Earthquake depth distributions in central Asia and lithosphere rheology

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This talk will examine the depth distribution of earthquakes in the greater Tibetan region in the context of our current understanding of lithosphere strength, composition and structure. Much has changed since the early studies of McKenzie & Fairhead (1997) and Maggi and others (2000) showed that accepted views which had remained unchallenged for 20 years needed some modification. In particular, a single generic view of the continental lithosphere is unable to account for the differences in earthquake depths, elastic thicknesses and geological histories commonly observed between ancient shields (or cratons) and younger orogenic belts.

An important conclusion of the studies by McKenzie & Fairhead (1997) and Maggi and others (2000) was that the long-term strength of the continental lithosphere resides only in its upper part, which was contained wholly within the crust, and that there was little evidence for substantial long-term strength in the continental mantle, contrary to previously accepted views. The effort to understand the physical mechanisms responsible led quickly to a series of developments in related subjects, including: (1) a re-examination of geotherms and thermal structure in both oceans and continents; (2) connections between seismic velocity and temperature; (3) relations between mechanical properties and the metastability of lower crustal rocks in mountain roots; (4) causes of the variations between the ancient continental shields (or 'cratons') and younger Phanerozoic orogenic belts; and, (5) the issue of how the continental cratons were created.

A recent review by Jackson and others (2008) summarised the developments above, in order to demonstrate that a coherent picture is emerging which reconciles observations from fields as diverse as seismology, gravity, heat flow, rock mechanics, metamorphic petrology and geochemistry. Furthermore, the insights, and agreement, that these widely differing disciplines offer on the same subject produce an overall view that is more robust than any obtained from just one of those disciplines alone. A relatively simple view of the distribution of lithosphere seismicity and its implications for rheology is now emerging, which can be summarized as follows:

1. Earthquakes in the mantle, in both oceans and continents, are confined to regions colder than about 600°C (McKenzie and others, 2005). In most places on the continents the uppermost mantle is expected to be at 600°C or more, and hence aseismic. But there are some circumstances in which the continental mantle might be colder, and experience some earthquakes (e.g. Priestley and others, 2008), one example of which is in the Himalaya (below).

2. With very few exceptions, earthquakes everywhere are confined to a single seismogenic layer, which in the oceans is limited by the 600°C isotherm, in young orogenic belts is typically limited to the upper crust (less than about 350°C), and in some regions, often in or adjacent to ancient shields, may include the whole crust. An important exception is in the Himalaya, where the seismogenic lower crust of India underthrusts the seismogenic upper crust of Tibet, giving an apparent bimodal depth distribution, but one that is not in steady-state and has no generic significance for continental rheology. In this particular example of the Himalaya, where the underthrusting Indian crust is unusually thin (~35 km) for a Precambrian shield and the Moho temperature is correspondingly unusually cold (~500°C rather than ~600°C), earthquakes extend from the lower crust into the uppermost 15–20 km of the mantle (Monsalve and others, 2006; Priestley and others, 2008).

3. The great strength of some of the ancient shields is associated with lower-crustal earthquakes and larger elastic thickness than in younger continental lithosphere. In such shields two effects are likely to be responsible: (a) the crust may be relatively cold because of a thick low-density mantle root, and (b) the composition of the lower continental crust is probably dominated by a dry

granulite-facies mineral assemblage.

4. Lateral strength contrasts in the continents between ancient shields and young orogenic regions are important, and cannot be represented by a laterally uniform continental rheology or composition. In spite of the lower-than-average Moho temperatures in shields, lower-crustal earthquakes within them occur in material up to 600°C, much hotter than the normal cut-off temperature of ~350°C for earthquakes in younger regions; a situation which probably requires the hotter seismogenic lower crust to be dry. These lateral strength contrasts allow mountains to be supported by their adjacent forelands without requiring the mantle beneath the forelands to be strong.

5. The stability and survival of the ancient shields and cratons over Ga of geological time is related to both their strength and buoyancy, neither of which can easily be changed.

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Cite as: Jackson, J., McKenzie, D., Priestley, K. and Sloan, A., 2010, Earthquake depth distributions in Central Asia and lithosphere rheology, *in* Leech, M.L., and others, eds., Proceedings for the 25th Himalaya-Karakoram-Tibet Workshop: U.S. Geological Survey, Open-File Report 2010-1099, 2 p. [http://pubs.usgs.gov/of/2010/1099/jackson/].