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Paleolandscape reconstruction and interplay of controlling factors of an Eocene pedogenically-modified distal volcaniclastic succession in Patagonia

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ABSTRACT

The middle Eocene Koluel-Kaike Formation, located in the San Jorge Basin, Patagonia, Argentina, is a strongly pedogenically modified succession associated with volcaniclastic input in an aggrading distal eolian-dominated fluvial system, located ~400 km downwind of the Eocene Andean volcanic arc. The coordinated study of sediments and paleosols of this unit allows (1) reconstruction of environmental conditions and landscape evolution, and (2) determination of the interplay of the main forcing factors in the evolution of the Kokuel-Kaike Formation. The landscape reconstruction attests to the existence of a loessic rolling plain drained by a subordinate fluvial system, composed of both unconfined and confined flows, with locally ponded areas. Over these, thick stacked cumulative paleo-Ultisols and vertic paleo-Ultisols developed with scarce simple and stacked compound vitric Entisols analogues and compound Inceptisols equivalents. This high-resolution sedimentological-pedological analysis of the Kokuel-Kaike Formation indicates that the interplay between episodic volcaniclastic supply and cyclic climate controlled landscape evolution and soil development.

1. Introduction

Analysis of paleosols and their various formation processes provides information about ancient environmental conditions, such as parent material, topographic relief, climate, organisms and time (e.g. Jenny, 1941; Retallack, 2001; Buol et al., 2011). Integration of paleopedological and sedimentological data provides a tool for reconstruction of environmental conditions and processes operating at different scales, and also helps to recreate the evolution of the landscape and describe the main forcing factors that control such evolution (e.g. Kraus and Aslan, 1999; Hamer et al., 2007; Varela et al., 2012; Beilinson and Raigemborn, 2013; Flaig et al., 2013; Di Celma et al., 2015; Kraus et al., 2015; Opluštil et al., 2015; Basilici et al., 2016). These studies are mainly based on fluvial or alluvial systems with stacked paleosols, and are most common in Quaternary loess–paleosol sequences (e.g. Kemp, 2001; Muhs and Bettis, 2003; Gocke et al., 2014). As a result, studies of pre-Quaternary paleosols associated with tephric input in eolian-dominated fluvial systems are relatively rare (Parrish, 1998; Bellosi, 2010; Bellosi and Krause, 2014). At the same time studies on remote fluvial/alluvial systems impacted by distal volcaniclastic materials are currently very few (Smith, 1988; Nakayama and Yoshikawa, 1997; Kataoka and Nakajo, 2002; Kataoka, 2005; Umazano et al., 2008; Kataoka et al., 2009). In alluvial systems distant from the sea, climate and/or tectonics, rather than sea-level fluctuations, are the major controls on sedimentation and paleosol development (e.g. Kraus, 1999; Kraus and Aslan, 1999; Bellosi, 2010). Climate exerts a strong control on changes in fluvial systems and their stratigraphic architecture due to changes in hydrology, which influences the amount of water available for fluvial processes and controls the kind of vegetation cover (Cecil, 2003; Cecil et al., 2003; Kraus et al., 2015; Opluštil et al., 2015). However, volcanic influx plays an important role in controlling distal volcaniclastic successions (Smith, 1991; Kataoka and Nakajo, 2002; Paredes et al., 2007; Umazano et al., 2008, 2012; Kataoka et al., 2009) and associated pedogenesis (e.g. Bellosi, 2010; Bellosi and Krause, 2014).

The Koluel-Kaike Formation (KKFm), an early Paleogene distal volcaniclastic succession in Argentine Patagonia, includes different stacked

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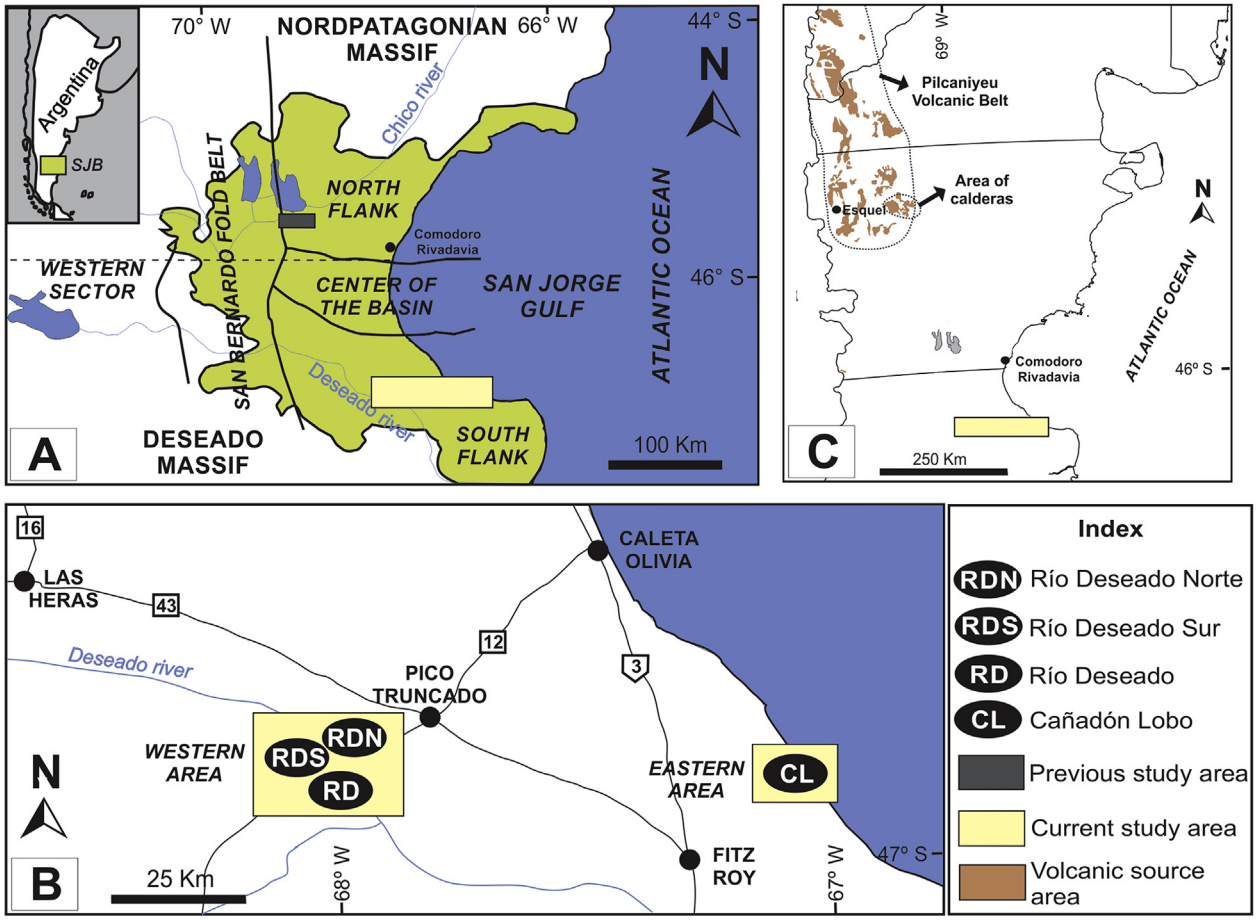

Fig. 1. Map showing position, boundaries and internal division of the San Jorge Basin, and position of the previous and current study localities (A); location of the localities analyzed on the South Flank (B); location of the volcanic source area (C) (modified from Raigemborn et al., 2014).

paleosols developed during a period in which the climate of the Earth experienced the last first-order alteration: the onset of a worldwide Icehouse (e.g. Zachos et al., 2001). In a previous study, Krause et al. (2010) described paleosol types and their temporal distribution throughout the KKFm in the northern area of the San Jorge Basin (Fig. 1A) and linked them to the tropical climate prevailing during the early Eocene. A fairly detailed reconstruction of these conditions, based on mineralogical assemblages, appears in Raigemborn et al. (2014). In both works, a shift in climate from humid and warm to subhumid and temperate conditions was established from abiotic proxies. However, a detailed landscape analysis—including a complete reconstruction of environmental conditions, sedimentological and pedological processes and their evolution, and the interplay of the main forcing factors—was not attempted. This high-resolution sedimentological and pedological analysis of the KKFm in the southern portion of the San Jorge Basin (Fig. 1A and B) aims at reconstructing sedimentary paleoenvironments and landscape evolution, and establishing the role that the control factors played in the evolution of the paleosol-dominated distal volcaniclastic system (Fig. 1C). These objectives were addressed by conducting analyses of these paleosol-bearing deposits, and performing a high-resolution paleosol study to establish which soil-forming factors and paleopedological processes controlled their formation. This research leads to identification of features and factors that may be used to interpret other distal pedogenically-modified volcaniclastic successions worldwide.

2. Geological context and age model

The study area is located along the South Flank of the San Jorge Basin (Fig. 1B), an extensional intracontinental basin in southern Argentina that developed on Paleozoic continental crust linked to the Gondwana break-up. From the early Paleocene (Danian) to the middle Eocene (Lutetian) (Clyde et al., 2014; Woodburne et al., 2014), the continental systems of the Río Chico Group (Las Violetas/Peñas Coloradas, Las Flores and Koluel-Kaike formations, in stratigraphic order; Raigemborn et al., 2010) were deposited. These units are overlain by marine and continental units that represent the Cenozoic infill of the basin (Fig. 2).

Two areas on the South Flank (Fig. 1B) were selected for this paper: a western area that includes the Río Deseado Norte, Río Deseado and Río Deseado Sur localities, and an eastern area represented by the Cañadón Lobo locality. The base of the KKFm is not exposed, and the lower boundary shows a local erosional relationship with the underlying La Flores Formation; meanwhile, the upper boundary with the overlying Sarmiento and El Huemul formations and Rodados Patagónicos is erosional in nature (Figs. 2 and 3).

On the North Flank, ~200 km to the north of the study area, the KKFm (46 m thick) is informally divisible into three parts: Lower, Middle and Upper sections. These were defined on the base of dominant paleosol type and temporally constrained using paleomagnetic analysis and U-Pb dating of volcanic ashes to 46.7–42.1 Ma (Krause et al., 2010, 2017). In the Lower section Ultisol-like and subordinate Andisol-like paleosols occur; the Middle section is composed of Ultisol-like paleosols; and the Upper section features Andisol- and Mollisol-like paleosols (Fig. 2). Due to the absence of age constraints for the KKFm on the South Flank, correlation with the North Flank was established on the basis of stratigraphic relationships with adjacent units and presence of the characteristic paleosols. Consequently, we assume that the KKFm on the South Flank correlates with the whole of the unit on the North