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Neogene marine isotopic evolution and the erosion of Lesser Himalayan strata: Implications for Cenozoic tectonic history

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ABSTRACT

An extensive, northward deepening blanket of Neoproterozoic and Cambrian sedimentary rocks once extended from the Himalayan margin far onto the Indian craton. Cambrian deposits of this “upper Lesser Himalayan” succession, which include deposits of the “outer” Lesser Himalaya tectonic unit, are enriched in radiogenic ^{187}Os. They make up part of a proximal marine facies belt that extends onto the craton and along strike from India to Pakistan. By contrast, age-equivalent facies in the Tethyan Himalaya are more distal in nature. Neoproterozoic to Cambrian strata of the upper Lesser Himalayan succession are now missing in much of the Lesser Himalaya, with their erosion exposing older Precambrian Lesser Himalayan strata. We suggest that exhumation and weathering of the upper Lesser Himalaya and related strata caused dramatic changes in the $^{187}Os/^{188}Os$ and $^{87}Sr/^{86}Sr$ Neogene record of seawater starting at ∼16 Ma. First-order estimates for the volume of upper Himalayan strata, as well as the volume of all LH rock eroded since this time, and geochemical box modeling, support this idea. Exhumation at 16 Ma is a fundamental event in the evolution of the Himalayan orogeny and the geochemical evolution of the oceans, and will be a critical part of the construction of future models of Himalayan thrust belt evolution.

1. Introduction

The uplift and erosional history of the Himalayan orogen had fundamental influence on climate and secular changes in ocean chemistry (Derry and France-Lanord, 1996; France-Lanord and Derry, 1997; Galy et al., 2007). Of key interest are the links between Neogene uplift and both the erosion of Himalayan bedrock and the record of the isotopic variations of Os and Sr in seawater. Quantification of the erosional history of the Himalayan orogen requires restoration of the geology prior to major unroofing. This objective, however, has been hampered by uncertainties in the timing of exhumation of lithotectonic zones of the Himalaya (Fig. 1), and debates on the pre-deformational configuration of the north Indian margin (e.g., Yin, 2006). Recent studies of the Neoproterozoic–early Paleozoic successions of the ancient northern Indian margin, both along and across the strike of the Himalayan orogen, provide insights into the stratigraphic, depositional, and tectonic relationships between these zones; in other words, the pre-collisional nature of the margin (Myrow et al., 2003; Hughes et al., 2005; Myrow et al., 2006; McQuarrie et al., 2008; Myrow et al., 2009, 2010; Long et al., 2011; McKenzie et al., 2011; Webb et al., 2011b; McQuarrie et al., 2013).

We comprehensively studied the spatial distribution of late Neoproterozoic–Cambrian successions across the northern Indian subcontinent in order to evaluate the uplift and erosion of various potential source rocks during propagation of thrust faults

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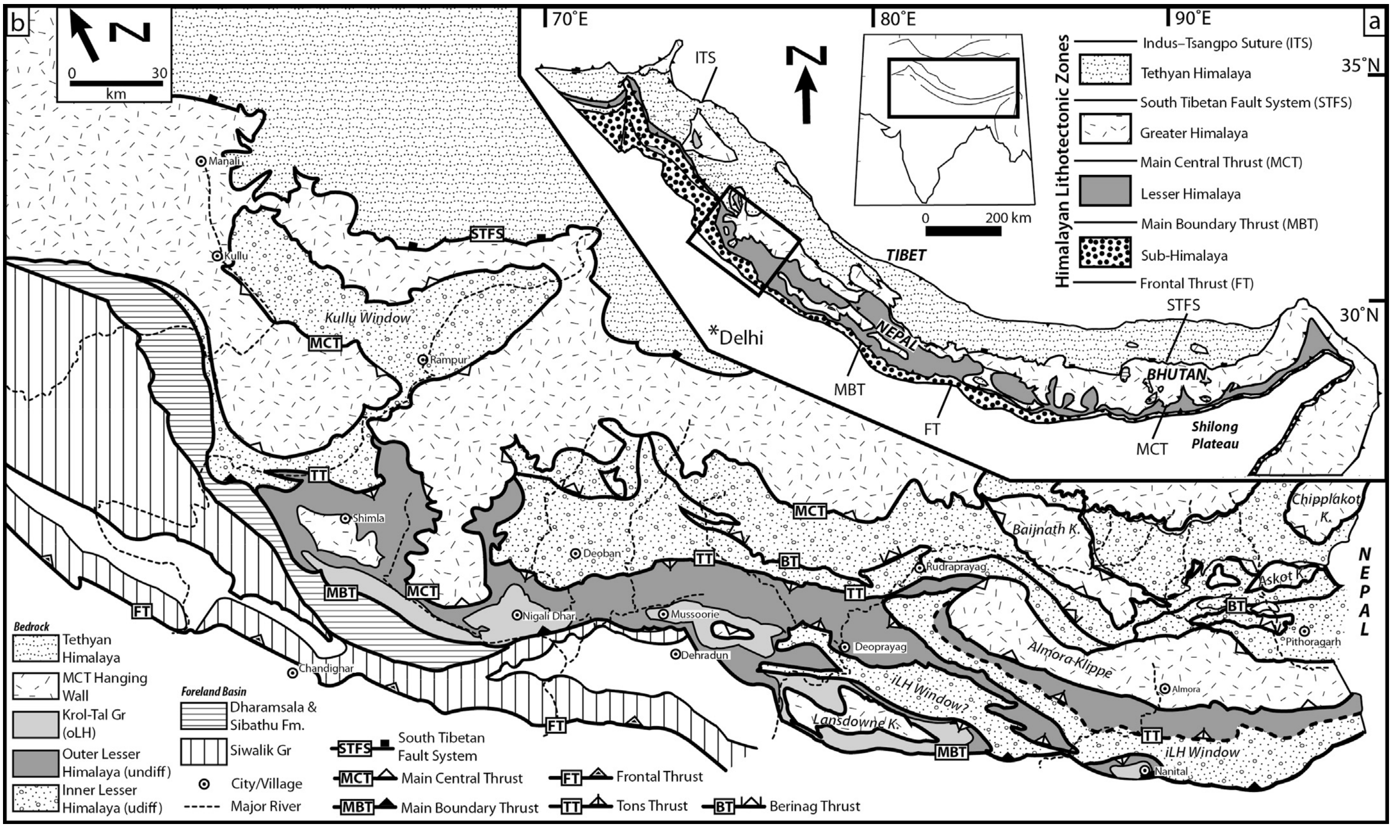

Fig. 1. (a) Overview Himalayan geologic map. (b) Simplified geological map of the northern Indian Himalaya west of Nepal (modified after Valdiya, 1980; Yin, 2006; Célérier et al., 2009b; Webb et al., 2011b; Webb, 2013).

associated with Himalayan deformation. Such eroded rocks may include the late Neoproterozoic–Cambrian strata of the Lesser Himalaya, some of which are enriched in radiogenic ^{187}Os, particularly a shale unit in the Tal Group (Singh et al., 1999; Pierson-Wickmann et al., 2000). The spatial and temporal pattern of erosion and chemical weathering of these strata may have been an important driving factor for secular changes in Neogene seawater ^{187}Os/^{188}Os and ^{87}Sr/^{86}Sr. If so, changes in the isotopic record of seawater may record significant changes in the thrust belt evolution of the Himalaya, including tectonic uplift and exhumation of changing source rocks. Therefore, we explore the feasibility, via geochemical modeling, that successive exhumation and weathering of two distinct Lesser Himalayan (LH) stratigraphic successions can quantitatively explain the observed trends in Neogene seawater ^{187}Os/^{188}Os and ^{87}Sr/^{86}Sr. The proposed exhumation history of the LH proposed here is consistent with foreland basin sedimentation and detrital zircon records, as well as the marine Os and Sr isotopic evolution.

2. Geologic background

Current convention is to divide the Himalaya into lithotectonic zones (e.g., Yin, 2006) (Fig. 1). The northernmost of these units, the Tethyan Himalaya (TH), is situated in the hanging wall of the South Tibetan Fault System (STFS) and consists of late Neoproterozoic to Eocene sedimentary successions. A central belt of high-grade metamorphic rocks, the Greater Himalaya (GH), is situated in the hanging wall of the Main Central Thrust (MCT) (but see Webb et al., 2011b, 2011a for discussion of various MCT definitions). The Lesser Himalaya (LH) is situated in the footwall of the Main Central Thrust (MCT) and consists mostly of Proterozoic strata with packages of younger Phanerozoic rocks scattered across the orogen. A series of thrust faults that place Himalayan bedrock structurally against Cenozoic basin deposits are generically referred to as the Main Boundary Thrust system (MBT) and uplifted foreland basin deposits reside in the hanging wall of the southernmost Frontal Thrust system (FT), which marks the boundary between the thrust belt and the foreland basin.

A prominent ∼500 million year unconformity that separates late Paleoproterozoic and older rocks (>1.6 Ga) from late Mesoproterozoic and younger rocks (<1.1 Ga) has been recognized across the Indian margin (McKenzie et al., 2011, 2013). In the Himalaya, this unconformity is generally recognized within the LH, and the terms "lower Lesser Himalaya" and "upper Lesser Himalaya" have been applied to the overlying and underlying units (e.g., Robinson et al., 2001, Richards et al., 2005; Robinson et al., 2006; McQuarrie et al., 2008; Gehrels et al., 2011 McKenzie et al., 2011). However, rocks with ages that are comparable to those above and below this unconformity have been recognized within the GH (cf. Yin et al., 2010; Webb et al., 2011b), demonstrating this is not a diagnostic feature of the LH, but occurs more widely. Therefore, we will use the broad terms "upper Lesser Himalayan succession" and "lower Lesser Himalayan succession" to refer to strata deposited above and below this unconformity, respectively.

Rocks of the upper and lower Lesser Himalayan successions are variably exposed along the orogen. Sedimentary rocks of both age groups are present in the LH of the eastern Himalaya in Bhutan (McQuarrie et al., 2008; Long et al., 2011; McQuarrie et al., 2013) and Arunachal Pradesh (Tewari, 2001), whereas rocks of the upper Lesser Himalayan succession are reportedly absent (due to later erosion) throughout the LH of Nepal (Robinson et al., 2001; DeCelles et al., 2004; Gehrels et al., 2011; Martin et al., 2011). Neoproterozoic and Cambrian rocks are also known along strike south of the Main Central Thrust in Pakistan, within the sub-Himalaya of the Salt Range of Pakistan, and on the Indian craton itself in Rajasthan, south of the Himalayan Frontal Thrust.