Investigation of the NW Fernandina Rift Zone, western Galapagos Archipelago, onboard the *R/V Thompson*, January 2006

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Project Summary

The NW Fernandina Rift Zone, off the northwestern coast of Fernandina Island, is located at the leading edge of the Galapagos Hot Spot and was created by hot-spot propagation mechanisms. The objective of the proposed investigation is to test the hypothesis that the NW Fernandina Rift Zone (hereafter referred to as NWFRZ) is currently at a developmental stage dominated by constructional axial and flank volcanic processes created by lateral diking of the central magma chamber under Fernandina Island. To investigate the volcanic processes responsible for the NWFRZ, I will be using the Kongsberg Simrad 30 kHz EM-300 multi-beam and BATHY-2000 12 kHz bathymetric and sub-bottom profiling technology available onboard the *R/V Thompson* to map the NWFRZ at 25m-resolution. If distinctive volcanic features that grow from eruptive vents overlying dike complexes and have previously been discovered on Puna Ridge, Hawaii (such as volcanic cones, submarine terraces, fissure ridges and flat-topped submarine cones) are found on the NWFRZ, it will be presumed that the NWFRZ is analogous to Puna Ridge, but – due to its previously-examined slope profile – is in a less-mature developmental stage. Obtaining a better understanding of hot-spot propagation mechanisms and developmental stages is important for comprehending tectonic processes governing hot-spot volcanic-platform building processes.

Introduction

The Galapagos Islands are anomalous compared to most hot-spot oceanic volcanoes, in that circumferential eruptive fissures are abundant around volcanic summit calderas and radial fissures dominate on volcanic flanks (Simkin and Howard 1970, Chadwick and Howard 1991, Chadwick and Dieterich 1995, Rowland 1996). The Galapagos Islands also lack the distinct, narrow rift zones dominated by radial diking that comprise the flanks of the Hawaiian Islands. Fernandina Island, Galapagos Archipelago, has the typical western Galapagos "over-turned soup bowl" shape, controlled by circumferential fissures around a central caldera overlying a shallow, flat-topped, diapiric magma chamber (Chadwick and Dieterich 1995, Allan and Simkin 2000). While circumferential fissures dominate the Fernandina summit caldera, abundant small-scale radial eruptive fissures are located on Fernandina's volcanic flanks (Simkin and Howard 1970, Chadwick and Howard 1991, Chadwick and Dieterich 1995). A broad topographic ridge with abundant radial fissures is located on the NW sector of Fernandina Island (Chadwick and Howard 1991, Rowland 1996), and is likely the subaerial expression of the submarine NWFRZ, analogous to the Kilauea East Rift Zone on the island of Hawaii. However, in contrast to the prominent Kilauea East Rift Zone and its submarine Puna Ridge, Fernandina Island's NW flank rift zone is relatively diffuse (Kurz et al. 2000). Rowland (1996) attributes this to the developmental immaturity of the NWFRZ and its subaerial counterpart, relative to the Kilauea Puna Ridge and its subaerial East Rift Zone.

Although the presence of a ridge originating from the NW sector of Fernandina Island has been general knowledge for many years (Simkin and Howard 1970), the rift zone morphology of the NWFRZ was discovered during the NEMO-2 cruise on the *R/V Melville* in 2000 (Kurz et al. 2000). This submarine rift, along with others located around the peripheries of Fernandina and Isabela Islands, were further explored during the DRIFT Leg-4 cruise on the *R/V Roger Revelle* in 2001 using MR-1 side scan sonar and EM-120 multi-beam sonar (Kurz et al. 2001, Harpp et al. 2003). These recent cruises were the first to examine the submarine rifting processes of the region west of Fernandina Island, believed to be the leading edge of the Galapagos Hot Spot (Kurz and Geist 1999).

Submarine rift zones are the building blocks of oceanic hot-spot shield volcanoes and are the products of local and regional stress fields controlling the propagation of hot spot volcanic platforms. Puna Ridge, the submarine portion of the Kilauea East Rift Zone, is a well-studied example of the lateral migration of magma from a central body, driven by magmatic pressure gradients (Lonsdale 1989). It is generally believed that the entire 75-km-long Puna Ridge is underlain by a dike complex ~11km in width (Malahoff and McCoy 1967; Smith et al. 2001, 2002; Leslie et al. 2004). The best-studied example of the other end-member of rift zone formation processes in the Galapagos Archipelago is the Genovesa Ridge, located between the central Galapagos Platform and the Galapagos Spreading Center to the north. The Genovesa Ridge is likely underlain by discontinuous dike swarms, resulting from passive magmatic upwelling in an extensional environment caused by interactions between the Galapagos Hot Spot and the Galapagos Spreading Center (Harpp et al. 2003).

To be tested in the current proposed research is the hypothesis that the NWFRZ is analogous to Hawaii's Puna Ridge, but that the NWFRZ is in a developmentally less-mature stage. Both the Puna Ridge and the NWFRZ are located at the leading edge of a hot spot (Kurz and Geist, 1999). Abundant constructional volcanic features have been identified by various mapping methods on the axis and flanks of the Puna Ridge (Fornari et al. 1978, Lonsdale 1989, Clague et al. 2000, Smith et al. 2002). Hummocky topography as well as volcanic cones (some containing pit craters) have been identified on the western, near-shore side of the NWFRZ at approximately 0°16' - 0°18' latitude (Fornari 2005). Distal rift-zone submarine lava flows have been identified surrounding the tips of both the Puna Ridge (Holcomb et al. 1988) and the NWFRZ (Fornari et al., 2001, Kurz et al. 2001), and are considered to be older than historical age due to > 50% sediment cover (Holcomb et al. 1988, Fornari et al., 2001, Kurz et al. 2001), making previous suggestions that the voluminous submarine lava flows were the result of

Kilauea (1924) and Fernandina (1968) caldera collapses unlikely (Simkin and Howard 1970, Holcomb et al. 1988, Fornari et al. 2001).

Employing the model of Leslie et al. (2004) (Fig. 1), submarine rift zones begin growth by early-stage voluminous eruption of sheet flows at the distal end of the rift zone. The second stage of rift-zone propagation begins when the pile of sheet flows reaches a height that favors dike intrusion, providing the rift zone with a well-developed slope of ~6°, and abundant near-shore surface eruptions (Fig. 1). The third and final stage of rift-zone growth demarks a mature rift, such as Puna Ridge, with a decrease in the slope to ~3° and a widening of the dike intrusive zone, accompanied by surficial mass wasting (Fig. 1). It is thus predicted that a mature rift zone such as the Puna Ridge will maintain a long, constant slope, consistent with modeling experiments that have suggested that the evenness of a volcanic ridge's slope is an indication of the continuity of the intrusive dike complex underlying the ridge (Fialko and Rubin 1999).

The slope of Puna Ridge is extremely constant (51m/km) from the coastline to a length of ~55km along-axis (2800m depth), where it plunges more steeply at 100m/km (Lonsdale 1989, Smith et al. 2002). The flanks of the Puna Ridge maintain gradients of 140-210 m/km (Lonsdale 1989). The slope of the 8km-wide NWFRZ is fairly constant for ~10km outwards from Fernandina Island (on average, 161 m/km, with flank slopes much steeper at 282-1245 m/km (Kurz et al. 2001)). At ~10km from the island (1700m depth) the slope steepens (Fig. 2). By ~20km along-axis from the shoreline, the slope of the rift is virtually zero (Fig. 2). Such a steep, variable profile near-shore that drops to a near-zero slope is predicted by models of shorter dike systems and those with low magmatic driving pressure (Fialko and Rubin, 1999), likely a characteristic of less-mature rift zones than the Puna Ridge. If the NWFRZ is indeed in the second stage of volcanic rift zone propagation, it is predicted (1) that most constructional volcanic morphologies will be focused on the near-shore end of the NWFRZ, (2) that old, low-angle volcanic flows will dominate the distal end of the NWFRZ, as recognized by previous mapping (Fornari et al., 2001, Kurz et al. 2001), and (3) that mass wasting scarps and other erosional, late-stage rift-zone developmental features will not be found during the upcoming mapping effort.

The main goal of the January 2006 research on the *R/V Thompson* is the search for constructional near-shore volcanic features indicative of Stage 2 (in the Leslie et al. (2004) model) of volcanic rift zone growth, abundant eruptive activity due to the establishment of an intrusive dike core. As a result of the upcoming mapping, small-scale volcanic features that have previously not been detectable at 100m-spacing such as volcanic cones, pit craters and grabens (Harpp et al. 2003), will become detectable at 25m-resolution.

The NWFRZ trends 310° for its first 11km outward from the shoreline, and then bends to the north for the remaining 1.7km (Kurz et al. 2001). Whether volcanic morphological changes accompany this northward bend will also be investigated on the *R/V Thompson* in January 2006.

Further goals for the January 2006 cruise will include investigation of the aerial extent of the NWFRZ distal rift zone lava flows with backscatter EM-300 and BATHY-2000. Higher resolution EM-300 mapping will be useful in delineating the length of the rift zone, which in previous studies has been unresolvable between one measurement of 35.5 km (Kurz et al. 2001) and 12.7 km (Harpp et al. 2003). This discrepancy relates to the definition of "rift zone," since distal lava flows appear to spread for many kilometers into the relatively flat basin north and west of the NWFRZ (Kurz et al. 2001).

Proposed Research

On Leg 1 of the Galapagos research onboard the *R/V Thompson* (January 12-20, 2006), I will be mapping the seafloor off the northwestern coast of Fernandina Island in an approximately 10 x 10 square nautical mile area, from 91°50' to 91°40' W (longitude) and from 0°10' to 0°20' S (latitude), traveling at 8 knots (Fig. 3). The mapping will be completed with the use of the *R/V Thompson*'s Kongsberg Simrad 30 kHz EM-300 multi-beam sonar (with 135 individual 1° (vertical) and 2° (horizontal) beams) and 12kHz BATHY-2000 bathymetric and sub-bottom profiling technology. Exact track-lines and way-point locations are presented in Table 1, and were plotted assuming a swath width of 3x water depth in shallow water (<1000m) and 2x water depth in deeper water (>1000m) (Glickson 2005). The mapping does not have to be conducted at a particular time of day or during a particular time interval. The time length for completion of this project will be on the order of 10 hours (Table 1).

EM-300 and BATHY-2000 bathymetric, backscatter and sub-bottom profiling data will be analyzed with the Fledermaus software program recently installed on the *R/V Thompson* computer system for viewing in that user-friendly format. Ecuadorian scientist Dr. Giorgio de la Torre, who will be on Leg 1 of the January 2006 cruise, has experience in EM-300 data processing and will be aiding in this process. A late-Fall Quarter 2005 training class in EM-300 mapping technology and Fledermaus user skills is planned, and will be led by Prof. Miles Logsdon starting as soon as possible.

After the collected data is imported into the Fledermaus software program, I will analyze the generated maps for the three characteristics mentioned in the above hypothesis (distal lava flows, constructional volcanic morphological features and mass wasting features). Recognition of such constructional volcanic morphologies will be aided by previous research and description of these features on Puna Ridge, Hawaii and Genovesa Ridge, Galapagos Archipelago. Volcanic morphologies indicative of primary eruptive vents from an underlying dike include: volcanic cones (Smith et al. 2002, Harpp et al. 2003), fissure ridges (Fornari 1978, Lonsdale 1989, Smith et al. 2002), pit craters (Lonsdale 1989), axial grabens (Lonsdale 1989), submarine terraces (Zhu et al. 2002, Smith et al. 2002, Harpp et al. 2003) and flat-topped submarine cones (Clague et al. 2000, Harpp et al. 2003).

This last feature (flat-topped submarine cones) could be expected at depths > ~700m (high confining pressure) on the NWFRZ in order to facilitate steady, effusive eruptions which are required to build flat-topped submarine cones (Clague et al. 2000). However, such cones also require low volatile contents (Clague et al. 2000) and may not be relevant for the case of the NWFRZ, since these lavas are relatively gas-rich (Kurz et al., 2000). If found, it may indicate previously-unknown long-time-scale eruptions on the NWFRZ.

Whether some of these small-scale features will be resolvable at the 25m-spacing that is the aim of the EM-300 mapping effort is debatable and will be ascertained after mapping is completed. Volcanic cones and submarine terraces should be resolvable at this spacing, but fissure ridges and flat-topped submarine cones are possibly unresolvable at 25-m spacing (Hughes Clarke 1998).

After mapping is completed, I will be collaborating with a fellow student, Wesley Thompson, in this project about the NWFRZ. Wesley is using CTD tow-yoing from the *R/V Thompson* to search for hydrothermal activity emanating from the NWFRZ. In order to zero in on possibly active regions, I will make my EM-300 maps available to Wesley. If active hydrothermal activity is found on the NWFRZ, Wesley Thomspon, myself and long-distance WHOI advisor Dr. Daniel Fornari will continue to collaborate to publish the results of this research starting Winter Quarter 2006 and likely continuing into Spring Quarter and Summer 2006.

Future gravity and magnetic studies will be required to resolve the nature of the dike complex underlying the NWFRZ. Also requiring further investigation is the question of the petrology of NWFRZ lavas, which may include basalts considerably more alkalic than the low MgO tholeiites erupted on subaerial Fernandina slopes (Graham et al. 1993, Kurz and Geist, Allan and Simkin 2000), possibly providing a counter-argument to the current hypothesis that the NWFRZ is an expression of laterally intruded magmas from the Fernandina magma chamber (Kurz et al. 2001).

Project Budget

Item	Cost for 10 hours
R/V Thompson EM300 system BATHY2000 system Computer system on ship	$7,500* (EM300 system, BATHY2000 system and computer system on ship included in ship-use cost above, unless renewal of ship's Fledermaus license should be considered here)
Total Cost	**$7,500**
* provided at no cost to project budget	

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Figures and Tables

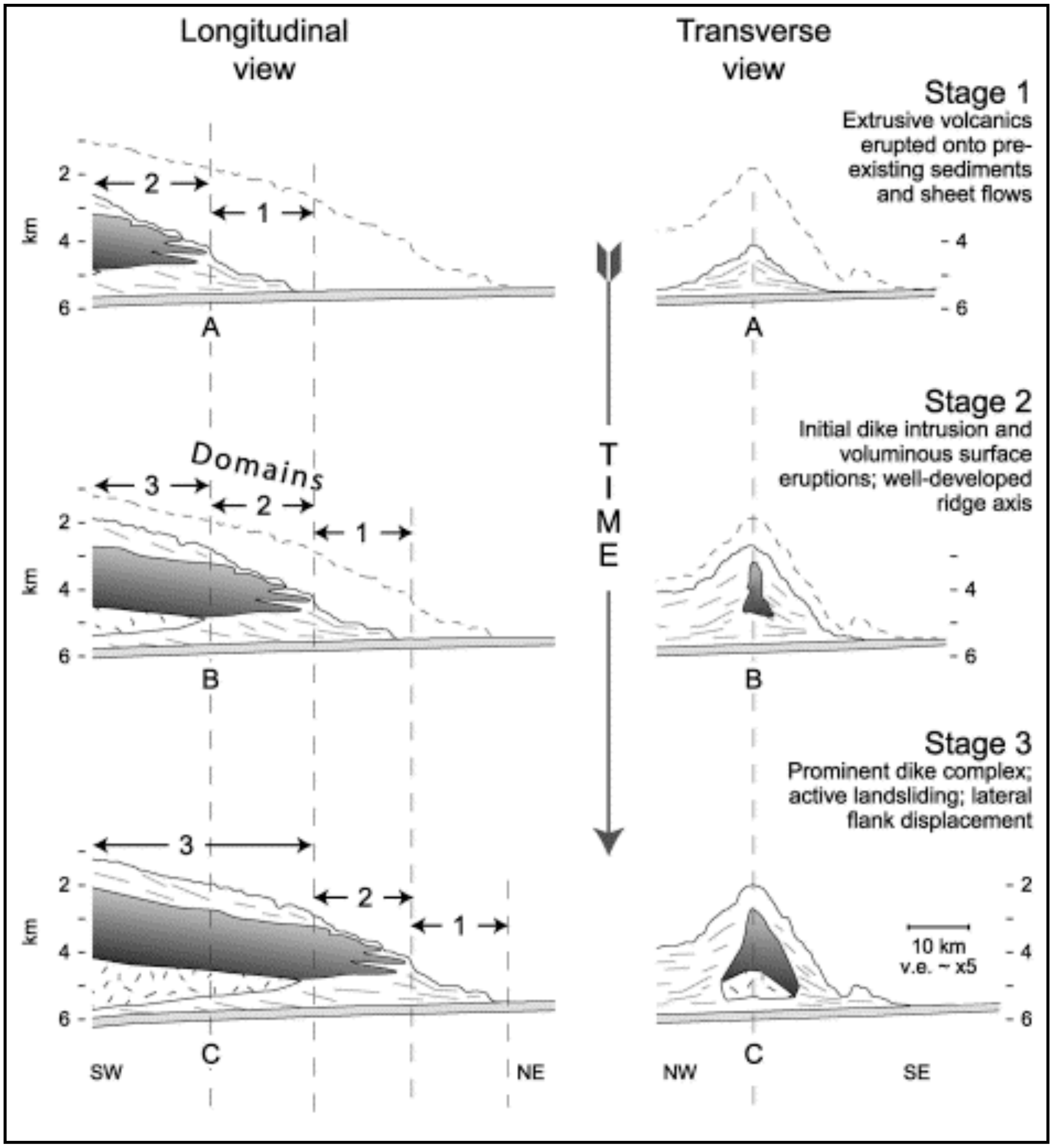

Figure 1. Reproduced from Figure 9 in Leslie et al. (2004). Proposed model for the evolution of a rift zone built adjacent to a mature volcanic flank.

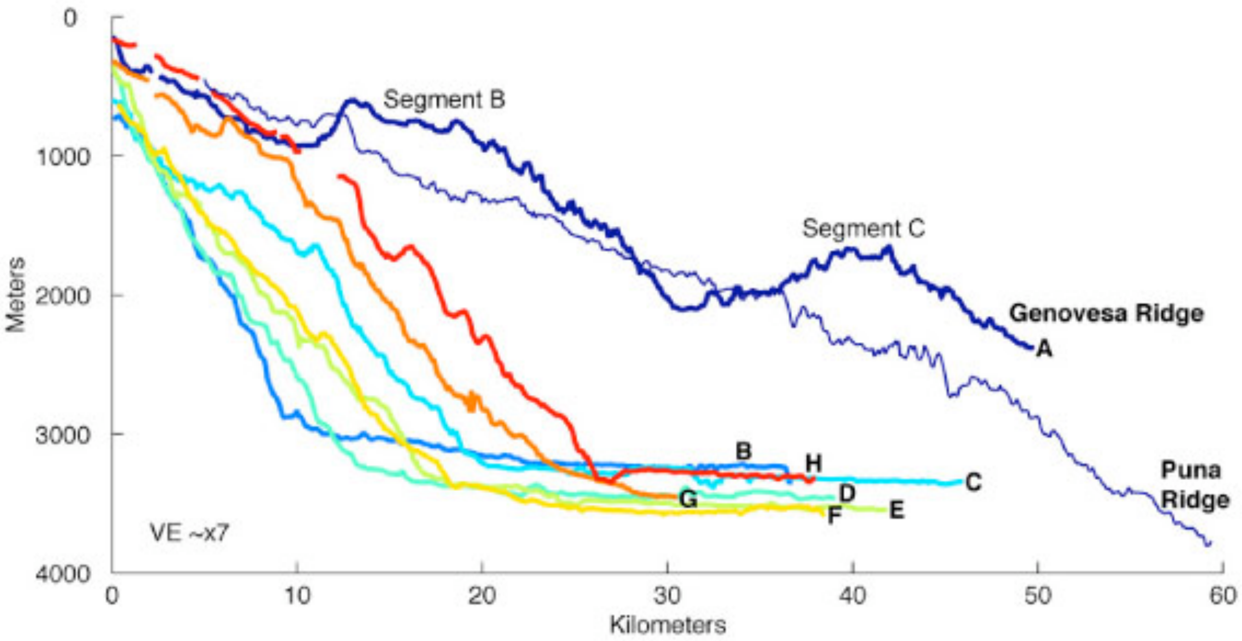

Figure 2. Reproduced from Figure 6 in Harpp et al. 2003. Profile C is the NW Fernandina Rift Zone. Profiles B, D-H are other Galapagos submarine ridges and rift zones.

Table 1. Trackline locations and time requirements.

Way Point	Latitude	Longitude	Equipment To be used	Approx. Distance to Next Station (nm)	Approx. Time to the Next Station (hrs)
JG1	**0º 10' S**	**91º 40' W**	EM300, Bathy/Subbottom profilers (Bathy2000)	8	1
JG2	**0º 18' S**	**91º 40' W**	EM300, Bathy	0.43	0.05
JG3	**0º 18.1' S**	**91º 40.45' W**	EM300, Bathy	9.43	1.18
JG4	**0º 9.1' S**	**91º 43.5' W**	EM300, Bathy	2.71	0.34
JG5	**0º 10' S**	**91º 46.2' W**	EM300, Bathy	10.07	1.26
JG6	**0º 18.45' S**	**91º 40.7' W**	EM300, Bathy	0.36	0.04
JG7	**0º 18.8' S**	**91º 40.75' W**	EM300, Bathy	10	1.25
JG8	**0º 12' S**	**91º 48' W**	EM300, Bathy	3	0.38
JG9	**0º 14.2' S**	**91º 50' W**	EM300, Bathy	10.71	1.34
JG10	**0º 19.05' S**	**91º 40.6' W**	EM300, Bathy	0.14	0.02
JG11	**0º 19.2' S**	**91º 40.5' W**	EM300, Bathy	9.79	1.22
JG12	**0º 17.2' S**	**91º 50' W**	EM300, Bathy	2.79	0.35
JG13	**0º 20' S**	**91º 50' W**	EM300, Bathy	9.71	1.21
JG14	**0º 19.3' S**	**91º 40.25' W**	EM300, Bathy		
Total				77.14	**9.64**

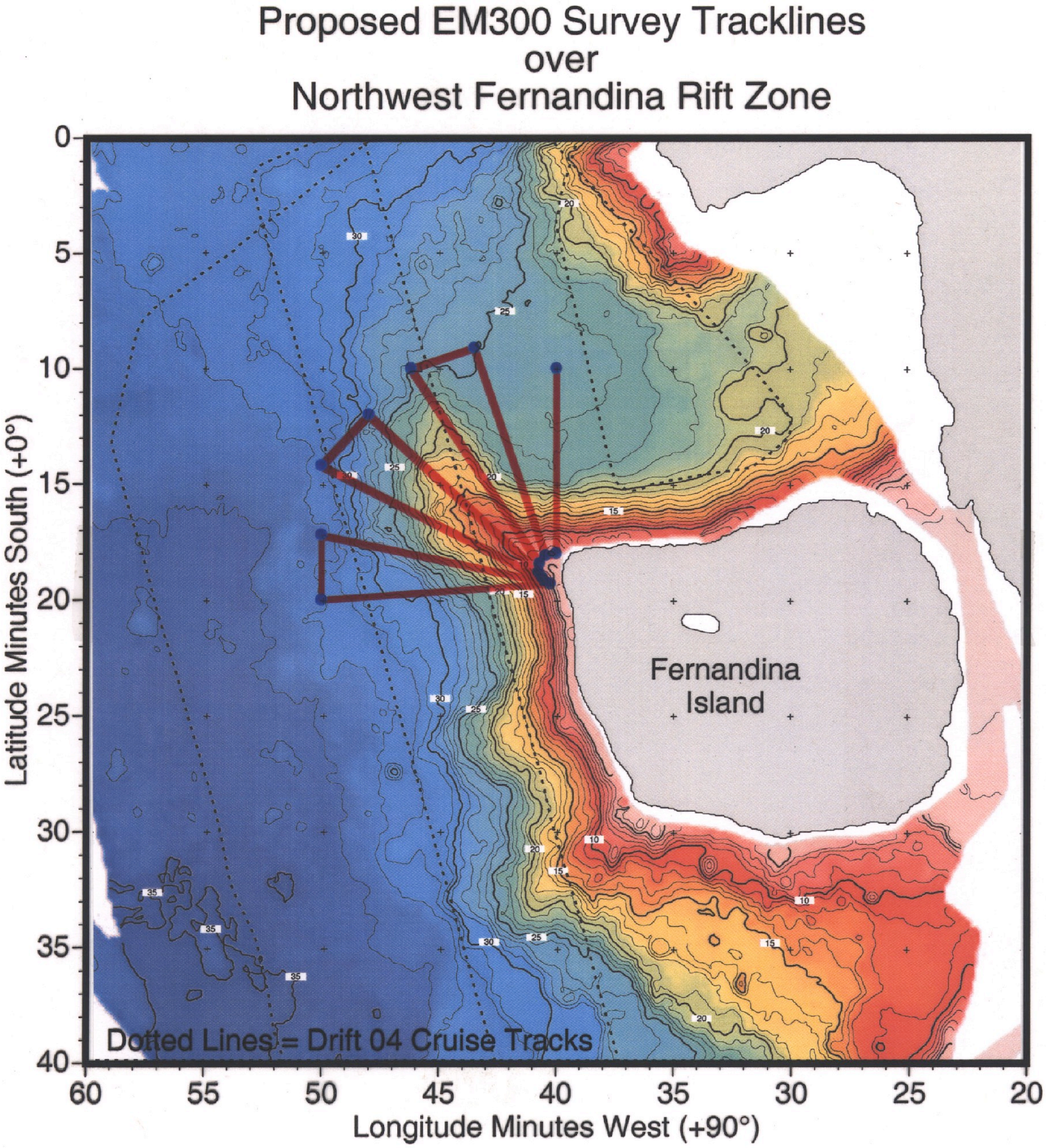

Figure 3. Track-lines and way-points planned for upcoming January 2006 cruise (with bathymetric map from Kurz et al. 2001).