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GEOSITES

Mid-Eocene (Bartonian) composite alluvial paleosol succession in NE Egypt: a key to terrestrial paleoenvironmental and palaeoclimatic reconstruction

Paleosols (soils incorporated in the stratigraphic column) are products of pedogenesis associated with physical, chemical and biological modifications of sediments formed on a landscape of the geological past (e.g. Mack et al. 1993; Retallack 2001; Kraus and Hasiotis 2006). Paleosol development is largely controlled by sediment aggradation rate, degree of erosion and pedogenesis (e.g. Kraus 1999; Retallack 2018). Paleosols can form in sediments as a result of prolonged period of little or no deposition and surface stability. Therefore, paleosols may serve as markers of stratigraphic unconformities that are very helpful in tracing genetically related packages and delineating regional accommodation trends (Demko et al. 2004). In the same context, paleosols can provide important clues necessary for high-resolution stratigraphic correlation, identifying depositional systems tracts, and reconstructing palaeoclimate, palaeogeography and palaeovegetation regimes (e.g. McCarthy and Plint 1999; Choi 2005). Macro-, micromorphological and petrographic investigations are essential to paleosol research, quantitative and geochemical analyses are also very helpful to infer the environmental, hydrological and climatological conditions at the time of paleosol formation (McCarthy et al. 1998; Sheldon and Tabor 2009).

A well-developed alluvial succession associated with composite paleosols (~ 45 m-thick) was recognized in the mid-Eocene (Bartonian) sedimentary rocks at Gebel El-Goza El-Hamra in the NE Eastern Desert of Egypt (Fig. 1). This alluvial paleosol succession gives important contextual information about the local and regional terrestrial paleoenvironmental and palaeoclimatic conditions in which it originated. Detailed facies and geochemical analyses of this sedimentary succession were undertaken by Wanas et al. (2015). Lithologically, the studied alluvial succession is unconformably underlain and overlain by lagoonal, shallow-marine foraminiferal limestone strata of Bartonian age (Sallam et al. 2018, 2022; Sinanoglu et al. 2018), and is composed of laminated sandstones (~ 10 m-thick) with some lenticular lags of conglomerate, followed upward by ~ 35 m-thick mottled mudrocks. These lithofacies are interpreted as representing, respectively, sheet floods, ephemeral braided channels, and distal floodplain alluvial deposits (Wanas et al. 2015; Sallam et al. 2015). Facies architecture and stacking pattern of these alluvial sediments were influenced largely by local tectonics and base-level fluctuation, which control sediment supply relative to accommodation space (Selim et al. 2016; Sallam and Ruban 2017). In this regard, the laminated sandstone and gravel lags (sheet floods and braided channel fills) in the lower part reflect low-accommodation conditions, whereas the overlying floodplain mudrocks define a high-accommodation systems tract indicating inconstant sediment aggradation rates. The floodplain mudrocks display horizonation (paleosol profiles), and are capped by ~ 15 m-thick lacustrine dolostones (dolocretes) interbedded with smectitic claystones and dissected by gypsum streaks.

Several pedogenic and biogenic structures were recognized within the studied alluvial floodplain mudrocks. The most common pedogenic features observed in these sedimentray rocks are horizonation, color mottling of different shades (multi-colored pattern), vertically-aligned purple, reddish-brown and bloody red stripes (Figs. 2, 3), calcrete nodules (3–5 cm in diameter), black Mn-oxide spots, and desiccation (shrinking mud) cracks filled with illuviated clays. The biogenic structures include the occurrence of calcareous rhizoliths (root casts) and burrows. The dominant

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Fig. 1 Field photograph showing the composite alluvial paleosol profiles at Gebel El-Goza El-Hamra, NE Eastern Desert, Egypt

purple, bloody red and reddish-brown mottles imply a well-drained floodplain that experienced episodic interruption of deposition, sub-aerial exposure, and subsequent oxidation in arid climate and fluctuating water table position (e.g. Bown and Kraus 1987). The abundant calcareous rhizocretions ascertain a well-drained floodplain environment (e.g. Kraus and Hasiotis 2006; Tabor and Myers 2015). The vertical structures including desiccation cracks filled with illuviated clays reflect shrink-swell processes, and also signify seasonal aridity and palaeopedogenesis (Mermut et al. 1996;

Fig. 2 Field photograph showing the calcisol horizon (at the base), and is overlain by an oxisol horizon at Gebel El-Goza El-Hamra, NE Eastern Desert, Egypt

Fig. 3 Close-up view of the oxisol horizon including abundant reddish-brown and bloody red mottles. The hammer handle for scale is 26 cm long

Zobaa et al. 2015). The pedogenic calcrete nodules were most likely formed in the vadose zone with increased water table, and seasonally arid to semi-arid climatic conditions (e.g. Huerta and Armenteros 2005). The occurrence of Mn-oxide black spots indicates fluctuations in redox potential associated with periodic water saturation (e.g. McCarthy et al. 1998). The abiotically formed, primary dolocretes overlying the floodplain mudrock succession imply deposition in an evaporitic saline, alkaline Mg^{2+}-enriched marginal-lacustrine environment (Wanas and Sallam 2016). Gypsic features associated with the lacustrine dolomite and claystones are generally indicative of aridity and high evaporation rate.

The studied paleosol succession can be classified as composite profiles in which sediment aggradation rates were rapid and intermittent (Marriott and Wright 1993). Following the paleosol-specific classification system of Mack et al. (1993), three types of paleosols are interpreted including, from base to top, argillisol, calcisol and oxisol. The argillisol is marked by desiccation cracks filled by illuviated clays, and the occurrence of biological structures such as rhizoliths and burrows within gray sandy mudrocks. The calcisol is characterized by the presence of pedogenic calcrete nodules disseminated randomly in yellowish-gray mudrocks, whereas the oxisol is attributed to the reddish-brown ferric strips and concretions within gray siltstones and claystones.

The given pedogenic and biogenic characteristics, isotopic-geochemical data, and recovered palynomorphs (despite their scarcity) collected from the studied composite alluvial paleosols indicate their origination in a changing seasonal palaeoclimate from tropical to subtropical and arid conditions during the mid-Eocene (Bartonian) age in the southeast Mediterranean, with fluctuating base-level, inconstant sediment aggradation rate, and low precipitation/evaporation ratio.

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Data availability All data generated or analysed during this study are included in this published article.

Declarations

Conflict of interest The authors declare no competing interests.

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