Crustal Deformation along the Nyainquentanglhe Detachment, Southern Tibet

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1. Introduction

Between November 2002 and January 2003 a swarm of Mw 3 - 4 earthquakes occurred near the Nyainquentanglhe (NQTL) Detachment in southern Tibet. The swarm was preceded by an increase in the eastward component of velocities recorded at a cGPS station in the nearby city of Lhasa. This increase in cGPS velocity, which lasted from the beginning of 2001 to the end of 2002, is thought to be evidence of a slow slip event (SSE) on the NQTL detachment. If this event is an SSE, it would be only the second intracontinental SSE ever observed. The goal of this project is to illuminate the nature of deformation along the NQTL by combining what is known about the surface and subsurface geology of the region with the source mechanisms of the earthquakes in the swarm, and the geometry of the fault (s) as delineated by the earthquakes in the swarm. If the source mechanisms, locations, and depths of the swarm events are consistent with the observed eastward cGPS velocity increase, it could be assumed that they were triggered by the SSE.

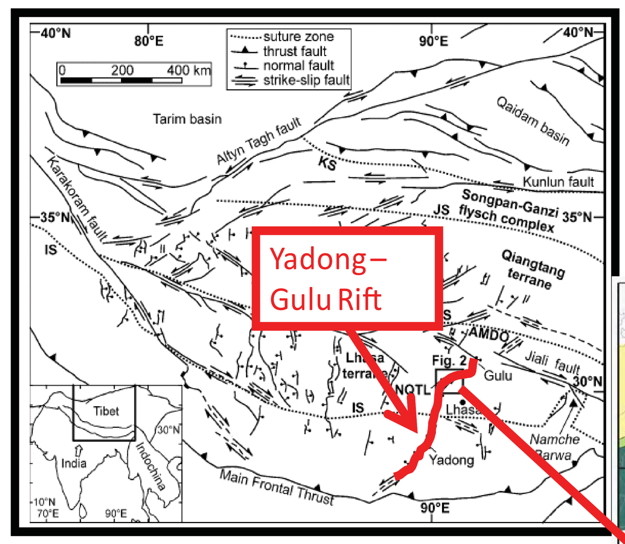


Figure 1.1 - The Yadong Gulu Rift is the most studied of the N-E striking rift systems in eastern Tibet. The Nyainquentanglhe (NQTL) detachment is located in the northernmost portion of the rift. It is a metamorphic core complex. Previous studies have produced detailed geologic maps and seismic reflection and refraction profiles of the region.

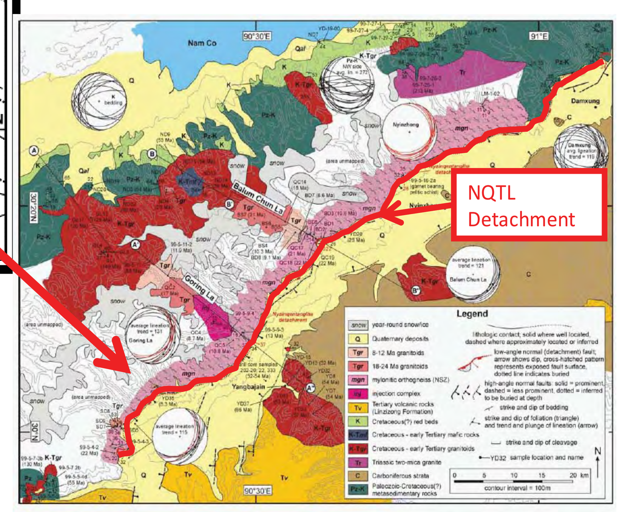
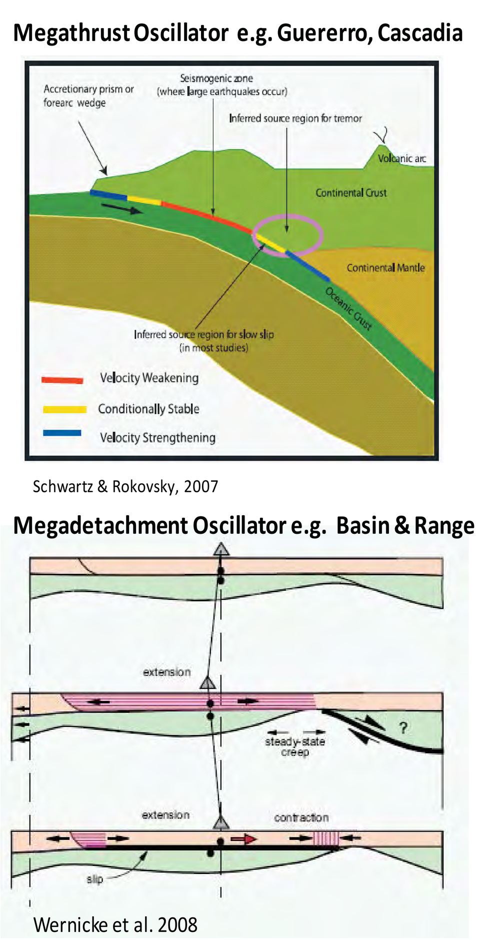


Figure 1.2 - Kapp et al., 2005 Geologic map. The NQTL detachment region is dominated by Cretaceous and Tertiary granitoids and orthogneisses as well as Paleozoic-Cretaceous metasedimentary rocks. The detachment is low-angle (22-37 degrees) and footwall mylonites reveal that the sense of motion on the fault is top to the southeast.

Kapp et al, 2005.



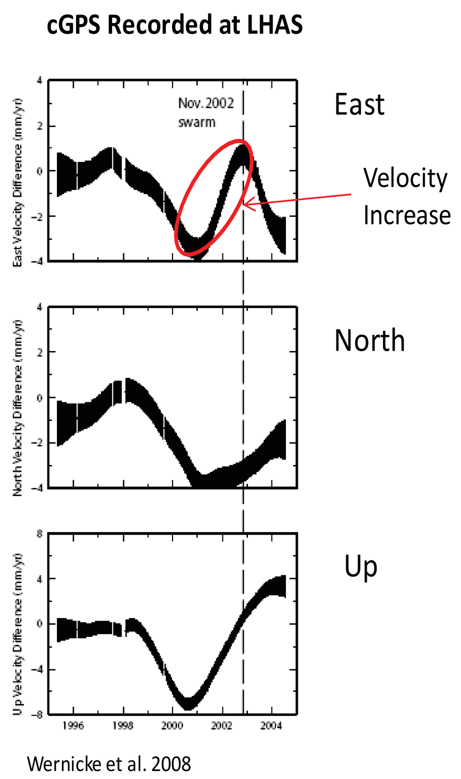
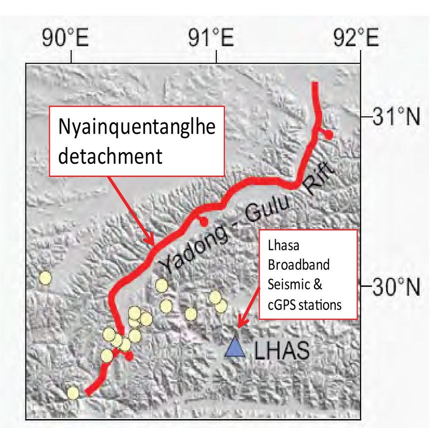


Figure 1.3 - The increase in the east component of velocity observed over the course of 1.5 years at the LHAS cGPS station in Lhasa, Tibet is likely evidence of a slow slip event (SSE) on the NQTL detachment, the region's largest fault. This SSE caused 1 cm of displacement at the surface and was followed by an earthquake swarm which lasted from November 2002 to January 2003. SSEs are most often observed at subduction zones at the transition between conditionally stable and velocity strengthening zones along the megathrust e.g. Guerrero, Mexico and Cascadia. Wernicke et al. 2008, observed the first intracontinental SSE along a subcontinental scale extensional detachment in the northern Great Basin of Nevada. The occurrence of the SSE was inferred from changes in velocities observed at cGPS stations dispersed across the region.



Wernicke et al, 2008.

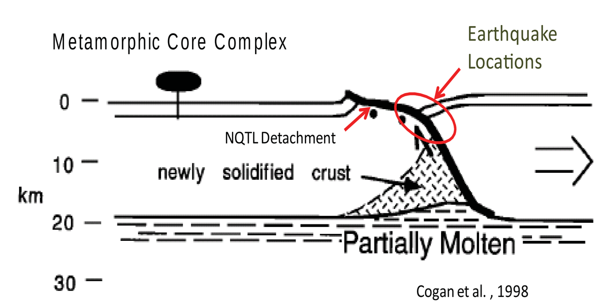


Figure 1.4 - The NQTL earthquake swarm was centered along the southeast corner of the region mapped in Kapp et al, 2005 near an area called the Yangbajain Valley. (Left) Earthquakes are shown in yellow and the Lhasa cGPS and broadband seismic stations are shown in blue. (Right) The position of the earthquakes with respect to the detachment are shown on a scehmatic drawing of a metamorphic core complex .

2. Method

Because the swarm events were too small to be detected teleseismically, their source mechanisms were determined using the Cut and Paste (CAP) inversion method. This method employs waveform modeling techniques to produce the synthetic seismogram which best fits the data. Records from one station, LHA at Lhasa, were used to perform all the inversions because no other regional station data was available at the time of this study.

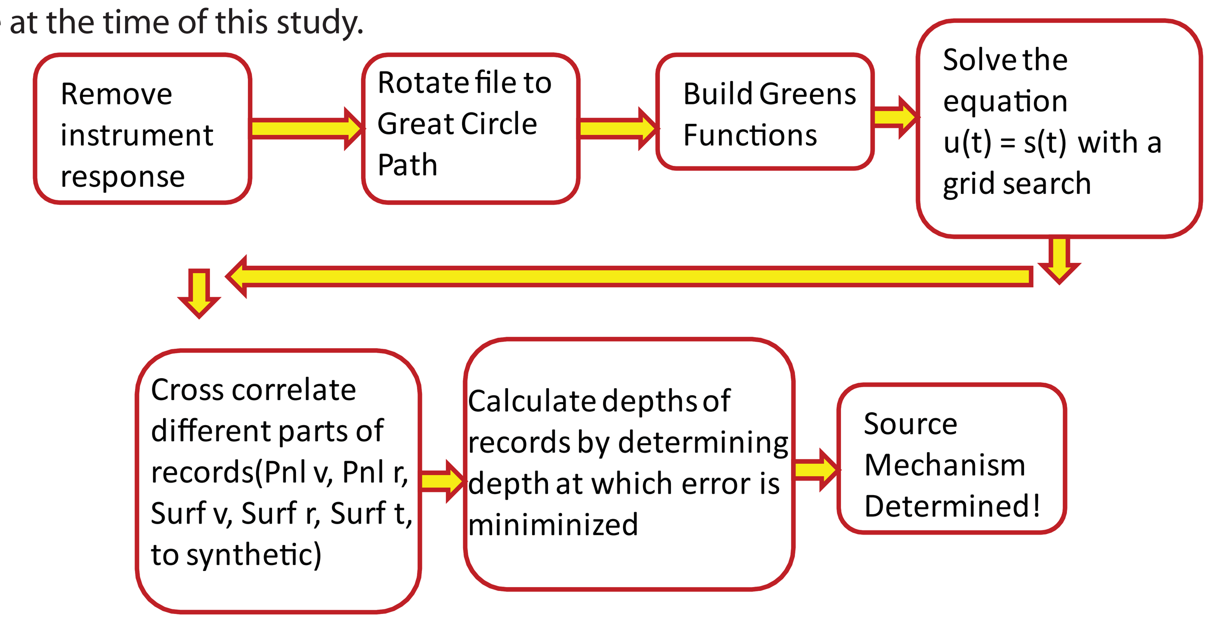


Figure 2.1 - Flow chart illustrating the steps in the CAP method.

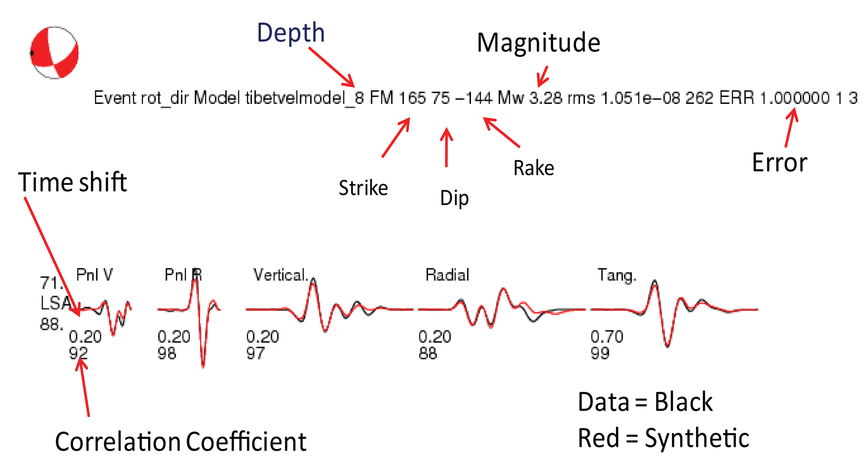
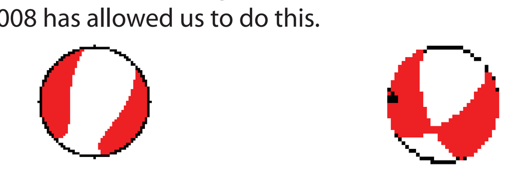


Figure 2.2 - An example CAP output. The magnitude and depth of the event as well as the strike, dip, and rake of the nodal planes are determined. The synthetic is shifted in time to fit the data.

2.1 Method Validation

Single Station inversions using CAP are approximately 80% accurate when performed in southern California. The accuracy of the inversion result is heavily dependent on the accuracy of the velocity model used during the inversion process. In the case of Tibet, one can confirm the accuracy of the inversion by comparing a teleseismically determined focal mechanism to one determined using CAP. The Mw 6.2 Yadong Gulu Rift event of October 6, 2008 has allowed us to do this.



Harvard CMT Solution 12 km depth | CAP Solution 8 km depth

3. Results

The resulting focal mechanisms reveal that all earthquakes occurred at 3-16 km depth and their mechanisms were strike-slip, normal, or a combination of strike slip and normal with slip vectors oriented along the strike of the NQTL detachment.

Figure 3.1 - Focal mechanisms obtained by CAP in chronological order.

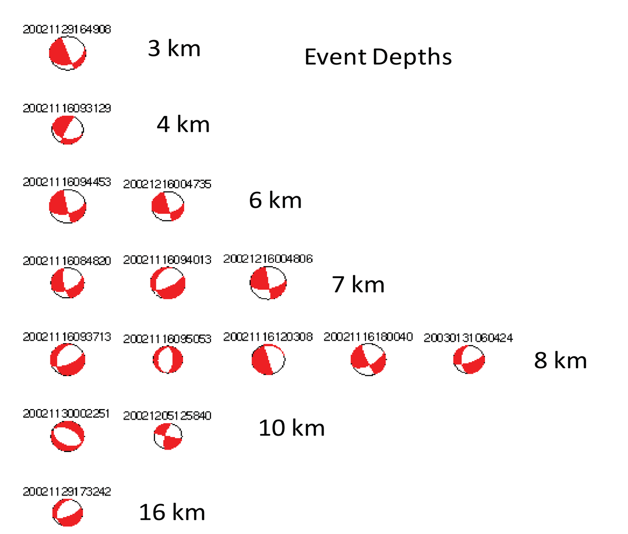


Figure 3.2 - Focal mechanisms in depth. Depths are accurate to within 1 km.

3.1 Error Determination

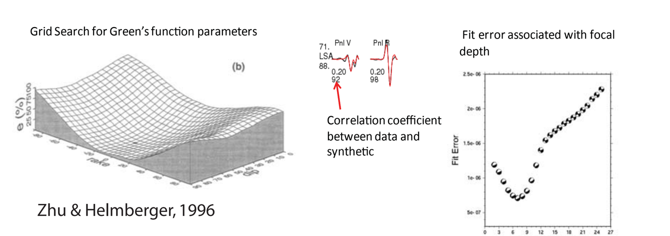


Figure 3.1.1 - Strike, dip, rake, and depth used in calculating Green's functions were determined using a grid search method which reduces error. The mechanism depth is focal depth with the lowest error. The correlation coefficient reveals the quaility of the fit between the data, and synthetic and the time shift reveals inaccuracies in the x,y location of the event entered into CAP during the inversion

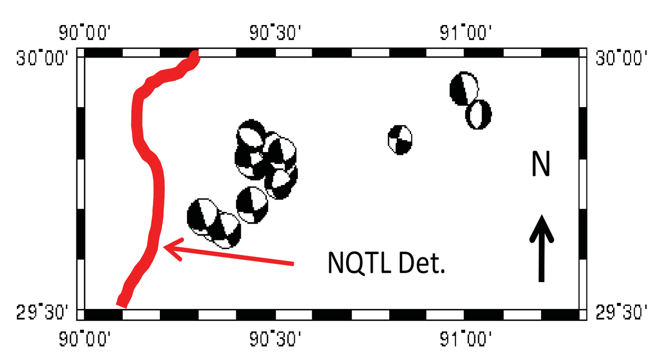
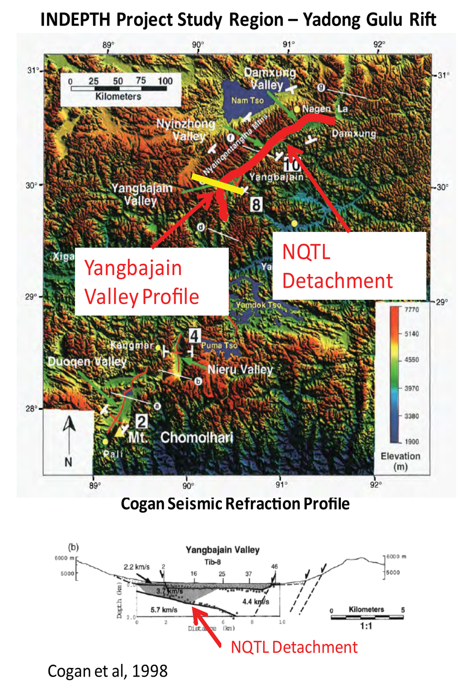


Figure 3.3 - Focal mechanisms in map view.

4. Interpretation

The earthquakes, when initially projected onto the NW striking Yangbajain Valley Seismic Reflection profile of Cogan, 1998, appeared to cluster around a plane with a dip near that of the NQTL detachment (~30 degrees). Upon closer inspection with ArcScene's 3D focal mechanism viewer, 10 of the 15 located earthquakes seem to be oriented along a plane striking N40E and dipping ~ 50 S.



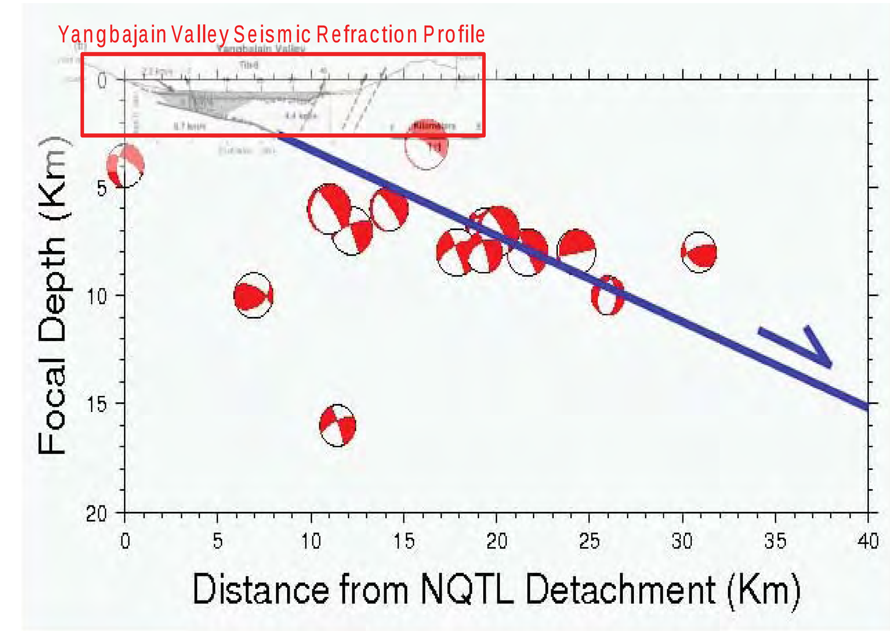
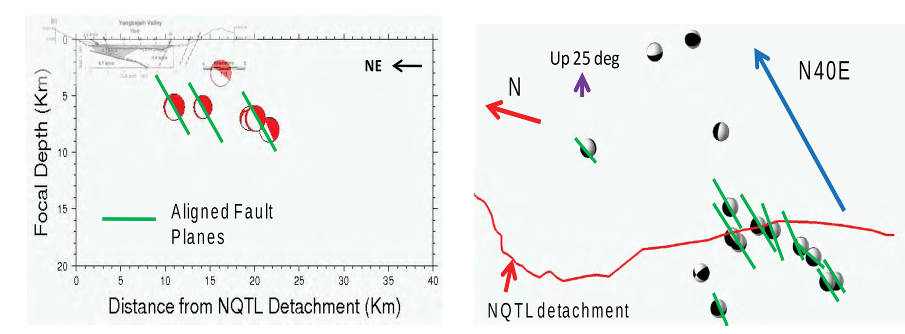


Figure 4.1 - During the late 1990s, project INDEPTH obtained seismic reflection and refraction profiles of the Yadong Gulu Rift. The Yangbajain Valley seismic refraction profile was obtained during this time. Focal mechanisms were projected onto the Yangbajain valley profile because it was the profile closest to the swarm region. The seismic refraction profile of the Yangbajain valley images the NQTL detachment and is shown in the top left corner of the cross section. The blue line shown is an extension of the NQTL detachment to the depth of the focal mechansims determined using CAP. The focal mechansims are shown in cross section. They all seem to cluster along the NQTL, suggesting that they are occuring on the detachment or on faults near the detachment.



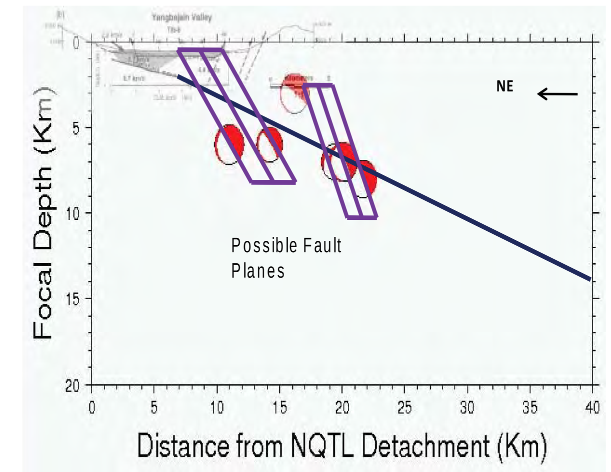


Figure 4.2. - Ten of the fifteen focal mechanisms in the swarm occur on faults which are much higher angle (50+ degrees) than the NQTL detachment. When viewed in ArcScene (top right), all these events seem to be occurring on planes (in green) which have a strike of N 40 E. It is likely that these events are occurring on faults located in the hanging wall of the NQTL detacment. When projected onto the Yangbajain valley profile many of the events appear to be located in the footwall of the detachment. This could be an effect of errors in the determination of focal depth and/or depth errors introduced by projecting the earthquakes onto the plane.

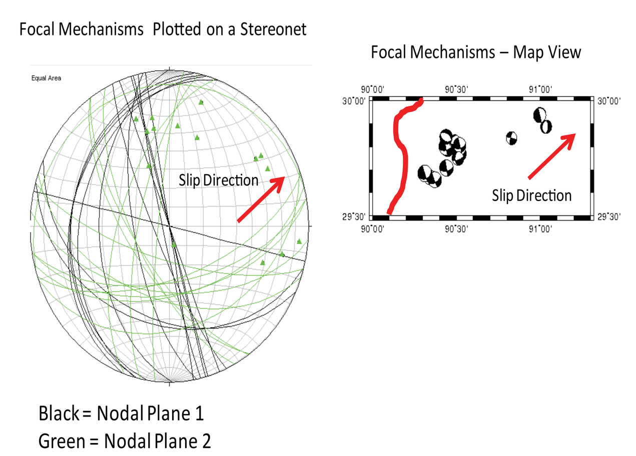


Figure 4.3 - Preliminary efforts at slip vector determination reveal that slip along the majority of the faults points east, the direction in which slip occurred during the SSE. This observation suggests that these earthquakes may have been triggered by motion along the NQTL during the SSE.

5. Conclusion

The earthquake swarm observed along the Nyainquentanglhe Detachment in Southern Tibet was triggered by a SSE on the detachment. These events occurred on higher-angle faults within the hanging wall of the NQTL detachment. Further study of the earthquakes which occurred in the NQTL region in October 2008 will reveal more about the structure of and deformation in this region.

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