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A recurrent question when interpreting lateral variations of velocity in the lithosphere is to know if their origin is thermal or mineralogical. On a large scale, the 10-15% velocity variations deduced from tomography is explained by changes in temperature and by partial melting. For Jordan (1978), Archean cratons are chemically distinct from the oceanic mantle but mineralogy only explains 1-2% velocity changes. For stable regions, one way P-vertical travel times are 1.5s faster (6%) through a craton than through a Paleozoic platform. We present several examples of tomographic studies - from teleseismics and from surface waves - which are difficult to reconcile with a thermal interpretation, as if short wavelength and long wavelength tomography results were contradictory. In many sites, velocity changes laterally within 20-50km on the entire thickness of the lithosphere. Some of these sutures have been inactive for a very long duration. In the Western Urals, a contrast in velocity has been preserved over more than 1.5 Ga. From a refraction survey recording 2 distant events, Masson et al. (1998) report abrupt local velocity variations beneath the moho of the Iapetus suture in Ireland. Any temperature effect should be smoothed and should not be preserved over several hundred million years. At a small scale, the subcrustal continental lithosphere appears as an assemblage of 50-200 km wide blocks with 2-3% different velocity and sharp subvertical or tilted limits. Subcrustal anisotropy is difficult to measure; but anisotropy is preserved with age and introduces local asymmetry (Babuska et al., 1993). The widespread observation of sharp and permanent lateral velocity gradients within stable continents implies chemical heterogeneity. At a larger scale, the seismic characteristics of subcontinental lithosphere can be related to the age of the overlying continents. The oldest > 3 Ga cratons have 200-250 km lithospheric roots with very high velocity. Peridotite xenoliths from this lithosphere have compositions different from those from younger lithosphere, being composed of unusually Fo-rich olivine and abundant orthopyroxene. The low density and high viscosity of this assemblage results in a buoyant, rigid lithosphere that has survived since the formation of continents. The origin of this lithosphere is related to high temperatures in the Archean mantle and efficient processes that extracted the low-density residual phases produced during high-degree mantle melting from denser normal mantle minerals. The secular variation in the seismic and chemical character of the continental lithosphere is thus related to the progressive cooling of the mantle.

T42A-0922 1330h POSTER

Three-Dimensional Structure of the Upper Mantle Beneath Fennoscandia (Baltic Shield) by High-Resolution Teleseismic Tomography

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SvekalapkoSeismic Tomography Wkg Grp

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We present new tomographic images of the upper mantle beneath the Baltic Shield down to 400 km. The input dataset is composed of 5127 handpicked first P arrivals that were recorded at 146 evenly spaced recorders covering an area of 1000 km by 800 km. A three-dimensional crustal model was constructed based on controlled-source seismology experiments following the principle of simplicity in order to determine the traveltime effects produced by the crust. The model obtained is in good agreement with previously published crustal models with a maximum Moho depth of 64 km and an anomalous high velocity lower crust. The associated teleseismic traveltime differences range between +0.3 s and -0.4 s for P-waves when compared with the standard reference crustal model of IASP91. The crustal-corrected teleseismic traveltimes were then inverted for upper mantle structure maintaining the crust fixed. The results show P-wave velocity variations between -4 % to +4 % relative to IASP91. Anomalies associated with the NW-SE Proterozoic suture in the north (Karelian-Svecofennian) extend down to the lower lithosphere at 150 km depth. Another even more remarkable feature in the south is a SW-NE trending boundary that separates a fast velocity zone in the center of the study area from a negative anomaly area in the Ladoga region. At present, the tectonic origin and significance of this deep seated, rather strong lateral velocity variation beneath the craton is not yet known. According to the tomographic images, however, no seismic asthenosphere in P-wave velocities exists beneath the central part of the study region.

T42A-0923 1330h POSTER

Insights Into Baikal Rift Lithospheric Structures From Joint Gravity and Tomography Study

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The causes and the localisation of extension in the Baikal rift area still remain a source of debate. The lithospheric structures beneath this region are not well defined, though they could give strong constrains on the geodynamical scheme of this area. In this study, we propose a multidisciplinary method, based on joint inversion of gravity and teleseismic data, to improve our understanding of this continental break-up. This method, tested on numerous synthetic tests, is able to discriminate between several models, and is a way to reduce the problems of non-unicity and smearing effects in both gravity and seismological inversions.

Our work is based on previously teleseismic studies and gridded gravity data. The first interpretation of teleseismic data seems to enlight an asthenospheric upwards just beneath the rift, whereas the results of various studies are not so conclusive about such a feature. We correct the gravity data from effects of outside structures and sediments, which are important in the central part of the rift. We first reprocess teleseismic and gravity inversion seperatly, with different initial models. Second, the combination of both data sets in a joint inversion is proceeded with an initial model deduced from geological and geophysical informations. We present here the preliminary results.

T42A-0924 1330h POSTER

Solubility of Water in Lower Mantle Minerals

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Water in the Earth's interior plays key roles in geodynamics since the presence of water dramatically influences the physical properties (ca. viscosity and melting temperature) of the mantle. It is well accepted that dense hydrous magnesium silicate (DHMS) phases, hydrous wadsleyite and hydrous ringwoodite are candidates for water reservoirs in the mantle. However, the possible sites for water in lower mantle minerals have been controversial. The lower mantle is believed to consist predominantly of Mg-perovskite with 20% magnesiowustite and Ca-perovskite by volume. To elucidate the water contents in these phases leads to an understanding the most promising strage site of hydrogen in lower mantle.

We measured the abundance of hydrogen in Mg-perovskite, magnesiowustite, and Ca-perovskite synthesized in the natural peridotitic composition. The synthesis was made at a pressure of 25.5 GPa and at temperature of 1600-1650 C* in a multi-anvil apparatus. Hydrogen measurements in three phases were performed with SIMS. SIMS measurements showed that both Mg-perovskite and magnesiowustite contain about 0.2 wt% H2O, and Ca=perovskite contains about 0.4 wt% H2O. We have also confirmed the OH absorption bands in Mg-perovskite and magnesiowustite by using FT-IR. Solubility of water estimated from IR measurements were consistent with that of SIMS analyses. These amounts are much higher than the previous estimates for the same minerals but with simple end-member compositions. It can be deduces that chemical impurities such as Al or Fe would promote the solubility of water in these phases dramatically.

Our results suggest that the lower mantle can potentially store considerable amounts of water. When the capacity of water in three phases is integrated over the mass of the lower mantle, the total mass of water is about 5 times that of seawater. This amount is comparable to that in the transition zone. The high solubility of water in representative lower mantle minerals also has implications for the rheological properties of the lower mantle.

T42A-0925 1330h POSTER

In-Situ X-ray Measurements of the Phase Relation of Antigorite

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The stability of antigorite (serpentine) in subducting lithosperic mantle is of great geological significance, for example, in relation to origins of arc magmatism (Ulmer & Trommsdorff, 1995) and of intra-slab double seismic zone (Seno & Yamanaka, 1996). In the model MSH system, one important invariant point (IP hereafter) defined as coexistence of antigorite, phase A, enstatite, forsterite and water occurs at P = 4-6 GPa, T = 550-600°C. From this IP, 5 univariant reaction curves radiate. The phase boundary Fo + H_2O (low P) = phA + En (high P) originates from this IP toward higher P-T side. For subducting slab, higher temperature side of this IP is occupied by dry region (no hydrous mineral is stable), whereas lower temperature side is hydrous region (phase A is stable). The fate of hydrated slab peridotite in deeper mantle depends on this IP. If the geotherm passes to lower T side of that IP, water would be transported into mantle transition zone. Therefore, the accurate position of this IP should be determined. However, the previous experimental results on antigorite stability (Ulmer & Trommsdorff, 1995; Wunder & Schreyer, 1997; Bose & Navrotsky, 1998) show large discrepancies in pressure. The discrepancy reaches to 2 GPa on the position of the IP. This may be due to the difficulty in pressure calibration at low temperature (below 600°C) and/or the differences in the compositions of antigorite as starting materials. Solving these problems, we operated high P-T in-situ experiments at SPring-8 (Japan) to determine the accurate phase relation of antigorite, particularly the location of the IP. Pressure-temperature conditions are 4.0-9.0 GPa and 520-800°C. The starting materials were both synthesized Mg-end and natural (MgO: 43.56, Al_2O_3: 1.86, FeO: 1.65, Fe_2O_3: 1.52, SiO_2: 43.56 wt.%) antigorites. Equation of state of NaCl (Decker, 1971) was used as a pressure scale. First, we determined the breakdown curve of antigorite. The results of two kinds of antigorite starting composition showed no difference. Antigorites were stable up to 6.5 GPa at 520°C and decomposed at 6.5 GPa, 550°C and at 4.0 GPa, 600°C. Second, the phase boundary Fo + H_2O = phA + En were bracketed. This reaction curve is almost linear and has a compositional dependence. This boundary in Mg-end composition locates at lower pressure than in natural composition and the Clapeyron slope in Mg-end composition of 10.52 MPa/K is steeper than that in natural composition. The intersection of antigorite breakdown curve with the reaction Fo + H_2O = phA + En defines the IP. The IP is concluded to be located at 5.5 GPa, 550°C in Mg-end composition and 6.8 GPa, 530°C in natural composition.

T42B MC: Hall D Thursday 1330h

Structure and Evolution of the Galapagos Volcanic Province II *(joint with OS, S, V)*

Presiding: **J P Canales,** Woods Hole Oceanographic Institution; **K S Harpp,** Colgate University

T42B-0926 1330h POSTER

The Influence of the Galapagos Hotspot on the Development of the Cocos-Nazca Spreading Center

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The Cocos-Nazca spreading center (CNS) has a complicated plate tectonic history. New magnetic data allow a detailed reconstruction. After the break-up of the Farallon plate at 22.7 Ma the newly formed CNS had a SE-NW strike direction and a high spreading rate. At 19.5 Ma, the spreading axis jumped south. The jump was coincident with a change of the strike direction to almost E-W and a significant decrease of the spreading rate. Another jump of the spreading axis to the south combined with a slight change in the strike direction occurred at 14.5 Ma. In younger times, multiple small scale jumps to the south are being observed. We interpret this pattern of jumps as the influence of the Galapagos hotspot: The plate motion vectors of the Cocos and Nazca plates result in a constant movement of the CNS to the north as long as spreading is symmetric. The repeated jumps to the south keep the spreading axis in the vicinity of the Galapagos hotspot. Similar behaviour of spreading axes has been observed around hotspots in the South Atlantic and Indian oceans.

T42B-0927 1330h POSTER

The Cocos and Carnegie Ridges: A Record of Long-term Galapagos Plume-Ridge Interaction

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The present-day Galapagos Archipelago exhibits an astonishingly wide variety of geochemical compositions, from enriched, hotspot-like signatures in the west and south to MORB-like lavas in the central and northern regions. The distinctive spatial zonation has been attributed to a heterogeneous plume and its extensive interaction with the asthenosphere. One of the controversial questions about the Galapagos system is whether the geochemical zonation in the present-day archipelago is a long-term phenomenon due to inherent plume heterogeneity or only the recent result of short-lived mantle contamination.

The aseismic Cocos and Carnegie Ridges record the last 20 Ma of plume activity as the Cocos and Nazca plates, respectively, have moved over the hotspot. During the 1999 PAGANINI expedition, we collected over 80 dredge samples from the ridges to explore the temporal variations of the Galapagos plume. Preliminary results suggested that lavas dredged off the west coast of Central America preserve the geochemical zonation observed in the Galapagos Archipelago today. Trace element determinations from dredge sites along the Cocos and Carnegie Ridges indicate, however, that the situation is (not surprisingly) more complex. Instead, the geochemical variations observed along the ridges may be controlled predominantly by the relative positions of the Galapagos plume and the Galapagos Spreading Center (GSC). The GSC has been migrating to the NE relative to the hotspot. For the oldest portions of the Cocos Ridge, the plume was located beneath the Nazca plate and did not interact with the GSC. Lavas produced during this time therefore represent pristine plume, with compositions more enriched than those of the present-day Galapagos; these are observed NE of Cocos Island. As the ridge migrates closer to the hotspot, plume-mid-ocean ridge interaction intensifies, resulting in the dilution of hotspot lavas by entrained, depleted asthenosphere. Consistently, younger lavas along the Cocos become increasingly depleted toward to the SW, as the GSC approaches and passes over the hotspot center. The GSC remains close enough to the plume in the current configuration that most of the lavas erupted in the Archipelago include a contribution from the upper mantle.

Fundamentally, while Galapagos plume heterogeneities may be long-lived, the hotspots variable interaction with the upper mantle may be the dominant factor in controlling regional geochemical patterns. The compositions of the lavas provide a new perspective on plume-ridge movements over the past 20 Ma.

T42B-0928 1330h POSTER

Hf Isotopic Variations in Volcanic Rocks From the Caribbean Large Igneous Province and Cocos Ridge (Central East Pacific)

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The Caribbean Large Igneous Province (CLIP) consists of the Caribbean oceanic plateau and associated magmatic terranes along the Pacific coast of central America and western Colombia and is interpreted to mark the initiation of the Galapagos hotspot 75-95 Ma ago. New 176Hf/177Hf data show: 1) a depleted end-member (176Hf/177Hf$_{in}$= 0.28324) represented by lavas from DSDP site 152 (~75 Ma) in the central Caribbean, lavas from the young Osa Peninsula (~62 Ma) and basalts from the Cocos and Carnegie Ridges portions of the Miocene Galapagos hotspot track, and 2) an enriched end-member (176Hf/177Hf$_{in}$ = 0.28298) represented by lavas from DSDP site 151 and by the younger Quepos terrane of Costa Rica (~59 Ma). Our results support previous interpretations, based on trace elements and Sr, Nd and Pb isotopic ratios (Hauff et al., 2000) that infer mixing between the regular depleted MORB mantle source, or alternatively a depleted plume component derived from recycled oceanic crust, and an enriched Galapagos plume source. Lavas from the Caribbean Island of Curacao and western Colombia have elevated epsilon Hf for a given epsilon Nd relative to the Nd-Hf mantle array, suggesting influence of a pelagic sediment component. Similar Nd-Hf isotope compositions are observed in lavas from the southern Galapagos island of Floreana (Blichert-Toft and White, 2001). High epsilon Hf relative to the mantle array is also observed in a lava from the Malpelo Ridge, part of the Galapagos hotspot track, ~200 km off the coast of Panama. In addition to the regular depleted MORB and enriched plume source, a crustal source component is required to account for the spatial and temporal isotopic variations in the magmatic products of the Galapagos plume.

F. Hauff, K. Hoernle, G. Tilton, D.W. Graham and A.C. Kerr (2000) EPSL 174, p.247-263

J. Blichert-Toft and W.M. White (2001) G-cubed, in press

T42B-0929 1330h POSTER

Seismic Structure of Malpelo and Cocos Volcanic Ridges and Implications for Hotspot - Mid-Oceanic Ridge Interaction

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In this work we investigate the seismic structure of the Cocos and Malpelo Volcanic Ridges along three wide-angle profiles acquired during the PAGANINI-1999 experiment. The 2D velocity field and Moho geometry have been obtained using a joint refraction/reflection traveltime inversion method. Uncertainty and robustness of the results have been estimated by performing a Monte Carlo-type analysis. The results show that maximum crustal thickness along the three profiles range between 16 km (Southern Cocos) and 19 km (Northern Cocos and Malpelo). Oceanic Layer 2 thickness is quite uniform regardless of the crustal thickness variations, and thus crustal thickening is mainly accomodated in Layer 3. Seismic velocities of Layer 3 are similar in all profiles. We found several low velocity anomalies in the long-wavelength structure (up to ~6.8 km/s), which lead to an overall anticorrelation between crustal thickness and bulk lower crustal velocities. The Moho geometry of the Southern Cocos profile is highly asymmetric. The steep transition into a normal oceanic crust in the easternmost segment of this profile can be associated with the presence of the Inca Fracture Zone at the Cocos-Nazca Spreading Center. The rapid thinning of the northernmost segment of Malpelo Ridge can be most likely related with a rifting process that splitted the ancient Malpelo Ridge into Regina and Malpelo Ridges after the initiation of the movement along the Panam Fracture Zone.

T42B-0930 1330h POSTER

Plume-Affected Geochemical Trends in Along-Axis Samples from the Galápagos Spreading Center, 90°30W to 98°W

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Chemical data on samples from 91 stations with an average along-axis spacing of ~10 km allow us to investigate the nature and effect of plume-derived mantle source components on the Galápagos Spreading Center (GSC) between 90°30W and 98°W. Forty-five glasses, distributed along axis, have been analyzed for dissolved H_2O and CO_2 by FTIR and for helium isotopes. These new data, plus a smaller set of new trace element analyses, complement major element data on more than 300 glasses. The propagating rift tip at 95.5°W marks a distinct boundary in lava geochemistry and defines the western limit of plume-affected mantle based on variations of K/Ti, Nb/Zr and H_2O contents. Approaching the hotspot from the west, K/Ti, Nb/Zr and H_2O gradually increase between 95.5° and 92.7°W, along with increasing crustal thickness [Ito et al., this meeting]. East of 92.7°W, enriched basalts (E-MORB) become dominant with K/Ti > 0.15, Nb/Zr > 0.09, and H_2O > 0.5 wt %. The boundary at 92.7°W coincides with an increase in $^3He/^4He$ and Na8, as well as decreases in Ca8/Al8 and the depth to subaxial magma chambers [Blacic et al., this meeting]. Incompatible element- (including H_2O -) enriched E-MORB also have higher Al_2O_3 and Na_2O, and lower FeO*, SiO_2, and CaO/Al_2O_3 relative to N-MORB at similar values of MgO. These characteristics are consistent with lower mean extents of partial melting relative to N-MORB. Preliminary modeling indicates that a combination of source incompatible element enrichment and lower degrees of melting best explains the element abundances of GSC E-MORB. The association of E-MORB with enhanced crustal thickness requires that total melt production be systematically decoupled from mean extents of melting. This result can be reconciled by a model involving lower mean melting of an expanded mantle source volume in response to solidus depression of hydrous, plume-affected mantle.

T42B-0931 1330h POSTER

Variations in Axial Magma Chamber Depth and Layer 2A Thickness Along the Hotspot-Influenced Galápagos Spreading Center, 91.3°-95.2°W

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As part of a study of magma storage and crustal accretion along the Galápagos Spreading Center, multichannel seismic (MCS) reflection data were obtained on board the R/V Maurice Ewing during the 2000 G PRIME cruise. We obtained MCS data along ~86%

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of the length of ridge axis between 91.3° and 95.2°W including 16 cross-axis lines. In processing the MCS data we used the nearest 3-4 km of the streamer to produce 40-60 fold CMP stacks. The stacked data reveal two prominent sub-seafloor interfaces. We interpret the shallowest interface to mark the base of crustal layer 2A and the deeper interface to be the top of the axial magma lens (AMC). Far from the Galápagos hotspot (95.2°-92.7°W), where axial morphology is "transitional" between an axial high and an axial valley, the layer 2A seismic event along the ridge axis is 0.3-0.5 s two-way travel time (TWTT) below the seafloor. The base of layer 2A appears faulted in some locations and vanishes over a few short intervals. The AMC reflector is discontinuous over this region and shows significant variations in TWTT below the seafloor (1.0-1.7 s). The presence of an axial high and disappearance of an axial trough near 92.6°W coincides with the shoaling of both the layer 2A event and the AMC. From 92.7° to 92.5°W layer 2A thins by ∼0.1 s TWTT. The AMC shoals from ∼1.1 s to ∼0.65 s TWTT below the seafloor over a much shorter distance (∼20 km) near 92.6°W. Near the Galápagos hotspot (east of 92.5°W) both the layer 2A event and AMC appear smoother and more continuous along the ridge axis. Layer 2A appears ∼0.15-0.35 s TWTT below the seafloor and AMC appears ∼0.55-0.9 s TWTT below the seafloor. Where an overlap basin is crossed between 91.7° and 91.6°W layer 2A thins by ∼0.1 s TWTT and AMC deepens by ∼0.5 s TWTT.

Far from the Galápagos hotspot (95.2°-92.7°W), axial morphology is transitional, the crust is 6-7 km thick and the AMC depth is similar to that found along other ridges with intermediate spreading rates, such as the Juan de Fuca ridge and the Lau back-arc-basin ridge. Near the hotspot (east of 92.5°W) the ridge is on an axial high, the crust is thicker (7-8 km), and the AMC is unusually shallow compared to other ridges with intermediate spreading rate. Here AMC depths are comparable to those found for AMC along the fast-spreading East Pacific Rise. The rapid shoaling of the AMC appears to be consistent with the hypothesis of a threshold magma supply about which small changes in magma supply lead to large changes in axial thermal structure and AMC depth (Phipps Morgan and Chen, 1993). In addition, we see a positive correlation between the depth of the AMC and the thickness of layer 2A. The ratios of layer 2A thickness to AMC depth observed on cross-axis profiles at the ridge axis support models that invoke a balance between overburden pressure on the AMC and the weight of a column of magma feeding surface eruptions (Buck et al., 1997).

T42B-0932 1330h POSTER

Crustal thickness variations along the Galapagos Spreading Center west of the Galapagos hotspot

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Wide-angle seismic refraction and multi-channel seismic (MCS) reflection data reveal crustal thickness variations along the Galapagos Spreading Center (GSC) 98°-91.5°W. Travel-time and amplitude modeling of wide-angle refraction data constrain the seismic velocity structure and thickness of mature crust along three ridge-parallel profiles centered at 96.8°W, 94.25°W, and 92.2°W. In addition, MCS data along ridge-parallel, off-axis profiles image reflections from the base of the crust (Moho) west of 95.5°W. Where MCS and refraction data coincide, zero-offset arrival times of Moho reflections agree closely between the two data sets. To compute crustal thickness from the Moho reflections, we interpolate velocity-depth profiles between the refraction sites using cubic splines. We observe the thinnest crust (5.6 km) along the GSC near 96.8°W. To the east, the crust thickens gradually toward the Galapagos hotspot (along-axis gradient ∼0.01 km/km) to 5.9 km near 94.25°W. Near the 95.5°W-propagating rift tip we do not resolve a local thinning of the crust that would otherwise be attributed to a "propagator effect". East of 94.25°W the GSC crust thickens more rapidly (along-axis gradient ∼0.05 km/km), reaching a thickness of 8 km at our closest approach to the hotspot near 91.5°W.

Constraints on along-axis crustal thickness variations are valuable in understanding processes of mantle melting as well as factors leading to changes in ridge morphology. The rapid thickening of the GSC crust east of ∼94°W suggests that the hottest and/or most rapidly upwelling mantle is confined to a distance of ∼400 km from the center of the Galapagos hotspot. West of ∼94°W the hotspot effect on crustal thickness is minimal though gravity and bathymetry anomalies extend 200-400 km further west [Canales et al. this meeting]. A prominent axial valley is sustained west of ∼95°W where crustal thickness is <5.9 km. East of ∼94°W, where crustal thickness is >6 km, the GSC shows a broad, EPR-like axial high even though spreading rates are only slightly higher than to the west. It thus appears that the loss of an axial valley and development of an axial high is associated with a small increase in crustal thickness. This result supports the hypothesis that axial topography depends on lithospheric strength, which is a strong, nonlinear function of the amount of heat supplied by magma intrusion [Phipps Morgan and Chen, 1993].

T42B-0933 1330h POSTER

Axial seismic crustal structure of the Galápagos Spreading Center at 92°W and 94.25°W

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We use wide-angle seismic refraction data acquired during the G-PRIME experiment to image the sub-axial seismic crustal structure of the Galapagos Spreading Center (GSC) at two morphologically distinct ridge segments spreading at similar intermediate rates (51-54 mm/yr full rate). At 92°W the GSC is shallow (1700 m) and its morphology is characterized by a 30-km-wide axial high, elevated 700 m from the surrounding seafloor. At this location, travel time and amplitude modeling of the seismic data reveal a 9-km-wide zone of low seismic velocities between 0.5 and 5 km beneath the axial summit. Between 2 and 3 km sub-seafloor depths, axial seismic velocities are 0.6 km lower than velocities in ∼0.6-My-old crust north of the spreading axis. This low velocity anomaly lies immediately below a bright reflector imaged with multichannel seismic (MCS) data, interpreted as the top of an axial magma chamber (AMC) [*Blacic et al.*, this meeting]. Seismic arrivals from rays crossing the ridge axis at mid-crustal levels have highly attenuated amplitudes, suggesting the presence of partial melt. However, the magnitude of the low velocity anomaly is only 25% of a comparable anomaly observed at the fast-spreading East Pacific Rise (EPR) at 9.5°N [*Dunn et al.*, JGR, 2000], where the relief of the axial high is only 400 m and the AMC is found at ∼1.6 km sub-seafloor depth. Therefore despite a more inflated axial morphology, the amount of melt within the mid-crust of the plume-influenced, intermediate spreading GSC is considerably less (as much as a few percent) than at the fast-spreading EPR. The uppermost 2 km of the crust displays a low velocity anomaly (<-0.4 km/s) 2-10 km off axis, suggesting thickening of the extrusive layer away from the axis. This anomaly is more pronounced in the southern flank of the ridge, where small, off-axis volcanic features are more abundant. This asymmetry is probably related to the nearby Wolf-Darwin volcanic lineament which extends between the GSC and the Galapagos platform. We will compare the axial crustal structure at 92°W with that at 94.25°W away from the influence of the Galapagos plume, where the ridge is deeper (2500 m) and characterized by rough topography without clear axial high or valley, and where MCS data suggest the presence of a deep AMC (∼2.5 km below seafloor) [*Blacic et al.*, this meeting]. Our results will provide important constraints on the influence of plume-related magma supply variations in crustal accretion processes at a constant spreading rate.

T42B-0934 1330h POSTER

Influence of the Galapagos hotspot on the crustal accretion along the Galapagos Spreading Center

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It is well established now that the crustal accretion at fast spreading ridges are controlled by the presence of a melt lens at shallow depth (1-2 km) beneath the sea floor. Such melt lens has not been observed at the slow spreading ridges, except recently at the Reykjanes Ridge, where various seafloor observations clearly indicate the influence of the Iceland hotspot. Both theoretical investigations and various observations suggest that intermediate ridges are most sensitive to other controlling parameters such as melt supply rate other than spreading rate. Galapagos Spreading Center is one of the sites, suitable for studying the influence of the nearby off-axis hotspot.

Seafloor mapping along the Galapagos Spreading Center indicated a transition in bathymetry from an axial high topography near the center (close to the Galapagos hotspot) to a rift valley toward the tip of the propagating ridge to the west. Recent seismic surveys have detected a magma lens beneath the ridge with an axial high and did not find an AMC reflector beneath the rift valley. These transitions in both axial topography and magma lens depth along this intermediate spreading ridge clearly reflect the influence of the Galapagos hotspot. Our crustal genesis ridge model has been applied to this intermediate spreading center. Model results that will be presented are consistent with the notion that these along-axis variations are primarily caused by increased magma supply rate from the influence of the nearby Galapagos hotspot.

T42B-0935 1330h POSTER

Galapagos Plume Ridge Interaction Part 1: Morphologic Variations Along the Eastern Galapagos Spreading Center. Results From the SO158 MEGAPRINT Expedition

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During the MEGAPRINT expedition (R/V Sonne Cruise SO158), we mapped and sampled the eastern Galapagos spreading center (GSC) between 85°and 92.5°W using the newly installed SIMRAD EM120 multibeam echosounder. The new maps reveal a wide range of axial morphologies, ranging through several axial valley types, some with pronounced graben structures, to both narrow and broad axial highs. The GSC shoals from 2700 meters at 86°W to as little as 1500 meters in the 89°- 90°W area, where it lies closest to the Galapagos platform. The eastern GSC encompasses the known range of morphologies for intermediate spreading ridges with frequent transitions presumably reflecting local variations in melt supply and eruption frequency. Periods in which spreading exceeds extrusive construction are characterized by axial valleys and, in one case by a rifted axial volcano at 87°W. The 91°W transform fault is marked by a 3500m deep pull-apart basin containing two small recently active volcanic cones. The western GSC between 90°and 92.5°W is characterized by two broad axial highs separated by axial lows (see also Sinton et al. 2000). The axial highs are connected with southeastward trending chains of seamounts and small ridges, sub-parallel to the larger Wolf Darwin lineament (WDL), commonly thought to reflect today's primary plume ridge connection. The junction of the WDL and the GSC is, however, an axial low suggesting that the maximum geochemical influence of the plume (e.g., Verma and Schilling 1982), may not correlate with the WDL. Seamounts in the region between the WDL and the 91°W transform are shallow and several display morphologic terraces. Dredge samples from several include rounded cobbles and nearshore sediment (beach deposits) suggesting that these seamounts may represent submerged ocean islands. It is yet not clear whether these are on-axis volcanoes or if they may have formed on older crust anologous to some of the seamounts along the Wolf Darwin Lineament.

J.M. Sinton, R.S. Detrick, B.J. Cushman, P. Canales and G. Ito (2000) EOS Vol. 81, No 48; F1095, AGU Fall Meeting

S.P. Verma and J.G. Schilling (1982) JGR 87, 10838-10856

T42B-0936 1330h POSTER

Galapagos Plume-Ridge Interaction Part 2: Variations in Seamount Morphology Around the Galapagos Platform

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A major objective of the MEGAPRINT expedition of R/V Sonne was to locate and sample seamounts between the Galapagos Platform and the nearby Galapagos Spreading Center (GSC) in order to document bathymetric and geochemical effects of plume-ridge interaction. Numerous previously undocumented seamounts were located and sampled. Their distribution and morphology varies systematically around the northern and eastern edges of the platform. Four distinct provinces are recognized: The Wolf-Darwin Triangle is bounded by the Wolf-Darwin lineament in the west, the GSC in the north and the 91°W transform in the east. It is characterized by large individual volcanic cones, many of which have summit craters, which appear to be aligned along three NW trending lineaments (including the Wolf-Darwin lineament). These trends are sub-parallel, perhaps suggesting that they have formed at slightly different times in an evolving stress regime. Several of the larger seamounts have prominent terraces at approximately 1500 meters water depth, suggesting that they have been islands at some time. This interpretation is supported by recoveries of highly vesicular lavas, occasional rounded cobbles and a variety of reworked clastic volcanogenic sediments from their upper slopes. Between the larger seamounts, numerous small volcanic cones and circular, flat topped structures interpreted as monogenetic pillow mounds are common on the seafloor. Their relationships to the NW trends defined by the larger structures is unclear. The Northeast Province is a region of large single cones lying close to the NE margin of the Galapagos Platform. Several of these have flat tops at the approximate depth of the adjacent platform as well as distinct terraces at greater depths. Farther from the platform, a number of smaller seamounts occur. Several of these lie along low ridges that extend NE from the larger volcanoes and are characterized by numerous small (monogenetic?) volcanoes similar to those of the Wolf-Darwin triangle. As with the NW lineaments, these trends are not exactly parallel. The Northern Province links the southern end of the Wolf-Darwin lineament to the Northeast province and partly overlaps both. Extending across the entire northern margin of the platform, it contains a number of elongate seamounts covered by numerous small volcanic cones suggesting that they have been built by dispersed, rather than centrally focused, magmatism. These structures have a NW alignment in the west becoming EW farther east. This province is also characterized by the common occurrence of highly plagioclase-phyric basaltic lavas. The Eastern Province links the Galapagos Platform to Carnegie Ridge. It is characterized by an unusual group of mid-sized seamounts that appear to be of volcanic origin, but are elongate EW suggesting control by axis-parallel seafloor structures. Dredging recovered primarily layered, reworked clastic volcanogenic sediments suggesting that they were once emergent (or at least in shallow water). Advanced alteration and thick (up to 3 cm) manganese crusts indicate that these volcanoes are inactive and represent the oldest of the four seamount provinces.

T42B-0937 1330h POSTER

RV SONNE SO144-3 Cruise: Insights in the Temporal-Spatial and Magmatic Evolution of the Galapagos Plume and -Archipelago

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The major objective of the cruise SO144-3 was systematic rock sampling of the aseismic Cocos-, Carnegie-, Malpelo-, and Coiba Ridges and adjacent seamounts in the area between Galapagos and Central- and South America. Beach cobbles, highly vesicular volcanic rocks, and low sulfur contents of fresh glasses dredged at these volcanoes, being believed by most authors to represent tracks of the Galapagos hotspot, show that ocean islands existed continuously above the Galapagos hotspot for at least the past 15 m.y.. This significantly extends the time period over which the unique endemic Galapagos fauna could have evolved. Sr-Nd-Pb isotopic compositions confirm that the structures sampled during this cruise formed from and above the Galapagos hotspot. The continuous isotopic zonation of the Cocos Ridge and adjacent seamounts matches exactly those of the recent Galapagos archipelago and suggests a complex spatial zonation of the Galapagos plume for at least the last 15 m.y.. This has important implications for the flow regime within mantle plumes and possibly for spatial zonation within the Galapagos plume source at the core/mantle boundary. Furthermore the Sr-Nd-Pb isotopic compositions of Carnegie- and Malpelo Ridges reflect a complex interplay between the Galapagos hotspot and the Galapagos spreading center throughout the past 15 m.y..

T42B-0938 1330h POSTER

The Leading Edge of the Galapagos Hotspot: Geochemistry and Geochronology of Submarine Glasses Coupled to New Sidescan Sonar Imagery

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Fernandina, the western-most volcano in the Galapagos archipelago, is at the leading edge of the hotspot with respect to plate motion. Recent mapping of the ocean floor west of Fernandina (on R/V *Revelle*, using the HMRG towed sidescan sonar MR1, and Simrad EM120 multibeam) provides a dramatic new view of the volcanic constructional processes that have created the islands. The western flank of the volcano is characterized by the prominent Northwest, West, and Southwest rift zones, which are constructed of hummocky pillow lavas. Older lava flow terrain is distinguished by weaker acoustic return, whereas extensive younger flows are characterized by strong backscatter patterns with distinctive flow-like margins. MR1 sidescan sonar mapping provides an important new geologic and stratigraphic context for understanding the submarine Galapagos platform, particularly from a geochemical perspective. Fernandina lavas have high $^3He/^4He$ ratios, up to 29 times atmospheric, and solar-like neon isotopic compositions, characteristics which suggest they are derived from the deep mantle. The high $^3He/^4He$ ratios, and rapid eruption rates at Fernandina also indicate that it lies directly above the center of the Galapagos hotspot. In order to place these geochemical data into a chronological framework, we have determined ages for Fernandina submarine glasses using the Th-U-He crushing/melting disequilibrium method. Preliminary Th-U-He ages (from the 2000 R/V *Melville* AHA-Nemo expedition), combined with the new MR1 sonar mapping, shows that the rift zones are characterized by extremely young ages (0 to 30 Ka) while older submarine lava flows with lower acoustic backscatter have significantly older ages (∼ 100 Ka). The geochronological data, and the geological context from the side-scan sonar, provide new evidence for volcano growth rates in oceanic hotspot provinces, and will be used to determine the growth rate of the Galapagos platform.

T42B-0939 1330h POSTER

Crustal Thickness Variations and Internal Structure of the Galpagos Archipelago

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We present the results of a marine refraction profile across the Galpagos platform that allow us to quantify the magma flux of the Galpagos hotspot and to distinguish among the volcanic processes that are building the islands and the supporting platform (volcanic eruptions and/or intrusions of lava within or at the base of the crust). The ∼250-km-long refraction line extends southwest from the center of the plateau, through the western area of young volcanism, and onto the oceanic crust beyond the edge of the Galpagos platform. The refraction line was shot using the 8000+ cu. in. airgun array of the R.V. Maurice Ewing and the data were recorded on two broadband three-component land seismometers and four ocean bottom hydrophones. The land stations are part of an ongoing broadband seismic experiment and during the airgun refaction profiling they recorded continuously at 80 sps. The ocean bottom hydrophones recording at 100 sps. The seismic refraction data are used to determine the thickness and internal velocity structure of the Galpagos platform and the adjacent oceanic crust. Arrival times of crustal refractions (Pg), mantle head waves (Pn), and Moho reflections (PmP) are analyzed. We first use a ray shooting method to forward model the Pg, PmP, and Pn arrivals. We then refine the fit to the Pg and PmP arrivals using a tomographic technique, which includes the Moho as a floating reflector. Crustal thickness varies from about 15 km beneath the Galpagos platform to 5.5-6 km on the oceanic crust beyond the edge of the platform. An abrupt decrease in crustal thickness and low velocities throughout the crust are found at the edge of the Galpagos platform. Lower crustal thickness is about 2/3 of the total crustal thickness both beneath the platform and beyond its edge. This implies that the ratio of extrusive to intrusive lavas is similar over the hotspot to that of oceanic crust.

T42B-0940 1330h POSTER

Transition Zone Structure beneath the Galpagos Archipelago from Receiver Function Analysis.

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In this study we determine if the Galpagos hotspot is associated with a deep mantle plume by investigating whether a thermal anomaly penetrates the upper mantle transition zone beneath the region of the archipelago. To do so we analyze P-to-S conversions from the 410 and 660 km upper mantle discontinuities. A thermal anomaly that passes through both of these discontinuities would result in thinning of the transition zone. We present teleseismic receiver functions from an ongoing broadband seismic experiment designed to define the first-order characteristics of the Galpagos hotspot. The 300 km by 200 km array consists of 10 broadband instruments on the islands spaced 50-70 km apart. The waveform data are of excellent quality, with good signal to noise and coherent waveforms across the array. Since P-to-S conversions from upper mantle discontinuities, P410s and P660s, are relatively poorly resolved in individual seismograms, we use stacking methods to more clearly resolve the mantle discontinuities. Normal moveout corrections are applied to project all the receive functions to a similar range. We will present results from differential P660s - P410s travel times, which will allow a preliminary interpretation of whether the transition zone is thinned due to the presence of a thermal anomaly at depths of 400-700 km.

T42B-0941 1330h POSTER

Widespread Uplift and Trap-door Faulting of Galapagos Volcanoes Observed with Satellite Radar Interferometry

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Satellite radar interferometer observations reveal widespread and continuous surface deformation on the western Galapagos Islands of Isabela and Fernandina during the period 1992-2001. All seven major volcanoes, save one, showed sigificant signs of activity although only two eruptions occurred during the observation period. These basaltic shield volcanoes are characterized by large summit calderas and a lack of rift zones. The radar images show caldera-centered uplift at four of the volcanoes: Wolf, Darwin, Alcedo, and Sierra Negra. The uplift rates are variable over time with a maximum of 90 cm/year at Sierra Negra volcano during 1997-1998. The total uplift of Sierra Negra volcano from 1992-2001 is about 3 m. Cerro Azul and Fernandina volcanoes erupted during the observation period and show evidence of inflation, co-eruptive deflation and shallow dike intrusion. No deformation is observed at Ecuador volcano; it is also the only volcano here that has not erupted during historical time. Although the distance between adjacent volcanoes on Fernandina and Isabela is only 30-40 km, this pattern of simultaneous uplift at many neighboring volcanoes is not typical of other ridge-hotspot systems. For example, in Iceland only one volcano is generally active at any given time.

The variable and varied deformation patterns seen in the high-resolution radar deformation maps show that several different subsurface magma flow patterns occur in the Galapagos. Increasing pressure in a single magma reservoir, as described by a point source (Mogi) model embedded in an elastic half-space, fairly accurately reflect observed inflation at Wolf, Darwin, Cerro Azul and Fernandina. The resulting source depth is 5 km at Cerro Azul but 2-3 km at the other volcanoes, or only 1-2 km below sea level. Fernandina, however, also shows a significant pattern from a shallow dike intrusion associated with a flank eruption in 1995. Sierra Negra exhibits both spatially and temporally variable uplift that can be modeled by a shallow inflating sill during 1992-1997 and 1998-1998. Inflation during 1997-98, however, was accompanied by trap-door faulting on a steeply dipping fracture system within the caldera. Field observations in 2001 support our earlier interpretation of the InSAR data that up to 1 m of faulting occurred. Repeated trapdoor faulting over geological time has formed an arcuate intra-caldera ridge within Sierra Negra and may have acted to relax stresses above the magma chamber, inhibiting summit eruptions.

T42B-0942 1330h POSTER

Consistent Melt Production From a Weak but Stable Galapagos Plume; Inferences From Fernandina Volcano

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Homogenous and evolved lavas from Fernandina Volcano, located at the leading edge of the Galapagos mantle plume, place constraints on plume thermal and material transport processes. Analysis of over 100 samples, selected for geographic, age, and petrographic variability, show that Fernandina, a 1476 m high, 32 by 24 km shield volcano with a highly active 850 km-deep caldera has erupted remarkably monotonous lavas over its subaerial history. These samples, including examples from all of the last 13 known historic eruptions (1958-1995), are notable for their accumulated plagioclase phenocrysts, nearly constant composition [La/Sm(N) of 1.4-1.7 and Pb207/204 of 15.52-15.57], and consistently evolved nature (MgO of 5.6-6.7% for fine-grained, non-cumulate samples). Inferred eruption temperatures cover a narrow range of about 1100 to 1140°C. Microprobe analysis of over 40 samples shows extensive evidence for active mixing in the shallow magmatic system, yet no evidence exists for shallow Fernandina melts with Mg# higher than 0.62 or temperatures hotter than about 1160-1180°C. Picritic lavas recently dredged from Fernandina's offshore NW rift are also of an evolved composition (D. Geist, pers. comm., 2001). They complement the subaerially-erupted plagioclase-rich lavas in indicating that active crystallization processes are occurring within a dynamic shallow magmatic system, with accumulation of unerupted olivine on the central magma chamber floor and plagioclase accumulation by flotation in the more evolved, erupted lavas. Caldera depth has fluctuated at least 800m in its history (implying dramatic changes in central magma chamber geometry); the thermal and chemical stability of this volcano is remarkable given the dynamism of its central, shallow magmatic system. As Fernandina's subaerial volume is about 170 km3, estimates of eruption rate (including those of Rowland, 1996) indicate that stability must have been maintained for at least 4-10 thousand years. During this time (within the timeframe of plume melt extraction and transportation estimates, e.g. Sims et al, 1999), melting in this demonstrably complex plume (Harpp and White, 2001) must have been relatively constant in terms of both source composition and source melting amount, thereby leading to consistent volcano melt supply. In addition, significant and consistent heat loss during lithosphere transport must have occurred to prevent primitive parental melts from entering the shallow Fernandina magmatic system, implying that deeper crustal storage and associated crystallization has been involved.

T42C MC: Hall D Thursday 1330h

Hotspot-Ridge Interactions III *(joint with OS, S, V)*

Presiding: **A Briais,** CNRS**; A H Barclay,** University of Washington

T42C-0943 1330h POSTER

Dynamical Models of Melt Migration and Crust Formation in a Plume Beneath a MOR

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The evolution of a mantle plume ascending through the upper mantle beneath a spreading mid-oceanic ridge and the generation and migration of melt is modelled for the case of temperature-dependent mantle viscosity. The interactions between melt generation and mantle convection are taken into account considering the effect of latent heat on temperature, the density reduction in the melting mantle due to depletion and melt retention of the matrix and the effect of transitions of Al-bearing phases on melt production and temperature. The migration of melt is modelled explicitly as porous flow in a deformable matrix, taking into account its buoyancy and dynamical forces from matrix-melt interaction.

The models, which differ in plume excess temperature, viscosity and threshold value for melt extraction/retention, result in a wide range of amounts of produced melt and crustal thickness for both normal crust and hotspot crust. The crustal thickness is quite sensitive to variations in threshold porosity; it seems that low porosity values are more likely to match observations at real oceanic crust. In the modelling of melt segregation, it is important to take into account the compressibility of the melt, because it controls the segregation velocity and thus also has influence on the porosity and crustal thickness.

T42C-0944 1330h POSTER

Experimental Constraints on the Tholeiitic-Alkalic Transition in Kerguelen Archipelago Basalts

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The Kerguelen Archipelago is the emergent part of the 19-20 km thick Northern Kerguelen Plateau (NKP), which is located on the nearly stationary Antarctic plate. The NKP began to form at ∼40 Ma, when the Southeast Indian Ridge and the Kerguelen mantle plume were coincident, and since 40 Ma, the ridge has moved to the north relative to the NKP. Lava compositions range from tholeiitic at Site 1140 (34 Ma) on the northern edge of the NKP, to transitional for the 26-29 Ma flood basalts on the archipelago, to alkaline for the youngest (24-25 Ma) volumetrically important lava sequences on the archipelago.

Primary variations in the alkalinity of basaltic magmas are considered to result from changes in the extents of partial melting or through the effects of clinopyroxene (cpx) fractionation. The presence of rounded, high-Al cpx phenocrysts in the mildly alkalic lavas of the 24 Ma Mont Crozier section on the Kerguelen Archipelago is suggestive of a high-pressure crystallization environment. We performed a series of equilibrium crystallization experiments on a powder of natural basalt from Mont Crozier (dry and slightly hydrous, 1.2 wt% H_2O) both at relatively high (0.4 to 1.4 GPa, piston cylinder) and low (<0.1 MPa, vacuum furnace) pressures to test the fractionation effect of cpx on alkalinity changes.

The observed geochemical trends for the experimental glasses show that hydrous, high-pressure (0.9 GPa), high-Al (8-10 wt% Al_2O_3) cpx-only fractionation produces nearly all of the required geochemical trends, especially Al-enrichment, observed in the Crozier lavas. Cpx-only fractionation, however, does not significantly increase alkalinity at these pressures. Major alkalinity changes must then reflect decreasing extents of melting, or deeper melting, within the Kerguelen mantle plume. The tholeiitic-alkalic transition on the Kerguelen Archipelago is related to progressive deepening of the lithosphere-asthenosphere limit (lowering melting) and of the crust-mantle interface (site of high-pressure cpx fractionation) with time as it moved from a ridge-centered position to an intraplate setting.

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Influence of the Reunion/Rodrigues Hotspot on the Structure of the Central Indian Ridge Near 19°S

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We present an analysis of multibeam bathymetry, backscatter imagery, and gravity data collected during the Magofond2 and Gimnaut cruises, and of satellite-derived gravity anomalies, on the flanks of the Central Indian Ridge (CIR). The bathymetry data reveal that the CIR axis near 19°S is about 1000 m shallower than normal, slow-spreading ridge axes. In this area, the ridge flanks display low-relief abyssal hills, up to 100 km long, which are similar to those observed on intermediate-spreading centers. The traces of the axial discontinuities in the ridge section between 18°30'S and 20°S are marked by series of low-relief bathymetric saddles, contrasting with the deep basins marking the ridge offsets farther south. Bathymetric highs are observed on the eastern flank of the ridge near the center of two segments at 19°10'S and 19°30'S. The Mantle Bouguer Anomaly map shows two small-amplitude, negative anomalies associated with the two bathymetric highs, superimposed on a broader regional negative anomaly, centered on the ridge segment at 19°30'S. The pattern is asymmetric, displaying more negative values on the west flank, towards a group of small off-axis, elongated ridges. The residual mantle Bouguer anomaly displays a similar pattern. The negative anomalies are suggestive of thicker crust and/or hotter mantle beneath the ridge axis and the western ridge flank. The low-relief bathymetry between 18°30'S and 20°S, the asymmetry of the gravity anomalies, and the good correlation between both the regional and more localized MBA lows and the off-axis volcanic ridges suggest an influence of the Reunion hotspot on accretion processes and volcanic construction near the CIR axis. The thermal influence appears to spread over a large area, certainly due to the large distance of about 1000 km between the ridge and the hotspot. The contrast between the low-relief bathymetry between 18°30'S and 20°S and the high reliefs observed farther south coincides with a contrast in roughness in the free-air gravity anomaly maps derived from satellite altimetry data.

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Geodynamic and Seismic Modeling of the MELT region of the East Pacific Rise: An Example of Plate Scale Hotspot-Ridge Interaction

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