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Climatically influenced denudation rates of the southern African plateau: Clues to solving a geomorphic paradox

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ABSTRACT

Southern Africa displays a high topography but paradoxically exhibits tectonic stability and low denudation rates. Here the present controls on denudation in southern Africa are investigated by comparing maximum denudation rates for Karoo dolerite surfaces in the region, determined from the abundances of cosmogenic noble gas nuclides (^{3}He, ^{21}Ne and ^{38}Ar) in pyroxenes, with the predictions of a climate-dependent weathering rate model. In general, we find an excellent agreement in the value ranges of both datasets (<4 m/Myr), and interpret this as evidence that present denudation in southern Africa is weathering-limited and climatically influenced due to an apparent absence of significant regional neotectonic uplift. The onset of this geodynamic coupling is unknown but may be of considerable antiquity, thus allowing for the prolonged tenure of southern Africa's inherited Cretaceous topography.

1. Introduction

The role of silicate weathering in modulating global climate has long been recognised (Ebelmen, 1845; Urey, 1952; Walker et al., 1981) but the relative importance of climate and tectonics in controlling long-term silicate weathering rates remains a complex subject of vigorous debate (Raymo and Ruddiman, 1992; Molnar, 2003; Willenbring and von Blanckenburg, 2010; Goudie and Viles, 2012). For example, it has been proposed that chemical weathering rates may only depend significantly on climate in tectonically active, high relief regions (e.g. the Himalaya orogen), where high rates of physical erosion facilitate the exposure of fresh mineral surfaces to chemical weathering (Raymo et al., 1988; Dupré et al., 2003). By contrast, stable low-lying cratonic regions in the humid tropics (e.g. the Congo and Amazon basins) display low chemical weathering rates despite apparently optimal climatic conditions, as the thick soil and regolith that has developed over time in an erosion-limited regime protects the bedrock from further chemical alteration (Gaillardet et al., 1999; Oliva et al., 2003).

The landscape of southern Africa, which has long influenced the development of geomorphological theory (e.g. Passarge, 1904; King, 1951; King, 1967; Gilchrist and Summerfield, 1991; van der Beek et al., 2002), represents a unique field area for the further examination of such earth system relationships. High relief escarpments flank an elevated interior plateau (>1000 m above sea level, Fig. 1) and soil cover is usually thin (<1 m deep), yet parodoxically, the region is tectonically quiescent and not currently associated with convergent plate boundaries or active rifting. Present denudation rates based on cosmogenic nuclide data are generally low (Table 1) but have led to a number of contrasting geomorphic models being applied at various scales, including accounts of near steady state (Bierman and Caffee, 2001), tectonically punctuated extreme steady state (Van der Wateren and Dunai, 2001) and non-steady state (Codilean et al., 2008). Studies have emphasised the influence of factors such as climate (Van der Wateren and Dunai, 2001), lithology (Kounov et al., 2007; Scharf et al., 2013) and slope (Codilean et al., 2008), and high anthropogenic soil erosion rate estimates have been discussed from a cosmogenic nuclide perspective (Decker et al., 2011).

In this paper, we present and discuss a suite of cosmogenic ^{3}He, ^{21}Ne and ^{38}Ar-based surface denudation rates for a single, widespread rock type — Karoo dolerite, sampled from a range of climatic and geomorphic settings in southern Africa, and a corresponding set of independent weathering flux estimates calculated from a climate-dependent model for the chemical weathering rate of basalt (Dessert et al., 2003). The relevance of these datasets to understanding present controls on denudation and the long-term geomorphic evolution of the region is then explored.

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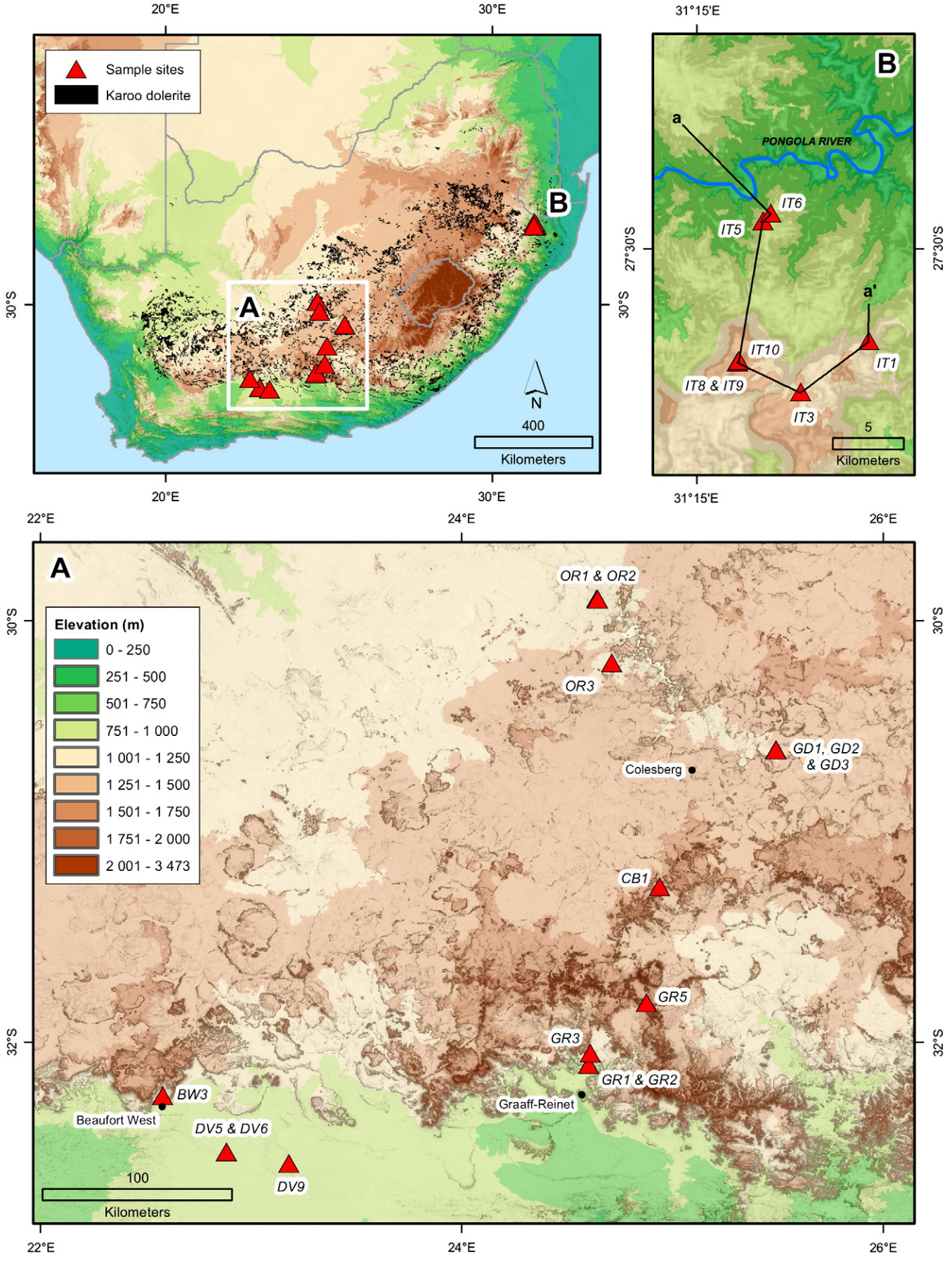

Fig. 1. The topography of southern Africa (relief-shaded SRTM elevation data after Jarvis et al., 2006), the outcrops of the Karoo dolerite suite (modified from Vorster, 2001) and the locations of Karoo dolerite sample sites (n = 22), expanded for clarity in panels A and B with dolerite outcrops omitted. The location of topographic profile a–a′ (Fig. 4) is also shown in panel B.