T41C-0906 0830h POSTER

Preliminary results of a high-resolution seismic imaging investigation on St. Paul Island, Pribilof Islands, Alaska

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St. Paul Island, one of the Alaskan Pribilof Islands, is located in the Bering Sea about 1100 km WSW of Anchorage, Alaska. Geologically, St. Pauls nearsurface lithology consists of basaltic lava flows and sills, with minor amounts of glacial sediments. To better understand the subsurface structure of St. Paul island, the U.S. Geological Survey acquired a series of high-resolution seismic imaging profiles across the island in June, 2000. The longest seismic profile is approximately 1.8-km-long and trends ENE. Shot and geophone spacing was 5 m, recorded with 162 channels. Seismic sources were generated using a Betsy Seisgun in ∼0.3 m-deep holes. Approximately 2 s of data were recorded at a 0.5-ms sampling rate. Our study was designed to investigate the relationship between groundwater flow, basement rocks, and faults on St. Paul Island in an attempt to mitigate the effects of subsurface chemical contaminants. Seismic velocities range from about 500 m/s in the near surface to about 5000 m/s at varying depths, some of the high velocity layers appear as shallow as 40 m below the surface. The reflection data show a thin vaneer of sediments overlying layered basalts. Layered basalts vary in thickness from about 5 to 40 m near the surface, and these layers are faulted in places. The groundwater supply for St. Paul is derived from a shallow-depth water table that is, in places, a mixture of seawater and freshwater (Anderson, 1976). Vertical and lateral flow of ground-water is affected by the depth to basement rocks, which are believed to be largely impermeable and thus restrict the flow of ground-water. In addition, a series of observed faults that have vertically displaced basement rocks may act as barriers or as conduits to the flow of ground-water. In unconsolidated sediments, the ground-water table typically has velocities of ∼1500 m/s. Using this velocity criteria, our data suggest that the ground-water table varies between 0 and 25 m depth along the profile. This result was supported by well log data.

T41C-0907 0830h POSTER

Crustal Thickness Across the Alaska Range

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Subduction of the Pacific plate beneath the North American plate dominates the tectonics of southern and central Alaska. One expression of this convergence is the Alaska Range, including Mount McKinley, the highest point in North America. The Broadband Experiment Across the Alaska Range (BEAAR) three year data acquisition phase is now complete. BEAAR utilized IRIS/PASSCAL instrumentation for thirty-six closely (∼ 10 km) spaced broadband stations along roughly north-south and east-west lines. The large quantity of data produced provides ample opportunity to examine the structure and tectonic setting of the Alaska Range. This study uses teleseismic receiver function analysis to determine Moho depths beneath the Alaska Range.

Teleseismic events recorded in 1999 and 2000 were processed individually, and events with similar back-azimuths were stacked to reduce noise and enhance phase information. Synthetic receiver functions were generated for each station using plane layered models, and Moho depths were determined using minimum root-mean-square misfits between data and synthetics. Moho depths from stacked traces range from 34 km deep north of the range, to 46 km deep beneath the heart of the range, and in general show crustal thickening beneath the mountains. In addition to the Ps conversion from the continental Moho, we also observe a conversion from the subducting Pacific plate. This slab phase can be correlated across the southern portion of the network, where the mantle wedge gradually pinches out. To incorporate as many events as possible, including the most recent data and smaller events, we are automating BEAAR receiver function analysis. Our automation efforts include quality control to eliminate anomalous receiver functions, and smoothed plots showing azimuthal variations beneath stations.

T41D MC: 309 Thursday 0830h

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

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

T41D-01 0830h INVITED

The 140 Ma (?) Evolution of the Galpagos Hotspot

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The Galpagos Islands and hotspot tracks on the Cocos and Nazca Plates (Cocos, Carnegie, Malpelo and Coiba Ridges) extend the activity of the Galpagos hotspot to nearly 20 Ma (Malpelo and Carnegie Ridges). The complex spatial zonation in trace element and isotopic composition found at the Galpagos Islands is also preserved in the hotspot tracks. Older parts of the hotspot tracks have presumably been subducted beneath South and Central America and therefore are not directly available for sampling. Detailed field, geochemical and 40Ar/39Ar age dating studies of accreted volcanic terranes in Costa Rica and Panama, however, show that they represent parts of the subducted history of the Galpagos hotspot. Samples from accreted ocean island, seamount and submarine ridge volcanoes range in age from 20-70 Ma and have intraplate major element, trace element and Sr-Nd-Pb isotopic compositions consistent with their derivation from the Galpagos hotspot. Our preliminary geochemical data also suggests that the unique spatial zonation of the Galpagos hotspot can be traced as far back as 65 Ma. Outcrops of radiolarian chert, which have been intruded by gabbros or basaltic dikes and sills or are overlain by basaltic sheet flows and pillow lavas, are also common along the Pacific margin of Central American. These rocks are tholeiitic in composition, have very uniform trace element and Sr-Nd-Pb isotopic characteristics, which are identical to other basalts from the Caribbean Large Igneous Province (CLIP). Despite their homogeneous geochemistry, 40Ar/39Ar dating yields a surprisingly large age range of 70-140 Ma. The oldest ages (133-139 Ma) are derived from pristine glasses from pillow rinds from three separate outcrops in North Nicoya. Questions posed by these data include: 1) Has the Galpagos hotspot been active for the last 140 Ma? and 2) Over what age span was the CLIP formed?

T41D-02 0845h INVITED

Correlated Geophysical, Geochemical and Volcanological Manifestations of Plume-Ridge Interaction Along the Galapagos Spreading Center, 90.5-98°W

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As the Galapagos plume is approached from the west along the Galapagos Spreading Center there are systematic increases in crustal thickness, and K/Ti and H_2O content of recovered lavas. These increases correlate with progressive transitions from axial deep to axial high morphology along with decreases in axial depth, residual mantle Bouguer gravity anomaly (MBA), average swell depth, average lava Mg # (atomic MgO/(MgO+FeO)), and the frequency of isolated axial seamounts. Although K/Ti, H_2O and Nb/Zr (likely indicators of plume source enrichment) show step-wise increases across the 95.5°W propagating offset, trends in crustal thickness, axial bathymetry, MBA, swell depth, and seamount frequency generally show either no effect or only local perturbations to regional trends. East of ∼92.7°W, sharp increases in K/Ti, Nb/Zr, H_2O, and Na8 (Na2O corrected for fractionation to 8 wt % MgO) coincide with the transition to axial high morphology, a rapid shoaling of axial magma chamber (AMC) seismic reflectors, and thinning of seismic layer 2A. Maximum values in K/Ti (>0.4), Nb/Zr (>0.10), H_2O (>1.0 wt %), Na8 (∼3.2) and crustal thickness (7.9 km), and minima in axial depth (<1700 m), Mg # (<40), and Ca8/Al8 (<0.7) all occur between 91.25°W and 92°W, whereas the minimum MBA (-25 mGal) and AMC depth (∼0.5 sec 2-way travel time) are found near 92.25°W. These general correlations can be modeled by the combined effects of changes in source composition and melt generation processes on the thickness, composition and structure of the oceanic crust. Key elements of this model include: (1) compensation of the swell is partitioned between crustal thickening (2.3 km) between 98°W and 90.5°W [*Ito et al.*, this meeting] and thermal and compositional buoyancy of the mantle [*Canales et al.*, this meeting]; (2) increased melt production near the hotspot is associated with lower mean extents of melting from a larger region of an increasingly hydrous, and other incompatible element-enriched mantle [*Cushman et al.*, this meeting]; and (3) higher magma supply results in stabilization of axial magma chambers at increasingly shallow crustal depths [*Blacic et al.*, this meeting] and the dominance of fissure-fed rather than point-source volcanism. The hotspot-related effect of increased magma supply on axial morphology, AMC depth and volcanic style along this intermediate-spreading ridge is similar to that between slow and faster spreading mid-ocean ridges.

T41D-03 0900h INVITED

Geophysical constraints on the compensation mechanism of the Galápagos swell

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We use geophysical observations such as bathymetry, gravity, and seismic crustal thickness to understand the origin of the Galápagos swell. Wide-angle refraction and multichannel reflection seismic data show that the crust along the Galápagos Spreading Center (GSC) between 97.5°W and 91°W thickens by 2.3 km as the Galápagos plume is approached from the west [*Ito et al.*, this meeting]. Axial depth along the GSC shoals by 1800 m, 60% of which is due to dynamic topography and changes in axial morphology. The remaining 700 m correspond to the amplitude of the Galápagos bathymetric swell, 75% of which is explained by crustal thickening. The eastward shoaling of the swell and increase in crustal thickness along the GSC is accompained by a progressive decrease in mantle Bouguer gravity anomaly (MBA). Assuming a constant crustal thickness model, the MBA reaches a minimum value of -70 mGal near 91.25°W. After correcting for changes in crustal thickness, however, the gravity anomaly shows a minimum of -25 mGal near 92.2°W, the area where the GSC is intersected by the Wolf-Darwin volcanic lineament.

We attribute the remaining 25% of swell bathymetry and 35% of gravity anomaly to an eastward reduction of mantle density above an effective compensation depth, constrained to be 50-200 km. Simple melting calculations assuming passive mantle upwelling predict that the observed crustal thickenning is consistent with a small eastward increase in mantle temperature of 15-25 °C. This thermal anomaly produces an eastward decrease in mantle density due to thermal expansion and the subsequent along-axis variation in melt depletion. For preferred mantle compensation depths of 50-150 km the thermal effects can explain 40 to 70% of the mantle density anomaly required by the geophysical observations. Therefore, our results require the existence of compositionally-buoyant mantle beneath the GCS near the Galápagos plume. We will discuss plausible origins for the mantle anomaly such as depleted mantle by the upwelling plume, melt retention, or a mantle source enriched in incompatible elements and volatiles [*Cushman et al.*, this meeting], and their implications for melting beneath the Galápagos plume-ridge system.

T41D-04 0915h INVITED

Upper Mantle Structure Beneath the Galpagos Archipelago From Body Wave Data

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We report on the initial results from an ongoing broadband seismic experiment conducted in the Galpagos Islands. The Galpagos offer an advantageous site for a reconnaissance seismic study of an oceanic hotspot, because the islands cover nearly the entire bathymetric swell or surface signature of the presumed underlying plume. In September 1999 we deployed 10 three-component broadband seismometers, which augment an existing GSN site and a telemetered array of high-frequency seismometers. The combined seismic networks record data suitable for imaging upper mantle structure, constraining crustal thickness variations, and characterizing local seismic activity associated with tectonic and volcanic processes. The resulting elliptically shaped array is 300 km by 200 km in aperture (east-west/north-south, respectively); stations are spaced 50-70 km apart. A primary goal of the experiment is to define the first-order characteristics of the upper mantle structure beneath the Galpagos hotspot in order to ascertain if the hotspot is associated with a plume-like feature in the upper mantle. To do so, we are inverting the delay times of teleseismic P and S body waves. The Galpagos hotspot is well situated with respect to regional and teleseismic earthquake sources, and the region displays remarkably low seismic noise, as it is located in the doldrums with calm winds (<5 m/s) over 60% of the time (90% of the time from February through April). Examination of our data and plots of magnitude versus epicentral distance indicates that teleseismic earthquakes with mb>5.5 and regional earthquakes with mb>4.2 provide useful data. P waves often show excellent signal-to-noise ratios in the frequency band 0.3 to 2 Hz. These phases can be picked, using waveform alignment, to an accuracy of 20 ms. The spectral content of the larger events is broad, with teleseismic earthquakes generating signals at frequencies up to 5 Hz, as well as at lower frequencies (< 0.1 Hz). The S wave data are also of excellent quality, with good signal to noise and coherent waveforms across the array. We observe S waves from events at 30° to 40° distance with good energy at frequencies approaching 1 Hz (wavelengths of about 4 km). Initial measurements indicate that the mean S wave delay varies by nearly 2 s across the array, with greater delays to the northwest. For a given station, the variation with respect to the mean is 0.5 to 1.0 s, a figure much greater than the error in an individual delay (∼0.1 s). The variation, for a given station, indicates that as the back azimuth and distance of the event vary, different anomalous structures are being interrogated. These observations suggest that the underlying structure is indeed three-dimensional.

T41D-05 0930h INVITED

Lithospheric Evolution of Galapagos Magmas

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The volcanoes of the western Galapagos are of two types: monotonous systems, which erupt lavas with a narrow compositional range, and variable systems, which erupt a wide range of compositions. Fernandina, Sierra Negra, and Wolf volcanoes are monotonous systems, with Mg# = 44 ± 4 for all but a few lavas. These compositions correspond to a narrow range of eruption temperature, typically 1130 ± 20 degrees. Cerro Azul, Alcedo, and Roca Redonda are variable systems; lavas range from picrites (Mg# > 70) to rhyolites, representing hundreds of degrees of difference in eruption temperature. Volcan Ecuador used to be a monotonous system but has changed to a variable one since it underwent sector collapse. Monotony is attributed to thermochemical buffering in the plumbing system beneath the caldera of each volcano. GPS and Insar deformation modeling indicate that the top of the "magma chamber" is < 2 km deep for the monotonous systems, with a sill-like shape. Cerro Azul is the only variable system that is well-modeled by geodetic data, and the active chamber there is at least 5 km deep. Compositional variations of both kinds of suites indicate that most magmas undergo cpx-dominated fractionation in the deep crust. All of the monotonous magmas and some of the variable ones undergo a shallow plagioclase-dominated phase, probably in the subcaldera sill. Extreme compositional variation in the 1998 Cerro Azul lava indicates that disaggregation of cumulates and magma mixing can be important in the variable systems. We present two hypotheses for the thermal and compositional steady state of the monotonous volcanoes. In one, a large (same diameter as the caldera; hundreds of meters thick) liquid chamber serves as a homogenizer, intercepting most batches of magmas. In the second, a thin sill (< 100 m thick; same diameter as the caldera) overlies a thick pile of olivine-gabbroic and wehrlitic cumulates, and each batch of magma reacts with the cumulates before a final stage of fractionation in the sill. Geochemical modeling indicates that the liquid reservoirs have volumes of only a few cubic kilometers, hence the second geometry is preferred. The variable systems are believed to be transient, which can develop as a volcano is still in a juvenile phase (Cerro Azul and Roca Redonda), a dying phase (Alcedo), or after severe disruption (Ecuador).

T41D-06 0945h INVITED

New Perspectives on the Structure and Morphology of the Submarine Flanks of Galápagos Volcanoes- Fernandina and Isabela

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The submarine flanks of oceanic volcanoes are dynamic environments that reflect the history of volcanic construction and mass-wasting. The submarine slopes of the Galápagos had only been investigated during two modern research cruises - the 1990 PLUME 2 cruise and during the 2000 AHA-Nemo cruise. These data provide the backdrop for a recent sonar mapping and dredging cruise, carried out in Aug-Sept., 2001 on board R/V *Revelle*, over the southwestern and western edge of the Galápagos platform. The survey included detailed MR1 side-scan sonar imagery (gridded at 8 m pixel resolution) and EM120 multibeam bathymetry (gridded at 100 m pixel resolution), which provided the basis for detailed dredging and towed camera investigations of the submarine flanks of Fernandina and Isabela.

The principal geologic provinces delineated by the MR1 sonar imagery include submarine rift zones, major landslides between the rifts, and inferred young lava flows at 3000-3500 m depth located 10-20 km west of the islands. Prominent submarine terraces extend for tens of kilometers along the platform edge south of Isabela and west of Floreana, and in the bight between Fernandina and Cerro Azul volcanoes. The depth range for the terraces is variable between 2000-3300 m.

Galápagos submarine rift zones are characterized by mottled backscatter reflectivity seen elsewhere on seamounts, Hawaiian submarine rifts, and the mid-ocean ridge, and are interpreted as constructional submarine volcanic terrain comprising pillow and lobate lava. Extensive spatial variability in acoustic contrast is visible in the MR1 sonar data and is interpreted as complex inter-fingering of submarine eruptive units. These areas of presumably young, high reflectivity flows are located away from the submarine rifts and appear to overlie sediment. These flows cover distances as great as ∼10-15 km and are located 10-20 km from the nearest coastline. These large submarine flows may relate to large subaerial events such as the 1968 Fernandina caldera collapse which was unaccompanied by subaerial eruptions.

Four prominent terraces characterize the slope south of Isabela and west of Floreana, covering an area of ∼600 km^2 between ∼1500-3000 m, and roughly occur at ∼400m depth intervals (2200m, 2500m, 2900m and 3300m). Landslides and sculpting of the platform edge by mass-wasting are imaged in the sidescan sonar data as down slope streaming of light/dark acoustic patterns. This contrasts with the western edge of the platform, north of Isabela and west of Fernandina, that is dominated by submarine rift zones and is interpreted as younger volcanic terrain. The complexity of the morphology and variability of constructional and erosional terrains along the western margin of the platform are clear indicators of the more youthful terrain immediately north and west of Fernandina, the leading edge of the Galápagos hotspot.

T41E MC: 310 Thursday 0830h

Active Tectonics of Taiwan II *(joint with G, S)*

Presiding: **C M Rubin,** Central Washington University**; Y Chen,** National Taiwan Univ.**; J Suppe,** Princeton University

T41E-01 0830h INVITED

Seismic Strain Field in Taiwan

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Centroid-moment-tensor (CMT) solutions determined by inverting waveform data of Broadband Array in Taiwan for Seismology (BATS) are collected for earthquakes that occurred in the Taiwan region. In total, the dataset contains more than 300 events that scattered across an area of 400 km by 400 km, including the devastating 1999 Chi-Chi earthquake sequence. The entire region is divided into 3 layers (0-40 km, 40-70 km, and greater than 70 km) with blocks of 0.2 degree by 0.2 degree in lateral dimension. Seismic moment tensors of all earthquakes that occurred inside each block are summed to give the strain tensor characterizing the corresponding seismic deformation. We calculate the eigenvalues and eigenvectors of the resulted strain tensor for each block and project the normalized maximum compressional (P) and extensional (T) axes on horizontal plane to resolve the strain field in Taiwan associated with regional seismic activities. For the majority of events with depths less than 40 km (i.e., at crustal scale), the strain field is characterized by nearly E-W compression along the eastern coastline and immediately offshore east of Taiwan. Once inland, clear fan-shaped trajectories of P-axes are observed, ranging from NW-SE in the northwest to NE-SW in the southwest. The Ryukyu and Luzon subduction systems show compression in the forearc region and extension in the backarc and outerrise regions. For depths greater than 40 km, a clear pattern of lateral compression is observed within the subducted Philippine Sea plate to the northeast of Taiwan. It is doubtless that the "slab-continent" collision is predominant at deeper depths near the junction between the Ryukyu arc and Taiwan Collision Zone, whereas the "arc-continent" collision is predominant in the central and southern Taiwan.