquarie Ridge and south of 48°S, the quite well-defined anomalies strike ENE and were produced at the Indian-Antarctic Ridge from Anomaly 21 (52 Ma) until present day. Zero-age crust at this spreading centre abuts the Macquarie Ridge at the Macquarie Triple Junction, and Macquarie Island itself falls on an extrapolation of Anomaly 7-8 (26-28Ma). East of Macquarie Ridge, the oldest clear magnetic lineations are Anomaly 34 (80Ma), immediately south of the Campbell Plateau; these trace back to zero-age crust being →

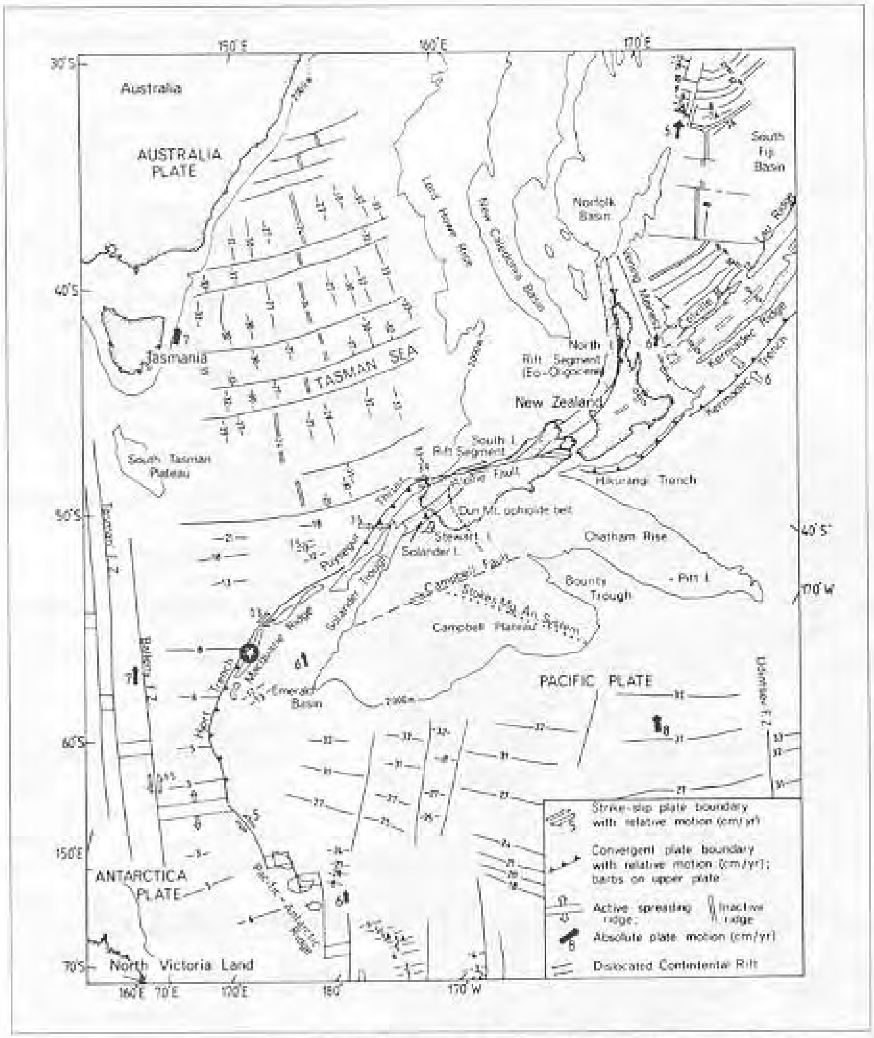

Figure 1. *Tectonic setting of the Macquarie Ridge and Macquarie Island (star) showing regional seafloor magnetic lineations, arrows indicating absolute plate motion vectors nd regional tectonic features (modified after Kamp, 1986).*

erupted on the Pacific-Antarctic Ridge, the site of highly oblique and complex spreading. A few weak and tentatively identified magnetic lineations (suggesting early Eocene ages) occur at the western edge of the Emerald Basin just east of the Macquarie Ridge. Williamson (1989) suggests that these may be artifacts of complex ridge-trough seafloor structure in this area rather than normal polarity reversals.

Plate motion models, magnetic lineations and seismic studies suggest that the Macquarie Ridge is transient and tectonically complex. It has had a complicated tectonic history over at least the last 20 m.y. It is presently an oblique right-lateral convergence zone (De Mets et al. 1990; Williamson, 1989; Ruff et al. 1989) with high seismicity levels (including the largest earthquake in the 1980's). This is largely due to the fact that the position of the Pacific-Australia relative motion pole (currently 60.1°S, 178.3°E) has been close to, and migrating south along, the Macquarie Ridge plate boundary over the last 10my, resulting in rapid changes of relative motion of the two plates along the Macquarie Ridge. Currently, a compressive component of motion exists across the Alpine Fault Zone in South Island New Zealand, and is apparently manifested by broad-scale crustal shortening and mountain building (Walcott 1978). Where the plate boundary runs offshore south of Fiordland, intermediate depth seismic activity presumably indicates that a relatively mature subduction environment may now exist at the northern end of the Macquarie Ridge system. Although a volcanic arc has not yet developed, Solander volcano off the southern coast of New Zealand may be a first manifestation of a future volcanic arc.

North of 50°S, the Puysegur Trench (Thrust) occurs to the west of the ridge (Fig. 1), and earthquakes with shallow-dipping reverse mechanisms indicate that the Australian plate is being subducted under the Pacific plate. This section of ridge developed at an Oligocene spreading centre, and the presently observed oblique convergence may have persisted since Miocene time. South of 58°S, the 6km deep, 300km long, arcuate Hjort Trench lies immediately west of the Macquarie Ridge (Fig.1). Young lithosphere is present to the west, and older lithosphere to the east, although no continuous bathymetric rise is associated with the trench, which shallows to the north and south, and does not extend to the triple junction. Relative plate motion in this region also has a large component of convergence, although poor definition of Pacific-Australia and Pacific-Antarctic ridge segments dictates that it is not possible to determine from plate geometry and triple junction stability constraints, whether the Australian plate is subducting beneath the Pacific plate, or vice versa (Ruff et al. 1989). Weissel et al. (1977), and Ruff and Cazenave (1985) suggested that shorter magnetic lineations on the Australian plate might indicate that some Australian plate oceanic crust is missing, presumably subducted beneath the Pacific plate along this trench.

The present tectonic setting of the Macquarie Ridge is one of oblique convergence with an increasing thrust component going northward from the triple junction. Subduction initiation appears to be occurring, and is reflected in the seismicity of the region, which consists mainly of numerous low-angle thrust events; however, most of the seismic moment is released in a few great right-lateral strike slip earthquakes, such as that on May 23rd, 1989 (M=8.1). Ruff et al. (1989) have argued that the Macquarie Ridge is best considered to be a 'soft' and transient plate boundary that must accommodate the plate motion mismatch between two major spreading centres (Antarctic-Australia and Pacific-Antarctic), which originally developed independent of each other.

Future and On-Going Study Programs

Several research projects have commenced on the Macquarie Ridge region, and several major marine geophysical programs are timetabled for 1993-94-95. Below, we provide some background and further details of these studies.

The Macquarie Triple Junction

Several marine geophysical cruises over the Macquarie Triple Junction have been carried out since 1988 by the

Osservatorio Geofisico Sperimentale (Trieste, Italy), using the R/V *OGS Explora*. During these cruises, multi-channel seismic, gravity, magnetics, and multibeam bathymetric data have been gathered in order to clarify the plate kinematics and structure in the vicinity of the triple junction. These data strengthen the conclusion that the triple junction is R-F-F type (the Hjort Trench loses definition some 200km north of the triple junction), and show that the Pacific-Antarctic Ridge is spreading around 32-34 mm/yr. They also show that the outer wall of the Hjort Trench is quite deformed, and clearly under compression. Drs. Emanuele Lodolo and F. Coren (OGS) have proposed another cruise (dependent on funding) in the triple junction area to further test whether the Hjort Trench is the site of incipient subduction. Patrick Quilty (Australian Antarctic Division) and David Christoffel and Robin Falconer (DSIR New Zealand) are collaborating with the Italian group on this program.

Macquarie Ridge, 50°S and 58°S

NSF plans to fund a marine geophysical program proposed by Mike Coffin, Cliff Frohlich and Paul Mann (UTIG), Garry Karner and Nancy Breen (LDGO) and Sandy Shor (HIG) to investigate the structure and tectonics of a 900km length of the Macquarie Ridge between 50°S and 58°S. Major aims of this proposal are to:

1. determine modes and mechanisms of deformation along the ridge,

2. test a 'paired bends' model of transform boundary evolution that builds upon a model suggested by Christoffel and van der Linden (1972), and predicts restraining bends characterized by oblique subduction alternating with releasing bends marked by pull-apart basins; and

3. test two models for subduction initiation: the 'diffuse' thrusting model that predicts widespread thrusting which eventually coalesces into a single major thrust fault, and the 'discrete' thrusting model that predicts nucleation of thrust faults into a pre-existing fracture zone.

To achieve these aims, sidescan sonar - bathymetric swath mapping (HAWAII MR1), magnetics, 6-channel seismic reflection and gravity data will be collected along the Macquarie Ridge. Existing regional earthquake data will be reviewed, and teleseismic data will provide information on the location and character of active faults on the plate boundary. Five long (~400km) gravity profiles perpendicular to the strike of Macquarie Ridge will be acquired, and gravity and topographic data will be used in modelling to constrain the amount of shortening.

Ship time for this program is presently set at Dec/Jan 1993/4. In addition to the proponents, it is possible that several Australian and New Zealand geologists-geophysicists will take part in this cruise. Robin Falconer (GeoResearch Associates in NZ) has been compiling available bathymetric data for the Macquarie Ridge region and hopes to soon be able to produce a regional bathymetric map. Prof. R. Arculus (U. of New England, Australia) and Drs. R. Varne and T. Crawford (U. of Tasmania) maintain a strong interest in the petrogenesis of the rocks that constitute the Macquarie Ridge, and hope eventually to use an Australian research vessel for sampling and surveying of the ridge, both north and south of Macquarie Island. A joint Australian-Russian cruise to the central portion of the Macquarie Ridge, involving the Vernadsky Institute of Geochemistry (Moscow) vessel R/V Boris Petrov (chief scientist Leonid Dmitriev) has been planned, but has been postponed due to funding cuts affecting both countries.

Macquarie Ridge, 45°S - 50°S

Also recently funded is a French program that will extend marine geophysical surveying from the east coast of New Zealand down to almost 50°S on the Macquarie Ridge. This Geodynz-Sud cruise (co-chiefs Jean-Yves Collot and Jean Delteil) is proposed by the Institute Geodynamique de Sophia-Anapolis of IFREMER, and ORSTOM, in collaboration with the New Zealand DSIR and several New Zealand universities. In this region, the Geodynz-Sud cruise will examine the tectonic transition from relatively well-developed subduction beneath South Island New Zealand, to the oblique convergence boundary along the Puysegur Trench. Using R/V L'Atalante, with a crew of nine French and six New Zealand scientists, the cruise will gather multibeam ba-

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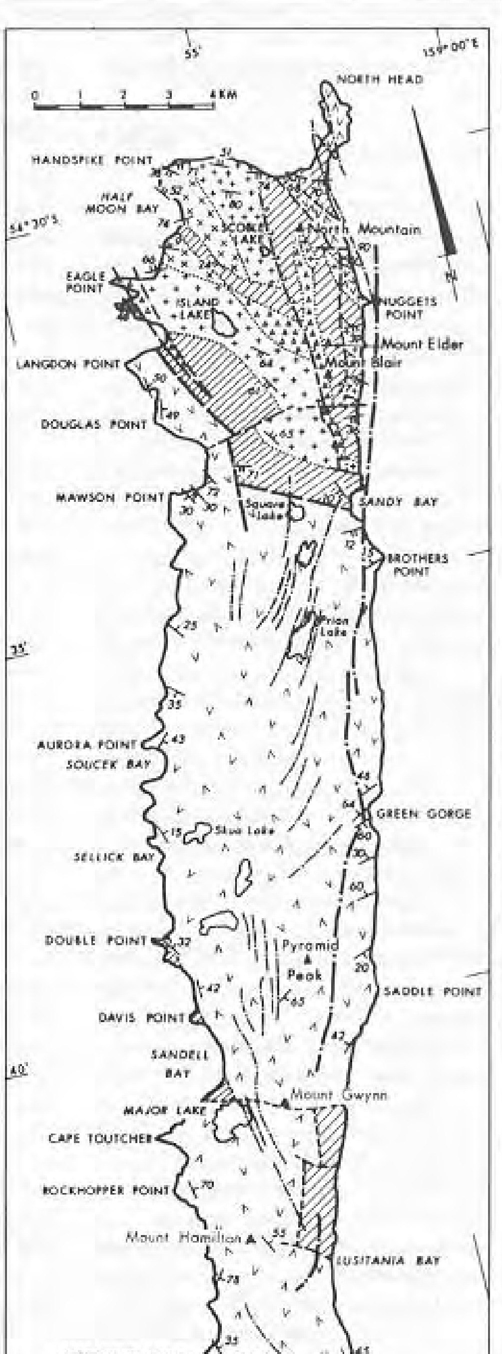

***Figure 2.** Geological map of Macquarie Island (from Duncan and Varne, 1988). Open triangles are serpentinized peridotites, crosses are layered gabbros, pluses are other gabbroic bodies, diagonal ruling shows dolerite dyke swarms, and random v's show volcanics and associated sediments.*

thymetry data, 6 channel seismic reflection, gravity and magnetic profiles. It is currently proposed to take place in mid-1994.

Macquarie Island

Macquarie Island lies on the Macquarie Ridge ~1100km SSW of the southern tip of New Zealand. It is elongated NNW along the ridge axis, and is 37km long and up to 5km wide. Paleomagnetic pole positions derived from the island indicate that it is part of the Indian - Australian plate, and regional tectonic considerations suggest that, unlike further north or south along the ridge where incipient subduction is east-directed, it appears to be west-dipping beneath Macquarie Island. Reconnaissance geological mapping (Varne and Rubenach 1972; Griffin and Varne 1980) shows that the entire island is composed of basalts, dolerites, gabbros and serpentinized peridotites (Fig. 2). Eastward extrapolation of magnetic anomalies 7 and 8 onto the island would suggest ages for these basalts of around 26-28Ma. However, poorly preserved coccoliths from inter-pillow calcareous oozes suggest an Early, or perhaps Middle Miocene (23-15Ma) age for the basalts (Quilty et al., 1973). To further complicate matters, Ar-Ar ages on several basalts and dolerites from the island yield younger ages again (9.7-11.5Ma; Duncan and Varne, 1989), suggesting some complexity in the lava sequence that dominates most of the island.

A hint that the magmatic history of Macquarie Island basalts may not be as straightforward as that for typical spreading center-generated MORB is given by some new major element analyses of fresh pillow rim glasses and the occurrence of occasional kaersutite phenocrysts in some of the basalts, including that dated by Duncan and Varne (1989). The existence of basaltic liquids with >6% MgO ranging from very depleted N-MORB compositions to samples with K_2O and P_2O_5 contents up to 2% and 0.7% respectively indicates major involvement of an OIB source component in the petrogenesis of these basalts. In addition, a significant number of the basalts analyzed by Griffin and Varne (1980) have Nb contents (10-60ppm) well above the typical range (2-10ppm) for N-MORB, and Zr/Nb values from 3-10. Such high Nb contents and low Zr/Nb values demand the presence of a significant ocean island basalt (OIB) component in the Macquarie Island basalt pile. On-going work is aimed at identifying that component, and determining the timing and extent of its involvement in the petrogenesis of the Macquarie Island magmas.

It has been suggested (Yan, 1991; Lanyon et al., 1992) that a mantle plume formed a hot-spot track defined by submarine seamounts extending from just east of Tasmania around 40Ma, to the presently active Balleny Island volcanoes just north of the Ross Sea in Antarctica. This plume was over-ridden by the Indian-Australian Ridge, probably around 17-15Ma according to the plate motion model of Yan and Kroenke (L. Kroenke, pers. comm. 1992), and Macquarie Island oceanic crust may have been generated at a plume-contaminated ridge segment at this time. Gill and Collerson (1992) and Lanyon et al. (in press) have shown that the Balleny plume, as indicated by Balleny Island lavas, has a characteristic HIMU isotopic signature. Unpublished Nd-Sr-Pb isotopic data for a series of lavas from Macquarie Island (Ruth Lanyon, pers. comm. 1993) strongly support the contention that these are mainly HIMU OIB-source contaminated MORB.

Macquarie Island provides the opportunity to walk across a dissected pile of plume-affected, ridge-generated MORB for which the gabbroic crustal section, and some of the mantle section, is exposed for sampling. Petrologists and geochemists from the University of Tasmania (Rick Varne, Tony Crawford, Ruth Lanyon, Vadim Kamenetsky) are working on the Macquarie Island basalt-dolerite-gabbro-peridotite sequence, in collaboration with micropalaeontologist Pat Quilty (Australian Antarctic Divn.) and geochronologist Bob Duncan (Corvallis) to clarify the age of the ophiolite, identify the magmatic components, and contribute to the regional tectonic understanding of the Macquarie Ridge. Structural petrological studies of high-T shear zones on the island should be revealing with regard to the changing kinematic regime of the central part of the Macquarie Ridge, and will complement data obtained from remote imaging of the submarine section of the ridge.

Any person interested in further information about future activities in the Macquarie Ridge region is invited to contact the authors, or proponents identified in this article.

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Initial Results of Drilling Actively Venting Massive Sulfide Structures on the Endeavour Segment, Juan de Fuca Ridge

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In October 1991 detailed sampling of active vent sites on the Endeavour Segment of the Juan de Fuca Ridge was carried out using ALVIN. The sampling strategy for chronology and mineralogy studies required the development of a small diamond-bit drill that could be deployed from the submersible (Stakes et al., 1992). The drill is hydraulically powered with pilot control on rotational speed, fluid circulation flow and weight on bit. The latter is obtained by observing the compression of a calibrated spring placed behind the hydraulic motor. The drill assembly, attached to the port side of the basket, includes a rigid frame to provide lateral stability and a hydraulic cylinder to provide forward (and reverse) thrust.

The drill allowed sampling of the previously inaccessible vertical sides of the vent structures. In general the massive sulfide edifices at the Endeavour Main and High Rise Fields rise 10 to 40 meters above the seafloor, and are 10 to 30 meters wide (Delaney et al., in press; Stakes et al., 1992; Robigou et al., in prep.). Multiple flanges protrude from the sides of the edifices, and vigorous black smokers exit from the tops of the structures. Cores were recovered from the massive vertical sides of five different sulfide structures. The drill has also been successfully deployed on two subsequent cruises, recovering cores that measure up to 48 cm in length through the walls of active black smoker chimneys and through portions of basalt exhibiting throughflow of hydrothermal fluid.

The drillcores from the Endeavour Segment offer a unique representation of the mineralogically complex walls of the vent structures. Four of the cores were recovered from the base of the structures, and two were recovered midway up the sides of the structures. The cores varied in length from 16 to 30 cm, and most included continuous pieces that permitted polished thin sections to be made along the length of the core as well as from cross sectional slices of the core. For each polished section, a matched slab was cut for sulfur isotope analyses to be done using the laser probe facility at the U.S. Geological Survey/Reston. Petrographic and isotopic analyses are underway on these sections. A quarter of each core has also been preserved for trace element analyses. In general the mineralogy of the cores is dominated by pyrite and marcasite with local concentrations of wurtzite and/or sphalerite and chalcopyrite, trace amounts of galena, cubic cubanite, and barite, and varying amounts of amorphous silica, always as the latest mineral phase to precipitate. Texturally and mineralogically the cores are similar to samples recovered in a dredge from the Main Field in 1982 (Tivey and Delaney, 1986). Below is a summary of preliminary petrologic observations obtained on four of the drillcores.

Two cores were recovered from the Godzilla edifice at the northern end of the High Rise Site (Robigou and Delaney, 1991; Robigou et al., 1992; Stakes et al., 1992). The first (2460-C01) was taken at the base of the structure, and the other (2464-C01) was recovered midway up the wall of the structure, 15 meters above the seafloor. The first core was 20.8 cm long. It is composed dominantly of pyrite and marcasite with large but varying amounts of wurtzite, sphalerite, and amorphous silica. Chalcopyrite is present in minor amounts, and galena and cubic cubanite are present in trace amounts. Barite is absent, but textural evidence indicates that it has been replaced by pyrite at the end of the core toward the interior of the structure (hereafter referred to as the interior end), and by amorphous silica at the end toward the structure's exterior (the exterior end). Trends along the length of the core include lesser amounts of wurtzite versus sphalerite, greater amounts of amorphous silica, and lesser amounts of void space toward the exterior end of the core.

The second core recovered from Godzilla, 2464 C01, was drilled from what appeared to be the scar, or attachment point, of a flange that had fallen from the structure. This core was 25 cm long. The exterior end is dominantly composed of wurtzite and/or sphalerite with minor amounts of silica, chalcopyrite, pyrite and marcasite, and trace amounts of barite. Mid-regions of the core are composed dominantly of pyrite and marcasite with large amounts of late stage silica. Large circular voids surrounded by iron sulfide aggregates are tentatively identified as preserved worm tubes. Toward the interior end of the core, pyrite and marcasite dominate. Large amounts (10-15%) of wurtzite, sphalerite, chalcopyrite, and silica are also present. The interior end of the core exibits a void infilled with large grains of zinc sulfide with inclusions of chalcopyrite. Chalcopyrite dominates in this portion of the core, and is present filling void space. The silica present in this core differs signicantly from the amorphous silica present in most of the other cores. In some areas it exhibits a radial texture, and a distinct yellow to brown coloration. This coloration becomes increasingly dominant toward the interior end of the core.

Core 2463 C01 was sampled from an inactive mound east of the Ventnor edifice in the High Rise Field. This core was 23 cm long. It is dominantly composed of chalcopyrite, pyrite and marcasite. Also present are small amounts of amorphous silica, wurtzite and sphalerite, covellite, and digenite. The exterior end of the core exhibits a texture of uniformly distributed, anhedral to massive chalcopyrite, euhedral to subhedral crystals of pyrite and marcasite, and small grains of covellite rimming and included in chalcopyrite. Mid-regions of the core exhibit larger crystals and less void space than at either of the two ends. The interior end of the core exhibits greater amounts of covellite and amorphous silica than in the rest of the core, and mineral aggregates are smaller in size as compared to in mid regions of the core.

One core, 2466 C01, was recovered from the Main Field, from the base of the

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Hulk edifice (Delaney et al., 1992). This core was 21 cm long. Pyrite and marcasite are the dominant minerals present, with minor amounts of wurtzite and/or sphalerite and trace amounts of galena also present. The exterior end of the core exhibits feathery barite laths intergrown with dendritic iron sulfide. In some areas barite has been replaced by amorphous silica. In mid regions of the core some of the silica exhibits a radial texture and yellow coloration similar to 2464-C01. Pyrite and marcasite exhibit massive, botryoidal, and dendritic textures, and sphalerite and/or wurtzite exhibits chalcopyrite disease. The interior end of the core is dominated by pyrite and marcasite which exhibits both dendritic and botryoidal texture. The silica in this portion of the core is clear and amorphous.

In summary, the cores provide much textural diversity resulting from the dynamic construction of the edifice wall. Porosity varies from <10 to 40%. Mineralogy is dominated by pyrite and marcasite. Amorphous silica is always present as the latest mineral phase, and varies in abundance from 1 to >50 volume %. In two of the cores some of the silica exhibits a yellow to brown coloration. Trace element analyses of this silica is in progress. There is textural evidence of relict worm tubes that have been overgrown by wall construction, and of replacement of barite by both iron sulfide and amorphous silica. Barite, a common mineral in smaller inactive structures in this area (Redding, 1992; Tivey et al., in prep), is only present in the outermost layer of the edifices where it occurs as laths intergrown with marcasite and pyrite.

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Gold Mineralization in Seafloor Spreading Centres of the Western Pacific

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Since 1986, a number of sulfide deposits have been located in seafloor spreading centres of the western Pacific. Thse include the Lau Basin, North Fiji Basin, Manus Basin, Mariana Trough, Okinawa Trough, and the Western Woodlark Basin (Fig. 1).

Polymetallic sulfides from the Valu Fa Ridge in the Lau back-arc have revealed gold contents of up to 29 ppm Au with an average of 3 ppm Au (n=75). These samples are among the most gold-rich hydrothermal precipitates yet reported from the modern seafloor, and they are the first known examples of visible primary gold (up to 18 microns) in polymetallic sulfides at active vents (Herzig et al., 1990, in press). In the Okinawa Trough, gold-rich sulfide deposits with up to 14 ppm Au occur in a back-arc rift within continental crust and resemble Kuroko-type massive sulfides (Halbach et al., 1989; Urabe et al., 1990). Preliminary analyses of sulfides reported from the Central Manus Basin indicate average gold contents of 30 ppm Au (n=10) and maximum concentrations of more than 50 ppm Au. High gold contents up to 21 ppm Au have been found in barite chimneys in the Western Woodlark Basin, where seafloor spreading propagates into continental crust off Papua New Guinea (Binns et al., 1991). Sulfides in mature MORB-dominated back-arc settings such as the North Fiji Basin and the Mariana Trough contain only 0.1-1.7 ppm Au.

Gold appears to be most abundant in sulfides associated with immature seafloor rifts in continental or island arc crust. These settings are dominated by calc-alkaline volcanics including andesites, dacites, and rhyolites (i.e., Lau Basin, Okinawa Trough, Manus Basin, Woodlark Basin). Sulfide deposits related to mature back-arc spreading centres associated with MORB-type volcanics (e.g., North Fiji Basin, Mariana Trough) have gold contents which are more similar to sulfide deposits on the mid-ocean ridges.

Preliminary data suggest that the gold contents of back-arc lavas are not significantly different from those of ordinary MORB, and therefore these rocks probably do not represent an enriched source. However, the source-rock geochemistry is an important factor in controlling the composition of the hydrothermal fluids and their ability to carry gold and may be related to the buffering of the hydrothermal fluids during water-rock interaction. For example, the oxidation state of vent fluids on the mid-ocean ridges is strongly buffered by reaction with abundant FeO-bearing minerals in the rocks, and the inability of these vent fluids to become saturated with gold at high temperatures is a consequence of their low aO2 and strong redox buffering capacity. In contrast, vent fluids derived from the high-temperature reaction of seawater with more felsic lavas tend to be more oxidized and have a lower redox buffering capacity because of the lower abundance of FeO-bearing minerals in the rock. These more oxidized solutions may become saturated easily following a relatively small amount of conductive cooling, mixing, or oxidation of H_2S, and this may lead to the more efficient precipitation of gold. These observations imply that factors such as rock-buffering of the hydrothermal fluids may be as important as source considerations in generating gold-rich sulfides.

Processes which have been recognized as being important for gold enrichment in back-arc sulfides are likely to have played a role in the precipitation of gold in the ancient analogues of these deposits. Sulfide deposits in the western Pacific are indeed strikingly similar to some gold-rich massive sulfide deposits on land and may be better analogs for many ancient ore-forming systems than the deposits found on mid-ocean ridges. For example, Phanerozoic Kuroko-type deposist (Zn-Cu-Pb) closely resemble massive sulfide deposits in modern back-arc settings created by rifting of continental crust such as the Okinawa Trough, and sulfide deposits in the Eastern Manus Basin have many common characteristics with Archean Zn-Cu sulfide deposits such as the Noranda district of Canada.

Known gold-rich seafloor deposits in the western Pacific occur along the axis of a major gold belt extending from Japan through the Philippines, New Guinea, Fiji, Tonga, and New Zealand (Sillitoe, 1989). Although the porphyry-type stockworks and epithermal gold deposits in this region are

(Herzig and Hannington, continued on page 17)

Figure 1. *Sulfide deposits in seafloor spreading centers of the western Pacific.*

Revisits to the mid-Mariana Trough Hydrothermal Site and Discovery of New Venting in the Southern Mariana Region by the Japanese Submersible *Shinkai 6500*

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Mariana Trough is an actively spreading back arc basin behind the Mariana Trench where the Pacific plate subducts under the Philippine Sea plate (Fig.1). Horibe et al. (1986) found significant water column CH_4 anomalies above the mid-Mariana Trough, possibly due to hydrothermal activity, during the CEPHEUS Expedition of R/V *Hakuho Maru* (Ocean Research Institute, University of Tokyo, Japan) in 1982. Five years later, detailed bottom surveys using DSRV *Alvin* (Woods Hole Oceanographic Institution, U.S.A.) in the mid-Mariana Trough revealed the existence of hydrothermal activity with high temperature vent fluids (up to 287°C) and biological communities along the axial region centered on 18°13'N (the filled square in Fig.1) (Craig et al., 1987; Campbell et al., 1987; Hessler et al., 1988).

Since the *Alvin* surveys, however, no research submersible has visited this area for more than 5 years. Recent works have demonstrated that many submarine hydrothermal systems show not only spatial but also significant temporal variations (e.g., Baker et al., 1987; Lupton et al., 1989; Haymon et al., 1992). It is of much interest, therefore, to revisit the hydrothermally active sites in the mid-Mariana Trough to compare the present situations with those observed by *Alvin* in 1987. In addition, it is also of interest to visit the southern Mariana region where no submarine survey has been done so far.

The Japanese submersible *Shinkai 6500* (Japan Marine Science and Technology Center: JAMSTEC) was available for those purposes. *Shinkai 6500* and her mother ship *Yokosuka* (e.g., Auzende et al., 1992) surveyed the Mariana area between November 5 and December 1, 1992 (Y9204 cruise). Preliminary results of this

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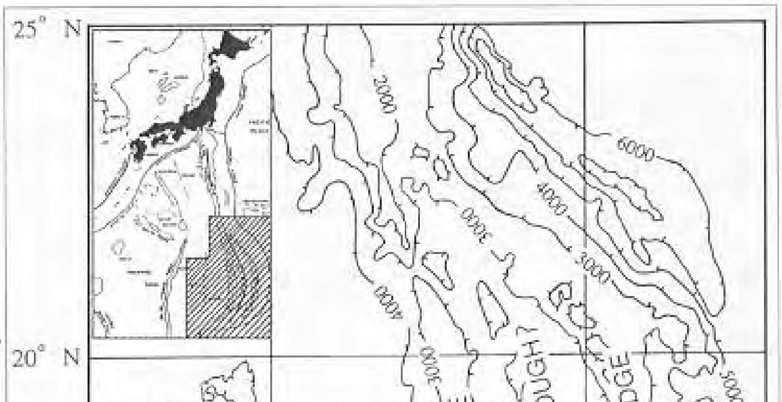

Figure 1. A topographic map of the Mariana area showing the locations of ten dives (#152-#161) of the submersible Shinkai 6500. Contours are every 1000 meters.

cruise are presented in this article. Eleven Japanese and five U.S. scientists participated in the cruise. We had 10 dives of *Shinkai 6500*, for the purpose of geochemical, geophysical, geological, ecological, and microbiological studies. As shown in Figure 1, five dives (#152 to #156) were devoted to revisits to the mid-Mariana Trough hydrothermal site called Alice Springs field (18°12'N, 143°30'E), which was found by *Alvin* in 1987, three dives (#157 to #159) were for the surveys of the landward slope of the southern Mariana Trench, and the rest two dives (#160 and #161) were performed in the southern Mariana Trough backarc basin.

We referred to the SeaBeam bathymetric map of the mid-Mariana Trough which was obtained during the *Hakuho Maru* KH92-1 cruise (Segawa, 1993; Kong et al., 1992). Alice Springs field was precisely located and transponders were deployed during the previous Y9203 cruise of the *Yokosuka* in September 1992 (Chief Scientist: H. Tokuyama, Ocean Research Institute, Univ. Tokyo). On the bottom of the #152 - #156 site, we found a marker plate with white letters of "R1" and an old ballast block with letters of "No. 29" which were probably released by *Alvin* . Active hydrothermal chimneys (Fig.2) were erupting clear solutions, whose maximum temperature was 280°C, almost the same value as was observed by *Alvin* (287°C) in 1987. Biological communities (hairy gastropod, crab, galatheid, shrimp, actinian, etc.) around the hydrothermal vents were examined in detail by S. Ohta (deep-sea ecologist), who dived the same site in *Alvin* in 1987. The density and biomass of the vent communities seemed to be similar to those observed in 1987, except for remarkable multiplication of a white whelk. The chemical characteristics of the 280°C fluid—pH(3.9), alkalinity(0.1mM), Si(12.3mM) and H_2S(2.5mM), which were measured on board *Yokosuka*—are similar to those observed during the *Alvin* dives (Campbell et al., 1987). Judging from the above shipboard data, it is likely that there is little significant change in hydrothermal activity between 1987 and this time at the Alice Springs field.

In addition, the following experiments were done during the #152-#156 dives. Detailed bottom temperature distribution was measured for heat flux estimation in a way similar to that of Rona and Trivett (1992). A "vent-cap" from Indiana University was deployed above a hydrothermal vent for *in situ* bacterial growth with successful retrieval. Many basaltic rocks, chimneys, sediments, particles and biological samples were taken as well as fluid samples. Their analyses

Figure 2. Hydrothermal chimneys observed at the Alice Springs field during dive #152. Their heights are between 50 and 100 cm. Enormous gastropods (Alviniconcha Hessleri) are seen at the foot of the chimneys.

are underway in shorebased laboratories.

In the southern Mariana, we conducted detailed topographic surveys from the trench to the backarc basin using *Yokosuka's* multi-narrow beam system. Figure 3 is a simplified bottom bathymetric map of the southern Mariana Trough area obtained in this cruise. The backarc spreading axis is recognized from (13°35'N, 143°48'E) to (13°03'N, 143°40'E) with an offset at around (13°30'N, 143°47'E). A significant transform fault (shown by a dashed line in Figure 3) is evident from a lateral shift of the seamount at (13°09'N, 143°50'E). There are many seamounts in various sizes along the eastern side of the spreading axis, which may be a southern extension of the Mariana Island Arc. During dive #161, we found a new hydrothermal vent site at the summit of a seamount (13°24'N, 143°55'E; depth: 1,470 m) located ~9 miles eastward from the spreading axis. Clear solution (maximum temperature: 202°C) was emanating from white chimneys (Fig.4), which mainly consist of an-

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Figure 3. A topographic map of a part of the southern Mariana Trough area. The covered area of this map is indicated by the box in Figure 1. Contours are every 250 meters. The two thick arrows and the broken line show Shinkai 6500 dive transects (dives #160 and #161) and a transform fault, respectively.

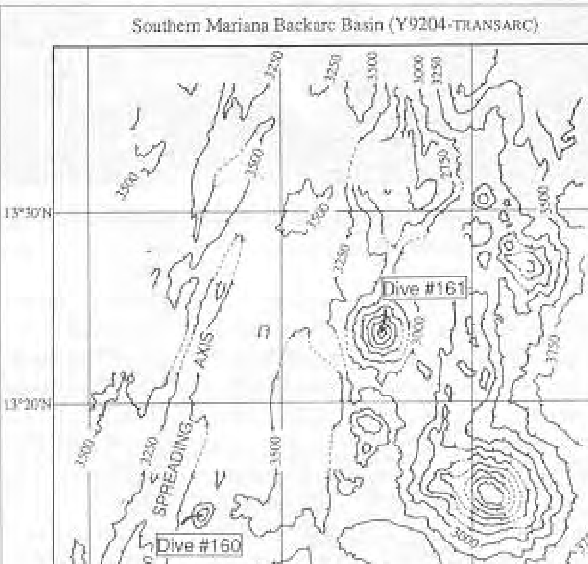

Figure 4. A hydrothermal chimney observed at the summit of the dive #161 seamount. The height of the chimney is about 1 m.

hydrite and barite, with much less abundance of sulfides than the chimneys from the dives #152-156 site. Although no hydrothermal activity was observed on dive #160 seamount (13°14'N, 143°46'E, summit depth: 2760 m), there is a fissure parallel to the spreading axis at the western foot of the seamount, which implies tectonic activeness of the spreading axis. Collected basalt rocks from sites #160 and #161 are in the course of chemical analysis. During dives #157 to #159, we took serpentinized harzburgites, basalt, and gabbro exposed on the southern Mariana Trench wall. These samples are expected to reveal the upper mantle characteristics in this area.

This study was performed as a part of the TRANSARC Program promoted by JAMSTEC. We thank K. Sakakura and the *Shinkai 6500* operation team, H. Hyodo and crew of *Yokosuka*, and H. Hotta and K. Fujioka of JAMSTEC for their valuable collaboration. H. Fujimoto kindly offered us the KH92-1 SeaBeam map of the mid-Mariana Trough. This study was partly supported by a grant-in-aid for the Scientific Research on Priority Areas "Ocean Fluxes" from the Ministry of Education, Science and Culture of Japan.

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News From FARA

(Projet Franco-Américain d'étude de la Ride Atlantique; French-American Ridge Atlantic Project)

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A FARA results and planning symposium, hosted by the U.S. RIDGE Office, was held at MIT in Cambridge, Massachusetts on November 8-10 and attended by 37 scientists from 14 institutions in the United States and France. J.R. Cann represented the United Kingdom community conducting expeditions within the same area of the MAR as the FARA Project.

The FARA project was initiated, and is organized, under the United States-France Cooperative Program in Oceanography to study the Mid-Atlantic Ridge between 15°N and 40°N. However, other InterRidge nations (UK, Portugal, Russia...) are carrying out their own ridge-crest research in the Central North Atlantic and are associated directly with FARA activities.

The FARA planning process resulted in a formal Project Plan, issued in 1989 and stating the scientific aims and logistical approach. Phase I of the project was to define the overall architecture characteristics with emphasis on their variability along a portion of ridge crest having the same spreading rate. These studies would then provide the necessary background for Phase II investigations, which would focus on smaller areas identified to be of particular interest, such as new hydrothermal sites, or on specific experiments such as detailed seismic investigations. The plan laid out general objectives. Funded work under the plan was to be proposed by independent investigators, with the proposals subject to the peer review process in each nation.

The program at sea began in summer 1991. Since then 12 cruises have been completed, most of which represented Phase I efforts (see Table 1). During this same period, three British cruises (*Charles Darwin* cruises 65, 76, and 77) were conducted within the FARA geographic window, between the Kane and Atlantis fracture zones. Preliminary results were reported at the 1992 and 1993 Fall Meetings of the American Geophysical Union and at the 1993 Spring Meeting of the European Union of Geosciences. Ten new FARA cruises are now funded (see Table 2). Some of these are Phase I efforts. Most are highly focused studies consistent with Phase II objectives. In addition a Portuguese cruise ("Escape") and a UK cruise ("Heat") are planned for the study of the Azores area within the context of the European Marflux Project. The MARK and TAG areas are sites for ODP drilling in 1993 and 1994 (legs 153 and 158 respectively).

Although seagoing activities are scheduled to end in 1994, it was agreed at the biannual bilateral meeting of the US-France Cooperative Program in Oceanography (Washington, DC, December 1992) that some final cruises under FARA may take place as late as, but not later than, 1995. The project will terminate with a general symposium currently planned for 1996.

Completed Seagoing Projects

Three of the 1991-1992 projects (Sigma, Seadma I, and EW-9210), taken

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Table 1

COMPLETED FARA PROJECTS

Date	Ship	Submersible	Name	Main Objectives	P / I	Main Area
1991	L'Atalante	-	Sigma	Underway multibeam and geophysics	H.D. Needham	41°-16°N
1991	L'Atalante	-	Seadma I	Underway multibeam and geophysics	P. Gente	On- and off-axis 23°-17°N
1992	*Knorr	-	-	Deep-tow side-scan/photography	J.R. Delaney/ F. Spiess	South side eastern end Kane F.Z.
1992	L'Atalante	Nautile	Faranaut	Observations/rock and water sampling	H. Bougault	Intersection areas 15°20'N F.Z.
1992	* L'Atalante	-	Dormasis	Multi-channel seismics	H.D. Needham/ F. Avedik	South Hayes F.Z. segment
1992	Ewing	-	CNR	Multibeam, MR1, underway geophysics	B. Tucholke	Off-axis to old crust North of Kane F.Z.
1992	Oceanus and Ewing	-	-	Passive seismic experiments	M. Purdy/ S. Solomon	Segments South of Atlantis and Oceanographer F.Zs.
1992	Ewing	-	9210	Multibeam/underway geophysics	J. C. Sempéré	On- and off-axis Atlantis F.Z. area
1992	Nadir	Nautile	Kanaut	Observations/rock sampling	J.M. Auzende	South side of eastern end of Kane F.Z.
1992	Atlantis II	-	Fazar	CTD/Zaps/water and rock sampling	C. Langmuir/ G. Klinkhammer	South of Hayes F.Z. to 42°N
1993	Atlantis II	Alvin	-	EM, fluxes, water sampling	R. von Herzen/ P. Rona	TAG
1993	Atlantis II	Alvin	Lucky Strike	Exploration of hydrothermal vents	C. Langmuir	37°15' N segment

*submitted pre-FARA

Table 2

SCHEDULED FARA PROJECTS

Date	Ship	Submer-sible	Name	Main Objectives	P / I	Main Area
May-June 1993	Knorr	-	ONR	Deep-tow geology/geophysics	B. Tucholke	Off-axis (W. side): 26°-27°N
June-July 1993	Atlantis II	Alvin	MAR	Biology	C. Van Dover	MARK and TAG
June-July 1993	Atlantis II	-	-	Fine Scale Rock Sampling	D. Desonie/ C. Langmuir	Night rock sampling during Van Dover Alvin program
June-July 1993	Charcot	-	MAR	Biology	A. Fiala-Médioni	Support ship for Atlantis/Alvin (above)
June-July 1993	Noroit	-	Seadma II	Petrology-rock sampling	M. Cannat/ C. Mével	South of Kane F.Z. on- and off-axis
July-Aug. 1993	Noroit	-	Geofar	Sediment coring/hydrothermal history	G. Auffret	Axial zone/Azores - 15°N
Sept -Oct. 1993	Nadir	Nautile	Gravinaut	Sea-floor gravity	J. Dubois	South of Kane and Intersection area
1994	Atlantis II	Alvin	* * *	Tectonics/Petrology	J. Karson	South Kane / Intersection area
1994	Nadir	Nautile	Diva 1***	Hydrothermal sites, petrology/structure	Y. Fouquet	Principally 37°15'N (Lucky Strike) segment
1994	Nadir	Nautile	Diva 2***	Biology	D. Desbruyères	- idem-
1994/95 (?)	M. Ewing	-	# # #	Crustal structure (seismic refraction)	R. Detrick *et al.*	Segments south of Oceanographer FZ

+++ To be rescheduled following interruption (for technical reasons) of April 1993 cruise *** Tentative : to be confirmed

funded but not scheduled.

together with previous work (e.g., Purdy *et al.*, 1990), have led to virtually continuous multibeam and routine underway geophysical coverage of the axial zone of the MAR over the whole length of the FARA area. Seadma I provided coverage out to 10 Myo crust between 20°N and 23°N; cruise EW-9210 carried out similar work between 29°N and 31°45'N to extend pre-FARA off-axis data between 28°N and 29°N; and ONR has mapped an off-axis corridor out to 30 Myo crust between 25°25'N and 27°10'N.

A 1992 US cruise ("Fazar") has provided densely spaced basalt samples for geochemical studies for all segments between 33° and 42°N, thereby complementing pre-FARA rock sampling efforts between 23°N and 33°N and between 15°N and 23°N. Furthermore, the Fazar cruise prospected for hydrothermal plumes using combined CTD and rosette sampling and the towed ZAPS vehicle. Thus, together with the results of work prior to FARA (the Jean Charcot cruise "Ridelente," which provided water samples from many segments between 23°N and 15°N), and with the most recent (1993) British expeditions to the 24-30°N area (CD 76 and 77), most of the axial zone of the Mid-Atlantic Ridge in the FARA latitude window has now been accurately sampled for rock and water on a reconnaissance basis. This effort has led to the identification of two new hydrothermal sites: the Lucky Strike site in the Exclusive Economic Zone (EEZ) of Portugal near 37°15'N (sampled during the Fazar cruise), and the Broken Spur site near 29°N (identified from transmissometer, temperature and manganese signals in the water column during the British cruise CD 76 in March, 1993).

Some Phase II-type studies were carried out early in the program because sufficient background data were already available. The southern Kane Fracture Zone wall was surveyed from R/V *Knorr* with a deep-tow instrument, and subsequently examined and sampled during a series of Nautile dives ("Kanaut"). Major crustal units were shown to be well preserved in the fracture zone walls. A submersible investigation ("Faranaut") of the Fifteen Twenty North FZ-Rift intersection areas and of the rift segment to the north of the FZ led to the mapping of large ultramafic outcrops and of large associated methane anomalies in the water column on the rift valley walls. A multichannel seismic reflection experiment ("Dormasis") and microseismicity experiment (R/V *Oceanus* and R/V *Ewing*) were made south of the Kane FZ and south of the Atlantis and Oceanographer FZ's respectively. Finally, a geophysical and fluid-sampling *Alvin* expedition to the TAG site was completed in late May 1993 and a short series of *Alvin* dives to the 37°15'N hydrothermal site has just ended as this FARA update goes to press.

Funded cruises and future objectives

Four main topics are identified at the Cambridge, MA meeting as being of primary interest for further detailed investigations: (1) hydrothermal studies, starting with the new site near 37°N; (2) segment variability with emphasis on end-member segments, particularly in the Hayes-Oceanographer FZ area; (3) further investigation of the geology of the unusual ridge segments linking with the Fifteen Twenty North FZ, and of the high methane/Mn water-column anomalies associated with them; and (4) off-axis MAR studies, to complete plate boundary investigations. In addition to actions under these themes, new studies (petrology/tectonics, gravity) of the MAR near, and south of, its intersection with the Kane FZ (MARK area) will build on and extend the mapping and sampling work already achieved in this best-known MAR area.

Most of the funded projects are Phase II research efforts. Some are a natural continuation of work that did not require Phase I results. Others extend upon new discoveries made during Phase I.

Hydrothermal studies. Understanding the nature and distribution of hydrothermal activity and associated biota and sulphide minerals along the MAR was one of the principal aims enunciated in the FARA project plan. Prior to 1992, only two hydrothermal sites with their associated fauna were known on the MAR (TAG and Snake Pit). The new site near 37°15'N (Lucky Strike) has a very different geographic and tectonic setting and very different physical characteristics: it is far from the two other sites; it is in relatively shallow water; it is on relatively enriched crust associated with hot-spot influence; it is located on a prominent central seamount in the rift valley. These differences lead to many questions concerning regional geological controls (e.g., water depth, segment style) on hydrothermal and biological activity that could not even begin to be addressed before. The site has the additional advantage that it is only a day and a half from a major port (Punta Delgada), which makes it a candidate for a long-term observatory on slow-spreading crust. The short *Alvin* dive program to the Lucky Strike vent site just completed will set the stage for the *Nautile* dive programs Diva I (geology and geochemistry) and Diva II (biology), tentatively scheduled to take place in 1994. In addition to these expeditions, biological studies of the previously known hydrothermal sites at Snake Pit and TAG are being pursued (see Table 2). At another scale, the "Geofar" cruise (summer 1993) will represent a Phase I exploratory investigation of the hydrothermal record preserved in recent sediments between 20°S and the Azores.

Contrasting segment styles. A second aim of Phase I studies was to define more precisely the properties of different segment types and styles and thus obtain new quantitative data necessary to guide and ultimately test theoretical models for the origin of ridge segments and their differences. For instance, the stretch of ridge from the rift south of the Hayes FZ to the Oceanographer FZ region has good examples of end-member segments in close proximity and thus provides a convenient natural experimental area to explore the differences in bathymetry and crustal structure, gravity, volcanic expression, chemical composition, and hydrothermal activity associated with contrasting ridge segments formed at a constant spreading rate. In particular, seismic experiments to determine crustal structure and crustal thickness are needed to investigate whether the apparent differences in magmatic budget are expressed at depth. One such cruise, using the refraction method, has now been funded. Detailed geological and sampling surveys are being considered with a view to identifying differing geological and volcanological characteristics of end-member segments in this area, and to examine whether and how these differences are expressed in the petrology and petrography of the recovered rocks.

Ultramafics and methane anomalies. The 15°N region has two characteristics that, at the present time, make it uniquely interesting in terms of our current understanding of ocean ridges: it has major outcrops of serpentinite, even away from the fracture zone, and it has a large water-column signature of high methane without high Mn, a different signal than is associated with known (hot) hydrothermal vents. The ultramafic outcrops provide a so-far-unparalleled window into the upper mantle beneath the MAR. Their existence calls into question most models of ocean crust formation, and raises the issues of how well-organized the 3D petrological structure of the crust is on a regional scale and what seismic crustal thickness actually means in such a complex and tectonically disrupted terrain as much of the MAR may be. At the Cambridge symposium, investigators interested in the ultramafics of the 15°N region and the elusive sources of fluids creating the high methane concentrations concluded that additional surface ship investigations were a necessary prelude to further submersible work in the region.

Off-axis studies. Numerous problems concerning formation of mid-oceanic ridges will not be solved as long as we concentrate exclusively on zero-age crust. For example, do ridge segments have a characteristic style that is long-lived, or do they progressively evolve from one end-member style to another? How stable is the segmentation pattern, and what causes it to change? Questions such as these are fundamental to an understanding of the growth of ocean crust and the processes that control its formation. They can be addressed only by comprehensive studies that add a fourth dimension to our knowledge of the narrow window of youngest seafloor. In 1993, ONR will conduct a deep-tow cruise to the western side of the Rift north of the Kane FZ between 26°N and 27°N, and which will follow up the 1992 general survey of this area.

Further information about the FARA project may be obtained from any member of the FARA Coordinating Committee*, from the US RIDGE Office, or from the InterRidge Office.

* *M. Cannat (Fr), J. Dubois (Fr), A. Fiala-Medioni (Fr), S. Hammond (US), C. Langmuir (US Co-Chair), R. Lutz (US), H.D. Needham (Fr Co-Chair), and M. Purdy (US).*

(Herzig and Hannington, continued from page 11)

associated with island arc volcanoes (as opposed to back-arc rifts), the close proximity of modern seafloor hydrothermal systems to these volcano-plutonic arcs is striking. Active seafloor hydrothermal systems may be operating on the submerged portions of some island arc volcanoes in the western Pacific, and the potential exists for the discovery of a gold-rich massive sulfide deposit with distinctive epithermal characteristics in this environment.

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World Ridge-Crest Cruises: 1993-1994

International ridge-related cruises*

Country	PI	Institution	Location	Research	Ship	Dates
Canada/ Australia	Binns/ Scott	CSIRO-Sydney/ U. Toronto	Eastern Manus Basin	PACMANUS II: camera/video, dredge, coring, CTD, hydrocasts of active vent field on Pual Ridge	FRANKLIN	June 93
Japan	Urabe	Geol. Soc. Japan	MAR 13°30'S - 19°S	Swath mapping, deep-tow (tow-yo) profiling w/chem. and phys. sensors, water/rk splg w/corer, geomag surv, OBS array	R/V Melville	Nov-Dec 93
Japan	Tamaki/ Fujimoto	Ocean Research Institute	Rodriguez TJ and Central Indian Ridge	Swath mpg, water splg, rk splg w/corer, geomag surv, shipboard grav. meas., earthq. obsv. and refraction crustal study w/OBS array, deep-tow TV obsv of hydr. colony	R/V Hakuho-maru	Jul-Sep 93
Germany	Thiede/ Wallrabe-Adams/ Lackschewitz	GEOMAR	Reykjanes Ridge between 58°-60°N	Sedimentation on ocean ridges	Russian vessel	mid- to end 93
France	Fiala-Médioni	INSU	MARK, TAG	Biology	Charcot	Jun-Jul 93
France	Cannat/ Mével	INSU/ U. Curie	S. of Kane FZ on- and off-axis *(Seadma II)*	Petrology, rock sampling	Noroit	Jun-Jul 93
France	Auffret	IFREMER/ Brest	MAR axial zone/Azores - 15°N *(Geofar)*	Sediment coring, hydrothermal history	Noroit	Jul-Aug 93
France	Dubois	IPG-Paris	S. of Kane and Intersection area *(Gravinaut)*	Seafloor gravity	Nadir/ Nautile	Sep-Oct 93
France	Fouquet	IFREMER/ Brest	Principally 37°10'N (Lucky Strike) segment *(Diva 1)*	Hydrothermal sites, petrology, structure	Nadir/ Nautile	1994
France	Desbruyères	IFREMER/ Brest	Principally 37°10'N (Lucky Strike) segment *(Diva 2)*	Biology	Nadir/ Nautile	1994
UK	Parson/ Murton	IOS-DL	Kane-Atlantis (KASP) *(BRIDGE Cruise 7)*	TOBI, dredging, water column	RRS C. Darwin	Feb 93
UK	Elderfield	Cambridge	Kane-Atlantis (KASP) *(BRIDGE Cruise 8)*	Dredging, water column	RRS C. Darwin	Apr 93
UK	German	IOS-DL	Reykjanes Ridge *(BRIDGE Cruise 9)*	Event detection	Bjarni Saemunds-son	Jul 93
UK	Murton	IOS-DL	Reykjanes Ridge *(BRIDGE Cruise 10)*	Swath, dredging, water column	RRS C. Darwin	Sep 93
UK	Sinha	Cambridge	Reykjanes Ridge *(BRIDGE Cruise 11)*	Seismics	RRS C. Darwin	Oct 93

* *Information requested from all InterRidge National Correspondents*

RIDGE cruises (US)

PI	Institution	Location	Research	Funding
Castillo/ Langmuir/Natland	SIO/LDEO/ RSMAS	EPR 30° - 65° S	Petrological investigation of Pacific-Antarctic EPR	MG&G
Childress	UCSB		Physiological ecology of hydrothermal vent chemoautotrophic symbioses	BO
Christie	OSU	SEIR 90°-120°E	Petrology/geochemistry	MG&G
Detrick	WHOI	MAR	Seismic tomography study of mantle Bouguer anomalies and crustal thickness MAR	MG&G
Hildebrand	SIO	EPR 9°50' N	Microseismicity of the EPR 9°50'N	MG&G
Jannasch	WHOI	MAR	Microbial ecology	BO
Lutz/Haymon/ Fornari	Rutgers/ UCSB/ LDEO-WHOI	EPR 9°N	Ecological succession and geology	BO
Van Dover	WHOI	MAR	Food-web analysis using multiple molecular and isotopic techniques	BO
Von Damm/Lilley	UNH/UW	EPR 9°N	Temporal evolution of hydrothermal, volcanic, and geological properties of EPR 9°N	MG&G
Vrijenhoek	Rutgers		Gene flow, dispersal and systematics of deep-sea vent organisms	BO

The U.S. National Science Foundation is also supporting other ridge-related cruises on these ridge sections: EPR (13); MAR (6); Juan de Fuca (6); PAR (2); Reykjanes (2); Chile (2); SEIR (1).

News from National Ridge Research Programs

BRIDGE (UK)

BRIDGE's profile has been high over the past few months, buoyed up with results from some extremely successful cruises as well as both scientific and planning meetings. Some highlights are as follows: the dates for the dry-docking of the RRS *Charles Darwin* for the fitment of the Simrad EM12 may be brought forward slightly. Fitting, commissioning and trials are now provisionally scheduled for between the 24/25 June and 21/22 August. (These dates to be confirmed.) The first BRIDGE cruise to use the system will be BRIDGE cruise 10, which will undertake a rock dredge probramme and surveying on the Reykjanes Ridge (4 September - 27 September; PI: Bramley Murton). The recent conversion at IOSDL of the United States Geological Survey's version of the GLORIA long-range side-scan system to acquire swath bathymetry data has been successfully tested by Dick Hey (SOEST, US) and Dave Naar (USF, US) during work on the EPR. The results look good - SeaMARC II-style data over a 24 km swath.

NERC have announced they have funds available during 93/94 for the building of a second TOBI vehicle. Provisional plans for the project are that the work will take place at IOSDL in collaboration with RVS personnel and with development/trials etc., this could take much of the year. There are no plans to include an optical fibre cable facility.

-- From BRIDGE News, April 1993 (Lindsay Parson, Editor; Cherry Walker, BRIDGE Coordinator). This issue also includes scientific articles, the BRIDGE Science Plan, meeting reports, cruises, MOR awards, and a BRIDGE diary. For further information about BRIDGE News or about other aspects of BRIDGE, please contact Dr. Cherry Walker at Department of Earth Sciences, University of Leeds, Leeds, LS2 9JT (tel: 532 335241; fax: 532 335259; e-mail: cherry@earth.leeds.ac.uk).

InterRidge/Japan

Start of the "Ridge-Flux" Project (1993-1997)

InterRidge Japan STA Sub-group: Melville cruise '93

Kiyoyuki Kisimoto and Tetsuro Urabe
Geological Survey of Japan Marine Geology Department

The "Ridge-Flux" (tentative name) proposal has been officially approved and funded by the Science and Technology Agency of Japanese government. The main purposes of this project are; 1) to observe and monitor the energy and mass flux from asthenosphere to earth's surface environment on the mid-oceanic ridge, and, 2) to compare the active ridge crest processes of the mid-oceanic ridges with that of the marginal basin systems. This project will be conducted as an international project with France (IFREMER, ORSTOM, and INSU), United States (NOAA), and others including SOPAC countries through InterRidge initiative.

The first seagoing work is scheduled in the area of the "Superfast" spreading center of East Pacific Rise (between Garrett Fracture Zone and Easter Microplate), using the R/V Melville from 23 November to 30 December, 1993. In the following year is planned the diving cruise of R/V Yokosuka with DSV "Shinkai 6500" and ROV "Kaiko" (depth limit 10km) at the same region.

Following is information about the Melville cruise this year.

Date & Port: From 23 November 1993 (San Diego, USA) to 30 December,1993 (Papeete, Tahiti) (38 days including 17 days of transit time)

Target area: Between 13.30°S - 19.00°S and 112°15'W - 113°45'W (Superfast EPR; ridge crest and adjacent area)

Survey items and personnel:

SeaBeam 2000 (T. Yabuki, T. Matsumoto)
Gravity and magnetics (T. Yamazaki)
Tow-yo Survey, Hydrocast (E. Baker, G. Massoth)
OBSs (K. Kisimoto, A. Nishizawa, Y. Kaiho)
Rock coring (and rock grab) (T. Shibata, K. Hirose)(Lab. Works)

On-board measurements:

(1) CTD (E. Baker)
(2) Transmissometer (E. Baker, T. Urabe)
(3) Scanner (G. Massoth)
(4) Eh (K. Nakamura)

On-board analyses (and on-shore):

(1) CH_4 and CO_2 (J. Ishibashi)
(2) Dissolved Fe and Mn (E. Nakayama)
(3) Dissolved Al (K. Shitashima)
(4) XRF analysis of particulate matter (K. Marumo, R. Feely)
(5) Dissolved DNA and microbiological studies (A. Maruyama and N. Ito)

Sampling

(1) ^3He (J. Lupton)
(2) Nutrients (R. Feely)

For further information (or official letter), write to Dr. Eiichi Kikawa, Ocean Development Division, Science and Technology Agency, 2-2-1 Kasumigaseki, Chiyoda, Tokyo 100 Japan (Fax: +81-3-3581-7442). Internet address: urabe@gsj.go.jp (after July 1st).

Research Plan: Rodriguez Triple Junction in the Indian Ocean

(Hakuho-maru KH93-3 Research Cruise)

Kensaku Tamaki and Hiromi Fujimoto
Ocean Research Institute, University of Tokyo

The KH93-3 Research Cruise by Hakuho-maru is the first intensive seagoing research at mid-oceanic ridges conducted by the Japanese scientist group. The shiptime for this cruise was endorsed on behalf of the InterRidge/Japan Project by the Ocean Research Institute, University of Tokyo. The target survey area is a 1-degree box at Rodriguez Triple Junction in the Indian Ocean. Port calls of the cruise are as follows: leaving Tokyo on July 8, 1993, Singapore from July 17 to 21, Mauritius from August 10 to 14, Penang from September 2 to 6, and arriving at Tokyo on September 17. Co-chief scientists are Kensaku Tamaki and Hiromi Fujimoto of Ocean Research Institute, University of Tokyo. Thirty five scientists on board compose five research groups: mapping geophysics, seismology, petrology, water chemistry, and benthic biology. The mapping geophysics group is directed by K. Tamaki and H. Fujimoto, the seismology group by Kasahara and N. Hirata (both at Earthquake Research Institute, University of Tokyo), the petrology group by N. Fujii (ERI), T. Ishii (ORI), C. Langmuir (LDEO), the water chemistry group by T. Gamo (ORI), and the biology group by S. Ohta (ORI). Three graduate students will participate in the cruise from the UK, France, and the United States. The R/V Hakuho-maru of Ocean Research Institute has the size of 3,980 tons and she is fully suitable for above multidisciplinary research groups all through the cruise.

The Rodriguez Triple Junction is the world's most remarkable R-R-R triple junction. The three ridges are the Central Indian Ridge, Southwest Indian Ridge, and the Southeast Indian Ridge. The triple junction was previously surveyed by the GLORIA system of the UK group and the SeaBeam system of R/V Jean Charcot. We plan to conduct all the principal surveys in the area previously mapped by R/V Jean Charcot. Eighteen OBSs (ocean bottom seismometers) are deployed around the triple junction in a 1-degree box and shot around by a large airgun array to get three dimensional crustal structure exactly on the triple junction. The OBSs stay on the floor about 20 days to record earthquake activity at the triple junction. Detailed bottom rock sampling at the exact spreading axes is conducted by using rock cores and dredges at 40 to 50 localities along three of spreading axes. Water sampling using a CTD-rosette water sampler is done at 15 to 20 localities along spreading axes to find hydrothermal activity at the spreading centers. Finally, a deep-tow TV system will finally be deployed at hydrothermal areas to observe vent biological colonies. As no biological vent colonies have been observed previously in the Indian Ocean ridges, this approach may be exciting for the ridge biologist community. In the mean time during the above observation, we will extend the geophysical mapping area around the 1-degree box

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by the SeaBeam system, gravity meter, proton magnetometer system, and three-component shipboard magnetometer system. The mapping is done with a ship speed of 17 knots.

We are now in a final phase of planning our research cruise. Please contact K. Tamaki (tamaki@aix3.ori.u-tokyo.ac.jp) or H. Fujimoto (fujimoto@aix3.ori.u-tokyo.ac.jp) for more details or on any matters on the above cruise.

CANRIDGE

Canadian Ridge News

Steve Scott (University of Toronto)
John Malpas (Centre for Earth Resources Research, Memorial University of Newfoundland)

Following the drilling activity on the Juan de Fuca ridge a year ago and the successful "corking" of hole 858, Canadian scientists and their colleagues have returned twice to retrieve data from the instrumented bore-hole seal. Video pictures show how successful this method of data collection can be and sets a future trend for on-site monitoring of ridge activity. Close by, Explorer Ridge, 200 km west of Vancouver Island, has been the focus of a concerted Canadian effort on the part of geologists, geophysicists, and biologists interested in ridge processes. The Canadian effort has entailed more than a dozen cruises to the area, and included government, industry, and university based scientists and international cooperation with U.S. universities and NOAA. The substantial data base that has been built up includes SeaBeam bathymetry, SeaMARC I and II imagery, magnetic, deep-tow camera and video, submersible operations with PISCES IV, dredging, sediment coring, and CTD/hydrocasts. The latest in a series of cruises (see last newsletter) was from July 6 to 19, 1992, as part of a coordinated research program involving the University of Toronto and the IOS Hydrothermal Vents Programme (Rick Thomson, Chief Scientist) of the Ocean Physics Division of IOS, Patricia Bay. Activities were centered on the Endeavour segment of the northern Juan de Fuca Ridge (IOS vents) and SER (CANRIDGE II and IOS vents). The major activity of the IOS vents programme was to obtain zooplankton biomass estimates using CTD/acoustic net tows with a deep tow platform (SCUID) towed at 2 knots from the surface to depths of 2500 meters parallel to the axis of the ridge and at off-ridge sites within 15 to 20 miles of the central hydrothermal vent sites. Hydrocasts to determine dissolved oxygen, nutrients, and other chemical constituents were taken separately. In order to determine the effect of 10 km scale topographic features on near-bottom currents, deep current meters were moored in a saddle between two large seamounts.

At SER, the primary activity was to map the distribution of the particulate plumes emanating from the "Magic Mountain" and "AGOR 171" hydrothermal vent sites that had been located on previous expeditions. This was accomplished by means of SCUID tows and conventional hydrocasts. The deep water samples were filtered through preweighed 0.4 micron Nuclepore membranes for determination on shore of the concentration of particulates and their composition and mineralogy. A series of ocean bottom magnetic and electromagnetic experiments were conducted at both the Endeavour segment and SER. Although two of the OBM lowerings obtained useful data, an attempted EM tow experiment was only partially successful but failed when the electrodes were ripped off by bottom obstructions.

At present, Canadian interests in ridge activity are clearly focused on the Juan de Fuca segment of the global system. However, as a result of the successful drilling of Hole 735B gabbros on the S.W. Indian Ridge by ODP, a Canadian/U.S. proposal is under development to return to that area to carry out detailed site survey observations with a view to future ODP drilling. The proposal is being developed by a number of collaborating scientists including Paul Robinson and John Malpas in Canada and Henry Dick in the U.S.

RIDGE

Conference Announcement

Third RIDGE Theoretical Institute

August 27 - September 3, 1993
Big Sky, Montana

Physical, Chemical, Biological, and Geological Interactions Within Seafloor Hydrothermal Systems

Convenors: J. Lupton, L. Mullineaux, and R. Zierenberg

Hydrothermal circulation at mid-ocean ridges is one of the fundamental processes controlling the transfer of energy and matter from the interior of the earth to the lithosphere and hydrosphere. Hydrothermal interactions influence the composition of the oceanic crust and the chemistry of the oceans. In addition, hydrothermal vent fields support diverse and unique biological communities by means of microbial populations that link the transfer of the chemical energy of dissolved species to the production of organic carbon. Traditionally, the physical, chemical, biological and geological sub-systems that constitute the hydrothermal circulation process have been studied in isolation. However, understanding the transfer and fluxes of mass and energy associated with these processes requires an integrated approach and the development of models that include the interactions between these subsystems.

The principal goals of the 1993 RIDGE Theoretical Institute will be to stimulate cross-disciplinary inquiry into the interactions within hydrothermal systems, and to encourage stronger links between biological/geological observations and the experimental and theoretical study of vents to focus future investigations on the problems that are critical to understanding the system as a whole. The Institute will comprise two parts:

- ***Short Course*** (August 27-31): open to all registered participants, the emphasis will be on defining outstanding problems and on identifying new information required to increase our understanding of these systems. Day 1 will provide an overview from theoretical, experimental and observational perspectives of the current state of knowledge of interactions within seafloor hydrothermal systems, and Days 2-4 will focus in turn on the interactions within the venting fluids, the associated deposits, and the hydrothermal plumes.
- ***Workshop*** (September 1-3): with limited attendance, the workshop will be designed to foster intensive scientific discussions and on-site computation and display of results for specific topics, and to encourage interdisciplinary approaches to research on hydrothermal systems.

Further information about the RIDGE Initiative. Questions concerning the RIDGE Initiative may be addressed to Dr. Susan E. Humphris at the RIDGE Office (Woods Hole Oceangraphic Institution, Woods Hole, MA 02543; Phone: 508-457-2000 ext. 3451; Fax: 508-457-2150; Internet: ridge@copper.whoi.edu).

DeRidge (Germany)

German Ridge Activities — Past and Present

Roland Rihm (Kiel, Germany)

A group of German geoscientists met on October 16, 1992, at GEOMAR research center in Kiel to discuss the German role in InterRidge and to initiate DeRidge, a German national program for ridge-related research. After a short presentation of the history of InterRidge (RIDGE, BRIDGE, InterRidge, meetings in Brest, Paris, and York) and of its structure and intentions (steering committee, InterRidge office, working groups, program plan, and proposed phases of implementation), specific past and present German activities and possible future contributions were discussed. Two key areas of most intense German ridge-related research were identified as the Red Sea and the northernmost Atlantic Ocean *(Reykjanes Ridge, Iceland, Kolbeinsey, and Mohns Ridge)*; other areas of strong interest have been the East Pacific Rise, Lau Basin, Indian Ridge/Rodriguez Triple Junction, Central Mid Atlantic Ridge, Juan de Fuca Ridge, Okinawa Trough, and Gulf of California. The majority of the research programs were carried out using the German RVs SONNE and METEOR, within the DSDP/ODP program or as participation in other international projects.

Recommendations for further German activities and contributions to InterRidge were decided (see Memorandum below) and include:

- full membership in the InterRidge program and its working groups and willingness to host the next InterRidge meeting,
- contributions to global mapping of the ocean ridges by cruises of RVs SONNE, METEOR, and POLARSTERN, and
- collection and synthesis of MOR-data, in the beginning focusing on one of the key areas, possibly the North Atlantic.

Memorandum of the DeRidge Working Group, Kiel, October 16, 1992

1. *German participation as a Principal member in InterRidge* is recommended.
2. German activities need some *national coordination.*
3. *National and international cooperation* is desired.
4. Importance of *systematic mapping* is emphasized.
5. German contribution to *technical innovation* is needed.
6. *Next InterRidge meeting* should be held in *Germany.*
7. *Support* for the *DeRidge* initiative is requested.

DeRidge Community Directory

Scientific Community

- Univ. **Kiel**: Geological-Palaeontological Inst.: *F. Stoffers, D. Mertz* (Hydrothermalism, Petrology)
- Inst. for Geophysics: *F. Theilen, S. Neben*
- GEOMAR, **Kiel**: *H.-U. Schmincke, J. Thiede, H.-J. Wallrabe-Adams, K. Lackschewitz, S. Straub, P. Rihm, H. Bäcker* (Volcanology/petrology, sedimentology, geophysics, marine technology)
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- Inst. f. Biogeochemie und Meereschemie: *W. Michaelis*
- BGR, **Hannover**: *H. Beiersdorf, U.v. Stackelberg, V. Marchig* (Geophysics, petrology, ore deposits)
- Univ. **Regensburg**: *K.C. Stetter* (Microbiology of hydrothermal vent areas)
- Univ. **Bremen**: *U. Bleil, V. Spieß, H. Villinger* (Geophysics)
- AWI, **Bremerhaven**: *Schenke* (Geophysics)
- RWTH, **Aachen**: *W.L. Plüger, P. Herzig, D. Schöps* (Mineralogy, ore formation)
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- Univ. **Marburg**: *W. Tufar* (Mineralogy, Petrology)
- Univ. **Karlsruhe**: *H. Puchelt* (Geochemistry, ore deposits)
- TU **Berlin**: *P. Halbach* (Mineralogy, ore deposits)
- Univ. **Greifswald**: *J. Mrazek* (Sedimentology, geochemistry)
- Berkakademie **Freiberg**: *O. Leeder, S. Uhlig* (Petrology, geochemistry)
- IOW, **Warnemünde**: *R. Endler, W. Lemke* (Sedimentology, physical properties)
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Notices & Announcements

InterRidge Meso-Scale Working Group
October 30-31, 1992; Cambridge, UK
Meeting Report

The meeting was attended by the following: Martin Sinha (Chair), Bob Detrick, Harry Elderfield, Takeshi Matsumoto, Catherine Mével, Roger Searle, Brian Taylor, and Cherry Walker (BRIDGE Coordinator).

The first issue addressed was the scientific objectives, as defined in the InterRidge Initial Program Plan. The three major scientific objectives (or themes) of the Meso-Scale studies were not changed, despite extensive discussion, but were modified and refined. Alterations made include the order in which the three will be addressed during the InterRidge program, and the actual titles of the three themes. The working gropu then addressed the necessary steps for implementation, and drafted amendments to Sections 3.3 to 3.5 of the InterRidge Program Plan.

Segmentation at MORs (theme A) is a well-studied aspect of MOR research in this area. The working group concluded that the InterRidge effort to address this theme should not simply be more mapping and sampling of any portions of the ridge, but should instead be in the form of a a coordinated set of actions to address a testable hypothesis. The hypothesis is that patterns of upwelling in the mantle beneath ridges perturb the thermal structure of the mantle; that this in turn affects both melt production rates and the rheology of the overlying lithosphere; that the resulting three-dimensional (and probably also time-dependent) patterns of melt production and lithospheric rheology affect both magmatism and the tectonic response of the newly created lithosphere to strains associated with spreading; and that the interactions between these tectonic and magmatic responses control the patterns of segmentation that we observe. The objective of the "segmentation" element of the Meso-Scale project is therefore to arrive at predictive numerical models of mantle behaviour at ridges, which can be tested successfully against observations of the patterns of segmentation of ridges under differing conditions.

The Working Group then concluded that, since a large volume of current work on this theme, including 3-D modelling of mantle flow patterns, is under way, the first step should be to hold an InterRidge Symposium over two days with about 70-100 participants to bring the InterRidge community up to date on recent progress and current work, and that this should occur prior to any segmentation workshop. At the symposium, the oral presentations should either be from invited speakers or carefully selected from the array of submitted contributions. This will focus the emphasis of the symposium towards the objectives of the segmentation theme within the Meso-Scale program. The Working Group also concluded that the Symposium should be immediately followed by a smaller Workshop lasting for one or two days, but with a smaller number of people involved (~30). The workshop will be concerned with defining the area(s), type of projects and experiments to be executed, and the role of InterRidge in the whole procedure.

The **Crustal Accretion in Back-Arc Areas** theme of the Meso-Scale project was also recognised by the Working Group as important to InterRidge. Two aspects of back-arc processes were identified as being of key importance. The first is the effect of the subducting slab on the mantle beneath the back-arc area — influencing the thermal and flow regime in which shallow-level melt production occurs, and introducing a deep source of slab-derived melt. The second is the recognition that both ophiolites and currently important economic ore bodies have much closer affinities to back-arc systems than to open ocean systems. However, despite our discussions, the specific objectives of the back-arcs theme remain to be defined. The Working Group therefore concluded that a small Workshop should be convened as soon as possible to define the most crucial scientific objective(s) for back-arc research to be coordinated by InterRidge. The Workshop should consist of 20-25 specialists, including people who would not normally be associated with back-arc research (e.g., specialists in EM, 3-D seismics, mantle modelling, etc.). The Workshop would decide how this theme of the Meso-Scale project could best be advanced thereafter. (This recommendation is very much in line with the conclusions of the Meso-Scale session at the York meeting.)

The **Fluxes** theme also was more specifically defined by the Working Group than it is in the current draft of the Initial Program Plan. The Working Group concluded that the real objective is to take a volume of ridge—in effect, a box extending from the mantle into the water column, and for appropriate distances along and across strike—and quantify *all* the fluxes occurring within this volume, and their spatial variability within it. This will require a highly coordinated effort involving significant contributions from many countries. It is therefore seen as a longer-term objective, which would become active once the other two themes had begun to produce scientific results. In particular, choice of relevant area(s) will be dependent upon suitable progress under the Segmentation theme. We are therefore proposing a phased approach to the Meso-Scale project, with the Segmentation and Back-arc themes taking priority during the earlier preiods, and the major, coordinated experimental work under the Fluxes theme occurring at a later stage. Until then, InterRidge could act as coordinator for ongoing activities related to the fluxes theme, and could promote activities on a smaller scale in preparation for the main experiment. The Working Group therefore proposes that InterRidge hold a Workshop on the Fluxes theme, to improve coordination in the short term and to begin planning for the longer term. This Workshop should be held concurrently with the Segmentation workshop, immediately after the InterRidge Symposium on the segmentation theme.

--From the meeting report by C. Walker and M. Sinha (Meso-Scale WG Chair); copies of the full report are available from the InterRidge Office.

Please see the Meeting Announcements for the Meso-Scale Segmentation, Fluxes, and Back-Arc Workshops, next page...

InterRidge Global Planning Meeting
April 8-9, 1993; Paris, France
Meeting Summary

Approximately 40 scientists participated in an InterRidge Global planning meeting held April 8-9, 1993, in Paris, France. The overall objective of the program is to characterize the entire mid-ocean ridge on a decadal time scale. The purpose of the meeting was to outline a strategy to conduct the InterRidge Global program in a timely manner.

Presentations concerning general characteristics of the Southwest Indian Ridge, the Southeast Indian Ridge, and the Pacific-Antarctic Ridge were followed by statements of research interests by the personnel involved, then working-group meetings and general discussion by the entire group.

There is clearly a critical mass of people ready to undertake global-scale studies on four major sections of ridge: the Southwest Indian Ridge, the Southeast Indian Ridge, the Pacific-Antarctic Ridge, and the Arctic ridges. Participants did not feel that any region could be excluded from potential InterRidge study in the next several years, but that particular priority should be assigned to the Pacific-Antarctic Ridge. Some studies of the Southeast Indian Ridge have already been funded, and therefore do not need particular help at this time. The Southwest Indian Ridge has sufficient data and interest on its own merits as the slow-spreading end-member of the global ridge system, so meeting attendees considered that strong proposals for this system would do well on their own within the peer-review system. Therefore the region that really needed clear assignment as a global priority, because proposals to investigate this region would be unlikely to succeed otherwise, is the Pacific-Antarctic Ridge. There was general agreement of priority assignment done in this way, recognizing that proposals for the other regions will nonetheless go forward. Participants also felt that the Arctic community must be allocated the same priority setting as the Southeast and Southwest Indian Ridges.

A summary of each region of interest and of the Paris meeting will be available upon completion in summer 1993. It will include a general statement of Global problems and objectives; specific project plans for various regions; priorities and methods; and general on-shore activities.

--C. Langmuir, Global WG Chair

FIRST ANNOUNCEMENT

INTERRIDGE SYMPOSIUM AND WORKSHOPS

-SEGMENTATION AND FLUXES AT MID-OCEAN RIDGES-

UNIVERSITY OF DURHAM, ENGLAND, SEPTEMBER 1993

SYMPOSIUM: September 22-23
Ridge Segmentation - Progress towards predictive models
Convenors: R.C. Searle (Durham), J. Lin (WHOI), J. Sinton (SOEST, Hawaii)
Format: Invited keynote addresses, submitted oral and poster presentations; limited to 100 attendees

WORKSHOP I: September 24-25
Ridge Segmentation - Development of testable hypotheses and field experiments
Convenors: R.C. Searle (Durham), J. Lin (WHOI), J. Sinton (SOEST, Hawaii)
Format: Workshop and discussion sessions with invited leaders, limited to 30 attendees

WORKSHOP II: September 24-25
Quantification of Fluxes at Mid-Ocean Ridges - Material, chemical, and thermal
Convenors: H. Elderfield (Cambridge, UK), C. Mével (Paris)
Format: Workshop and discussion sessions with invited leaders, limited to 30 attendees

All participants in the Symposium or Workshops will be expected to contribute to the proceedings, either by formal presentation (Symposium) or in Discussion and Workshop assignments. Prospective participants are invited to contact the InterRidge Office (see below) before August 1, 1993, indicating the nature of their proposed contribution.

MEETING ANNOUNCEMENT

INTERRIDGE WORKSHOP

BACK-ARC BASIN STUDIES

University of Washington Seattle, USA
October 11-13, 1993

Convenors: Julian Pearce (University of Durham, England) and Kensaku Tamaki (Ocean Research Institute, Tokyo, Japan)

Prospective participants in this meeting are invited to contact the InterRidge Office (see below) as soon as possible before June 30, 1993, concerning their attendance.

InterRidge does not itself have funds to support attendance, but it is expected that limited support will be available from national ridge programs such as US RIDGE, UK BRIDGE, etc., to whom applications for travel grants should be made.

Additional information on the Symposium and Workshops or InterRidge itself is available from the InterRidge Office, School of Oceanography WB-10, University of Washington, Seattle WA 98195, USA; phone (+1) 206-543-9893; fax (+1) 206-685-0596; Internet intridge@u.washington.edu; Omnet INTER.RIDGE, telex 7402021 GLBL.

—These announcements appeared in EOS on April 6 (Segmentation and Fluxes meetings) and May 25 (Back-Arc Basin meeting)—

Korea

Current State of Korean Oceanographic Research Cruises

The Korea Ocean Research and Development Institute (KORDI) has conducted deep-seabed mineral resources exploration since 1983. During 1989 to 1991, four cruises were dedicated to surveys of ferromanganese deposits in the Pacific Ocean in cooperation with the United States Geological Survey, using R/V *Farnella* in the Clarion-Clipperton Fracture Zone. The purposes of the cruises were environmental, geological, and geophysical investigations of the manganese nodule belt. Three cruises were conducted in the EEZ of the Marshall Islands, Federated States of Micronesia, and the Republic of Palau to investigate Mn-crusts and hydrothermal deposits in seamounts and volcanic arc areas. The cruises aimed for the surveying seamount coated with cobalt-rich manganese crust and volcanic arc evolution. Survey items were comprehensive work for geology and mineral resources involving mostly dredging, but also gravity coring, a single-channel seismic survey, bathymetry including 3.5 kHz profiling, CTD-oxygen probe profiling, and bottom photography with a camera sled.

In 1991, KORDI acquired a newly-built 1400-ton class research vessel, *Onnuri*, which was built at Mjellem and Karlsen Verft AS in Norway. The R/V *Onnuri* is equipped with the most sophisticated navigation and controlling system, and is also reinforced with an ice-resistant system for use in surveying in any climate.

-- Sang-Joon Han, Korean National Correspondent

Russia

At the end of last year, the Russian Academy presented a request to the Russian Ministry of Science, High School, and Technical Politics for a tentative program of marine expeditions for 1993. This request contains a schedule for 39 cruises, including 6 expeditions related to InterRidge interests:

R/V Akademik Boris Petrov:
- 30-40 N on MAR ("Ridge-Crest Processes on the MAR")
- Equatorial Atlantic
- Indian Ocean

R/V Akademik Nikolai Strachov:
- Azores Plateau
- Bouvet Triple Junction

R/V Academik Alexandr Nesmejanov:
- Line Ridge

Another 33 expeditions were planned for ecology, water chemistry, hydrophysics, biology, etc. **The Ministry of Science has no hard currency, but it will support expeditions with rubles if any foreign companies, projects, or institutes will cover hard currency expenses of these expeditions.**

-- Leonid Dmitriev, Russian National Correspondent

Please see the Conference Announcement (next page) for a Plate Tectonics Conference, including a section on Mid-Ocean Ridges. The meeting, in memory of Professor Lev Zonenshain, will be held in Russia in late November 1993.

PLATE TECTONICS CONFERENCE

In the Memory of Professor Lev Zonenshain, who passed away on November 4, 1992

The L.P. Zonenshain Laboratory of the Institute of Oceanology, Russian Academy of Sciences (Moscow), and Research Center for Marine Geosciences GEOMAR (Kiel) will convene the 4th International Conference on Plate Tectonics in the second part of November 1993. The Conference will be held during four days at a Holiday hotel near Moscow. The past three Conferences were organized by Lev Zonenshain, a great Russian geologist, creator and chief of the Laboratory of Paleogeodynamics in the Institute of Oceanology.

The aim of the Conference is to discuss the problems of plate tectonics; in particular, onshore and offshore geology of the former USSR territory. The following items are to be considered.

1. *L.P.Zonenshain memorial symposium*
2. *Mid-Ocean Ridges (structure, petrology, geophysical fields)* ; Conveners: L.V.Dmitriev, I.M.Sborshikov
3. *Processes in the subduction zones and terranes accretion*; Conveners: B.V.Baranov, R. Fon Huene
4. *Tectonics, volcanism and hydrothermal activity of the marginal seas*; Conveners: N.A.Bogdanov, A.P.Lisitcin
5. *Regional geology of the former USSR territory (folded belts,suture zones and continental rifts)*; Convener: N.V.Koronovsky
6. *Geology and plate tectonics of the Arctic region;* Conveners: L.A.Savostin, J.Thiede
7. *Seismicity and neotectonics at the plate boundaries of the former USSR territory;* Conveners: Yu.K.Schukin, S.V.Lander
8. *Sedimentary basins: data and geodynamic models;* Conveners: L.I. Lobkovsky, S.Clotine
9. *Paleogeography of Northern Eurasia based on plate tectonics;* Conveners: V.G.Kasmin, L.M.Natapov
10. *Tectonics and magmatism of "hot spots";* Conveners: M.I.Kusmin, S.A.Kurenkov.
11. *Geodynamics of the Deep Earth;* Conveners: A.P.Trubitsin, A.G.Kirdjaschkin

Your participation in the Conference will be appreciated. Your expenses during your stay on the Conference will be paid by the Russian side; you are to pay only your airfare to Moscow and back, and the registration fee, 100 US$, to be paid by participants in Moscow after arrival.

You are invited to present a talk according to the Conference items. Deadline for abstracts presentation and registration is August 1st, 1993. Registration form is below. Please, confirm your attendance at the Conference. An official invitation with application for the Russian visa and exact data of opening will be send to you after receiving your ansver.

Academician VICTOR KHAIN
Co-Chairman of Conference

Professor JORN THIEDE
Co-Chairman of Conference

Address for communication and information: Dr. Elena Pristavakina, Scientific Coordinator of the Conference, Institute of Oceanology, 23 Krasikova Street, Moscow 117 851, Russia. Phone: (095) 124 79 42; TX: 411 968 OKEAN SU ; FAX: (095) 124 59 83

REGISTRATION FORM
4th International Conference on Plate Tectonics
Moscow, Russia—November, 1993

Dr./Ms./Mr. (Name)____________________
Given Name____________________
Data and place of birth____________________
Organization or Company____________________
Title or Position____________________
Address____________________
Country____________________
Phone: _______________ Fax:_______________
E-mail: _______________ Telex: _______________

Abstracts should be typed single-spaced on A4 size papers and limited to one page. Order of contents is as follows: title; author(s)' names and affiliations; body of abstract excluding figures, tables and references.

Mexico

The following abstracts were taken from reprints sent to the InterRidge Office by the InterRidge Mexican National Representative, Dr. J. Eduardo Aguayo Camargo, in order to give the InterRidge community a sample of the type of ridge-related research being conducted by Mexican researchers. In addition, in April 1992, two Mexican investigators participated in a cruise on the *Atlantis II* at 20°50'N and 109°06'W. We anticipate that future issues of *InterRidge News* will contain further information concerning Mexican geological and geochemical ridge research, both for the Guaymas Basin and 21°N.

GEOCHEMICAL STUDY OF HYDROTHERMAL CORE SEDIMENTS AND ROCKS FROM THE GUAYMAS BASIN, GULF OF CALIFORNIA

A. Carranza-Edwards, L. Rosales-Hoz, J.E. Aguayo-Camargo, R. Lozano-Santa Cruz, and Y. Hornelas-Orozco

A geochemical study of core sediments from the Guaymas Basin was undertaken by X-ray analysis and showed minerals such as barite, gypsum, wurtzite, chalcopyrite, marcasite, galena, and calcite. The random relation between metal concentration and core depth apparently reflects the changes in hydrothermal activity. Mineral grains with holes and cavities were observed by SEM photomicrography. These holes are probably due to degasification of the samples, which can be related to the presence of migrated light and heavy petroleum. The high variation of hydrothermal activity over short distances in the Guaymas Basin is due to active extensional tectonics, the associated seismic activity in the Southern Rift Valley, and the high rate of sedimentation.
Applied Geochemistry, v. 5, pp. 77-82, 1990.

SUBMARINE HYDROTHERMAL ACTIVITY AND ITS IMPORTANCE IN THE GENERATION OF SULFIDE MINERALS

A. Carranza-Edwards, J.E. Aguayo-Camargo, and L. Rosales-Hoz

The importance of the generation of sulfide minerals as pyrite, chalcopyrite, sphaelerite, and wurzite by the emanation centers in the East Pacific Rise at 21°N was analyzed. The similarities among the mineral sulfide from the East Pacific Rise and Chipre's ophiolitic sequence were compared. Metallogenetic analogies are observed between oceanic spreading centers and continental areas with rift processes like the Transmexican Volcanic Belt.
Boletín de la Sociedad Geologica Mexicana, v. 48, n. 1, p. 1-7, 1987.

SUBMARINE METALLIC SULFIDES SOUTH OF THE BAJA CALIFORNIA PENINSULA, MEXICO

A. Carranza-Edwards, L. Rosales-Hoz, M. Guadalupe Villaseñor Cabral, R. Lozano-Santa Cruz, and Y. Hornelas-Orozco

X-ray fluorescence and diffraction, electronic microscopy, and atomic absorption data are discussed for samples collected in the Alvin submersible at 2600 m on the East Pacific Rise. The main compound in the samples are the metallic sulphides with up to 42.7% zinc, 19.4% copper, and 31.4% iron. These sulphides are formed and ejected on the hydrothermal chimneys which are in contact with the asthenosphere higher levels or with a shallow magmatic chamber. The sulphides are mainly formed by sphalerite, wurzite, pyrite, pyrrhotite, and chalcopyrite.
An. Inst. Cienc. del Mar y Limnol. Univ. Nal. Autón. México, v. 13, no. 1, pp. 287-296, 1986.

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