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Tectonic versus climate influence on landscape evolution: A case study from the upper Spiti valley, NW Himalaya

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ABSTRACT

We have undertaken structural, geomorphological, and morphometric analyses to investigate the role of tectonism and climate in the landscape evolution in the upper Spiti valley, NW Himalayas. Geomorphometric analyses coupled with field investigations reveal active tectonic deformation in the Spiti region. The calculated geomorphic indices (steepness, concavity and Hack) demonstrate uplift/subsidence along the Kaurik–Chango fault, whereas transverse topographic index (T-index) reveals basin tilting associated with active faulting near Hansa and Lingti valley. Investigation of well-dated Mane palaeolake sediments also provides evidence of regional tectonic instability. Four episodes (ca. 7.8, 7.4, 6.5 and 6.1 cal ka) of neotectonic activity have been identified during the period of the lake's existence. We have also compiled data on the regional climate variability and compared it with the age of the Mane palaeo-landslide. Our results indicate that the landslide occurred towards the end of the early Holocene intensified monsoon phase and is located near an active fault. Our data on regional tectonic instability and the coincidences of modern and palaeo-landslides with zones of active deformation suggest that tectonism is an important factor governing landscape stability in the Spiti region.

1. Introduction

Tectonism (Barnard et al., 2001) and intensified monsoon (Bookhagen et al., 2005) are considered to be the dominant factors governing landscape evolution in the Himalayan region. Recent studies have drawn attention to the increased frequency of occurrence of landslides during phases of intensified monsoon (e.g. Bookhagen et al., 2005; Dortch et al., 2009), and highlighted the link between terrace formation in NW Himalaya and monsoon dynamics (Bookhagen et al., 2006). In particular, large-scale mass movements (landslides) in the Spiti valley (Mane and Hansa, Fig. 1) have been attributed to intensified monsoon (Bookhagen et al., 2005; Phartiyal et al., 2009). However, the role of regional tectonic instability in triggering landslides has not been sufficiently explored in the Himalayan region. This lacunae needs to be addressed as numerous conceptual models and field investigations suggest that deformation and large-scale mass movements triggered by tectonic activity can have a direct control in shaping the landscape and drainage evolution (Delcaillau et al., 1998; Burbank and Anderson, 2000). We propose that an understanding of the long-term regional tectonic history that can provide information about the stability of the region, against the background of climate change, is essential for deciphering the relative influence of both factors in initiating mass movements. Morphometric analyses, in combination with the investigation of Quaternary landforms (e.g. river terraces, lake sediments etc.) can provide information about regional tectonic stability. Lake sediments in particular can be used as excellent archives (Sims, 1973, 1975; Upadhyay, 2003; Perucca et al., 2009; Wang et al., 2011) that can potentially provide a long-term chronologically constrained palaeoseismic record.

In the present study we focus on the Spiti region (northwestern Himalayas, India) that lies in the transitional zone between the westerlies and the Indian summer monsoon — the modern-day precipitation is, however, dominated by the westerlies (Singh and Kumar, 1997; Wulf et al., 2010). Most of the studies in this region have focused on large landforms (e.g. landslide debris, Bhargava and Bassi, 1998; Bookhagen et al., 2005) and few lacustrine outcrops in the Lingti valley and Hansa palaeo-lake sediments (e.g. Phartiyal et al., 2009). The Spiti valley shows extensive lake outcrops that were deposited due to the landslide damming of the Spiti River during the geologic past; however, not all the deposits are chronologically constrained. In the present work, we have investigated only the early Holocene palaeo-lake sediments formed by the landslide damming near Mane village (hereafter referred to as Mane palaeo-lake) in the upper Spiti valley. Previous dating on the Mane palaeo-lake sediments

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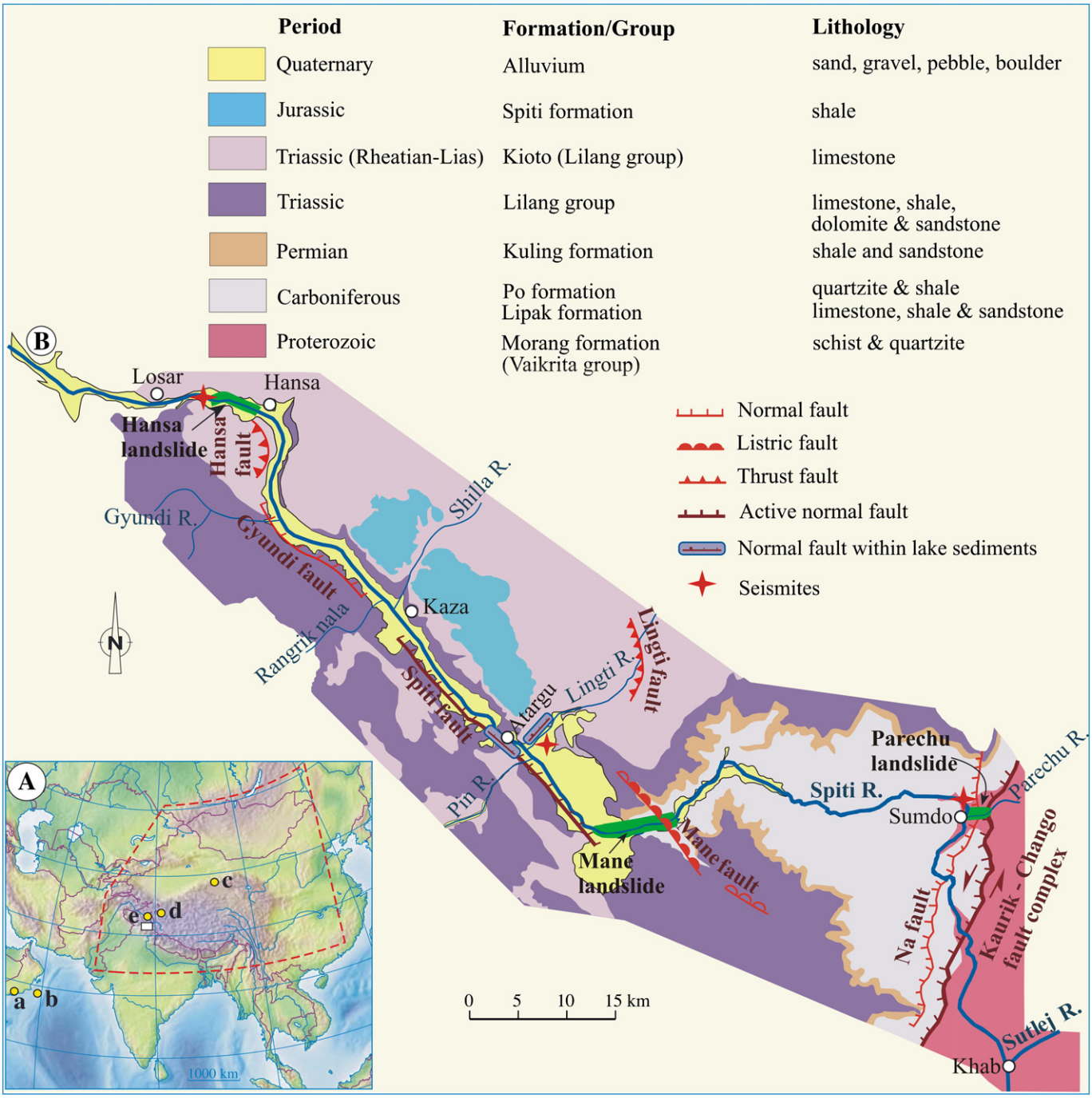

Fig. 1. (A) The map showing investigated region (white rectangle) and sites referred to in the text (a) Qunf cave, Oman (Fleitmann et al., 2003), (b) Arabian sea core (Gupta et al., 2003), (c) paleoclimate records from central Asia (the area shown in red dotted line), (Herzschuh, 2006), (d) Western Tibetan lakes (Van Campo and Gasse, 1993), (e) Tsokar lake (Demske et al., 2009). (B) The geologic succession and tectonic map of the Spiti valley (compiled after Mohindra and Bagati, 1996; Bhargava and Bassi, 1998; Steck, 2003; Phartiyal et al., 2009; Hintersberger et al., 2010). The seismites and landslides reported from the region are also shown.

indicates an early Holocene age: ^{14}C dates show lake existence between 8.7 and 6.1 cal ka (Bookhagen et al., 2005), while Optically Stimulated Luminescence (OSL) dating indicates age boundaries between 13 ± 2 ka to 8 ± 1 ka (Phartiyal et al., 2009). Based on the inferred age of the Mane landslide in the Spiti valley, and its comparison with the monsoon proxy records, Bookhagen et al. (2005) and Phartiyal et al. (2009) have suggested that this landslide occurred during the early Holocene intensified monsoon period. However, the continuously deposited Mane palaeo-lake sediments have a high potential of recording tectonic perturbations and providing data on the long-term stability of the region. Our objective is to explore the relative importance of tectonics and climate in shaping the Holocene landscape in this region. For this we have (i) undertaken field mapping of geomorphic features and palaeo-lake sediments in the upper Spiti valley; (ii) analysed digital elevation models to evaluate geomorphic parameters for active deformation in the region; (iii) for the first time, compiled a detailed tectonic map of the upper Spiti valley based on previously published and new data from our study; (iv) examined the Mane palaeo-lake sediments for evidence of neotectonic activity; and (v) compared the timing of the Holocene (Mane) landslide with the newly available