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Distribution of the Late-Quaternary deformation in Northwestern Himalaya

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ABSTRACT

Three main Cenozoic thrusts at the front of Northwestern Himalaya have accommodated most of the India–Eurasia convergence across the belt over the last million years and produced the present relief. Their recent tectonic activity is poorly known because of the long period of inaccessibility of the Jammu and Kashmir state, and because the latest and only large earthquake recorded in the region occurred in 1555 AD. We show where the deformation is localized during the Late-Quaternary, and determine shortening rates across the structures by analyzing the geometry and chronology of geomorphic markers. The Main Boundary Thrust in this region ceased moving at least ~30 ka ago. On the contrary, the more external Medlicott–Wadia Thrust and Main Frontal Thrust, both merging at depth on the sub-flat detachment of the Main Himalayan Thrust, exhibit hectometric-scale deformations accumulated during the last thousands of years. The total shortening rate absorbed by these faults over the last 14–24 ka is between 13.2 and 27.2 mm/yr (11.2 ± 3.8 and 9.0 ± 3.2 mm/yr, respectively). Part of this deformation may be associated to the geometry of the Chenab reentrant, which could generate an extra oblique component. However, the lower bound of our shortening rates is consistent with previously determined geodetic rates. Active deformation on these structures follows an in-sequence/out-of-sequence pattern, with breaking of both ramps being possible for earthquakes triggered on the main detachment.

1. Introduction

The active deformation due to the collision between India and Eurasia in the Northwestern Himalayan belt has a complex pattern in terms of structural geometry and temporal evolution (Burbank and Johnson, 1983; Powers et al., 1998). During Cenozoic times, the shortening across the belt in this region has been accommodated by a series of sub-parallel South-verging thrusts (Fig. 1A) that merge at depth on a sub-flat detachment plane, the Main Himalayan Thrust (MHT) (Srinivasan and Khar, 1996; Yin, 2006; Jouanne et al., 2011; Mugnier et al., 2013). Stress accumulating on these faults is partly released seismically, with historical events $M > 7.5$ (Ambraseys and Jackson, 2003; Ambraseys and Douglas, 2004; Hussain et al., 2009).

The last two main regional seismic events were the 1905 Kangra Mw 7.8 earthquake and the 2005 Muzaffarabad Mw 7.6 earthquake (Fig. 1A). The former, depending on the authors, occurred either beneath the frontal part of the belt or on a more internal thrust (Ni and Barazangi, 1984; Seeber and Armbruster, 1984; Bilham, 2001; Ambraseys and Douglas, 2004; Wallace et al., 2005) while the latter was clearly triggered on an internal thrust (Avouac et al., 2006; Kumahara and Nakata, 2006; Yeats et al., 2006; Kaneda et al., 2008). In between these two ruptures, a 200-km-long zone has experienced a period with no major events since 1555 AD, when the Kashmir earthquake estimated to be larger than Mw 7.5 caused damages over a vast region extending from the front of the range to the Kashmir basin (Ambraseys and Douglas, 2004). The localization of its epicenter remains unknown and so its origin cannot be assigned to any given structure.

This lack of information and the occurrence of earthquakes on internal and external structures in the region at the historical

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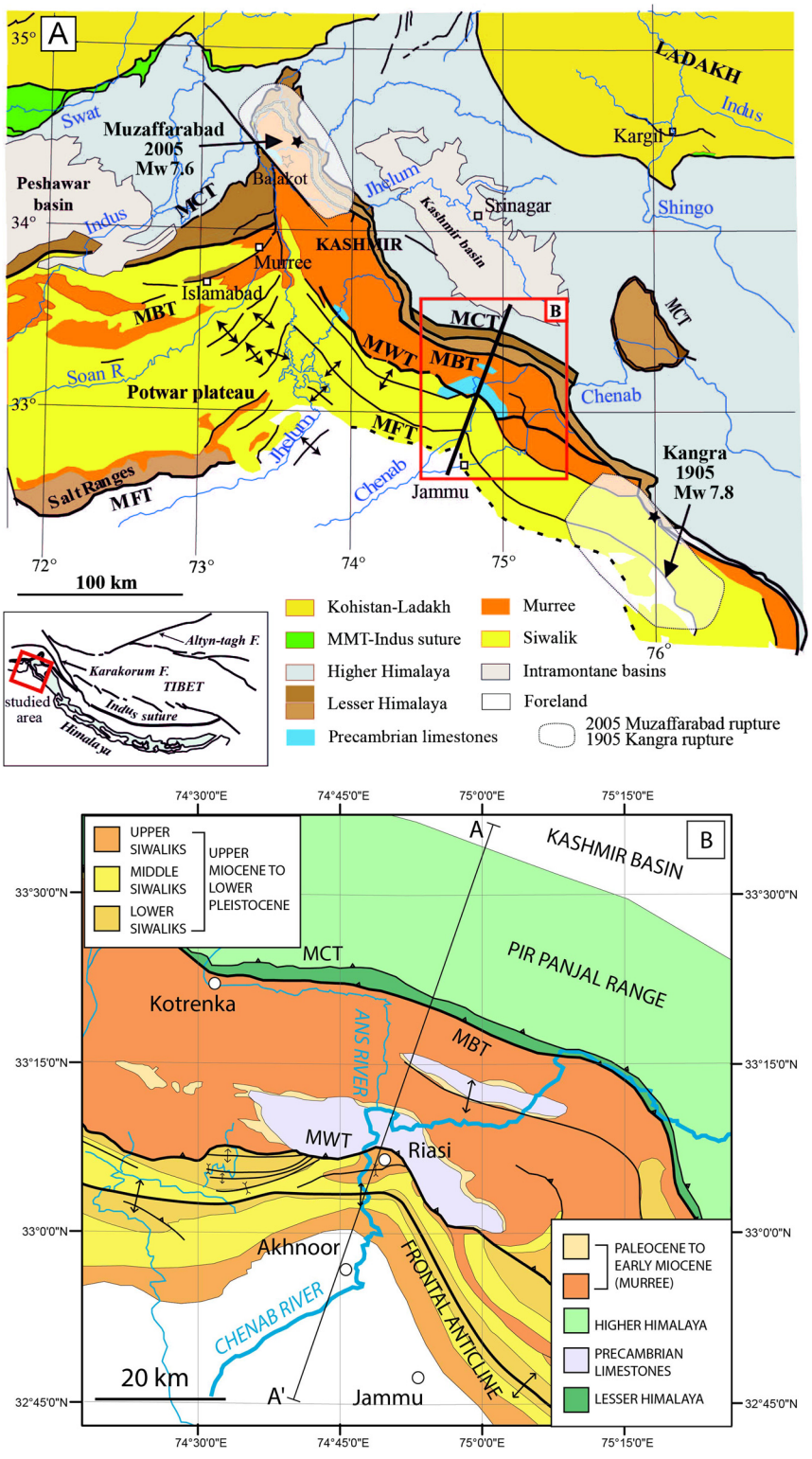

Fig. 1. A) Simplified structural map of the Northwestern Himalayan front in the Northwestern syntax region. Modified from Pêcher et al. (2008). B) Regional geological map of the study area with the principal tectonic structures: the Main Central Thrust (MCT), the Main Boundary Thrust (MBT), the Medlicott–Wadia Thrust (MWT), and the Frontal Anticline (FA) above the Main Frontal Thrust (MFT). Realized from our fieldwork data and from the geological map of Karunakaran and Rao (1979); C) Crustal cross-section of the transect indicated in B. MHT stands for the Main Himalayan Thrust and PT for the Panjal Thrust.

time-scale rise two fundamental questions about the localization of the seismogenic structures over the millennial time-scale in this part of the belt. Does deformation follow an in-sequence or an out-of-sequence pattern? And which are the most active tectonic faults capable of producing destructive earthquakes?

The present shortening across the Northwestern Himalaya is between ~12.5 and ~14 mm/yr in Kashmir/Ladakh (Schiffman et al., 2013; Jade et al., 2014) and ~13 mm/yr in northern Pakistan (Jouanne et al., 2014). Morphotectonic rates are only available 200 km to the West (Kaneda et al., 2008) and 400 km to the East