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Genesis and implication of soft-sediment deformation structures in high-energy fluvial deposits of the Alaknanda Valley, Garhwal Himalaya, India

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ABSTRACT

Valley-fill terraces and fluvio-lacustrine sediment successions were investigated for the nature and type of soft-sediment deformation structures (SSDS) in the Alaknanda Valley of the Garhwal Himalaya. Based on their morphologies, sediment characteristics and comparison with existing data on SSDS, these features are classified into seismic and aseismic categories. The study indicates that, despite the terrain being in the seismically active domain of the Central Himalaya, the majority of the deformation structures seem to have been generated aseismically. We attribute their genesis to uneven loading, slope failure and, most importantly, turbulent flow and sudden loading by flash floods. The study suggests that a cautious approach is needed before assigning a seismic origin to deformation structures in sediments deposited in high-energy fluvial systems.

1. Introduction

Soft-sediment deformation structures (SSDS) include a wide range of structures that form in unlithified/unconsolidated clastic sediments (Mills, 1983; Maltman, 1984; Owen, 1996a; Hibsch et al., 1997; Van Loon, 2009; Owen et al., 2011; Ghosh et al., 2012) under the scenario of adequate driving force(s), deformational mechanism and trigger (Allen, 1982; Owen et al., 2011; Rana et al., 2013a). Temporary reduction in sediment strength due to liquefaction, fluidization or thixotropy is the main processes implicated for deformation in clastic sediments (Lowe, 1975; Owen, 1996a, 2003). These processes can be triggered by rapid sedimentation, artesian groundwater movement, earthquake shaking, storm currents and gravity flows (Lowe, 1975; Obermeier, 1996; Owen and Moretti, 2011). Despite the variety of potential triggers, these structures are widely exploited in paleoseismic studies (e.g. by Obermeier et al., 1987; Mohindra and Bagati, 1996; Moretti, 2000; Neuwerth et al., 2006; Pandey et al., 2009; Ghosh et al., 2012; Rana et al., 2013a).

Seismically induced SSDS are crucial for reconstructing the paleoseismicity of an area where the historical records of earthquakes are either insufficient or not well documented. Garhwal Himalaya is a seismically active area within the central seismic gap which is considered as a potential zone for an impending large earthquake (Fig. 1B) (Khattri and Tyagi, 1983). The terrain experienced moderate to high-magnitude earthquakes in the historical as well as in the recent past. For example, the great earthquake of 1803 that devastated a large area in the Garhwal had its epicenter around Srinagar (Rajendran and Rajendran, 2005). Similarly, the 1991 Uttarakashi and 1999 Chamoli earthquakes had epicenters in the south of the Main Central Thrust (Kayal, 2010) (Fig. 1A). As mentioned above, the terrain lies in the central seismic gap, which implies that it is due for a large-magnitude earthquake in the near future. Therefore, it is important to understand the frequencies and magnitudes of past earthquakes (beyond the historical and instrumental records) in order to ascertain the recurrence interval of large-magnitude earthquakes in the region. The sedimentary records of past earthquakes in the form of SSDS are considered as potential archives that can contribute towards achieving this aim.

In this study we analyze SSDS and some brittle deformation features in fluvial and fluvio-lacustrine deposits in the Alaknanda Valley with the following objectives: (i) to document the morphologies of the deformation features; (ii) to determine the driving forces, deformation mechanism and possible triggers; and (iii) to consider the paleoseismic/environmental implications for the area. The present study is a contribution towards improving our ability to distinguish aseismic from seismic SSDS, particularly in a high-energy fluvial environment.

2. Geological and tectonic setting of the study area

The geological and tectonic evolution of the Himalaya is a result of the convergence of the Indian and Eurasian plates. This convergence is active at the rate of ~50 mm/year (DeMets et al., 1994) and is

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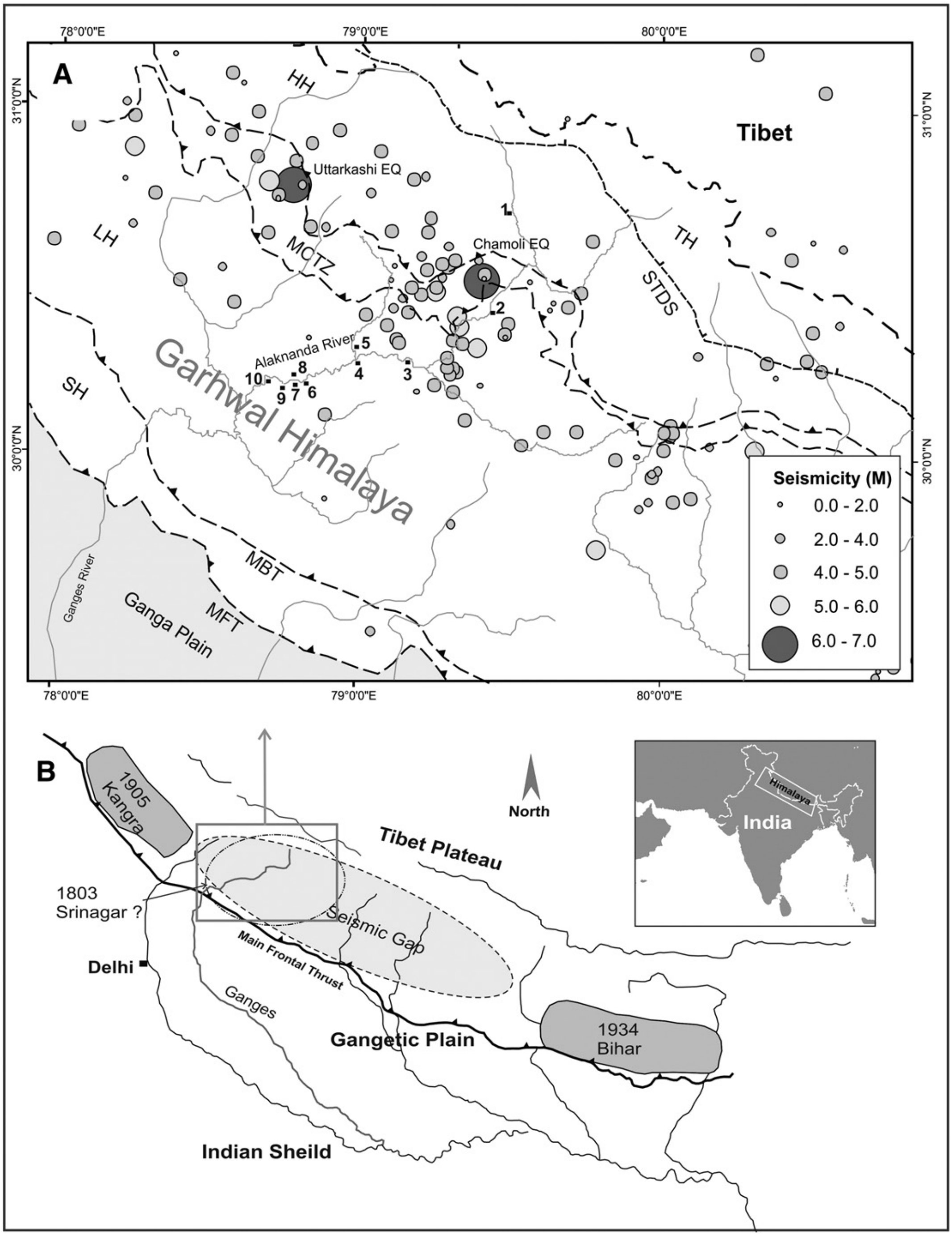

Fig. 1. Study area. (A) Location and seismotectonics of the Alaknanda catchment of the Garhwal Himalaya. (B) Darker polygons are the rupture zones of great earthquakes. STDS—South Tibet Detachment System, MCT—Main Central Thrust, MBT—Main Boundary Thrust, MFT—Main Frontal Thrust, SH—Sub-Himalaya, LH—Lesser Himalaya, HH—Higher Himalaya, TH—Tethyan Himalaya. 1—Badrinath, 2—Birehi, 3––Gauchar, 4—Rudraprayag, 5—Tilwara, 6—Swit, 7—Srinagar, 8—Chauras, 9—Kirtinagar and 10—Khandukhal. Tectonic structures after Valdiya (1980). Seismic data plotted according to the USGS (http://earthquake.usgs.gov/earthquakes/eqarchives/epic/).

episodically manifested in the form of moderate to large-magnitude earthquakes. However, a zone of ~700 km length located between the rupture zones of the 1905 Kangra and 1934 Bihar–Nepal earthquakes has not experienced any great earthquake for at least the last two centuries (Fig. 1B). This zone is called the *Central Seismic Gap* and is considered to be the potential zone for an impending large magnitude earthquake (Khattri and Tyagi, 1983). The Garhwal Himalaya, which lies in this zone, has witnessed three earthquakes of magnitude >6, namely the Srinagar (1803), Uttarkashi (1991) and Chamoli (1999) earthquakes (Rajendran and Rajendran, 2005). Geologically from north to south, the Alaknanda Valley can be divided into three distinct lithological zones. These are the Tethyan Sedimentary Sequence, the Higher Himalayan Crystalline and the Lesser Himalayan Meta-sedimentaries (Fig. 1A). The Tethyan Sedimentary Sequence is dominated by fossiliferous shales, limestone and sandstone of Precambrian to Eocene age, whereas Proterozoic–Ordovician schists, gneisses and migmatites dominate the Higher Himalayan Crystalline. The Lesser Himalayan Meta-sedimentaries are dominated by quartzite, slate, carbonate and phyllite of Precambrian age (Heim and Gansser, 1939, Srivastava and Ahmad, 1979, Kumar and Agarwal, 1975, Valdiya, 1980).