S52J-08 1745h

Mantle Seismic Structure Beneath Southern Africa

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In this study, we examine mantle seismic structure for a broad region beneath southern Africa. The goal of this work is to provide detailed constraints regarding the relationship between surface geology and tectospheric structure beneath southern Africa and their implications for craton formation and evolution. We also characterize deeper mantle structure beneath the region to provide new constraints on structural variations between the tectosphere and mid-mantle. Waveform data for this analysis were recorded on an 82-station broadband seismic array located in South Africa, Zimbabwe, and Botswana. The complete array has a footprint of ~1 million km^2, and was one component of the multidisciplinary Kaapvaal Project conducted by the Carnegie Institution of Washington, MIT, and several southern African academic institutions and industry collaborators.

We present results of body wave tomography for both P- and S-waves using a nonlinear inversion technique that determines relative velocity perturbations across the study region. Our results indicate P-wave velocity variations of ~±1.2%, and S-wave velocity variations of ~±1.6% that are similar in lateral and depth distribution to P-wave velocity variations. The tomographic images provide clear evidence of mantle structures that mimic the dominant surface geology features across southern Africa. Specifically, a thick (~250-300 km) mantle keel exists beneath the Kaapvaal craton; a slightly thinner (~225-250 km) keel exists beneath the Zimbabwe craton and parts of the Limpopo mobile belt. No subtectospheric low velocity zone exists across the region. These results are consistent with previous surface wave analyses for the region [Ritsema and van Heijst, Geology, 2000], as well as more recent surface wave analyses using data from the Kaapvaal Project seismic waveform dataset [A. Li, pers. comm.]. Additionally, lower than average cratonic mantle velocities exist at smaller scales beneath the surface expression of the Bushveld Complex, a 2.05 Ga layered mafic intrusion. These reduced velocities may be due to mantle refertilization during the Bushveld intrusion, or they may be caused by a thermal perturbation of more recent origin, perhaps related to the Karoo magmatic event. Finally, we observe a well-resolved, concentrated zone of anomalously lower than average velocities at ~1000 km and deeper beneath the Kaapvaal craton. We suggest that this region is likely related to previously observed low velocity deep mantle associated with the South African superplume.

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

S52K MCC: 3011 Friday 1600h

Collateral Damage: Earthquake Source Characteristics II *(joint with T)*

Presiding: **S Baher,** U.S. Geological Survey**; J Ampuero,** Princeton University

S52K-01 1600h

Seismic Constraints on Mechanisms of Deep Earthquake Rupture

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Observations of the depth distribution of seismicity suggest that several mechanisms cause deep earthquakes. Cold subducting slabs exhibit a broad peak in seismicity between 300 and 530 kilometers depth that is best explained by transformational faulting of metastable olivine. Cumulative seismic moment release increases sharply at about 530 km depth in both cold and warm slabs, implying that events deeper than this are controlled by an equilibrium rather than a metastable phase change, which would be temperature dependent. This, together with the observation that deep seismicity predominates near the garnet-rich upper boundary of the subducting plate (former oceanic crust), suggests that the transformation of garnet to perovskite, which may release considerable water, is integral in the cause of earthquakes deeper than 530 km, where most deep earthquakes occur.

S52K-02 1615h

Very Deep Earthquakes Occur Above the Depressed Top of the Lower Mantle

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We present unequivocal evidence that very deep earthquakes near 690 km still occur above the "660-km" discontinuity which separates the lower mantle and the transition zone. The strongest evidence comes from two recent earthquakes that occurred at great depths of 688±10 km and 693±10 km along the Tonga and the Kurile-Kamchatka subduction zones, respectively. The focal depths are constrained by relative timing (with respect to direct *P* and *S* arrivals) of *pP*, *sP*, and *sS* phases along paths unaffected by subduction or *pwP*. Then we directly determine the **relative** position of the foci and the "660-km" discontinuity based on the principle that triplicate arrivals are strong from a source located above a discontinuity, but such arrivals would be completely absent for a source located just below the discontinuity. We observe strongly triplicate *P* and *S* waveforms that exhibit distinct move-outs across broadband (high-resolution), permanent seismic arrays at regional distances (7°-20°). Thus these earthquakes at depths near 690 km must have occurred above a strong discontinuity. We matched the observed waveforms with synthetic seismograms and the results show the prominent contrast in seismic wave speeds across the discontinuity is consistent with that across the "660-km" discontinuity of the average Earth. Thus the "660-km" discontinuity is apparently deflected downward by about 5 km farther below the hypocenters, reaching a depth of about 695 km. Downward deflection of the "660-km" discontinuity below earthquakes as deep as 690 km implies that the Clapeyron slope associated with the "660-km" discontinuity is large and the necessary conditions to trigger deep earthquakes exist only above the lower mantle.

S52K-03 1630h

The mechanism of great Banda Sea earthquake of 01 February 1938: Applying the method of Preliminary Determination of Focal Mechanism to a historical event

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A moment tensor solution is derived for the 1938 Banda Sea earthquake, one of the largest events for which no definitive focal geometry has been published. We apply the PDFM method, which consists of inverting for a moment tensor using exclusively the spectral amplitudes of mantle waves, while discarding the phase information affected by uncertainties in relative timing between historical records. From a dataset of 17 records at 7 stations, we obtain a robust solution, featuring a very large moment of 8.4*10**28 dyn-cm, the centroid depth being constrained at 60 km by minimizing the r.m.s. residual of the inversion. The method involves an inherent two-fold 180-deg. indeterminacy on strike and slip, which is lifted by the polarization of long-period body waves read individually on original records, resulting in a mostly thrust-faulting mechanism (strike: 276 deg.; dip: 63 deg.; slip: deg.). This confirms the event as ranking among the ten largest moments ever published. Its deeper than normal focus agrees well with the minor level of reported damage, and with the generation of a relatively benign tsunami. The 1938 event shares its compressional axis with that of the smaller and deeper 1963 shock to the Southwest, which probably expresses coherence in the regional contortion of the subducting Australian plate lithosphere.

S52K-04 1645h

Rupture Characteristics and Aftershocks of the July 15, 2003 Carlsberg 'H' (Indian Ocean) M_w 7.6 Earthquake

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The occurrence of a M_w 7.6 earthquake near the Carlsberg ridge (15 July, 2003) provides valuable information about earthquake rupture processes in oceanic lithosphere, which are not well understood, and the distributed deformation of the India-Australia plate. The earthquake had a strike-slip mechanism opposite to that of the transform faults on the ridge, and appears to have ruptured a fracture zone (designated as 'H' by *Royer et al.*, 1997) within the India-Australia composite plate. We examine the rupture characteristics of this earthquake using the full spectrum of seismic radiation. Inversion of the body waves indicates rapid rupture propagation toward the NE, away from the Carlsberg Ridge, for a distance of ~200 km. The average rupture velocity is well constrained and is ~3.6 km s^{-1}. The total source duration is ~60 s; however, nearly all of the moment release occurs in the last 30 s. The age of the lithosphere in the area of largest moment is release is 10-15 Ma. The body waves can be well fit with a simple rupture model and no jump of fracture zones is required, as has been suggested for some oceanic earthquakes (e.g., *McGuire et al.*, 1996). The source process is very similar to the well-studied 1994 M_w 7.0 earthquake along the Romanche transform in the equatorial Atlantic (*Abercrombie and Ekström*, 2001). We also analyze the aftershock distribution using multiple-hypocenter relocation techniques and moment-tensor analysis using intermediate-period surface waves. Only 15 aftershocks ($M > 4.5$) are listed in the USGS catalog, which is typical of large oceanic earthquakes (e.g., *Boettcher and Jordan*, 2001). Moment tensors obtained from five of the aftershocks show a diversity of focal mechanisms. We interpret a cluster of aftershocks located at ~1° S as representing extension which results from the stress field of the mainshock at the end of the rupture. This interpretation is consistent with the 200-km rupture length inferred from body waves. The focal mechanism of the July 15 earthquake indicates N-S extension within the oceanic lithosphere east of the Carlsberg Ridge. *Royer and Gordon* (1997) interpreted this extension as part of the deformation associated with a diffuse plate boundary between the Indian plate and a hypothesized Capricorn Plate. They placed the northern boundary of the diffuse region of deformation near 7° S. The occurrence of the July 15 earthquake indicates this diffuse boundary is wider than previously believed.

S52K-05 1700h

Spatial Variation of Aftershock Stress Drops in the focal Area of the 2000 Western Tottori Earthquake (Mw=6.6)

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Stress drop is one of key parameters for understanding the source of an earthquake. Many researchers have been interested in the distribution of static stress drop on the fault plane of large earthquakes [e.g. Miyatake, 1992; Mikumo and Miyatake, 1995]. However, the relationship between the slip/stress drop distribution on the mainshock fault plane and spatial distribution of aftershock stress drops has not been studied well.

We estimated stress drops of 450 aftershocks of the 2000 Western Tottori earthquake using seismograms recorded at nearby NIED Hi-net stations. Observed velocity spectra are first corrected for radiation pattern obtained from focal mechanisms. Then, the optimal

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corner frequency, seismic moment, and the propagation effect (Q and site) at each station are calculated by grid-search using genetic algorithm by comparing the corrected observed spectrum with the synthetics calculated by BoatwrightOs (1978) method. A stress drop for each aftershock is calculated from its corner frequency and seismic moment according to Brune (1970). We compare the obtained spatial distribution of aftershock stress drops with the slip/stress drop distribution of the mainshock proposed by Mikumo et al (2003). The results show that (1) the large slip and/or high stress drop area (the possible asperity) indicated by Mikumo et al. (2003) is surrounded by aftershocks with high stress drops. And in the contrast, aftershocks that occurred inside the asperity have relatively low stress drops. This maybe explained as that the occurrence of the main-shock released most of the stress concentrated inside the asperity, and caused the stress concentration in the surrounding area; (2) Aftershocks located in the northern part of the aftershock area show lower stress drops relative to those in the southern part. Surface geological studies (Sakamoto et al.,1982, and Teraoka et al., 1996) revealed that the northern part of the aftershock area is dominated by rhyolitic lava and pyroclastic rocks, whereas the southern part by granite. The difference of stress drops between the northern and southern parts may be attributed to the spatial variation of the strength of the rocks.

S52K-06 1715h

Regional Moment Tensor Inversion With Application to the 2003 Algeria Earthquake

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Earthquake moment tensor (MT) solutions provide important parameters for seismotectonic studies and for calibrating earthquake size. The broadband seismic station network in the European-Mediterranean region allows MT analysis and since the year 2000 the Swiss Seismological Service provides regional MT solutions. For larger events ($M_w \geq 4.8$), we automatically determine MT solutions using near real-time available data. Our solutions provide accurate estimates of earthquake size, depth and deformation style that are available within 90 minutes after event occurrence. We post our results on the Web and disseminate them via the European-Mediterranean Seismological Center. Merging of near real-time data with off-line data available days to months after an earthquake allows routine MT analysis in the entire European-Mediterranean region from 25^{o}N to 90^{o}N and from 35^{o}W to 55^{o}E. For areas with dense station coverage, like Switzerland, events as small as $M_w = 3.5$ are analyzed; in areas far from seismic stations, like the North Atlantic Ridge, the lower analysis threshold is near $M_w = 4.8$. We determine about 200 MT solutions per year. The solutions are posted on the Web and are included in the ISC data base. For the recent, destructive earthquake in Northern Algeria on May 21, 2003, we provided 7 automatic MT solutions for the main shock and larger aftershocks. The mechanism, size, and depth estimates were later confirmed by Harvard CMT solutions for the largest events and by routine MT analysis. Routine analysis, in addition, allowed source parameter retrieval for several immediate aftershocks, that could not be analyzed automatically due to main event coda, and of many smaller events, where it is crucial to use all available waveform data to obtain a well constrained mechanism. All events were shallow and showed a thrust-type mechanism with NNW to N oriented P-axes (median 338^o) parallel to the predicted Africa-Eurasia plate motion direction (330^o). The P-axes orientation of a single strike-slip event is consistent with the thrust events.

S52K-07 1730h

The Miyagi-ken-hokubu, Japan, earthquake, 2003 July 26 and its the largest fore-shock and largest after-shock

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On the morning of July 26, 2003, a destructive earthquake (Ms 6.1) struck Miyagi-ken, northeastern Japan. More then 600 people were injured mainly by fallen furnitures. The moment tensor determined by NIED shows a reverse-faulting with P-axis rotated slightly counterclockwise from the maximum compressive stress axis of the tectonic stress northern Japan. The moment tensor for the largest fore-shock (Ms 5.5) and the largest after-shock (Ms 5.4) show reverse faulting, while the strike directions for those three large earthquakes are different from each other. In this study, we apply a joint inversion (Yagi et al., 2003) for both strong ground motion and teleseismic body wave data to study the source process for the largest fore-shock, the main-shock, and largest after-shock. We use 3-component acceleration data recorded at 8 K-net stations, and vertical component teleseismic P-waveform data recorded at 7 stations provided by IRIS-DMC. Applying a multi-time window inversion to above data set, we determined spatial and temporal distribution of fault slip. To get stable and better resolution for rupture model, we incorporated prior information into observed data, and determined the optimal relative weights of information from the observed data and prior constraints using an optimized ABIC. We found that the sites for the largest fore-shock, the main-shock, and the largest after-shock are partitioning, which suggest three fault segments ruptured, separately. The P-axis of the fore-shock is consistent with the maximum compressive stress axis for tectonic stress, while P-axis for the main-shock and largest after-shock rotated counterclockwise form the maximum compressive stress. Our results suggest a sequence of fault motions as follows. The main-shock started the edge of fore-shock rupture area, and the largest aftershock started in northern side of main-shock, where the rupture of the mian-shock terminated.

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S52K-08 1745h

The source process of the 1971 Sakhalin earthquake estimated using tsunami waveforms

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On September 5, 1971, the Sakhalin earthquake (Ms 7.1) occurred off southeast coast of Sakhalin, Russia. The earthquake generated a tsunami observed at tide gauges in Sakhalin and Hokkaido. This earthquake is one of several large earthquakes occurred along the eastern margin of the Japan Sea in the last century. Other large earthquakes are the 1940 Shakotan-oki (Mw 7.5), 1964 Niigata (Mw 7.5), 1983 Japan Sea (Mw 7.9), 1993 Hokkaido Nansei-oki (Mw 7.8) earthquakes. Those earthquakes are considered to be the underthrust events occurred along the convergent boundary between the Eurasian and North American plates. The 1971 Sakhalin earthquake has not been well studied although the other large earthquakes have been studied well using both seismic and tsunami waveforms. In this paper, we studied the source process of the Sakhalin earthquake using the tsunami waveforms observed at tide gauges in Hokkaido, Japan. The tsunami waveforms are computed numerically using the finite difference method of the linear long wave equation. The grid size is basically 20 sec arc (about 600m), but finer grids (4 sec) are used around the tide gauge stations. The dip angle of the fault is assumed to be 45 degree which is typical in this region. The length and width of the fault are assumed to be 70 km and 25 km, respectively. Comparison of computed and observed tsunami waveforms shows that the slip amount of the fault is about 1.5 m. By assuming that the rigidity around the fault is 4 x 10**10 N/m2, the seismic moment is estimated as 1.05 x 10**20 Nm (Mw 7.3). The tsunami waveforms observed at tide gauges in Hokkaido, Japan, were explained by the fault model. This confirms that the Sakhalin earthquake is another underthrust event occurred along the convergent boundary existing near the eastern margin of the Japan Sea.