

## **Roca Redonda as a result of an extensional transform zone**

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## **Project Summary**

A 1580 km<sup>2</sup> area will be mapped to the northwest of Roca Redonda using an EM300 multibeam mapping system and a subbottom profiler aboard the *R/V Thomas G. Thompson*. Although much of the complex geology of the Galápagos Islands remains unresolved, it is thought that the Wolf- Darwin lineament is a result of stresses produced by the transform fault at 91° W. The lineament forms an oblique extensional transform zone (ETZ) that would be present at any mid-ocean ridge transform fault but is serendipitously illuminated by excess melt from the adjacent Galápagos mantle plume. Roca Redonda may also result from this same ETZ as indicated by its shape, alignment, and other features distinct from the rest of the southern archipelago. Mapping the area to the northwest of Roca Redonda will provide evidence for how much the island's formation is due to a regional stress zone versus that which is due to the hotspot. Additional evidence will be determined by graphing available data for the area directly around Roca Redonda.

## **Introduction**

The geology of the Galápagos Islands is puzzling and complex. In general the seamounts and islands to the east are older than those to the west, ranging from ~0.5 Ma for Fernandina to 3.4 Ma for Española. The oldest lavas on Española, Santa Fe, San Christobal, Santa Cruz and Floreana are older than 1.5 Ma (White et al. 1993). This conforms to what would be expected from a stationary hotspot and plate motion to the east. However location and age show no linear relationship when considering Wolf and

Darwin islands, the Wolf-Darwin lineament seamounts, Pinta, Marchena and Genovesa Islands, collectively called the northern islands (Figure 1). Further complicating the geology of the archipelago is that some of the older islands are still active. The only main islands not considered active are Wolf, Darwin, Pinta, Santa Fe, and Española.

Additionally, there is no clear evolutionary pattern of Galápagos volcanism. In contrast to Hawaii where evolutionary stages of volcanic growth are exposed at a single volcano, the slow erosion rate at the Galápagos rarely exposes any stratigraphic thickness (Standish et al. 1998). Theories about which volcanoes represent the young, intermediate, and mature stages of Galápagos volcanism are based mainly on geochemical evidence (White et al. 1993, Standish et al. 1998).

There is also the matter of the Galápagos platform that underlies most of the islands. This platform gradually slopes deeper as it goes to the east, probably due to contraction as the lithosphere moves away from the hotspot. The western edge is more puzzling as it rises sharply from the seafloor. Particularly interesting is the series of submarine terraces mapped during DRIFT04 to the southwest spanning  $\sim 5000 \text{ km}^2$  and ranging from 90- 245 m. tall (Kurz et al. 2001, unpubl.; Geist, D., pers. comm.). The structure and ages of the terraces have been investigated but the process of how they were formed is unknown. No other similar structures are known to exist. Ages indicate that the platform developed first and the volcanoes grew on top (Geist, D., pers. comm.)

Harpp and Geist developed a theory about the formation of the northern islands (2002). They postulate that the transform fault along the Galápagos spreading center at  $91^\circ \text{ W}$  creates a tensional stress field in combination with absolute plate motion. This stress creates a zone of regional extension, which is illuminated by the presence of the

nearby hotspot (Figure 2). The transform fault is oblique to the spreading zone by  $15^\circ$ , which falls into the description of an extensional transform zone (Taylor et al. 1994). According to Harpp and Geist the extensional region is bounded by the Wolf-Darwin lineament in the west and the transform fault in the east (2002). The intended research project proposes that the influence of the transform fault at  $91^\circ$  extends further than the Wolf-Darwin lineament and has influenced the formation of Roca Redonda.

Roca Redonda is usually classified as a young shield volcano created by and at the leading edge of the Galápagos hotspot (Standish et al. 1998). It is thought to represent the most juvenile phase of Galápagos volcanism, comparable to a stage of evolution between the submerged Loihi seamount and subaerial Kilauea volcano of Hawaii (Standish et al. 1998). Standish et al. also mention that Roca Redonda is in a stage of subaerial growth. Other evidence suggests that Roca Redonda may be deteriorating. An abstract for a research symposium talk entitled “Evidences for potential future sector collapse at Volcano Roca Redonda, northern Galápagos- tectonics, simulation and consequences” used backscatter and bathymetry data to identify a partial sectorial collapse towards the west and predicts that another will occur towards the south (Cando, M., P. Arreaga, T. Toulkeridis, and G. de la Torre, unpubl.). The subaerial portion of Roca Redonda has vertical walls composed of 20- 25 lava flows that are covered by a thick subsurface talus apron. Palagonite tuff is exposed about 10 m below the summit and there is no caldera. These observations suggest that the exposed lavas once filled the crater of a palagonite tuff cone, which has subsequently been eroded (Standish et al., 1998).

Roca Redonda could either be a “stillborn” volcano created by the hotspot, a volcano created by the illumination of an extensional transform zone due to the transform fault at 91°, or some mix of these two processes. A comparison of the similarities and differences of Roca Redonda with other Galápagos volcanoes provides clues as to which of these hypotheses dominates. One similarity is the location of Roca Redonda in line with the other active volcanoes of Isabela Island. A straight ridge has also formed between Roca Redonda and Wolf Volcano, which is typical of hotspot volcanism (Geist, D., pers. comm.) Conversely, the vertical walls of Roca Redonda are much more like Wolf and Darwin islands and not the “upside-down soup bowl” shape typical of Galápagos shield volcanoes. As mentioned before, Roca Redonda has no caldera and it is the only island in the southern portion of the Galápagos that is not on the platform. The oblong alignment of the submarine portion of the volcano is also parallel to the Wolf-Darwin lineament.

Other information about Roca Redonda does not support either of the two possible formation processes. Only one rock, collected near the bottom of the exposed portion, has been analyzed for age data yielding a K-Ar date of  $53 \pm 54$  ka (White et al. 1993). There are numerous fumaroles within 30 m of water depth that are venting only 1-2°C above ambient seawater (Standish et al. 1998). No fumaroles or hydrothermal venting systems have been looked for on the flanks of the volcano deeper than 30 m. Geochemical analysis of the lavas on Roca Redonda indicate that there is a high plume component (Standish et al. 1998). The geochemical range of lavas found on the Wolf-Darwin lineament almost match the range of the entire archipelago, so that a high plume

component is not necessarily indicative of formation by the hotspot (Harpp and Geist, 2002).

If the formation of Roca Redonda resulted from extensional transform zone processes then evidence of the tensional stress zone would be expected, particularly in a line from Roca Redonda that parallels the Wolf-Darwin lineament. The current bathymetry data to the northwest of Roca Redonda is very poor (Figure 1, Figure 3). There is some suggestion of low seamounts along the predicted line. There is also two elongate bed forms aligned north-south extending towards Roca Redonda from the Wolf-Darwin lineament, which may have formed through an interaction between the two locations. The proposed research will map and collect sidescan imagery of the area to the northwest of Roca Redonda along a line parallel to the Wolf-Darwin lineament and over the western bed form. The presence of exposed lava flows and seamount would support the claim that the extensional transform zone influences Roca Redonda. Conversely, the existing assumption of hotspot formation would be supported if no such flows or seamounts were found.

Additional evidence can be found through a close look at the bathymetry and sidescan data collected on the DRIFT04 cruise around Roca Redonda. One of the ways in which Genovesa Island exhibits extensional transform zone stress is by the broken en echelon pattern of the crest of its eastern submarine rift. En echelon structures are consistent with passive upwelling of the underlying mantle and not active magmatic processes. In contrast, Kilauea's Puna ridge in Hawaii, which has a substantial magma supply, has a straight continuous ridge crest (Harpp, K., pers. comm.). Roca Redonda's northwest ridge curves to the left, but its ridge crest has not been examined yet for

continuity. For unknown reasons many Galápagos island ridges curve. A continuous ridge crest on Roca Redonda's northwest rift would support hotspot influenced formation. If the ridge crest were found to exhibit a broken en echelon pattern stress zone formation would be supported. Comparison with the ridge crest on Fernandina's right-curving northwest ridge would give a better idea of the typical ridge crest of hotspot formed volcano in the Galápagos.

### **Proposed Research**

Mapping will take place on the *R/V Thomas G. Thompson* between 12 and 20 January 2002. Mapping will be done using a Simrad EM 300 mapping system, which operates at 30 kHz with a swath width approximately 2.5 times that of the water depth. Resolution of the map generated from this system is expected to be a 3 m pixel size. Concurrent backscatter imagery will be collected with a 3.5 kHz subbottom profiler. The total length of the track line to be mapped is 142 nm at 7.5 kts to maximize map resolution (Figure 3, Table 1). Turn around time at the end of each line on the track is estimated to be 30 minutes. Four turnarounds and the time for the mapping add up to a total of 21 hrs of ship time. Data collected will be stored MBsystems and then transferred to Fledermaus visualization software to be created into a grid.

Further information will be obtained through mapping of Fernandina's northwest rift to be done on the same cruise by J. Glass. Graphics of Roca Redonda's northwest rift will be generated with Fledermaus software using data collected on the DRIFT04 cruise with an EM 120 mapping system.

## Project Budget

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Equipment/Supplies	Origin	Cost	Days Required	Total Cost (\$)	Effective Cost (\$)
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Platform					
<i>R/V Thomas G. Thompson</i>	School of Oceanography	\$18000/day	1	18000	0.00
Shipboard Equipment					
EM300 mapping system		Included			
3.5 kHz subbottom profiling system		Included			
Computer Programs					
Fledermaus visualization software					0.00

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## References

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Harpp, K. and D. Geist. 2002. Wolf- Darwin lineament and plume-ridge interaction in the northern Galápagos. *Geochem. Geophys. Geosy.* **3**. [doi: 10.1029/2002GC000370]

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## **Figure Captions**

Figure 1- A. Bathymetry map of the northern Galápagos islands showing locations of samples analyzed in B. GSC is the Galápagos spreading center. B. Variations in ages of the Wolf-Darwin lineament with latitude (both from Harpp and Geist, 2002).

Figure2- Conceptual diagram of the processes involved in creating the Wolf-Darwin lineament. Orange tones indicate area of Galápagos mantle plume influence. Long arrows show spreading direction of the Nazca plate. Short arrows show extension necessary to accommodate plate spreading when strike-slip component of the transform fault is removed. Bold red lines show observed volcanic lineaments. Ellipses are from Gudmundsson's model for stresses resulting from transform fault- spreading center intersection (1995). Inset shows vector representation in velocity space of a model for strain partitioning through a combination of transform and extensional motions (from Harpp and Geist, 2002)

Figure 3- Bathymetry map of the Galápagos showing proposed ship track lines over bed forms of interest.

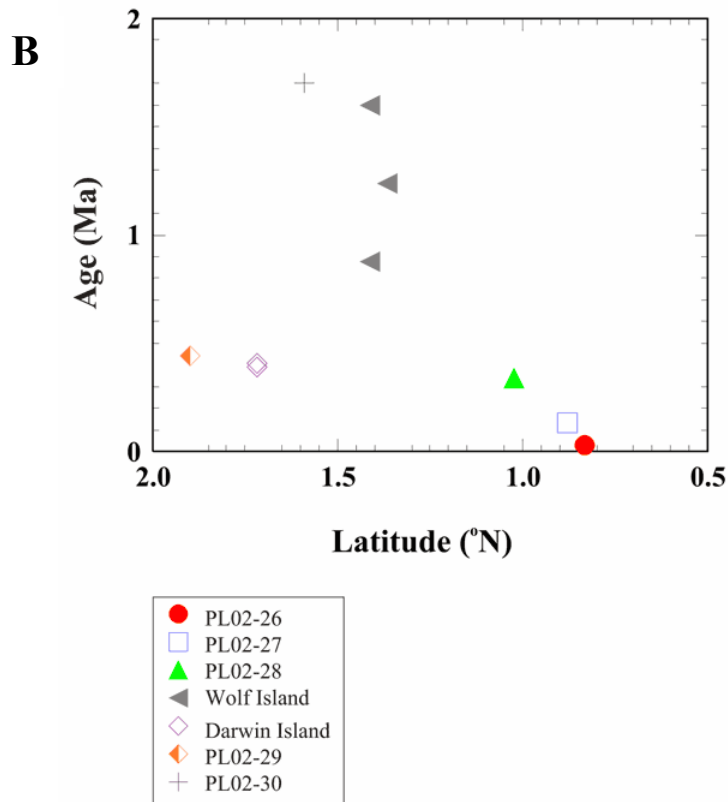
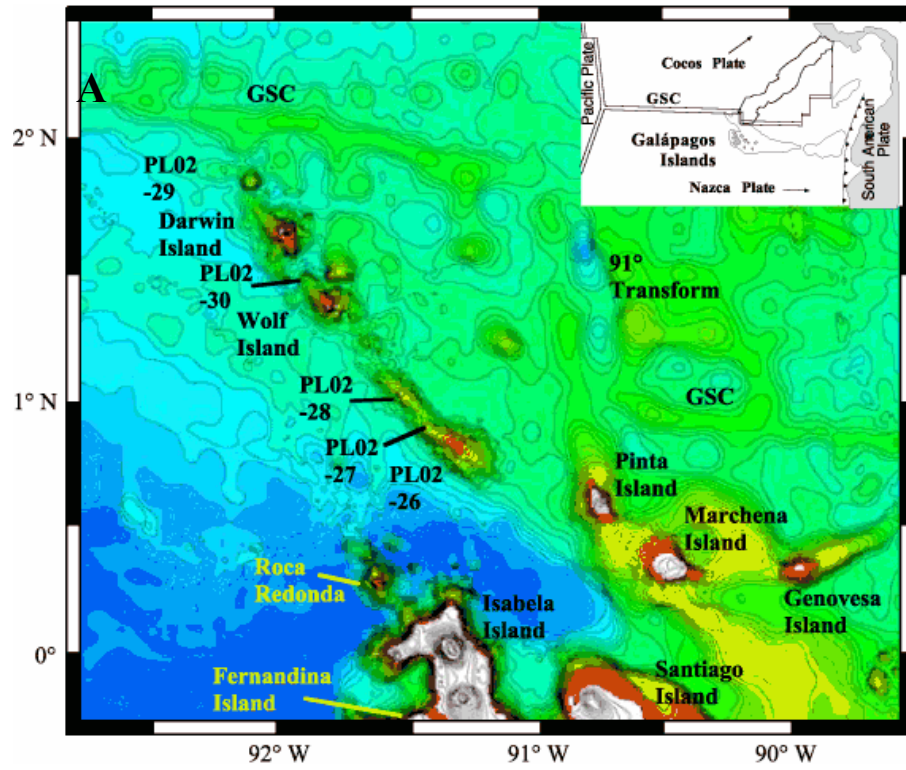


Figure 1- Heidi Berkenbosch

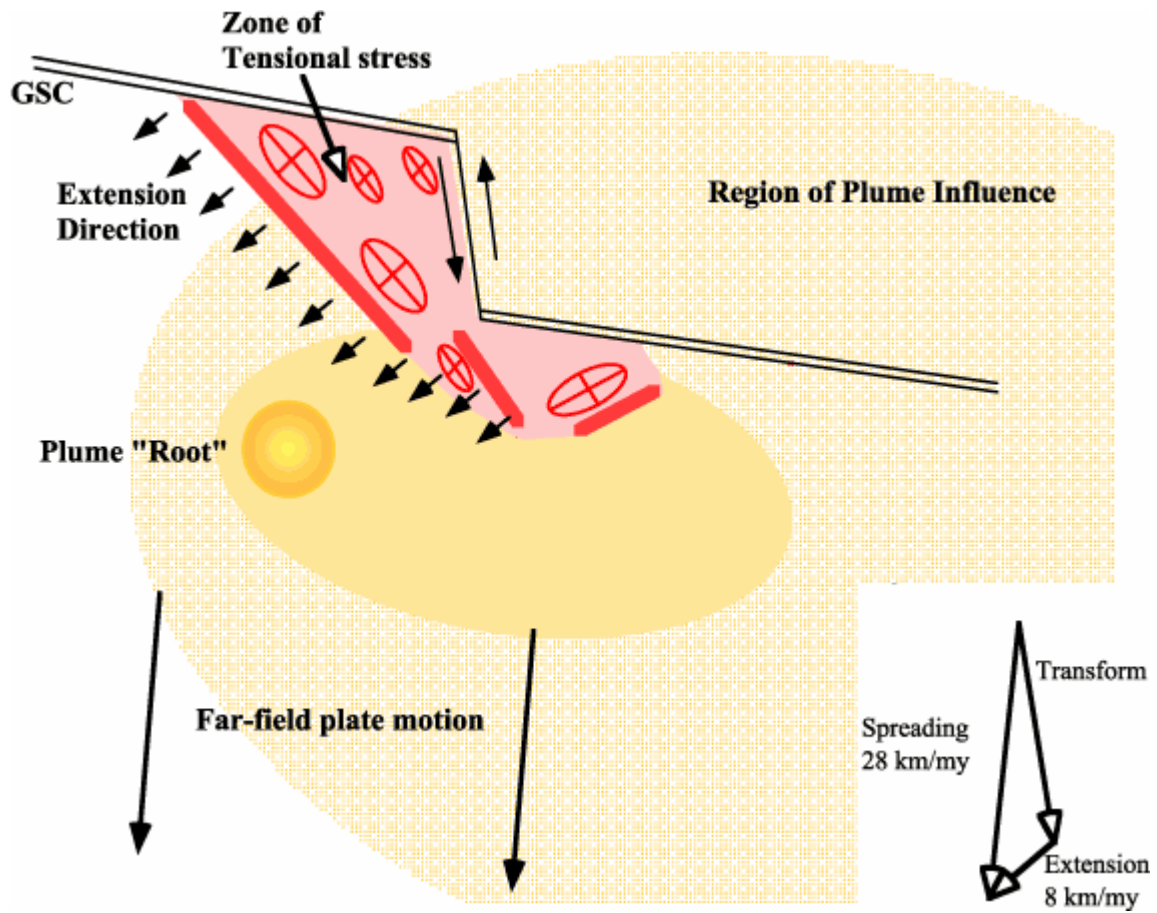


Figure 2- Heidi Berkenbosch

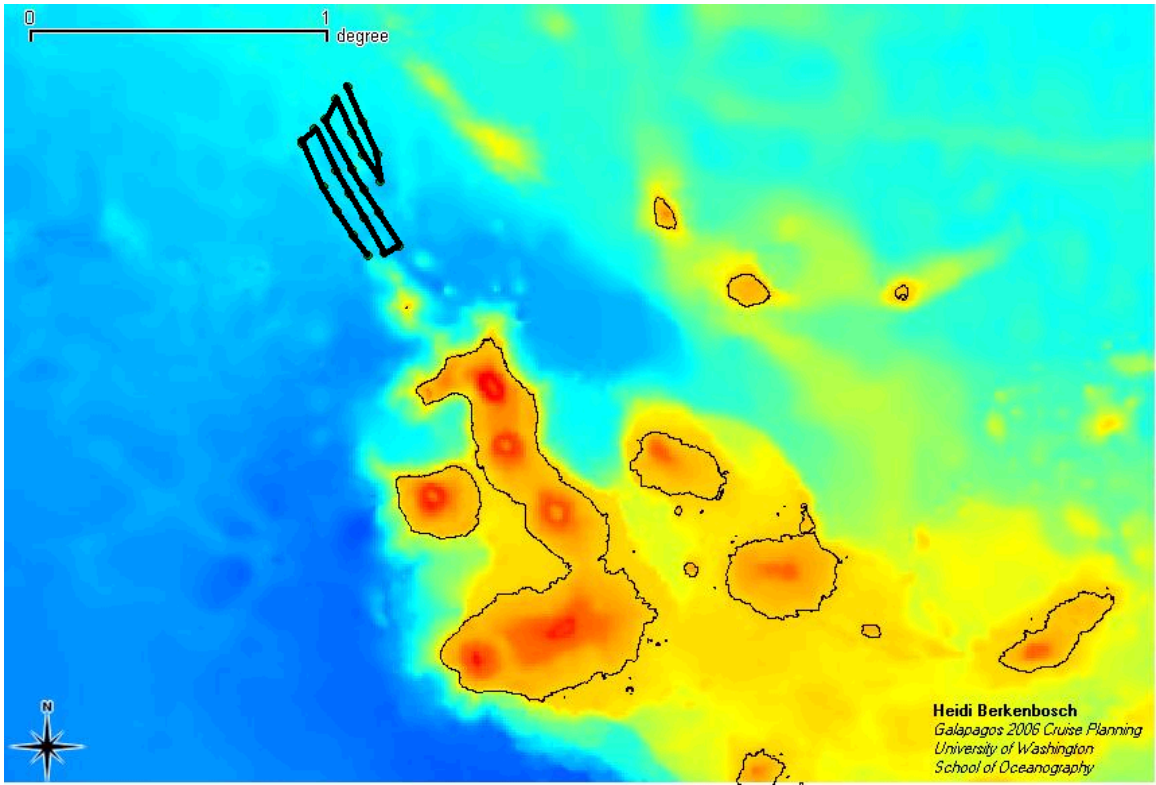


Figure 3- Heidi Berkenbosch

Table 1- Location of stations along ship track line.

Station Number	Latitude	Longitude
HB1a	0 26.78' N	91 45.16' W
HB1b	0 30.88' N	91 48.31' W
HB1c	0 35.75' N	91 51.51' W
HB1d	0 40.71' N	91 54.29' W
HB1e	0 49.48' N	91 58.64' W
HB2a	0 52.3' N	91 56.23' W
HB2b	0 44.02' N	91 51.77' W
HB2c	0 35.25' N	91 49.2' W
HB2d	0 34.48' N	91 46.16' W
HB2e	0 27.47' N	91 41.96' W
HB2f	0 28.64' N	91 39.02' W
HB3a	0 35.65' N	91 43.11' W
HB3b	0 40.23' N	91 46.05' W
HB3c	0 44.22' N	91 48.62' W
HB3d	0 54.35' N	91 54.13' W
HB4a	0 58.54' N	91 51.72' W
HB4b	0 51.53' N	91 48.62' W
HB4c	0 47.24' N	91 56.37' W
HB4d	0 41.69' N	91 42.9' W
HB5a	0 47.34' N	91 43.27' W
HB5b	0 53.86' N	91 46.37' W
HB5c	1 0.97' N	91 49.3' W

