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Combining satellite image data and field observations to characterize fresh-water carbonates in Kurkur Oasis, Southern Egypt

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ABSTRACT

Several fresh-water carbonate deposits (tufa and travertine) were formed at different elevations within the Kurkur paleolake, 50 km west of Aswan, Egypt. Such paleolake was unique and confined in sag between the cuesta and the capping platform of Sin El-Kaddabaa Plateau. This work aims at integrating the remote sensing data together with the chemical and petrographic analyses to map and characterize these tufa and travertine deposits to define their paleo-depositional environment. A DEM with 2.5 m spatial resolution was generated from two ALOS/PRISM images to show geomorphological and hydrological parameters. In addition, full-polarimetric SAR data were used to investigate the scattering response of these tufa and travertine deposits. These deposits show a volume scattering response, with an increase in the pedestal height of the co- and cross-polarized signatures. The tufa and travertine deposits range from Pleistocene (older upper level) to Recent (younger lower level). The young tufa is hard, light brown porous and thinly-laminated, while the old tufa is generally coarse crystalline and consists of columnar pseudo denderitic calcite crystals. The travertine displays a stromatolitic fabric, where thin dark micritic algal laminae alternate with relatively thick calcitic bands (~1 cm). Conducted XRD and chemical analyses reveal that these tufa and travertine are entirely composed of low magnesium calcite, with traces of quartz (<2%). Moreover, the $\delta^{13}C$ and $\delta^{18}O$ values suggest that the old tufa have been developed during warm pluvial periods, while the younger ones were precipitated in drier periods. Two hypotheses were introduced to explain the changes in the hydrological regime of Kurkur paleolake; the first proposes a hydrological breaching due to water overflow on the lake's low periphery areas that led to their desiccation (where the tufa and travertine were deposited) and the second is the possible integration into the regional drainage networks of the area presently occupied by Lake Nasser.

1. Introduction

Fresh-water carbonates are calcareous sediments precipitated from groundwater, surface or groundwater-fed rivers and lakes with a high content of calcium bicarbonate in a wide range of depositional and diagenetic settings. They include a wide spectrum of terrestrial carbonates extending from calcretes and dolocretes, through tufas and travertines, as well as palustrine carbonates formed in wetlands, ponds and lakes (Alonso-Zara and Wright, 2010; Arenas-Abad et al., 2010; Toker et al., 2015, 2017). Several models for precipitation and lithification of these sediments have been suggested, ranging from being entirely microbial (Krumbein et al., 1977; Burne and Moore, 1987; Merz 1992; Visscher et al., 1998, , 2000; Braissant et al., 2003; Khadkikar and Rajshekhar, 2003; Mazzini et al., 2004; Baumgartner et al., 2006; Riding, 2006; Bundeleva et al., 2012) to purely chemically mediated mechanisms (Arp et al., 2003). However, Khalaf and Al Zamel (2016), Khalaf (2017) and AlShuaibi and Khalaf (2017) suggested that these sediments are mostly microbialitic. They commonly developed through alternation of biologically induced process, where bacteria playing a significant role, and chemically mediated process which governs the transformation of dissolved bicarbonate to precipitated carbonate.

Tufa is commonly defined as consolidated to unlithified porous terrestrial freshwater carbonates rich in calcified plant remains, while travertine is well-lithified, laminated sparitic freshwater

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carbonates (Pedley, 1990; Carthew et al., 2003; Viles, 2004). These deposits form along alkaline spring-fed streams and lagoons and at sites of waterfalls and rapids (Viles and Goudie, 1990), which are commonly associated with karstic limestone terrains. They precipitated when water is saturated with calcium carbonate and becomes supersaturated due to degassing of carbon dioxide.

This may occur as a result of atmospheric absorption of carbon dioxide, increase in temperature, decrease in pressure, physical agitation, aquatic plant photosynthesis (Lorah and Herman, 1988) or microbial activities (Pedley and Rogerson, 2010). Tufa and travertine are deposited during periods following pluvial episodes and are characterized by enhanced groundwater discharge (Livnat and Kronfield, 1985; Heimann and Sass, 1989; Abotalib et al., 2016) therefore; they encompass important geologic records of paleo-hydroclimatic conditions (Pazdur et al., 1988; Goudie et al., 1993; Jimenez, G., 2014).

Tufa and travertine deposits at the Kurkur area of the Western Desert of Egypt attracted the attention of many geologists and archaeologists (Caton-Thompson and Gardner, 1932; Caton-Thompson, 1952; Butzer and Hansen, 1967; Issawi, 1971; Wendorf and Schild, 1980; Simmons and Mandel, 1986; Nicoll, 1996; Nicoll et al., 1999; Marinova et al., 2014; Jimenez, 2014; Abotalib et al., 2016). They were first described by Ball (1902) as Pleistocene freshwater deposits. Butzer (1965) suggested that the Kurkur area landforms developed during semi-arid to hyper-arid conditions in the Late Tertiary and early Pleistocene. Issawi (1968) reported that these tufa and travertine were deposited on deeply eroded surfaces. Ahmed (1996) described the geomorphological setting of the Kurkur area and recognized four types of tufa and travertine deposits on the basis of their geomorphic and geographic locations. Recently, the travertine and tufa deposits within Kurkur Oasis were described (Jimenez, 2014; Abotalib et al., 2016; Nicoll and Sallam, 2016) as well as around the world (Manzo et al., 2012; Benjamin et al., 2017 and discussed the favourable conditions that led to their formation.

Traditional investigations of sedimentary rocks and their diagenetic processes have relied on costly and time consuming ground-based data collection and laboratory analyses to define their characteristics, spatial distribution and depositional and geological history. Although these ground-based and laboratory studies result in accurate information about the depositional history of an area, they provide only limited spatial coverage. However, such small-scale surveys are not adequate for investigating large areas. On the other hand, remote sensing technology represents a tremendous leap in delivering data at a reasonable scale. However, the integration of the round-based and laboratory data with the proper space-borne information is the most promising approach to investigate large areas with the required scale. Such space-borne spectral data, digital elevation models (DEM) and radar remote sensors provide various levels of information about a region based on their capabilities that can be translated into significant and often unique knowledge of geomorphological, geological and environmental information.

Recently, the fully polarimetric Synsetic Aperture Radar (SAR) data (HH, HV, VH and VV) have been used to identify and distinguish between different geomorphic targets based on their scattering response (van Zyl et al., 1987; van Zyl, 1989; Papathanassiou and Buchroithner, 1993; Cloude and Pottier, 1997; Lee et al., 1999; Zhang et al., 2011; Gaber et al., 2015). The relative variations between the surface sediments in non-vegetated areas in terms of radar scattering response and surface roughness can be extracted by investigating the power and mechanism of the backscattered SAR signals (Peake and Oliver, 1971). Meanwhile, the polarization signature technique shows the backscatter response of the target in all combinations of transmitted and received polarizations, which are represented as either co-polarized or cross-polarized (van Zyl et al., 1987; Ray et al., 1992). Polarization signatures are extracted from the scattering matrix data for identifying pixels representing specific dielectric constant or surface roughness. However, increasing surface roughness leads to increase in the pedestal height of the 3D representation of the polarization signature and makes a shift in the peak from the VV toward the HH polarization in the co-polarized signature shape (Zebker et al., 1987; Evans et al., 1988). The differences between the dielectric constants of the targets affect only the backscattered power values (z axis) of the 3D graph of the polarization signature.

Therefore, this study aims at correlating the petrographic examination, the mineral composition and the isotopic makeup together with the space-borne information to characterize the vertically arranged tufa and travertine deposits at Kurkur Oasis and to define their spatial distribution, radar scattering response, and paleo-depositional environment.

2. Field occurrence

The oasis of Kurkur is situated on a platform of limestone beds (i.e. Gara Formation), which generally dip westward toward the escarpment of Sin El Kaddab Plateau. This plateau covers a large area in the southeastern part of the Western Desert of Egypt (Fig. 1). It is bounded by the Gallabah plain and Lake Nasser in the east, and the depressions of Darb Al Arbain and Paris in the west. The southern scarps of this plateau overlook the depressions of Tushka, while the northern part gradually merges with the main limestone plateau that fringes the Nile Valley for approximately 250 km from Isna to Asyut. The published geological maps of EGSAMA, NARSS, UNDP and UNESCO (2005) show that the eastern and western piedmonts of the plateau are mainly composed of sandstone of the Kiseiba Formation of the Upper Cretaceous (Fig. 1). The Paleocene shale (Dakhla Formation) and limestone (Kurkur Formation) outcrop on the foot slopes of the eastern and western sides of the plateau. Wide platforms of Paleocene limestone (Gara Formation) occur on both sides below the main escarpments of Sin El Kaddab Plateau, which is capped by the chalky limestone of Lower Eocene age (Thebes Group\Dungul Formation).

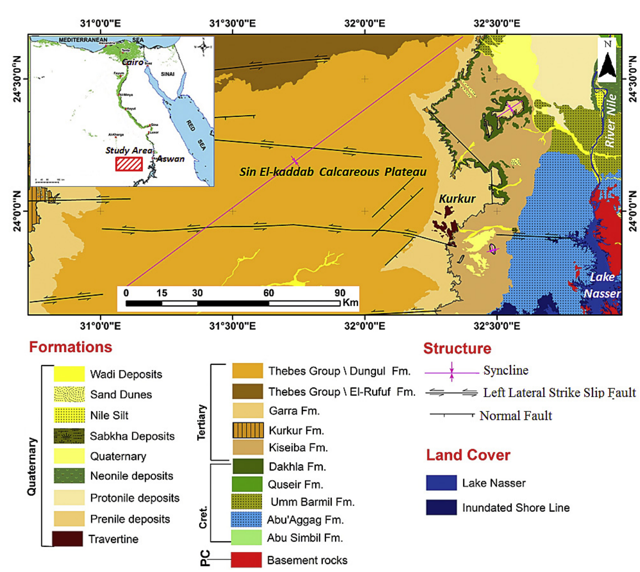

Fig. 1. Geologic map of the study area in the southern part of Western Desert plateau of Egypt, with the Kurkur Oasis at its eastern edge (modified from NARSS, UNDP and UNESCO, 2005).