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Drainage network morphometry and evolution in the eastern Lesotho highlands, southern Africa

Jasper Knight*, Stefan W. Grab

School of Geography, Archaeology & Environmental Studies, University of the Witwatersrand, Private Bag 3, Johannesburg 2050, South Africa

A R T I C L E I N F O

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A B S T R A C T

Present-day drainage patterns in mountain regions are strongly affected by antecedent tectonic and geologic factors. In the mountains of eastern Lesotho, southern Africa, bedrock comprises flat-lying Jurassic basalts which have given rise to a relatively uniform initial land surface. Here, we present key morphometric measurements of river drainage patterns from this region, from six 4th order river basins, including principal river sinuosity, river long profiles and valley cross profiles, in order to evaluate geological controls on drainage evolution and the potential ages of river elements. Results show that there are highly variable spatial patterns of river morphometric properties, even between adjacent basins, despite identical geologies and altitudes across the region. However, northerly catchments show knickpoints, variable long profiles and have steep sided and V-shaped valley cross profiles. Southerly catchments have much smoother long profiles, no knickpoints, and concavo-convex valley cross profiles. There are also differences in river sinuosity values, both for the catchments as a whole and for reaches of different lengths within the catchments. These spatially varying river morphometric and drainage properties most likely are the long-preserved outcomes of epeirogenic forcing on the land surface (including tectonic uplift, mantle relaxation and rebound during the Cenozoic), and subtle long-term variations in climate from north to south across the region, including in precipitation and weathering.

1. Introduction

Many studies have examined the interrelationships between geologic, tectonic, topographic and climatic controls on river patterns (including drainage system morphometry) in mountainous regions (e.g., Duvall et al., 2004; Turowski et al., 2008; Hayakawa and Oguchi, 2009, 2014; Allen et al., 2013; Brown and Pasternack, 2014; DiBiase et al., 2015; Johnson and Finnegan, 2015; Yunus, 2016). Disentangling the relative importance of these factors in different locations is necessary in order to consider how different fluvial landforms can be used as diagnostic indicators of the existence of a dominant control on river system dynamics. This has been attempted most commonly in tectonically-active mountain environments, such as in Japan, New Zealand and western USA, where tectonic uplift has driven patterns of river incision and the formation of distinctive features such as waterfalls and knickpoints (e.g., Kale, 2005; Wobus et al., 2006; Bishop, 2007; Stark et al., 2010; Petrovszki et al., 2012). The formation and maintenance of meanders in bedrock channels are less well known, even though these features are quite common in mountain landscapes (e.g., Stark et al., 2010; Petrovszki et al., 2012). Several studies have approached this problem using numerical modelling (Hooke, 2003; Schwenk et al., 2015), in which changes in meander sinuosity are shown to be related to substrate hardness and flow resistance (Turowski et al., 2008; Lazarus and Constantine, 2013; Johnson and Finnegan, 2015). Other studies have linked meander sinuosity to hydrological regime and thus climate (Stark et al., 2010), and to epeirogenic uplift (Petrovszki et al., 2012; Duvall et al., 2004). In southern Africa, river meanders have been examined along different lowland river systems. Partridge (1969) showed that river long and cross profiles and meander wavelengths do not match clearly with contemporary discharge values, thus that these geomorphic elements may have been inherited from past climatic conditions. On the Okavango River delta (Botswana), changes in meander sinuosity represents an autogenic adjustment of channel form to variations in discharge (Tooth and McCarthy, 2004). Along the Luangwa River (Zambia), meander development corresponds to bank erosion and deposition patterns (Gilvear et al., 2000). A study on three different lowland rivers in South Africa showed that river behaviour reflects a continuum from bedrock to alluvial substrates

* Corresponding author.
E-mail address: jasper.knight@wits.ac.za (J. Knight).

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(Tooth et al., 2004). A combination of geology (substrate) and climate (hydrology) controls on bedrock and mixed-substrate lowland rivers in southern Africa is therefore considered to be controls on meandering behaviour and meander sinuosity (McCarthy et al., 2011; Grenfell et al., 2014).

A key research gap is the geomorphology and evolution of bedrock upland rivers, which are less well monitored in terms of present morphodynamics and hydrology, but are areas of relatively enhanced fluvial incision and associated high erosional sediment yield, contributing to floods, mass movements and sediment aggradation downstream (Compton and Maake, 2007; Temme et al., 2008). Such bedrock upland river systems are thus important landscape components as they are agents of geomorphic change across multiple spatial scales. Several studies have considered the long term (10^4–10^6 years) evolution of large scale river systems and mountain landscapes in different areas of southern Africa (Moore et al., 2009a, 2012; Kounov et al., 2013; Key et al., 2015). However, the river systems of the Drakensberg sector of southern Africa's Great Escarpment are less well known. This study aims to document the morphometric properties of river systems in this mountainous region of eastern Lesotho, southern Africa. In detail, this study explores the different properties of adjacent valleys and river reaches based on map and field evidence, including river sinuosity and long profile, valley asymmetry and cross sectional profiles, and presence of sediments within river valleys. These properties can be used to inform on long term landscape evolution and the potential age of the observed drainage morphologies.

2. Study area

The study area is located in eastern Lesotho, southern Africa, in the highest sector of the Great Escarpment, a geologic and topographic feature located some 60–200 km inland of the present coast (Fig. 1). This mountain sector, termed the Drakensberg, encompasses the highest peaks in southern Africa, reaching 3482 m asl at Thabana Ntlenyana, in the north of the study area. The outermost edge of the Great Escarpment in this sector marks the international boundary between Lesotho and South Africa and is characterized by an indented and in many cases very steep-faced (>60°) cliffline with faces reaching 400 m in height (Fig. 2). This cliffline today is affected by significant landslides and rockfalls. The uppermost land surfaces are poorly vegetated by a nutrient-deficient alpine ecosystem (the Drakensberg Alpine Centre of the wider Afromontane phytochorion). Trees are absent from the landscape and the soil cover is patchy and thin (few tens of cm) with many steeper slopes showing bare bedrock because of factors such as overgrazing and accelerated sediment mobilization (e.g., periglacial solifluction on some high south-facing slopes). Mean annual precipitation for 1975–1990 in different flow-gauged catchments in eastern Lesotho varied from 821 mm to 1059 mm with a runoff coefficient for the same period of 0.14–0.27 (Sene et al., 1998). Most precipitation falls between October and March (70%), and less than 10% during winter (May to August) (Tyson et al., 1976), and shows some interannual variability related to ENSO. Although occasional snowfalls occur during the colder seasons, the water equivalent depth is usually less than 10% (Sene et al., 1998). However, snowfalls and snow depth/longevity would have been a more significant environmental and geomorphic/hydrologic factor during past colder periods.

The study region is entirely underlain by basalts of the Drakensberg Group (Karoo Supergroup), comprising the Barkly East

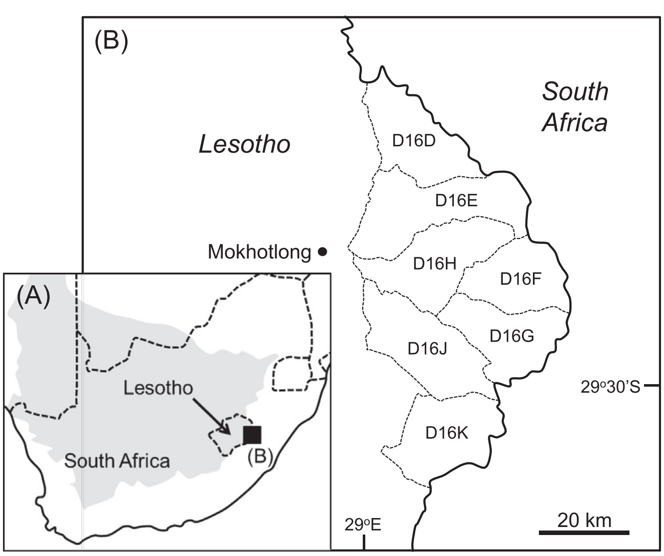

Fig. 1. Location of the study area. (A) Regional map of southern Africa showing the location of the study area of eastern Lesotho (boxed, B). The catchment of the west-flowing Vaal/Orange River system is shaded. (B) Map of quaternary catchments in eastern Lesotho (codes given by Department of Water Affairs and Sanitation, South Africa).

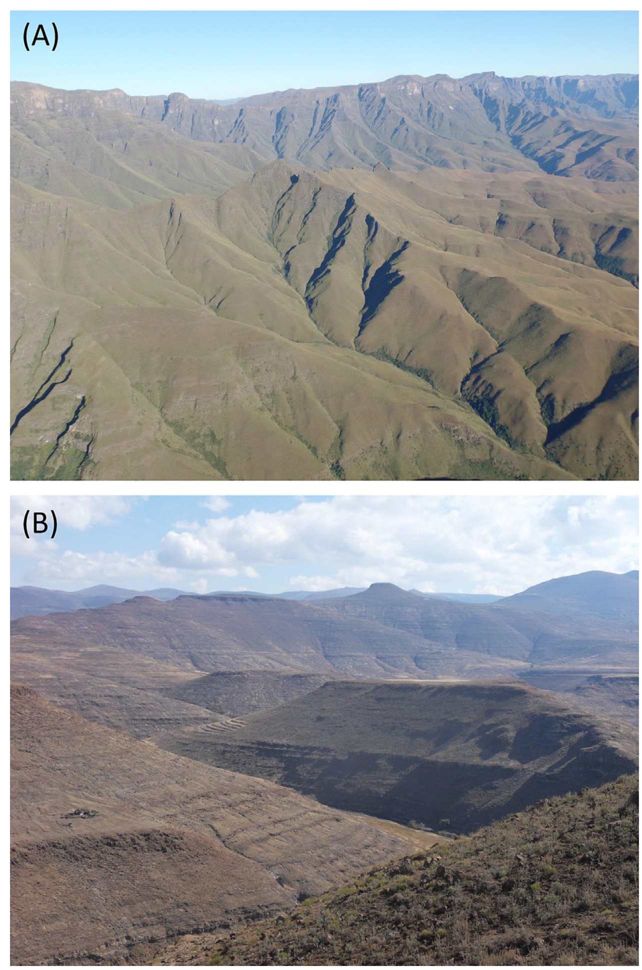

Fig. 2. Topographic characteristics of the study area. (A) Arial view of the South African side of the Great Escarpment, showing steep rectilinear slopes and V-shaped fluvial valleys. (B) View of the basalt landscapes of interior Lesotho (catchment D16F), showing flat basalt lava flows, flat plateau surfaces, rectilinear bedrock slopes, and bedrock meanders separated by interlocking spurs.