Geomorphology 107 (2009) 285–299

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Exhumation and incision history of the Lahul Himalaya, northern India, based on (U–Th)/He thermochronometry and terrestrial cosmogenic nuclide methods

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A R T I C L E I N F O

Article history:
Received 12 September 2008
Received in revised form 19 December 2008
Accepted 22 December 2008
Available online 9 January 2009

Keywords:
Himalaya
strath terraces
terrestrial cosmogenic nuclides
AHe thermochronology
exhumation
fluvial incision

A B S T R A C T

Low-temperature apatite (U–Th)/He (AHe) thermochronology on vertical transects of leucogranite stocks and ^{10}Be terrestrial cosmogenic nuclide (TCN) surface exposure dating on strath terraces in the Lahul Himalaya provide a first approximation of long-term (10^4–10^6 years) exhumation rates for the High Himalayan Crystalline Series (HHCS) for northern India. The AHe ages show that exhumation of the HHCS in Lahul from shallow crustal levels to the surface was ~1–2 mm/a and occurred during the past ~2.5 Ma. Bedrock exhumation in Lahul fits into a regional pattern in the HHCS of low-temperature thermochronometers yielding Plio-Pleistocene ages. Surface exposure ages of strath terraces along the Chandra River range from ~3.5 to 0.2 ka. Two sites along the Chandra River show a correlation between TCN age and height above the river level yielding maximum incision rates of 12 and 5.5 mm/a. Comparison of our AHe and surface exposure ages from Lahul with thermochronometry data from the fastest uplifting region at the western end of the Himalaya, the Nanga Parbat syntaxis, illustrates that there are contrasting regions in the High Himalaya where longer term (10^5–10^7 years) erosion and exhumation of bedrock substantially differ even though Holocene rates of fluvial incision are comparable. These data imply that the orogen's indenting corners are regions where focused denudation has been stable since the mid-Pliocene. However, away from these localized areas where there is a potent coupling of tectonic and surface processes that produce rapid uplift and denudation, Plio-Pleistocene erosion and exhumation can be characterized by disequilibrium, where longer term rates are relatively slower and shorter term fluvial erosion is highly variable over time and distance. The surface exposure age data reflect differential incision along the length of the Chandra River over millennial time frames, illustrate the variances that are possible in Himalayan river incision, and highlight the complexity of Himalayan environments.

1. Introduction

Processes at convergent plate boundaries that build topography are widely understood to be episodic on timescales of 10^6–10^7 years (for example, Lamb et al., 1997; Lister et al., 2001; Quarles van Ufford and Cloos, 2005). Transient landscapes, too, can persist on time scales of 10^6 years (Kirby et al., 2002; Clark et al., 2006; Riihimaki et al., 2007). How erosion responds to changes in uplift, whether erosion rates vary with time, and whether mountain landscapes are transient or can achieve steady-state conditions remain important questions in geomorphology. Key processes in addressing these issues are exhumation and erosion. The rates of these processes constrain the interplay and relative roles of tectonic *vs.* surficial geologic processes in mountain belts.

The Himalayan orogen is an archetype natural laboratory for the study of exhumation and erosion because it is tectonically active and characterized by extreme relief (relative relief can exceed 3000 m), large-scale mass wasting (large avalanches, debris flows, and rock falls), and glacial landforms (over steepened valleys, moraines, and glacial dam bursts). Exhumation rates of the northern Indian Himalaya have not been well defined in spite of their significance for surficial and tectonic dynamics. To further understand the timing and rates of exhumation and erosion in the Lahul region of the Greater Himalaya, we have obtained quantitative data using (U–Th)/He apatite (AHe) thermochronology and terrestrial cosmogenic nuclide (TCN) methods.

Lahul is located approximately midway between the Indo-Gangetic Plain and Tibet (Fig. 1) in the Pir Panjal and Greater Himalaya of northern India. Lahul is an impressive, rugged landscape comprising U-shaped valleys, mountain sides and peaks underlain by massive jointed faces of granite, large granite and meta-sedimentary debris deposits, and smaller fluvial and glacial landforms.

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doi:10.1016/j.geomorph.2008.12.017

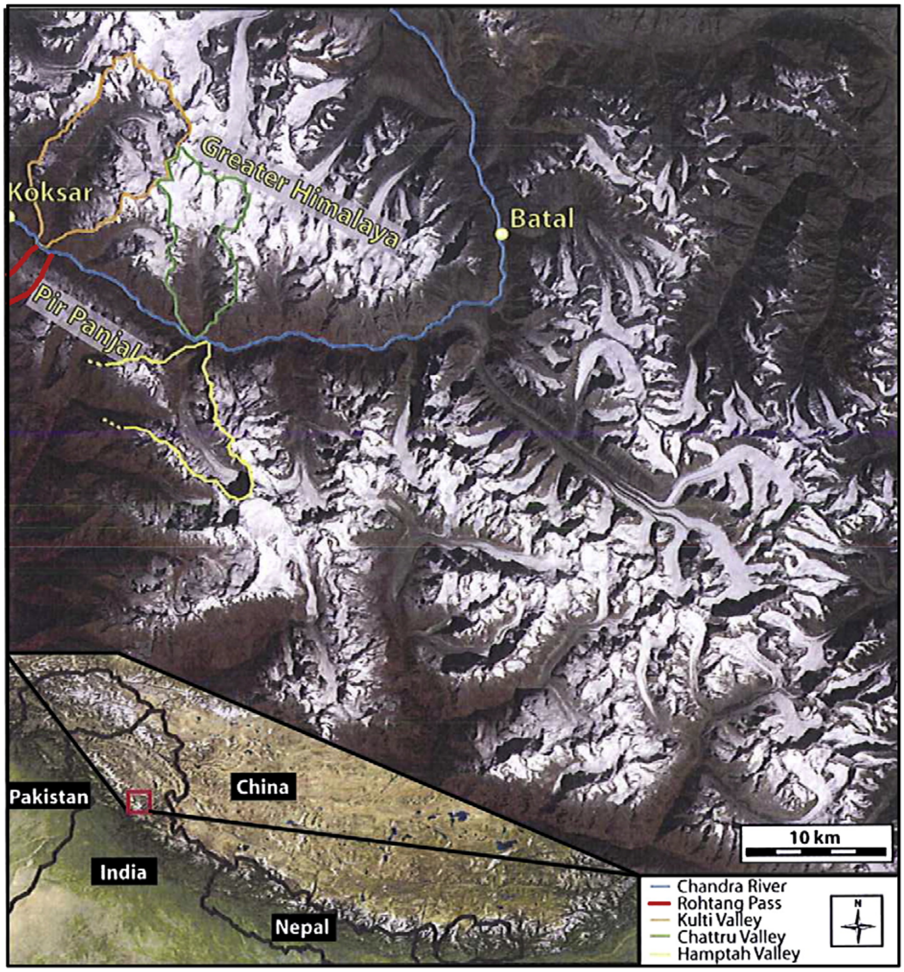

Fig. 1. Regional location of the field area (red square) and ASTER satellite imagery of the Lahul region. Areas of interest where samples for AHe and TCN geochronology were collected are outlined in varying colors. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Several general aspects of the exhumation history of the Lahul Himalaya are well characterized. These are derived from studies of regional deformation and faulting (Steck et al., 1993; Vannay and Steck, 1995; Wyss and Steck, 1999), chronology of emplacement of igneous rocks and regional metamorphism (Searle and Fryer, 1986; Walker et al., 1999), and geomorphic evolution (Owen et al., 1995, 1997, 2001). Some specific aspects of erosion in Lahul have been studied, including catastrophic flooding (Coxon et al., 1996), glaciation, and paraglaciation (Owen et al., 1995). However, results from these studies are too spatially or temporally narrow to define regional exhumation or erosion rates. Moreover, longer-term exhumation and erosion rates, on timescales of 10^5–10^7 years, are lacking from Lahul. Recent thermochronologic studies elsewhere in the Himalaya have defined exhumation rates of 3–7 mm/a at time scales of 10^6 years (Harrison et al., 1997; Zeitler et al., 2001). Fission track (FT) data have revealed that significant erosion occurred in the Pakistan Karakoram during the Pliocene. Foster et al. (1994) proposed that at least 7000 m of rock were eroded during this period, yielding exhumation rates of 3–6 mm/a.

To build on these studies, we employed low-temperature AHe thermochronology on vertical transects of leucogranite stocks and ^{10}Be terrestrial cosmogenic nuclide (TCN) surface exposure dating (SED) on strath terraces exposed along the Chandra River and one of its tributaries. Our primary goals in using AHe thermochronology in Lahul were first, to determine whether long-term (10^6 years) exhumation rates could be established, and second, to gather data bearing on whether the topographic and thermal structure of Lahul have reached steady-state. Changes in erosion rate and the rate at which topography develops can significantly affect the migration and geometry of isotherms and can disturb cooling ages at the surface (Braun et al., 2006, p.105–176). TCN methods can quantify surface processes at millennial timescales back to 20–30 ka, and our goal of dating strath terraces was to determine recent river incision rates. Any spatial and temporal variation in surface exposure ages of strath terraces along the Chandra will provide a gauge of the heterogeneity of fluvial bedrock incision in this active Himalayan environment.

Our data can be used to test whether the Lahul Himalaya has undergone rapid exhumation. i.e. 3–7 mm/a, as proposed for elsewhere in the orogen and to determine whether local river incision rates are as high as other regions of the Himalaya, of the order of 1 to 20 mm/a, where more is known about uplift and erosion histories (Burbank et al., 1996). The timing of low-temperature cooling and the fluvial incision of the High Himalayan Crystalline Series (HHCS) in Lahul further bears on the linkage between local topography, regional rock deformation and strain partitioning, and surface erosion.

2. Background

Two main NW–SE-trending mountain ranges traverse Lahul, the Pir Panjal to the south and the Greater Himalaya to the north (Fig. 1). Both ranges include peaks exceeding 6000 m in elevation above sea