Yi-Hau Chen[2] (+886-2-27835611-303; yhchen@stat.sinica.edu.tw)

[1]Inst. Earth Sciences, Academia Sinica, 128 Academia Rd., Sec. 2, Nankang, Taipei 115, Taiwan

[2]Inst. Statistical Science, Academia Sinica, 128 Academia Rd., Sec. 2, Nankang, Taipei 115, Taiwan

The 1999 Chi-Chi earthquake created a significant increase of strong-motion data set in Taiwan. Data from the main shock and aftershocks of the Chi-Chi event and those occurred elsewhere around this area offer an opportunity to explore the variability of ground motion estimates in Taiwan. Using the variance components technique, Chen and Tsai (2002) decomposed efficiently the prediction errors of ground motions into three components: the earthquake-to-earthquake, the site-to-site, and the residual. From a data set of over thirty thousand records of various site conditions, the percentages of variances of the prediction errors, partitioned into the earthquake and site components, are dependent on the numbers of earthquake events and stations in the sampled records; however, both the variances are in general smaller than that of the residual. It is apparent that the path-to-path component of the variability of ground motions is embedded in the residual. Empirically based on the estimated variance components, the path component of variance is approximately comparable to those of the earthquake and the site. Thus, the prediction errors of ground motions can be further partitioned into earthquake-to-earthquake, site-to-site, and path-to-path components, and the remaining smaller residual. From the data in Taiwan, the variability of the site and path components is more coherent in space than that of the earthquake. This implies that the site and path components of variability are more feasible to be extracted from the total prediction errors than the earthquake component. The results show that the prediction errors of ground motions reduce dramatically after ground motion estimates have been corrected for the site-to-site and path-to-path components of variability. This reduction of ground motion variability has significant implications for probabilistic seismic hazard analysis.

S51E-0105 0830h POSTER

Azimuthal Dependence of Strong Ground Motions from Three California Earthquakes

Lawrence D. Porter[1] (1-925-837-8064; ldporter@pacbell.net)

David J. Leeds[2] (1-310-472-0282; davidjleeds@aol.com)

[1]Geocarte International, PO Box 564, Alamo, CA 94507, United States

[2]David J. Leeds Associates, 11972 Chalon Road, Los Angeles, CA 90049, United States

Strong ground motions from three major California earthquakes are studied for several station locations. Records from free field instruments for the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge events are examined for epicentral distances up to 120 km. The radial and transverse components with respect to the station-epicenter directions are reviewed in terms of their time histories and spectra. In addition, the particle motions are evaluated for the three principal planes (horizontal, vertical-radial and vertical-transverse) associated with each station. The time histories and spectra for each of these components are computed. The objective of this study is to develop methods for estimating strong ground motions as functions of station azimuth with respect to source location and source mechanism orientation. Previous investigations have shown correlations between closely spaced stations which increase as the periods of the motions increase. Thus, displacements in station clusters generally show less variation than accelerations. The present analysis extends this approach by using spectra data and particle motions as additional tools to search for recognizable correlations between stations which are more widely spaced or symmetrically located (or nearly so) with respect to direction of the source mechanisms.

S51E-0106 0830h POSTER

Estimation of site-dependent decay parameter κ for strong motion simulation in southern Korea

Nam-Dae Jo[1] (++82-2-872-2713; endyjo@seismic.snu.ac.kr)

Chang-Eob Baag[1] (++82-2-880-6137; baagce@snu.ac.kr)

[1]School of Earth and Environmental Sciences, Seoul National University, San 56-1, Sillim-dong, Gwanak-gu, Seoul 151-747, Korea, Republic of

We estimated site-dependent decay parameter κ using 1049 accelerograms of small earthquakes (M2.5-M4.0) in southern Korea occurring from January 1999 to April 2003. The spectral decay parameter κ controls high-frequency contents of the model amplitude spectrum for the strong motion simulation using stochastic process. Generally, the κ is defined by a 1st order equation in hypocentral distance (R) as $\kappa_s + \kappa_q R$. The conventional procedure for estimation of κ cannot find the characteristics of the each site because it is for the computation of κ for a wide area. We estimated site-independent κ_q and dependent κ_s, separately. The procedure is to use the coda normalization method for the computation of site independent Q or corresponding κ_q as the first step followed by the next step, the computation of κ_s for each site using the given κ_q evaluated at the first step. With use of the technique, we found the distribution pattern of κ_s in southern Korea.

S51E-0107 0830h POSTER

Shear Wave Velocity Estimation Using PS Converted-Wave

Naomi Kano[1] (n.kano@aist.go.jp)

Takanobu Yokokura[1] (taka..yokokura@aist.go.jp)

Kazuo Yamaguichi[1] (yamaguchi-k@aist.go.jp)

Tsutomu Kiguchi[1] (kiguchi.t@aist.go.jp)

[1]Geological Survey of Japan/AIST, Higashi 1-1-1 Chuo 7, Tsukuba, Iba 305-8567, Japan

Shear (S-) wave velocity structure over the basement is one of the key elements for the estimation of strong ground motion generated by earthquakes. PS converted-wave reflection survey is superior to S-wave reflection survey in imaging the deeper structure, thus give us the deeper S-wave velocity information. But in the large Vp/Vs area, conventional velocity analysis and RMS velocity assumption fails to give us a good estimate of the S-wave velocity. The P-wave velocity derived from the velocity analysis is relatively reliable. When we get good images in both P-wave and PS converted-wave sections, correlation of the reflectors in the two sections gives us good estimates for Vp/Vs. Using these Vp/Vs values and P-wave velocities derived from P-wave velocity analysis, we can calculate S-wave velocities. We applied this methodology to a 3-component survey at Fuchu, Tokyo in Japan. The survey line was along the river and there is a well near by which is deep enough to reach the basement, about 2000m. The source was two vibrators. Three-component geophones are set in 10m interval. Geophones are fixed in 192 locations. The source-line was 3080m long so that we can get long offset data to use in PS converted-wave processing. From the P-wave sections, we can see the strata are inclining towards east. P-S converted-wave section has a good agreement with P-wave section. By correlation of the two sections, we derived Vp/Vs map of the section. Then we calculated the S-wave velocity using Vp/Vs value and P-wave velocity. We compared the velocity structure with the well log data. The derived S-wave velocities, ranging from 570m/s to 1780m/s, are in good agreement with the well data.

S51F MCC: 3009 Friday 1020h

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

Presiding: **C Ebinger,** Royal Holloway University of London**; S Klemperer,** Stanford University

S51F-01 1020h INVITED

The Origin of the African Superswell

Andrew A. Nyblade (814 863-8341; andy@geosc.psu.edu)

Penn State University, Department of Geosciences, University Park, PA 16802, United States

The African Superswell is comprised of three contiguous regions of anomalous topography, the East African Plateau, the Southern African Plateau, and the southeastern Atlantic Ocean basin. The long wavelength anomalous topography and bathymetry associated with the African Superswell is about 500 m, and many shorter wavelength features are superimposed on this long wavelength swell. The anomalous topography in East Africa and the anomalous bathymetry in the southeastern Atlantic Ocean basin can be readily attributed to buoyant support from thermally perturbed upper mantle structure. A region of low seismic wave speeds has been imaged in the upper mantle beneath much of East Africa, providing strong evidence for thermally perturbed upper mantle structure. Numerous hotspots, manifest as seamount chains, ridges and rises, are found within the southeastern Atlantic Ocean basin, and provide evidence of lithospheric reheating. In addition, some global tomographic images show a broad region of low seismic wave speeds in the upper mantle beneath the southeastern Atlantic Ocean basin, consistent with the presence of thermally perturbed upper mantle structure. In contrast, the anomalous topography of the southern African Plateau cannot be easily explained by Cenozoic heating of the upper mantle and consequently, it is difficult to attribute uplift everywhere within the African Superswell to Cenozoic thermal modification of the upper mantle. Several other explanations for plateau uplift in southern Africa have been advanced, such as dynamic uplift induced by anomalous structure extending upward from the core mantle boundary under southern Africa, delayed phase changes within the upper mantle, dynamic rebound after slab detachment following the cessation of subduction below the Cape Fold Belt at the end of the Triassic, and the underplating of low-density melts to the underside of the lithosphere at the time of Karoo volcanism. To these, we add the possibility of long lasting plateau uplift caused by Mesozoic mantle plume activity. The uplift history of southern Africa is poorly understood and new constraints on the timing of uplift are needed to advance further our understanding of plateau uplift in southern Africa.

S51F-02 1040h INVITED

The "African Anomaly"

Lianxing Wen[1] (631-632-1726; Lianxing.Wen@sunysb.edu)

Yi Wang[1] (631-632-1790; biphor@mantle.geo.sunysb.edu)

[1]State University of New York at Stony Brook, Dept. of Geosciences, Stony Brook, NY 11794, United States

Seismic results have consistently shown a significant low-velocity anomaly in the lower mantle beneath Africa. This "African anomaly" has a broad base near the core-mantle boundary, extending from the south Atlantic ocean to the Indian ocean, with steeply dipping edges, rapidly varying thicknesses (0-300 km) and geometries, and anomalously low shear wave velocities decreasing from -2% at 300 km above the core-mantle boundary to -9% to -12% at the core-mantle boundary. The base exhibits a L-shape changing from north-south orientation in the south Atlantic ocean to east-west direction in the Indian ocean, and occupies an area of about $1.7 \times 10^7 km^2$ and a volume of at least 4.6 $\times 10^9 km^3$. The "African anomaly" extends about at least 1300 km above the core-mantle boundary beneath southern Africa. It appears that its edges dip toward its center in the lower mantle. The structural features and velocity characteristics of the basal layer unambiguously suggest that the base is compositionally distinct. The seismic characteristics associated with the basal layer can be best explained by partial melt driven by a compositional change produced early in the Earth's history. The geometry of the African anomaly in the lower mantle suggests that the portion in the lower mantle may have a same origin as its base. A dense "African anomaly" is also not inconsistent with the surface uplift and geoid, even if we assume the surface uplift is caused by the "African anomaly". In this presentation, we present seismic and geodynamical modeling results associated with the "African anomaly" and discuss their implications to the origin of the "African anomaly".

URL: http://geophysics.geo.sunysb.edu/wen/

S51F-03 1100h

Influences on the Development of the Great Escarpment of Southern Africa

Nico Pieter Jan De Koker[1] (27835938584; johandk@uskonet.com)

Susan Jane Webb[1] (27117176606; webbs@geosciences.wits.ac.za)

Kevin Burke[1,2,3] (2024788816; burkek@dtm.ciw.edu)

[1]School of Geosciences, University of the Witwatersrand, Private Bag 3, Wits 2050, South Africa

[2]Department of Geosciences, University of Houston, Houston, TX 77204-5007, United States

[3]Department of Terestrial Magnetism, Carnegie Institution of Washington 5241 Broad Branch Road, Washington, DC 20015, United States

The topography of southern Africa has been modeled along a set of E-W profiles extending across the full width of the continent and in all cases crossing the Great Escarpment. Various combinations of lateral variation in elastic thickness, erosion and deposition rate, dynamic uplift and applied load are capable of accounting for the present day topography. Our aim is to contribute to testing the utility of models of African topography that relate Superswell development to a deep mantle Low Velocity Zone. Modeling the topography of the full width of the continent represents

progress in that direction but consideration of the timing of changes, as modelers of Apatite Fission Track results have long recognized, is also very important. We used offshore seismic reflection and oil well data, as well as paleoclimatology, including Global Circulation Model (GCM) results, in an attempt to improve resolution of the timing of southern African topographic evolution.

S51F-04 1115h INVITED

Formation and Evolution of Cratons: Insights from the Kaapvaal Project of Southern Africa

David E James[1] (202-478-8838; james@dtm.ciw.edu)

Mark D Schmitz[1] (schmitz@dtm.ciw.edu)

Matthew J Fouch[2] (fouch@asu.edu)

Steven B Shirey[1] (shirey@dtm.ciw.edu)

Richard W Carlson[1] (carlson@dtm.ciw.edu)

[1]Carnegie Institution of Washington, DTM, 5241 Broad Branch Rd., N.W., Washington, DC 20015, United States

[2]Department of Geological Sciences, Arizona State University, Tempe, AZ 85287, United States

The Kaapvaal Project examined fundamental questions of craton formation and mantle differentiation in the early Earth. The principal aim of the project was to characterize the physical and chemical nature of the crust and mantle of the Archean cratons of southern Africa in geologic detail, and to use the 3-D seismic and geochemical images of crustal and mantle heterogeneity to reconstruct cratonic evolution. 3-D body wave tomographic images reveal that high velocity mantle roots extend to depths of at least 200 km, and locally to depths of 250-300 km beneath cratonic terranes. No low velocity channel has been identified beneath the cratonic root. Seismic velocity determinations in both on-craton and off-craton mantle xenoliths are consistent with observed seismic structures. The Kaapvaal craton was modified ca. 2.05 Ga by the Bushveld magmatic event, and relatively low seismic velocities characterize the mantle beneath the Bushveld province. The crust beneath undisturbed Archean craton is comparatively thin (35-40 km), unlayered, and characterized by a strong velocity contrast across a sharp Moho. Post-Archean terranes and Archean regions disrupted by large-scale Proterozoic events tend to be characterized by thicker crust, complex Moho structures and higher lower crustal velocities. Re-Os depletion model age determinations confirm that the mantle root beneath the cratons is Archean in age. No age progression with depth is observed in the mantle keel, indicating that it was at least 200 km thick even in Archean time. Both laboratory experiments and geochemical results from inclusions in diamonds, eclogite xenoliths, and coeval crustal rocks suggest that subduction processes played a central role in the initial formation of Archean crust, the melt depletion of Archean mantle, and the assembly of continental lithosphere from smaller cratonic blocks. Coordinated geochronological studies of crustal rocks and mantle xenoliths have also shown that the timing of final stabilization of the extant craton correlates with convergent margin processes and assembly of terranes along its northern and western ramparts. Numerous lines of evidence thus appear to support the petrogenetic coupling of continental crust and lithospheric mantle through a model of continental arc magmatism, subduction zone mantle wedge processing and terminal collisional advective thickening to form Archean continental tectosphere. Analysis of lower crustal xenoliths has shown that much of the deep craton experienced a dynamic and protracted history of tectonothermal activity that is temporally associated with events seen in the surface record. Recent studies show, moreover, that compositions of diamonds and diamond inclusions are correlated with seismic P-wave velocities at depths in the diamond stability field. Although the deep root structures beneath the southern Africa cratons have been basically stable since the Archean, they have been repeatedly subjected in post-Archean time to thermal perturbations and varying degrees of metasomatic modification.

URL: http://www.ciw.edu/kaapvaal

S51F-05 1135h

Mantle Anisotropy, Collisional Rifts and the Magmatic Evolution of Southern Africa: Old (Mantle) Fabric Never Dies.

Paul G Silver[1] (202-478-8834; silver@dtm.ciw.edu)

Matt Fouch[2] (480-965-9292; fouch@asu.edu)

Stephen Gao[3] (785-532-2243; sgao@ksu.edu)

Mark Schmitz[1] (202-478-8458; schmitz@dtm.ciw.edu)

[1]Carnegie Inst. of Washington, DTM, 5241 Broad Branch Rd. NW, Washington, DC 20015, United States

[2]Arizona State University, Box 871404, Tempe, AZ 85287-1404, United States

[3]Kansas State Univerisity, Dept. of Geology 207 Thompson, Manhattan, KS 66506-3201, United States

The observed seismic anisotropy of the southern African mantle, made possible by data from the Southern African Seismic Experiment, provides important constraints on modes of mantle deformation beneath this ancient continent. We find that the mantle anisotropy is dominated by deformational events in Archean times occurring within the lithosphere, and can thus be used to assess the mantle's role in the tectonic evolution of this region. The pattern of mantle anisotropy derived from shear wave splitting observations reveals two noteworthy characteristics. First, there is a spatially continuous arc of mantle anisotropy extending from the western Kaapvaal and Zimbabwe Cratons to the northeastern Kaapvaal. All along the arc, the splitting fast polarization direction, ϕ, is subparallel to the trend of the arc. Given the crust/mantle chronology associated with these regions, the anisotropy likely represents deformation that occurred at ca. 2.9 to 2.7 Ga during collisional accretion of both the western Kimberley and northern Pietersburg blocks onto the ca. 3.2 Ga eastern shield of the Kaapvaal, with accretion on the northern ramparts of the Kaapvaal ultimately culminating in the Neo-Archean Limpopo orogen. Second, there is mantle anisotropy closely associated with the Great Dyke with values of ϕ parallel to the Dyke, just north of and distinct from this arc of anisotropy. We present evidence that the mantle fabric that generates seismic anisotropy also constitutes preexisting structure in the mantle that is subsequently reactivated, much like the more commonly cited reactivation of crustal structures. In particular, we argue that the Neo-Archean collision imparted a mechanical anisotropy to the mantle that controlled the subsequent magmatic history of cratonic southern Africa (old fabric never dies!). Study of mechanical anisotropy of olivine aggregates suggests that failure is most likely parallel to the olivine b-plane, which for transcurrent deformation is a vertical plane striking parallel to the splitting fast polarization direction. In particular, we suggest that three major Precambrian magmatic events: the Great Dyke, the Ventersdorp, and Bushveld all represent extensional failure along planes oriented parallel to the local splitting fast polarization direction. In each case, the rift orientations associated with these magmatic events are locally subparallel to values of ϕ, with the Great Dyke being the most dramatic example. In addition, each of these magmatic events is likely a collisional rift, similar to the Baikal rift of northern Eurasia, where the stress field associated with a collision produces extension and rifting for orientations at a high angle to the belt of the collision. Precise crustal geochronology associates the Ventersdorp and Great Dyke with the earliest and latest phases of the Neo-Archean Limpopo collision, respectively, whereas the Bushveld is temporally linked to the Proterozoic Magondi orogen, which is also responsible for the reactivation of Neo-Archean structures in the Limpopo and surrounding areas. In all cases the rifts are at a high angle to the collisional belt as predicted for a collisional rift.

S51F-06 1150h

Anisotropic complexity in Tanzania and Kenya from teleseismic shear-wave splitting

Kristoffer T. Walker[1] (ktwalker@pangea.stanford.edu)

Andrew A. Nyblade[2] (andy@geosc.psu.edu)

Goetz H.R. Bokelmann[1] (goetz@pangea.stanford.edu)

Simon L. Klemperer[1] (sklemp@pangea.stanford.edu)

Thomas J. Owens[3] (owens@sc.edu)

[1]Department of Geophysics, Stanford University, Mitchell Building, Stanford, CA 94305, United States

[2]Department of Geosciences, Penn State University, 503 Deike Building, University Park, PA 16802, United States

[3]Department of Geological Sciences, University of South Carolina, 701 Sumter Street, Columbia, SC 29201, United States

Previous studies have found that shear-wave splitting fast directions in western Kenya are roughly parallel to the Kenya Rift, part of the East Africa rift system. This anisotropy can be explained by three different mechanisms: fossilized anisotropy in the lithosphere from previous orogenic events, vertically oriented magma-filled lenses in the lithosphere and asthenosphere, and asthenospheric flow along the base of the plate that is guided by a background asthenospheric flow current and/or channeled by upwarped basal lithospheric topography beneath the rift. Preliminary results from Ethiopia appear to be similar to those in Kenya (M. Kendall, pers. commun., 2003). Resolving between these mechanisms has major implications on the evolution of rifting, the geodynamics associated with rift/hotspot interactions, and the origin of anisotropy detected by shear-wave splitting. Tanzania and Kenya comprise a unique, tectonically complex region due to the presence of a rigid craton, paleo-thrust belts and shear zones, active magmatism and rifting, and possibly even a nearby mantle plume. We present new results of teleseismic splitting analysis of SKS, SKKS, PKS, and S recorded by 20 broadband seismic stations in Tanzania, 7 broadband stations in Kenya, and 3 permanent broadband GSN stations in Kenya and Uganda. Fast directions (phi) from most of the craton stations are oriented WNW and are subparallel to both absolute plate motion and the strike of the well-defined surficial fold axes. The delay times (dt) are $\sim$0.5 s, and when combined with previously published surface-wave results, suggest anisotropy in the lower lithosphere and asthenosphere beneath the craton, which would be expected due to relative motion between the WNW moving plate and a fixed underlying mantle. However, the fast direction/structural fabric correlation at the surface, and the lack of WNW plate-motion parallel fast directions in the Kaapvaal craton in southern Africa suggests that vertically coherent deformation best explains craton splitting. In the mobile belts and rifts, phi is roughly parallel to the strike of the rifts, the paleo-shortening directions, and the edge of the craton, with significant variations between stations. For most of these stations, dt ranges from $\sim$0.8-1.5 s, and suggests that at least a significant part of the anisotropy is in the asthenosphere. We interpret the dominant off-craton mantle anisotropy in Kenya and Tanzania to be due to shear along the base of the plate associated with plume flow around the craton keel. Significant variations between nearby stations are assumed to be due to the secondary effects of fossilized anisotropy or anisotropy due to magma-filled lenses or partially molten dikes in the lithosphere/asthenosphere. Our data strongly suggest that extension has not led to the development of a resolvable LPO in the lithospheric mantle, which is surprising given the long history of extension in the region. This suggests that mantle-lithosphere extension in East Africa occurs within narrow rift zones via ductile thinning and/or dike intrusion, possibly facilitated by mechanical lithospheric anisotropy from fossilized N-S fabrics that originated from prior orogenic events.

S51F-07 1205h

Melt migration and mantle anisotropy beneath the Ethiopian rift

J-Michael Kendall[1] (44 113 343 5258; m.kendall@earth.leeds.ac.uk)

Graham Stuart[1] (g.stuart@earth.leeds.ac.uk)

Ian Bastow[1] (i.bastow@earth.leeds.ac.uk)

Cindy Ebinger[2] (c.ebinger@gl.rhul.ac.uk)

[1]University of Leeds, School of Earth Sciences, Leeds LS2 9JT, United Kingdom

[2]Royal Holloway - University of London, Department of Geology, Egham TW20 0EX, United Kingdom

The EAGLE broadband experiment aims to study the crust and upper-mantle structure in the northern Ethiopian rift, a region of transition from continental to oceanic rifting. 30 broadband seismometers have been deployed for a period of 16 months over an area of 250 km^2, centered on the Nazret volcanic zone. These stations are complimented by data from a 3-month deployment of 50 instruments concentrated in the rift valley. We present analysis of upper-mantle anisotropy from measurements of shear-wave splitting in SKS, SKKS and PKS phases. The concentrated station coverage and nearly 500 splitting measurements provide a detailed picture of mantle anisotropy in a rifting environment. In general the results are of high quality with low error estimates. The highest splitting ($>$ 2 secs) occurs on the rift flanks, where the strain partitioning is expected to be highest. There is an asymmetry in results from either side of the rift (i.e., the Ethiopia plateau vs. the Somalian plate). Within the Rift there is a consistent increase in delay times towards the north and Afar, from 1.0 secs in the south to 1.6 secs in the north. Outside the Rift, the polarisations of the fast shear-wave lie in a NE–SW rift–parallel trend and do not align with the direction of absolute plate motion. Within the Rift the orientations swing to more northerly azimuths, following magmatic segments and faulting patterns. The increase in rift splitting times northwards correlates with the amount of magma within the system. Large variations in magnitude of splitting or orientation of the shear-wave over short distances suggests that the source of the anisotropy is quite shallow ($< 100km$). Cumulatively, these results suggest that the anisotropy is associated with melt migration beneath the rift. To explain these results we appeal to recent deformation experiments of Holtzman et al. (2003) which show anisotropy in partially molten rocks being due to a combination of preferred melt inclusion alignment, layering and olivine crystal alignment.

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