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Landsat imagery-based visualization of the geomorphological development at the terminus of a dryland river system

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ABSTRACT

In this remote sensing-based study, we present the analysis of the geomorphological development at the low-gradient terminus of the modern Río Colorado dryland river system in the endorheic Altiplano Basin (Bolivia). Changes in the river morphology occur after short periods of catastrophic peak discharge which result in the expansion of existing crevasse splays, formation of new crevasse splays and in river path avulsion. Episodic peak discharge events in the study area were pinpointed and quantified by combining daily precipitation records from gauging stations in the vicinity with catchment area analysis from ASTER global DEM (GDEM) remote sensing data. A time series of Landsat imagery for the period 1975–2001 was then used to analyze the river morphology changes after major peak discharge events. Compensational stacking of crevasse splays in combination with river avulsion produced a thin but aerially extensive connected sand sheet at the terminus of the fluvial system.

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1. Introduction

River systems in dryland areas are characterized by long intervals of river channel inactivity in the dry periods, alternating with short, episodic periods of peak discharge (Knighton and Nanson, 1997; Tooth, 2000b). Water discharge in the low-frequency, high-magnitude peak discharge periods greatly exceeds the river capacity, hence immediate and massive river flooding and over-spill of floodwaters and sediment onto the adjacent floodplain occur. These processes are especially active in the dryland river terminus, where the dryland river channels show downstream decrease in cross-sectional area by the combination of low gradient, strong evapo-transpiration potential and water percolation through the channel floor. This results in significant downstream decrease in channel capacity of transporting water and sediment (Tooth, 2000a; Donselaar et al., 2013). It is in these peak discharge periods that the major geomorphological changes and landscape development take place, such as the formation and/or expansion of crevasse splays, changes in river course, and channel avulsion (Baker, 1977; Graf, 1983, 1988a;, 1988b; Knighton and Nanson, 1997). However, it is difficult to access or directly observe the geomorphological changes, due to the hazardous environment during peak discharge. In this paper we investigate geomorphological changes in a modern ephemeral river delta in Salar de Uyuni Bolivia. The lack of vegetation along the river and absence of human interference enable full analysis of channel and splay morphology under natural conditions with Landsat time-series imagery.

The present paper aims to analyze the relationship between peak discharge events in an ephemeral dryland river system and the development of river avulsions and crevasse splays, and to visualize with remote sensing imagery the resulting morphological changes at the terminus of the river system over the very short time period of 27 years. We use daily precipitation data in the study area over the period 1975–2001, complemented with precipitation datasets around the catchment of the Río Colorado. In combination with ASTER and Landsat TM images the precipitation data analysis allows to quantify and pin-point the short, episodic flood periods. ASTER global digital elevation model (GDEM) data will be used to acquire the catchment information such as its boundary, area and slope. Double mass curves will be used to investigate the consistency of precipitation data from different meteorological stations. With the catchment information, the Thiessen polygon method will be used to calculate the areal precipitation in the catchment area. Landsat TM data will be used to extract spectral information about vegetation cover in the catchment area. Together with areal

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precipitation and catchment information, an empirical model will be used for peak discharge modeling and the magnitude of flood can be quantified. Through the results of discharge modeling and precipitation analysis in the study area, the flood periods will be pinpointed. In the process, Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) images are selected before and after flood events and the changes in the river morphology triggered by peak discharge will be analyzed. The visualization of the avulsion history and the development of crevasse splays are of significant importance in establishing three-dimensional sedimentary architecture models of sheet deposits in distal fluvial systems.

2. Geological and climatic settings

The study area is located in the southern part of the Altiplano Basin in Bolivia, Chile, and Peru (Fig. 1). The basin is a high-altitude hinterland plateau (elevation 3650–4200 m above sea level) and is bordered by the Cordillera Oriental and Cordillera Occidental, which form part of the Central Andean ocean-continent convergent margin (Argollo and Mourguiart, 2000; Horton et al., 2001; Rigsby et al., 2005; Risacher and Fritz, 2009). The Altiplano Basin is an internal drainage (or: endorheic) basin filled with Paleogene, Neogene and Quaternary fluvial and lacustrine sediments and volcaniclastic deposits (Horton et al., 2001; Elger et al., 2005).

The Altiplano Basin has a semi-arid climate with an annual precipitation of more than 800 mm in the north and less than 200 mm in the south (Argollo and Mourguiart, 2000) and an evapotranspiration potential of 1500 mm (Grosjean, 1994; Risacher and Fritz, 2009). The north-to-south decrease of precipitation is caused by the low pressure systems of the Altiplano Basin, strong low-level north–westerly winds with warm moisture, and unstable air flow along the eastern flank of the central Andes giving rise to convection precipitation (Lenters and Cook, 1999). Poleward low-level air flow helps to maintain the intense convection (Lenters and Cook, 1999). Furthermore, studies on the relationship between the interannual variability of summer precipitation on the Altiplano Plateau and El Niño-Southern Oscillation (ENSO) phenomenon show a tendency towards increased air temperatures and

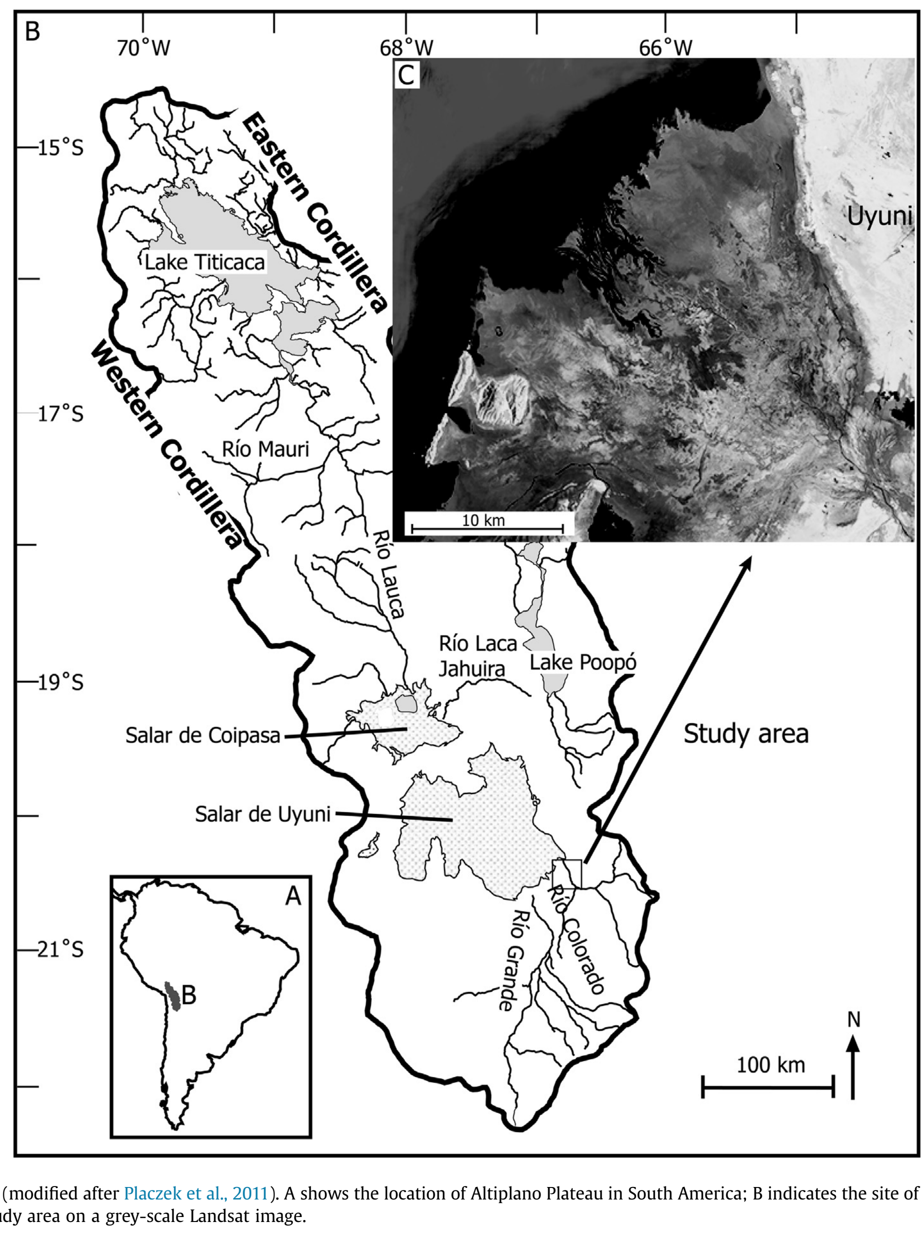

Fig. 1. Map of the study area (modified after Placzek et al., 2011). A shows the location of Altiplano Plateau in South America; B indicates the site of the study area in the Altiplano plateau; and C shows the study area on a grey-scale Landsat image.

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