S51C MCC: Level 1 Friday 0830h

African Superswell Province: From Core to Crust I Posters *(joint with T, V)*

Presiding: **T Furman,** Pennsylvania State University**; A Nyblade,** Pennsylvania State University

S51C-0054 0830h POSTER

Waveform Modeling Constraints on the South African Superplume

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Tomographic studies of the lower mantle structure beneath South Africa reveal large-scale slow velocities from the core-mantle-boundary (CMB) to about a depth of 1500 km. Predicted SKS delay patterns (up to 3 sec) for some of these models fit observations (South African Array Data) quite well except for magnitude level, explaining less than ($\frac{1}{2}$) the anomaly. Moreover, the sharpness in travel time offsets and waveform complications require nearly vertical walls separating the anomalous structure from the normal PREM mantle. We present numerous record sections along with 2D and 3D synthetics displaying multi-pathing of arrivals (S_{diff}, SKS, SKKS, S and S_cS) based on our previous plume model. This ridge model has a crescent shape with one apex beneath the Indian Ocean (Kerguelen) with the other beneath the mid-Atlantic (Cape Verde). The structure extends upward through the lower mantle similar to Grand's model but with an average uniform velocity decrease of about 3% relative to PREM, although there is some evidence for a still slower core or upward doming near the middle of the structure. Some record sections fit the observed waveform complexity better than our standard model by injecting a thin (50 km wide) thermal boundary layer along the walls with depressed velocities. We have not found any evidences for ULVZ's beneath the main structure but ample evidence at some locations near the edges. We also analyzed P_{diff} and the differentials of (P_cP-P) along the same great circle paths (same events). The P-velocity is not very anomalous, perhaps -.5%, arguing for a chemical origin.

S51C-0055 0830h POSTER

Seismic Constraints on the African Anomaly in the Lower Mantle

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Seismic studies have consistently shown a significant low-velocity anomaly in the lower mantle beneath Africa. For convenience, we term it "African anomaly". While it is now clear that the base of the "African anomaly" is compositionally distinct, it remains unclear whether the portion in the lower-mantle has a same origin as its base. To further understand the origin of the "African anomaly", we study seismic velocity structure and geometry of the "African anomaly" in the lower mantle along the great-circle path from Passage Drake to Hindu Kush. We use the broadband data recorded in two PASSCAL seismic arrays in Africa, the Kaapvaal seismic array (1997-1999) and the Tanzania seismic array (1994-1995), for earthquakes occurring in the southern Pacific Ocean, Passage Drake, the South Sandwich islands, the Hindu Kush area and the Japan sea. The seismic data from those earthquakes sample the "African anomaly" in opposite directions and within a narrow azimuth range of less than 11°. They thus provide an opportunity to study the lower mantle structure of the "African anomaly" from both directions. The southwest side of the anomaly is sampled by direct SH, ScS and SKS phases from earthquakes occurring in the South Sandwich islands and the south Pacific Ocean. SH phases travel times from the South Sandwich islands earthquakes show no delay with respect to the preliminary reference earth model (PREM) between 44° and 59°, but they are increasingly delayed from about 3 s at 68° to 11.7 s at 74°. These direct SH travel times suggest that the "African anomaly" extends about 1300 km above the core-mantle boundary. The ScS travel time delays have a simple trend increasing from 4.5 s at 44° to 20.5 s at 74°. The SKS phases for an earthquake occurring in the south Pacific Ocean have a uniform delay about 6 s before 101°, gradually increasing to a uniform delay of 12 s after 106°. These ScS and SKS travel time observations are consistent with a model that, in the southwest side of the "African anomaly", the basal layer extends further southwest and the anomaly extends into the lower mantle dipping toward its center. The northeast side of the anomaly is sampled by the SKS phases from an earthquake occurring in Passage Drake, direct SH and ScS phases from events in Hindu Kush, and SKS and SKKS phases from an earthquake in the Japan sea. The SKS phases recorded for a Passage Drake earthquake show decreasing delays from 10 s at 86.9° to 5.6 s at 93.5°. Both the SH and ScS waves from earthquakes occurring in the Hindu Kush area do not exhibit travel time delays with respect to PREM, placing bounds on the extent of the anomaly in northeast side. The SKKS phases from an earthquake in the Japan sea are slightly delayed only after 140° whereas the SKS phases have a uniform delay about 4 s between 129° and 140°. These travel times delays are consistent with a model that, on the northeast side, the anomaly also dips toward its center. The geometry of the "African anomaly" with both edges dipping toward its center, suggests that the portion of the "Afrian anomaly" n the lower mantle likely has a same origin as its base. It also indicates that the "African anomaly" may represent a stable and long-living compositional anomaly, similar to those in the geodynamical models and the laboratory experiments.

S51C-0056 0830h POSTER

Seismic Structure of the African Upper Mantle Determined from Multi-Mode Rayleigh Waveform Inversion

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We present a high-resolution shear wave velocity model of the African upper mantle based on waveform analysis of a large fundamental and higher mode Rayleigh wave data set. Our model is derived from all data currently available from permanent seismographs and temporary field experiments in the region. This allows us to restrict our analysis primarily to short epicenter-station paths (< 6000 km) and minimizes spurious effects such as multipathing or focusing/defocusing while still achieving high path density. In addition, the analysis is undertaken at relatively long period (∼50-160 s) with a small number of higher modes (up to the fourth) to avoid artifacts due to the neglect of mode coupling while still preserving good resolution in the whole upper mantle. The dense path coverage, wide azimuthal distribution, substantial higher mode content, and short path length of the data set enable us to build an upper mantle model for the region with a horizontal resolution of a few hundred kilometers extending to ∼400 km depth. The resulting model confirms that the high velocity lid associated with African cratonic roots is relatively thin extending to 180-200 km depth beneath southern Africa and ∼250 km beneath west Africa. The cratons are generally delimited by sharp boundaries. Eastern Africa is underlain by a well-resolved deep low velocity anomaly that extends from shallow depth beneath Afar to at least the transition zone suggesting deep upwelling with a possible connection with the tilted lower mantle, low velocity anomaly that has been observed in the global tomographic results. Some other Africans hotspots seem however, to have a shallower origin that could involve other processes such as small-scale convection in the upper mantle.

S51C-0057 0830h POSTER

Hotspots and Superswell Beneath Africa Inferred From Surface Wave Anisotropic Tomography.

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In order to study the interaction at depth between hotspots and lithosphere we present a new anisotropic S-wave tomographic model of Africa which is derived from Rayleigh and Love wave phase velocity measurements. The strongest negative anomaly corresponds to the Afar plume which is presently the most active area of Africa. This slow anomaly, visible down to the deepest inverted depth (400km), is associated with azimuthal anisotropy that is weak right beneath the Afar and whose direction at further distances is diverging around the plume. This is consistent with active upwelling beneath the Afar. The smaller hotspots of Tibesti, Darfur, Hoggar and Mt Cameroon have appeared in regions that had been weakened by Late Jurassic-Early Cretaceous (145 Ma) rifting of West and Central Africa. They are associated with slow velocities down to about 200km. The smaller amplitude of these anomalies with respect to the Afar area and their limited depth extent may indicate that these hotspots have their origin in the uppermost boundary layer between asthenosphere and lithosphere. Nevertheless, there may be a complex relationship at depths shallower than 150km between these hotspots and the Afar. The superswell, located in the southern part of Africa is characterized by a broad area of positive velocity anomaly visible down to 300km depth. The base of Kalahari craton ($\sim 280km$) is evidently characterized by an increase of azimuthal anisotropy. The direction of azimuthal axis is roughly North-South that rotates at the longitude of the Eastern rift to move around the Afar. This may suggest a feeding of Victoria and Afar hotspots from the deep South African superplume.

S51C-0058 0830h POSTER

Comparison of S-Wave Velocity Structure Beneath the Kaapvaal Craton From Surface-Wave Inversion With Predictions From Mantle Xenoliths

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Results from two-station surface-wave inversions across the Kaapvaal craton of southern Africa are compared with seismic velocities and densities estimated from approximately 100 mantle xenoliths brought to the surface in kimberlite pipes. These cratonic xenoliths from the southern Kaapvaal, all less than 100 Ma in age, have been analyzed thermobarometrically to obtain the equilibrium P-T conditions of the cratonic mantle to about 200 km depth. Seismic velocity-depth and density-depth profiles calculated on the basis of these P-T data and the mineral modes of the xenoliths (James *et al.*, *G-cubed*, in press, 2003) are used to produce theoretical surface-wave dispersion curves and to generate starting models for inverting the observed surface-wave dispersion. Preliminary results obtained as part of this study and from previous surface-wave inversions in Ph.D. theses (in preparation) by Nguuri and Gore are broadly consistent with the predicted velocity-depth curves from xenolith studies that show uppermost mantle S-wave velocities of ∼4.7 km/s, decreasing slightly to about 4.65 km/s at 180–190 km. The current research extends the work of Gore and Nguuri by including additional events and a direct-search inversion scheme (Neighbourhood Algorithm) that allows direct comparison with results from the xenolith studies. Finally, preliminary results from surface-wave inversions are presented that contrast mantle velocity-depth profiles off-craton with those on-craton. The implications of results are discussed in terms of the thermal state and recent thermal history of the mantle beneath southern Africa.

S51C-0059 0830h POSTER

Spatial variations in crustal thickness and V_P/V_S ratio in southern Africa and their geological implications

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Measurements of crustal thickness (H) and V_P/V_S ratio (R) at about 80 broadband seismic stations in southern Africa were made using data from the Southern African Seismic Experiment, by stacking receiver functions. Our results suggest systematic spatial variations in both H and R that appear to be geologically controlled. Regarding H, we observe relatively thick crust beneath the Limpopo belt, younger collisional belts to the south of the Kaapvaal craton, and beneath the Bushveld intrusion, compared to the crust beneath the Kaapvaal and Zimbabwe cratons, a result that is consistent with previous studies. There are noteworthy spatial variations in R. The most dramatic change in R actually occurs within the Kaapvaal craton. In particular, going from the Neo-Archean Kimberly block to the Meso-Archean Witswatersrand block (east), the average value of R increases systematically from 1.76 to 1.81. Taken at face value, this suggests that, on average, the Meso-Archean crust is more mafic than the Neo-Archean crust, which may indicate temporal differences in crustal formation processes. R is anomalously high in the general region of the Bushveld intrusion. Indeed the highest value in the entire data set is found at the western edge of the Bushveld, and suggests a more mafic crust, consistent with the characteristics of the intrusion. Finally, there is a region of very low R (<1.7) at the southern edge of the Kaapvaal craton, that may reflect processes active during accretion at this margin. These observations, and particularly the values of R, provide important constraints on the processes that have formed and modified the composition of the ancient southern African crust.

S51C-0060 0830h POSTER

Upper mantle attenuation structure beneath East Africa from relative t* measurements

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We are studying the attenuation structure of the upper mantle beneath east Africa using body waves recorded by a PASSCAL array that was deployed in Tanzania between 1994-1995. The array runs along two profiles (EW and NE-SW) that traverse the Tanzania craton and the surrounding rifted mobile belts. Studying this region may provide important clues on the initiation of Cenozoic rifting in east Africa and hence, give us insights into the tectonic and geodynamic processes that occur during the initial stages of rift development. The same dataset has been used to obtain tomographic velocity models, so we can compare the velocity structure to the attenuation structure. We determined the P wave spectral amplitude ratios of data from the same earthquake recorded at different stations (thereby eliminating the source effect), and computed relative t* (path integrated attenuation) from the slopes of these ratios. We then used a least-squares inversion to determine the t* at each station relative to the average t* of the array. We applied the same procedure to determine relative t* for S waves from the transverse components of the data (i.e., SH only). To simplify the problem, we selected events that have azimuths along the two profiles, and we have initially focused on events along the EW profile. On comparing the estimates of t* to the residual travel times estimated by Ritsema et. al., (1998), we observe that the t* values and residual travel times are not always correlated. Also, the observed t* values from P wave data are anti-correlated to the observed S wave data for stations within the craton. We are planning to compute forward models in order to isolate elastic from anelastic effects on our t* measurements, and to place constraints on upper mantle Q values.

S51C-0061 0830h POSTER

The Effect of Plume Impingement on Lithospheric Preservation Beneath the Kenya Rift, East Africa

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The Kenya Rift is located at the transition between Archean Tanzanian craton and Proterozoic mobile belt. Currently, discrepancies exist between geochemical and geophysical interpretations of lithospheric preservation in the Kenya Rift. Seismic data show a sharp vertical boundary between low velocity mantle in the axis and higher velocity mantle on the flanks, which is interpreted to reflect lithospheric erosion from the axis (Mechie et al., 1997; Prodehl et al., 1997). However, geochemical data suggest that the lithospheric mantle is intact beneath both the axis and the flanks. Different elemental groups are observed for rocks from Kenya (Hamblock et al., 2003). One group is characterized by elemental concentrations greater than ocean island basalts (OIB), negative K and Sr anomalies, and Lan and Cen greater than 100. These characteristics are found in silica-undersaturated rocks such as nephelinites, basanites, and some alkali basalts from the flank and the axis and are interpreted to represent melting of an enriched lithosphere. A second group is characterized by elemental concentrations less than OIB, a flat overall pattern, and Lan and Cen less than 100. This pattern is found in alkali basalts and hypersthene-normative rocks. The multi-element pattern varies minimally between axis and flank lavas, with axial lavas containing higher concentrations of Ba (Macdonald et al., 2001). Because rocks of both groups are present in the axis and the flanks, lithosphere appears to be intact across the Kenya Rift, and strong lateral contrasts in composition do not exist. Sr, Nd, and Pb isotopes also suggest that ancient lithospheric mantle is present in Kenya and Tanzania (Macdonald et al., 2001; Paslick et al., 1995). A consistent difference between axis and flank is lower La/Yb for axis lavas, indicating that they originate in the spinel stability field. Flank lavas, regardless of their silica saturation, have higher La/Yb and are interpreted to come from garnet peridotite. Discrepancies between geophysical and geochemical data exist for other parts of the East African Rift as well. In the axis of the rift in Tanzania, tomography suggests that upwelling asthenosphere has eroded the lithosphere (Nyblade, 2002). However, gravity models (Simiyu and Keller, 1997, 2001) and the presence of subchondritic 187Os/188Os in spinel and garnet-bearing xenoliths (TRD of 2.6 Ga) suggest that the lithosphere is intact (Chesley et al., 1999). In contrast, for the Tanzanian craton, Os isotopes, gravity, and tomography are consistent with 2.5-2.9 Ga lithosphere existing to depths of 140 km and a broad thermal and geochemical anomaly (plume?) below the lithosphere (Chesley et al., 1999; Owens et al., 2000; Nyblade et al., 2000; Simiyu and Keller, 1997, 2001). In the Sidamo region of Ethiopia, Os isotopes suggest that ancient depleted mantle is present and has been modified by recent melt percolation (Lorand et al., 2003; Reisberg et al., in press). Finally, for Ethiopian flood basalts, element chemistry, petrology, and 3He/4He (Marty et al., 1996; Scarsi and Craig, 1996) indicate a dominant role for plume. Os isotopes (Davies et al., 2003), however, are lower than PUM, indicating that an ancient lithospheric mantle reservoir is present. In order to help resolve the discrepancies between geophysical and geochemical interpretations, we will obtain petrologic and isotopic data for xenoliths and mafic lavas in both east-west and north-south directions. The lavas span a wide range of silica saturation and La/Yb ratios, and thus are intended to represent lithospheric as well as asthenospheric sources.

S51C-0062 0830h POSTER

A Rayleigh Wave Analysis at the DESERT Broadband Array

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A variety of geophysical experiments conducted in the 2000/2001 DESERT project in Israel, Palestine and Jordan provided a rich palette of datasets to examine the crust and uppermost mantle beneath one of Earth's most prominent fault systems, the Dead Sea Transform system (DST). As part of the passive seismic component, thirty broad–band sensors were deployed across the DST for roughly one year. During this deployment we recorded 115 teleseismic earthquakes that are suitable for a fundamental mode surface wave analysis at intermediate periods (20-120s). Analyzing arrival angle measurements we are able to determine the orientation of the horizontal components to within one degree. Some sensors were misaligned by nearly 10 degrees which is confirmed by the station operators (e.g. one station was oriented parallel to a road because the compass broke). The frequency–dependent Rayleigh wave phase at each station is measured with respect to each other rather than relative to a synthetic. This results in a much more precise dataset than what is common for global dispersion datasets. A preliminary analysis reveals a seismically fast but thin lid (about 80 km) to the west of the DST. Toward the east, shallow seismic velocities are low while a deeper low velocity zone is not detected. This contradicts the currently favored thermo-mechanical model for the DST that predicts lithospheric thinning toward the east. Unfortunately, the distribution of sensors at the array was not ideal for a surface wave analysis. The stations west of the DST were equipped with true broad-band sensors (Streckeisen STS-2 or Guralp CMT-3T), while the stations east of the DST were equipped with "wide-band" Guralp-40T that are considerably noisy at periods longer than 40s. We we able to measure dispersion down to 80 s, sometimes below that, depending on the size of the earthquake, but not for all earthquakes. Dispersion at these periods are needed to trace the bottom of the lithosphere. The apparent absence of the low–velocity zone on the eastern side of the DST is therefore somewhat uncertain. A follow–up deployment of ten STS-2 sensors in Jordan should resolve this issue within the coming year.

URL: http://www.gfz-potsdam.de/pb2/pb22/projects/deadsea/ds-home.html

S51C-0063 0830h POSTER

Tomographic Imaging of the Northern Ethiopian Rift - a Transition From Continental to Oceanic Rifting

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The EAGLE broadband array consisted of 30 sensors distributed over an 250 km x 250 km area of the northern Ethiopian Rift in order to study the crust and upper mantle structure of a region of transition from continental to oceanic rifting. Analyses of teleseismic relative residual travel times indicate a variation of the order of 1 sec; slower arrivals to the NW of the Rift on the uplifted Ethiopian Plateau and faster arrivals to the SE towards the Somali plate. Tomographic inversion of 3614 P-wave and 800 S-wave relative arrival times using the method of VanDecar images a narrow ∼70 km wide low velocity upwelling (1.5% P-wave velocity anomaly), well resolved to 300 km beneath the Rift in the southern part of the array. This anomaly broadens with depth northwards into Afar as asthenospheric (oceanic) rifting processes begin to take over from the lithospheric (continental) ones prevalent in the south. An off-rift axis E-W low velocity anomaly just south of Addis Ababa corresponds to the surface manifestation of a line of Quarternary volcanoes. Interestingly the maximum upper mantle low velocity anomaly is offset by about 25 km to the NW from the location of rift magmatic segments. S-wave anomalies show a similar rift structure to the P-wave results but are of twice the magnitude.

S51C-0064 0830h POSTER

Shear-Wave Splitting due to Rifting and Precambrian Accretion of Ethiopia

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We have utilized a dataset from the broadband seismic experiment of Nyblade and Langston (EOS v.83 p. 405, 2002) for a shear-wave splitting analysis in Ethiopia. A total of twenty-five broadband seismic stations, widely distributed in various physiographic regions in Ethiopia, were used. Six stations were installed on the southeastern plateau, twelve stations on the western plateau, and seven stations inside the Rift Valley, which runs northeast-southwest and separates the western and eastern highlands. The distribution of the broadband stations in the present study spans a broad region and allows us to compare the results of shear-wave splitting analysis inside the rift and on the rift-bounding plateaus. Previous shear-wave splitting results in Kenya, located south of Ethiopia, show

fast polarization azimuths sub-parallel to the strike of the rift which are interpreted to be the result of vertical magma-filled cracks in the lithosphere opening in the direction perpendicular to the extension direction (Gao et al., 1997; Barruol and Ismail, 2001). However, this orientation is also perpendicular to the collision direction for the Mozambique belt and thus consistent with the fast azimuth being the result of fossilized anisotropy in the Precambrian lithosphere. Results from an SKS splitting analysis in Ethiopia (Maguire et al., EOS 2003 in press; Kendall et al., this session) show the orientation of the fast polarization azimuth within the Main Ethiopian Rift to be approximately NNE-SSW. Similar to the results from Kenya, this is parallel to the volcanic centers in the rift and perpendicular to the geodetically determined opening direction. Splitting directions on the rift shoulders are closer to NE, parallel to both the rift-bounding faults (perpendicular to the inferred average Neogene opening direction) and to the Precambrian accretionary structures. Our preliminary result from Addis Ababa suggests a fast azimuth of N23E, sub-parallel to the rift orientation in agreement with previous results by other workers. Further south near Arbaminch, results suggest an azimuth of N6E possibly due to the shift of rift orientation from NE-SW to nearly N-S in this region. Stations 250 km NW of the rift axis (Debre Markos) and 250 km SE of the rift axis (Goba) both show more north-easterly trends (N37E and N21E, respectively). Because of the distance of these stations from the rift, we suggest that this NE fast splitting direction is more likely related to fossilized anisotropy in the Precambrian lithosphere than to Neogene rifting.

S51C-0065 0830h POSTER

Crustal Structure Beneath the Ethiopian Plateau, Afar Depression, and the Main Ethiopian Rift from Receiver Functions

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Between March 2000 and February 2002 a network of 25 broadband seismic stations was operated in Ethiopia to investigate crust and upper mantle structure using data from teleseismic earthquakes. Stations were evenly distributed between the regions of rifted crust and highlands adjacent to the rifts. We have used two methods to analyze receiver functions for crustal structure, the H-κ (Moho depth(H) and Vp/Vs ratio(κ)) method, and direct stacks of the waveforms. The former technique is based on the idea that a stack of the weighted sum of receiver function values at the arrival times for the Ps converted phase from the Moho and the first two multiple converted phases will attain their maximum when there is coherent stacking. The two approaches yield consistent results for most of the stations. Moho depths vary from 24 to 30 km within the Main Ethiopian Rift and the Afar Depression, and the crust is characterized by high Poisson's ratios of 0.30-0.35. Beneath the western and eastern plateaus on either side of the Main Ethiopian Rift, crustal thickness ranges from 32 to 46 km, and Poisson's ratio varies from 0.23 to 0.28, typical for Precambrian crust. Thus, these results suggest that Precambrian crustal structure beneath the Ethiopian Plateau has not been significantly modified by the Cenozoic rifting and volcanism, whereas the Precambrian crust beneath the rifted regions has been dramatically thinned in some places and compositionally altered by the addition of mafic rocks.

S51C-0066 0830h POSTER

Along-Axis Segmentation of the Main Ethiopian rift from Tomographic Inversion of Local Earthquakes and Controlled Sources: EAGLEII

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Geophysical, structural, and geochemical data indicate that the East African rift system in Ethiopia is in a stage of development transitional between continental and oceanic spreading. In the northern Main Ethiopian rift (MER) the archetypal continental rift stage border fault systems bounding the asymmetric rift basins formed at approx 11 Ma. After 3.5 Ma, strain localised to fault systems within the central rift. By 1.8 Ma, faulting and magmatism localised to an en echelon series of 20 km-wide zone, 50-60 km-long magmatic segments' comprising felsic shield volcanoes and basaltic fissural flows and dikes. As part of the international EAGLE project, 50 broadband Guralp 6TD seismometers were deployed across 3 magmatic segments, and a sector of the rift without magmatic segments. These instruments are nested within the Leeds University broadband array, and the combined net of 80 instruments was used to locate local and regional events (Keir et al., this session). Velocity information was provided by across and along-axis refraction profiles (Mackenzie et al., this session; Keller et al., this session). Over 600 local events, plus 19 controlled explosive sources from EAGLE III provide good ray coverage, with higher resolution in the more seismically active northern sectors of the MER. We present P-wave velocity models of the variations in crustal structure corresponding to rift sectors with and without magmatic segments.

S51C-0067 0830h POSTER

Crustal Structure From 3-D Tomography in the Main Ethiopian Rift

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The Main Ethiopian Rift (MER) is an ideal location to study the transition between continental rifting and oceanic seafloor spreading. A 3-D refraction and wide-angle reflection survey was completed in the MER as part of the Ethiopia-Afar Geoscientific Lithospheric Experiment (EAGLE) in January, 2003. Approximately 680 Texans were deployed in a region 100-km in diameter, 231 exclusively for the 3-D survey and over 450 as part of two 400-km-long 2-D profiles that intersected at the center of the 3-D array. Nineteen borehole shots, two lake shots, and two quarry blasts were recorded, fourteen of which have been used in a 3-D tomographic inversion. Shot spacing was 50 km and station spacing was nominally 2.5 km for the 3-D array and 1 km for the instruments on the 2-D profiles. The 3-D survey was centered at the intersection of the Boset and Fantale magmatic segments. Primary targets include crustal magma chambers and/or crustal modifications related to recent magmatic activity, crustal structure between the two magmatic segments, determination of the depth to which segmentation persists, and structure and reflectivity of the Moho. Preliminary results indicate a correlation between the surface expression of the rift and deeper structures both in the upper and lower crust. In the upper crust, linear, 60-km-wide low-velocity regions (3.5-4 km/s) are imaged to depths of 5 km, likely associated with rift sediments along the axis of the rift. These sedimentary basins are separated between the Boset and Fantale magmatic segments by 20 kilometers in a right-lateral sense. At greater depth, the 6.5-6.7 km/s lower crust appears to be upwarped beneath the rift axis. Moho reflectivity has been mapped and suggests that reflectivity is greatest beneath the northwestern and southeastern rift shoulders, also the regions of greatest elevation. Future inversions will include intracrustal and Moho reflections to map the 3-D structure of these discontinuities.

S51C-0068 0830h POSTER

Sub-basaltic Imaging of Ethiopian Mesozoic Sediments Using Surface Wave Dispersion

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The Ethiopia Afar Geoscientific Lithospheric Experiment (EAGLE) involved the deployment of a 400km NW-SE cross-rift profile across the Main Ethiopian Rift. The profile extended to about 150km on either side of the rift over the uplifted Ethiopian plateau characterized by voluminous Tertiary flood basalts covering a thick sequence of Mesozoic sediments. These consist of three major stratigraphic units, the Cretaceous Upper Sandstone (medium grained, friable and moderately to well-sorted) overlying the Jurassic Antalo limestone (with intercalations of marl, shale, mudstone and gypsum) above the Triassic Adigrat sandstone. These sediments are suggested to be approximately 1.5km thick at the north-western end of the profile, thickening to the south-east. They are considered a possible hydrocarbon reservoir and therefore crucial to the economy of Ethiopia. The EAGLE cross-rift profile included the deployment of 97 Guralp 6TD seismometers (30sec - 80Hz bandwidth) at a nominal 5km spacing. A 5.75 tonne explosion from the Muger quarry detonated specifically for the EAGLE project generated the surface waves used in this study. Preliminary processing involving the multiple filter technique has enabled the production of group velocity dispersion curves. These curves have been inverted to provide 1-D shear wave models, with the intention of providing an in-line cross-rift profile of Mesozoic sediment thickness. Preliminary results suggest that the sediments can be distinguished from both overlying plateau basalt and underlying basement, with their internal S-wave velocity structure possibly indicating that the three sediment units described above can be separately identified.

S51C-0069 0830h POSTER

Environmental Impact of Controlled-Source Explosions in Ethiopia (Project EAGLE): Surface Shaking, Ground Velocities, and Effects on Buildings

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In January 2003, as part of the Ethiopia-Afar Geoscientific Lithospheric Experiment (EAGLE) we conducted a refraction and wide-angle reflection survey of the Main Ethiopian Rift. 757 RefTek "Texan" seismographs with vertical geophones were deployed in 400 km-long axial and cross-rift lines, with another 231 in a central 3D array 100 km in diameter. An 80-instrument passive array of intermediate and broadband sensors was active during our experiment. We recorded 19 borehole shots loaded in nominal 50-meter boreholes, 2 quarry shots, and 2 lake shots. The shots ranged in size from 50-5750 kg, with the most common shot size being 1 tonne. Prior to loading each shot-hole, we measured distances between shots and the nearest structure, typically un-reinforced mud-and-wood houses, occasionally concrete irrigation ditches and aqueducts. We then used semi-empirical formulae derived by Oriard (Hendron and Oriard, 1972) to calculate expected maximum and minimum bounds on ground velocity at these structures, and selected an appropriate shot size to keep the predicted velocity below the "threshold for cosmetic damage", or 2 inches per second, at the most vulnerable structure. The Oriard formulae are derived from measurements associated with blasting for mining and civil engineering purposes and may not accurately predict the ground velocity from the source depths and explosive type used in the EAGLE and other controlled-source experiments. A detailed, trace-by-trace analysis of maximum ground velocities at our closest seismographs can provide data that will be useful in planning future large-scale seismic experiments. Preliminary results from traces within 20 km of our borehole shots suggest that maximum recorded ground velocities were within or below the maximum-minimum range predicted by Oriard, and hence that larger shot sizes could have been used with acceptable risks. A lake shot fired at the optimum depth (84 m for a 1 tonne shot) produced ground velocities that exceeded the predicted maximum at a few recodrers. However, optimum-depth shots are typically a significant distance offshore (c. 2.3 km for our shot) because of the required depth, so are unlikely to present a hazard to onshore structures. A lake shot fired in a shallower lake at half the optimum depth did not produce ground-velocities that exceed the Oriard maximum. Although we fired shots within 100 m of an unreinforced concrete aqueduct, and within 200 m of poorly engineered native buildings in poor structural condition, no damage was recorded. Our "Texan" seismometers recorded only vertical component velocity, using 4.5 Hz geophones. After removal of the geophone response the peak vertical velocity is typically measured at about 3 Hz and occurs shortly after the first arrival, presumably due to surface waves (ground roll). We are currently extending our analysis to include data from broadband, three-component recorders.

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S51C-0070 0830h POSTER

Environmental Impact of Controlled-Source Explosions in Ethiopia (Project EAGLE): Geochemical Effects on Lakes and Streams

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Controlled-source seismologists seek to detonate charges in lakes or rivers because source coupling is an order of magnitude larger in water than in drill holes. Previous studies have documented the biological impact of dynamite explosions on small fish populations; however, little attention has been paid to the potential chemical changes associated with the dispersal of a dynamite charge in a body of water. At the request of the Ethiopian Environmental Protection Authority, we sought to examine the effects on water chemistry resulting from the detonation of one tonne dynamite charges used during the Ethiopia-Afar Geoscientific Lithospheric Experiment (EAGLE), an active source seismic survey of the Main Ethiopian Rift. Water samples from two Ethiopian lakes and six Ethiopian streams were collected in January 2003. Samples were collected immediately preceding and following the detonation of the 2 lake shots and those 6 of our 19 borehole shots for which a stream was present in the surrounding area. Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) analysis has provided concentrations of 16 elements, including: As, B, Ba, Be, Ca, Cd, Co, Cu, Mg, Mn, Mo, Na, Ni, Sr, V, Zn. Additional elements were also examined, however elements such as Cr, Fe, and Pb, had concentrations residing close to the detection limits of the ICP-OES, and the certainty of these numbers is not reliable. We plan to make measurements of Cl and S using the Ion Chromatograph (IC) method. The sites from which the water samples were collected include: (1) Lake Shala, a 12 by 15 km lake, 266 meters deep, (2) Lake Arenguade, an approximately 800m diameter crater lake, 32 m deep, and (3) six streams, each located within close proximity to one of the 19 borehole shots. All samples were filtered using a 2 micron nalgene filter to remove any biotic material. Prior to each shot, water samples were collect. To the extent possible, lake samples were taken 1 hour before the shot, 10 minutes post shot, 1 day after the shot, and 10 days later. Samples where collected every 10 meters in depth from 1 to 30 m, and for the deeper lake, Shala, samples were also taken at 60 m and 90 m. Samples were collected both at the location of the shot as well as 300 m away from the shot (Lake Arenguade) and 1 km from the site of the shot (Lake Shala). Elemental concentrations were plotted both as a function of time and as a function of depth. Preliminary results suggest that while some elemental concentrations varied slightly after each shot, no concentrations were drastically altered from their pre-shot values. The elemental concentrations tended to revert to pre-shot values within a few hours to a few days after the initial explosion. The explosions of the two dynamite lake shots and the borehole shots do not seem to have significantly impacted the water chemistry of the surrounding lakes and streams.

S51C-0071 0830h POSTER

Seismicity of the Northern Main Ethiopian and Southern Red Sea Rifts: EAGLEII

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The northern Main Ethiopian rift (MER) developed within the Paleogene flood basalt province of NE Africa, and forms the youngest arm of the Afar triple junction. High angle, large-offset border faults formed after 12 Ma, providing a linkage between the East African rift system and the southern Red Sea-Gulf of Aden rifts. However, active subsidence migrated to a narrower zone in the central rift by 3.5 Ma. Since 1.8 Ma magmatism and faulting has become more localized to 20 km-wide, 60 km-long 'magmatic segments' marked by aligned eruptive centers, fissures, and small offset normal faults. Local seismicity in the northern Main Ethiopian rift is studied using data recorded on an array of up to 80 broadband instruments operational during the period Oct 2001 - Feb 2003, thus providing a glimpse of activity within a rift transitional between continental and oceanic in style. Earthquakes are relatively sparse on rift border faults and are of low magnitude (<3.5). Activity is concentrated around faults where the northern Main Ethiopian and southern Red Sea rifts link and around Quaternary eruptive magmatic centres within the rift. This seismicity in magmatic segments is mostly as swarms of shallow events that form clusters of concentrated activity in the northern Main Ethiopian rift. Seismicity is less common in the south, a reflection of a difference in the stage of rift evolution.

S51C-0072 0830h POSTER

Atypical Normal Faults Morphology in the Main Ethiopian Rift

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The seismically active northern part of the Main Ethiopian Rift (MER) is one of few sites worldwide showing the transition between continental and oceanic rifting. The northern MER has been active since 12 Ma, with increased activity in a narrow belt of faulting and magmatism since 2 Ma. This approx 20 km-wide zone of magmatic construction and closely-spaced faults lies within the central 70 km-wide rift valley bounded by relatively inactive border faults. Within these segments we observe an intimate relationship between the generation of faults and the localisation of basaltic flows and eruptive centers. The atypical morphology of these faults can be quantitatively described on Displacement/Length (D/L) and cumulative dimensions frequency diagrams. The faults are very long (up to 20 kms) with relatively extremely small vertical displacements (10-20 m) and a relatively large horizontal displacements (1-20 m), composed of numerous segments, flat hanging-walls, and convex foot-walls. These patterns suggest that the extension on the faults is not directly related to the fault lengths; the lateral growth of a fault is due to hard linkage of segments which origin maybe linked to low-depth dykes.

S51C-0073 0830h POSTER

Deformation Distribution and Type in the Main Ethiopian Rift

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The Main Ethiopian Rift central graben is magmatically segmented and seismically active. These magmatic segments are about 50 km long and up to 20 km wide, oriented about N10-20, and therefore oblique to the main direction of Mid-Miocene border faults (N35E). We use the association of the high spectral resolution of Landsat data and the very high spatial resolution of digitized aerial photographs to characterize and quantify the deformation along the rift. Several Digital Elevation Models of metric resolution have been produced at different locations along the segments in order to quantify and describe the fault deformation. We have analysed the Landsat data (texture analysis, PCA, classifications) in order to refine the existing geological maps and to propose a relative chronology of the deformation. The deformation within the segments varies from their centres, usually highly faulted and mainly rhyolitic and trachytic calderas (Gedemsa, Bosetti, Fantale, Dofan), to their tips where the deformation is brittle at the surface and associated to recent basaltic flows and aligned cones. There we propose that the atypical (by their morphologies and Displacement/Length ratios) faults are dyke induced (see Gloaguen et al., same session). The overlap of the segments, the cross-cuttings of faults on the rift margins and the associated seismic activity are in agreement with the longitudinal growth of the magmatic segments via along-axis magma injection.

S51C-0074 0830h POSTER

Temporal compositional variation of early syn-rift rhyolites along the western margin of the southern Red Sea and northern Main Ethiopian rift

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New structural and geochronological analyses indicate that the felsic volcanism at the top of the Oligocene flood basalt sequences along the western margin of the Afar Depression marks the onset of rifting in the southern Red Sea. Geochronological studies show a pattern of riftward migration of the locus of magmatism and faulting from 28 Ma to present-day. Preliminary geochemical analyses (trace and major elements; Sr, Nd and O isotopic compositions) of syn-rift rhyolites ranging in age from 28 to 2.5 Ma indicate that the rhyolites are derived from mantle-sourced basaltic magma through fractional crystallization accompanied by variable amounts of crustal contamination (e.g. $^{87}Sr/^{86}Sr$ = 0.705445-0.706508; $^{143}Nd/^{144}Nd$ = 0.512576-0.512836). The input of crust tends to increase with time, which suggests the weakening and heating of the crust in response to lithospheric thinning and magma injection in the past 30 My. These results support earlier structural and thermo-mechanical models for rift formation in the southern Red Sea rift and the younger, less-evolved northern Main Ethiopian rift system.

S51D MCC: Level 1 Friday 0830h

Red Heat: Volcano Seismology and Small-Scale Tomography I Posters

(joint with V)

Presiding: **B R Julian,** U.S. Geological Survey**; J Pujol,** Center for Earthquake Research and Information, University of Memphis

S51D-0075 0830h POSTER

3-D Shallow Shear-Wave Velocity Structure around the Source Area of the 1999 Chi-Chi (Taiwan) Earthquake by Tomographic Inversion of Short-Period Rayleigh Waves

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