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Eocene Tibetan plateau remnants preserved in the northwest Himalaya

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The northwest Himalaya shows strongly contrasting relief. Deeply incised mountain ranges that are characterized by extremely rapid exhumation[1-3] and some of the highest peaks in the world are in contrast with high-elevation, low-relief areas such as the Deosai plateau in northern Pakistan, which lies at an altitude of 4,000 m. The origin and evolution of such plateau regions at the convergence of the most active continental collision in the world remain elusive. Here we report low-temperature thermochronology data from the Deosai plateau and use thermal history modelling to show that the plateau has undergone continuous slow denudation at rates below 250 m Myr^{-1} for the past 35 Myr at least. This finding suggests tectonic and morphologic stability of the plateau since at least Eocene times, only 15–20 Myr after the onset of the India–Asia collision. Our work contradicts the hypothesis that widespread low-relief surfaces in the northwest Himalaya result from efficient kilometre-scale glacial erosion during Quaternary times[4]. We show that similarly stable surfaces exist throughout the entire northwest Himalaya and share common morphologic characteristics and denudation histories, which are comparable to those of the western Tibetan plateau. Our results suggest that these surfaces are preserved remnants of an Eocene southwestern Tibetan plateau that was more extensive than today.

The Himalayan syntaxes have attracted much attention over the past decade because they appear as areas in which potential coupling between tectonics and surface processes can be demonstrated (see, for example, refs 2, 5). In the northwest Himalaya (Fig. 1), studies have mainly focused on the very rapidly exhuming Nanga Parbat massif [2,3,5] and, to a lesser extent, the Karakorum mountains[6,7]. However, the northwest Himalayan syntaxis also contains widespread low-relief regions that are characterized by much slower exhumation rates[8] and that have received much less attention.

The observed morphological variations correlate with major geologic units in the northwest Himalaya. High-elevation, low-relief regions are mainly found within the Kohistan–Ladakh arc complex; the backbone of the northwest Himalaya that separates the Indian and Asian plates. The Karakorum range to the north constitutes the former Eurasian margin that collided with the Kohistan–Ladakh arc along the Shyok suture zone after ~75 Myr (ref. 9 and references therein). The Kohistan–Ladakh arc was in its turn thrust over Himalayan rocks of the Indian plate along the Indus–Tsangpo suture zone after the onset of Himalayan collision at ~55 Myr (refs 10–12). Major crustal thickening, high-grade metamorphism and building of topography occurred between ~55 and 40 Myr (ref. 13), followed by rapid exhumation of the Nanga Parbat antiform since Late Miocene time[3].

We use morphologic analyses to identify high-elevation low-relief surfaces throughout the northwest Himalaya and western Tibetan plateau (Fig. 1), defining them as broad (at least several tens of km^2) regions with elevations over 3,800 m and topographic slopes less than 17° (excluding modern glacier surfaces; see Fig. 1, caption). The widespread Tibetan plateau surface is clearly mapped out by this approach, rising from ~4,900 m in the Lhasa terrain south of ~33° N to ~5,500 m in the Qiantang and Kunlun terrains to the north.

The Karakorum fault is generally regarded as the western border of the Tibetan plateau (see, for example, refs 9, 14). However, our morphologic analysis identifies several prominent plateau areas to the southwest of this boundary. From east to west, these are the Zada basin in southwest Tibet, Tso Morari in northwest India and the Deosai plateau in northern Pakistan. Although the former constitutes a Neogene internally drained basin that was only recently captured by the Sutlej River[15], both Tso Morari and Deosai clearly represent externally drained low-relief erosional surfaces. Moreover, both the Kohistan region to the west of Nanga Parbat, and the Ladakh batholith to the east of Deosai, contain widespread summit regions with low slopes (Fig. 1). A topographic swath profile from Kohistan to southwest Tibet, across Nanga Parbat, Deosai and the Ladakh batholith, highlights remarkable continuity in the plateaux and low-slope summit regions, which rise gently from ~4,000 m in the west to ~5,000 m in Tibet.

The relief characteristics of the Deosai plateau and surrounding regions are further illustrated in Fig. 2. The mean and modal elevations of the Deosai plateau and Kohistan are similar to that of the intervening Nanga Parbat massif (Fig. 2a), lending support to the hypothesis that uplift and exhumation in the latter is fundamentally driven by localized incision of the Indus River[2,5]. The modal elevations of the Karakorum range and Ladakh batholith are significantly higher (~4,700 m) than those of the regions to the west. In contrast, the frequency distributions of normalized elevations (Fig. 2c, d) indicate a strong morphologic contrast between Kohistan, Deosai and the Ladakh batholith on the one hand, and Nanga Parbat and the Karakorum on the other: the former show negatively skewed elevation distributions and high hypsometric integrals (~0.7), whereas the latter are characterized by much more symmetric distributions of topography (hypsometric integrals of 0.5 and 0.58, respectively).

Slope distributions as a function of elevation (Fig. 2b) show that the modal elevation peaks in Kohistan and Deosai correspond to low-slope regions. In a previous morphometric study of the region[4], it was suggested that such high-elevation low-relief areas resulted from efficient glacial erosion during Quaternary times, independent of morphology or exhumation rate. However, the slope minima are

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