Abyssal Horizons
A plan for the third decade of InterRidge science

The background for this framework is the recognition of a number of key areas of research that are needed to underpin our developing understanding of the formation and evolution of the oceanic crust and its interaction with the ocean, biosphere, climate and human society. The role of InterRidge has evolved from facilitating cooperation between ridge crest scientists to helping science focus on the major and fundamental aspects of ocean crust generation and evolution; from genesis at the ridge crest, to evolution on the flanks and under the abyssal plains to its fate at convergent margins, subduction zones, arcs and back-arc systems. Hence InterRidge is the only scientific organisation that spans the single largest geological domain on the planet: the Earth's oceanic crust.

The following sections describe the results of a process of consultation of the ocean crust scientific community that was initiated in 2011 by InterRidge through an online forum and culminated on December 3rd 2011 at an open meeting in San Francisco. Following summaries from the current and future working groups, the process of science prioritisation was led by the InterRidge Chair (Bramley Murton) with assistance from three previous Chairs (Colin Devey, Jian Lin and Roger Searle). All of the attendees were asked to post their key scientific questions on a bulletin board. These were then organised into broad scientific themes. Attendees were then asked to self organise into groups under each of the science themes and draw up a list of the big scientific questions, their context and background, and how they might be implemented. Each group then elected one or two members that formed the writing group on the 4th December to compile each of the report sections presented here.

Five current working groups represented:
1) Hydrothermal Energy and Ocean Carbon Cycles
2) Long Range Exploration
3) Mantle Imaging
4) Seafloor Mineralisation
5) Vent Ecology

Four new working groups proposed:
1) Oceanic Detachment Faults
2) SMART (South Mid Atlantic Ridge Targeted Area)
3) Circum-Antarctic Ridges
4) Arc-Backarc Systems

The meeting recognised the desire of the community to expand to accommodate all ocean crust research, from the ridge crest to the arc and backarc systems. We then went on to define five areas of research priority:
1) Mid-Ocean Ridge Tectonic and Magmatic Processes
2) Seafloor and Sub-Seafloor Resources
3) Mantle Controls
4) Ridge-Ocean Interactions and Fluxes
5) Off-axis Processes

This is a draft document and is being prepared for consultation. Feedback from InterRidge members will be incorporated and a new draft prepared for adoption at the 2012 InterRidge Steering Committee meeting in St Petersburg, Russia.

If you would like a Word document to edit, please contact the InterRidge Office (coordinator@interridge.org). Alternatively, you can send your comments by email to the Office.

SECTION A
MID-OCEAN RIDGE TECTONIC AND MAGMATIC PROCESSES

Background:

The past ten years has seen a revolution in our understanding of the formation, structure and evolution of oceanic crust. In the same way that orbiting space telescopes have revealed the origins of the universe, and genetics have shown us the fundamental basis of life, new technologies for imaging and exploring the deep ocean crust have transformed our view of our planet.

Over 40% of the entire Earth's surface has been formed at active slow and ultra-slow oceanic spreading ridges. During the latter half of the 20th century, our view of this deep seafloor was seen through a blurred lens. Sonar images were coarse and the resolution low. Visual observations were of limited extent and the recovery of rocks from below the seafloor was sparse. As a result, we developed a simplistic model for this oceanic crust. We thought all spreading ridges formed a similar type of structure: a layer-cake of volcanic lavas overlying coarse crystalline rocks that in turn rested on the mantle. Where there were differences these were limited to local processes such as faults, hotspots and unusual plate boundary geometries.

With the birth of the 21st century, a new view has emerged. Informed by high-resolution geophysical imaging techniques, robotic underwater vehicles and deep-ocean drilling, we have discovered that the ocean crust is far from homogeneous. With decreasing spreading rate, the crust becomes increasingly complex. Large areas of the seafloor expose gaping holes in the magmatic crust in which the underlying mantle is revealed. Entire ridge segments are found to spread by long-lived, low angle extensional faulting. The exposed mantle rocks are found to contain multiple small bodies of coarse crystallised magmatic rock but the overlying volcanic lavas are absent. Seawater reactions with the exposed mantle form a new material: serpentinite. Fluids released by this reaction are completely different to those at conventional hydrothermal vents: they have high pH, are rich in hydrogen and methane and, where hot, create complex organic molecules. These chemical and thermal fluxes have significant implications for the composition of the global ocean. The vents are also host to unusual species of macro and microorganisms whose genetic potential are just being explored. The mineral deposits formed at the hydrothermal vents are rich in non-ferrous metals such as copper, zinc and gold. The lack of volcanism allows such deposits to accumulate large tonnages. In turn, these have attracted the attention of industries interested in exploring for new, metal-rich resources to meet the growing global demand for raw commodities.

The heterogeneous structure of the oceanic crust is also expressed in time as well as space. Changes in melt supply have been found to vary through time resulting in dramatic variations in crustal structure, thickness and hydrothermal fluxes. Even the spreading process, previously regarded as continuous, has been found to be episodic. Where new ocean crust is generated behind convergent margins, the ridges stop and start, often jumping to new sites by rifting older crust. Why this happens is unknown but is thought to link to changes in the structure and geometry of the subducting plate, its effects on the mantle wedge and with consequences for arc volcanism. Thus there is a connection to the entire Earth System: oceanic crust formed at spreading ridges is heterogeneous, evolves through interaction with the ocean, is modified by intra-plate volcanism, and as a result effects changes in convergent margins that in turn affect the formation of new oceanic crust in the arc and back-arc basins. This holistic approach is now recognised and embraced by InterRidge. The linkages between the mantle, lithosphere and biosphere are an integral part of the Earth system. The mineral resources formed by the oceanic crustal spreading are of growing economic importance. Hence, society at large is increasingly aware of the fundamental role played by the oceanic crust and its potential to meet the resource needs of the future.

Big Questions:

1) What controls the structure of the oceanic crust?
2) What is the real extent of tectonic-dominated spreading?
3) How does oceanic spreading at slow and ultra-slow spreading rates work?
4) What is the diversity of structure and architecture of OCCs?
5) What is the variation of oceanic crustal structure through time and how is this controlled?
6) What controls the variation and episodicity of spreading ridges in complex tectonic settings?

1) What controls the structure of the oceanic crust?

While the formation of heterogeneous oceanic crust is most prevalent with increasingly slow spreading rates, the link is not exclusive. New or dying rifts where the spreading rate is ultra-slow are not necessarily dominated by tectonic spreading. Is there a mantle effect? And if so, what is this: composition, temperature or both? Or are there some other processes, maybe a crustal one, in which shallower processes cause the crust to become heterogeneous? Could there be positive feedback between faulting, hydrothermal cooling and the suppression of volcanism? Are there links to global sealevel such that rapid changes result in fluctuation in melt supply?

2) What is the real extent of tectonic-dominated spreading?

Oceanic core complexes (OCCs) are the expression of tectonic-dominated spreading. These are the result of low-angle detachment faults that uplift and expose large sections of upper-mantle. Where they are identified, they occur as isolated features on the ridge flank. But are these merely the surface expression of deeper, inter-linked structures that extend for tens to hundreds of kilometers along the ridge? Are they related to vast areas of ocean crust, exposed on some ridge flanks, which are described as smooth? Likewise, are they related to the even larger areas of smooth ocean crust, which have been discovered beneath several kilometers of sediment, bordering continental margins?

3) How does oceanic spreading at slow and ultra-slow spreading rates work?

Where OCCs form and the crust spreads asymmetrically, how is this accommodated? What is the structure of the conjugate flank? Are all OCCs alike or are there significant differences in their structure and architecture? And what controls these differences?

4) What is the diversity of structure and architecture of OCCs?

Are all OCCs ‘plum-pudding’ structures with gabbro bodies embedded in a peridotite/serpentinite matrix or are some completely peridotite? What is the proportion of magmatic material in OCCs and how does that compare with ‘normal Penrose’ oceanic crust?

5) What is the variation of oceanic crustal structure through time and how is this controlled?

Transform faults allow time slices through crustal sections to be exposed. Can they be used to allow studies of the variation in crustal architecture and melt supply? How does the lower oceanic crust form? Can we resolve the gabbro glacier model from the multiple intrusive sill one? Can we resolve how the ocean crust cools and the magnitude of its effects on ocean chemistry through alteration? What is the depth of serpentinisation where magmatic flux is low? How does serpentinisation affect the seismic potential of fault zones and can we apply this information to seismogenic zones in continental settings and subduction zones?

6) What controls the variation and episodicity of spreading ridges in complex tectonic settings?

Backarc basin spreading centres are unstable and jump in space and time often with hiatus in spreading. What controls this? Are there links to the subduction process and arc volcanoes? How does the mantle wedge link to backarc spreading? What are the ages of back arc spreading jumps and can we calibrate or unravel complicated magnetic anomaly signatures in backarc basins? Are there links between the structure, composition and morphology of the subducting slab of old oceanic crust and the formation of arc volcanoes and backarc spreading systems?

Implementation:

New tools and observations: Accessing the subsurface is essential to understanding the composition, structure and evolution of heterogeneous oceanic crust. IR will develop closer links with IODP drilling. Scientists should be encouraged to form closer links with engineers developing new emerging technologies such as active and passive EM, high-resolution seismic imaging, and seafloor drilling.

Areas where ocean crustal diversity and heterogeneity are well developed should be identified and where a concerted and coordinated research effort can be applied. A variety of techniques are needed and these should be focused on particular areas where the combined effort exceeds the sum of the individual parts. This is the role of InterRidge: to coordinate and encourage collaboration.

SECTION B
SEAFLOOR AND SUB-SEAFLOOR RESOURCES

Background:

Research into seafloor and sub-seafloor hydrothermal systems over the past ~30 years has focused primarily on active vent sites, because: 1) plumes from active vents can be detected at kilometre-scale distances from their source; 2) active vents host lush, unique chemosynthetic ecosystems; and 3) active vents provide the opportunity for direct measurements of fluid fluxes, compositions and temperatures. Current estimates of the number of vent sites along the oceans' neo-volcanic zones and the total amount of hydrothermal sulfide on the ocean floor are biased towards active systems.

Growing evidence suggests that the total number of inactive/extinct vent sites, and total tonnage of sulfide from those sites, may be greater than that what has been discovered and estimated from active sites. The fate of seafloor sulfides after the hydrothermal system that fed them turns off is also poorly constrained. Little is known regarding the rate of sulfide oxidation on the seafloor or the biological communities that inhabit these deposits. The need for a better understanding of inactive sulfide deposits is further enhanced by the growing targeting of these deposits by exploration companies for their precious and base metal contents. Due to technical limitations and ecological concerns, inactive systems are a more likely source for metal resources than sulfides from active hydrothermal vent sites.

Big questions:

1. How to identify inactive hydrothermal sulfide deposits on the seafloor?
2. How much hydrothermal sulfide is contained in inactive vent deposits?
3. How old are SMS deposits?
4. What types of organisms inhabit inactive sulfide deposits?
5. What is the geologic fate of inactive sulfide deposits?
6. Does basement lithology and water depth affect the mineral resource potential and biology of seafloor massive sulfides (SMS)?
7. What is the chemical toxicity of deposits and their sediments?

The following are several knowledge gaps regarding inactive/extinct vent systems that can be addressed by the InterRidge community:

1. **How to identify inactive hydrothermal sulfide deposits on the seafloor?**
   Unlike active vent sites, which are easily identifiable by plume surveys, camera tows, etc… inactive sulfide deposits can often be indistinguishable from volcanic structures. Methods for the detection of inactive sulfides using high-resolution mapping and remote sensing geophysical methods are critical to locating sulfide deposits that are invisible using many of the methods used to locate active deposits. How can we detect buried sulfide deposits? Likewise, we need to verify remote sensing techniques by characterising the sub-surface expression of mineral deposits and their altered host rock.

2. **How much hydrothermal sulfide is contained in inactive vent deposits?**
   A number of recent publications provide estimates of the total global resource of SMS (seafloor massive sulfide) deposits. These estimates are based almost exclusively on data from known active deposits. Surveys of inactive deposits from different seafloor tectonic environments are required to update global resource estimates to include inactive sulfides. These estimates are critical to organizations that hope to either explore for, or regulate, the exploration and exploitation of seafloor sulfide resources.

3. **How old are SMS deposits?**
   What is the accumulation rate of sulfide, and how does it compare to the amount of sulfide that vents into the water column? What is the lifespan of a typical hydrothermal system? Are lifespans dependent on tectonic environment? How episodic is venting at s single vent site?

4. **What types of organisms inhabit inactive sulfide deposits?**
   How do the ecosystems of inactive sulfide deposits compare with those of active sulfide deposits or normal basaltic substrates?

5. **What is the geologic fate of inactive sulfide deposits?**
   What is the rate of oxidation? What are the effects of microorganisms on the breakdown of sulfide? How does the rate of oxidation compare to the rate of burial?

6. **Does basement lithology and water depth affect the mineral resource potential and biology of seafloor massive sulphides (SMS)?**
   Is there a systematic variation in chemistry and metal tenor of SMS formed at mafic-hosted or ultramafic-hosted hydrothermal systems? What is the chemical and thermal flux at slow and ultra-slow spread crust and does this vary with tectonic spreading and the formation of OCCs? What is the effect of different basement lithologies on vent biology?

7. **What is the chemical toxicity of deposits and their sediments?**
   What biologically active, toxic elements are present in deposits and their associated sediments? Are there secondary enrichment processes, linked to diffuse fluid flow or redox fronts that might enhance the toxicity of deposits? What are the effects of plumes of detritus that might be introduced from seafloor mining activities, on the surrounding benthic communities?

Implementation:

Many of these questions might be answered by large-scale, high-resolution characterizations of entire vent fields at ridge segment scales and integrating those with basin-wide modelling. This could be accomplished using properly instrumented AUVs and other distributed ocean observing platforms, supplemented by high resolution seafloor surveys and monitoring. Awareness must be built and guidance provided as to what “properly-instrumented” means. Sub-seafloor assessment of mineral deposits and occurrences should involve new technologies such as seabed drilling and wire-line logging to characterise mineral and host-rock types and their geophysical properties. These data will also be used to both calibrate remote detection methods (active and passive electro magnetism, resistivity, magnetism and active seismic detection) as well as the chemotoxic nature of the deposits and their surrounding sediments.

InterRidge should work with other agencies such as the International Seabed Authority and the Underwater Mining Institute towards developing guidance for best practice in assessing, monitoring and minimising environmental impact from resource exploration and exploitation.

SECTION C
MANTLE CONTROLS

Background:

Geochemical studies of basalt sampled at mid-ocean ridges have demonstrated that the Earth's mantle is strongly heterogeneous. Heterogeneities are observed at different scales, from a few to thousands of kilometres. These heterogeneities result from fundamental processes of Earth evolution involving mixing and stirring of Earth's material. In turn they play a major role in controlling variations in the crustal formation through partial melting, both in the amount of the crustal production and in the geochemical signature of the products. The amount of magmatism will control the type of crust and the tectonic expression of seafloor spreading. The petrology and geochemistry effects the composition of percolating hydrothermal fluids, the vent mineralization, and their ecosystems.

The effects of mantle controls at mid-ocean ridges can be addressed in two complementary ways. First, the ridges are windows that allow better constraints of mantle heterogeneities at the different scales. Second, variations in ridge processes can be understood in relation to mantle heterogeneities: both compositional and temperature.

Big Questions:

1) How are mantle heterogeneities expressed at different scales in time and space?
2) What are the relationships between variations in ridge processes and mantle heterogeneity?

1) How are mantle heterogeneities expressed at different scales in time and space?

Ridges represent essential windows to image, quantify and map mantle heterogeneities at different scales in both space and time. Such heterogeneities include mantle provinces, including their spatial and temporal limits, (e.g. at slabs or in mantle down-welling areas such as at the AAD) and geochemical domains (such as the DUPAL anomaly). A specific case is ridge-hotspot interactions: although many examples of ridge-hotspot interactions have been described, there is no clear deep-earth imagery (e.g. seismic tomography) of such an interaction involving a ridge and a hotspot separated by a thousand kilometres. Although links are suggested on the grounds of basalt geochemistry, a combined geochemistry and geophysical approach needs to be made to clearly resolve what features belong to the ridge, the hotspot, and their interaction.

An emerging frontier is the extent and nature of small-scale heterogeneities (10 to 50 km) which seems to be ubiquitous but whose effects on the ridge are still poorly understood. Addressing these various scales would help to better understand the mantle mixing processes, i.e. the different scales of mantle convection. Again, special attention should be put on hotspots and their possible origin(s) in the deep or intermediate mantle.

Ridges provide windows to both the spatial scale of mantle heterogeneities as well as temporal ones. Where ridge-hotspots interact, the spreading process leaves behind a trial of crust that records the history of ridge hotspot interaction. Some of the best examples are the Iceland-Reykjanes Ridge couplet in the north Atlantic and the Central Indian Ridge-Reunion couplet in the Indian Ocean. Here, the ocean crust records time varying fluxes of hotspot mantle, mantle plumes and their tectonic effects on the spreading processes.

2) What is the relationship between variations in ridge processes and mantle heterogeneity?

A better understanding of ridge processes requires us to address how the mantle processes and heterogeneities affect the mechanisms of melt generation and migration to form the oceanic crust. Equally important, and probably as a consequence, is how do the mantle processes and heterogeneities control the tectonics of the ridge axis, including at small scales. Examples of the interaction between mantle and mid-ocean ridge spreading are the formation of areas of so called 'amagmatic' spreading and the generation of ocean core complexes. These are regions of mainly slow spreading ridges where tectonic strain, low-angle faulting and uplift and exposure of the lower oceanic crust and upper mantle accommodate plate separation. Many of these regions are associated with E-MORB – enriched mid-ocean ridge basalts – resulting from either or both reduced melting and enriched mantle. It is not know how this relationship develops, by what process mantle thermal heterogeneity is conserved or how mantle heterogeneity effects the melt generation process and hence the spreading style.

Implementation:

Various approaches will be used to address these questions:

1) Of prime interest, but quite demanding and therefore requiring international collaboration, is mantle imaging through geophysical techniques such as seismic tomography, refraction and reflection, electromagnetic and potential field and gravity.
2) Integrating the regional seismic experiments with wider scale global tomography is important as well as extending the imagining resolution at depth.
3) Mapping the heterogeneities through high-resolution geochemical studies of rock samples (drilled, dredged, or collected by deep-sea vehicles), complemented by high-resolution (i.e. AUV-type) multibeam surveys, can be addressed by individual nations. However, collaboration is required to establish a synthesis of significant sections of the world's mid-ocean ridges.
4) The collection of geophysical and geochemical data should be complemented by physical property analyses of mantle rocks, where available.
5) Numerical geodynamic modelling should help to better understand the mantle mixing processes.
6) Key to this approach is to combine geophysics with rock geochemistry to better constrain melt fraction, crustal thickness and hence to unravel the effects of mantle composition and melting history.

SECTION D
RIDGE-OCEAN INTERACTIONS AND FLUXES

Background:

From an oceanographic viewpoint, it has been generally assumed that geothermal heating has a small effect on global circulation, but recent modelling investigations have demonstrated that this assumption is wrong and geothermal heating has an influence on mixing in the abyssal ocean and wider effects on the global thermohaline circulation. However, these modelling results are based on passive heating above an impermeable seabed using coarse grids, and hence do not include the dynamic uplift created by the hydrothermal plumes which may, through entrainment, provide a mechanism to lift some of the densest water away from the bottom boundary layer nor do they include mixing caused by tidal and current flow over the rough sea-floor. Over the next decade ocean circulation models will increase in resolution and will be able to include more accurate bathymetry maps and geothermal flux models. Our challenge is to provide accurate estimates of the heat and mass fluxes at the ocean floor that can be integrated into these new models. Better models will lead to better prediction of the global circulation. We will be able to test the veracity of these models using chemical tracers and through biological mapping using novel DNA mapping techniques.

Big Questions:

1) Mixing and heating in the abyssal oceans
2) Biological/chemical tracer distribution - spatial/depth
3) Distribution of fluxes – focused vs. diffuse

1) Mixing and heating in the abyssal oceans

Heating of the abyssal ocean is necessary to maintain the global thermohaline circulation system that transport heat, nutrients, biological, chemical around the globe. Cold abyssal water, formed at the poles, fills the deep ocean basins from depths of about 1000 to over 5000m. This water has to be warmed to make it buoyant to rise to the surface to complete the circulation loop. To date, the current coarse resolution simulations of ocean circulation means that the large contrasts in the spatial distribution of geothermal and hydrothermal fluxes are not properly represented. Within the next decade ocean circulation models will achieve spatial resolutions capable of including more realistic seabed topography, geothermal heating and entrainment. These models will then provide more reliable predictions of abyssal ocean circulation. Ridges provide three mechanisms that may drive this process: the rough topography interacts with flow in the abyssal ocean caused by tides or by large-scale ocean currents. Recent measurements have shown increased levels of mixing that may mix heat down from the surface into the deeper water masses; direct thermal heating of the abyssal ocean by cooling of the newly formed ocean crust, approximately 70% of the Earth's heat loss is through oceanic lithosphere and, of that, most is through young oceanic crust at spreading ridges or along their flanks. Unlike surface heat fluxes, geothermal fluxes are unidirectional, always contributing towards increasing the buoyancy of the deep ocean; lastly the flow of hydrothermal fluid focused in so-called black-smokers close to the ridge crests create a third type of mixing through entrainment. It has been estimated that this process may increase the volume of the hydrothermal plume by a factor of ten thousand.

2) Biological and chemical distribution (or tracers)

Hydrothermal activities usually accompany flourishing biological communities and provide huge chemical outputs to the oceanic system. Some of them stay or are deposited around the hydrothermal vent; others are entrained by hydrothermal plumes, to be transported by oceanic circulation. Understanding of the transportation processes will improve our knowledge of global oceanic circulation, through recognition of global biogeographical provinces, population connectivity, ecological features of planktonic and benthic animals in all life stages, chemical distribution, as well as direct measurement of hydrothermal plumes and oceanic currents, and accumulation of knowledge on hydrothermal vent fields in unexplored areas, e.g. Southern Ocean.

The deep-sea hydrothermal biological communities themselves attract the peoples' (researchers') interest, but they also provides much information about the environment of hydrothermal vents and invisible connectivity among hydrothermal vents, caused by a combination of hydrothermal plume and oceanic circulation. The animal distribution is closely correlated to environmental factors provided by hydrothermal activities. Understanding of the ecological and physiological features of the animals will lead us to understand how animal distributions correlate with the physical and chemical properties around hydrothermal vents, and furthermore, the speciation and subsequent evolution processes around hydrothermal vents.

The connectivity among vents is classified at least at two levels; global or historical level and localized or temporal level. At the historical level, the connectivities are shown as biogeographical provinces, or similarity of community composition. The present-day biological distribution is a part of the biodiversity problems. On the other hand, in the temporal level, the connectivities are the result of embryo and/or larval dispersal and caused by gene flow among the different populations in the same species.

3) Distribution of fluxes – focused vs. diffuse

A challenge for a more complete model of both heat and mass fluxes through the seafloor is estimating the distribution of the various forms of vents. There is strong spatial and temporal variation in heat and mass fluxes through the seafloor. There is also a paradox between the apparent deficit of hydrothermal cooling required to solidify the newly formed oceanic crust and the flux of hydrothermal discharge of key elements (such as Sr) to the ocean. One key to solving this paradox may be the partitioning between high and low-temperature fluxes. While the most spectacular vents, that are associated with high-temperature black-smokers that discharge mineral and chemical laden fluids into the ocean in plumes, are found close to the ridge axis, over the past decade diffuse vents that discharge low temperature heat-fluxes with a much lower chemical flux have been located on the ridge flanks. These have lower heat and chemical flux rates but are spread over large areas.

Many questions remain as to the role of low temperature venting relative to the total heat flux from hydrothermal systems. What is the proportion of heat and mass flux that occurs through discrete vents (black-smokers) close to the ridge as opposed to diffuse vents on the ridge flanks? What methods can be developed for quantifying heat flux from low-temperature, diffuse flow? How are the spatial and temporal controls on low-temperature venting related to high-temperature venting? How do hydrothermal systems evolve through time from a volcanic eruption event to the off-axis? The hydrothermal plumbing in the ocean crust is likely to vary with spreading rate and spreading process. These variations need to be quantified to understand the nature and quantity of the fluxes in the deep ocean that can then be linked to improved circulation models.

Implementation:

1) New high-resolution ocean circulation models to be built in collaboration with physical oceanographers.
2) Long term observatories at both ridge and flank to monitor fluxes over a volcanic cycle.
3) Integrated high-resolution studies including physical, chemical and biological data.
4) Development of new synthesis of DNA data to map filters to the larval dispersal.
5) The addition of new chemical/biological sensors to distributed observing platforms such as ARGOS floats and Ocean gliders used to map the internal structure of the oceans.
6) Involvement with policy makers to develop a common environmental policy.

SECTION E
OFF-AXIS PROCESSES

Background:
The on- and off-axis mid-ocean ridge processes have a major control on the formation and evolution more than 70% of the Earth's crust and solid surface. The oceanic lithosphere is where the ocean and the solid earth interact, with a large variety of implications ranging from the global heat and chemical budgets to the effects of the subducting plates on earthquake genesis. Previous IR science plans focussed on axial ridge processes and greatly improved our knowledge of accretionary processes and hydrothermal fluxes. Detailed investigations have brought insights into volcanic and tectonic processes generating the new ocean lithosphere. In situ observatories have monitored hydrothermal fluxes specific localities for more than 10 years now, collecting precious information on the evolution over time of heat loss, chemical fluxes, mineralization and vent fauna. But we still observe a misfit between axial and global heat flux estimates, implying that the contribution of off-axis processes is significant. Hence it is time to investigate what happens on the ridge flanks.

The concept of "off-axis" evolution of the ocean lithosphere implies that we know the limit of the "axial" zone, which is not true, as its definition depends on which processes are concerned. Magmatism is active beyond the ridge crest at fast and slow spreading ridges, and fluid flow is active in crust of tens of millions of years old. New technologies should help detect events and processes that become subdued away from the plate boundary, but remain significant at a planetary scale.

Big Questions:
1) How do the accretion-driven processes (faulting, volcanism, hydrothermal circulation, and ecosystem dynamics) evolve, diminish, or change character with increasing distance off-axis?
2) Where is the edge of the "ridge crest"? How does it vary with time? How does it vary according to processes (tectonically active zone vs volcanically active zone vs hydrothermally active zone)?
3) What are the relative contributions of hot vents and diffuse flow when going off-axis?
4) How could we improve our estimate of the "ridge axis" heat budget?
5) What is the contribution of diffuse "cold" flow on the heat budget and on mineralization?
6) What are the integrated processes that lead to the architecture of a subducting plate?
7) What is the extent of serpentinization and how far off-axis does this process occur? Does it stop before the plate enters subduction?
8) What is the lifetime of an abyssal hill? How are abyssal hills "rejuvenated" far from plate boundaries?
9) What characteristics of the ocean plate architecture created near the axis influence the behaviour of the subducting plate?
10) Why does off-axis volcanism have very different expressions from one ridge to another, both on near-axis and intraplate areas? How does the ocean lithosphere filter and alter off-axis volcanism?

Implementation:
1) It is a vast area! Take every opportunity to collect data off-axis!
2) AUV surveys of near-axis areas with ultra high-resolution bathymetry and profiling.
3) Better use of transit routes: systematic coverage of ridge flanks, and collection of bathymetry data for all cruises and transits.
4) Improve monitoring of hydrothermal vents to capture spatial distribution and temporal variation of fluxes: better estimate of the global fluxes.
5) Develop methods and tests for extrapolation from local to regional or global estimations of fluxes.