HIGH-RESOLUTION SEISMIC VELOCITY AND ATTENUATION MODELS OF WESTERN CHINA

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ABSTRACT

Development of high-resolution seismic velocity and attenuation models of the Qinghai-Tibet Plateau and adjacent regions of western China are critical to monitoring efforts because of their close proximity (~380 km) to the nuclear test site at Lop Nur. Previous studies have demonstrated the great complexity in crustal and uppermost mantle seismic velocity structure and propagation characteristics. As a result, regional seismic phases show strong lateral variability in travel time, amplitude, and frequency content. New broadband stations in the region give unprecedented two-dimensional coverage of the northeastern portion of the Plateau. The NETS (North-Eastern Tibet Seismic experiment) and ASCENT (A Seismic Collaborative Experiment of Northern Tibet) arrays (5/07-6/09) consisted of more than 110 temporary broadband stations in the northeast Tibetan Plateau, Ordos Plateau, and Qaidam basin. We are using this data set to develop and calibrate high-resolution regional velocity and attenuation models of the crust and upper mantle for these regions. We have already worked with collaborators in China to construct a preliminary catalog of 400 well-located events within the northeastern Tibetan Plateau. Preliminary results of seismic attenuation studies show a remarkable correlation between Lg and Pg Q values and surface tectonics and crustal velocity estimates. These include relatively high Q values in the Qaidam basin and very low Q values in the Songpan-Ganzi and northernmost Qiangtang terranes.

OBJECTIVES

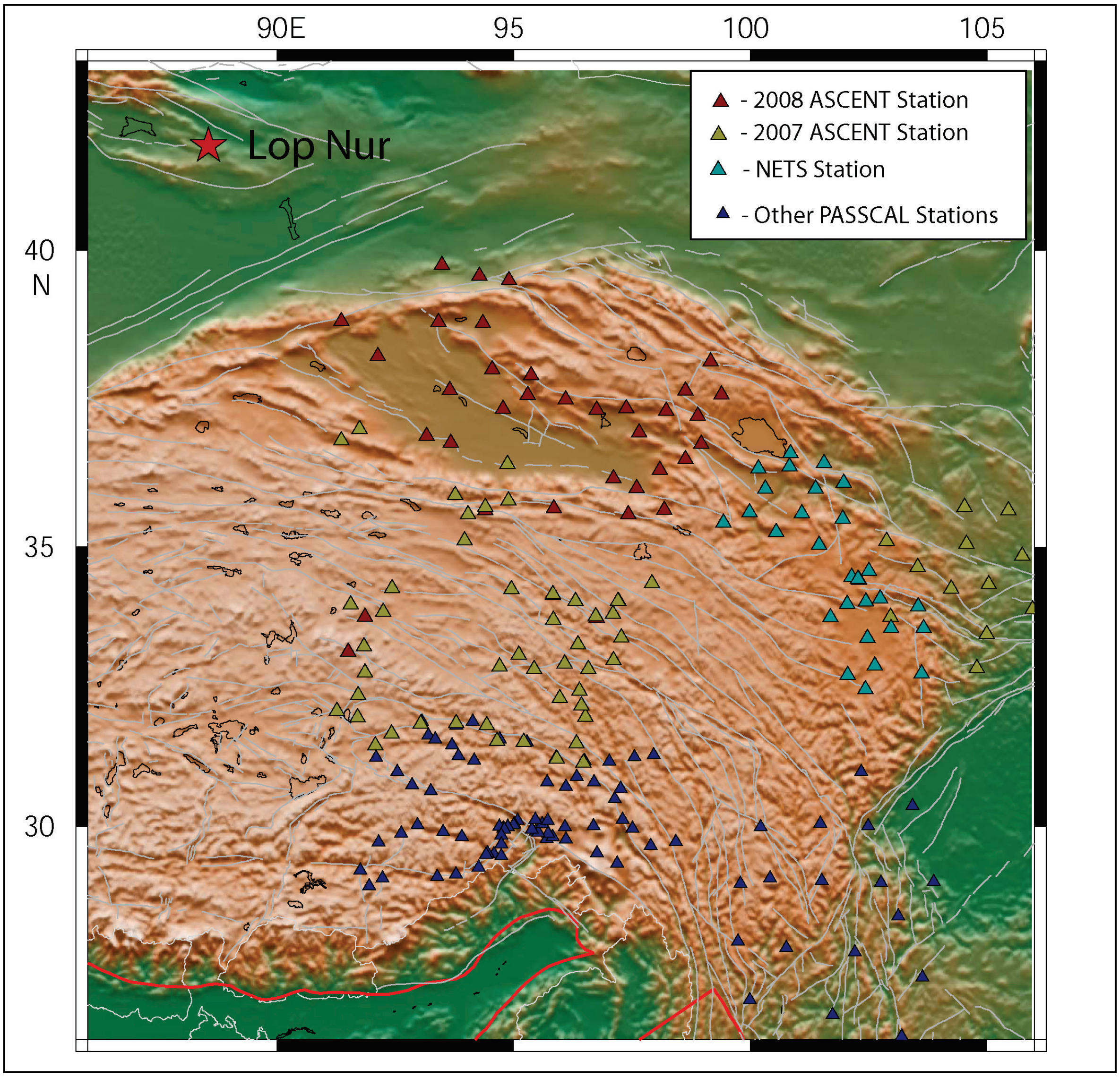

Figure 1. A regional topographic map showing the broadband stations (triangles) from all of the temporary networks that have been deployed across the Tibetan Plateau. The data from the newly available ASCENT and NETS networks are shown as dark red, yellow and cyan triangles. All remaining temporary stations are shown in dark blue. We have access to at least two years of data for all of these networks.

The objective of this project is to construct and validate both 3-D P wave and S wave velocity models and attenuation models (Pn, Pg, Sn, and Lg) for the crust and upper mantle in western China. This research will dramatically increase the seismic characterization of critical areas in western China. It will use new data collected by the 90-station ASCENT and 25-station NETS arrays (total 116 broadband stations; Figure 1) and integration of waveform data from broadband stations in western China suitable for surface wave tomography and attenuation studies. These data sets allow the application of new techniques designed to create robust models of seismic velocity and attenuation in which we reliably estimate the absolute amplitude of the velocity and Q variations across western China.

The ASCENT and NETS arrays (Figure 1) cover much of central northeastern Tibet and the Qaidam basin in Qinghai and Gansu provinces. The location of these arrays is ideal for studying aspects of monitoring research, namely the Chinese test site at Lop Nur and regions 400 km to the south. The initial installation in June 2007 covered the northeastern Tibet Plateau and part of Gansu province. This was fortuitous as it allowed us to widely record the May 12, 2008, Wenchuan earthquake and aftershocks. In August of 2008, these stations were moved to Qaidam Basin to better cover the northern Qinghai-Tibet Plateau. All stations are equipped with broadband CMG-3T, CMG-3ESP, and STS-2 sensors with continuous recording. Using both travel-time body and surface wave tomography, we are producing 3-D P and S wave velocity models and regional wave attenuation models for the crust and upper mantle. In the following sections we describe the data, Pn and Sn travel time tomography, short and long wavelength surface wave tomography, and regional wave attenuation modeling.

RESEARCH ACCOMPLISHED

Background

Tibet and surrounding areas have been the focus of many studies related to seismic wave propagation and velocity structure (Li et al., 2008; Tilman et al., 2000; Mitchell, 1997; Rodgers et al., 1997; Rapine et al. 2003b; McNamara et al., 1997). Here we summarize the current state-of-the-art knowledge of the seismic structure of the Tibetan Plateau and its relationship to tectonic hypotheses.

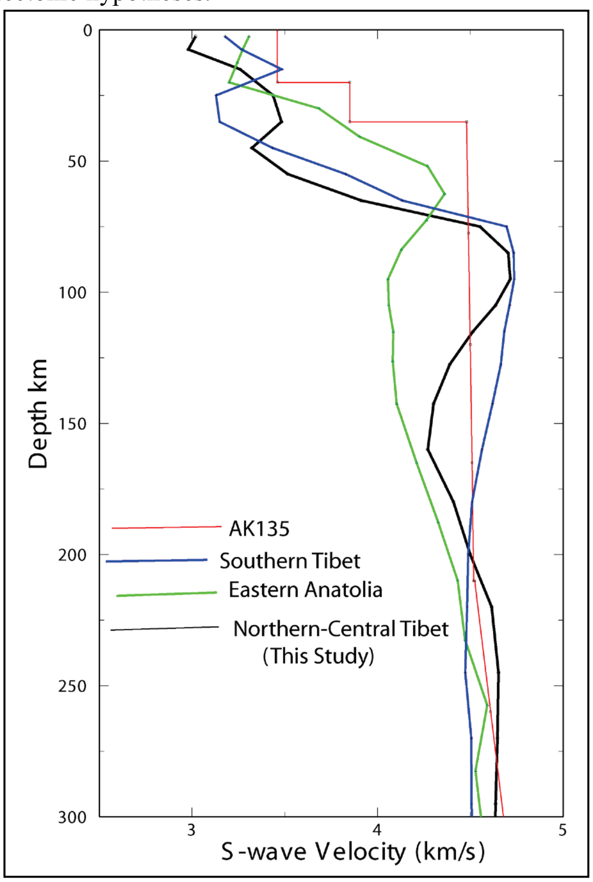

Figure 2. Velocity models from Rayleigh wave phase dispersion curves from the northern and southern Tibet as well as eastern Anatolia for comparison. The low velocities are most likely a result of anomalously slow velocities in the uppermost mantle beneath northern Tibet but not as low as seen in regions like eastern Turkey and the Basin and Range.

Recent P-wave tomography images of the Tibetan Plateau indicates that the Indian continental lithosphere underlies southern Tibet and that an estimated minimum of 1000 km of post-collisional convergence between India and Asia has occurred. The downwelling Indian lithosphere extends to depths near 400 km beneath central Tibet without significant internal deformation (Kind et al., 2002; Tilmann, et al., 2003; Kumar et al., 2006). Body wave and surface wave studies have indicated a seismically low velocity and highly attenuating uppermost mantle for much of northern Tibet (Ni and Barazangi, 1983; McNamara et al., 1997; Rapine et al., 2003a). In contrast, in southern Tibet and the Qaidam basin (north of Kunlun fault), colder mantle has been implied (Ni and Barazangi, 1983, 1984; Tilmann et al., 2003; Galve et al., 2002; Li et al., 2008) (Figure 2). In southern Tibet, a variety of seismic observations (Alsdorf et al., 1998; Makovsky and Klemperer, 1999; Yuan et al., 1997; Kind et al., 2002; Tilmann, et al., 2003; Huang and Zhao; 2006; Li et al., 2008) and electrical conductivity (Wei et al., 2001) all point to a weak low-velocity middle crust (Nelson et al., 1996). The cause of this low-viscosity and low-velocity channel in the mid-crust is predominantly due to wet melting of the subducted Indian sediments and metasediments (Nelson et al., 1996; Cotte, 1999; Rapine et al., 2003b). The mid crustal low velocity zone is also the culprit of high attenuation of Lg waves in southern Tibet (McNamara et al., 1996; Reese et al., 1999; Xie, 2002a; Phillips et al., 2000, 2001, 2005). Lg attenuation is also observed beneath northern Tibet (Qiangtang terrane), but crustal velocities there are only about 8% lower than normal continental crust (Rapine et al., 2003a). The cause of such a high Lg attenuation is not completely understood, but it seems related to high temperature and a partially melted crust of northern Tibet (Hacker et al., 2000; Fan and Lay, 2003).

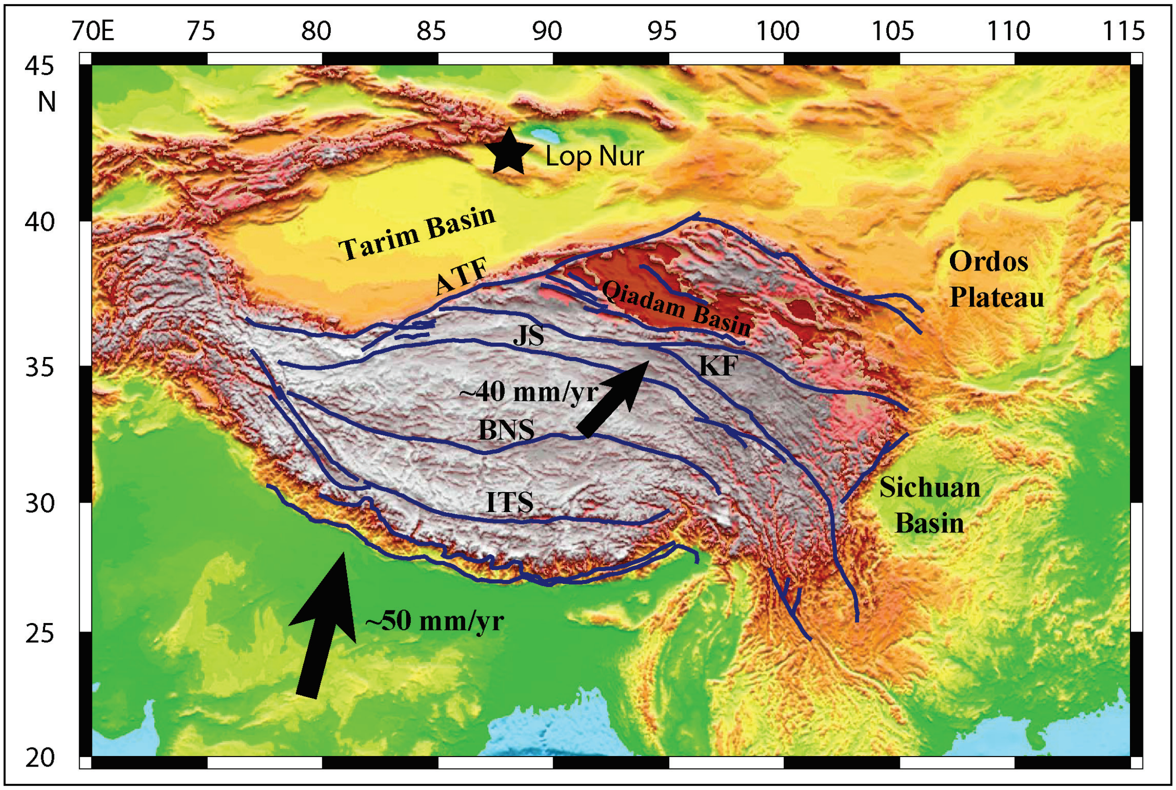

Figure 3. **A simple tectonic map for the Tibetan Plateau. The major features shown are ITS- Indus Tsangpo Suture, BNS-Bangong-Nujiang Suture, ATF-Altyn Tagh Fault, KF-Kunlun Fault.**

A maximum seismogenic thickness of 25 km (Langin et al., 2003) is observed for northern Tibet. The lithosphere thickness is about 140 km according to S-P converted phase (Kumar, et al., 2006); however, it could be thinner in the interior of the northern Plateau. Rayleigh wave phase velocity inversion indicates a lithosphere thickness of only about 120-140 km thick.

Attenuation and Amplitude Tomography Method

Attenuation tomography uses estimates of path-averaged attenuation to delineate laterally varying Q. This includes most spectral methods, which use the ratio of spectral slopes to estimate Q independent of wave amplitude (Zor et al., 2007). An example of attenuation tomography for Asia using coarsely spaced stations is shown in Figure 4 (Xie et al., 2006). We have used this method to create phase blockage maps for regions of the Middle East

(Sandvol et al., 2001). A major advantage of attenuation tomography is that it is a two-station method, and this allows the cancellation of all source effects and gives high quality estimates of path-Q; however, two-station methods require the two stations to be on the same raypath, and this requirement substantially reduces the amount of data that can be obtained. We are measuring attenuation with both the two-station method (Xie and Mitchell, 1990; Xie, 2002a; and Zor et al., 2007 for descriptions of the method, including rigorous error analysis) and reversed two station methods (Chun et al., 1987). The preliminary results of this method is shown in Figure 4. The reversed two station method eliminates site as well as source effects. Path averaged Q measurements are inverted tomographically to create a Q model. Using these methods and the newly collected data from the ASCENT arrays we have found that the attenuation structure of the Tibetan crust is far more complex than previously thought. It appears as if there are fairly large regions of low attenuation within Tibet with Q values exceeding 300.

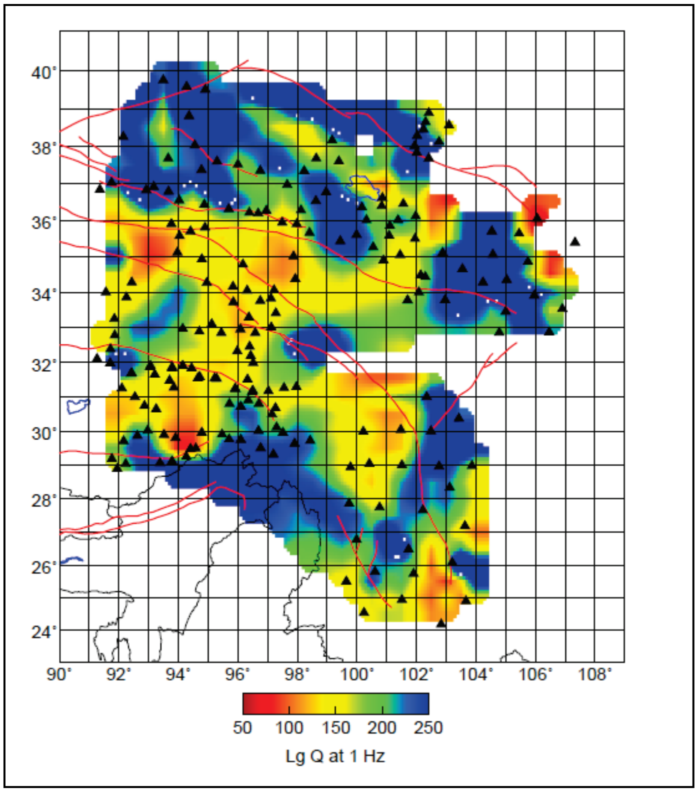

Figure 4. **A preliminary map of Lg Qo in the northeastern corner of the Tibetan Plateau based on two-station Lg spectral ratios applied to waveform data from a variety of 2-D networks spread across the eastern portion of the plateau. The black triangles are the ASCENT seismic stations and the major tectonic boundaries are show as red lines. This result suggests much more inter-plateau Lg Q heterogeneity that previously thought**.

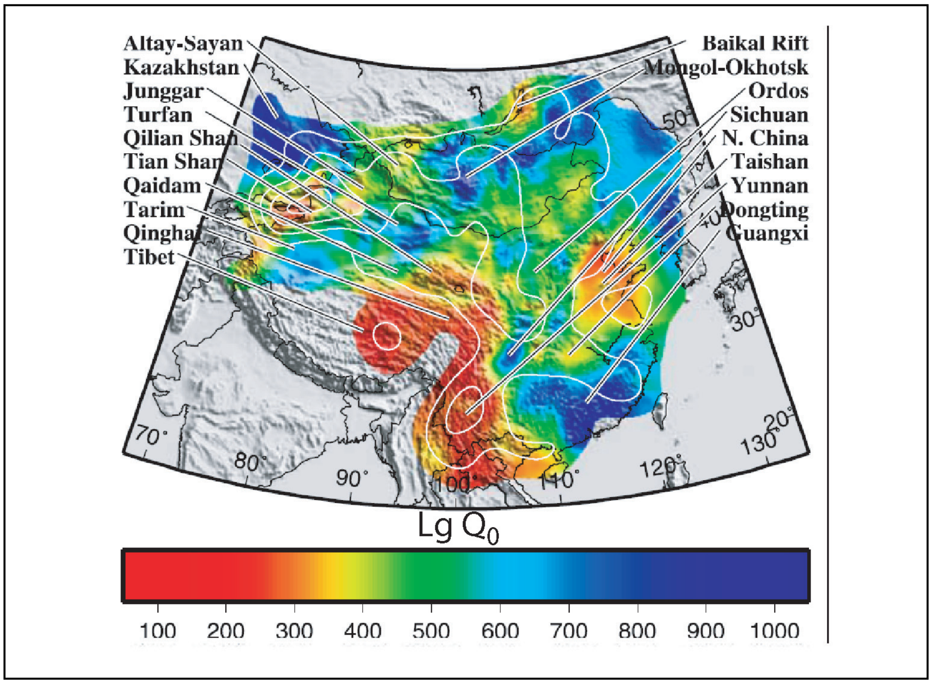

Figure 5. Q estimated using 1-Hz Lg amplitudes obtained from digital waveform data (Phillips et al., 2005). White contours represent the model resolution at levels of 0.1, 0.2, 0.3, and 0.4.

We are also investigating attenuation using amplitude tomography as well as attenuation tomography. Amplitude tomography uses raw amplitudes as opposed to Q-estimates based on spectral ratios. It assumes an isotropic source radiation pattern, and solves for source and site terms in addition to 2-D attenuation. Its advantage over attenuation tomography is that there is no two-station geometry requirement so that all recorded amplitudes may be used in the tomography. Examples of amplitude based tomography for Asia are shown in Figures 5 and 6 from Phillips et al. (2005), and Hearn et al. (2008a), respectively. The amplitude tomography method has proven successful and performs well even for lower quality data sets such as the surface-wave amplitudes archived by the International Seismological Centre (Hearn, 2008b). Constraints from high quality path averaged Q such as those described above, can be incorporated into the inversion.

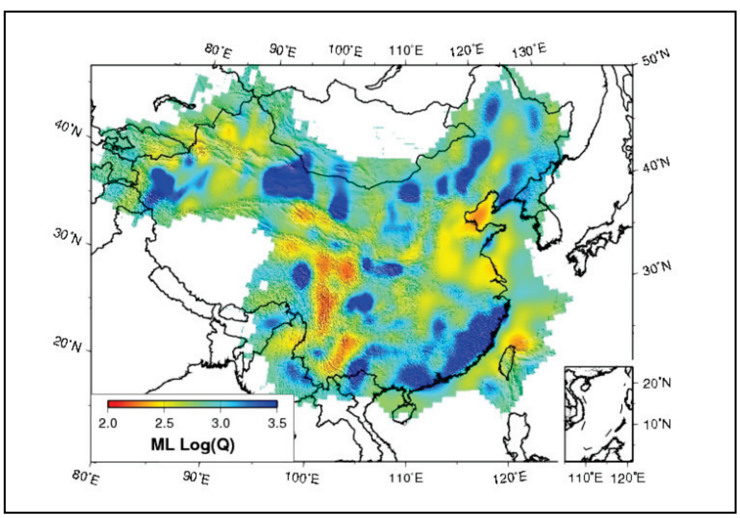

Figure 6. Q estimated using 1-Hz maximum amplitude measurements collected for ML magnitude estimation (Hearn et al., 2008a).

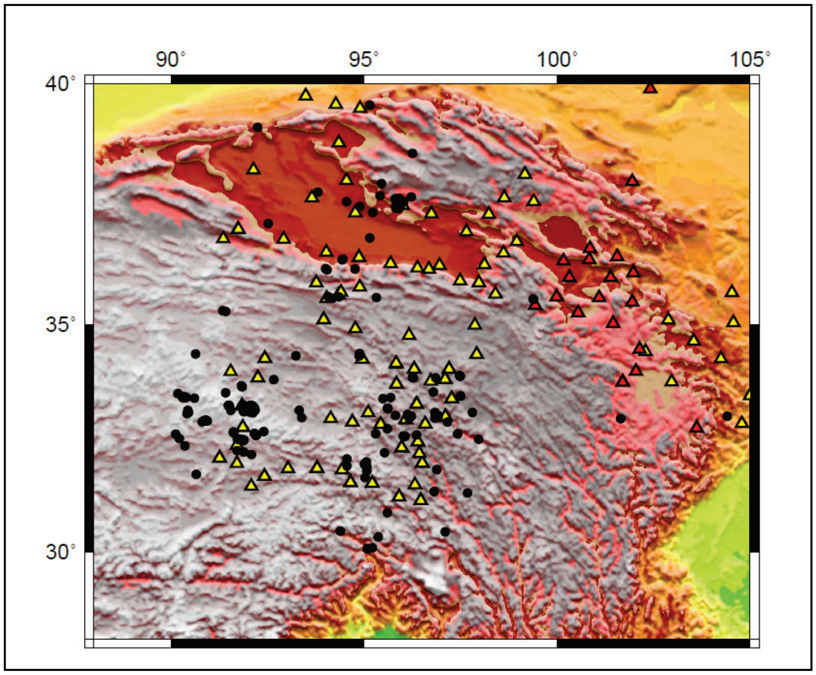

Figure 7. **A plot of the 450 well located local and regional earthquakes recorded by the 2007-2009 combined INDEPTH-IV/ASCENT arrays. The black dots are the earthquakes and the yellow triangles are the stations used to locate the events**.

Seismic Event Location

Our collaborators at Peking University have already conducted a thorough review of all of the continuous data from the ASCENT arrays and have located a total of 592 regional earthquakes for the period of May 2007 to June 2009 (Figure 7). The even distribution of these earthquakes in the study area is compatible with the hypothesis of continuous deformation of the Tibetan Plateau from GPS observations. Our network recorded a Ms = 6.3 event in the Qaidam Basin and this region was recently struck by a damaging Ms = 7.1 earthquake near Yushu. The vast majority regional earthquakes are broadly scattered in the depth range of 8-10 km, but no event deeper than 35 km. This observation strongly supports the existence of a hot and weak lower crust beneath the Qaidam Basin, the Qilian Mountains and the 5 km elevated northeastern Tibetan Plateau. The crustal seismogenic zone appears slightly thicker beneath the northeastern Tibetan Plateau than in southern Tibet, reflecting a difference in both the rheological structure of the crust and the amount of stress that the crust is experiencing. The absence of lower crustal and uppermost mantle earthquakes in northeastern Tibet is consistent with a hot asthenosphere mantle upwelling under the Qiangtang and Songpan-Ganze terranes, associated with regional convective removal of lithosphere. In contrast to southernmost Tibet, this part of northeastern Tibet has no evidence of any type of continental subduction of Asian continent beneath the northeastern Tibetan margin. The present tectonics of northeastern Tibet is mainly controlled by trans-extensional deformation that is associated with the strike-slip Kunlun and Altyn Tagh.

CONCLUSIONS AND RECOMMENDATIONS

In this project, we are processing a large set of new broadband waveform data to obtain both seismic velocity and attenuation results for major portions of western China. The resulting tomographic models shown in Figures 4 through 6 clearly show the variation in Lg Q across the boundary between the Qaidam basin and the northern Tibetan Plateau. The Lg Q_o values are generally higher outside the high elevation regions of the Tibetan Plateau than the surrounding regions. Other studies have similarly concluded that Lg propagation in the Tibetan Plateau is usually blocked or highly attenuated. We also observe substantial variation in Pg and Lg Q_o values within the Tibetan Plateau itself; for example, we observe higher values along the Bangong-Nujiang suture and along the eastern syntaxis of the Plateau.

High Lg attenuation within the Tibetan Plateau (Q_o ~100–200) may be caused by a combination of scattering and intrinsic attenuation. Scattering attenuation is due to the large strike slip faults like the Kunlun and the intrinsic attenuation could be due to crustal partial melting in northernmost Qiangtang terrane. However, we observe that most of the rapid changes in Lg Q occur across major fault zones or sutures suggesting that scattering due to structural changes in the crust plays an important role in Lg attenuation. By quantifying anisotropic Q we can help to distinguish between scattering and intrinsic Q in this tectonically complex region. Furthermore, we recommend the use of multiple Q techniques in these seismically complex regions in order to formulate a robust attenuation model. This approach, utilizing both two station, reversed two station, and single event-station pairs should help us not only to define the shape of the attenuation anomalies but also to constrain the size of the anomalies. These models should ultimately help to create transportable, physically based discriminants for much of western China.

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