Images of crustal and mantle structure across the northern margin of the Tibet-Pamir plateau

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The main goal of this contribution will be to present a deep crustal and mantle section across the northeast margin of Tibet and a deep crustal section across the northern margin of the Pamir, based mainly on seismological studies during the INDEPTH IV (INternational DEep Profiling of Tibet and the Himalaya) and TIPAGE (TIen shan—PAmir GEodynamic program) projects. The northern margin of the Tibet-Pamir plateau represents an important boundary as it is here that most of the outward growth of the plateau possibly occurs. Important faults occur here, such as the Kunlun fault which hosted the M8.1 Kokoxili earthquake in November 2001. Further, the large Qaidam basin in the northeastern part of the plateau is important for its mineral and hydrocarbon reserves.

Beneath the northeast margin of Tibet, the change in crustal thickness from about 70 km beneath the Songpan-Ganzi terrane and Kunlun mountains to 54 km beneath the Qaidam basin is actually located almost 45 km north of the southern edge of the Qaidam basin [1]. The Qaidam basin Moho is underlain by crustal velocity material for almost 45 km near the crustal thickness transition. The apparently overlapping crustal material may represent lower crust of northern Tibet underthrusting or flowing northward beneath the Qaidam basin Moho. Thus the high plateau may be thickening northward into south Qaidam as its weak, thickened lower crust is injected beneath stronger Qaidam crust [1]. The INDEPTH IV seismic studies found no evidence that the Kunlun mountains are involved in large-scale northwards overriding of the Qaidam basin along a shallow south-dipping thrust [1,2]. Instead there is a significant decrease in uppermost crustal seismic velocities going north from the Songpan-Ganzi terrane and the Kunlun mountains to the Qaidam basin [1,2,3]. The Poisson's ratios in the upper 10-15 km of the crust are often lower than 0.25, indicating a preponderance of quartz-rich rocks in the upper crust. Below 10-15 km depth, the remainder of the crust down to the Moho has an average Poisson's ratio of 0.24 beneath the Songpan-Ganzi terrane and Kunlun mountains and 0.25 below the Qaidam basin [2]. These low Poisson's ratios are similar to other low Poisson's ratios found along other profiles in the northeast part of the plateau. Assuming an isotropic situation and no significant variation in Poisson's ratio between 10-15 km depth and the Moho, then the lower crust with compressional (*P*) velocities varying from 6.6 km s^{-1} at the top at 25-30 km depth below sea level to around 6.9 km s^{-1} at the base and Poisson's ratios of 0.24-0.25 should comprise intermediate granulites in the upper part transitioning to granulite facies metapelites in the lower part. As the pre-Cenozoic Qaidam basin crust has probably not lost any of its lower crust during the present Himalayan orogenic cycle in the Cenozoic and only has a Poisson's ratio of 0.245-0.25, then it appears that this crust involved in the collision is more felsic and thus weaker and more easily deformable than normal continental crust with a global average Poisson's ratio of 0.265-0.27 and the Tarim and Sichuan basin crusts. This situation then probably facilitates the collision and promotes the formation of new high plateau crust at the northeast margin of Tibet. South of the Qaidam basin, the crust of the

Songpan-Ganzi terrane and Kunlun mountains has an even lower average crustal Poisson's ratio of 0.23-0.24 and is thus presumably even weaker and more easily deformable than the crust beneath the Qaidam basin. This then supports the hypothesis mentioned above that the high plateau may be thickening northward into south Qaidam as its weak, thickened lower crust is injected beneath stronger Qaidam crust [1]. At greater depths beneath northern Tibet, the Asian lithospheric mantle is overlain by a low-velocity, less dense and warm Tibetan plate consisting of both an upper lithospheric and a lower asthenospheric part [4].

The recent TIPAGE project in the Pamir and southern Tien Shan has produced new insights into this part of the Alpine-Himalayan orogenic belt [5,6,7]. A section through the Pamir and southern Tien Shan based on analysis of wide-angle seismic phases from earthquakes [5] shows that crustal thickness varies from 65 to 74 km beneath the Pamir itself and decreases to about 58 km beneath the southern Tien Shan. Average crustal *P* velocities are low with respect to the global average, varying from 6.26 to 6.30 km s^{-1}. The average crustal shear (*S*) velocity varies from 3.54 to 3.70 km s^{-1} and thus average crustal Poisson's ratio varies from 0.23 beneath the central Pamir in the south central part of the section to 0.265 towards the northern end of the section beneath the southern Tien Shan. The upper crust is about 30 km thick. Beneath an assumed 2 km thick cover layer, the basement has average *P* velocities of about 6.05–6.1 km s^{-1}, except beneath the south central part of the section where they decrease to around 5.95 km s^{-1}. This is in contrast to the *S* velocities which range from 3.4 to 3.6 km s^{-1} and exhibit the highest values of 3.55–3.6 km s^{-1} where the *P* velocity is lowest. Thus, Poisson's ratio for the basement is 0.26 except beneath the south central part of the section where it decreases to 0.22. The low value of 0.22 for Poisson's ratio under the central Pamir, the along-strike equivalent of the Qiangtang terrane in Tibet, is similar to that within the corresponding layer beneath the northern Lhasa and southern Qiangtang terranes in central Tibet and is indicative of felsic rocks rich in quartz in the α state. The lower crust has *P* velocities ranging from 6.1 km s^{-1} at the top to 7.1 kms^{-1} at the base. Further, Poisson's ratio for this layer is 0.27–0.28 towards the northern end of the section but is low at about 0.24 beneath the central and southern parts of the section, which is similar to the situation found in northeast Tibet. The low values can be explained by felsic schists and gneisses in the upper part of the lower crust transitioning to granulite-facies and possibly also eclogite-facies metapelites in the lower part. Within the uppermost mantle, the average *P* velocity is about 8.10–8.15 km s^{-1} and Poisson's ratio is about 0.26. Assuming an isotropic situation, then a relatively cool (700–800°C) uppermost mantle beneath the profile is indicated. This would in turn indicate an intact mantle lid beneath the profile. The section presented here for the crustal and lithospheric mantle structure beneath the Pamir calls for nearly horizontal underthrusting of relatively cool Indian mantle lithosphere, the leading edge of which is outlined by the Pamir seismic zone. This cool Indian mantle lithosphere is overlain by significantly shortening, warm Asian crust. The Moho trough beneath the northern Pamir, a feature seen beneath other orogenic belts (e.g. the Alps and the Urals), may mark the southern tip of the actively underthrusting Tien Shan crust along the Main Pamir thrust.

[1] M.S. Karplus, W. Zhao, S.L. Klemperer, Z. Wu, J. Mechie, D. Shi, L.D. Brown and C. Chen, J. Geophys. Res., 116, B07301 (2011).

[2] J. Mechie, W. Zhao, M.S. Karplus, Z. Wu, R. Meissner, D. Shi, S.L. Klemperer, H. Su, R. Kind, G. Xue and L.D. Brown, Geophys. J. Int., 191, 369 (2012).

[3] M.S. Karplus, S.L. Klemperer, J.F. Lawrence, W. Zhao, J. Mechie, F. Tilmann, E. Sandvol and J. Ni, Geophys. Res. Lett., 40, 808 (2013).

[4] W. Zhao, P. Kumar, J. Mechie, R. Kind, R. Meissner, Z. Wu, D. Shi, H. Su, G. Xue, M.S. Karplus and F. Tilmann, Nat. Geosci., 4: 870 (2011).

[5] J. Mechie, X. Yuan, B. Schurr, F. Schneider, C. Sippl, L. Ratschbacher, V. Minaev, M. Gadoev, I. Oimahmadov, U. Abdybachaev, B. Moldobekov, S. Orunbaev and S. Negmatullaev, Geophys. J. Int., 188, 385 (2012).

[6] C. Sippl, B. Schurr, X. Yuan, J. Mechie, F.M. Schneider, M. Gadoev, S. Orunbaev, I. Oimahmadov, C. Haberland, U. Abdybachaev, V. Minaev, S. Negmatullaev and N. Radjabov, J. Geophys. Res., 118 (2013).

[7] F.M. Schneider, X. Yuan, B. Schurr, J. Mechie, C. Sippl, C. Haberland, V. Minaev, I. Oimahmadov, M. Gadoev, N. Radjabov, U. Abdybachaev, S. Orunbaev and S. Negmatullaev, Earth Planet. Sci. Lett., 375, 101 (2013).

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