BACK-ARC BASIN STUDIES: A WORKSHOP

Seattle, WA, USA
October 11-13, 1993

Convenors:

JULIAN PEARCE AND KENSAKU TAMAKI

I. LIST OF PARTICIPANTS

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II. WORKSHOP MINUTES

Back-arc Basin Studies Workshop

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

MINUTES

Location: South Campus Center Room 348/350, University of Washington
Convenors: Julian Pearce and Kensaku Tamaki
Participants: See preceeding list

October 11th (Mon)

9:00-9:30
1. Objectives of this meeting
Present status of InterRidge was reported by K. Tamaki. J. Pearce summarised the principal objectives of this meeting as follows.
A. Define the current critical problems for the back-arc basin (BAB) spreading system
B. Exchange information about recent research cruises and plans for upcoming cruises
C. Shape proposals to study the crustal formation of back-arc basins by international efforts
D. Write a white paper on the research targets of the InterRidge project

9:30-13:00
2. Status reports
To summarise current state of knowledge of back-arc basins and major problems to be resolved, the following four keynote speeches were presented.

- S. Uyeda summarised the history of BAB studies and presented several key models for the formation of BABs. Uyeda stressed the importance of seismic tomography for future studies of BABs.
- B. Taylor summarised crustal accretion processes in several BABs by introducing several case studies.
- T. Crawford summarised petrological studies of BAB lavas and stressed the importance of water content in understanding magma genesis in BABs.
- T. Urabe summarised the current level of understanding of BAB hydrothermal activity, presenting comparisons of MOR activity and Kuroko ore deposits.

14:00-18:00
3. Activity reports
Twenty-two activity reports on BAB research were presented by participants. Speakers and their brief titles are summarised in the following.

3.1. General BAB researches
J. Hergt (mantle discontinuity between the Indian Ocean mantle and the Pacific Ocean mantle), J. Gill (mantle tomography and petrology), K. Suyehiro (crustal studies in BAB), T. Hilde (reversed correlation of BAB and arc volcanisms), M. Yamano (long-term temperature monitoring and bare-rock HF measurements)

3.2. Recent cruises in back-arc basins
L. Parson/J. Hawkins (synthesis of ODP Leg 135 Lau Basin), A. Hochstedter (Bonin cross-chain seamounts), B. Taylor (Woodlark Basin swath mapping), J. Madsen (Bismark Sea swath mapping), R. Keller (Bransfield basin), N-S. Li (East China Sea MCS transect), H. Gnibifenko (South Okhotsk Sea), E. Ruellan (North Fiji Basin ridge segmentation)

3.3. Coming cruises already funded or proposed

E. Ruellan (North Fiji Basin French-Japanese co-operation, May-June 1994), M. Fisk (Bransfield basin, 1995), R. Livermore (East Scotia Sea Bridge/BAS Project, the first cruise: 1994-95), T. Crawford (French-Australian rock sampling cruise at the south of North Fiji Basin, 1993), J. Hildebrand (OBS-slab earthquake tomography at Lau basin, 1994), J. Pearce (North Lau Basin), E. Kikawa (STA projects: Ridge Flux and Venus optical cable), K. Tamaki (R/V Hakuho-maru Mariana/Lau, 1996-97)

18:00-20:00

Reception at the Marine Science Building

October 12th (Tue)

9:00-10:30

4. Discussion of InterRidge studies for back-arc basins and formulation of working groups

Through the discussion based on the first days' information exchange, "subduction influence on crustal formation in BAB" was accepted as the primary objective for the InterRidge BAB studies. Under this common objective, three working groups were formulated. The three working groups were "Melt generation", "Spreading process", and "Bio-geochemical fluxes". Topics suggested for these categories were as follows.

- "Melt generation": tomography, mantle flow, source components, geochemistry, viscosity.
- "Spreading process": magma chamber imaging, rift-drift transition, segmentation, evolution, crustal structure, propagation, petrology.
- "Bio-geochemical fluxes": thermal flux, permeability of crust, isolation of biological colonies, crustal composition and gas flux.

10:30-13:00

5. Working group meetings

Three working groups, "Melt generation", "Spreading process", and "Bio-geochemical fluxes", had separate discussion meetings. Chairpersons were J. Pearce for "Melt generation", K. Tamaki for "Spreading process", and T. Urabe for "Bio-geochemical fluxes".

13:00-17:00

6. Initiation of white papers

Three working groups started to draft white papers.

17:00-19:00

7. Joint meeting of working groups

J. Hawkins, L. Parson, and T. Urabe summarised the discussion of each groups, "Melt generation", "Spreading process", and "Bio-geochemical fluxes", respectively.

October 13th (Wed)

8:30-10:30

8. Revision work of white papers

Each group wrote revised drafts of the white papers.

10:30-12:00

9. Summary discussion of white papers and investigation of implementation

The principal objective of "subduction influence on crustal formation in BAB" was reconfirmed. The following proposals were made for implementation .

1. It is recommended that a geographic index of existing geophysical and geochemical data sets and funded proposals in back-arc basins be established. This index would be compiled, co-ordinated and distributed by the InterRidge Office. The Working Group would also like to propose to the Steering

Committee that geochemical and geophysical database archives, to be administered through the InterRidge Office, be established. The geochemical database archive would be complied by Julian Pearce. The geophysical database archive would be organised by co-ordinators for the different back-arc basins. The following were suggested as compiler/co-ordinators for the following basins: Scotia - R. Livermore; Manus - B. Taylor; Lau - L Parson; Mariana - P. Fryer; N. Fiji - E. Ruellan.

2. Future tomographic studies in basins other than in the Lau are strongly recommended to cover a wide range of back-arc situations.
3. High quality mantle Bouguer anomaly and refraction crustal studies are recommended to image the crust and upper mantle beneath BAB ridges.
4. Geophysical and geochemical studies of segmentation including swath mapping and conventional geophysical mapping are recommended to achieve a level of data accumulation comparable with that of MORs.
5. Long-term monitoring by using existing communication cable systems, more logistically feasible in BAB than in MOR, is recommended.
6. Linking of BAB studies with ODP as much as possible is recommended. Hydrothermal deposits of Okinawa Trough were discussed as a possible ODP target.

III. BACK-ARC BASINS

1. PREAMBLE

Spreading ridges in back-arc basins (BABs), while accounting for only 10% of the global ridge system, are disproportionately important in terms of their influence and impact on the Earth's environment (biological and chemical fluxes, and the presence of mineral resources).

InterRidge, in its Meso-Scale Working Group Workshop: "Back-Arc Basin Studies" held in October 1992, identified two aspects of back-arc basin processes as being of key importance:

1. The effect of the subducting slab on the mantle beneath the back-arc area - influencing the thermal and flow régime in which shallow-level melt production occurs and introducing a deep source of slab-derived fluid;
2. The recognition that both ophiolites and currently important economic ore bodies have much closer affinities to back-arc systems than to open ocean systems. In many respects, back-arc spreading ridges may appear to be similar to mid-ocean ridges (MOR). However, it is clear that their spatial, temporal and geochemical characteristics are variably influenced by subduction processes.

The same InterRidge workshop expanded these points as follows:

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

This workshop was set up at InterRidge request to facilitate information and equipment exchange, encourage piggy-back and tandem field experiments, and define future InterRidge co-ordinated back-arc experiments.

2. PRINCIPAL OBJECTIVE

As proposed by the InterRidge committee (above), we define our principal goal as follows:

to study the influence of subduction on ocean ridge processes.

The term 'influence of subduction' covers a wide range of processes, including geochemical influence on melt generation and hydrothermal activities, geophysical influence on ridge segmentation and ridge evolution in back-arc settings, and biological influence in terms of isolation of BAB spreading systems from the MOR system.

Within this framework, we define three sub-topics:

1. Melt generation.
2. Spreading processes.

3. Energy, biological and mass fluxes.

These are described below.

3. MELT GENERATION

There are currently two complementary methods for investigating melt generation: direct seismic imaging; and inversion of lava geochemistry. Key questions to address include:

1. How does the subducted slab affect mantle flow and mantle melting in BAB settings?
2. What is the depth range of melt segregation from mantle sources under back-arc basins?
3. How does mantle flow and mantle melting differ between back-arcs and mid-ocean ridges?

i. Seismic Tomography

BABs provide excellent opportunities for using seismic tomography to study mantle flow and melt generation because Benioff-zone earthquakes are local sources that can be used to image the overlying regions in detail. Moreover, the islands that commonly fringe the basins enable ocean bottom seismometry (OBS) to be augmented by land-based seismic observations. In addition, the majority of the Earth's deep seismic events underlie back-arc basins so that many events can be recorded even during short periods of instrument deployment.

Mantle seismic tomography provides information on both the temperature structure of the mantle (from P-wave velocities, S-wave velocities and seismic attenuation) and the percentage and distribution of partial melt (from S-wave velocities and seismic attenuation). Seismic anisotropy also has the potential to indicate crystalline alignments in the mantle and hence provide information on the directions of mantle flow.

The ideal geophysical experiment utilises a substantial array of land and ocean bottom seismometers recording earthquakes for as long as possible. This experiment should be augmented by other studies in the same region: large-source multi-channel seismic (MCS) reflection and OBS refraction experiments can be used to determine the crustal structure; swath-mapping (side-scan and bathymetric) and underway geophysical measurements can be used to determine tectonic history and surface structures; magnetic-electric field studies can be used to delineate mantle conductivity and thus provide an alternative test for the presence of melt; and petrologic and geochemical studies can be used to constrain the temperature and composition of the mantle, together with the degree and nature of partial melting, beneath the ridge axis.

Dorman and Hildebrand have designed an initial experiment for the Lau Basin which will take place in September 1994. Their present plan is to position 22 OBSs and 9 land seismometers to create a 2-D cross-section of the Central Lau Spreading Centre at 18°S. The local crustal structure at each OBS site will be determined from surveys employing air guns and explosives. Through this meeting, additional investigators have been invited to extend the seismic array. Japan and Britain have indicated their interest in this project and possibility of additional OBSs.

Future seismic tomographic experiments to investigate the subduction zone influence on BAB melt generation and mantle flow should include the fast- and slow-spreading, as well as the mature and immature, BAB end-members. A particularly inviting target is the Valu Fa Ridge south of the area to be imaged by Dorman and Hildebrand, where evidence already exists for an intracrustal magma lens and for lavas with high volatile contents indicative of extreme subduction zone influence.

In addition to sea-based studies, an understanding of the relationship between physical parameters and field measurements is critical to development of mantle flow models. Support is required for laboratory experiments that address the effect of melt and volatiles on seismic velocity and attenuation, the effect of crystal alignment on seismic anisotropy (and the connection between flow and alignment), the effect of melt and volatiles on electrical conductivity, and the effect of volatile content on viscosity and seismic properties.

ii. Geochemistry and petrology

The extent of melting beneath ridges in back-arc basins is influenced by several factors. These include: the fertility of the supra-subduction zone mantle; the addition of a subduction-derived, volatile-rich component; and the potential temperature of the mantle. The major element geochemistry of BAB basalts indicates that the melting process often resembles that at mid-ocean ridges to a first approximation. However, many back-arc basin basalts have enhanced volatile contents (H_2O, CO_2) which appear to be related to subduction. This in turn implies that the indicators of mantle melting that are commonly applied to mid-ocean ridges may have to be modified for use in back-arc basins. At present, however, the influence of volatiles on mantle melting is poorly understood.

Evidence for the nature and extent of melting can be obtained from the lava geochemistry coupled with ridge structure, segmentation and crustal thicknesses, just as they can at mid-ocean ridges. In contrast to the mid-ocean ridge setting, where a more-or-less uniform mantle source may prevail over long distances (50-200 km) and for long time periods, the back-arc setting has a small scale (tens of km) heterogeneity and exhibits changes in composition on the scale of 106 yr. We have detailed knowledge of temporal and along-axis heterogeneity in several BAB ridge systems. For example, the comparatively well-sampled, slow-spreading Mariana Trough near 18° N (100's m sample spacing with ALVIN) shows isotopic evidence for at least three major mantle sources. On the other hand, with the exception of a single seamount, the fast-spreading Manus Ridge erupts relatively homogeneous magmas. The North Fiji Basin also appears to have formed from melts derived from a relatively homogeneous source. The Eastern Lau Spreading Center exhibits a spectrum in compositions from more MORB-like chemistry at its north end to more arc-like chemistry at its southern end where it converges on the Tofua Arc.

In order to address these compositional variations along the axial ridges, closely spaced sampling is now needed and comprehensive isotopic and trace element data sets are now required. While the initial tomographic experiment is designed to reveal the mantle flow in a two-dimensional section orthogonal to the spreading axis, geochemical heterogeneities emphasise the importance of extending experiments to include the third dimension. The distribution of the geochemical provinces along the ridge segments will also guide the locations chosen for future tomographic experiments.

The processes and time scales of melt generation cause disequilibria within the U-decay series which differ between MORB and arc basalts. By combining such disequilibria studies with tomographic and elemental information, greater constraints can be placed upon the depth distribution of melting. This in turn will provide the opportunity to evaluate differences in mantle porosity and melting rate between BAB and MOR sources. Correlations between U-series radionuclides and geochemical parameters such as 10Be, B and H_2O can also be used to assess the age of subduction-related components in the mantle sources of BAB magma. Variations in these correlations within BABs may define the spatial and temporal scale at which these components migrate through the mantle wedge.

High-pressure experimental studies are also required to evaluate the effects of volatiles on the percentage of melting and the temperature and composition of magmas produced.

4. SPREADING PROCESSES

In contrast to mature MOR spreading systems, the total life of a BAB is short, usually less than 20 Ma. Moreover, BAB spreading systems are characterised by repeatedly-changing stress régimes which are strongly linked to the arc volcanic system and the subducting slab. The tensional stress régime that develops at convergent plate margins typically leads to BAB spreading adjacent to, or within, the volcanic arc, with extension and spreading often synchronous with arc activity. Thereafter, the BAB spreading system dynamically adjusts its geometry in response to stress changes in the back-arc system.

To understand BAB spreading systems completely, we need to study their whole evolutionary cycle, from the initial rifting stage to termination of spreading, an objective which was not targeted in the InterRidge MOR study program. We emphasise that a comprehensive understanding of BAB ridge processes throughout its whole evolution is critical to solve the unique problems of the BAB spreading system. The key questions to address then include:

1. How are segmentation, the crustal accretion process, crustal structure, upper mantle flow, and volcanism at BABs different from those of MORs?

2. How does the spreading system initiate, evolve, and terminate in BABs?

i. Comparison of spreading processes between back-arc basin and mid-oceanic ridge systems

One of the main questions to be resolved is the nature of the difference between spreading processes in BABs and those at MORs. Studies to date indicate that there may be substantial differences, resulting largely from evidence that the back-arc spreading system may be affected by the input of fluids from subducting slabs, and that BABs exhibit a more variable stress régime linked to complex microplate rotations. We recognise, however, that most back-arc systems do not have a sufficiently comprehensive data set to enable a meaningful comparison to be made. We therefore suggest that a small number of key sections of back-arc spreading systems be selected that offer a range of parameters such as different spreading rates, variable distance from arc volcanic front and variable maturity. These areas should act as the focus of InterRidge effort to ensure that as complete a data set as possible is available, in order to rigorously test our hypothesis that MOR and BAB spreading systems are fundamentally different and to document those differences. We believe that a thorough understanding of the detailed picture of the BAB system could provide insights into spreading processes at the MOR system, especially the earliest stages of MOR development.

There are certain key themes upon which we can focus our comparative studies. These include: ridge segmentation and its temporal variation; crustal structure; mantle flow patterns; volcanic activity; and magma chamber configuration. Even though we already have detailed tectonic interpretations of several sections of back-arc axis, we have less knowledge of the temporal variability and evolutionary histories of this segmentation, and their effects on petrogenesis. We are equally uncertain of the crustal structure of BAB spreading systems, and its relationship to parameters such as spreading rate and arc proximity. We need to establish the deeper patterns of mantle flow, and how they control the location and evolution of BAB spreading systems. Finally we must determine and explain the temporal and spatial variations in the extrusive volcanogenic products of BAB spreading axes.

Ridge Segmentation

A major difference between spreading in BABs and MORs is the instability of individual BAB ridge segments. Spreading ridge fabrics away from ridge axes are rarely ridge-parallel: ridges change orientation frequently and rapidly, presumably in response to changes in regional stress. Furthermore, transform faults are rare within back-arc basins, ridge segments usually being separated by propagating rifts, overlapping spreading centers, and other second or lower order offsets. These offsets are often highly complex and located within zones of deformation.

Another difference is the extreme morphologic variability (from rifted to smooth) that individual BAB ridges can display over a short distance. In the major ocean basins, these differences reflect different spreading rates whereas in BAB they can exist even when spreading rates do not vary greatly (e.g., the North Fiji Basin).

All these features strongly suggest that the state of the lithosphere and the underlying mantle dynamics at BAB ridge systems are substantially different from those at MORs. The detailed study of ridge segmentation in BABs will provide valuable examples of mantle/lithosphere interaction at ocean spreading systems that may contrast with their MOR equivalents.

The most intensively sampled back-arc spreading systems are characterised by a heterogeneity which is largely dissimilar to that found at MORs We have to establish the parameters controlling BAB axial volcanism, and to determine whether this variability is a function of such parameters as proximity to arc volcanism, maturity of the ridge system and enrichment/depletion history of the mantle source. Back-arc spreading systems contain many of the second and lower order segmentation observed at MORs, where geochemical and geophysical discontinuities often coincide. Reconnaissance data suggest greater spatial heterogeneity within segments in BABs than that observed at MORs, both in the slow-spreading Mariana Trough and the fast-spreading Manus Basin. However, few closely-spaced, along- or across-strike dredging programs have been carried out. If greater heterogeneity is confirmed, this implies either that magma segregation and storage are less effective homogenising processes in BABs, or that the spatial scale of heterogeneity is smaller in BABs. In particular, the spatial and temporal scale of subduction-related heterogeneity can be documented in ridges that converge on the volcanic arc by studying tectonic and geochemical segmentation as a function of arc proximity.

We can summarise some of the specific questions as follows.

1. Are the second and third order ridge segmentation patterns (morphotectonic, geochemical) observed in BAB systems comparable to those mapped in "normal" MORs?
2. Are there any fundamental reasons why few, if any, first order discontinuities exist in BABs?
3. Are the temporal and spatial variations in ridge segmentation patterns in BABs and MORs comparable?

Crustal structure

There are several fundamental questions that need to be addressed in order to develop models for the structure of crust generated at back-arc basin spreading centers.

1. Do BABs have a characteristic crustal thickness or is every basin unique?
2. What is the degree of variability in crustal thickness along and across back-arc basin spreading centers?
3. Are steady-state axial magma chambers present along back-arc basin ridge segments? If magma chambers are present, what is their geometry (e.g. size, shape, depth), and how does this geometry vary along a given ridge segment?
4. Do lower crustal samples from fault scarps in BAB systems differ from those at MORs in response to variations in such parameters as volatile content, recharge, or eruption rates?
5. If magma chambers are consistently deeper than at MORs, what are the effects on processes of formation and structure of the crust? How representative of BAB spreading systems is the deep magma chamber identified beneath the Valu Fa Ridge?

In order to develop answers to these, and other, questions detailed gravity and multi-channel seismic and ocean-bottom seismometer experiments are needed.

Mantle Flow

Because the 3-dimensional (and time-dependent) patterns of melt production effect the accretion and tectonic response of newly created lithosphere, and therefore ridge segmentation, it is important to understand the pattern of mantle flow beneath back-arc basin spreading centers. Key questions to be addressed are:

1. What is the pattern of shallow-level mantle flow beneath BAB spreading centers?
2. Is there focused upwelling at discrete locations along a given ridge segment?
3. To what level does the presence of subducted lithosphere effect the pattern of mantle flow beneath the spreading centers?

To address these questions, field programs involving seismic and gravity data collection are required. As at MORs, particularly useful information on shallow-level mantle flow is likely to come from the analysis of mantle Bouguer gravity anomalies. Modelling of large-scale mantle flow patterns will need seismic tomographic experiments coupled with theoretical analyses.

Volcanology

Volcano morphology at spreading systems is related to magma supply rate and eruption style. The latter, in particular, may differ in BABs because the volatile content of the magmas is greater. Thus we might expect such magmas to vesiculate at greater depth, which in turn could increase their viscosity and result in more extensive hyaloclastites. Indeed, some BAB magmas do erupt explosively even at depths greater than a kilometre. Differentiated magmas, including dacites and rhyolites, are more common in BABs, resulting in steeper volcanoes than at MORs with similar spreading rates. The seismically-imaged magma lens beneath the Valu Fa Ridge is located beneath differentiated volcanic rocks, although comparable studies elsewhere are needed to determine whether magma bodies of the size and depth of this lens are typical of ridges in a supra-subduction zone setting.

The physical volcanology of eruptions and the life cycle of individual volcanic edifices in back-arcs are important to document because back-arc volcanoes are more likely to be preserved in the geologic record. Further work aimed at establishing the degree of variability of such features, both within and between different BABs is thus urgently needed. Such projects are a high priority for InterRidge back-arc studies, since they enable future work to be focused upon those aspects which are truly characteristic of back-arc spreading.

ii. Problems unique to the spreading process in back-arc basins

We recognise that some of the processes that contribute to the geological evolution of marginal basins in a broad sense fall outside those associated with "normal" seafloor spreading. These include those involved in youngest and oldest parts of marginal basin formation and relate closely to those of continental rifting. They are however of such fundamental importance to BAB evolution that we consider their study to be integral to InterRidge.

It is widely observed that, prior to the establishment of a mature BAB spreading axis, there is a protracted period of crustal rifting and attenuation which deforms the overriding plate to form an irregular horst and graben (basin-range) topography. Extension is commonly accompanied by localised magmatism, both as ephemeral rift intrusives or, as in the case of arc splitting/migration, a series of arc constructs. The controls on the length of this period of extension without seafloor spreading are unknown. The initiation of seafloor spreading into this anisotropic terrain is usually by a propagating rift tip. It is knowledge of the timing of this event, the mechanism which drives this event and the processes which control this event which are essential to the understanding of the early evolution of back-arc systems.

In addition to the need to assess the initial history of ridge formation, BABs commonly cease spreading after a relatively short period of time. Extension is taken up by relocation of the BAB spreading axis, usually closer to the trench. In some examples of back-arc basins, this process has been repeated several times, resulting in a series of abandoned spreading systems which increase in age away from the trench. We must address the factors which control the time at which spreading terminates and how quickly a new spreading system (and its products) is established.

Key questions are:

1. What factors control the length of time that the basin opens by amagmatic and local magmatic processes before establishing a true spreading axis?
2. What controls the speed and style of advance of the initial propagating ridge tip into the already attenuated crust?
3. What factors serve to locate the point of initiation of the propagator?
4. How quickly is the extension transferred from the horst and graben terrain to the newly established propagating ridge?
5. Do magma sources differ between rifting and spreading stages?
6. Does back-arc spreading replace arc volcanism?
7. How long does it take the spreading axis to shut down, and what indications are there in the axial geology that this is occurring?
8. How much influence does the proximity to arc volcanism affect petrogenetic processes in BAB spreading systems?

5. ENERGY, BIOLOGICAL AND MASS FLUXES

Key questions to be addressed are:

1. What is the subduction contribution to the chemistry of the hydrothermal fluids?
2. What is the influence and impact of the biological and chemical fluxes from BAB on the global environment?
3. What controls the diversity of hydrothermal activity known to occur in BAB and arc systems?
4. What is the importance of BABs as sites of formation of volcanogenic massive sulphides (VMS) deposits?

Hydrothermal processes in arc-BAB systems are more varied than their analogues in MOR systems. This diversity results from differences in crustal composition, tectonic setting, associated volcanism, and sedimentation between BAB and MOR spreading ridges. Thus, although BAB hydrothermal systems can resemble those from MORs, they can also, for example, contain greater amounts of Pb, Ba, Au and Ag. This, in turn, raises the genetic question of the extent to which the differences lie in the more variable composition of BAB crust, the often greater volatile content of BAB magmas, the often greater extent of differentiation of BAB magmas, or differences in the physical states of the two systems. Hydrothermal systems in BABs thus involve a wider variety of physical and chemical variables than are found in MORs, and hence provide a greater opportunity to obtain a general understanding of hydrothermal processes at ocean ridges.

It is widely accepted among economic geologists that VMS deposits, which currently produce about 6% of the world's lead, 11% of its copper and 22% of its zinc, are fossil examples of hydrothermal systems which have operated almost continuously throughout the history of the Earth. It is worth noting that most of the economically important VMSs are likely to be formed in BAB rather than MOR. For example, Kuroko deposits are thought to have formed in association with rhyolitic volcanism by intra-arc rifting within the Japanese island arc when it underwent its most rapid phase of extension at 15 Ma. The two other major types of VMS, Besshi-type and Cyprus-type deposits, have volcanic or sedimentary rocks of supra-subduction zone affinity in their hanging-wall sequence.

The heat flux from BAB spreading centers cannot make a very significant contribution to the total heat loss from the Earth, as heat loss is likely be approximately proportional to the amount of crust accreted and BABs make up only 10% of the world's ridge system. However, the hydrothermal processes in BABs are not insignificant if we consider their influence on the surface environment of the Earth. For example, the CO_2 and CH_4 contents of hydrothermal solutions at the JADE site in the Okinawa Trough (NW Pacific), are 209 mM and 7.6 mM, respectively (Ishibashi et al., 1990). These values are about two orders of magnitude greater than those of MOR: compare, for example the equivalent values of 5.7 and 0.06 obtained at EPR 21°N and 4.2 and 0.1 at the Juan de Fuca Ridge. Therefore, at least for some volatile components, the mantle discharge from BABs may be no less significant than MORs despite their much shorter ridge length.

The geological isolation of BABs from MORs is an important variable when considering the biological and ecological evolution of vent communities. Several new species of mega-fauna, which were not observed at MORs, have been found in BABs. The chemosynthetic bacteria also show a unique character in each hydrothermal community. There is a great potential for carrying out experiments to monitor the interaction between the hydrothermal flux and the ecosystem in BABs.

The temperature structure and hydrothermal circulation pattern at BAB rifts must be quite different from those at MORs, not only because the deep thermal structure is different but also because the BAB rifts often have thick sediment covers. It is very important to understand the differences in temperature structure and circulation patterns since these parameters also have a significant influence on chemical fluxes. In sedimented BAB rifts, we can obtain this kind of information by making detailed surface heat flow measurements. At spreading centers without a sediment cover, it is impossible to measure heat flow using ordinary instruments and we need to develop a new type of instrument or to estimate heat flux by some indirect method.

Long-term monitoring of heat flow or temperature of venting fluid is important, because it can provide information on temporal variation of chemical flux, which is more difficult to measure. Long-term temperature monitoring tools have already been developed for this purpose and have successfully collected data for up to one year. The CORK (circulation observation retrofit kit) developed for ODP can hydrologically seal a drill hole and monitor formation temperatures and pressures. Combining surface and downhole monitoring systems should enable temporal variation in hydrothermal circulation to be clearly delineated.

6. IMPLEMENTATION

We make the following recommendations to InterRidge for implementing the BAB proposals discussed above.

1. Databases

We recommended the establishment of a geographic index for BABs containing a list of existing geophysical and geochemical data sets and funded proposals. Ideally, this would be compiled, co-ordinated and distributed by the InterRidge Office. We also recommend that geochemical and geophysical database archives, also ideally administered through the InterRidge Office, be established.

2. Tomographic experiments

We encouraged international commitment by InterRidge countries to the 1994 Lau tomographic experiments. We also recommend setting up future tomographic experiments to study different BAB ridge systems.

3. Lithosphere/mantle interaction

High quality gravity/swath mapping and refraction crustal studies are encouraged to investigate interaction of crust and upper mantle beneath BAB segment.

4. Accumulation of BAB data

The geophysical and geochemical data accumulation in BABs lags behind that of MORs. We encourage data accumulation in BABs, specially targeting along-ridge studies that highlight the effects of subduction proximity.

5. Long-term monitoring

Long-term monitoring of energy, biological and mass fluxes, as well as seismic activity, will provide valuable information on tectonic and hydrothermal processes at BAB rifts and spreading centers. Abandoned ocean floor communication cables (e.g. TPC-1 and 2) are ideal tools to connect sea-floor monitoring stations to land. We should make every effort to utilise these cables for studies of BAB.

6. ODP-link

Strong links between BAB studies and ODP are highly recommended and very important to the accomplishment of the principal InterRidge objectives for BAB studies.