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Depositional morphotypes and implications of the Quaternary travertine and tufa deposits from along Gafsa Fault: Jebel El Mida, southwestern Tunisia

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ABSTRACT

The diversity of depositional morphologies of tufa and travertine in the field, which are controlled by a complex set of bio-physio-chemical parameters, can make them difficult to distinguish. In Jebel El Mida, the Late Villafranchian faulted alluvial deposits are overlain by complex lithofacies and growth patterns of spring-fed tufa and travertine. Travertine facies include travertine pinnacles, microterraces, thermal ponds, pisoids and conical structures, oncoids, microbial crusts, bacterial shrubs, microstromatolites, lithified bubbles (foam rocks) and microfans and cones. Their formation is controlled by (i) the volume of spring water and gas supplies and their respective daily, monthly or annual fluctuations, and (ii) topography and location with respect to the spring vent. The travertines highlight the predominance of physico-chemical processes over biochemical processes in their formation. In this context, water turbulence, temperature, and/or pressure changes are the dominant agents in releasing CO_2. Tufa facies include rhizocretions and cushions, plant moulds and imprints, lithified terrestrial land snails, gyttja and paleosols. Their formation is linked to the dominance of biochemical processes over physio-chemical processes. In this context the amount of CO_2 in calmer waters is regulated by photosynthesis, which indirectly regulates the rate of calcium carbonate precipitation. Gafsa strike-slip Fault, in addition to its tectonic role in creating fluid paths to the surface through flowing springs, acts as a major regional sill that controlled paleoflow directions, discharge locations, volume, rate and fluctuations of the water supply.

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1. Introduction

Travertine and tufa have essentially the same chemical composition and share many common features (Pentecost, 1995). However, their diverse depositional morphologies in the field, controlled by a complex set of hydrochemical, microbial, vegetational, topographic, tectonic and climatic parameters, can make them difficult to distinguish from each other (Ford and Pedly, 1996). Travertine and tufa originate in different depositional environments. However, rapid facies change is a major characteristic of these deposits, even though they are small in extent (Guo and Riding, 1999). Warm water systems such as karstic hydrothermal springs and fissure ridges gives rise to travertine, whereas cool fresh-water systems such as calcite-rich perched spring lines, cascades, fluvial, and lacustrine environments produce tufa (Julia, 1983). Recent researches including some landmark papers (Chafetz and Folk, 1984; Pedley, 1990; Viles and Goudie, 1990), has tried to decipher the full spectrum of fabrics of spring-fed carbonates and their associated geometries using various sedimentological and geomorphological schemes that facilitate their recognition in the field (more complex than previously thought and difficult to discern because of rapid facies change where tufa and travertine are interlayered). The travertine and tufa of Jebel El Mida, even though extinct (fossil) sites, they are well preserved and easy to distinguish because their well lithified fabrics resisted erosion and compaction. The precipitation of Jebel El Mida spring-fed carbonates, regardless of the mechanisms involved (i.e. microbial mediation or direct physico-chemical precipitation), produced complex lithofacies and great diversity of fabrics and growth patterns and their interpretation can help to understand the rapid facies change and the geographic distribution of carbonate spring deposits.

This paper is a detailed sedimentological study of Quaternary travertine and tufa deposits exposed locally and along the slopes of Jebel (range) El Mida in Gafsa, Tunisia. The study (1) documents and describes the full spectrum of fabrics of the spring-fed carbonates and their associated geometries, using the classification of Pedley (1990), (2) interprets the depositional processes involved in precipitation of these carbonates, (3) proposes a geological and paleogeographic model for the tufa and the travertine incorporating the roles of spring hydrochemistry, flow regimes, tectonics and climate on carbonate sedimentation and development of fabrics seen in outcrop.

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2. Previous work

Early studies principally by French researchers (Vaufrey, 1932; Denizot, 1935) dealt almost exclusively with prehistoric aspects of Jebel El Mida (‘‘Escargotières’’ and pebble-culture artifacts). Since 1945, sedimentological issues related to Jebel El Mida have received much less attention and most work has focused on mapping the Tunisian Atlas Mountains in the region and on the palaeontology, stratigraphy and tectonics (Castany, 1950; Burollet, 1956). Recent studies have provided details on the tectonic regimes of the major tectonic corridors and strike-slip fault systems associated with Gafsa Major Fault in the field area (Zargouni, 1986; Bédir, 1995; Chalbaoui and Ben Dhia, 2004; Zouaghi et al., 2005). Seeps and springs along the Gafsa strike-slip Major Fault, which is a conduit for groundwater flow, are reported by Ricolvi (1976), Ben Dhia (1990), Farhat (1984) and Yermani (2002), but the carbonates precipitated at these seeps and springs are not discussed. All these studies are devoted to the hydrochemistry, the location of groundwater recharge/discharge areas, the nature of the groundwater flow system and the paleoflow directions. So far, no serious attempt has been made to investigate in detail the sedimentology of the travertine and tufa deposits along the Gafsa strike-slip Fault.

3. Location and geographic setting

The study area (Fig. 1A) is located within the northwest-trending ranges of southern Atlas in Tunisia, approximately 1 km west of the city centre of Gafsa. The Quaternary travertines and tufas are exposed along the north-facing slopes of a small northwest-trending sill, known locally as Jebel El Mida. Much of the study area is accessible only by foot or four-wheel-drive vehicle. Summer and fall are exceedingly hot; with temperatures frequently exceeding 40 °C. Dry, hot, gusty winds laden with sand from the south are frequent in the afternoon. Topography is rugged with the exception of the broad, flat, alluvial valleys and tributaries of Oued Beyesh. The mountain ranges rise 1000 m above the valley floor and attain a maximum elevation of 1200 m. Vegetation is sparse, consisting of brush and grasses, except for the agricultural fields on the flood plains of Oued Beyesh valley. The arid desert climate inhibits extensive weathering of outcrops and facilitates mapping of the stratigraphic and structural relationships.

4. Regional geological and tectonic evolution

Gafsa Fault is a major morphostructural feature in Tunisia and North Africa, characterized by narrow asymmetric south-plunging anticlines of the Triassic and Cretaceous sequences, which show many stratigraphic gaps and unconformities (Fig. 1B) as well as condensed series deposited in an intracratonic mobile belt (Fig. 2) (Burollet, 1956; Zouari et al., 1990; Boukadi, 1994; Zargouni et al., 1995; Bédir et al., 2001). Structural data (Fig. 3) show that the most of the deformation involves large-scale NW–SE trending transpression. The ranges of Ben Younes and Orbata, as well as Jebel El Mida, are coincident with a deep seated fracture zone situated along the northern boundary of the Saharan shield (African Craton). South-western Tunisia has undergone several periods of deformation since Palaeozoic time, and the fracture zone is likely the site of recurrent orogenic activity, suggesting a long-lived fracture zone (Zouaghi et al., 2005). Subsequent tectonic activity occurred during the Oligocene–Miocene Alpine orogeny (Castany, 1953; Zargouni and Ruhland, 1981). This resulted in the uplift and unroofing of the Ben Younes and Orbata mountains, resulting in the present-day topographic expression. Thick southwest oriented sheets of alluvial conglomerates, sandstones and mudstones, representing turbulent streamflood deposits, lie along the flancs of the mountains in the region, and developed on poorly drained slopes in this tectonically active zone in an arid climate.

5. Alluvial substrate

The travertines and tufas studied developed on drainage slopes of thick faulted sheets of alluvial fanglomerates, sandstones and mudstones flanking the mountains in the region (Fig. 4). These siliciclastic rocks (mudstones, sandstones, and fanglomerates), derived from the pre-Pleistocene unroofing of the Ben Younes Mountain to the north of field area, were deposited in an alluvial fan system overlain by the travertine deposits (in Jebel El Mida) and have sharp contacts and truncations.

The alluvial fan deposits, ranging in thickness from 8 to 12 m, consist of fanglomerates distributed in paleostreams flowing from high pacts of Ben Younes. They form normally graded to stratified sequences indicative of wanning flow conditions. The boulder, cobble and pebble fanglomerates with sandstone facies-association consists of three distinct facies interpreted to have resulted from deposition on alluvial fans as turbulent streamflood deposits, sheetfloods, and debris flows. The fanglomerates, which have channelized bases, possibly with large flutes, show crude, thick and irregular cross-strata in gravel (some gravel clasts >1 m in diameter) with well developed clast-supported texture. Crude imbrications are also common. Paleocurrent data from the alluvial fan deposits, obtained from pebble, cobble and boulder imbrications, indicate that the fans were built by runoff that flowed southwards onto flatter terrains. In Jebel El Mida, these alluvial deposits interfinger with, and are overlain by, spring-fed carbonates. The fanglomerates show in places some stone tools attributed to a Villafranchian age (i.e., Late Pleistocene to Early Holocene) (Vaufrey, 1932; Burollet, 1956) (Fig. 4C and D).

6. Depositional morphotypes of travertine and tufa

6.1. General appearance

The travertines and tufas in the study area have a characteristic sedimentary appearance (Fig. 5). They occur as very irregular and chaotic bodies and display concretionary, amalgamated and botryoidal mounds, and yellowish tan to pale beige colours with local staining with iron oxide crusts (Fig. 5A). These carbonate precipitates are characterized by cavernous porosity (Fig. 5B) (voluminous pores exceeding 1 m diameter with various shapes and geometries) and locally important *in situ* brecciation (tufa) and collapse structures. The latter are attributed to abundant thermal waters and gases venting through various conduits, i.e., fissures and vents surrounded by carbonate mounds. The mounds on the northern slope of Jebel El Mida show more porous fabrics than those exposed on the uppermost surfaces of the Jebel El Mida hill, which are considered as thermal pools of first spring vents. Travertine and tufa field fabrics, including large and small scale morphologies and respective topographic positions, are summarized in Table 1. Definitions for the different facies and structures are in Table 2.

6.2. Travertine petrofacies

6.2.1. Travertine mounds

These narrow linear mounds are *in situ* accumulations found in fault zones along spring resurgences on elevated substrates (Fig. 6A). They usually occur as discontinuous and irregular masses. In the field area we counted from 12 to 20 irregularly spaced travertine mounds. They include small closely spaced mounds (20–50 cm high, 10–20 cm diameter across at their base) and large mounds (1–2 m high, 1–2 m diameter). On the northern slope of

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