From Continental Collision to the Earth’s Deep Water Cycle

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The Himalayan-Tibetan orogen, the most prominent case of active mountain building, has been a focus of international research for almost 100 years. While there is an overall consensus that the orogen is a consequence of collision between the Asian continent and the Indian shield, a broad range of specific tectonic models have been proposed. Mantle dynamics is important in all these models, but processes in the mantle are not explicitly addressed in most cases. Here we discuss this important issue emphasizing new methodology and high-resolution, broadband seismic array data that are readily available in the public domain.

Combining results from a variety of seismic methods and additional constraints from plate motions, mineral physics, geodesy, and petrology, the current configuration of overlapping lithospheres is constrained down to depths above the lower mantle. We then reconstruct position of the Indian lithospheric mantle relative to Asia back to 15 Ma ago or the onset of the latest magmatic activity in Tibet. By then the leading (northern) edge of the Indian lithospheric mantle (Indian mantle front, IMF) has advanced subhorizontally past the entire Lhasa terrane (now southern Tibet), and thickened the lithospheric mantle of the Qiangtang terrane (now central Tibet). Rayleigh-Taylor instability ensued, causing widespread but small volume of magmatic activity in northern Tibet. Meanwhile, detached lithospheric mantle foundered quickly through the upper mantle and now rests at the bottom of the mantle transition zone (MTZ) just above the lower mantle. The remnant of detached lithospheric mantle of the Qiangtang terrane manifests itself as a large-scale seismic anomaly of high compressional wave speed but curiously is undetectable through shear-waves.

The discordant results between $P$- and $S$-waves indicate that the foundered lithospheric mantle is rich in hydroxyls, a conclusion supported by other evidence including hydrous minerals in recent volcanic rocks found in northern Tibet. Since olivine and its high-pressure polymorphs, all nominally anhydrous minerals, can hold ~1 wt% of water throughout the upper mantle and the MTZ, foundering of thickened lithospheric mantle caused by continental collision is an unappreciated but potentially effective pathway for water to enter the deep mantle.

Finally, preliminary results from virtual deep seismic sounding suggest that the IMF is also where a major boundary of the thickened crust lies in central Tibet.