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A two-step underthrusting and delamination model that explains deep structures beneath Pamir and Hindu Kush

Christian Sippl (1), Bernd Schurr (1), Felix Schneider (1), Xiaohui Yuan (1), Mustafo Gadoev (2), Sagynbek Orunbaev (3), Sobit Negmatullaev (4), and Christian Haberland (1)

(1) GFZ Potsdam, Germany (sippl@gfz-potsdam.de), (2) Institute of Geology, Tajik Academy of Sciences, Dushanbe, (3) CAIAG, Bishkek, Kyrgyzstan, (4) PMP International, Dushanbe, Tajikistan

The Pamir-Hindu Kush region, situated at the western Himalayan syntaxis, is one of the tectonically most complex and least well understood regions on earth. Frequently occurring intermediate-depth earthquakes, which define two seismic zones at mantle depth, attest to ongoing subduction or delamination processes during continental collision. The presence of deep seismicity and the complexity of mantle structures set the Pamir-Hindu Kush apart from Tibet, i.e. imply a different tectonic style between the front and the syntaxes of the Indian indenter.

Automatically identified and located local earthquakes from the TIPAGE data set (2008-2010) outline two distinct, seismically active zones at mantle depths. Beneath the Hindu Kush, earthquake locations to first order define a subvertically northward dipping planar structure with high internal complexity. At depths greater than 150 km, this plane appears to be broken into several fragments. Focal mechanisms of intermediate-depth earthquakes uniformly show downdip extension, i.e. T axes oriented around vertical, whereas retrieved P axes are horizontal, perpendicular to the strike of the Hindu Kush seismic zone.

The Pamir seismic zone, in contrast, resembles a single, strongly curved slab dipping southward at its eastern termination towards the Tarim Basin and progressively changes its dip direction to purely eastward at its southwestern end. Focal mechanisms of Pamir deep seismicity are less uniform than for the Hindu Kush, but show a prevalence of along-arc extensive mechanisms in the shallower part of the slab, where earthquake hypocenters outline an along-strike continuous structure. At deeper levels, where the slab might be torn (which could be indicated by an absence of seismic activity), T axes are oriented more steeply.

A local earthquake tomography study, utilizing a selection of 56,229 P and 25,221 S phases to perform an inversion for v_p and v_p/v_s throughout the Pamir and its surroundings, clearly shows the arcuate Pamir slab as a high-wavespeed anomaly (v_p = 8.2-8.3 km/s). The hypocentral locations of earthquakes outline the upper edge of this lithospheric slab, in fact appear to be confined to an about 10 km wide low-velocity channel atop it, which has been identified with receiver function analysis. Directly above the updip end of seismicity (at depths of 70-80 km), very low values of v_p (around 7.1 km/s) and high v_p/v_s ratios ($>$1.80) are retrieved, probably indicative of the entrainment of upper or middle crustal material in the subduction process, which leads to the burial of buoyant material to mantle depths. South of the Pamir slab, velocities around or slightly below normal mantle values are observed, no indication of cold underthrusted Indian lithosphere is found.

We interpret the obtained seismological evidence with a two-step model of continental overthrusting of the Pamir over the basin material to the north and west of it, followed by the delamination of the underthrusted material into the mantle, possibly due to the acquisition of negative buoyancy by phase transformation reactions (e.g. eclogitization). The entrained upper or middle crustal material imaged with tomography is not involved in the delamination process due to its low density. However, a thin layer of possibly eclogitized lower crustal material sits atop the sinking lithospheric slab and hosts the intermediate-depth seismicity. A pure delamination scenario could not explain the observed presence of slow material at mantle depths, whereas the retrieved stress axis orientations in the Pamir slab are hard to reconcile with a classical subduction process.