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Case Report

Quaternary Fossilized - Spring Calcareous Tufa at Kharga Oasis (Western Desert, Egypt): Sedimentary Records of Past Humidity in the Eastern Sahara

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Case Report

Geosites in Egypt are diverse and display important clues on sedimentological, palaeoclimatic, paleoenvironmental and palaeogeographical reconstructions (e.g, Plyusnina et al. [1]; Al-Dhwadi [2]; Mashaal et al. [3]; Abd-Elhakim et al. [4]; Ruban et al. [5]; Mashaal [6]). Among these geosites is the palaeospring calcareous tufa carbonates that are well-preserved at Kharga Oasis in the southern Western Desert of Egypt. Tufa is a variety of carbonate rocks formed as a result of abiotic (physiochemical)/microbially precipitation of calcium carbonates from inland alkaline freshwaters including fluvial streams, shallow lakes, lacustrines, palustrines and natural springs at ambient temperature (e.g. Ford [7]; Riding [8]; Carthew et al. [9]; Andrews [10]; Gandin [11]; Arenas et al. [12]; Sallam [13]). An essential prerequisite for tufa formation is that waters be highly saturated with calcium bicarbonate-Ca $(HCO_3)_2$. Classification and environmental models of freshwater tufa carbonates were proposed by Pedley [14]. The Kharga Oasis, an erosion-related depression in the south-central part of the Egyptian Western Desert, appears to be a world-class geosite and a natural laboratory for the study of the fossilized-spring calcareous tufa. A comprehensive study of the Kharga tufa deposits in terms of stratigraphy, geochronology and geoarchaeology was carried out by Smith et al. [15,16]. Geologically, The Kharga Depression originated most probably in the Neogene by the interplay of tectonics, karstification and denudation, which resulted in the continuous lowering of the depression area. The Kharga Depression is made up of a thick-bedded sedimentary succession of Late Cretaceous-Paleogene age representing the Nubia and Qusseir formations (Coniacian-Santonian) at the base, followed upward by the Duwi (Campanian), Dakhla (Maastrichtian-Danian), Tarawan (Paleocene) and Esna (Paleocene-early Eocene) and El-Rufuf (Ypresian) formations (Issawi et al. [17]). The depression comprises large, thick accumulations of Quaternary paleospring-deposited tufa being localized at carbonate-dominated areas where karstification process was working actively during periods of increased rainfall and groundwater discharge. Accordingly, calcareous tufa deposits are widely distributed along the retreated eastern and southern escarpments of the Kharga Depression at the Naqb El-Kharga, Naqb El-Rufuf, Naqb Bulaq, Naqb El-Rizeiqat, Naqb El-Mata'na and Wadi El-Midawara where Paleocene and Eocene carbonate rock units are well-developed. Tufa deposits in these localities rest unconformably on different bedrocks and are found at different elevations on the plateau surface, scarp-faces, and along the courses of wadis (dry valleys). Thickness of individual tufa terraces ranges from 5.0m along wadis up to 35m on scarp and plateau surface. Lithologically, the investigated tufas are characterized by surficial, soft, semi-friable to solid carbonate crusts, highly porous and vesicular textures, with abundant microbiological components dominated by in-situ encrusted phytoherms and bryophytes (empty/solid casts of calcified plant stalks and branches of reeds, grasses and mosses) (Figures 1-3), charcoal, invertebrate snails, algal mats and cyanobacteria. These tufas were most likely deposited by spring-fed fluvial-lacustrine systems, characterized by terraced, vegetated stagnant pools surrounded by arcuate tufa dams and separated by small waterfalls (Smith et al. [15]). Photosynthesis and respiration processes by macrophytes, algae and cyanobacteria contributed to CO_2-degassing, which, in turn, facilitated the precipitation of tufa carbonates. Structurally induced fissures in the older bedrocks provide good paths for groundwater to emerge from shallow karstic aquifers perched above the main Nubian Groundwater Reservoir, which were developed during Pleistocene pluvial times (Bakhbakhi [18]).

Figure 1: Field photograph showing phytohermal tufa at Naqb El-Kharga, Kharga Depression. Tufa is distinguished by horizontally-oriented solid casts of calcified plant stems. The local coin for scale is 2.4cm in diameter.

Figure 2: Field photograph showing phytohermal tufa at Wadi El-Midawara, Kharga Depression. Tufa is composed of vertically-aligned (growth position) casts of encrusted plant stalks and branches. The hammer handle for scale is 30cm long.

Figure 3: Close-up view of phytohermal tufa with abundant stromatolitic-like encrustations around empty casts of plant stems of reeds at Naqb El-Refuf, Kharga Depression. The local coin for scale is 2.4cm in diameter.

X-ray Diffraction (XRD) analysis of the Kharga tufas showed the predominance of low-Mg calcite. Macroscopic and microscopic investigations revealed the occurrence of both allochthonous (clastic) and autochthonous components, which consist of clotted, micritic lime-mudstones, peloidal/pisolitic grainstones, phytohermal boundstones, intraclastic rudstones/packstones, laminated crystalline flowstone, and wavy laminated, stromatolitic-like boundstones. Diagenetic features include cementation, recrystallization, micritization and subaerial karstic dissolution. Isotopic signatures from the Kharga tufas displayed negative δ18O values (average -10.34% V-PDB) and negative δ13C values (average -2.54% V-PDB) suggesting precipitation from meteoric environment, probably phreatic under humid conditions with increased rainfall and continental weathering. The Kharga tufas were dated using uranium-series geochronological method from >400ka of plateau tufa to 103±14ka of scarp tufa and 50.4±0.1ka of wadi tufa, which correspond to the late marine isotope stage (MIS) 6 to MIS 5e humid phase determined across N Africa (Smith et al. [16]).

Tufas are susceptible sediments to environmental and climatological oscillations (e.g. Ford [19]; Andrews [10]; Pedley [20]; Nicoll [21]; Sallam [22]; Sallam [23]), therefore, the Kharga tufas can provide critical records of the local/regional terrestrial paleoenvironmental, hydrogeological and palaeoclimatic conditions of the eastern Sahara during the recent geological past, the conditions which were fairly humid (rainy) and, thus, differ from the presently hyperarid climate. Floral pollen-grain records incorporated within tufa deposits can also give important signals about plaeovegetation and paleoclimate (e.g. Tagliasacchi [24]). Additionally, the common occurrence of lithic artifacts encased within the Kharga fossil-spring tufas ascertains that the Quaternary pluvial, wet periods of the eastern Sahara were concomitant with human/hominid occupations (e.g. Caton-Thompson [25]; Caton-Thompson [26]; Petit-Maire [27]; Haynes et al. [28]; Mandel [29]; Smith et al. [15,16]).

Therefore, the great geoscientific importance of fossilized-spring tufa carbonates, as worldwide well-preserved archives helpful for the reconstruction of the past environmental and climatic conditions, encourages us to recommend the establishment of "Tufa World Geopark" at the Kharga Oasis (e.g., Sallam et al. [30]), which, consequently, will promote geo tourism, geo conservation, and social-economic sustainable development in this remote oasis in the Sahara.

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Conflict of Interest

The authors declare no competing interests.

Author Contribution

Field work, data acquisition and interpretation were performed by F.A. Mousa, M. Abu El-Hassan and E.S. Sallam.

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