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Partial melt in the upper-middle crust of the northwest Himalaya revealed by Rayleigh wave dispersion

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ABSTRACT

Seismic shear-wave velocities are sensitive to the partial melts that should be present in the Himalayan orogen if low-viscosity channel flow is active at the present day. We analyzed regional earthquakes in the western Himalaya and Tibet recorded on 16 broadband seismometers deployed across the NW Indian Himalaya, from the Indian platform to the Karakoram Range. We used a multiple filter technique to calculate the group velocity dispersion of fundamental-mode Rayleigh waves, and then inverted the dispersion records to obtain separate one-dimensional shear-wave velocity models for five geologic provinces: the Tibetan plateau, Ladakh arc complex, Indus Tsangpo suture zone, Tethyan Himalaya, and Himalayan thrust belt. Our velocity models show a low-velocity layer (LVL) with 7–17% velocity reduction centered at ~30 km depth and apparently continuous from the Tethyan Himalaya to the Tibetan plateau. This LVL shows good spatial correspondence with observations of low resistivity from magnetotelluric studies along the same profile. Of the possible explanations for low velocity and low resistivity in the mid-crust, only the presence of melts or aqueous fluids (or both) satisfactorily explains both sets of observations. Elevated heat flow observed in the NW Himalaya implies that if aqueous fluids are present in the mid-crust, then the mid-crust is well above its solidus. Comparison of our results with laboratory measurements and theoretical models suggests 3–7% melt is present in a channel in the upper-middle crust of the NW Himalaya at the present day, and the physical conditions to enable active channel flow may be present.

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1. Introduction

1.1. Geologic setting

The Tibetan plateau consists of a series of accreted terranes separated by sutures (e.g. Yin and Harrison, 2000) (Fig. 1a). In western Tibet, the southernmost terrane is the Ladakh arc complex, a magmatic arc formed at 70–50 Ma above the subduction zone consuming the Neo-Tethys Ocean (Weinberg and Dunlap, 2000). The Ladakh arc complex is separated from crust originating on the Indian plate by the Indus Tsangpo suture zone (ITSZ), a complex composed of oceanic crust and mantle that was emplaced on the passive continental margin of India. South of the ITSZ lies the Tethyan Himalaya, a fold-and-thrust belt of metasedimentary rocks originally deposited on the Tethyan continental margin of India. South of the Tethyan Himalaya are high-grade crystalline rocks of the Greater Himalayan Sequence (GHS). The GHS is separated from the Tethyan Himalaya by the South Tibetan Detachment (STD), a shear zone most recently exhibiting normal movement, and from the Lesser Himalayan Sequence (LHS) to the south by the Main Central Thrust (MCT), a shear zone most recently exhibiting thrust movement. South of the LHS are the Main Boundary Thrust, Subhimalaya, Main Frontal Thrust, and the Indian platform (e.g. Yin and Harrison, 2000; Jain et al., 2003).

1.2. Tectonic models for the Himalaya and Tibet

Two end-member models exist to explain the large-scale shortening and deformation of the Himalaya: a traditional thrust belt model (e.g. Srivastava and Mitra, 1994; DeCelles et al., 2001), in which deformation is accommodated by brittle faulting and folding in the upper crust and localized ductile shear zones in the lower crust, and a channel-flow model (Grujic et al., 1996; Nelson et al., 1996; Beaumont et al., 2001), in which underthrust material from the subducting Indian plate undergoes partial melting and returns to the surface via mid-crustal flow towards the thinner, lower-elevation crust of the foreland. In the channel flow model, focused erosion along the southern slopes of the Himalaya from the Indian monsoon leads to rapid exhumation, promoting advection in the channel and a resulting southward flow of material (Beaumont et al., 2001). This material is exhumed as the high-grade crystalline rock of the GHS. In the field, the GHS is bordered by two shear zones with opposite sense of movement: in the north by the north-dipping, top-to-the-north STD, and in the south by the north-dipping, top-to-the-south MCT. Because the

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