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A preserved Late Cretaceous biological soil crust in the capping sandstone member, Wahweap Formation, Grand Staircase-Escalante National Monument, Utah: Paleoclimatic implications

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ABSTRACT

Modern biological soil crusts develop under semiarid to arid conditions and are characterized by diverse communities of micro- and macro-organisms. The upper meter of the Upper Cretaceous capping sandstone member of the Wahweap Formation in Grand Staircase-Escalante National Monument, Utah contains an outcrop of an ancient biological soil crust preserved in matrix-rich quartz sandstone. The interpretation is based in comparison with modern biological soil crust analogs, specifically similarities in morphological expression, sorting, and proximity to associated eolianites. This study reports on this rarely recognized type of paleosol, a biological soil crust and discusses the sedimentologic and paleoclimatic implications.

1. Introduction

In modern arid to semiarid environments, both hot and cold, biological soil crusts (BSCs — also termed as cryptobiotic, cryptogamic, microbiotic or microphytic crusts) stabilize vast land surfaces by the binding action of cyanobacteria, green algae, lichens, microfungi, and mosses and commonly host diverse microarthropod communities (Friedmann and Galun, 1974; Friedmann and Ocampo-Paus, 1976; West, 1990; Johansen, 1993; Eldridge and Greene, 1994; Belnap and Gillette, 1998; Belnap et al., 2001a,b; Neher et al., 2009). The sediment binding and aggregation of BSCs deter wind and water erosion and can significantly modify the hydrologic regime of an area by increasing infiltration (Belnap and Gillette, 1998; Belnap et al., 2001a,b; Warren, 2001; Eldridge and Leys, 2003; Bowker et al., 2008; Neher et al., 2009). The development of some types of BSC may have played an important role in stabilizing and colonizing Cambrian and earlier continental landscapes (Campbell, 1979; Eriksson et al., 2000; Prave, 2002; Retallack, 2008, 2009; Finkelstein et al., 2010).

This paper describes, interprets, and discusses the implications of a rarely reported paleosol type, BSC, discovered in the Upper Cretaceous capping sandstone member of the Wahweap Formation in southern Utah, USA (Fig. 1).

2. General geology

Within the Kaiparowits Basin, Utah, the Cretaceous system accumulated in a foreland basin that was bounded eastward by the Cretaceous interior seaway, westward by the Sevier orogenic front and southwestward by the Mogollon Highlands (Eaton and Nations, 1991). In the Kaiparowits Basin, from the oldest to the youngest, the Straight Cliffs, Wahweap, and Kaiparowits Formations are recognized (Fig. 1; Peterson, 1969; Eaton, 1991; Lawton et al., 2003; Titus et al., 2005; Roberts, 2007). Four informal members compose the Wahweap Formation, the lower, middle, upper, and capping sandstone members (Fig. 2; Eaton, 1991). In the study area, the capping sandstone consists of white quartz arenites that are lithologically distinct from the tan to grey sublithic to lithic arenites of the upper member and the Kaiparowits Formation (Eaton, 1991; Eaton and Nations, 1991; Pollock, 1999; Lawton et al., 2003; Roberts, 2007). This lithologic change is coupled with a shift in overall paleocurrent directions reflecting a paleogeographic change in sediment source area, from the southwardly located Mogollon Highlands, for the upper member and

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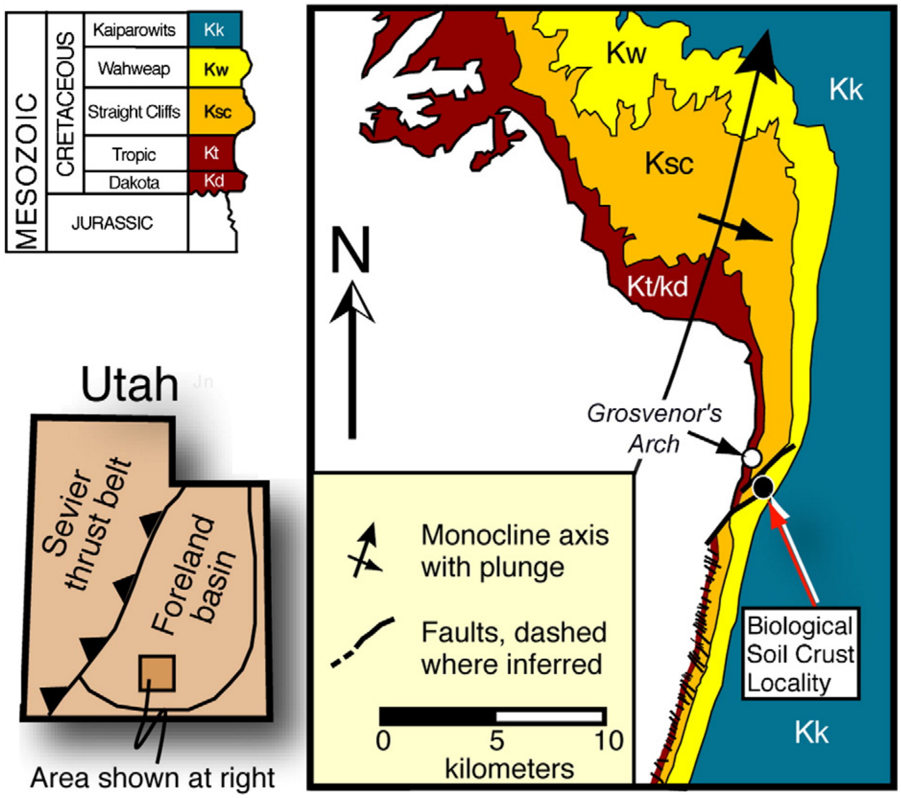

Fig. 1. Location and geologic map of the study area in the Kaiparowits Basin. Geologic map modified from Sargent and Hansen (1982).

Kaiparowits Formation to the northwestly located Sevier thrust belt, for the capping sandstone member (Pollock, 1999; Lawton et al., 2003; Roberts, 2007).

Ar^{40}/Ar^{39} radiometric dating by Roberts et al. (2005) on tuffs distributed throughout the overlying Kaiparowits Formation and from the lower and middle members of the Wahweap Formation by Jinnah et al. (2009) supports the assignment of the Late Cretaceous, Campanian age that was originally based on microvertebrate biostratigraphy (Eaton, 1991, 2002).

Pollock (1999) and Lawton et al. (2003) interpret the capping sandstone member depositional environments as a series of amalgamated braided-stream channels with limited preserved overbank deposits. Their sedimentological analysis recognized trough cross-bedding as the most common stratification type. Sedimentary structures encountered in our measured section are consistent with their observation that trough cross-bedding dominates (Fig. 2B). However, Simpson et al. (2008) reports the presence of eolian stratification within the capping sandstone member, both as thin, wind-reworked caps on fluvial-bar sandstones deposited within low-sinuosity braided streams and as more extensive dune deposits that formed small dune fields geomorphically linked to the fluvial system. Near the top of the capping sandstone member, eolian deposits have been recognized at several geographic localities, including the BSC locality (Figs. 1, 2A, and 2C; Simpson et al., 2008). In addition, this locality is associated with syndepositional normal faults that were active during the accumulation of the capping sandstone member (Hilbert-Wolf et al., 2009; Tindall et al., 2010).

3. Description of the cretaceous features

The capping sandstone features are developed approximately 1 meter below the contact between the capping sandstone and the overlying Kaiparowits Formation on the east flank of the East Kaibab monocline (Figs. 1 and 2). The outcrop is approximately 20 meters by 5 meters in area (Fig. 3A). In close association with this feature, two vertical meters below in stratigraphic section, are medium-scale, low-angle eolian cross-beds composed of inversely graded laminations (Fig. 2A). Thin section analysis confirms that these low-angle cross-bedded quartz sandstones are wind-ripple deposits because of the distinct inverse grading preserved in the laminations (Fig. 4A; Simpson et al., 2008); inverse grading is characteristic of the ballistic eolian transport of sand (Hunter, 1977, 1981).

The bedding plane outcrop is characterized by an irregular, pinnacled surface morphology (Figs. 3A, C, E, and 5) developed on fluvial strata above the eolian deposits. Fluvial and eolian deposits are interbedded. The maximum vertical relief on this pinnacled crust is over 3 cm. Approximately 10 cm of the overall relief is preserved across the exposed surface. In cross section, weakly developed irregular mm- to cm-scale prismatic columns and structureless sandstones are preserved in cross section (Fig. 5). The prismatic pinnacles are approximately 6–9 cm in length in cross section view (Fig. 5).

In thin sections of the Cretaceous features, the quartz arenite displays a range in grain size from silt to medium-grained sand (Figs. 4B, 6A, and C); the features have a greater amount of lithic grains in comparison to the eolian sandstones (Fig. 4A and B). Additionally, sorting is poor across the thin sections (Figs. 4B, 6A, and B). Slightly sinuous, subvertical to oblique oriented, high porosity, and well-sorted zones are recognized in the thin sections cut perpendicular to bedding (Fig. 6A). In the thin sections cut parallel to bedding, the high porosity zones are ovate in cross section. No vertical or horizontal trend in grain size was recognized within the irregular bed.

Organic material was not found during the thin section examination of the Cretaceous feature. Because of the absence of organics and because the host sediment of the feature is a porous arenite, geochemical analysis was not conducted.