RIDGE 2000 PROPOSAL FOR AN INTEGRATED STUDY SITE AT A FAST-SPREADING RIDGE: THE EAST PACIFIC RISE, 8º-11º N

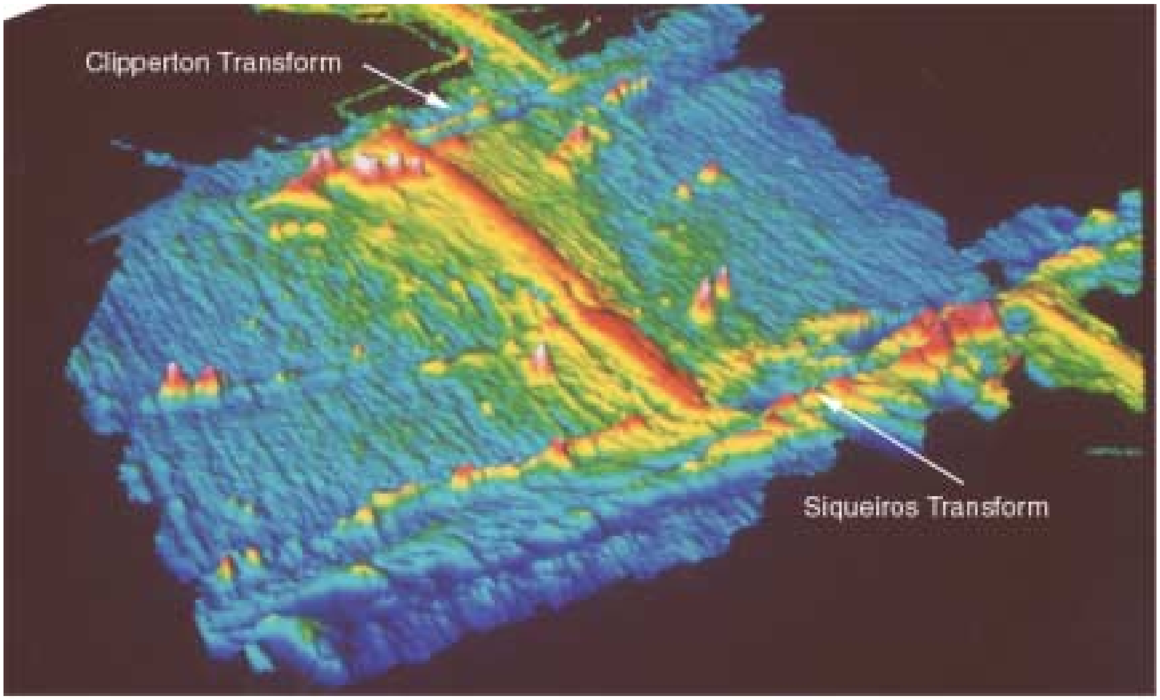

Fig. 1: Bathymetry of the East Pacific Rise in the proposed site area.

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RIDGE 2000 Integrated Studies Overarching Goal: "To understand the mid-ocean ridge as a complex geobiological system with interconnected parts related through diverse controls and feedbacks. This understanding requires integrated and often simultaneous investigations of all aspects of the system, and the linkages among them, at a small number of sites that encompass a range of external forcing functions." (RIDGE 2000 Science Plan).

Summary

Most of the ocean crust on Earth today was created at fast spreading ridges, as was most ocean crust that is presently being subducted. Because magma chambers are almost always present beneath fast-spreading ridges, hydrothermal activity is prolific, and plume studies suggest that fast-spreading ridges may dominate global mid-ocean ridge hydrothermal fluxes. Fast spreading ridges are excellent for integrated studies (IS) because they are dynamic and present opportunities to observe and measure mid-ocean ridge processes on a decadal time scale. These ridges also sustain many biological communities, which respond to frequent crustal accretion events in measurable ways. The East Pacific Rise at 8º-11º N is the best choice for a fast-spreading IS site because: this site includes most of the geological/geophysical, biological, and chemical diversity observed on fast-spreading ridges; this site has no significant atypical features that would complicate understanding of basic fast-spreading ridge processes; and, there is a remarkable breadth and uniqueness of previous work in this area that provides a vastly superior context of background information in comparison to any other fast-spreading site. Our ability to pose important questions, test hypotheses, and design fully-integrated experiments is better here than anywhere else on fast-spreading ridges; and, for key aspects of integrated studies, better than anywhere on the mid-ocean ridge.

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Part I: Justification for Selecting EPR, 8°-11°N as a Fast-Spreading Ridge Integrated Studies (IS) Site

1. Introduction

Fast-spreading ridges are inherently advantageous for conducting integrated time-series studies of ridge processes because the probabilities of observing accretionary events (e.g., episodes of cracking, intrusion, or eruption) in any 10 year time period are much enhanced by accelerated plate separation. Significantly higher densities of biological communities on fast-spreading ridges also allow for successful integration of biological and geoscience programs on almost any expedition. The 325 km-long portion of the East Pacific Rise (EPR) extending from 8°N to 11°N (Fig. 1) spreads at a full rate of 11 cm/yr, and has been intensively studied by the mid-ocean ridge (MOR) community since the early 1980's. The attributes of this superb natural laboratory (described below), and the extensive, unique multidisciplinary and interdisciplinary data sets that have been collected here, make this site ideal for future coordinated studies of the integrative sum, rather than the individual parts, of a fast-spreading MOR system. The sheer number of publications from the proposed site (over 220 between 1980 and 2000; Part V) attest eloquently to the abiding and ongoing interest of the MOR community in the EPR at 8°-11°N, and to the public availability of much of the data that has been collected here (see also Part IV).

The primary advantages of the EPR at 8°-11° site for conducting integrated studies (IS) of a fast-spreading MOR are: tectonic and morphologic diversity; well-known history of the plate boundary; absence of major perturbations to spreading ridge processes (no nearby subduction zones or major mantle plumes); unparalleled knowledge of shallow (<10 km) seismic properties and velocity structure; ongoing monitoring of seismicity using NOAA's Acoustic Hydrophone Array (AHA); abundance and diversity of known hydrothermal vents, plumes, and biological communities, and high potential for discovery of additional hydrothermal sites; direct observations of seafloor phenomena associated with a 1991 volcanic eruption, and ongoing multidisciplinary/ interdisciplinary time-series studies of the impact and aftermath of this event; evidence for direct magmatic influences on hydrothermal systems; opportunity to compare active hydrothermal vents that lie within and outside of the eruption area; significant potential for magmatic and cracking events in the near future; extensive petrologic/geochemical, photographic, and acoustic databases; links to LARVE; links to ODP databases and future programs; close proximity to major port facilities; and, almost year-round accessibility.

2. Tectonic and Morphologic Diversity and Well-Known History of the EPR

The tectonic configuration and evolution of the EPR in the proposed area are very well known, and encompass a great diversity of fast-spreading ridge environments including the full hierarchy (1st-4th orders) of segments and ridge axis discontinuities (see table in Part II-3, also

Parts II-4 and III-1a,b). Hence this area is ideal for conducting nested, integrated studies at the multiple length and time scales needed to address MOR problems at scales ranging “from mantle to microbes”. The EPR at 9º-10ºN is one of only two fast-spreading MOR areas where data allow the finest scales of segmentation of the ridge crest to be known.

Existing regional magnetic, gravity and multibeam/Sea MARC II sonar surveys have completely imaged the ridge flanks out to >100 km (~2 million years) from the axis on both sides (Fig. 1; see Parts II-3,4 and III-1a). Careful analyses of these data sets have revealed: the structure, duration, migration, and temporal behavior of segment boundaries; changes in spreading directions and corresponding changes in ridge segment configuration over the past million years; the development of faults and abyssal hills; and, the distribution of off-axis volcanoes. Near-bottom imaging of the ridge crest at 9º-10º N has revealed the recent ($<10^4$ yr) fine-scale volcanic segmentation of the ridge crest, and its relationship to the distribution of ridge crest hydrothermal and volcanic features. Our proposed site thus benefits from a rich context of geologic information and insight about how the EPR plate boundary has evolved over the past two million years. Furthermore, the “normal” behavior of the plate boundary is not perturbed or obscured by close proximity to trenches, continents, or major volcanic “hot spots”.

A wide variety of ridge crest morphologies are found within the proposed site area (see Parts II-4 and III-3), ranging from broad/shallow morphology (e.g. 9.5-10ºN, 9º 03’N to the Siqueiros Transform) to narrow/deep morphology (e.g. north of Clipperton Transform, from 9º 12’-03’N, and south of Siqueiros Transform). Axial summit troughs are present in some areas, and are absent elsewhere (e.g. 9º 21’-03’ N, and north of 9º 52’N). Examples of “magma-rich” and “magma-starved” ridges are juxtaposed across the Clipperton Transform. Inclusion of the EPR north of Clipperton and south of Siqueiros permits investigation of why these transforms are major boundaries for mantle melting processes, and also tests if they are boundaries for biota. Because Clipperton and Siqueiros Transforms step in opposite directions, changes in spreading direction since 1 Ma have produced compression across the Clipperton and extension across the Siqueiros, causing a median ridge to form within Clipperton and intra-transform spreading centers to form within Siqueiros. The diverse structures and morphologies of spreading ridge segments and their bounding discontinuities in the EPR 8º-11ºN area provide ample choice of possible tectonic and volcanic settings for integrated MOR studies.

3. Knowledge of Shallow Seismic Properties, Velocity Structure, and Seismicity

The seismic velocity structure and seismic properties of the upper 10 km are known better at EPR at 8º-11ºN than anywhere else on the global MOR (see Part III-1c). The unparalleled diversity, quality/resolution, and regional extent of seismic data within the proposed study area are a tremendous asset for planning three dimensional integrated studies of ridge processes. Major seismic experiments conducted here over the past 15 years include: the first 3-D multichannel seismic reflection and wide-angle reflection/refraction experiments to be conducted at an MOR (seismic tomography experiments at 9º 30’N, at 9º 03’N); several other multichannel and refraction experiments, including one across the Clipperton Transform; a unique near-bottom refraction experiment (NOBEL) to resolve the velocity structure of Layer 2 at 9º 30’N; seismic compliance measurements; and a unique mantle imaging experiment (Undershoot experiment) from 8º 15’-10º 15’N. These studies have revealed a great deal about the distribution of heat and melt beneath the ridge (see Part III-1c), and have generated new hypotheses about the nature of melt generation, ridge segmentation, and hydrothermal circulation. Observations that seismic Layer 2a rapidly increases in thickness, from ~150 m at the topographic ridge axis to ~300 m at 1-2 km from the axis, have been used to constrain models of how the volcanic layer of ocean crust is accreted at fast-spreading ridges.

The proposed study site lies well within range of the moored acoustic hydrophone array (AHA) deployed in 1996 by NOAA for remote detection of seismicity along the EPR. Hence there is an ongoing monitoring effort in place to detect earthquakes associated with volcanic eruptions and tectonic events, and to show patterns of activity within the proposed IS region. Previous on-bottom microearthquake studies on the EPR near 9º 50’N(see Part III-1d) revealed a coupling between seismic events, changes in hydrothermal fluids, and coincident changes in the biological communities, findings that led to new understanding of these linkages (see Part II-7 and III-2). Proximity to AHA is thus highly advantageous to the design and deployment of integrated studies experiments in the proposed EPR study area.

The value of conducting integrated studies in a region where so much already is known about the distribution of melt, heat, and seismicity beneath the ridge crest and about the tectonic/volcanic segmentation, shape and history of the ridge, cannot be overemphasized. A well-designed IS program can test hypotheses that have arisen from these previous observations; and the existing databases provide essential information for selecting future sites of seafloor sampling, experiments and boreholes.

4. Abundance and Diversity of Known Hydrothermal Vents and Biological Communities, and Excellent Potential for Finding Additional Sites

The EPR at 8º-11ºN is an excellent candidate for an IS site because it supports numerous vent fields and communities, and habitats within fields (see Parts II-1 and III-2d,e). Furthermore, the precise age of many vent sites located within the 1991 eruption area (9º 45’-52’N) is known, and chemical variation among sites has been documented. These attributes allow vent scientists to test hypotheses relating to: spatial variation in community structure; chemical controls on community composition and productivity; and time-series changes in community structure and development (including recruitment processes). A near-bottom *Argo I* survey in 1989 mapped the locations of hundreds of hydrothermal vents and animal communities along the EPR crest at 9º54’-09’N. The hydrothermal systems have evolved since that time, such that some of these sites have flourished biologically, others have died, new ones have developed or been found, and the fates of sites that were never investigated remain unknown. Currently there are a wide variety of ongoing research programs to study hydrothermal vent fauna, fluids, and minerals at over 16 different vent areas that include a spectrum of immature-to-mature black smoker, white smoker, and diffuse flow vents of highly diverse fluid properties (including high, low and normal chlorinities, temperatures from >380ºC to <10ºC, and large variations in pH, CO_2, H_2S, H_2, and oxidation state). This temporal, thermal and chemical spectrum of vent habitats supports a diverse microfauna and macrofauna, including all of the dominant species of the eastern Pacific (see Parts II-1 and III-2d,e). The exceptionally broad, shallow 2nd order segment of the EPR between the 9º 03'N OSC and the Siqueiros Transform has never been explored for hydrothermal vents. The inflated morphology of the ridge suggests a robust magmatic system, and it is highly likely that this unexplored segment is a hydrothermally-active ridge where many more vents may be found. It is important for an IS program to have access to a sufficient number and diversity of hydrothermal communities and active vents so that multiple experiments and sampling efforts can proceed without significantly perturbing one another or the overall regional ecosystem. The proposed site fulfills this need by including many known vents as well as areas with excellent potential for discovery of additional vents.

5. 1991 Eruption, Time Series Studies, and Probability of Future Events

In 1991-92, the results and consequences of a mid-ocean ridge volcanic eruption were directly observed for the first time along the EPR at 9º 45-52'N by divers in *Alvin* during the AdVenture 1 an 2 dive programs. Nowhere else on the MOR have seafloor observations and sampling been achieved so soon after an eruption. These landmark observations established a "time-zero" baseline for time series studies conducted within the eruption area during the AdVenture 3-8 submersible programs in 1993, 1994, 1995, 1997, 1999, and 2000 (see Part III-2). In early1992, a line of markers was placed along part of the 1991 eruptive fissure (the "Biogeotransect" from 9º 51'- 9º 49'N) to aid time series documentation of recruitment, colonization, larval dispersal, and faunal succession at hydrothermal vents (see Parts II-1,9 and III-2d). The time series studies initially revealed a rapid geochemical evolution of vent fluids and plumes, from gas-rich, low-chlorinity vapors immediately following two discrete magmatic events (in 1991 and 1992), to higher-chlorinity brines by 1994. Vent fluids continued to evolve from 1994-2000, but the changes have not been in unison or unidirectional at all the sites (see Part III-2c). Changes in temperatures and chlorinities that were observed at two vents in 1995 appear to have been the result of a local cracking event (see Parts II-7 and III-2c,f). Responses of biota and mineralization to the eruption and cracking events have revealed linkages between geologic, geochemical, and biological processes. The rates and sequences of change in the biota, fluids, plumes, mineral deposits, and lava flows since the eruption have provided a widely-applicable means of estimating how much time has elapsed since the occurrence of a MOR magmatic event. Because there are known hydrothermal vents and biological communities at locations south of the 1991-92 eruption area, as well as within this area, comparisons can be made along the same ridge between sites that have and have not been affected by recent volcanic events. Also, observations from vents that are older than those within the eruption area can be compared and added to the decade-long time-series observations within the eruption area.

The value of the EPR at 8º-11ºN as a site for future integrated MOR studies is enhanced greatly by using the time series studies as a springboard for designing a new generation of integrated multi- and interdisciplinary experiments. The time-series studies show that none of the vents in the eruption area have chemically stabilized since1991 (see Part III-2c). At some vents, fluid chlorinities increased at first, but never reached seawater Cl concentrations, and recently have exhibited decreases in chlorinities accompanied by increases in fluid temperatures. These observations and high CO_2 at some vents indicates that the probability for renewed magmatic activity in the near future is high. The 9º 50'N area is particularly magmatically robust, and is one of only two sites on the global MOR where there is direct chemical evidence for recent magma re-supply (see Parts II- 7 and III-2c). The active and changing state of the ridge crest system from 9º-10ºN thus represents a great opportunity to study linkages between biological, chemical, geological, and oceanographic processes using an IS approach.

6. Extensive and Detailed Petrologic, Photographic, and Acoustic Databases

There has been extensive petrologic sampling and near- and on-bottom imaging along the EPR crest, 9º-11ºN (see Parts II-6 and III-3). From 9º-10º N, there is moderate-to-high density petrologic sampling of the ridge both on- and off-axis. The 8°37’N offset region was sampled in 1989, and the Siqueiros Transform also was well-sampled during a submersible program in 1991. Some samples were collected in the Clipperton Transform as well (Klein et al., 1987). These data and their interpretations add essential information about magmatic and tectonic processes along the ridge crest during the past 100.000 years, and yield insights that are extremely useful for designing and planning future integrated studies of ridge crest processes.

7. Links to Other Programs and Logistical Advantages

A proposal has been submitted to ODP for drilling 4 holes into the EPR at 9º-10ºN, beginning in 2005 (see Part II-8). If the IODP is approved and if this drilling proposal is accepted, it will bring added resources and possibilities for linkages to the goals of an IS program sited here. The LARVE project (NSF/RIDGE) also is supporting ongoing studies within the proposed IS area (see Part II-9).

Logistical considerations for the proposed site are excellent. It is accessible three-quarters of the year (except July to mid-October during hurricane season); it is in international waters; it is less than a 2 day steam from major port facilities in either Manzanillo or Acapulco, Mexico; and it is a 5 day steam from the U.S port of San Diego.

Part II: How EPR, 8º-11ºN Fulfills Selection Criteria For An IS Site

1) *Does the site encompass a representative variety of micro- and macrofauna; hydrothermal venting styles; fluid and particulate compositions?*

Vent communities in the proposed area are known to be frequent (Haymon et al., 1991) and diverse (Shank et al., 1998). Over 90 vent-endemic species have been documented from a wide variety of habitats. These habitats include a full spectrum of immature-to-mature black smokers, white smokers, and diffuse flow vents. The vents at which fluids have been measured (>20 vents) exhibit highly diverse fluid properties including high, low and normal chlorinities, temperatures (T) from >380ºC to <10ºC, and large variations in pH, CO_2, H_2S, H_2, and oxidation state (see Part III-2c). Unique studies of near-field plume particles from these vents (see Part III-2b) reveal vent-specific variations in mineral assemblages and metal contents, and a distinct change to more Zn-rich and oxidized mineral particle assemblages at mature vents where $T < 330$ºC. These site specific signatures of the buoyant plume particles are undetectable in the particle assemblages of the far-field neutrally-buoyant plumes. This is the only site on the MOR where there is enough data on buoyant plume particles to substantiate these conclusions.

The temporal, thermal and chemical variety of vent habitats and fluid compositions provide excellent opportunities to explore the complex association between microbial diversity and geochemistry. Several important types of microbes have been discovered here, including sulfide-oxidizers that bloom during magmatic events, and produce a microbially-precipitated "blizzard" of sulfur particles and mats; abundant hydrogen-oxidizing microbes thriving in the plumes; very primitive thermophilic bacteria (Aquifales); and unique epibiotic sulfide oxidizers associated with Alvinelline worms (see Part III-2d). Macrofaunal communities here include vestimentiferan tube worms, mussels, clams, archaeogastropod limpets, alviniocarid shrimp, bythograeid crabs, serpulid worms, anemones, and others. Because many of the same (or similar) species inhabit the Galapagos Rift and southern EPR, it is possible to conduct comparative studies linking fluid chemistry and animal physiology to a variety of chemical habitats along ridges spreading at different rates.

The exceptional time-series geochemical, geological and biological databases acquired within/outside the 1991-92 eruption area (see Part III-2), in conjunction with LARVE studies in this area (see Part II-9), and the dynamic nature of the hydrothermal systems here, contribute to making the EPR at 8º-11ºN into one of the premier sites in the world for investigating interactions and linkages between: volcanic/tectonic events; changes in vent fluid and plume properties; changes in vent styles and mineral deposits; and, biological changes in macrofaunal community structure, microbial community diversity and function, organismal physiology, and larval dispersal.

2) ***Does the site display a significant hydrothermal signature in the water column?***

There have been several studies of hydrothermal plumes within the EPR 8º-11º N area (see Part III-2b). A November 1991 survey covered the area from 8°40’N to 11°50’N and indicated that the most intense plumes were present over the eruption site (9º45’-52’N). During this survey, intense and continuous plumes were seen at 8°48’-58’N, 9°29’ - 10°01’N, and 11°05’-27’N, and weak and discontinuous plumes were seen from 8°58’ - 9°29’N (Lupton et al., 1993). Significant CH_4 and Mn plume anomalies were reported, with $CH_4/Mn > 1$ occurring only over the new eruption site (Baker et al., 1994; Mottl et al., 1995). Studies of neutrally-buoyant plume particles by Feely et al. (1994) showed high levels of organic S over the new eruption site with S/Fe ratios as high as 10, indicating gas-rich plumes. Outside the eruption area, the ratios of volatile/non-volatile plume components were variable, and were much lower compared to plumes inside the eruption area. Regionally, iron oxyhydroxide particles in the plumes efficiently scavenged REE elements and phosphorous from bottom waters (Field and Sherrell, 2000; Feely et al., 1994; Baron, 1998). Additional plume studies have shown that the plumes are populated by highly productive hydrogen-oxidizing microbes (McLaughlin, 1998), and that larval dispersal is facilitated by bottom currents more than by plumes (Kim et al, 1994, 1998).

These diverse plume studies have shown that vigorous, chemically-diverse and biologically-active hydrothermal plumes are extant in the proposed IS area.

3) ***How does the site encompass a representative range of ridge offsets?***

The proposed IS site contains examples of ridge morpho-structural segmentation at all of the recognized segmentation scales (see Part II-1a). Segments and ridge axis discontinuities (RAD’s) along fast-spreading ridges typically are classified within a tiered hierarchy of scales from 1st order (largest, longest-lived) to 4th order (smallest, short-lived). The study site encompasses the 1st order ridge segment between the Clipperton and Siqueiros transform faults (Fig. 1). The two transform faults (1st order RAD’s) included within the study area represent two contrasting modes of transform tectonics. The Clipperton is a transpressional single-strand transform fault. It offsets the ridge axis by 85 km to the right. The Siqueiros is a transtensional multi-strand transform fault with multiple intratransform spreading centers. The total offset across the Siqueiros is 140 km to the left. The overlapping spreading center (OSC) at 9°03'N is a 2nd order RAD. The 10 km right-stepping offset is clearly visible from near-surface sonar mapping. The 9°03'N OSC shows a prominent magnetic high and highly fractionated MORB. The off-axis trace of the 9°03'N OSC shows that it has propagated south at the rate of 52 mm/yr for the past 1 Myr (Carbotte and Macdonald, 1992).

3rd order ridge segments have an average 20 km length within the survey area, and are more difficult to recognize than the 1st and 2nd order segments because they are at the limit of resolution in typical ship-based multibeam bathymetry. Their identification on the EPR from

9°08'-10°03'N has been aided by DSL-120 sidescan sonar data acquired in April, 2000 (White et al., 2000). The proposed study site is one of the few areas anywhere along the MOR where data resolution permits 4th order segments to be recognized. 4th order segments have an average length of ~7 km within the proposed study site. Their locations and offsets may be found in the table below, along with the other RAD’s within the proposed IS site area.

Note that the table below does not include RAD’s at 9º 28’N or at 9° 17'N. Some investigators have identified devals at these latitudes using multibeam bathymetric data; however, careful analysis of higher resolution data (SeaBeam 2000, *Argo I* and DSL-120 sonar) show that there are no offsets at either 9º 28’N or at 9° 17'N (White et al., 2000).

Latitude	Order	Offset	Structure
8° 24'-30'	1	140 km Left	Siqueiros
8° 27'	4	<1 km Right	
8° 37'	3	1 km Right	non-overlapping offset
8° 46'	4	none	start ASCT
8° 53'	4	none	end ASCT
8° 57'	4	0.5 km Left	deval
9° 03'	2	10 km Right	OSC
9° 12'	3	0.5 km Right	deval
9° 20'	3	1 km Right	deval
9° 26'	4	none	start ASCT
9° 35'	4	<0.5 km Right	ASCT widens
9° 37'	3	0.5 km Right	overlapping ASCT, deval
9° 45'	3	0.5 km Right	non-overlapping offset
9° 49'	4	0.5 km Right	deval
9° 51'	4	none	end ASCT
9° 57'	3	none	saddle
10° 06'	4	<0.5 km Right	deval
10° 15'	1	85 km Right	Clipperton

4) *How does the site encompass a representative range of ridge morphologies?*

The EPR morphology from 8°-11°N is in general typical of fast-spreading ridges (Carbotte and Macdonald, 1994; Macdonald et al., 1992). Between the Clipperton and Siqueiros transforms, the ridge axis maintains a minimum depth in the range of 2500-2600 m, making this one of the more shallow sections of the EPR. The general cross-sectional shape of the axial high varies greatly throughout this area, encompassing a full range from triangular through domal to rectangular (Part III-1b; Macdonald and Fox, 1988). The cross-sectional area of the axial high, calculated from a reference level of 2938 m, is 3-4 km^2 along the majority of the ridge axis, a value that is near average for the EPR (Scheirer and Macdonald, 1993). Two local maxima in cross-sectional area, associated with depth minima and very broad summit plateaus, are present at the north ends of both 2nd order ridge segments in the study area (just south of Clipperton at 10°06'-10°00'N, and just south of the 9º 03'N OSC at 8°57'-45'N). The summit plateau south of the OSC is exceptionally broad (~5 km wide). From these inflated areas at the north ends of the 2nd order segments, depths increase and cross-sectional areas decrease steadily to the south ends of the segments (from 10°15'-9°03'N and from 9°03'-8°24'N). North of Clipperton and south of Siqueiros, the EPR axial high is deep, narrow and triangular.

An axial summit collapse trough (ASCT) exists from 9°26'-51'N and 8°53'-46'N (Haymon et al., 1991; Macdonald et al., 1992; Fornari et al., 1998). Near- and on-bottom studies of the northern ASCT show that this trough varies from 50-200 m in width, and from 5-20 km in depth, and is the locus of most of the volcanic and hydrothermal activity on the ridge crest in this area (Haymon et al., 1991). The southern ASCT has not been explored, but it is anticipated to be similarly active. Both ASCT's are excellent areas for integrated studies of interrelated hydrothermal, magmatic, tectonic, and biological processes.

The near-ridge area contains the typical array of tectonic and volcanic features found on fast-spreading ridge flanks, including seamount chains, small isolated off-axis volcanoes, fault-bounded abyssal hills, the discordant zone associated with the 9º 03'N OSC, and two fracture zones (Fig. 1 and Part II-1b). Several seamount chains in this area remain largely unexplored, and are potential sites of hydrothermal activity and biological habitats.

5) Is the site logistically feasible in terms of weather windows, technological constraints, and port availability?

Logistical considerations for the proposed site are excellent. It is accessible three-quarters of the year (except July to mid-October during hurricane season); it is in international waters; it is less than a 2 day steam from major port facilities in either Manzanillo or Acapulco, Mexico; and it is a 5 day steam from the U.S port of San Diego.

Other logistical advantages of the site are: relatively shallow water depths for the MOR (2500-2600 m); excellent navigation data for geophysical, bathymetric, near-bottom, and on-bottom observations; durable syntactic foam markers deployed at all of the vents that have been sampled for fluids to prevent ambiguities in time-series sampling and to serve as aids to navigation; and finally, the line of well-located plastic markers in the 1991-92 eruption area that were deployed in 1992 along the Biogeotransect to guarantee precise locations of time-series experiments and observations in this area.

6) ***Is the background data available for the site sufficient?***

The body of background data for the EPR at 8º-11ºN is remarkable for its volume, breadth and uniqueness (see Part III). Over 220 papers have been published about this area (Part V), encompassing virtually every subdiscipline in the field of MOR studies, and large blocks of published and unpublished data are (or will soon be) publicly available via the internet (see Parts IV and VI). There is more extensive background available at EPR 8º-11º N than for any other fast-spreading ridge; and possibly more than for any other part of the global MOR system. Many of the cornerstone hypotheses for fast-spreading ridges have arisen from data collected at EPR 8º-11ºN, and are testable here by an IS approach that builds on the knowledge accumulated by previous multi- and interdisciplinary studies conducted at this site.

Of particular note is the unrivaled diversity, quality, and extent of geophysical data sets within the EPR, 8º-11ºN area (Part III-1c). Seismic investigations of a wide range of the physical components of the ridge and fracture zones provide a framework for future studies of ridge tectonics, magma plumbing system, and hydrothermal systems. We have a more detailed view of the 3-D distribution of melt in the crust and uppermost mantle here than for any other fast-spreading site, and we can build upon the existing seismic data to develop a fully 3-D view of the crust and mantle for this IS site. At this site we know the spatial relationships between magma distribution, ridge morphology/structure, and hydrothermal vent distribution better than at any other site. Regional and fine-scale surveys of the ridge crest have shown how the EPR crest is morphologically partitioned into volcanic and tectonic segments, and seismic surveys show that the underlying magmatic system pinches and swells from one volcanic segment to the next, and that the origin of the volcanic segmentation lies in the mantle. Ongoing seismic analysis of the crust and mantle at the 9°03N OSC are currently shedding new light on the structure of this ridge offset and its underlying magma supply. These studies are the only ones of their kind and will provide a powerful base for launching future work in this area.

We have as much or more geologic information about the evolution of the ridge system here than anywhere else. Because the history of ridge segmentation has been revealed from bathymetric and magnetic studies, it will be possible to develop a 2 million year time line of past ridge processes (magma supply, tectonics) in this area, and explore the nature of off-axis volcanism in this context. On a shorter time scale, the 1989 *Argo I* survey provides uniquely important baseline data for interpreting changes in the ridge crest and its inhabitants after the1991 eruption. Imaging of 83 km along the ridge crest in 1989 gives the northern part of the proposed IS site a visual and high-resolution acoustic record at a 2nd order length scale which extends farther back in time than at anywhere else on the MOR. On-bottom observations of this area have been maintained following the discovery of an eruption in 1991, producing unique time-series data sets (see Part III-2) including monitoring of changes in vent biota, hydrothermal fluids, vent temperatures, plumes and plume particles, mineral deposition, and microseismicity. Experiments can be designed to test the hypotheses and models that are arising from these time-series observations, and from the results of unique LARVE studies that have been conducted to determine how vent fauna maintain their populations and geographic distributions.

The 1989 *Argo I* data sets also give a rare synoptic view of fine-scale ridge segmentation and spatially correlated distributions of volcanic features, relative axial lava flow ages, cracks, hydrothermal vents, and biota. These data provide necessary information for siting experiments and designing integrated studies; also, published hypotheses about how the distribution of features reveal linkages between the magmatic and hydrothermal systems can be investigated and tested with an IS approach. The EPR at 9º 09'-54'N is one of only two places along the global MOR where a synoptic view of the distribution of fine-scale ridge crest features has been obtained.

The proposed IS area also includes one of the few places along the MOR where detailed maps of lava flow units have been made (Kurras et al., 2000; Engles et al., 2000; Smith et al., submitted). Some areas within the study site still await detailed geologic mapping, including the fresh-looking lava flows centered on 9°16'N, the 9°03'N overlap basin, and the inflated 9º 03'N-Siqueiros segment. The site also includes areas extending 1-3 km off-axis where petrologic sampling is more dense than anywhere else on the MOR (Perfit et al., 1994); additionally, much of the ridge crest and Siqueiros Transform have been petrologically sampled at a moderate density (Part III-3).

7) ***Does the site display significant potential for magmatic or tectonic events?***

Several lines of evidence suggest that the 9°-10°N area was, continues to be, and likely will be, magmatically and tectonically active. A first-order estimate of eruption frequency of 5-10 years is obtained from seismic estimates of the thickness of the extrusive layer and lava volumes obtained from the documented eruptions at 9°N (Perfit and Chadwick, 1998). It is ~10 years since the last known eruptive events occurred in this area (two in 1991-92 at 9°45'-51'N and one at 9°17'N a few years prior), suggesting one is likely to occur in the near future.

The area near 9°50'N has excellent evidence for very recent magma migration and crustal cracking events. Fluid compositions and temperatures in the 9°50'N area suggest that the magma chamber in this area has been resupplied with fresh magma since the 1992 eruption. In addition, although the eruptions were only observed in the ~9°45'-52'N area in 1991-92, various lines of evidence suggest this was accompanied by diking event(s) that propagated south, perhaps by several tens of kilometers (e.g., Von Damm, 2000; Smith et al., submitted). While some seismic measurements were made close to the time of the observed 1991-92 eruptive events, a more detailed survey was conducted during a 105 day OBS deployment carried in 1995 (Sohn et al., 1998). A swarm of microearthquakes detected at 9°50'N were suggestive of a cracking event ~1 km below the seafloor. Several days following the swarm, changes in hydrothermal fluid temperatures and chemistry were recorded at a nearby instrumented vent (Fornari et al., 1998; Sohn et al., 1998). The temporal correlation between these events indicates the cracking perturbed the fluid pathways feeding this vent, and also affected the biological communities located at this site. Other seismic signals recorded during this experiment were attributed to magma migration near 9°49'N.

Earthquake magnitudes recorded during the 1995 OBS experiment are lower than the detection threshold for the NOAA acoustic hydrophone array deployed to remotely monitor seismicity along the EPR. However, during the four years since this array was deployed, a large number of events have been recorded in the 9°N region (>2000). Most of the seismicity appears to be associated with the small intra-transform spreading centers within the Siqueiros transform fault. Hence there is good potential for both magmatic and tectonic events at this proposed IS site, and a historical context in which to place new events and new data sets.

8) ***Does the site incorporate appropriate drilling targets?***

Drilling of unsedimented ridges has been a technologically-difficult challenge in the past. However, development of new drilling technology (Hammer-Drill-In-Casing and Advanced Diamond Core Barrel systems, and improved heave compensation and drill bits) has led to successful tests in 2000 that promise future success in drilling the EPR in the proposed study area. A proposal already has been submitted for a three-leg program to drill four 200-600 m holes through Layer 2A on the EPR at 9º-10ºN. These include two holes at 9º 32’N, near the middle of the 2nd order segment between the 9º 03’N OSC and Clipperton Transform (one hole on the axis within the ASCT, and one hole 7 km east of the axis). A third hole has been proposed on- axis at 9º 40’N, on the next 3rd order volcanic segment to the north. A fourth hole is proposed on-axis at 9º 08’N, near the end of the 2nd order segment and within the area where 3-D imaging of the OSC has been conducted (ARAD experiment).

If approved, the proposed drilling program will address the physical/petrologic nature of the seismic Layer 2a/2b boundary; the geochemical history of magmas erupted on different volcanic ridge segments and at the middle vs the end of a 2nd order segment; the nature of the microbes living in the upper crust at the ridge crest; the nature of hydrothermal alteration of the crust during the first 100,000 years as the crust migrates out of the plate boundary zone (and before it becomes sedimented); and, the nature of fluids and fluid/rock reactions in the uppermost crust on different segments.   We anticipate that this drilling will commence in 2005.

9) ***How does the site allow for active liaison with other programs and infrastructure?***

<u>NOAA/AHA</u>: The EPR at 8º-11º N benefits immensely from its location within the range of the NOAA acoustic hydrophone array (AHA). This system is monitoring seismicity of the eastern Pacific region, and can detect earthquakes with magnitudes as low as 2 on the Richter scale. There is now on-line access to these data at: www.pmel.noaa.gov/vents/oceanseis.html.

NOAA/VENTS Program: While no formal connection has existed between researchers on the EPR and those in the NOAA/Vents Program, the NOAA group has often collaborated and provided various items of equipment for taking samples and making measurements of fluids and plumes. If an IS program is undertaken at EPR 8º-11º N, this collaboration is likely to expand.

IODP/NSF-ODP Program: As outlined in the previous section, we anticipate the start of a proposed international ocean drilling program (IODP) in 2005 that will provide many exciting opportunities for conducting seafloor experiments and site surveys in the proposed IS area. In addition, a previous attempt to drill the EPR axis at 9º 30'N was made in 1992 during ODP Leg 142. Analysis of samples and site survey data from Leg 142 can be found in the ODP scientific reports for Leg 142 (Batiza et al., 1995). A large body of site data for Leg 142 and for the proposed drilling legs are compiled and accessible through the ODP databank (ODP site survey databank: http://www.ldeo.columbia.edu/databank/.

LARVE: The main objective of the LARVE (Larvae at Ridge Vents) project is to explore how hydrothermal vent species maintain their populations and geographic distributions in the patchy and ephemeral vent environment. The project has been funded by NSF through RIDGE and coordinates efforts of a variety of scientists studying reproduction, larval biology, dispersal, colonization, gene flow and succession in vent communities. Many of these field studies have been centered on the vents near 9º-10ºN on the EPR because the region is well described geologically, has an abundant and diverse vent fauna, and hosts a dynamic hydrothermal vent system. Eight dedicated LARVE cruises, and many others with LARVE participants have visited the site between 1994 and 2000. A LARVE results symposium is scheduled for May 2000; it is very likely that current and new participants in these types of studies will want to conduct studies along this part of the EPR.

InterRidge: There is a long history of international cooperation in ridge studies at 9ºN and 13ºN on the EPR. Scientists from a variety of nations, including the US, France (e.g., the HOT expedition), UK, Japan, Germany, Austria, Canada, and Spain have participated in cooperative biological and geological cruises to 9ºN. Although these studies have not been organized by InterRidge, it has facilitated them by distributing information and enhancing communication. Reports on biological cruises with international participation are routinely published in the InterRidge Newsletter. This region continues to be of interest to InterRidge scientists, but it is not one of InterRidge's formal focus regions.

Sensor Development Studies: There is interest in testing and deploying (measuring and monitoring) in-situ sensors in vent fluids at EPR, 8º-11º N. The sensors have been developed with NSF funding at University of Minnesota and are well suited for the in-situ measurement of dissolved H_2, H_2S and pH in fluids at temperatures as high as 400ºC. Initial testing of the sensors during several cruises to Endeavour Segment, Juan de Fuca Ridge(1998-1999) revealed for the first time the effects of complex and very non-conservative mixing phenomena on redox variations in vent fluids on an incredibly fine scale. Considering the importance of seawater mixing on mineralization and biogeochemical effects, the new insight the sensor data provides should enhance greatly understanding of the temporal and spatial evolution of MOR hydrothermal systems. The arsenal of sensors is currently being expanded to include sensors that are smaller and more robust.

Theoretical Modeling Studies: There already exists a well-developed capability in the community for doing theoretical modeling of seafloor hydrothermal systems, and new methods are being developed (see Part III-2h). The EPR at 8º-11ºN is an ideal site for modeling, which should form an important component at any IS site. Some current problems to be addressed include the transformation of “F” vent (9º 16.8’N) from vapor to brine, the long-term secular decay of “A” vent (9º 45.6’N), and the evolution of diffuse to black smoker flow at “V” vent (9º 47.5’N).

III. Background Data And Currently Funded Projects

1. Geological and Geophysical Datasets

a. Plate Boundary Configuration and History

The EPR between 8ºN and 11ºN (Fig. 1) is spreading at a full rate of 11 cm/yr (Klitgord and Mammerickx, 1982) and includes: a complete 1st order ridge segment bounded by the right-stepping Clipperton and left-stepping Siqueiros transforms; two 2nd order segments created by an overlapping spreading center (OSC) at 9º 03'N; multiple finer-scale segments (see table in Part II-3), including 3rd order volcanic segments with boundaries detectable in multibeam bathymetry data (White et al., 2000), and 4th order segments bounded by smaller, more transient ridge axis discontinuities that are below the resolution of multibeam sonar systems (Haymon et al., 1991).

Magnetic, gravity and multibeam/Sea MARC II sonar surveys that completely image the ridge flanks out to >100 km from the axis on both sides (Fig. 1) reveal the duration, migration, and temporal behavior of the different types of ridge axis discontinuities (Macdonald et al., 1992; Carbotte and Macdonald, 1992; Begnaud et al., 1997). These datasets demonstrate that the entire plate boundary has rotated approximately 3-6º counter-clockwise over the past million years (Carbotte and Macdonald, 1992 and 1994), and that the 9º 03’N OSC has migrated southward at 52 mm/yr during this time period (Carbotte and Macdonald, 1992), shedding onto the ridge flanks a V-shaped wake of abandoned, highly-magnetized ridge tips and overlap basins (Macdonald et al., 1992; Carbotte and Macdonald, 1992). The regional surveys also reveal the distribution of volcanic seamounts and seamount chains that have developed off-axis (Scheirer and Macdonald, 1995), including the Lamont seamount chain investigated by submersible in 1985 (Fornari et al., 1988).

Because the Clipperton and Siqueiros Transforms step in opposite directions, recent changes in spreading direction caused by rotation of the plate boundary have produced compression across the Clipperton and extension across the Siqueiros (Carbotte and Macdonald, 1992; Pockalny et al., 1997a,b), causing a median ridge to form within Clipperton (Kastens et al., 1986) and intratransform spreading centers to form within Siqueiros (Fornari et al., 1988).

b. Ridge Crest Morphology

Large-scale: Multibeam and SeaMARC II sonar surveys revealed that a wide variety of ridge crest morphologies are found within the proposed study area (Fig. 1; Macdonald et al., 1984 and 1992). From 11ºN to the Clipperton Transform, the ridge crest narrows and deepens along strike, and is triangular in cross-section . Morphologically and petrologically, this portion of the ridge is considered to be “magma-starved” (Macdonald et al., 1984; Langmuir et al., 1986). From the Clipperton Transform southward to ~ 9º 45’N, the ridge crest is broad and shallow, exhibits an inflated, domed-to-rectangular cross-section, and reaches a minimum depth of 2500 m at ~9º 50’N. This portion of the ridge is morphologically and petrologically “magma-rich”, with MgO reaching a maximum value of ~9 wt % at the axial high (Batiza and Niu, 1992; Perfit et al., 1994). From the axial high southward to the segment tip at ~9ºN , the ridge crest steadily deepens and narrows, assuming a triangular cross-section south of ~9º 12’N, and MgO also steadily decreases (Batiza and Niu, 1992). South of the 9º 03’N OSC, the ridge crest shallows rapidly to a minimum depth of 2520 m and broadens dramatically to a width of 5 km at 8º 52’N (Macdonald et al., 1992; Carbotte and Macdonald, 1992). From there the ridge crest narrows and deepens southward to the EPR/Siqueiros intersection, and from south of the transform to 8ºN, the EPR crest is narrow and triangular.

Fine-scale: Fine-scale regional surveys of the ridge crest in the proposed area include a SeaMARC I sonar survey of the Clipperton/EPR intersection area (Kastens et al., 1986); *Deep-Tow* surveys of the 9º 03’N OSC and the ridge axis at 8º 45’N (Sempere and Macdonald, 1986; Lonsdale and Spiess, 1980); camera tows over the 3rd order offset at 8°37’N (Bender et al., 1986; 1990); an ANGUS/Argo I photographic survey of the neovolcanic zone at 12ºN to the EPR/Clipperton intersection (Uchupi et al., 1988); a dense and continuous *Argo I* photographic/acoustic survey of the axial zone from 9º 09’-54’N (Haymon et al., 1991; Fornari et al., 1998a); a complete DSL 120 kHz sonar survey of the ridge crest from 9º 08’-57’N (Fornari et al., 2000; White et al., 2000); and numerous camera tows that extend off-axis (Kurras et al., 2000). These surveys have shown that an axial summit collapse trough (ASCT) with associated lava channels is present along the ridge crest from 9º 52’-21’N. The trough dimensions vary greatly. At the site of the 1991 eruption near 9°45'-50'N the trough is ~50m wide and ~20 m deep. Farther south, the trough disappears into a zone of en echelon fissures, stepping 0.5 km to the right between 9°45'N and 9°43.5'N. Throughout much of its length, the trough is ~200 m wide and ~20 m deep from 9°43.5'N to 9°26'N.

A second ASCT is present from 8°53'-46'N (Macdonald et al, 1992). The axial trough at 8°53'-46'N is approximately the same size as the trough to the north, however sufficiently high resolution data for precise estimate of the trough dimensions have not yet been acquired here. The ASCT in the 9°37'-51'N region has been the geological structure defining a region of interest for a host of detailed studies of mid-ocean ridge biology, water chemistry, hydrothermal mineral deposits, and volcanology described in other sections of this document. It is to be expected that hydrothermal activity also is occurring along the 8°53'-46'N ASCT.

White et al. (2000) have demonstrated that the EPR crest in the 9º 08'-57'N area is morphologically partitioned into 3rd order (~20 km-long) "volcanic segments" that show consistent along-strike variations from collapsed sheet and lobate flows near segment centers to clusters of small pillow-lava domes at segment boundaries. The observed variations in volcanic structures and lava flow morphologies reflect a consistent decrease in effusion rate from the centers to the ends of 3rd order segments, and show the extent of the individual volcanic systems that comprise the ridge crest. Smaller 4th-order segments (~7 km-long), bounded by discontinuities that offset the ASCT by <500 m, also have been identified; these small segments are attributed to individual eruptive dike systems (Haymon et al., 1991).

Off axis: The near-ridge area contains seamount chains, small isolated off-axis volcanoes, fault-bounded abyssal hills, discordant zones associated with the 9 03'N OSC, and two fracture zones. The abyssal hills are bounded by normal faults, with small outward facing scarps and high inward facing scarps (Carbotte and Macdonald, 1994; Macdonald et al., 1996). The outward facing faults are often modified by volcanic activity, producing volcanic growth faulting (Macdonald et al., 1996) and cease growing within <10 km of the ridge axis (Alexander and Macdonald, 1996). Outward-facing faults appear to keep growing over a much wider zone, possibly extending the tectonic plate boundary zone to >60 km full width (Crowder and Macdonald, 2001). The distribution of small isolated off-axis volcanoes suggests that random off-axis eruptions occur up to 10 km from the ridge axis (Alexander and Macdonald, 1996). Seamount chains are sources of long-lived volcanic activity on the ridge flanks that initiate within ~5 km of the ridge crest (Scheirer and Macdonald, 1995). Many near-axis seamounts, including the Lamont Seamount chain and surrounding lava fields, have been extensively studied and mapped in detail (Batiza et al., 1984; Fornari et al., 1984; Fornari et al, 1988; Allan et al., 1989; Barone and Ryan, 19900. Several other seamount chains in this area remain largely unexplored and are potential sites of hydrothermal activity and biological habitats.

c. Seismic Experiments

The EPR from 8ºN to 11ºN stands out as the part of the global MOR for which the seismic velocity structure of the upper 10 km is by far the best known. The diversity, quality and regional extent of seismic data within the proposed study area are invaluable for planning integrated studies of ridge processes. Major seismic experiments conducted here over the past fifteen years include: the first fully 3-D wide-angle refraction/reflection experiment conducted at a mid-ocean ridge (Toomey et al., 1994; Wilcock et al., 1995; Dunn and Toomey, 1997; Dunn et al., 2000); the first 3-D multichannel seismic reflection experiment conducted at a mid-ocean ridge (ARAD experiment; Kent et al., 2000; Bazin et al., in review); numerous other multichannel and refraction experiments (Detrick et al., 1987; Mutter et al., 1988; Vera et al., 1990; Kent et al.,1993; Harding et al., 1993; Barth and Mutter, 1996; Tian et al., 2000), including one across the Clipperton Transform (Begnaud et al., 1997; Van Avendonk et al., 1998 and in press); a unique near-bottom refraction experiment at 9º 30'N (NOBEL experiment; Christeson et al., 1994); measurements of seismic compliance (Crawford et al., 1999); and a unique mantle imaging experiment (Undershoot experiment; from 8º 15'-10º 15'N; Dunn et al., 2001).

These studies reveal the presence of a thin (tens of meters thick) and narrow (1-2 km wide) melt sill at ~1.5 km beneath the ridge axis (Detrick et al., 1987; Kent et al., 1993; Harding et al., 1993), underlain by a 5-7 km-wide, steep-sided low velocity volume (LVV) in the crust that extends into the mantle (Dunn et al., 2000), and that pinches and swells along strike (Toomey et al., 1994; Dunn et al., 2000). Within the mantle, the LVV widens to ~18 km, which suggests that heat removal in much more efficient in the crust (Dunn et al., 2000). At the base of the crust, compliance studies indicate that a second melt lens may exist in locations with a relatively large magma flux (e.g., 9º 50'N; Crawford et al. 1999). The melt sill in the upper crust is continuous along strike between large ridge axis discontinuities (Kent et al., 1993), but is discontinuous and offset at transform faults (Detrick et al, 1987) and at the 9º03N OSC (here melt is present beneath both spreading centers, and extends from the eastern spreading center westward beneath the overlap basin; Kent et al., 2000). From the 3rd order discontinuity at 9º35N to the OSC at 9º03N, the LVV is shifted westward relative to the morphologic ridge axis (Mutter et al., 1988; Vera et al., 1990; Dunn et al., 2000; 2001). Some along-strike variations in the LVV beneath the Moho suggest that while there is a continuous partial-melt zone along strike within segments, there are variations in the extent of partial melting/or melt transport at a 3rd order length scale (Dunn et al., 2000 and 2001).

The upper crustal structure consists of a thin (<75 m) surficial low-velocity (<2.5 km/s) layer, a 100 to 150-m-thick transition zone in which velocities increase to ~5 km/s, and a layer with velocities of ~5 km/s at a depth of ~130-200 m beneath the seafloor (Christeson et al. 1992, 1994; Kappus et al. 1995). The surficial low-velocity layer and transition zone is defined as seismic Layer 2a, and the 5 km/s layer as seismic Layer 2b. The layer 2a/2b boundary has been mapped by means of a reflection-like event in multichannel seismic reflection profiles. There is remarkably little variation (<75 m) in seismic layer 2A thicknesses at the axis (Harding et al. 1993; Vera and Diebold 1994; Kappus et al. 1995); however, off axis Layer 2a approximately doubles in thickness to an average value of ~400 m within 1-2 km of the rise axis, and then remains relatively constant in thickness out onto crust at least ~0.5 Ma (e.g. Christeson et al. 1992; Harding et al. 1993; Christeson et al. 1994; Vera and Diebold 1994). These data have been used to constrain models of Layer 2a accretion by Hooft et al. (1996), and by Schouten et al. (1999) who compared Layer 2a thickness to models of extrusive layer thickness based on the amplitude of the central magnetic anomaly.

d. Microseismicity Studies

Several microearthquake studies have been carried out on the EPR between 9º and 10ºN (Wilcock et al., 1992; Hildebrand et al., 1991; Kappus and Scheirer, 1992; Sohn et al., 1998). Three of these studies were conducted near 9º 50'N. Hildebrand et al. (1991) deployed ocean bottom seismometers in this area and recorded a swarm of syn- or post-eruption microearthquakes at depths < 1.5 km beneath the ridge axis in May, 1991. Eleven months later, a sonobuoy study of earthquakes in the eruption area established that the microseismicity associated with the eruption had subsided (Kappus and Scheirer, 1992). Ocean bottom seismometers that were deployed here in 1995 detected a swarm of microearthquakes ~1km beneath the west margin of the axial trough at 9º 50.3'N (Sohn et al., 1998). This microseismicity is thought to be associated with a cracking event that also influenced the temperatures and compositions of fluids discharging from nearby hydrothermal vents (Sohn et al., 1998; Fornari et al., 1999).

2. Hydrothermal and Eruption Time-Series Data Sets

a. Distribution of Vents and Related Geologic Features

In Nov.-Dec., 1989, a near-bottom, photographic-acoustic survey using *Argo I* was conducted along the axial zone of the EPR from 9º 09'-54'N (Haymon et al., 1991). This survey produced images of the configuration and character of the axial trough (Haymon et al., 1991; Fornari et al., 1998) and revealed a fine-scale (5-15 km) segmentation of the ridge (Haymon et al., 1991). The axial trough here is interpreted to be formed by pooling of lava on the seafloor above eruptive fissures and by subsequent drainback and collapse (Haymon et al., 1991; Fornari et al., 1998a; Macdonald and Fox, 1988). Fornari et al. (1998a) proposed late-stage tectonic development of bounding faults. Along the axial trough, hydrothermal activity was found to be abundant, and 45 active high-temperature smoker areas were mapped during the *Argo I* survey. In addition, scores of diffuse flow vent sites, biological communities, and extinct sulfide deposits were located and photographed (Haymon et al., 1991). Variations in axial lava age and morphology and distribution of axial fissures also were mapped (Haymon et al., 1991; Wright et al., 1995a; White et al., 2000). Two areas of young lava flows were identified at 9º 45'-52'N and at 9º 21'-12'N. All of the *Argo I* datasets have been compiled into digital files and co-analyzed using a geographic information system (GIS) approach (Wright et al., 1995a,b).

In April, 2000, a DSL-120 kHz sonar survey of the ridge crest from 9º 09'-57'N produced sidescan sonar images and meter-scale bathymetry maps that revealed new features of the ridge crest, including axial lava domes (White et al., 2000) and lava distribution systems funneling lava off-axis (Fornari et al., 2000). Integration and analysis of the DSL-120 data sets and *Argo I* data sets within a GIS has made it possible to delineate a 3rd-order volcanic segmentation of the ridge crest, and to distinguish 3rd order and 4th order segments (White et al., 2000 and in prep.).

Studies using the *Argo I* and DSL-120 data sets have led to a recognition that morphological segmentation of the ridge is reflected in segmentation of the hydrothermal system (Haymon et al., 1991, Wright et al., 1995a, Haymon, 1996, White et al., 2000). The EPR at 9º-10ºN is one of only two areas globally where this type of analysis has been possible, and where the segmentation of the magmatic and hydrothermal systems have been discerned and correlated. These analyses, and the models for volcanic and hydrothermal processes that have resulted from them (e.g.,, Haymon et al., 1991; Wright et al., 1995; Haymon, 1996; Fornari et al., 1998; White et al., 2000), provide an exceptionally well-known geologic context in which to test model predictions and conduct future integrated studies of ridge crest processes.

The AdVenture 1 *Alvin* program took place fifteen months after the *Argo I* survey, and was designed to sample hydrothermal vents on segments of different ages to determine how hydrothermal systems on fast-spreading ridges evolve. Dives to one of the youngest segments (on the axial high at 9º 45'-52'N) discovered extremely fresh lava flows, a tremendously increased level of hydrothermal activity, an astonishing microbial bloom that covered the seafloor with white mats and filled the bottom waters with a blizzard of swirling white particles, and biological communities that had been engulfed by fresh lava flows at sites such as Tubeworm Barbecue at 9º 50.3'N (Haymon et al., 1993). Subsequent dating of the fresh lava flows by Rubin et al. (1994) verified that these phenomena were caused by an eruption of the ridge axis in 1991, and that a second, smaller eruption occurred in 1992. There is no other site on the mid-ocean ridge where direct submersible observations and sampling have been achieved so soon after an eruption event. These observations of "time-zero" established a baseline for a unique time-series study of how the ridge crest evolves following an eruption.

From 1992-2000, a series of eight dive programs (AdVenture 2-8) have been conducted to document the evolution of the ridge crest, hydrothermal vent fluids and minerals, and biota within and outside of the eruption area (Haymon and Fornari, 1992; Von Damm et al., 1995, 1997; Von Damm, 2000; Shank et al., 1998; Fornari et al., 1998b). Most of these efforts were focused on an area extending from 9º 51'-45"N, however there have been multiple returns to vents located from

9º 42’-17’N. Although work is still in progress on these data sets, the sections below summarize some of the research highlights and data sources that have resulted from the time-series studies.

b. Plume Studies

An initial plume study that was conducted during the first *Alvin* dives at the 9°48’N eruption site in April 1991 (Macdonald et al., 1992) showed an isothermal layer in the bottom 350 m with a temperature anomaly of 0.03°C (Baker et al., 1994). By November 1991, this temperature anomaly had decreased significantly (Baker et al., 1994). The November, 1991, plume survey covered the area from 8°40’N to 11°50’N and indicated the most intense plumes were over the eruption site at 9º45’-52’N (Lupton et al., 1993). During this survey, intense and continuous plumes were seen at 8°48’-58’N, 9°29’-10°01’N, and 11°05’-27’N, and weak and discontinuous plumes were seen from 8°58’-9°29’N . Significant CH_4 and Mn plume anomalies were reported, and CH_4/Mn >1 occurred only over the new eruption site (Baker et al., 1994; Mottl et al., 1995).

There have been several studies of particles in 9ºN plumes. In the neutrally-buoyant plumes, Feely et al. (1994) reported high levels of organic S over the new eruption site, with S/Fe ratios as high as 10, indicating gas-rich plumes. In contrast, the area north of Clipperton had S/Fe ratios ranging from 0.04 to 0.8, more typical of mature, Fe-rich hydrothermal plumes. Field and Sherrell (2000) conducted kinetic studies of Fe(II) oxidation in the 9°45’N plume and concluded that Fe(II) had a half-life of about 3.3 hr. They attribute this long half-life to the relatively low pH and O_2 concentrations in Pacific Ocean deep water. These authors calculate Fe (II) half-lives as short as 17 min for North Atlantic plumes. A study of rare earth elements adsorbed onto plume particles in the 9°45’N region indicated that Fe-oxyhydroxides accounted for the major uptake of REE from seawater and that manganese oxides were not important in the scavenging process. They also concluded that REE behavior in hydrothermal plumes was more consistent with equilibrium adsorption than kinetic uptake control.

A unique study of buoyant plume particles was done on the EPR at 9º-10 N (Baron et al., 1998; Baron, 1998). This study showed that for plume samples with seawater/hydrothermal fluid mixing ratios < 200 (i.e., for samples collected close to vent orifices), there is significant vent-to-vent variation in plume particle mineral assemblages that corresponds to variations in vent fluid compositions. However, as the plume ascends and more seawater is mixed into it, a combination of rapid settling, dissolution and oxidation of particles alters the mineral assemblages and erases vent-specific signatures. At the level of the neutrally-buoyant plume, the particle assemblages were similar at all the vent sites studied. Another finding of this study is that buoyant plume particle assemblages are much more oxidized and Zn-rich at vents with temperatures less than ~330ºC, and comparatively more reduced and Cu-rich at vents with higher temperatures.

The rate of microbial hydrogen oxidation in the 9°50’N plume was investigated by McLaughlin (1998) where an average turnover time of 3.8 days was determined for hydrogen in the neutrally buoyant plume. She determined that the production of organic carbon produced from hydrogen oxidation was significant relative to that raining down from surface production in the area beneath the plume. Additional biologically oriented plume studies have shown that larval dispersal in the 9°50’ area is more strongly associated with near bottom currents than the neutrally buoyant plume (Kim et al, 1994, 1998).

c. Chemistry of Vent Fluids

The hydrothermal systems which are known between ~9º17’-52'N comprise a wide range of fluid compositions, fluid temperatures, as well as styles of venting. The vent fluids at this site encompass much of the global range of composition. A very unique aspect of several of the vent fluids is their extraordinarily high gas contents, primarily CO_2 (but also H_2 and H_2S, mainly right after the eruptive events). This is evidence for degassing of magma, which was first observed at this site, and has been observed at only one other location on the MOR (~32ºS EPR).

In addition, some of these vents have among the most detailed chemical and temperature records available on the global ridge crest system (e.g., Von Damm et al., 1995; Oosting and Von Damm, 1996; Von Damm et al., 1997; Bray, 1998; Fornari et al., 1998; Von Damm, 2000; Bray & Von Damm, 2001; Bray and Von Damm, 2001). Since most of these vents were first discovered using the *Argo I* system, their geologic setting is also well defined. For several of the vent areas, detailed collaboration with biological studies also means the relationships between fluid compositions/temperatures/venting styles and associated (megafaunal) biological communities is well documented, if not yet well understood (Shank et al., 1998). Most of the vent sites have visual documentation dating back to the *Argo I* work in 1989, and fluid composition and temperature data back to 1991, although the detail of the time series record varies considerably from vent-to-vent.

While the vents north of ~9º45’N were clearly affected by eruptive/diking events in 1991-92, those farther to the south largely were not (a few of the more southerly vents showed some ephemeral signals in 1991 of perhaps the dike extending farther south; Von Damm, 2000). Hence we have a comparison between "younger" as well as "more mature" hydrothermal systems at this fast spreading center. The range of fluid compositions is large (Von Damm et al., 2000), hence the types of hypotheses that can be tested in this system is also large and relatively unrestricted. Perhaps what is most exciting about the hydrothermal sites in this region, particularly the ones north of 9º 45'N, is their dynamism. Approximately a decade after the eruptive events, the fluid compositions exiting from single vents have not yet stabilized. This is in contrast to the more chemically stable vents south of 9º 45'N. Hence these vents provide the opportunity for cause and effect hypothesis testing. The vent fluids at this site encompass much of the global range of composition - of course some of the extremes are tied to the eruptive events. While we cannot predict if another such event will occur, we know how many given vents have responded in the past to at least one such event - as well as to a cracking event in 1995.

Another unique aspect of this site is the abundance, temperature range (up to 35ºC routinely) and apparent longevity of sites of diffuse flow. (There also are two sites where diffuse flow has developed into high temperature focused flow.) This facilitates studies linking the energy sources in the vent fluids to the biological communities. In summary the hydrothermal systems in the proposed IS site provide the diversity, dynamism and historical (time series) record to put any future observations and measurements into the context that leads to understanding of ridge crest processes as an integrated system.

d. Macrofauna

Vent communities in the proposed area are known to be both frequent (Haymon et al., 1991) and diverse (Shank et al., 1998). Over 90 vent-endemic species, including all of the dominant species of the eastern Pacific, have been documented from a wide variety of habitats (Shank et al., 1998). The16 active vent areas at 9°45’-51’N (1991-92 eruption area) alone support many community assemblages that include the textbook hydrothermal vent organisms: vestimentiferan tube worms, mussels, clams, archaeogastropod limpets, alviniocarid shrimp, bythograeid crabs, serpulid worms, anemones, etc. Our current understanding of vent organismal physiology and unique chemo-symbiotic relationships stems from these well-characterized species.

The April, 1991 discovery of newly-formed hydrothermal vents in volcanically active areas of the fast-spreading (11-12 cm yr^{-1}) East Pacific Rise (EPR) (Haymon et al., 1993) presented a rare opportunity to document the biological and chemical evolution of newly-formed vents. Biological, geochemical, and geological time-series studies over the past 9 years between 9°45'N and 9°52'N has provided the unique examination of the chemical, geological, and oceanographic processes which impact biological community establishment, and to define time-scales over which communities develop, undergo structural/faunal changes, and eventually die. As a result, numerous databases have fostered new predictive models of faunal succession at deep-sea hydrothermal vents (Shank et al., 1998) that now provide the ecological context for a broad spectrum of manipulative experiments (e.g., Mullineaux et al., 1998), as well as the basis for assessing the impact of a variety of anthropogenic perturbations (e.g., intensive sampling of constituent fauna, drilling of active vent sites, and extraction of polymetallic minerals from accreting hydrothermal deposits) on biological communities at deep-ocean vents.

In addition to video analysis of macroinvertebrate succession along the Biogeotransect by Shank et al. (1998), a quantitative, time-series study of community structure in mussel beds has been initiated by Van Dover (unpublished). Initial replicate sampling of Train Station, East Wall, and Biovent mussel beds was made in 1999, with deployment of a pair of temperature loggers at each site. Samples are being analyzed for species richness, species composition, relative abundance, biomass, size-frequency distributions, and an integrated measure of productivity based on mussel dry weight-length relationships. These same beds will be resampled in Dec 2001 and again at a date to be scheduled. In addition to obtaining a within-field analysis of changes over time, the mussel bed work will be placed in a regional context through comparable single-time-point sampling efforts at mussel beds of 13ºN and 11ºN vent fields; analysis of southern EPR mussel bed community structure (17ºS) is complete (Van Dover submitted).

e. Microfauna

Several significant advances in our understanding of the microbial ecology at deep-sea vents were first achieved at EPR 9º-10ºN. These include the confirmation that microbes are involved in the significant filamentous sulfur 'floc' formation observed in the aftermath of eruptive events (Nelson et al., 1992; Taylor et al., 1998), the characterization of novel epibiotic associations that occur with alvinellid worms (Haddad et al., 1995), and identification of relatives of the deeply diverging thermophilic bacterial order, the *Aquificales*, which were fist isolated from 9°N (Reysenbach et al., 2000).

f. Temperature Time-Series

Temperature measurements of hydrothermal vent fluids provide an important indication of the physical and chemical state of MOR hydrothermal and magmatic systems, and of the effects those primary processes have on biological communities inhabiting these unique ecosystems. The temperature data set for the EPR near 9° 50'N is the most comprehensive and longest time series for any high-T and low-T MOR vents in the world.

Along the "Biogeotransect", which is a well-mapped ~1.3 km-long array of seafloor markers in the floor of the EPR axial trough (Lutz et al., 1994; Shank et al., 1998), submersible visits at intervals from ~9 to 18 months have provided opportunities to collect quantitative observations of these hydrothermal systems and samples of the hydrothermal fluids and associated fauna. Also, starting in 1993, eight high-T vents and eight low-T diffuse flow sites have been monitored continuously with self-recording temperature probes (sampled at rates from 1-sec to 30-min). These two data sets, the biological observations and samples and the time-series temperature measurements, provide a complementary and unique perspective to the evolution of the different components of the 9°-10°N hydrothermal system over nearly a decade since the eruption. The temperature data set consists of continuous temperature records from low-temperature diffuse flow sites and high temperature chimneys in the EPR axial summit trough along the Biotgeoransect.

A recently funded NSF proposal (Shank/Scheirer/Fornari are PIs) to study and analyze the correlative temperature and biological data has the following key objectives:

1) Fully analyze time-series biological data to quantitatively and qualitatively characterize the temporal and spatial changes in vent community structure over what may be a significant portion of the "life-span" of many of the diffuse-flow vents at a fast-spreading mid-ocean ridge,

2) Comprehensively analyze multiple temperature records within individual diffuse-flow sites and compare them with those from all of the other diffuse-flow sites. Analyze the high-T records for both long term variations, relationships to adjacent diffuse-flow sites, and punctuated temperature increases and decreases.

Those investigators will combine the analysis of biological and temperature data in the proposed studies because initial results from subsets of these large data sets reveal compelling temporal and spatial relationships between how various vent communities evolve and long-term variations in diffuse flow fluid temperature, as well as long-term changes in high-T fluid temperature. Similarly, preliminary fluid and gas chemistry data (for which analysis is almost complete; Von Damm and Lilley, pers. comm., 2000) show that some interesting relationships are already apparent (see Shank et al., 1998). However, samples of vent fluids, samples of biology, and imaging of the vent communities and geological features has taken place at 9 to 18-month intervals, not "continuously" (except for several time-lapse camera deployments, which we will analyze as part of this proposal). The importance of the continuous temperature data at multiple low-T and high-T vent sites since 1993 is that they provide a quantitative indication of how these hydrothermal system(s) have changed over time. This temperature perspective is the only one that exists for these vent communities between the punctuated, 9 to 18-month visits to the sites using *Alvin* since 1993.

g. Mineral Deposits

The EPR at 9º-10º N is an ideal natural experiment on the evolution of mineral deposits with time, the influence of fluid properties on mineral deposition, and the influence of organisms on chimney growth. Mineral samples were collected from active and inactive vents along the ridge crest between 9º and 10º N during submersible programs in 1991, 1992, 1994, and 1995. Samples were obtained from every hydrothermally-active ridge segment within the *Argo I* survey region. Mineral samples obtained from active vent orifices usually were complemented by acquisition of fluid samples and temperature measurements, and in 1994 the particles in the buoyant plumes above the orifices were collected as well.

The growth of new chimneys on top of the 1991 lava flow provided an extraordinary opportunity to observe directly how chimneys develop and change with time. A longer-term perspective on chimney development was gained from studying active chimneys on older lava flows outside the eruption area, as well as from study of extinct chimneys. Haymon (1992, 2001 and in prep.) found that previous petrologic models for chimney evolution that proposed early, anhydrite-dominated Stage I growth followed by later, sulfide-dominated Stage II growth (Haymon and Kastner, 1981; Haymon, 1983; Goldfarb et al., 1981) were essentially correct for growth of individual spires during the first 2 years. However, the sulfide mineral assemblages and zonation sequences that developed in Stage 2 varied in a vent-specific manner (e.g., at the L-vent site, one chimney developed a chalcopyrite interior zone, while another chimney located only 20 m to the north developed an interior zone of pyrrhotite + sphalerite). The early chimneys began as clusters of small cylindrical spires that coalesced as they grew taller and expanded in girth. After only 11 months, some of the chimneys in the eruption area were as tall as 4 m (Haymon and Fornari, 1992) and had entered Stage II. After 2 years, the chimneys became populated by organisms and developed a spectrum of more complex morphologies; but, the morphologies that developed also were vent-specific. These observations demonstrate that vent-specific differences in fluid compositions, flow dynamics, and possibly also biogenic factors are causing chimneys to develop differently at individual vents.

Studies of chimneys and buoyant plume particles show that vents with temperature above ~330ºC have Cu-rich chimneys and plume particles, but chimneys below this temperature precipitate Zn-rich assemblages (Baron et al., 1998; Baron, 1998). Extinct chimney samples are almost always very Zn-rich, and virtually all of the anhydrite has been replaced by sulfide minerals. The extinct chimneys are sometimes silica-rich as well, indicating late-stage precipitation of this mineral as vents wane.

Efforts to integrate the fluid and mineral time series data sets are still in progress. Fluid inclusion analyses of chimney samples to investigate growth mechanisms are ongoing as well.

h. Theoretical Modeling Studies

Lowell and Xu (2000) used the rapid chlorinity and Si changes in the vent fluids in the first weeks after the 1991 eruption to estimate subsurface permeability. This study represents the only attempt so far to incorporate the chemical data from the proposed IS site into a hydrothermal model. However, the EPR 9°N area provides many excellent opportunities for hydrothermal modeling. Time series data are available for a number of vents since 1991, and these data provide unique perspectives into the behavior of a ridge crest hydrothermal system following a significant magmatic event. The data depict rapid changes in vent temperature and chemistry. For example, at "A" vent fluids changed from 30 mmol to 450 mmol Cl over a few years (Von Damm et al., 1995) while the temperature decreased from ~400 °C in 1991 to ~200°C at present (Von Damm, personal communication). The "F" vent, however, went from vapor to brine between 1991 and 1994 (Von Damm et al. 1997); whereas the "V" vent evolved from a vent emitting clear fluids at 78°C 1991 to a black smoker fluid by 1997 (Von Damm, 2000). Modeling can help to elucidate processes involved in the transformation of "F" vent from vapor to brine, the long-term secular decay of "A" vent, and the evolution of diffuse to black smoker flow at "V" vent. In addition to these current data, new data obtained during a future IS program here can be used to constrain models of hydrothermal processes. A variety of modeling approaches can be applied, including the newly developed two-phase finite difference flow model GTHSW (Xu and Lowell, 2000), as well as the earlier single-phase model GTH. It will be possible to incorporate thermoelastic and geochemical processes such as quartz and anhydrite precipitation into GTH to address issues of time dependent permeability.

3. Petrological And Geochemical Datasets

Petrologically, the 8º-11º N region of the East Pacific Rise has been moderately to heavily sampled. At present, this part of the EPR is the most densely sampled segment of the mid-ocean ridge system. The axis and bounding transforms were sampled at a coarse scale (a few to 10's of km between samples) in the late 1970's (Batiza et al 1977; Batiza and Johnson, 1980; Schrader et al., 1980; Natland and Melson, 1980; Natland, 1980, 1989) and early 1980's (Langmuir et al., 1986; Natland et al., 1986; Thompson et al., 1989; Batiza and Niu, 1992; Castillo et al., 2001). The 8°37'N offset region was sampled in 1989 (Bender et al., 1986; 1990). Considerably more detailed sampling both on and off-axis began in 1991 with the first AdVenture cruise in the 9°17' to 10° N area of the EPR. That cruise was followed by 10 cruises to the area that had sampling as part of their objectives (Haymon et al, 1993; Perfit et al., 1994; Gregg et al., 1996; Perfit and Chadwick, 1998; Smith et al., in press). In addition, major petrologic programs were completed in the Siqueiros Transform in 1991 (Kirk et al., 1991; Perfit et al., 1996) and along off-axis abyssal hills in 1992 (Macdonald et al., 1996; Perfit et al., 1995; Kutza et al., in prep). Some samples from the Clipperton Transform have been analyzed by Klein and others (1987). During 1992, a small amount of basalt was also recovered from the ASCT by bare rock drilling during ODP Leg 142 (Batiza et al., 1995).

The distribution of basalt types is not symmetric across the crestal plateau in any of the areas studied in detail. Geochemically enriched (T-and E-type) MORB only exist in small areas (< 1 km^2) on the crestal plateau and appear to be related to prominent scarps or fissures from which pillows were erupted. Relatively voluminous and mafic volcanism appears to be related to new magmatic episodes whereas off-axis volcanism is characterized by more evolved (and sometimes enriched) lavas fed from smaller and cooler magma bodies. Axial MORB all seem to be derived from a similar parental magma composition. There is a distinct increase in fractionation at the 9º 03'N OSC, and some punctuated geochemical distinctions also occur at some of the smaller ridge-axis discontinuities. Along fast-spreading ridges, ridge axis offsets are the only locations from which evolved, high-silica lavas such as andesites and dacites have been recovered. In the EPR, 8°-11°N region, high-silica lavas occur at the 9°03'N OSC (Natland et al., 1986) and just north of the 3rd order offset at 8°37'N (Bender et al., 1986; 1990). The 8°37'N is by far the smallest offset known to be associated with high-silica lavas; all other cases are 1st and 2nd order ridge offsets.

The Siqueiros transform fault comprises a broad, ~20 km-wide-swath of non-ridge-parallel terrain offsetting the East Pacific Rise (EPR) by 140 km in a left lateral sense. Seabeam and SeaMARC II surveys revealed an orderly structure within the transform domain: three "intra-transform" spreading centers (A, B, and C) are connected by strike-slip fault segments forming a stair-step pattern in plan-view (Fornari et al., 1989, Pokalny,et al. 1997). In 1991, 17 *Alvin* submersible dives, an extensive rock dredging program (39 dredges), and a SeaBeam survey were completed in the Siqueiros transform and along the adjacent EPR where it overlaps the transform (Fornari et al., 1991; Kirk et al., 1991). Dive observations, analysis of the Seabeam sonar maps and initial petrochemical data confirmed that three of the four intra-transform spreading centers within the transform domain were volcanically active and have predominantly erupted normal, incompatible element-depleted (N-type) MORB. However, very depleted picritic basalts (D-type) and relatively enriched E-type basalts have also been recovered. (Ridley et al. 1991; Perfit, 1996; Lundstrom et al., 1998) Geochemical and isotopic investigations suggest the non-steady state magmatic plumbing system in the transform domain allow the variety of melts generated in the sub-EPR mantle to be erupted in this environment.

Detailed studies of basalts from near-axis seamounts (e.g. Lamont seamounts at ~ 10ºN) have also been completed (Fornari et al., 1988, Allan et al., 1987, 1989, Batiza et al. , 1989, 1990; Graham et al. 1988). Two cross-axis sampling traverses that extend out to approximately 800 ka were completed around 9°30' and 10°30'N Batiza et al, 1996, and Regelous et al, 1999) These studies suggested that a steady-state magmatic system existed in the 9° 30' N region for the past 800 Ka but that the rate of magma input has been much lower and more variable in the 10° 30' N region over the same time period.

The most detailed geological and petrological investigations have been carried out between the 9° 30'N to 9° 52'N on crust up to approximately 100 ka old. *Alvin* dive data and lava samples have been collected during ten different research cruises (1991, 1992, 1993, 1994 (2), 1995, 1996, 1997, 1999, 2000) to the EPR in the 9° 30'N to 9° 52'N region, though the majority of the geological investigations were carried out during the cruises in 1991, 1992 and 1994. This petrologic/geochemical/ volcanologic research has principally focused on the ASCT, the crestal plateau up to 4 km off-axis around 9° 30-32'N and 9° 49-52'N, and around the small overlapping spreading centers at 9°37' N. (Perfit et al., 1994; Gregg et al., 1996; Perfit and Chadwick, 1998; Smith 1999, and Smith et al. submitted). *Alvin* video and 35mm still photography and camera tow have been used to plot the distribution of various lava types and sea floor morphologies along dive traverses facilitating the correlation of lava geochemistry with sample location and inferred geologic history (Kurras et al 2000; Smith et al., in press, Engels et al., in prep.). Age-dating of the lavas using U-isotope disequilibrium techniques has provided temporal constraints on eruptions and magmatic processes, and was used in concert with geologic and geochemical data to conclusively prove that volcanism occurs outside of the ASCT up to 4 km from the axis (Goldstein et al., 1994). Detailed sampling, mapping, and analysis of the physical volcanology of the different lava terrains has yielded estimates of eruption volumes, effusion rates, eruption frequency and chemical heterogeneity along this fast spreading segment (Gregg et al., 1996, Chadwick and Perfit, 1998; Rubin et al., submitted).

Documentation of each *Alvin* dive is available as transcripts of in-sub recordings of observer logs, video tapes of the external SIT/color cameras, video tapes from a hand-held Hi-8 camcorder of selected areas of the ridge, 35mm still-camera photos taken every 7 to 60 seconds by *Alvin*'s bow camera, and digital data compilations of in-situ measurements of bottom temperature, sub. depth, altitude and heading. In addition, high-resolution CCD digital still photographic imagery was collected on some dive transects. These data represent the first digital seafloor images collected along an *Alvin* track and provide high-resolution characterization data for the lava flow surfaces that were sampled and documented.

A unique suite of submersible collected samples (over 475 basaltic lavas) has been collected from the ASCT and crestal plateau (up to 4 km off-axis) in this area. In addition, approximately 90 samples collected by K. Macdonald and J. Fox were recovered from off-axis abyssal hill sites (Macdonald et al. 1996), extending temporal sample coverage to beyond 100 ka. Hand-specimen descriptions of each lava recovered are availible from M. Perfit at the University of Florida. The suite of *Alvin* samples are complemented by a set of over 375 rock cores primarily from the crestal plateau region outside of the ASCT and axial regions not well-investigated by submersible. Nearly all of the rock core and *Alvin* glasses have been analyzed by microprobe for major and minor elements. Maps have been made that show the spatial distribution of basalt chemistry and lava types in the most completely studied areas (Perfit and Chadwick, 1998). In addition, over 90% of the *Alvin* samples have been analyzed for trace elements by XRF. A representative set of basalts (both *Alvin* and rock core) has been analyzed for rare earth elements (REE) and other trace constituents (by laser ablation ICP-MS or TIMS), and for Sr, Nd, Pb, Hf and U-series isotopes (Sims, et al., submitted). Glass splits have also been provided to other investigators for magnetic and low-temperature alteration studies (e.g. Meijer et al. 1996, Pick and Tauxe, 1993). Nearly all of the data discussed above is available in digital form.

4. Currently Funded Projects

99-02 NSF/OCE Accomplishment Based Renewal: ALVIN studies of volcanic growth faults and lava morphology on mid-ocean ridges (PI: K. Macdonald).

The focus of this project will be on two aspects of the architecture of the volcanic section: the role of volcanic growth faults on slow-spreading ridges, and the relative abundance of different types of lava flow morphologies as a function of spreading rate, and within spreading segments (at a given spreading rate). Volcanic growth faults are created by a complex interplay between faulting and syntectonic volcanism, and are an important aspect of the architecture of the volcanic section on fast-spreading ridges (Macdonald, 1996). To date, however, they are only documented on fast-spreading ridges; it is time to see if this fundamental process of crustal creation and deformation occurs to any significant degree on slow-spreading ridges as well.

The relative abundance of different types of lava flows is an important, first-order observation concerning volcanic crustal architecture that will be useful for inferring volcanic effusion rates (Gregg, 1995) under different circumstances (spreading-rate, magmatic budget, proximity to segment boundary). The relative abundance of different types of lava flows have been estimated previously using limited areal coverage at several spreading centers; however, areal exposure may not be representative of the volcanic section as a whole. Several models predict that pillow lava is the dominant morphology during the waning stages of an eruptive cycle. If this is true, then areal observations will be biased toward pillow lavas. Ophiolite observations suggest that the volcanic section is dominantly pillowed, but these observations are of limited applicability because spreading rate and exact location within a segment are poorly constrained. Ocean drilling samples have problems with limited recovery which may be biased toward more competent units.

This project will address the two fundamental problems outlined above by mining a potentially rich, but underutilized existing data set: *Alvin* traverses across scarps on the Mid-Atlantic Ridge, the Galapagos Spreading Center, the East Pacific Rise, the Cayman Trough, and the Juan de Fuca/Gorda Ridge. Primary data sets for this work will be: precision bathymetry (pressure depth +altitude, also Mesotech and Imagenex pencil beam data where available), video imagery, and outboard 35 mm camera stills. These data sets offer an excellent opportunity to address the proposed problems with existing data. With over 100 dives in useful locations for this study, new insights are assured.

99-02 NSF/OCE Amplitude variation with offset studies and pre-stack imaging of the ARAD 3-D reflectivity volume (PI's: Harding/Kent).

The Anatomy of a Ridge Axis Discontinuity (ARAD) 3-D seismic experiment is a cooperative experiment between Scripps Institution of Oceanography and Cambridge University. The field experiment was conducted aboard the R/V Ewing in September-October 1997 and was located over the 9ºN overlapping spreading center on the East Pacific Rise. Key elements of this experiment included the first 3-D reflection survey of a mid-ocean spreading center and a coincident 3-D crustal tomography experiment. Preliminary data analysis suggests that the observed distribution of crustal magma accumulations beneath the overlapping spreading enter appear to be inconsistent with either a simple, broadly symmetrical structure or with models which depict the limbs at attenuated ends of magmatic systems fed largely by horizontal flow. Instead the magma seems to be fed from directly beneath the offset basin. Further analyses are planned during the period of this grant.

98-01 NSF/OCE Species composition and biodiversity in mussel bed communities of deep-sea hydrothermal vents (PI: C. L. Van Dover).

This project addresses patterns of biodiversity and convergence at deep-sea hydrothermal vents using fauna associated with mussel beds for comparisons at various spatial scales including i) within a vent field, ii) annually at a single vent over 3 years, iii) among vent fields of different ages on a ridge segment, iv) at vent fields on segments of different spreading rates on a single ridge system, and v) between ridge systems in different ocean basins. Biodiversity and biogeography contrasts at these scales repeatedly arise in discussions of vent ecology and deep-sea ecology, but until this work, there was little or no information that allowed quantitative comparisons.

The study developed from a comparison of biodiversity at Lucky Strike mussel beds on the Mid-Atlantic Ridge and intertidal mussel beds on the south central Alaskan coast. An intensive field program was funded to sample a variety of mussel bed sites on the East pacific Rise and Mid-Atlantic Ridge using Alvin, including 11ºN, 9ºN and 17ºS on the East Pacific Rise (i.e., 2 "fast" and 1 "superfast" spreading segments) and Lucky Strike, Snake Pit and Logatchev sites on the slow-spreading MAR. The 9ºN effort includes 3 repeat visits (2 of which will be completed by 1 Jan 2002). Additional time-series sampling at the 9ºN site is supported through a CAREER award to the PI.

<u>00-03 NSF/OCE Evolution of EPR Hydrothermal Systems: Causes of Continued Chemical Instability at 9-10ºN vs Stability at 21ºN (PI's: Von Damm/Fornari/Seyfried).</u>

The main objective of this project is to sample hydrothermal fluids at the 9º-10ºN EPR and 21ºN EPR hydrothermal sites, in order to address the questions detailed below. Our objectives are to continue to make progress on the following 4 questions:

1. What controls the composition of vent fluids exiting from a single vent over time?
    - why are some vent fluids stable and others varying with time?
    - how long after a (volcanic) perturbation does it take for a hydrothermal system to become stable?
    - why do individual vents have different compositions?
    - what does this tell us about important "active processes" within the oceanic crust?
2. Do changes in fluid compositions and temperatures correlate with changes in the associated animal communities? Do biological processes affect the compositions of the fluids?
3. What is the relationship between adjacent diffuse and focused hydrothermal fluids?
4. What is the flux of chemical species from hydrothermal vents to the ocean?

These objectives will be accomplished by making coupled chemical and temperature measurements in the 20+ high temperature vent sites at 9º-10ºN, and the 6 areas of diffuse flow venting that we have been following, in some cases, since just after the eruption at this site in 1991. The 21ºN EPR area, the quintessential hydrothermal site with stable compositions on the global MOR system, will be an important comparison for constraining our ideas on what is causing the continued variation in the fluids from 9º-10ºN, as well as helping to constrain time scales of hydrothermal activity on the MOR.

01-02 NSF/OCE Analysis of Temperature and Biological Data From Diffuse-Flow Hydrothermal Vents on the East Pacific Rise (9°49'-51'N): Continuing Time Series Studies (PI's: Shank/Scheirer/Fornari).

We will analyze two well-documented time series data sets that have not been fully exploited by shore based analysis and that have important implications for our understanding of the temporal and spatial variability of physical, chemical and biological processes at hydrothermal vents on fast spreading mid-ocean ridges. One data set consists of quantitative, high resolution biological observations and samples collected approximately yearly over the nine year period since the 1991 eruption near 9° 50'N on the East Pacific Rise (EPR). The other data set consists of continuous temperature records over the same time period from low-temperature diffuse flow sites and high temperature chimneys in the EPR axial summit trough between 9° 49'-51'N (the Biogeotransect). This temperature perspective is the only one that exists for these vent communities between the punctuated, 9 to 18-month visits to the sites using *Alvin*. Even after two decades of study, not enough is known about the temporal response of MOR hydrothermal systems to chemical, biological and geological events. Our analysis of existing biological and fluid temperature data will provide important baseline information and fundamental insights on a range of topics of broad interest to biologists, chemists, and geologists studying hydrothermal phenomena at MOR's at a range of temporal scales. They will provide important constraints for modeling hydrothermal systems and designing future integrated and long term seafloor observatory experiments at mid-ocean ridges world-wide.

00-01 NSF/OCEBasic Seafloor Reconnaissance of T-Phase Data from the NOAA Autonomous Hydrophone Array: Assessing the Nature of Magmatic/Volcanic Events on the East Pacific Rise 20°N - 25°S (PI's Fornari/Perfit/Tolstoy).

This project is investigating sources of microseismicity detected in 1998-99 at several sites on the EPR and Galapagos Rift by NOAA's eastern Pacific Autonomous Hydrophone Array (AHA). The study areas include the EPR at 3° 20'-25'N event site where detection of t-phase swarms suggests that a magmatic event occurred. The seagoing phase of this project took place in Mar-May, 2000, and collected multidisciplinary, *in situ* field data using the full suite of ROV and tethered vehicles of the UNOLS National Deep Submergence Facility (ROV *Jason*, Argo-II, and DSL-120 sonar). At the outset of this cruise, 4 days were spent acquiring DSL-120 near-bottom sonar data along the crest of the EPR from 9º 57'-08'S. These data are being analyzed to better understand volcanic processes along this portion of the EPR.

00-02 NSF/OCE Investigating volcanism, tectonism, and formation of crustal layer 2a on the East Pacific Rise crestal plateau: ongoing analysis of digital photographic data (PI: M. Edwards).

00-02 NSF/OCE Central anomaly magnetization high: constraints on the volcanic construction and architecture of young upper oceanic crust at EPR 9°-10°N"3 (PI's: Schouten/ Tivey/Fornari/Smith).

We will test the hypothesis that the off-axis thickening of seismic layer 2A, at the fast-spreading East Pacific Rise (EPR) between 9°N and 10°N, is caused by the deposition of significant volumes of lava on the upper flanks of the ridge, roughly between 1 and 2 km off axis. A doubling of layer 2A thickness, which is typical for the EPR implies that only half the total lava deposition occurs in or near the axial summit trough, while the other half is deposited on the flanks of the ridge. The test of this hypothesis thus requires an estimation of the volume of lavas recently deposited on the flanks of the EPR.

In order to calculate this volume estimate we will map the near-bottom character of the Central Anomaly Magnetic High (CAMH) over the EPR neovolcanic zone and estimate the distribution of magnetization in the shallow ocean crust. From the near-bottom magnetic field over the EPR neovolcanic zone, for a given magnetization decay function, we will obtain a robust estimate of the volume or thickness of young lavas deposited within the past 10-20 kyr on the flanks of the rise. Questions addressed by our research include: 1) What is the along-axis variation in the distribution of highly magnetized young lavas?, i.e. is the distribution mostly two-dimensional or a does it consist of a string of discrete three-dimensional depocenters? 2) How do the young lava depocenters relate to the recent volcanic and tectonic history of the EPR as defined by bathymetry, morphology, and near-bottom side-scan imagery? We will use the autonomous underwater vehicle, ABE to collect data along densely spaced (250 m) tracklines, producing a high-resolution near-bottom magnetic survey over two areas of the EPR crest, approximately 6 km wide by 10 km centered on the rise axis. The two study areas at 9°30'N and 9°50'N represent contrasting areas from both volcanic and tectonic observations and from limited magnetic field data. We will augment the magnetic survey with near-bottom, DSL-120 sidescan sonar mapping to map the volcanic and tectonic features and seafloor morphostructural contact relationships in the two study regions. ROV *Jason* will be used to provide ground-truth information that is essential for accurate identification of seafloor contacts and correlation to magnetic data and sonar imagery. Use of ROV *Jason* will also permit us to collect lava samples at important seabed contacts for U-series age dating and paleomagnetic measurements.

99-00 NSF/OCE Investigating the Potential of Determining Short-Wavelength Crustal Density Variations in Fast-Spreading MOR crust at 9° 36'-38'N: A Small Grant for Exploratory Research (SGER Grant) (PI's: Fornari/Cochran/Coakley).

The central objective of this project is to map short-wavelength Bouguer anomalies along two, distinctive ~5-7 km-long, segments of the EPR axis near 9° 35'-38'N and 9° 47'-50'N to study density variations in the shallow crust. Determining the areal pattern of small-scale density variations, and their linearity and relationship to prominent ridge crest features (e.g. the ASCT, lava flow contacts, small scarps, and off axis young pillow ridges), will allow us to better interpret the shallow crustal structure of a fast-spreading MOR and develop models for volcanic emplacement processes. We used Alvin to collect continuous, precision gravity data, geologic bottom observations, and near-bottom multibeam sonar (Simrad EM2000) data along closely spaced tracklines across the East Pacific Rise (EPR) axis near 9° 35'-38'N and 9° 47'-50'N. These data will allow us to discriminate between areas of shallow collapse or fissuring that could lead to regions of lower density in the uppermost crust and areas of higher density that could be interpreted as zones of intrusion and shallow dikes. We will use the data to constrain the relative importance of intrusion and eruption at the axis, versus that which occurs ~1-2 km away from the axis, in building the upper oceanic crustal layer.

We also conducted some night time camera tows and additional rock coring at selected sites which to provide the needed observational and sampling coverage to permit correlation of the geophysical results to the surficial geology in each off-axis area.

The implications of our proposed work are far reaching because they will provide quantitative data on crustal accretion processes that will help us refine our understanding of how ocean crust forms and evolves; an important element of the RIDGE program.

97-00 NSF/OCE Community development and structure at hydrothermal vents (PI: L. Mullineaux).

96-01 NSF/OCE In-Situ measurement and monitoring of dissolved H_2, H_2S and pH in mid-ocean ridge hydrothermal fluids (PI's: Seyfried/Ding).

The hydrothermal geochemistry research group at the University of Minnesota has focused its efforts over the years on developing experimental approaches to assess the chemistry of fluids at elevated temperatures and pressures. Although early efforts were largely confined to mineral solubility studies using quenched fluid samples from hydrothermal reactors to constrain mass transport processes, more recently we have redirected our efforts to in-situ sensor development. This research was largely motivated by our desire to avoid the uncertainties imposed by quench effects, which effectively preclude unambiguous interpretation of highly non-conservative species, such as pH, as well as dissolved gases- H_2 and H_2S. If quench problems are a concern for accurate reconfiguration of fluid chemistry at high temperatures from analyses at low temperatures for experimental systems, they all but preclude this for natural vent systems where seawater mixing and fluid-mineral requilibration effects are so common. At the same time, however, these most non-conservative of species are master variables in hydrothermal reaction zones, which along with total dissolved Cl-, effectively control fluid chemistry in natural or analogue (experimental, theoretical models) systems. Thus, it should not be surprising that the very first chemical sensors for hydrothermal applications developed at Minnesota involved pH, H_2 and H_2S. Sensors for these species were calibrated in the lab and then re-configured into an array with self-contained electronics package for seafloor applications. The sensors were tested at the Main Endeavour field in F/99 and provided spectacular new insight on hydrothermal alteration processes at vents (Ding et al. 2001a, 2001b).

IV. Data Archiving and Dissemination

For an IS program to be successful, data from the IS site must be collected and archived digitally, and disseminated to others in the community, in a timely and cost/science-effective manner.

In recent years there has been a tremendous increase in the amount of data that is generated and recorded in digital form during cruises and post-cruise research. Until now, archiving digital data and making it widely available has been left mainly up to individual PIs (or groups of PI's); for example, shipboard compilation of multiple data sets into a data base with a total volume exceeding 6GB was accomplished recently for the AHA-Nemo2 cruise to the EPR (see http://128.128.21.37/). A few examples of larger, cooperative data archives are the RIDGE multibeam database (http://coast.ldeo.columbia.edu/) and the petrology database (http://www.ldeo.columbia.edu/datarep/index.html) that have been developed and managed by W.B.F. Ryan and C. Langmuir, respectively, at LDEO. Some other examples of group efforts to provide data archives for large programs are: 1) the MELT group's creation of extensive online databases for their experiment, using technology and protocols developed for large-scale government and industry programs (e.g IRIS); 2) the National Deep Submergence Facility at Woods Hole, which provides metadata and web-based links to deep submergence data archived at WHOI, as well as technical information about the vehicle systems and cruise scheduling; and, 3) the NGDC geophysical data base which is widely used in the community. In addition, there is the ODP databank at LDEO.

For the EPR at 8º-11ºN, there are photographic, geologic, petrologic, bathymetric (multibeam and side-scan sonar) and vent-related data archived and available through the U. Hawaii HMRG EPR web site managed by M. Edwards, G. Kurras and P. Johnson (http://www.soest.hawaii.edu/HMRG/Mesotech/EPR_Archive.htm). The recently-collected DSL 120 sonar data along the ridge crest from 9º 08'-57'N is accessible via the AHA-Nemo2 web site (http://128.128.21.37/). However, a wide variety of digital data sets from the EPR 8º-11ºN area are not posted on public web sites (for example, geophysical data sets, *Argo I* visual and acoustic data, and spreadsheets of time series data for fluids, fauna, temperature, and sulfides). M. Edwards, D. Toomey, D. Wright and others are investigating the best method for providing full access to the large data base that exists for the EPR, 8º-11º N area (e.g. Toomey and Wright, pers. comm.); however, at present there is no consensus as to the best method for storing, accessing and handling the very large volume and variety of data from this area. A RIDGE meeting to discuss broad issues of data storage and management will be held in May, 2001. This meeting will lead to a comprehensive plan for RIDGE and other oceanographic data archiving and access in the future (the web site for the meeting is: http://humm.whoi.edu/DBMWorkshop/).

Until this comprehensive plan is formulated and put into place, an interim means of archiving data is needed. Because the infrastructure (and much data) is already in place for the petrologic/geochemical and multibeam data bases, it is likely that NSF will continue to provide modest yearly funding of the groups at Lamont to maintain these web-based databases. Both of these data bases are available through links from the RIDGE home page. Beyond this, the RIDGE office currently has no personnel or funding to support data archiving for integrated study sites. All PI's involved with an integrated studies effort will be expected to make data available in accordance with current NSF data dissemination policies: normally, cruise/grant related data can remain proprietary for two years following acquisition, after which they become part of the public domain. We therefore recommend that funding be included in all RIDGE program IS proposals to provide for proper digital archiving, access and management of data sets. This will enable IS PI's to comply with NSF data dissemination policies, and to make their data Internet-accessible in commonly used digital formats. This will simplify integration of all data into more comprehensive data bases and computational environments once these are developed. We envision that links to individual PI-constructed data bases will be facilitated by the RIDGE office through the RIDGE web site.

The AHA-Nemo2 online data archive mentioned above provides a good example of what can be compiled at sea and made available when the ship gets to port. This archive includes useable data products in various, commonly available data formats (e.g. text files, Excel spread sheets, .pdf files, .jpg or .tiff images), that are all easily downloadable to the public via the Internet. In planning for IS cruises, it will important to recognize that similar real-time data compilation and data base construction efforts require adequate technical support at sea to implement them, and fast computer facilities and network solutions to make them function properly.

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VI. Links To Data Sources

Multibeam sonar data: http://coast.ldeo.columbia.edu/

Petrology database: http://www.ldeo.columbia.edu/datarep/index.html

AHA-Nemo2 DSL 120 sonar data, 9º 08’57’N: http://128.128.21.37/

EPR 9º-10ºN photographic, geologic, petrologic, bathymetric (multibeam and side-scan sonar) and vent-related data:
http://www.soest.hawaii.edu/HMRG/Mesotech/EPR_Archive.htm

ODP site survey databank: http://www.ldeo.columbia.edu/databank/