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Dryland anabranching river morphodynamics: Río Capilla, Salar de Uyuni, Bolivia

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ABSTRACT

The dryland anabranching river Río Capilla is characterized by nonvegetated and vegetated reaches with prominent channel morphology. To identify the morphodynamics of such dryland anabranching systems and their controls, we investigated the Río Capilla of the southern Altiplano Plateau using high-resolution satellite imagery and field measurements. Comparison of high-resolution satellite data reveals that erosion exceeds deposition for the main channel, accompanied by changes in channel planform, such as meander and channel morphology. On-site surveys combined with high-precision GPS and high-resolution satellite imagery show that channels are characterized by shallowness and poor development of levees. The study area of the Río Capilla is divided into two zones of different slopes: zone 1 with a high slope and zone 2 with a low slope. Zone 1 has a relatively straight main channel with few anabranches and grass-covered banks that are stable despite the high gradient; whereas zone 2 is typified by more anabranches with nonvegetated banks, and the main channel experiences prominent bank accretion and erosion. Excavations show that point-bar deposits are fine-sand-dominated in two reaches and that river banks primarily consist of silt and clay. The limited vegetation cover and abundance of desiccation cracks and macropores make the river bank more erodible leading to pronounced lateral migration in this low-gradient dryland river system. Shallow channels and poor development of levees in combination with in-channel accretionary benches result in frequent overbank flooding, which results in a high density of crevasse splays over unconsolidated river banks and accretionary benches. Connection of headcuts and crevasse channels together with lateral migration and chute channels and reactivation of partially abandoned meanders produces an anabranching pattern in such dryland river systems.

1. Introduction

Anabranching rivers, referred to as multiple channel rivers clearly separated at bankfull by subaerial vegetated islands or ridges, have been widely considered as a fourth class in addition to meandering, braided, and straight rivers (e.g., Rust, 1978; Schumm, 1981, 1985; Brice, 1984; Knighton and Nanson, 1993; Nanson and Knighton, 1996; Makaske, 2001). Anabranching rivers occur globally in a wide variety of environments (e.g., Rust, 1978; Schumm, 1981, 1985; Smith, 1976; Gibling et al., 1998; Goswami et al., 1999; Tooth and Nanson, 1999; Jain and Sinha, 2004; Nanson et al., 2005; Burge, 2006; Rodrigues et al., 2006; Tooth et al., 2008; Makaske et al., 2009; Kemp, 2010; Phillips, 2014) and observations in modern sedimentary environments have shown significant differences between anabranching rivers, which can be divided into separate humid and dryland types (Nanson and Knighton, 1996; North et al., 2007). Unlike humid regions with dense vegetation cover, dryland anabranching rivers are characterized by sparse vegetation, which plays an important role in channel morphodynamics of dryland anabranching rivers by changing bank strength and flow dynamics (Tooth and Nanson, 2000). Previous studies that have reported about dryland anabranching rivers (e.g., Riley, 1975; Schumann, 1989; Tooth and Nanson, 2000; Fagan, 2001) indicate that these dryland rivers systems are characterized by at least sparse vegetation (shrubs or teatrees) along levees; however, few studies have investigated channel morphodynamics in nonvegetated and vegetated reaches within a dryland anabranching river system.

Methods such as field measurements, maps and aerial photographs of different dates, and dateable sedimentary and biological evidence have been widely used in quantifying the magnitude of river bank activities (Hooke, 1980, 2007a, b; Lawler, 1993; Millar, 2000; Couper et al., 2002; Bartley et al., 2008; Yao et al., 2011). Many recent technologies (including digital photogrammetry, terrestrial laser scanning, and structure from motion photogrammetry) have received increased attention for their role in high-accuracy topographic mapping (e.g., Westaway et al., 2000; Lane et al., 2001, 2010; O'Neal and Pizzuto, 2011; Westoby et al., 2012; Micheletti et al., 2015). Some of these studies

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included GIS and remote sensing techniques. Recently, Yao et al. (2011) employed a time series of Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) data and successfully detected bank erosion and accretion in the Yellow River system. However, because of some critical issues such as low resolution of the images and registration problems between aerial photographs, the data was insufficient to accurately determine the rates of change in many smaller rivers. Field measurements such as using erosion pins can achieve an accuracy that is at a centimetre level (Couper et al., 2002; Bartley et al., 2008), but these methods are time-consuming and costly, especially in remote regions. This study presents a viable alternative using high-resolution satellite images (0.5 m) to accurately analyse channel morphodynamics of a dryland anabranching rivers the Río Capilla, with nonvegetated and sparely vegetated reaches in the semiarid endorheic basin of the Salar de Uyuni, Bolivia. In this paper we have three objectives: (i) to use satellite imagery and field investigations to document dryland anabranching river bank dynamics and channel morphology; (ii) to investigate key factors contributing to river channel morphodynamics in such a semiarid river system with little or no vegetation cover; and (iii) to outline the implications of findings for the mechanisms of changes in channel planforms in the study area.

2. Regional setting and climatic conditions

Located in the southern part of the Altiplano Basin in Bolivia, the study area lies within the catchment of the world's largest salt lake, Salar de Uyuni, which has an area of about 12,000 km^2 and elevation of more than 3600 m above sea level (Fig. 1A and B). The basin formed as part of the Andean ocean-continent convergent margin with eastward subduction of the oceanic Nazca Plate beneath the continental South American Plate (Dewey and Bird, 1970; Horton and DeCelles, 2001). The central Andes developed eastward during the Cenozoic and regional horizontal shortening led to increasing thickness of the continental crust (Isacks, 1988; Jordan et al., 1997). The Altiplano Basin, an endorheic basin, is filled with Tertiary to Quaternary fluvial and lacustrine sediments and volcaniclastic deposits (Horton et al., 2001; Elger et al., 2005).

The Altiplano Basin has a semiarid climate with an annual precipitation of >800 mm in the north and <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 the Altiplano Plateau precipitation is because of the local atmospheric circulation, where strong low-level northwesterly winds with warm, moist, and unstable air flow along the eastern flank of the central Andes giving rise to convection precipitation. Moreover, poleward low-level air flow helps to maintain the intense convection (Lenters and Cook, 1999).

The Río Capilla is characterized by a network of anastomosing sinuous channels that flow from east to west and joins the Río Colorado at the edge of the Salar de Uyuni, Bolivia (Fig. 1C). The channel belt is around 1.5 km in width and can include as many as 10 channels with intervening floodplains and crevasse splays. The main channel is sinuous with the sinuosity increasing downstream; typical channel width is around 20 m with a bankfull depth of around 1 m. The study area has been tectonically quiescent in the late Pleistocene and Holocene despite young fault escarpments (Bills et al., 1994; Baucom and Rigsby, 1999; Rigsby et al., 2005; Donselaar et al., 2013). The tributary streams in the catchment of the Río Capilla have a dendritic pattern (Li et al., 2014a), and the surface sediment consists of Quaternary alluvium, which comprises upper Oligocene to Quaternary sedimentary and volcanic rocks (Marshall et al., 1992; Horton et al., 2001). The catchment profile shows a maximum slope to be up to 1.57 m/m with a mean slope of 0.0008 m/m; the highest slope is near the upper margin and gradually decreases downstream (Li et al., 2014a). The rainy season in the study area is from December to March, and according to the precipitation data of 1975–2012, the average annual rainfall is about 185 mm (Li, 2014), which is greatly exceeded by the evapotranspiration

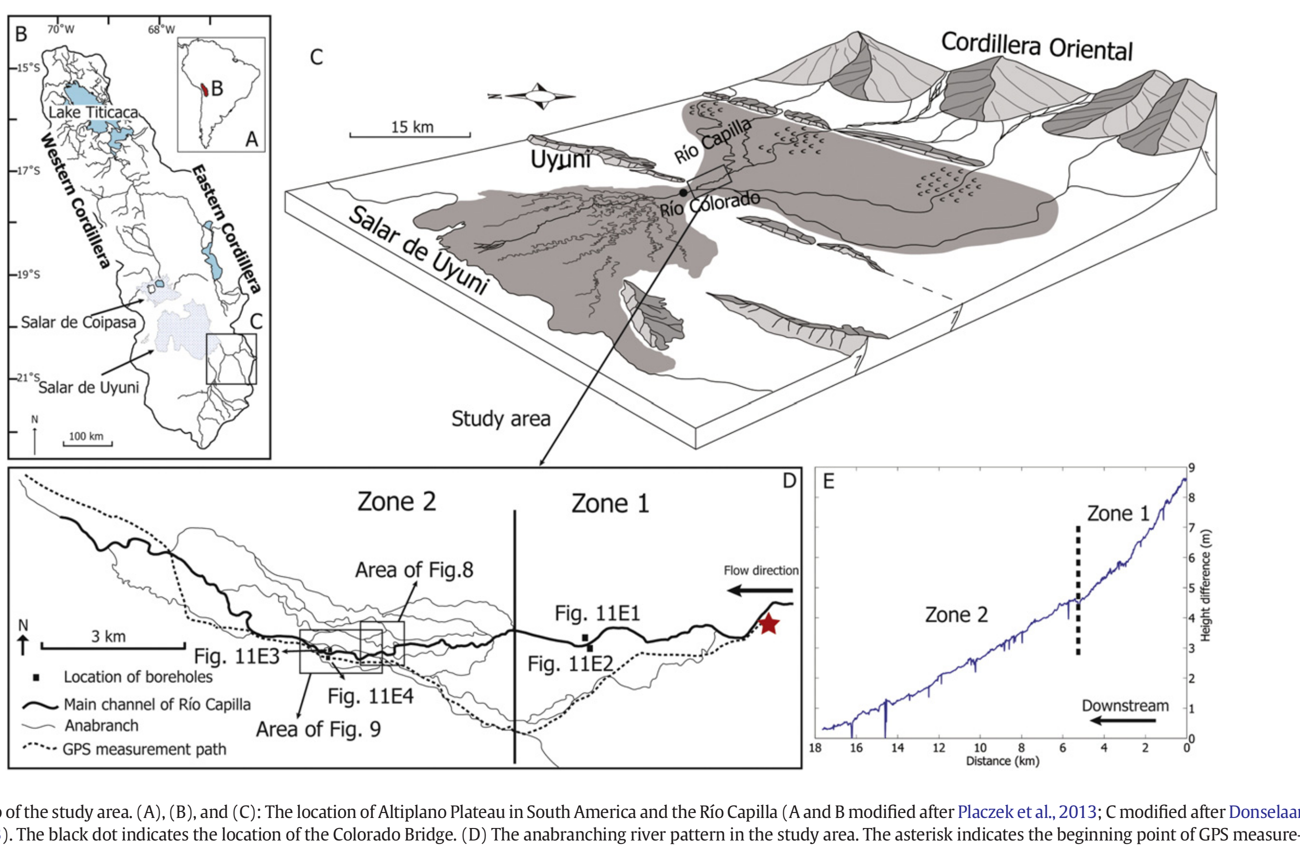

Fig. 1. Map of the study area. (A), (B), and (C): The location of Altiplano Plateau in South America and the Río Capilla (A and B modified after Placzek et al., 2013; C modified after Donselaar et al., 2013). The black dot indicates the location of the Colorado Bridge. (D) The anabranching river pattern in the study area. The asterisk indicates the beginning point of GPS measurement. (E) A high-precision GPS profile of the profile along the dashed line in (D).