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Erosion rates and landscape evolution of the lowlands of the Upper Paraguay river basin (Brazil) from cosmogenic ^{10}Be

Fabiano do Nascimento Pupim [a,*], Paul R. Bierman [b], Mario Luis Assine [c], Dylan H. Rood [d,e], Aguinaldo Silva [f], Eder Renato Merino [a]

[a] Universidade Estadual Paulista (UNESP — IGCE), Programa de Pós-Graduação em Geociências e Meio Ambiente, Av. 24-A, 1515, Rio Claro, SP 13506-900, Brazil
[b] Department of Geology and Rubenstein School of the Environment and Natural Resources, University of Vermont, Burlington, VT 05405, USA
[c] Universidade Estadual Paulista (UNESP — IGCE), Departamento de Geologia Aplicada, Av. 24-A, 1515, Rio Claro, SP 13506-900, Brazil
[d] Department of Earth Science and Engineering, Imperial College London, South Kensington Campus, London SW7 2AZ, UK
[e] Scottish Universities Environmental Research Centre, East Kilbride G75 0QF, UK
[f] Universidade Federal de Mato Grosso do Sul — UFMS, Campus do Pantanal, Av. Rio Branco, 1270, Corumbá, MS 79304-020, Brazil

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ABSTRACT

The importance of Earth's low sloping areas in regard to global erosion and sediment fluxes has been widely and vigorously debated. It is a crucial area of research to elucidate geologically meaningful rates of land-surface change and thus the speed of element cycling on Earth. However, there are large portions of Earth where erosion rates have not been well or extensively measured, for example, the tropical lowlands. The Cuiabana lowlands are an extensive low-altitude and low-relief dissected metamorphic terrain situated in the Upper Paraguay river basin, central–west Brazil. Besides exposures of highly variable dissected metamorphic rocks, flat residual lateritic caps related to a Late Cenozoic planation surface dominate interfluves of the Cuiabana lowlands. The timescale over which the lowlands evolved and the planation surface developed, and the rate at which they have been modified by erosion, are poorly known. Here, we present measurements of in situ produced cosmogenic ^{10}Be in outcropping metamorphic bedrock and clastic–lateritic caps to quantify rates of erosion of the surface and associated landforms in order to better understand the Quaternary landscape evolution of these lowlands. Overall, slow erosion rates (mean 10 m/Ma) suggest a stable tectonic environment in these lowlands. Erosion rates vary widely between different lithologies (range 0.57 to 28.3 m/Ma) consistent with differential erosion driving regional landform evolution. The lowest erosion rates are associated with the low-relief area (irregular plains), where clastic–laterite (mean 0.67 m/Ma) and quartzite (mean 2.6 m/Ma) crop out, whereas the highest erosion rates are associated with dissection of residual hills, dominated by metasandstone (mean 11.6 m/Ma) and phyllite (mean 27.6 m/Ma). These data imply that the Cuiabana lowland is comprised of two dominant landform sets with distinct and different dynamics. Because the planation surface (mostly lowlands) is lowering and losing mass more slowly than associated residual hills, regional relief is decreasing over time and the landscape is not in steady state. The extremely slow erosion rates of the clastic–laterite are similar to the slowest outcrop erosion rates reported worldwide. These slow rates are due to the material's properties and resistance, being comprised of quartzite fragments cemented by an iron-rich crust, and reflecting long-term weathering with iron chemical precipitation and ferricrete formation, at least since the Middle Pleistocene. The lateritic caprock appears to be a key factor maintaining hilltop summits of the planation surface over long timescales.

1. Introduction

The Earth's continental surface is ~90% dominated by low relief and gently sloping areas (Larsen et al., 2014). Understanding how important these flat landscapes are as controls on erosion rates, sediment fluxes and biogeochemical cycling has been vigorously debated in the recent literature (Willenbring et al., 2013, 2014; Larsen et al., 2014; Warrick et al., 2014). Underlying much of this debate is the observation that we know little about the erosion rate of large portions of Earth because limited measurements have been made there (Portenga and Bierman, 2011). Specifically, the lowlands of Africa and South America are two large landscapes where few erosion rate measurements exist. In these continents, cosmogenic measurements of erosion are concentrated in the Andean mountain belt (e.g. Safran et al., 2005; Placzek et al., 2010; Bookhagen and Strecker, 2012), passive margin escarpments (e.g.

* Corresponding author at: Programa de Pós-Graduação em Geociências e Meio Ambiente, Av. 24-A, 1515, Rio Claro, SP 13506-900, Brazil. Tel.: +55 19 3526 9321.
E-mail addresses: fabianopupim@yahoo.com.br (F.N. Pupim), paul.bierman@uvm.edu (P.R. Bierman), assine@rc.unesp.br (M.L. Assine), d.rood@imperial.ac.uk (D.H. Rood), aguinald_silva@yahoo.com.br (A. Silva), ermerino82@yahoo.com.br (E.R. Merino).

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Bierman and Caffee, 2002; Salgado et al., 2008, 2013; Cherem et al., 2012; Scharf et al., 2013; Bierman et al., 2014) and large-scale Amazon rivers (e.g. Wittmann et al., 2010).

Situated in central-west Brazil, the Upper Paraguay river drainage basin is an inlier of Precambrian rocks exposed due to erosion of Phanerozoic rocks that crop out in its surroundings (Fig. 1). The Quaternary Pantanal basin developed in the inner part of the inlier and is an extensive modern alluvial depositional tract (Assine and Soares, 2004), one of the world's largest freshwater wetland ecosystems (Hamilton, 2002). The inlier margin known as Upper Paraguay lowland (also called a depression) is dominated by low-altitude and low-relief dissected metamorphic terrains (Fig. 1A). The Upper Paraguay lowlands are comprised of three major geomorphological units; the Cuiabana lowlands are the site we focus on in this paper (Fig. 1B). Besides exposures of highly variable dissected metamorphic rocks, flat residual lateritic caps related to a Late Cenozoic planation surface dominate interfluves of the Cuiabana lowlands. The timescale over which the lowlands evolved and the planation surface developed are uncertain, and the rate at which they have been modified by geomorphic processes are poorly quantified over long temporal scales. The planation surface age was indirectly estimated as Plio-Pleistocene through geomorphological methods and regional correlations (Ab'Saber, 1988).

Terrestrial cosmogenic nuclides have become invaluable tools in geosciences because they allow quantitative evaluation of geomorphologically relevant parameters, including exposure ages, erosion rates, and burial ages (e.g., Gosse and Phillips, 2001; Granger et al., 2013). In particular, beryllium-10 (^{10}Be) is useful in the study of landscape evolution over timescales of 10^3 to 10^6 years (e.g., Brown et al., 1994; Bierman and Caffee, 2001; Jakica et al., 2011; Portenga et al., 2013; Scharf et al., 2013). In Brazil, for example, Braucher et al. (1998), based on cosmogenic ^{10}Be analyses in one lateritic stone-line (similar to samples we collected BRC 21 and 22, which are remnants of the Cuiabana planation surface), proposed that this stone-line resulted from depositional events occurred at least 500 ka ago.

In this paper, we present measurements of in situ produced cosmogenic ^{10}Be in outcropping metamorphic bedrock and clastic–lateritic caps to determine minimum exposure ages and maximum limiting erosion rates of the planation surface and associated landforms. The results are discussed in the context of a general landscape evolution of the Cuiabana lowlands, as well as in the context of the outcrop erosion rates from around the globe. Our work begins to address the lack of erosion rate measurements in large, tropical, flat areas.

2. Regional setting

The plateaus surrounding our field area are dominated by planation surfaces (Fig. 1B), the formation of which has been linked to erosion and deposition during a long period of arid climate and relative tectonic stability following the Cretaceous (Ab'Saber, 1988). Contemporary Brazilian planation surfaces are thought to reflect inheritance of ancient surfaces and their ages are constrained indirectly through stratigraphic and geomorphologic correlation (e.g. King, 1956; Bigarella and Andrade, 1965; Braun, 1972; Ab'Sáber, 2000; Peulvast and Claudino Sales, 2004; Valadão, 2009).

Cenozoic tectonic reactivation caused uplift of this portion of the South America platform and raised the planation surfaces to high elevation on the Brazilian plateau (Tello Sáenz et al., 2003; Hackspacher et al., 2004). Apatite fission track data from southeastern Brazil are consistent with regional uplift events and consequently a response that includes both significant denudation and deformation of ancient planation surfaces during the Cenozoic (Tello Sáenz et al., 2003; Hackspacher et al., 2004). In the Quadrilátero Ferrífero, Brazil, ^{40}Ar/^{39}Ar dating of deep weathering profiles indicated ages of 51–41 Ma for a higher surface at 2100 m of altitude (Spier et al., 2006) and 10–8 Ma for mid-level surface at 1100 m (Carmo and Vasconcelos, 2004). These ages suggest long weathering periods, low denudation rates, and the preservation of ancient landscapes (Carmo and Vasconcelos, 2004; Spier et al., 2006).

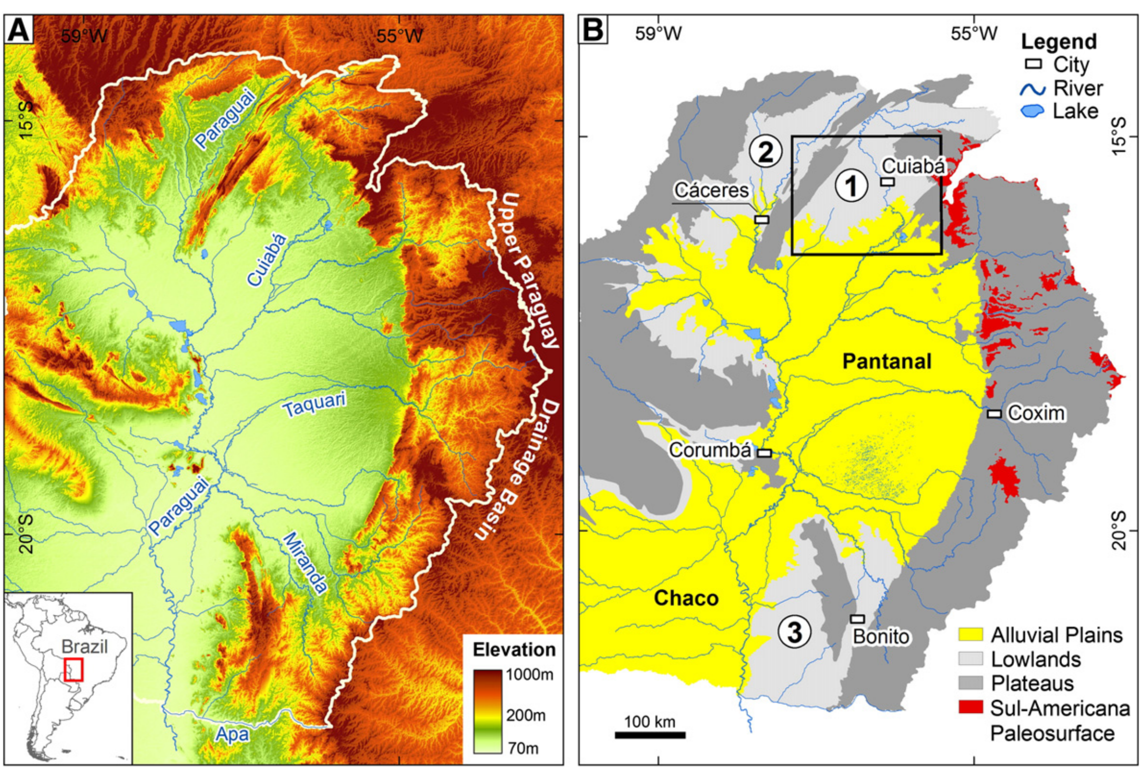

Fig. 1. Study area location and physiographic provinces (black square is the location area). (A) Study area location and regional topographic overview at the Upper Paraguay river basin, central west region of Brazil (image from Shuttle Radar Topographic Mission — SRTM); (B) The main physiographic provinces of the Upper Paraguay river basin (regional lowlands: 1 — Cuiabana; 2 — Paraguay; 3 — Miranda).