Intracontinental Deformation and Crustal Structure: Hangay Dome, Central Mongolia

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Abstract

Mongolia has a complex tectonic history. The lithosphere was formed from multiple plate collisions in the Neoproterozoic - Early Paleozoic associated with the Central Asian Orogenic Belt. The region has since been modified by Mesozoic rifting, Cenozoic magmatism, and major strike-slip faulting along terrane boundaries and sutures. Central and Western Mongolia are part of the larger high elevation, low-relief Mongolian Plateau. To gain deeper understanding of modern deformation within the Hangay Dome in Central Mongolia, two years of teleseismic, regional, and local seismicity, recorded by a dense array of 72 temporary broadband seismic stations, was used to determine the distribution of seismicity and crustal structure. Results from receiver function analysis indicate the Hangay Dome has a crustal thickness ranging from 41-59 km. The thickest crust resides under areas of high topography and generally thins to the east. Average Vp/Vs ratios range from 1.77-1.8. We located the 7680 events detected by the array using a local 1D velocity model. Many events outline the Bulnay and Bogd faults, where historic Mw 8 earthquakes have occurred. Considerable seismicity is observed on the South Hangay – Bayan Hongor Fault System, including a Mw 4.6 earthquake. Seismicity is also observed along the Egiin Davaa and Mogod Faults. Preliminary results from a joint tomographic inversion for earthquake location and 3D velocity structure show a relatively uniform crust, where P-wave velocities in the uppermost crust range from 5.8-6 km/s. In these preliminary inversions, large portions of the region show Vp exceeds 7.0 km/s in the lower 10-15 km of the crust. The depth to the Moho is consistent with results from the receiver function analysis. Lateral velocity variations generally align with terrane boundaries and faults, such as the South Hangay - Bayan Hongor Fault System. Seismicity relocated in the inversion outline the South Hangay, Egiin Davaa, and Bulnay Faults. In addition, a cluster of seismicity locates between the Egiin Davaa and Hag Nuur faults, where no fault has previously been mapped. Seismicity in the Hangay Dome is generally confined to the upper 20 km, suggesting a rheological transition from brittle to ductile at this depth.

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INTRACONTINENTAL DEFORMATION AND CRUSTAL STRUCTURE: HANGAY DOME, CENTRAL MONGOLIA

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OBJECTIVES

- Facilitate a deeper understanding of modern deformation, and develop an understanding of the role of inheritance in modern deformation within the Hangay Dome region of Central Mongolia
- Determine the distribution of seismicity and crustal structure in the Hangay Dome of Mongolia using a joint tomographic inversion for earthquake location and 3D velocity structure

MOTIVATION

- The Hangay Dome is located within the Asian continental interior where large magnitude intracontinental seismicity is poorly understood.
- Mongolia was formed from multiple plate collisions in the Neoproterozoic - Early Paleozoic associated with the Central Asian Orogenic Belt (CAOB) (Figure 1), and is comprised of many accreted terranes which generates a complex inherited crustal structure.
- Large to moderate seismicity on major strike slip faults, demonstrates the potential seismic hazard within an intracontinental setting (Figure 2), and seismicity is localized around ancient terrane sutures.

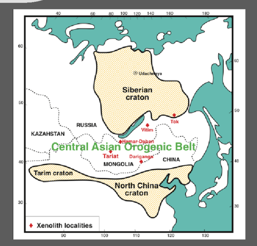


Figure 1: Location of Mongolia within the CAOB

Figure 2: Location of historic M_w 8 earthquakes in Mongolia.

TECTONIC SETTING

- The Mongolian lithosphere was formed from multiple plate collisions in the Neoproterozoic - Early Paleozoic associated with the Central Asian Orogenic Belt (Figure 1).
- The region has since been modified by Mesozoic rifting, Cenozoic magmatism, and major strike-slip faulting along terrane boundaries and sutures (Figure 2).
- Central and Western Mongolia are part of the larger high elevation, low-relief Mongolian Plateau.

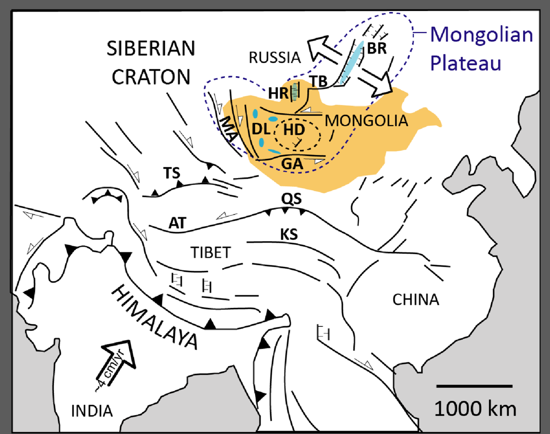


Figure 3: Far field effects of the India-Eurasia plate collision

- Far-field effects from the India-Eurasia plate collision create differing strain and kinematic regimes throughout Mongolia.
- Shortening from the collision is being accommodated by large left-lateral strike-slip faults, where escape tectonics is causing a lateral extrusion of the Eurasian plate (Figure 3).

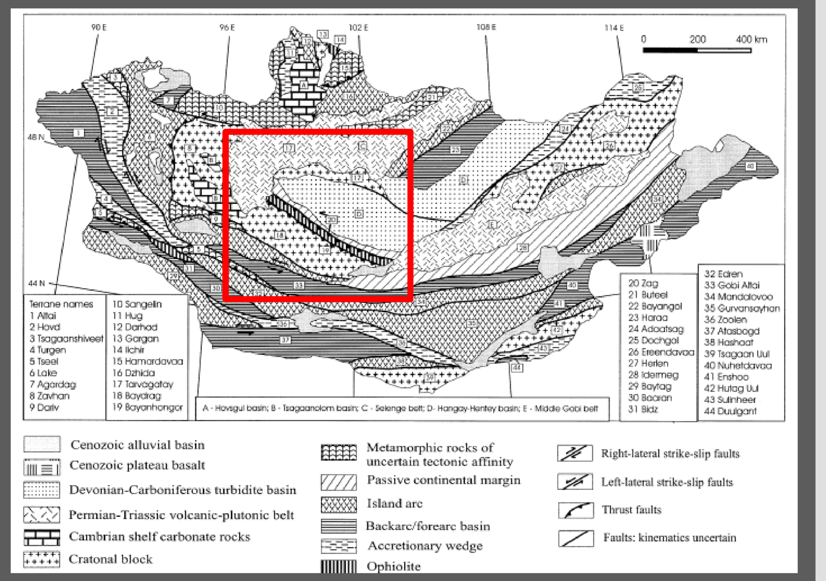


Figure 4: Terrane boundaries of Mongolia[2]. The Hangay Dome study area is outlined by the red square.

BUILDING THE INITIAL CATALOG

- We use local seismicity recorded by a 72 station array from the Central Mongolia Seismic Experiment to characterize seismicity and 3D velocity structure in the Hangay. We start by using the REST Autopicker[3] to develop a catalog of P and S arrival times and event locations. The catalog includes 24,585 events (318,104 P and 203,550 S picks), 8,378 of which are depth ≤ 50 and have at least 15 defined phases.
- A Traditional STA/LTA[1] detection algorithm was originally used on the dataset, resulting in 38,406 detected events (479,626 P and 100,080 S picks), 3645 of which are depth ≤ 50 and have at least 15 defined phases.
- Manual review of events detected by REST show its accuracy matches that of the traditional STA/LTA detection scheme for P-picks, improves the accuracy (Figure 5), and increases the number of S-picks (Figure 6).
- REST is able to generate a more complete catalog than a traditional STA/LTA detection algorithm.

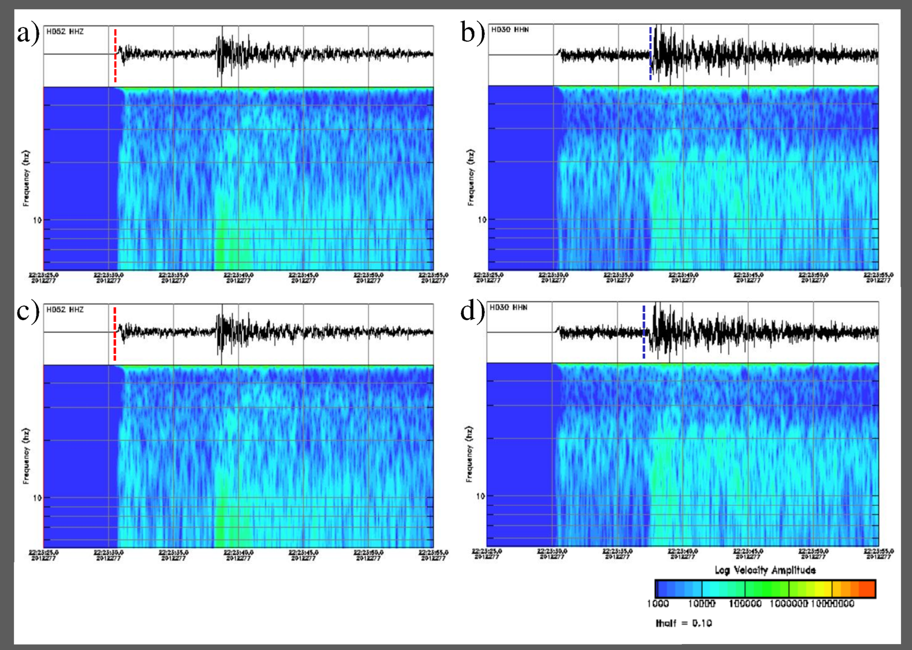


Figure 5: a) REST picking a P-wave arrival on station number HD52 from an October 3rd, 2012 event. **b)** REST picking a S-wave arrival on station HD30 for the same event. **c)** STA/LTA picking a P-wave arrival on station number HD52 for the same event. **d)** STA/LTA picking a S-wave arrival on station number HD30 for the same event.

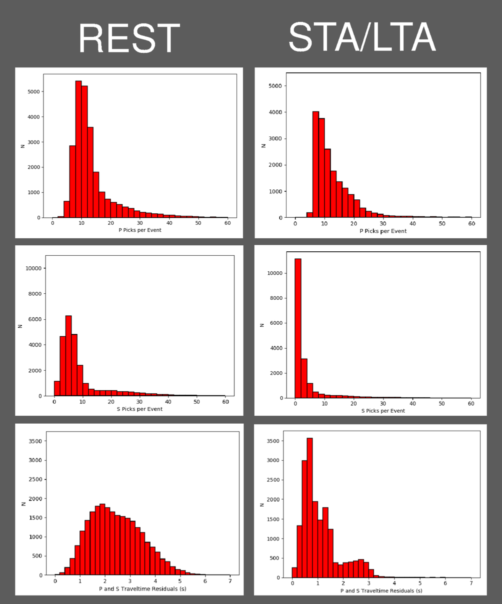


Figure 6: Histograms of P, S, and time residuals for the REST detection scheme versus STA/LTA.

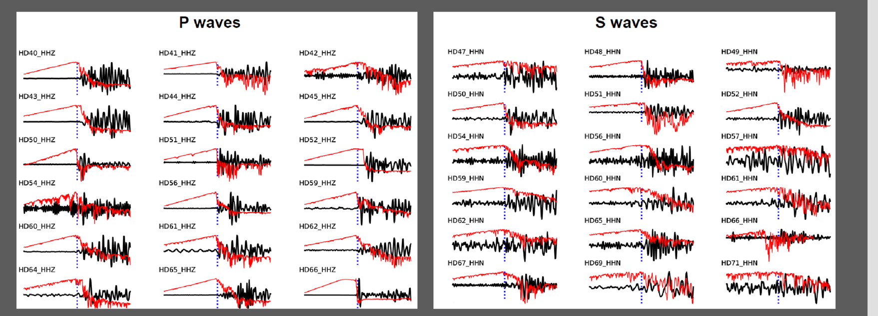


Figure 7: Examples of onset estimation functions for P and S waves.

- REST starts by producing rough estimates of earthquake onsets which are refined iteratively.
- A moving window progresses through the time series and uses autocorrelations computed within that window to assess how different the autocorrelation is from zero (mean Gaussian noise).
- REST defines the onset of an event where the waveform is comparatively dissimilar to a segment of noise windowed on the waveform from earlier in time (Figure 7).

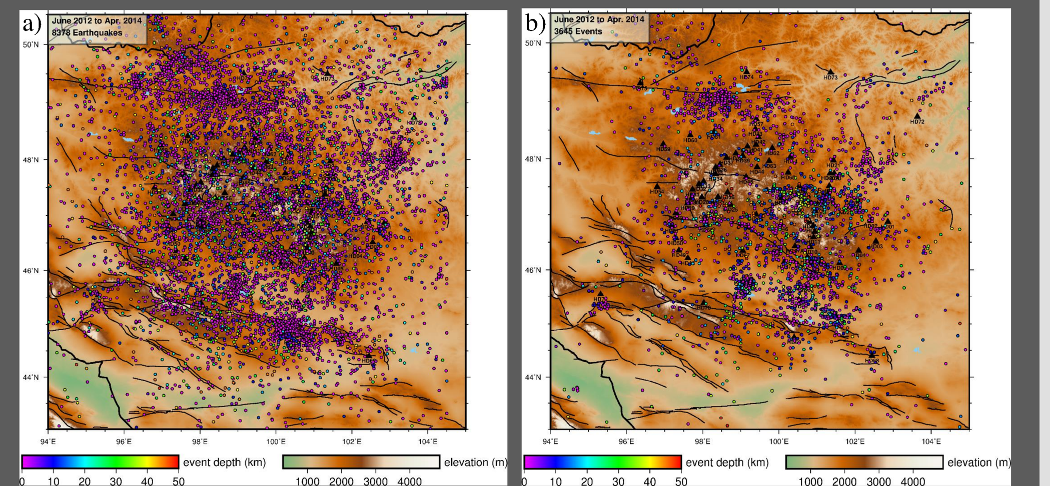


Figure 8: a) Catalog of the 8378 events detected and located by the REST, and **b)** the 3645 events detected and located by the STA/LTA detection scheme, where depth ≤ 50 and the events have at least 15 defined phases for both databases.

RESULTS AND CONCLUSIONS

CRUSTAL THICKNESS

- Results from receiver function analysis indicate the Hangay Dome has a crustal thickness ranging from 41-59 km (Figure 9).
- The thickest crust resides under areas of high topography and thins to the east.
- Average Vp/Vs ratios range from 1.75-1.77.

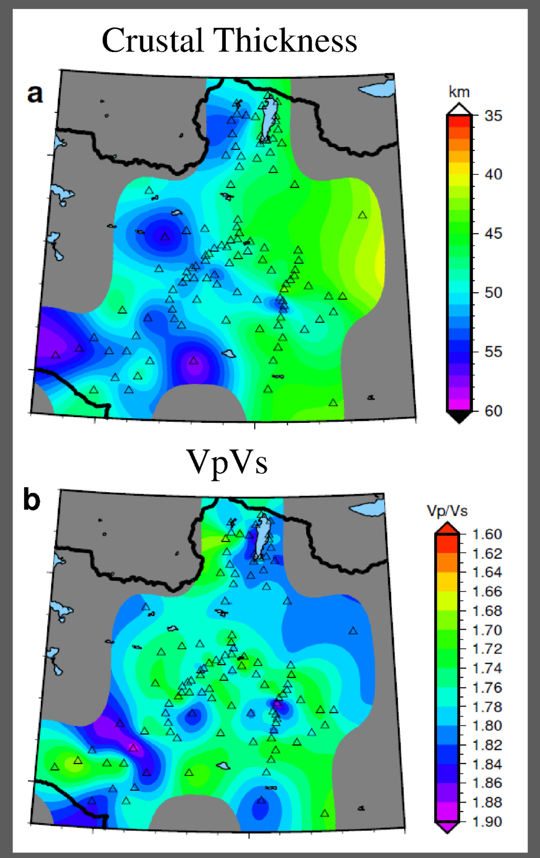


Figure 9: Map of Western/Central Mongolia with the seismic station locations and crustal thickness contours as determined by receiver function analysis.

TOMOGRAPHIC INVERSION

- Finite difference tomography[4] was used to invert the P and S travel times and initial locations from the REST processing scheme. The REST database was culled prior to the inversion to only incorporate events with depth ≤ 50 km, uncertainty for the major and minor axes ≤ 20 km, depth uncertainty ≤ 25 km, at least 15 phases inclusive of both P and S, and at least two S phases.
- FDtomo[4] uses an iterative technique to update the 3D velocity model and earthquake hypocenters until P and S wave traveltime residuals are minimized and a best fit to the data is determined. Velocity perturbations are smoothed over 30 km in latitude and longitude, and 20 km vertically.

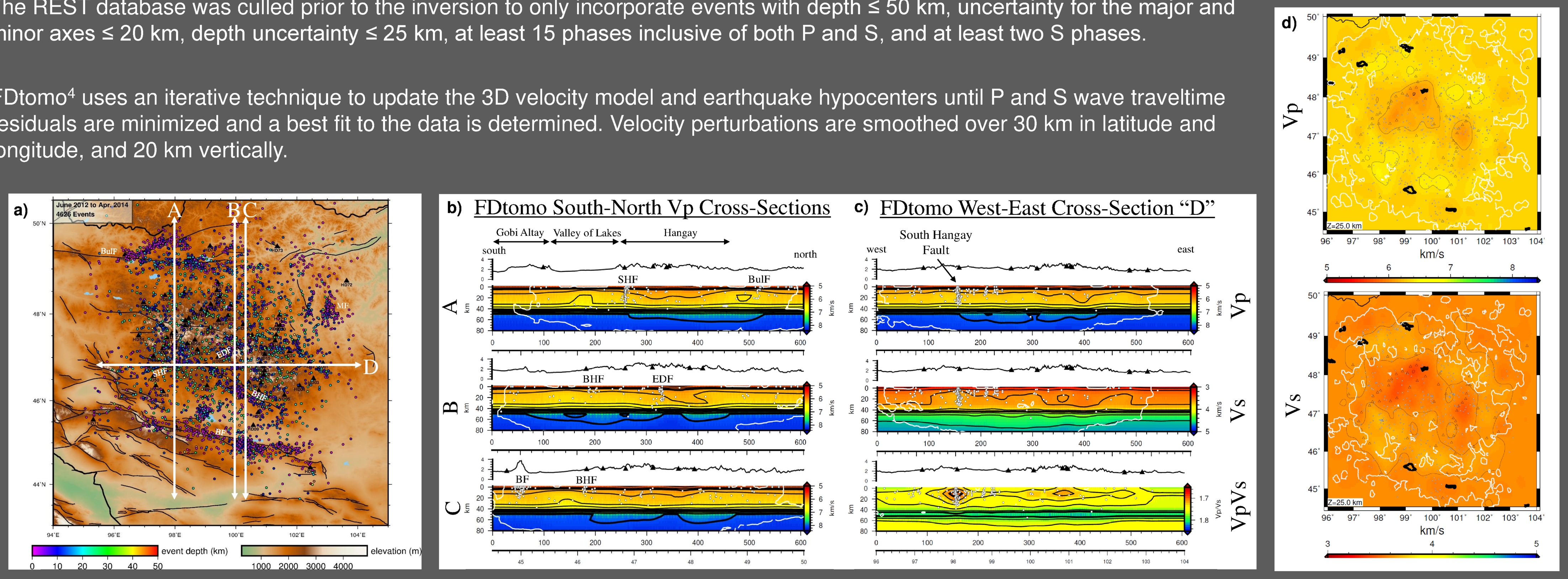
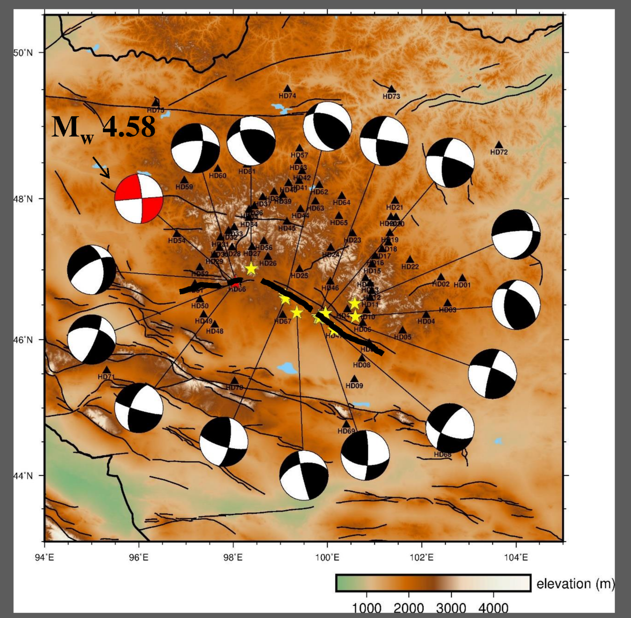
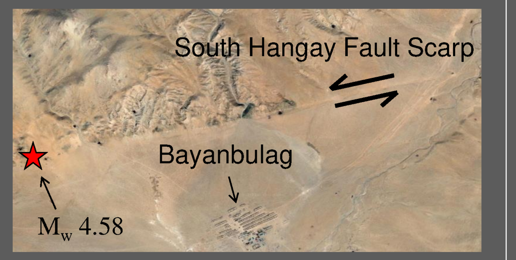


Figure 10: a) Final event location map from FDtomo, cross-section locations for b and c, and seismically active faults (SHF: South Hangay Fault, BulF: Bulnay Fault, EDF: Egiin Davaa Fault, BF: Bogd Fault, MF: Mogod Fault, BHF: Bayanhongor Fault). **b)** Crustal and upper mantle cross-sections A, B, and C, showing P-wave velocities. **c)** Cross-section D showing crustal and upper mantle Vp and Vs velocities, and VpVs ratios. **d)** Depth slices at 25 km for both Vp and Vs.

- Results from the inversion show a relatively uniform crust, where the depth to the Moho is consistent with results from the receiver function analysis. P-wave velocities in the uppermost crust range from 5.5-6.2 km/s, and Vp exceeds 7.0 km/s in the lower 10-15 km of the crust,.
- Lateral velocity variations in the crust align with terrane boundaries where ophiolites along sutures lie north and south of cratonal blocks in the Hangay.
- Many events outline the Bulnay and Bogd faults, where historic M_w 8 earthquakes have occurred, and considerable seismicity is observed on the South Hangay – Bayanhongor Fault System, including a M_w 4.6 earthquake and aftershock sequence. Seismicity is also observed along the Egiin Davaa and Mogod Faults.
- Seismicity in the Hangay is generally confined to the upper 20-25 km, suggesting a rheological transition from brittle to ductile at this depth.

SOURCE CHARACTERIZATION





- 16 focal mechanisms were generated for events with good azimuthal coverage on the South Hangay Fault (Figure 11).
- 11 indicate oblique strike slip motion, while 3 indicate oblique reverse slip, and 2 indicate oblique normal slip.

Figure 11: Focal mechanisms of 16 M_L > 3 earthquakes along the South Hangay Fault. The M_L 5.4 epicenter and focal mechanism are highlighted in red. The South Hangay Fault is bolded in black. An areal image of the South Hangay Fault Scarp is included to the right.

- Overall, the results from this process suggest the predominant sense of motion along the South Hangay Fault is transpressional.
- Results from the moment tensor solution (Figure 12) agree with the focal mechanism from the M_w 4.58 earthquake.

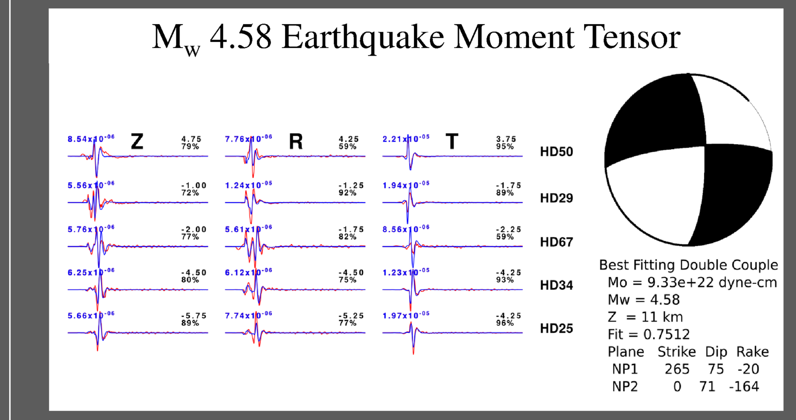


Figure 12: Moment tensor depicting the best fitting double couple and example waveforms (vertical, radial, and transverse components) used in the solution for the M_w 4.58 event on the South Hangay Fault.

CONCLUSIONS

- Results from the tomographic inversion for crustal structure and earthquake location in conjunction with source characterization of moderate to large magnitude seismicity indicate that the modern tectonic regime is reactivating terrane sutures formed from multiple plate collisions in the Neoproterozoic - Early Paleozoic.
- The Hangay Dome region of Central Mongolia is deforming in accordance to the modern tectonic regime, with seismicity occurring mainly on the left-lateral South Hangay – Bayanhongor Fault System and the Egiin Davaa Fault.
- Structural inheritance appears to have a large control on the distribution of seismicity in Mongolia.
- Complex accreted terranes show relatively uniform crustal thickness and Vp/Vs ratios that cross cut terrane boundaries reflecting post accretion crustal modification.

References

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Acknowledgments

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