# Mantle Helium Signature of the Karakoram fault is that of an Active Plate-Boundary

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The Karakoram fault (KKF) of southwest Tibet has been argued, from geologic and geodetic data, either to function as a lithosphere-penetrating plate boundary with ~1000 km of offset at ~30 mm/yr, or to be essentially locked (motion ~1±3 mm/yr; total offset only a few tens of km) and be just the near-surface localization of distributed deformation at depth. Various seismic data have been claimed to preclude direct penetration of the KKF into the mantle, including the similarity of Moho depth immediately south and north of the KKF that has been used to argue for continuity of the Indian plate beneath the KKF, and the transition from efficient to inefficient high-frequency Sn propagation over 200 km NE of the KKF that has been used to argue for underthrusting of Indian crust beneath Tibet to that location.

We tested the depth of penetration of the KKF by measuring $^3He/^4He$ ratios (R) in springs within and away from the KKF (Fig. 1). Helium from atmospheric, crustal and mantle sources is characterized by unique $^3He/^4He$ ratios, respectively Ra, Rc ≈ 0.02 Ra, and ≈ 8 Ra. Plate-boundary strike-slip faults that penetrate from earth's surface to the mantle are obvious pathways for migration of mantle fluids. Helium studies measured R/Rc > 200 close to the San Andreas fault (SAF) (Kennedy and others, 1997) and North Anatolian fault (NAF) (Dogan and others, 2009), with minimum values of R/Rc ≈ 5 just a few 10s of km distant indicative of mantle fluids penetrating the thin, warm and ductile lithosphere of these areas in a process now well-established across the western USA. The ratio (≈ 40) of the highest-to-lowest observed $^3He/^4He$ values is a strong argument that the SAF and NAF penetrate through the whole crust or the whole lithosphere. Previous studies of helium isotopes in eastern Tibet (Fig. 2) have identified a "crustal helium domain" (R/Rc < 2.5) and a "mantle helium domain" (R/Rc > 5) separated by a transition ≈ 90 km north of the Indus suture zone that is considered to mark the mantle suture (Hoke and others, 2000). $^3He/^4He$ ratios up to R/Rc ≈ 10 may represent degassing of Quaternary mantle-derived melts intruded deep into the crust (Hoke and others, 1999) with pathways to the surface enabled by diffuse deformation of a very weak, albeit very thick crust. Our new measurements from hot springs and a fumarole within 50 km of the KKF show a significant influx of mantle helium along the KKF, up to 25 Rc, more than double the highest values observed elsewhere in Tibet. The ratio of highest-to-lowest observed $^3He/^4He$ values is ≈ 60 across the KKF, comparable with the equivalent ratios across the SAF and NAF. The lower absolute values than in California and Turkey are consistent with the three-times thicker thick crust in Tibet that – at least to the south of the KKF – includes subducting Indian craton. The very rapid transition from "crustal" to "mantle" helium values over < 40 km suggests that the upward transport is more focused in the NW Himalaya, presumably by the KKF. In contrast, the 50% smaller increase over three times the distance in southern Tibet is presumably controlled by widely distributed deformation facilitating an active upward migration of aqueous fluids through the crust, as imaged by Makovsky and Klemperer (1999). The lack of enhanced $^3He/^4He$ ratios at orogen-normal rift valleys (Tso Morari fault) shows that these are only an upper-crustal feature, not the lithospheric-scale rifts suggested by Yin (2000).

Our observations provide unequivocal evidence for the presence of mantle-derived fluids transported through the crust to the surface along the KKF. These mantle fluids are not widely disseminated through a fractured, continuously deforming crust, because the Indus suture zone just tens of kilometers southwest of the KKF does not show any evidence of mantle helium. The KKF must be accessing sub-continental or asthenospheric mantle. Our observations imply unbroken Indian crust does not underthrust and underly Asian crust for any significant distance north of the KKF.

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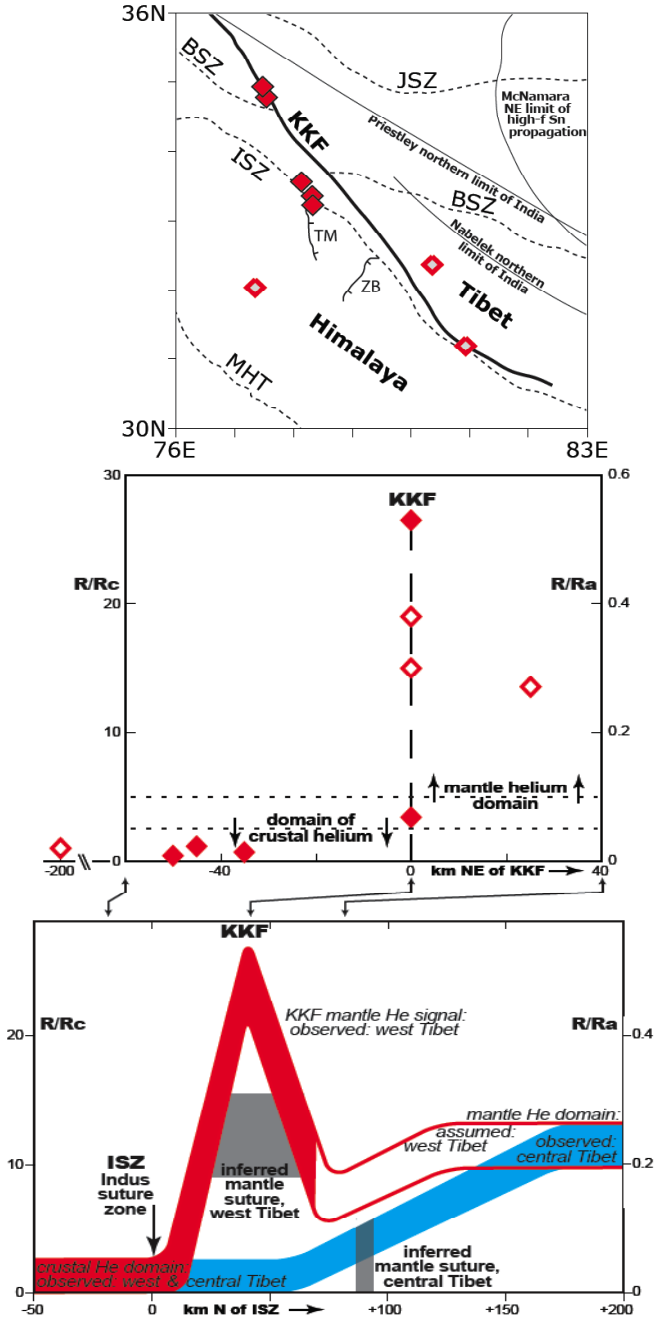


**Figure 1.** Location of $^{3}He/^{4}He$ samples along the Karakoram Fault (KKF) and Indus Suture Zone (ISZ). Solid diamonds: our new data; open diamonds: data of Hoke and others (1999) and Giggenbach and others (1983). Dashed lines: Main Himalayan Thrust (MHT), Banggong Suture Zone (BSZ), and Jinsha Suture Zone (JSZ). TM and ZB: Tso Morari and Zada Basin (LeoPargil) normal faults. Northern limit of Indian crust inferred by Nabelek and others (2009) from interpretations of receiver function images, and by Priestley and others (2007) from the northern limit of supposed deep-crustal earthquakes; northeastern limit of propagation of high-frequency Sn (seismic phase propagating just beneath the Moho) (McNamara and others, 1995) has been taken to be the northern limit of Indian cratonic mantle.

**Figure 2a.** $^{3}He/^{4}He$ values measured in hot springs, expressed as ratios of standard continental crustal and atmospheric ratios (respectively R/Rc and R/Ra), plotted as a function of distance NE of the Karakoram Fault (KKF). Atmospheric helium has a $^{3}He/^{4}He$ ratio, Ra, of $1.4\ 10^{-6}$, whereas crustal helium (dominated by radiogenic $^{4}He$), is characterized by a $^{3}He/^{4}He$ ratio Rc of ~0.02 Ra. Definition of "crustal" and "mantle" domains, and open symbols at and NE of the KKF from Hoke and others (1999); open symbol SW of the KKF from Giggenbach and others (1983).

**Figure 2b.** Schematic results from south-central Tibet (blue, R/Rc ≤ 10, from Hoke and others (1999)) and new results from western Tibet (red, R/Rc ≥ 25 at the KKF: this paper) aligned with respect to the Indus suture zone (ISZ), to show the very different spatial gradients in each region. Grey boxes show the inferred mantle suture (the northward limit of penetration of Indian lithosphere in contact with Asian crust) of Hoke and others (1999) 90km north of the ISZ, and our inferred mantle suture just 30–60 km north of the ISZ, and essentially at the KKF.

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