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Paleoclimatic records of Late Triassic paleosols from Central Ethiopia

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ABSTRACT

The present study documents the major paleosols types within the Lower Adigrat Sandstone in the Blue Nile Basin of central Ethiopia, with the aim of unraveling the paleoclimatic signatures embedded in them. The paleosols developed within an 80-m-thick siliciclastic succession deposited in a mixed tide- and wave-dominated incised valley estuary during the Late Triassic.

Based on down-profile variations in pedogenic features, three major paleosol types (i.e., types I, II and III) were identified. Type I paleosols dominate the lower part of the section and are interpreted as moderately well-drained argillic Vertisols. The dominant pedogenic process was shrinking and swelling of expandable clays (i.e., smectite) through repeated wetting and drying cycles. The morphologies and the mineralogy of the paleosols provide persuasive evidence for pedogenesis under semi-arid subtropical climatic conditions with pronounced wet-dry seasonality, highly fluctuating soil moisture regime, and deep groundwater table. The presence of a calcic Bk horizon deep in the profiles is consistent with elevated soil moisture deficits and low to moderate mean annual precipitation (MAP). Type II paleosols, interpreted to represent vertic Gleysols, are more common in the middle part of the section. The pervasive gleying reflects poor soil drainage and a shallow groundwater table where the soil is waterlogged most of the year. These paleosols suggest a humid tropical climate characterized by alternating wet-dry seasonality but with more wet months per year. The top of the unit is dominated by type III paleosols that represent gleyed Oxisols, reflecting a more humid equatorial climate marked by wet seasons, elevated annual soil moisture content, and a high water table. The presence of plinthite/laterite is in agreement with a wet equatorial climate characterized by extensive chemical weathering and long periods of landscape stability. The observed vertical progression in the major paleosol types from Vertsols to Gleysols and Oxisols implies a systematic change in the number of wet months, most probably in response to regional tectonics and long-term climate change. Because the number of wet months is, in part, related to latitude and monsoonal climates, the upward stratigraphic trend in paleosol orders is interpreted to signal the northward or equatorward migration of the Blue Nile Basin and central Ethiopia within Pangea from dry subtropical low-latitudes in the early Late Triassic (Carnian-Norian) toward the humid, wet equatorial, possibly monsoonal, paleoclimatic zone in the Late Triassic (Norian-Rhaetian).

1. Introduction

Significant advances have been made in the past decades in unraveling Early Mesozoic climate evolution across equatorial Pangea (e.g., Steel, 1974; Nairn and Smithwick, 1976; Parrish, 1985, 1993; Ziegler et al., 2003; Tramp et al., 2004; Schneider et al., 2006; Tabor et al., 2007). Numerical modeling studies based on climate-sensitive sediments, such as coals and evaporites, as well as on fossil flora and fauna, indicate that Earth's climate system underwent significant evolutionary change during the Early Mesozoic (Visscher and van der Zwan, 1981; Parrish, 1993; Wilson et al., 1994; Ziegler et al., 2003). It is generally believed that climate change occurred in response to the formation of the supercontinent Pangea and the accompanying global-scale reorganization of atmospheric circulation systems (Rowley et al., 1985; West et al., 1997; Cecil, 1990; Gibbs et al., 2002; Parrish, 1993).

The supercontinent Pangaea assembled during the Triassic and achieved its greatest dimension as a single landmass (Ziegler et al., 1983, 2003; Parrish, 1985). During this time, Pangea migrated 10° northward so that the landmass became symmetric with respect to the equator by the Late Triassic, i.e., the landmass was distributed equally between the northern and southern hemispheres (Ziegler et al., 2003). This configuration is presumed to have brought about a global climatic pattern, i.e., "megamonsoonal" climate with pronounced seasonality that had influenced the distribution of sedimentary deposits both in continental and marine environments (Kutzbach and Gallimore, 1989; Parrish, 1993; Wilson et al., 1994). During the Late Triassic, what is now the Blue Nile Basin of central Ethiopia was positioned near to the western margin of the Tethys, about 20° south of the equator (Fig. 1a; Scotese et al., 1999). This western equatorial Tethys region was interpreted as an arid belt as confirmed by widespread Late Triassic evaporite deposits in the Arabian

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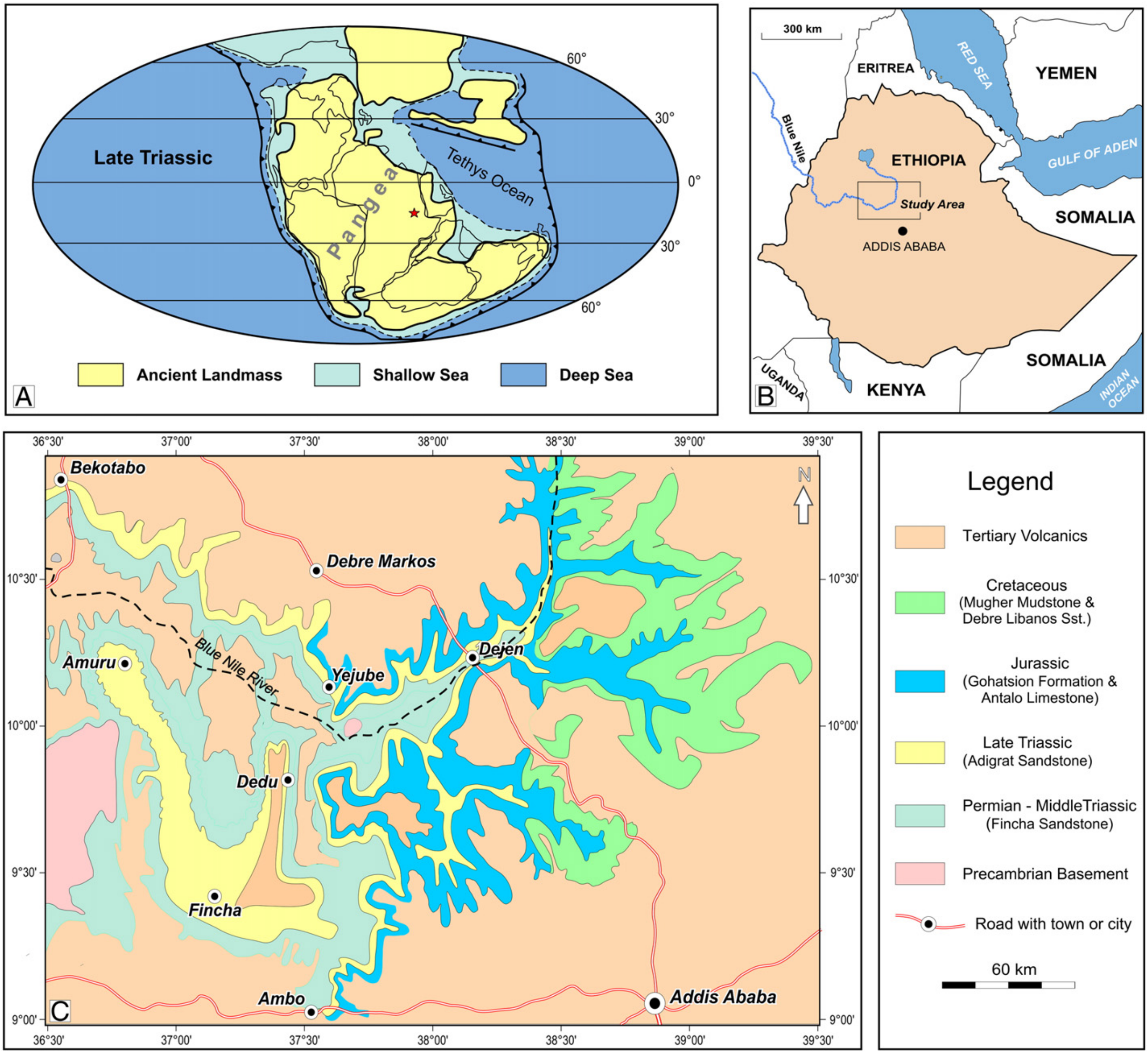

Fig. 1. Generalized geology of the study area. (A) Schematic reconstruction of Pangea in the Late Triassic, with the red star showing the approximate paleogeographic position of the Blue Nile Basin (modified after Ziegler et al., 1983). (B) Map showing the geographic location of the Blue Nile Basin within Ethiopia and East Africa. (C) Simplified geological map of the Blue Nile Basin. Black dots indicate nearby towns where Late Triassic sections are accessible; black dots near the towns Dejen and Yejube mark the location of sections with abundant paleosols.

Peninsula and in Madagascar (van der Zwan 1981; Pollard and Schulz, 1994; Visscher and Wilson et al., 1994; Ziegler et al., 2003). In contrast to the evaporite basin model, the occurrence of widespread lateritic paleosols in the Late Triassic section studied herein is partly in conflict with the predicted trans-equatorial aridity.

This paper focuses on morphological and mineralogical descriptions of paleosols from outcrops of the Lower Adigrat Sandstone in the Blue Nile Basin (Fig. 2), with the aim of providing insight into the palaeoclimate that prevailed in southeastern-equatorial Pangea in the Late Triassic. Although, other factors, such as parent material, landscape position, vegetation, or time, may also affect soil development or mask the climatic signatures, this study attempts to address those types of paleosols that are most significant to infer different paleoclimate proxies. The results presented here provide, for the first time in the region, useful geologically-based proxy data that can help refine the available paleoclimate models that exist for the Late Triassic of East Africa and equatorial Pangea at large.

2. Geological setting

The study area is located in the Blue Nile Basin, central Ethiopia (Fig. 1b and c), which was situated in southeastern-equatorial Pangaea, about 20°S of the equator in the Late Triassic (Fig. 1a). The Blue Nile Basin is one of a series of NE and NW-trending intracontinental rifts and pull-apart basins, known collectively as Karoo rift basins (Schandelmeier et al., 2004; Papini and Benvenuti, 2008), which were subsequently filled with the Permo-Triassic siliciclastic sediments. Although the geodynamic evolution of these complex rift basins is not yet entirely clear, they were believed to have formed along a zone of weakness of the former Pan-African mobile belt (Montenat et al.,