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Quaternary landscape evolution of the Helmand Basin, Afghanistan: Insights from staircase terraces, deltas, and paleoshorelines using high-resolution remote sensing analysis

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ABSTRACT

The Helmand Basin in southern Afghanistan is a large (310,000 km^2), structurally controlled, endorheically drained basin with a hyperarid climate. The basin hosts a high elevation (~200 m) plateau (the Dasht-i Margo), 11 fluvial staircase terraces (T11 to T1), 7 delta systems (D1 to D7), and 6 paleolake shorelines (SL1 to SL6) within the Sistan Depression on the western side of the basin. Mapping and surveying of these features by remote sensing is integrated with geological observations to reconstruct Quaternary landscape evolution of the basin. The fluvial systems, deltas, and paleolake shorelines are correlated with one another and with the younger terraces (T7 to T1). The shape of fluvial longitudinal profiles changes depending on whether they formed pre-, syn-, or post-growth of the Koh-i Khannesin volcano on the southern margin of the Helmand River. The age of the volcano (~0.6 Ma) and correlation of the terraces with the global history of glacial-interglacial cycles constrain the age of the younger terraces to the late Pleistocene and indicates that the older terraces are middle Pleistocene (dating back to 800 ka). The Helmand Basin once hosted a large lake, called here the Sistan paleolake, which at SL6 times and before had a surface area >50,000 km^2. Since that time the lake elevation and area have decreased, evolving to the present-day dried out Sistan Depression with small ephemeral playa lakes. Episodic formation of terraces, deltas, and paleolake shorelines is attributed to changes in base level modulated by climate change related to Milankovitch cycles.

1. Introduction

The majority of landscape development is based on reconstructions from a single geomorphic surface, e.g., fluvial terrace (e.g., Lavé and Avouac, 2000; Demir et al., 2004; Bridgland et al., 2012; Stokes et al., 2017), deltas (Horton and DeCelles, 2001; Hartley et al., 2010; Syvitski et al., 2012), or paleoshorelines (Currey, 1990; DeVogel et al., 2004; Drake and Bristow, 2006; Garcin et al., 2012). Within the Helmand Basin, the exceptional preservation of a large-scale plateau, staircase terraces, deltas and paleoshorelines allow these surfaces not just to be mapped and characterised individually but also to be linked into current and former longitudinal fluvial profiles over a basin scale. These studies enable an assessment of how landscape has responded to climate and tectonic processes within the Quaternary period.

The large scale of these surfaces and the hostile location lends itself to using remote sensing for analysis. With the increase in freely available satellite remote sensing data of Earth's surface, studies investigating geology and geomorphology in areas where field work can be difficult have seen an upsurge (e.g., the high Himalaya: Cooper et al., 2012; or the Pakistan/Afghanistan border: Ul-Hadi et al., 2013). Numerous studies looking at large-scale geomorphic features have exploited the use of remote sensing, for example in mapping fluvial terraces (Bridgland et al., 2012; Stokes et al., 2012), megalakes (e.g., Drake and Bristow, 2006; Garcin et al., 2012; Bachofer et al., 2014; Perkins et al., 2016), and deltas (e.g., Horton and DeCelles, 2001; Hartley et al., 2010). In this study we combine a number of different remotely sensed data sets to reconstruct the Quaternary evolution of the landscape within an area that has received little geological research since the 1970s (e.g., Pias, 1972, 1976; Smith, 1974).

The Helmand Basin is a large (310,000 km^2), structurally controlled, endorheically drained basin situated in a region with a hyperarid climate (precipitation < 100 mm/y). It is primarily fed by the Helmand River, which drains the Hazarajat Mountains and flows west into the Sistan Depression on the western edge of the basin (Fig. 1). Despite the hyperarid climate, the Sistan Depression contains numerous shallow lakes fed by the Helmand River, which host important agricultural and wetland areas with a long history of human habitation over at least the last 5000 years (Whitney, 2006; Lu et al., 2009). However, fluctuations in climate over the past century have led to regional droughts and conflict with neighbouring countries (Whitney, 2006). The communities of the Helmand Basin have relied heavily on sparse

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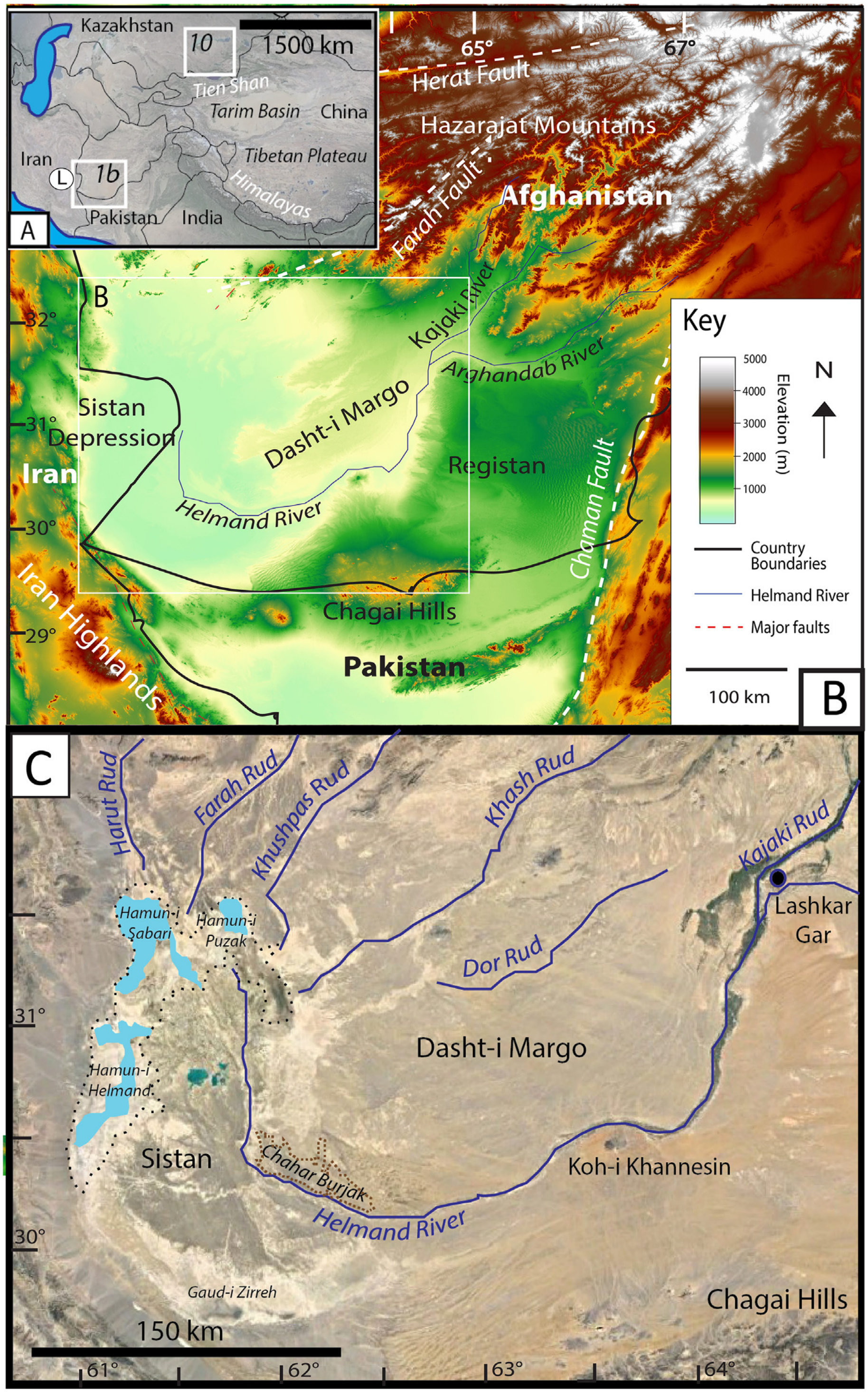

Fig. 1. (A) Regional Google Earth image of the Himalayan-Tibetan region with locations of figs. 1b and 10 denoted by white boxes, white circle L = Lut Desert in eastern Iran. (B) Digital elevation model of the Helmand Basin showing the main geomorphic regions and large-scale faults. (C) Google Earth image of the Helmand Basin showing the main rivers that flow into the basin and the playa lakes.

water supplies for drinking, irrigation, and energy production. This study places new constraints on how the landscape of the Helmand Basin has reacted to past climate fluctuations, which could be used to predict how this region could react to future climate change.

2. Physical geography of the Helmand Basin

The Helmand Basin dominates the southern part of Afghanistan and extends into eastern Iran and western Pakistan. The region is structurally enclosed, bordered on four sides by mountain ranges. The Hazarajat Mountains, part of the Karakoram-Himalayan mountain chain, form the northern border of the Helmand region and are the main source of sediments deposited in the basin (Fig. 1B) (Whitney, 2006). To the south, the Chagai Hills border the basin. In the west, the basin is bordered by the eastern Iranian highlands (Fig. 1B). The eastern margin of the basin is defined by the edge of the Registan Plateau rising up abruptly to the east of the Helmand River.