Formation of the Galapagos Microplate and its Effect on Rifting at the Galapagos Triple Junction

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Abstract

The Galapagos microplate formed at 1.4 Ma, initiating Nazca–Galapagos magmatic spreading along its southern and eastern borders. We examine in detail the formation and evolution of the microplate and its effect on the major rift boundaries of the Galapagos triple junction region. We show that the microplate originated by breaks along three pre-existing zones of structural weakness in the Nazca lithosphere: 1) to the south, an active 'secondary rift' located ~50 km south of the Pacific-Cocos-Nazca triple junction; 2) to the east, faults associated with the off-axis East Pacific Rise (EPR) abyssal hill fabric, and 3) to the north, the deep normal faults of the southern scarp of the Galapagos gore (the faulted boundary between the Pacific-Nazca and the Cocos-Nazca regimes). The breaks were likely forced by the appearance of a significant magmatic anomaly that crossed the EPR, flooded the 'secondary rift' in the south with lavas and shortly thereafter, created two large seamounts (~1500 m and ~1000 m in relief) on the southern boundary. This magmatic anomaly may also be associated with the unusually high elevation of Dietz Volcanic Ridge west of the seamounts, which resembles the rift zones of Axial Seamount on the Juan de Fuca Ridge in height, width and length. Dietz Volcanic Ridge is the present southern boundary of the Galapagos microplate and opens at ~33 mm/yr. It is ~900 m in relief and 7.5-8 km wide at its shallowest section. Rock samples dredged from the shallow section of the ridge in 2018 on the R/V Sally Ride support the idea of a magmatic anomaly in this area. The rocks are transitional MORB that are more enriched than any Cocos-Nazca lavas or the adjacent EPR that were sampled (see Wernette et al. 2019 abstract). The residual mantle Bouguer anomaly indicates thicker crust associated with the two seamounts and the eastern section of Dietz Volcanic Ridge (see Zheng et al. 2019 abstract). We also examine the response of the Cocos-Nazca rift and the EPR to the arrival of the magmatic anomaly and microplate formation. The Galapagos triple junction region is complex, but this complexity provides an opportunity to obtain a better understanding of how plates deform internally near their boundaries, and the relationship between this deformation and upwelling mantle material.

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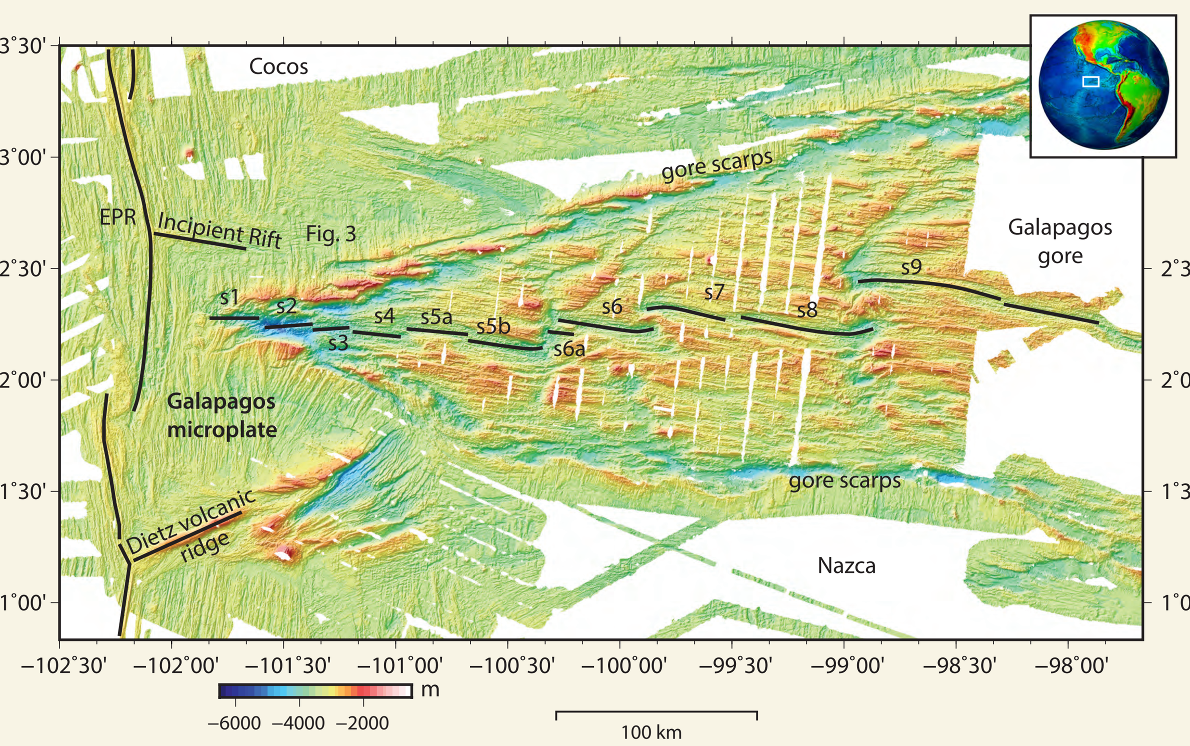
Introduction.

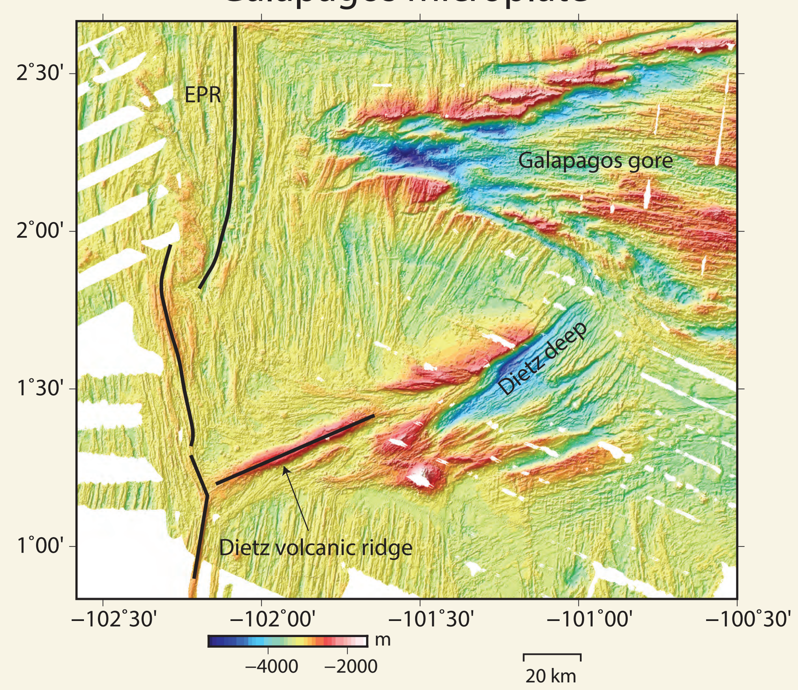
The Galapagos microplate formed at ~1.4 Ma, initiating Nazca–Galapagos magmatic spreading along its southern and eastern borders. We examine in detail the formation and evolution of the microplate and its effect on the major rift boundaries of the Galapagos triple junction region. We show that the microplate originated by breaks along three pre-existing zones of structural weakness in the Nazca lithosphere: 1) to the south, an active 'secondary rift' located ~50 km south of the Pacific-Cocos-Nazca triple junction; 2) to the east, faults associated with the off-axis East Pacific Rise (EPR) abyssal hill fabric, and 3) to the north, the deep normal faults of the southern scarp of the Galapagos gore (the faulted boundary between the Pacific-Nazca and the Cocos-Nazca regimes). The breaks were likely forced by the appearance of a significant magmatic anomaly that crossed the EPR, flooded the 'secondary rift' in the south with lavas, and shortly thereafter created two large seamounts (~1500 m and ~1000 m in relief) on the southern boundary. This magmatic anomaly may also be associated with the unusually high elevation of Dietz Volcanic Ridge west of the seamounts, which resembles the rift zones of Axial Seamount on the Juan de Fuca Ridge.

Dietz Volcanic Ridge is the present southern boundary of the Galapagos microplate and opens at ~33 mm/yr. It is ~900 m in relief and 7.5-8 km wide at its shallowest section. Rock samples dredged from the shallow section of the ridge in 2018 on the R/V Sally Ride support the idea of a magmatic anomaly in this area. The rocks are transitional MORB that are more enriched than any Cocos-Nazca lavas or the adjacent EPR that we sampled. The residual mantle Bouguer anomaly indicates thicker crust associated with the two seamounts and the eastern section of Dietz Volcanic Ridge. We also examine the response of the Cocos-Nazca rift and the EPR to the arrival of the magmatic anomaly and microplate formation. The Galapagos triple junction region is complex, but this complexity provides an opportunity to obtain a better understanding of how plates deform internally near their boundaries, and the relationship between this deformation and upwelling mantle material.

1. Study Location

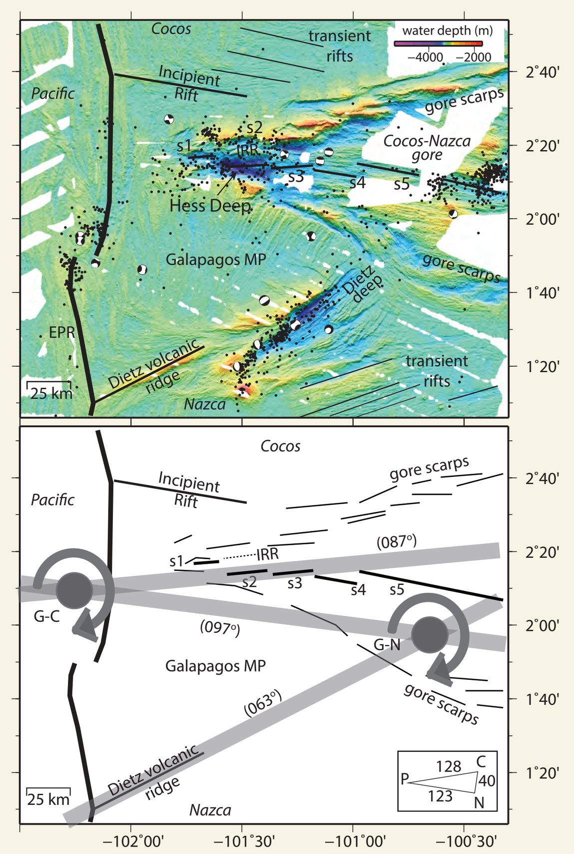


Galapagos microplate



2. Current Spreading Regimes

Smith and Schouten, GRL, 2018



Estimated opening rates:
s1 = 16 mm/yr
s2 = 19 mm/yr
s3 = 24 mm/yr

Assuming open rates

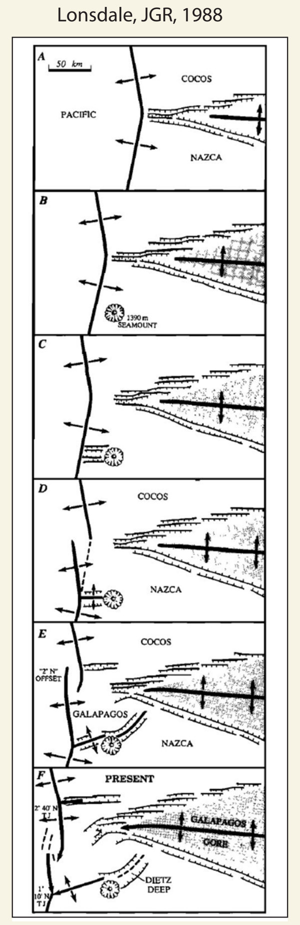
DVR = 33 mm/yr (Smith and Schouten, 2013)

C-N = 40 mm/yr (NUVEL 1a, DeMets et al. 1994)

Top Panel: Bathymetry with earthquake locations from (Fox et al., 2001) and (Ekström et al., 2012). Bottom:: Diagram of the instantaneous relative rotation axes G-C and G-N. Velocity triangle: motions of the major plates (NUVEL 1A (DeMets et al., 1994)). (097) is a great circle through the faraway C-N axis, and the locus of G-C and G-N axes (Schouten et al., 1993). (063) runs along Dietz volcanic ridge. (087) runs along segments s2 and s3, and are the locus of the G-N and G-C axes assuming orthogonal spreading. The G-N velocity equals 40 mm/yr (C-N velocity) at the location of the G-C axis (i.e., at this point G does not move relative to C) and 33 mm/yr at Dietz volcanic ridge (Smith and Schouten, 2013).

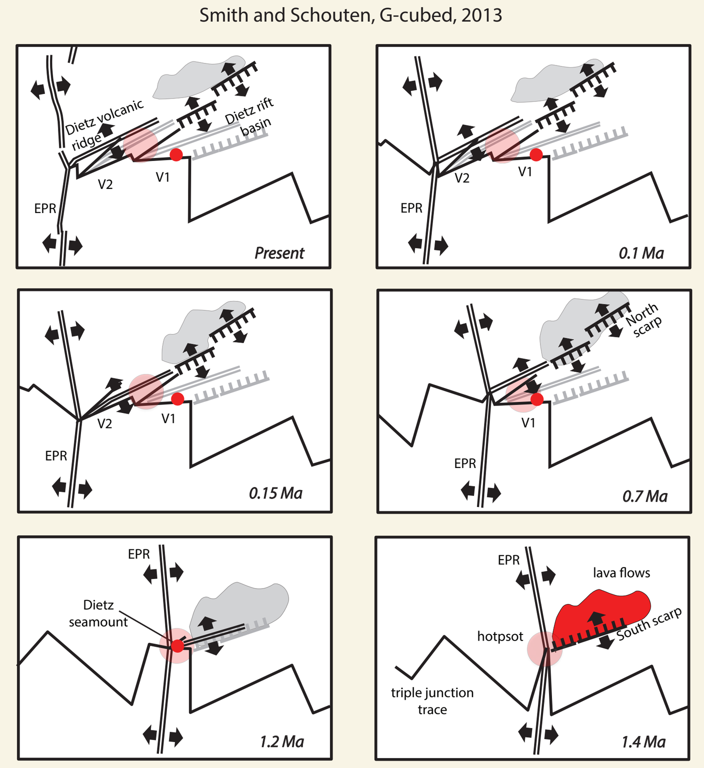
3. Previous Models for GMP Initiation

Lonsdale, JGR, 1988



The Nazca plate is fixed; C-N rift propagates west at a steady rate. Panels B, C, and D show rapid changes at ~1 Ma. Dashed lines in D and F mark dead or dying spreading axes. Note the seamount that appears in B that leads to the development of a southern spreading center.

Smith and Schouten, G-cubed, 2013

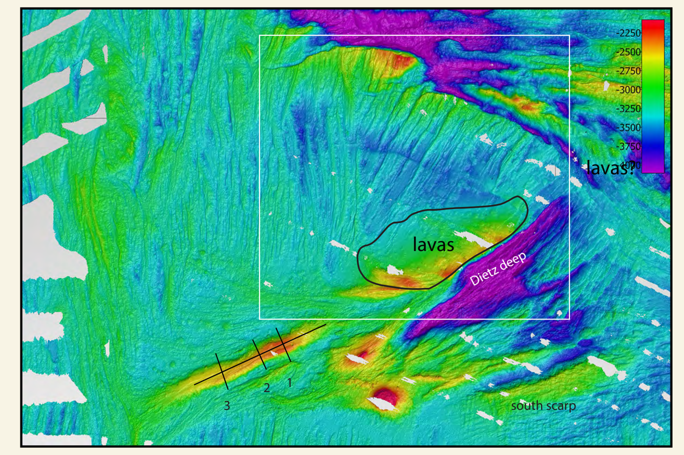


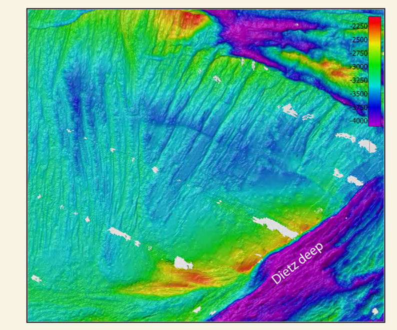
1.4 Ma: Hotspot approaches the EPR; extension is fixed on the South scarp; lavas flood the area north of the scarp. 1.2 Ma: Hotspot has crossed to the Nazca plate; Dietz seamount forms within the young Galapagos-Nazca spreading center (V1). 0.7 Ma: Magmatic spreading has jumped north to V2; amagmatic extension to the east is on North scarp of Dietz rift basin. 0.15 Ma: Magmatic spreading on V2 continues. 0.1 Ma: Magmatic spreading jumps north to Dietz volcanic ridge. Present: Magmatic spreading continues on Dietz ridge; amagmatic extension continues on the North scarp.

4. Evidence for a Magmatic Anomaly

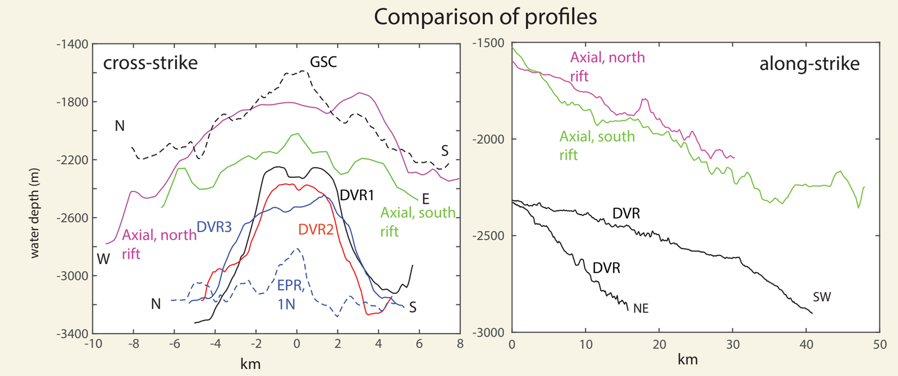
Bathymetry

Lavas erupted when extension fixed on south scarp





Comparison of profiles



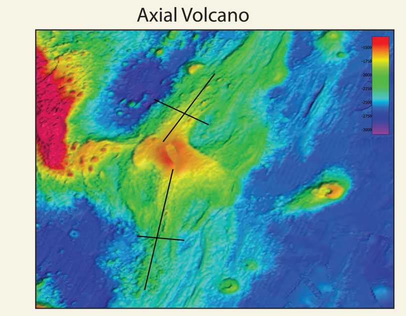
--GSC = Galapagos spreading center at 92W (see sample map below)

--DVR = Dietz volcanic ridge

--Axial = Axial volcano on the Juan de Fuca ridge

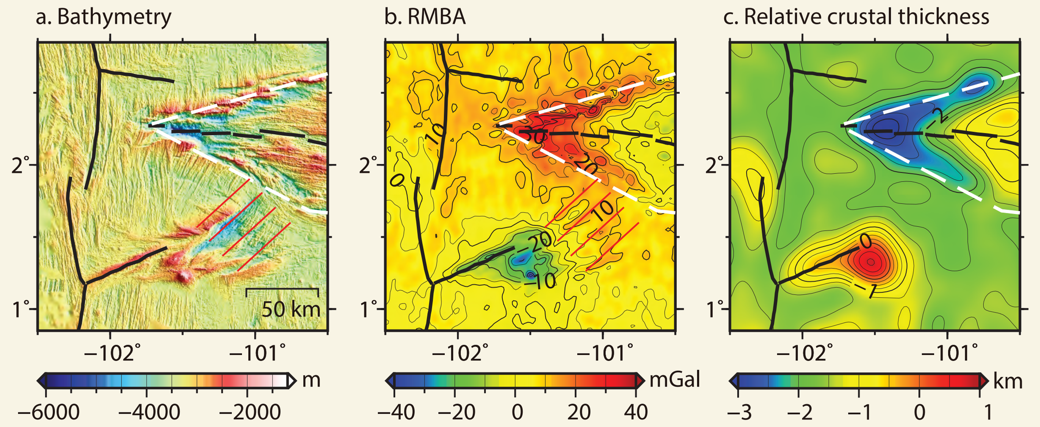
--EPR = East Pacific Rise at 1N, just south of the triple junction

Axial Volcano



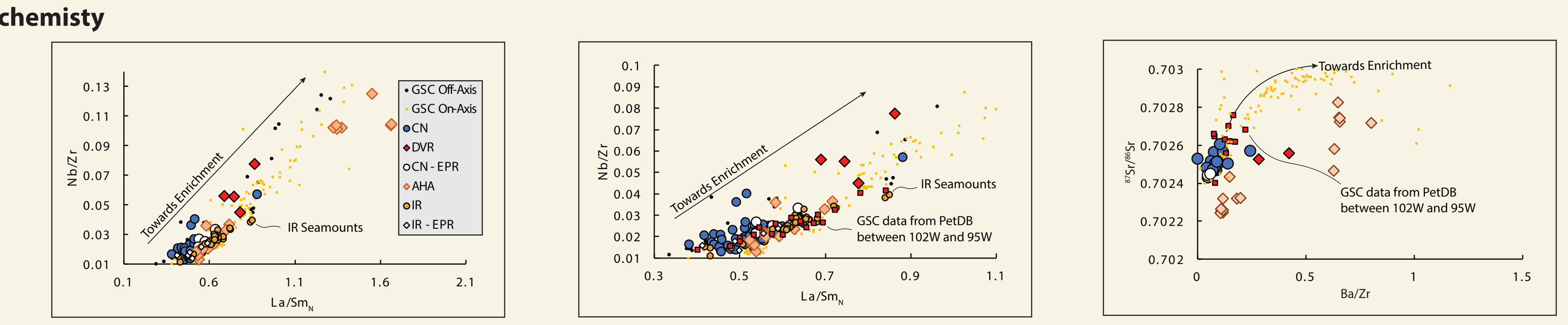
Bathymetry data indicate extensive lava flows erupted when extension was fixed on south scarp. Profiles show that DVR has anomalously high relief.

Gravity

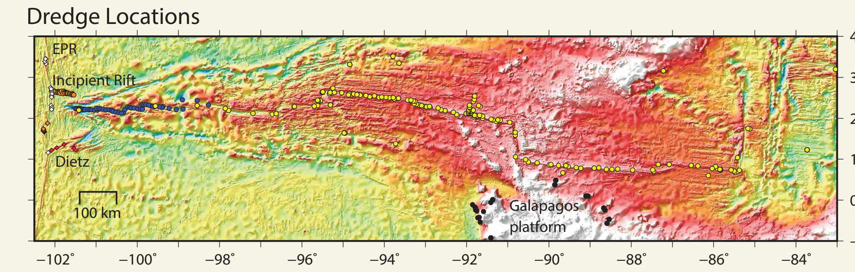


Gravity data suggest thicker crust in the region of Dietz volcanic ridge and seamounts.

Geochemistry

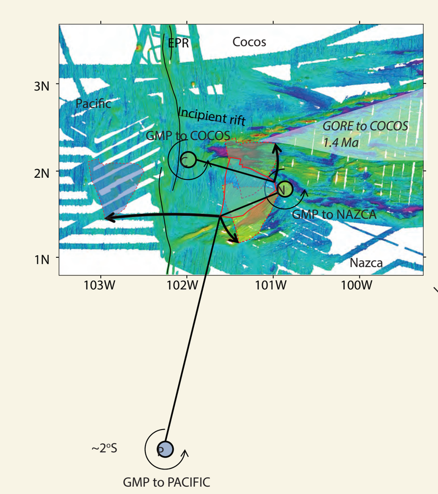


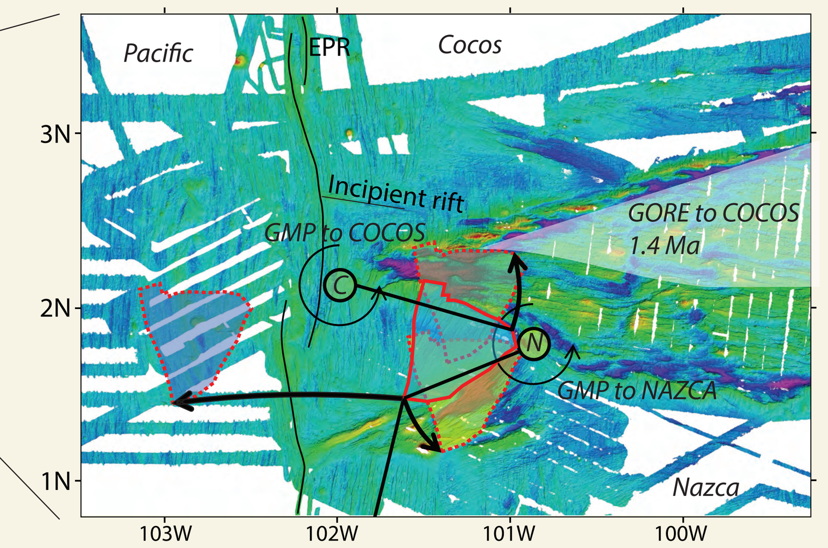
Dredge Locations



Geochemical data suggest samples from Dietz volcanic ridge and seamount are more enriched than most samples from the C-N rift, the nearby EPR, and the Incipient rift. Data from Wernette et al. Fall AGU 2019; Hannah et al. Fall AGU 2003; PetDB (https://www.earthchem.org/petdb)

5. Reconstruction



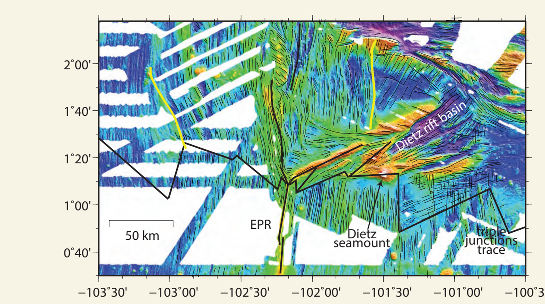


Reconstruction of the Galapagos microplate (GMP) at the time of its formation ~1.4 Ma. Solid red line outlines the GMP at 1.4 Ma; transparent blue (far left panel) and area outlined by red dashed line to the west: GMP relative to Pacific plate; transparent yellow and area outlined by red dashed line to the south: GMP relative to Nazca; transparent green and area outlined by dashed red line to the north: GMP relative to Cocos.

Black arrows show the ~26° rotation relative to the respective plates about their respective reconstruction poles (dots with arrows showing sense of rotation). Although these poles are only reconstruction poles they do approximate somewhat the general motion.

The GMP reconstructions are well constrained by the 26° clockwise rotation of the microplate's abyssal hills, the fit of its northern boundary to the northern Cocos gore and of its western boundary with disruptions in the Pacific abyssal hill fabric (see panel to the right); the fit of GMP's southern and eastern boundary to the Nazca plate is less well constrained and calculated indirectly from the fit to the Cocos and the Pacific plate.

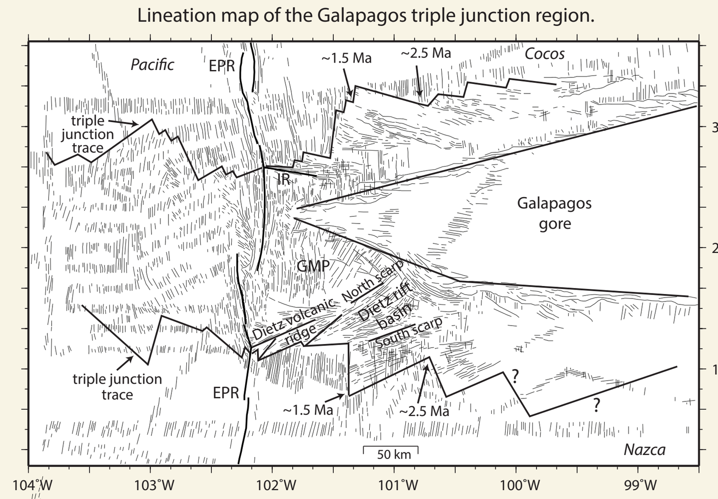
Note how close two of the reconstruction poles lie near the microplate's boundaries; this would lend support to the hypothesis that the rotation of GMP is driven mostly by its edges by the motion of the Cocos and the Nazca plates, similar to the Easter microplate by Nazca and Pacific (Schouten et al., 1993).



Yellow lines: possible western boundary of the GMP at 1.4 Ma.

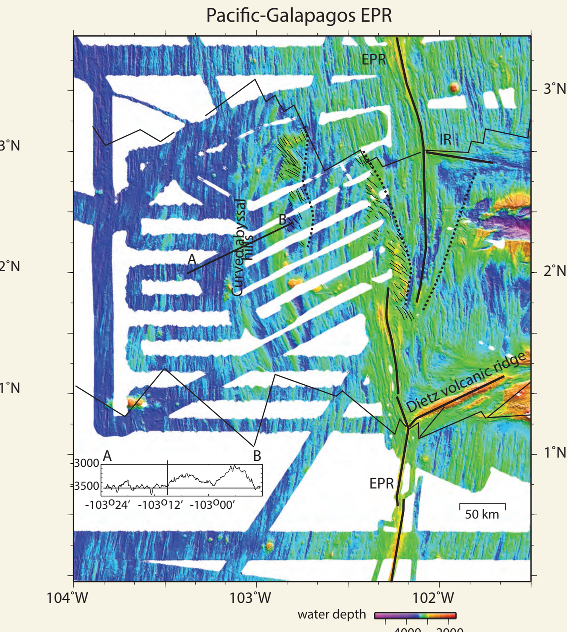
6. Response to the magmatic anomaly

Lineation map of the Galapagos triple junction region.



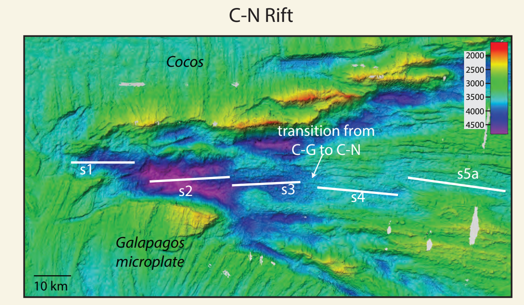
Lineations identified from the bathymetry. Black lines: trace of the triple junctions, edges of the Galapagos gore and EPR. Times are marked along the triple junction trace. Extension is fixed on the South scarp ~1.4 Ma.

Pacific-Galapagos EPR



Black dashed lines: pseudofaults of two southward propagation events of the EPR initiating at the northern triple junction. Black lines: rotated highs between the overlapping limbs of the EPR. Thin black lines: trace of the triple junctions. Profile marked A-B shows a transition in the character of the abyssal hills midway along the profile. At ~1.5 Ma the abyssal hills become broader and shallower between the two triple junctions.

C-N Rift



White lines mark C-N rift segments. When the spreading regime changed from C-N to C-G, the rift axis changed orientation and opening rate slowed.

7. Conclusions

1) The Galapagos microplate originated by breaks along three pre-existing zones of structural weakness in the Nazca lithosphere.

--The southern boundary formed along a transient rift induced by CN propagation. Extensive eruptions support the idea that a magmatic anomaly initiated the break.

--The eastern boundary formed along the pre-existing abyssal hill fabric on the Nazca plate.

--The northern boundary formed along the deep faults of the Galapagos gore.

2) The magmatic anomaly was responsible for Dietz Seamount, a series of northwestward jumps of the southern boundary and, presently, for Dietz Volcanic Ridge, which is anomalously high. Gravity data indicate thicker crust in this region.

3) The chemistry of the very fresh volcanic glasses dredged from Dietz Seamount indicate that the lavas are enriched.

4) The arrival of the magmatic anomaly coincided with a change in the character of the abyssal hills flanking the EPR.

5) The rifted basins at the western tip of the Galapagos gore changed orientation and their opening rates decreased.

Acknowledgments:
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