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Bedrock channels response to differential rock uplift in eastern Qilian Mountain along the northeastern margin of the Tibetan Plateau

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A B S T R A C T

The response of bedrock channels to differential rock uplift in eastern Qilian Mountain significantly dictates the topographic evolution of the northeastern margin of the Tibetan Plateau. Our ability to extract tectonic information directly from channel profiles mainly depends on the calibration of incision processes laws. Here we assess the degree and nature of channels response to differential rock uplift in eastern Qilian Mountain base on an empirical calibration of the shear-stress incision model utilizing field survey data (lithologic resistance, sediment flux, discharge and channel width). Parameters calibration indicates that channels developed in the high mountain zone (HMZ) show an approximate 1.1–1.3 times increase in erosion coefficient *K* than in the low mountain zone (LMZ), mainly attributing to the adjustments of channel width and discharge. Moreover, profiles analysis reveals a systematic geographic distribution of steepness indices and concavity in this area. The regions of high and low steepness indices are spatially associated with the higher (high rock uplift rates) and lower (low rock uplift rates) parts of landscape, respectively, suggesting that the spatial distribution pattern of channel steepness mainly reflects the differential rock uplift. Channels with abnormal high concavity values apparently associate with the major thrust faults, suggesting that the differential rock uplift is controlled by the thrusting of major active faults. Combining parameters calibration with profile analysis between the two zones, the possible increase in rock uplift rates is 2–4 times in the HMZ than in the LMZ indeed.

1. Introduction

Bedrock channel fluvial systems has became the forefront of tectonic geomorphology with the deepening of recognition of potential interactions between climate, surface processes and tectonics (DiBiase, 2014; DiBiase and Whipple, 2011; Ferrier et al., 2013; Finnegan et al., 2014; Hartshorn, 2002; Molnar and England, 1990; Raymo and Ruddiman, 1992; Whipple et al., 1999). Bedrock channels dictate critical relationships among relief, elevation, and denudation rate, thus transmit tectonic and/or climatic signals throughout the landscape (Howard, 1994; Howard et al., 1994; Pritchard et al., 2009; Whipple et al., 1999). Therefore, bedrock channel longitudinal profiles have been regarded as more sensitive indicators of uplift rates than other morphological properties in active orogen (Whipple, 2004). The spatial distribution of rock uplift and substrate active faults can be determined directly by analyzing the systematic behavior of stream profiles in tectonically active region (e.g., Allen et al., 2013; Hack, 1957, 1973; Kirby et al., 2007, 2003; Kirby and Ouimet, 2011; Kirby and Whipple, 2001; Lavé and Avouac, 2001; Oskin et al., 2014; Pritchard et al., 2009; Wobus et al., 2003; Yanites et al., 2010).

Multiple models have been established for modeling the dynamics of bedrock channel systems (Whipple, 2004), in which shear-stress (or stream-power) model family is most satisfying (Royden and Taylor Perron, 2013; Whipple and Tucker, 1999) for bases directly on the physics of erosion (Howard and Kerby, 1983). However, the generality of this class of models results in poorly understood for a number of parameters whose effective values represent, let alone the complex interactions among a series of physical processes (Whipple and Tucker, 1999), which hampers the correct application of the models (Gasparini and Brandon, 2011; Lague, 2014; Pritchard et al., 2009; Tomkin, 2003). Even in the simplest situation, the shear-stress (or stream-power) model depends on at least two key unknown parameters: the coefficient of erosion and the exponent associated with channel gradient (Whipple and Tucker, 1999).

Although these parameters can be estimated to a certain extent base on field survey, the available data is relatively sparse (e.g., Duvall et al., 2004; Oskin et al., 2014; Snyder et al., 2003a; Stock and Montgomery, 1999; Whipple et al., 2000b), because of the complexity of various influencing factors such as hydraulic

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geometry characteristics, substrate erodibility, sediment supply, and transient conditions of channel morphology (Lague, 2014; Pritchard et al., 2009; Whipple, 2004). Our ability of extracting tectonic information directly from channel profiles requires a quantitative understanding of relationships between channel gradient and rock uplift rate, which depends in large part on the ability of isolating the various influences in field-based studies (Whipple, 2004).

In this paper, we analyze the longitudinal profiles form of bedrock channels draining in eastern Qilian Mountain along the northeastern margin of Tibetan Plateau, in an effort to explore systematic variations of rock uplift rates and assess the manner and degree to which bedrock channels respond to differential rock uplift. Although we have carried out extensive researches of river incision rates by chronology of fluvial terraces, the survey locations are relatively discrete and sparse attributing to the preservation and accessibility of the terraces (Pan et al., 2001, 2003, 2007, 2013).

In this study, we provide empirical calibration of key model parameters with all available data including lithologic resistance, sediment flux, discharge and channel width. Then, we attempt to infer the possible variations magnitude of uplift rates between different topographic zones, and explore unknown substrate structures on the basis of calibrated geomorphic indices. In addition, we place bounds on acceptable model parameters in this field site with rock uplift rates inferred from fluvial terraces.

2. Eastern Qilian Mountain field site

The Qilian Mountain bounds the northeastern margin of the Tibetan Plateau (Fig. 1) and consists of actively growing mountain ranges and intramontane basins that are gradually incorporated into the northeastern Tibetan Plateau (Métivier et al., 1998; Meyer et al., 1998; Tapponnier et al., 2001). Our study area is located in the easternmost segment of the Qilian Mountain between the longitudes of 101°30′E and 103°00′E (Fig. 1). Topography in this area exhibits a pronounced stepwise distribution with the maximum height near the crests and gradually decreasing toward the range front. From the south to the north, it can be divided into three different topographic zones (Pan et al., 2013) (Fig. 1): the high mountain zone (HMZ, 3700–5000 m), the lower mountain zone (LMZ, 2500–3200 m), and the corridor plain zone (CPZ, 1500 m) which is generally regarded as a natural local base-level for the streams originated from the mountain area (Fig. 1). Particularly, the boundaries between the different zones roughly coincide with the major thrust fault systems in this field including the Fengle, Kangningqiao, Huangcheng-Shuangta and Lenglongling faults (Fig. 1). Hetzel et al. (2004) have pointed out that these systematic changes perpendicular to the mountain range strike in relief are likely to reflect the slip distribution on the range-bounding thrust faults and indicate that these ranges continue to grow laterally and vertically.

In our study area, Paleozoic stratums are widely exposed, including early Paleozoic volcanic and metamorphic sediments, late Paleozoic sediments and metasediments, and Caledonian granites (Fig. 2). Cenozoic sedimentary stratums, commonly red sandstones, are mainly distributed along the northern margin of the mountain and in lower elevations (Fig. 2). Generally, rock type in the HUZ mainly consists of Ordovician metasedimentary and metavolcanic and Caledonian volcanic and volcaniclastic (Fig. 2). By

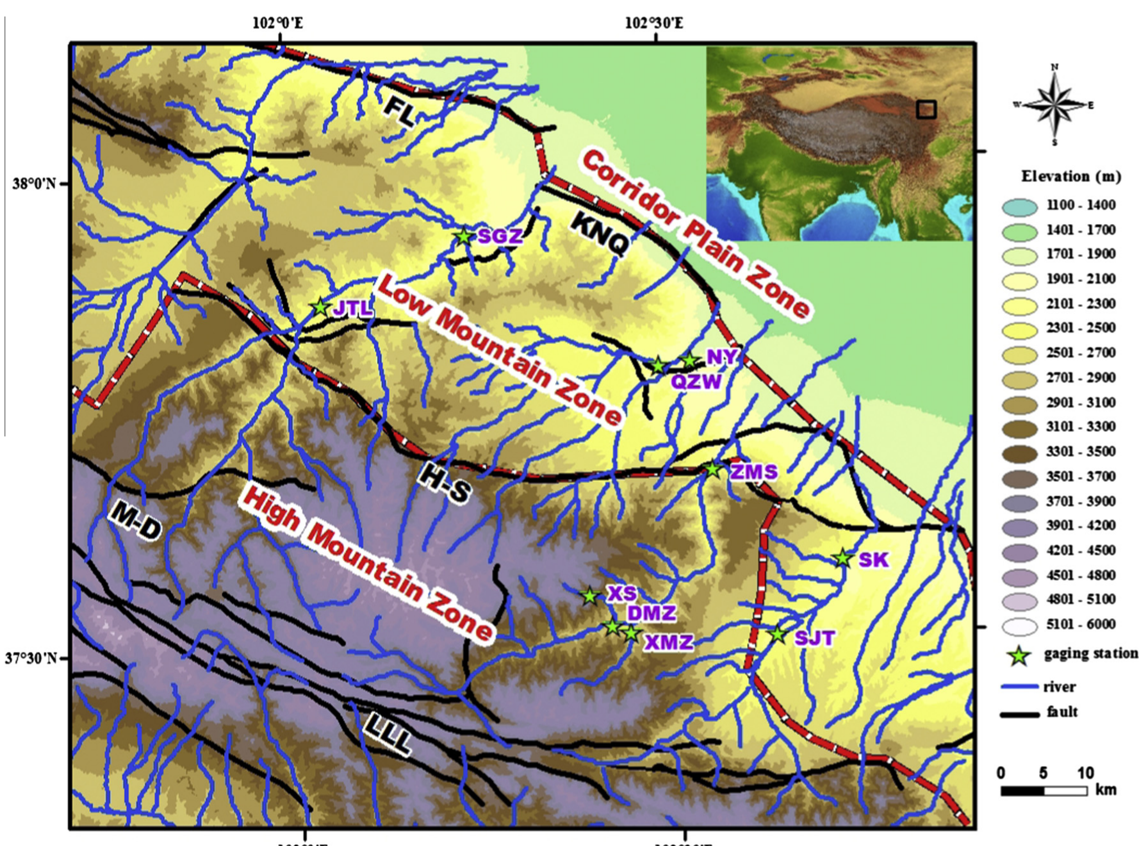

Fig. 1. Topgraphic characteristics of the eastern Qilian Mountain along the northeastern margin of the Tibetan Plateau (inset shows location). Major streams draining in the region are shown in dark blue lines. Major faults are shown in bold black lines (M-D, Minle-Damaying fault; H-S, Huangcheng-Shuangta fault; LLL, Lenglongling fault; FL, Fengle fault; KNQ, Kangningqiao fault). Gaging stations used in this study are indicated by stars (JTL, Jiu TL; SGZ, Si GZ; QZW, Qing ZW; NY, Nan Y; ZMS, Za MS; XS, Xiang S; DMZ, Da MZ; XMZ, Xiao MZ; SJT, Sha JT; SK, Shui K). Red heavy dashed lines indicate the boundaries of the HMZ, LMZ and CPZ (Modified from Pan et al., 2013, Fig. 13). Note that the incision rates are high (~1.2 mm/yr) in the HMZ relative to the low incision rates (~0.5 mm/yr) in the LMZ (Pan et al., 2013, Fig. 14).