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Analysis of the interaction between neotectonic and surface processes in a low-land intracratonic setting of South America

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A B S T R A C T

The Quaternary sedimentary record in the continental interiors has generally been studied taking into consideration the climatic forcing. However, episodes of uplift controlling the development of landforms have often been dismissed. The interiors of continents are typically considered to have low deformation rates, lower than the rates of exogenous processes. Deformation in the middle of the Pampean plains, an intracratonic setting of South America, has been observed to have generated an elevated area surrounded by lowland plains. This elevated area is susceptible to fluvial erosion. From this fact we developed a geomorphologic modelling constrained from geomorphic markers in order to estimate the relative incidence of the different factors that control erosion in lowland landscapes. An adapted erosion code was employed, which combines fluvial incision equation (the stream power law), an uplift function spatially distributed and the hillslope diffusion equation. A low-DEM was achieved for restoring an initial non-deformed topography affected by low fluvial incision. It represents a palaeosurface chrono-stratigraphically constrained. The estimation of the model parameters was achieved by applying the inversion method. The best-fit between the numerical solution (calculated topography) and the measured topography (simulated by means a DEM) was approached by comparison of the stream longitudinal profiles. The yield numerical approach suggests that a geomorphological modelling based on the stream power law is possible to be applied in low-land landscapes. For this, a large scale change of the magnitude of the processes modelling the landscape should be expected in comparison with mountain erosional environments. Remarkably low K empirical values ($K = 5 \times 10^{-6}$–6×10^{-6} yr^{-1}) suggest that the extremely low slopes exert a larger influence on the stream power in low-land landscapes. Also the diffusion coefficient D values resulted largely lower (3×10^{-4}–1.9×10^{-3} cm^2/yr) than presented in tectonically active landscapes (>0.03 cm^2/yr). Regional uplift rates can be higher (0.35 mm/yr) than it is generally expected in low uplift rate settings (0.1–0.25 mm/yr). These estimations evidence highly dynamic surface and tectonic processes controlling the landscape evolution over intermediate time scales in an intracratonic setting.

1. Introduction

An intracratonic basin is a broad area with low-relief and slow subsidence rates developed in continental crust away from plate margins (Klein, 1995). They are considered as acyclic areas where landforms and the sedimentary record are constantly reworked (Klein, 1995; Peulvast et al., 2009). Such continental interiors are typically considered to be tectonically inactive. However, extensive regions of stable continental lithosphere have experienced prolonged subsidence, interrupted by phases of uplift (Armitage and Allen, 2010). The long-term subsidence history cannot be considered as a linear process because the cratonic basin-fill is responding to changes in the far field plate boundary regions (such as flexure and in-plane stress) and mantle dynamics (Armitage and Allen, 2010). For example, episodes of uplift have occurred in the interior of a sedimentary environment because of

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flexural loading in foreland basins (De Celles and Giles, 1996; Horton and De Celles, 1997; Dávila et al., 2010) or by tectonic inversion occurring in midcontinent settings (Smalley et al., 2005). As a consequence, the resulting uplands located in sedimentary domains can constitute headwater areas susceptible to fluvial incision.

In addition, the Quaternary sedimentary record in intracratonic settings has been mainly studied over intermediate timescales of landscape evolution (1×10^5–1×10^6 yr) in the context of exogenous processes. Controls such as climatic forcing that rule out rock erosion, velocity of streams or winds and sedimentary flux and sea-level change have been largely analysed (Walling and Webb, 1996; Blum and Törnqvist, 2000; Paola, 2000). However, in intracratonic basins, where sedimentary accumulation has dominated for a long-time (1×10^7–1×10^8 yr), Quaternary uplift episodes have generally been dismissed.

Studies that report evidence of Quaternary tectonic deformation in intraplate settings are progressively growing (Talwani, 2014 and references therein). In South America, most of the Quaternary deformation has been reported in the Brazilian Shield, mainly in Precambrian basement rocks related to reactivations of geologically old structures (Riccomini et al., 1989; Assumpção, 1992; Saadi, 1993; Riccomini and Assumpção, 1999; Bezerra and Vita-Finzi, 2000; Saadi et al., 2002, 2005; Bezerra et al., 2006, 2008). A few examples referring to a clearly sedimentary domain were reported from the Amazonas River basin (Assumpção and Suarez, 1988; Cunha, 1988).

In the last years, with the development of the geomorphometry applied to geomorphology and morphotectonics, a number of exhaustive data were gathered from Digital Elevation Models (DEM), especially in intracratonic regions. Grohmann (2004, 2005) developed morphometric maps and a trend-surface analysis on data from morphometric parameters (hypsometry, slope, aspect, swath profiles, lineaments and drainage density, surface roughness, isobase and hydraulic gradient) in the south São Francisco Craton, Southeastern Brazil. Grohmann et al. (2007) generated also in this region a morphotectonic analysis of the Poços de Caldas Massif, a Late Cretaceous collapsed volcanic caldera. Recently Kröhling et al. (2014) deduced that morphometric analysis is an appropriate method for the reconstruction of long-term landscape development of the Paraná Basaltic Plateau (Northeastern Argentina and Southern Brazil). The authors included a first correlation of the main recognised discrete erosion palaeosurfaces to the main uplift episodes post-break-up of Gondwana. Complementary, independent approaches for identifying recent deformations are now available by applying geodetic tools such as measurements of tiny displacements from permanent GPS stations (Alves et al., 2003; Marotta et al., 2013; Sobrero and Brunetto, 2015). This information dealing with Tectonic Geomorphology issues holds a great potential but it needs to be integrally analysed.

More broadly, most of the works studying tectonics and fluvial incision have been developed for tectonically active mountain environments (Seidl and Dietrich, 1992; Whipple and Tucker, 1999; Whipple, 2004; Whipple and Meade, 2004; Gasparini and Brandon, 2011). For this propose, the classical stream power equation (SPL) is commonly used for describing the rate of fluvial incision (Howard and Kerby, 1983; Whipple and Tucker, 1999). The SPL assumes that parameters are kept constant over time and space, e.g. lithology and precipitation (Whipple and Tucker, 1999). It is also assumed that incision occurs in bedrock rivers which are usually steeper and lacking a sediment cover. This is the case of detachment-limited river channels, where it is the resistance to erosion that limits the rate of incision (Braun and Willett, 2013). Alluvial rivers have a lower gradient and have an inverse dependence upon drainage area (Howard and Kerby, 1983). They correspond to a transport-limited state, where it is the ability of the river to transport sediment that limits its evolution (Braun and Willett, 2013). This widely accepted generalisation does not consider the case of headwater systems located within low relief sedimentary plain settings (Iriondo and Drago, 2004), where a complex succession of endogenous geomorphic processes could have been operating, even during the geological evolution over an intermediate-time scale. As the channel transport ability exceeds supply, we can consider that channel incision in this case is limited primarily by the resistance of the underlying substratum to the boundary shear stress imposed by stream flows (Seidl and Dietrich, 1992).

Most of the previous research on low uplift rate in intracratonic settings is lacking comprehensive modelling approaches. They are mainly concern about detection of neotectonic activity through geomorphic indices. Recent quantitative approaches have been achieved in lowland areas of Northwestern Europe that shows the effects of tectonics on the landforms and streams in intraplate areas with low uplift rates (Lagarde et al., 2000, 2003; Lague et al., 2000; Font et al., 2010). The sensitivity of river profiles to detect changes in areas of low uplift rate has also been analysed from gradient variations of river profiles crossing different uplift zones in the Southern Upper Rhine Graben (Carretier et al., 2006).

New studies about the geological evolution of the Northern Pampa in Argentina during the Late Pleistocene have arisen from a geologically integrated approach (Brunetto, 2008; 2012; Brunetto et al., 2010; 2015a). Previously, evidence of Quaternary tectonic activity had been reported in this region from the observation of Late Pleistocene palaeostreams that were perturbed by reactivation of inferred faults (Pasotti, 1974, 1975). But those descriptive studies are lacking a quantitative understanding. A preliminary analysis of one longitudinal profile was tested in the Northern Pampa region in order to identify areas of potential differential uplift (Brunetto, 2008). Anomalies on the stream channel were detected by estimating the stream length index (SL) and the local slope index (S) considering the drainage area for each reach of the stream. However, this partial analysis was not able to discriminate an unequivocal tectonic origin for the anomalies, rather than a lithologic control.

Studies that define rates of erosion and uplift are the main concern of the Tectonic Geomorphology. They typically include geochronology, structure, stratigraphy, geomorphology, and numerical modelling (Burbank and Anderson, 2001). If recent deformation is recognized for low uplift rate settings, a calibration of the rates and relative contributions of each process at a particular time or over some span of time is pending to be achieved. The modern interdisciplinary research in intracratonic settings needs to start this way over shorter timescales.

The Northern Pampa plain case study can be useful to generate a discussion about how the different factors that control erosion/sedimentation in the landscape evolution interplays with tectonic activity in lowland regions, on an intermediate-time scale (1×10^5 yr). The preliminary research presented so far suggests that deformation rates seem to be much higher than previously envisaged in such geological settings.

In this contribution, we try to make a comparison between geomorphic and tectonic rates in order to understand the relative magnitude of the factors that interact for modelling the surface. Geomorphologic modelling is presented, by applying an erosion code that includes uplift, flexural scarp generation, diffusion of sediments and fluvial incision in a representative catchment basin located in the Chaco-Paraná intracratonic basin. The aim of the paper is to obtain a preliminary numerical model of the landscape evolution in a region of widespread low relief plains affected by Quaternary tectonics.

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