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Quaternary Travertine Deposits, Al-Fat'ha Area, Iraq

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Abstract. Travertine crusts of Al-Fat'ha area, Iraq, are situated in a mountainous and tectonically-active area overlying a major subsurface fault. The deposits display morphological and petrographic features resembling those described from North America. Calcite spar crystals, comprising the bulk of these accumulations, are elongate and columnar resulting from aggrading neomorphism. Blue-green algae filaments obtained from these crusts clearly belong to two separate genera (*Phormidium* and *Schizothrix*). However, the most striking feature of these travertines is the presence of microtube-rich calcite crystals primarily occurring in the dark layers. The precursers of these microtubes are bacterial rods approximately 0.3 μm in diameter. The coexistence of bacteria and the blue-green algae *Schizothrix* in the dark layers, strongly indicate that the latter must have adapted to living in sulfide-rich water. Travertine crusts, therefore, are not restricted to forming in normal nonsulfide-rich waters, as has been assumed, but can form in harsh (sulfide-rich water) environments as well. In addition, the precipitation of either dark or light crusts could have been the result of the changing H_2S content in water.

Introduction

Travertine deposits exhibit a wide variety of textures and structures resulting from the accumulation of calcium carbonates in springs, lakes, swamps, and rivers. The morphology of these deposits and the geochemistry of waters in which they form have attracted the attention of many workers for several decades. However, detailed petrographic studies appeared only in the past several years [1–5]. Chafetz and Folk [4] recognized five major varieties of travertine deposits; terraced mounds, lake deposits, mounds or cones, fissure ridges, and waterfall or cascade accumulations.

Active and inactive sites of travertine deposits have been investigated in several parts of the world, particularly in the United States and Italy. Travertine is quarried in several locations in Italy and slabs are exported worldwide for use as ornamental stone. To the writers' best knowledge, this work represents the first attempt dealing with origin and petrography of waterfall travertine crusts in Iraq. In fact, the fine work of Chafetz and Folk [4] stimulated the authors to undertake this research.

Location and General Setting

Al-Fat'ha area is located 230 km north of Baghdad (Fig. 1). The River Tigris flows through two en echelon structures where the area of investigation is situated on the west bank of the river and adjoins the eastern margin of the southeastern plunge of Makhul anticline.

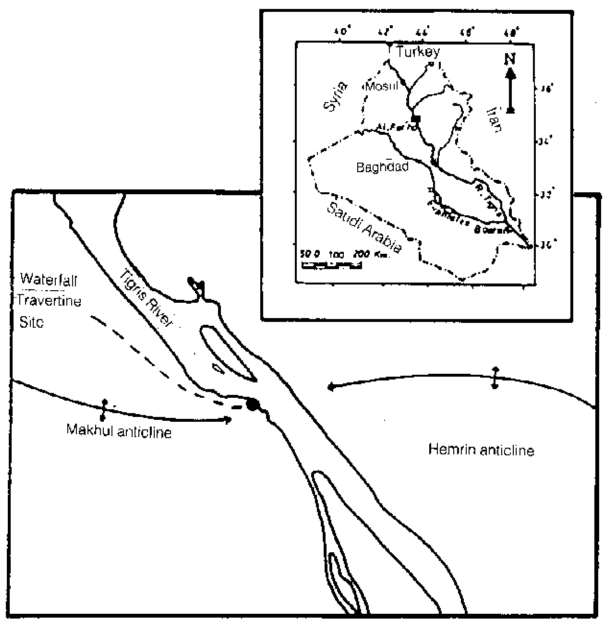

Fig. 1. Generalized map of study area

Several sulfur springs which are 50 to 300m apart from each other characterize the investigated area. All the springs are alligned in a direction parallel to the river bank. This phenomenon may suggest the existence of a subsurface fault as indicated by Al-Shaikh [6] and Naqash *et al.* [7]. The latter authors pointed out that major and minor tectonic events dominated the area during the Late Tertiary time. Barnes *et al.* [8] also recognized the relationship between travertine accumulations and seismically-active areas.

Temperature of spring water varies from 26 to 33 degrees centigrade and pH values range from 6.6 to 7.0.Spring water is rich in H_2S and oil seepages have been observed in a few locations.

Travertine accumulations, in the study area, overlie beds of Tertiary age as well as alluvial deposits. The majority of the deposits are inactive except for minor accumulations that are currently forming at the toe of the larger travertine deposits.

Fig. 2. Inactive travertine deposits along the southeastern plunge of Makhul anticline. Active travertine deposits are located at the toe of the older accumulations. Hammer for scale

Morphology

Travertine accumulations in the study area occupy a narrow strip, approximately 200m wide, alongside the southeastern plunge of Makhul anticline. These travertine deposits are largely inactive and their morphology, waterfall or terraced mounds, (Fig. 2) is analogus to those described from other locales [4, 5]. Though the general morphology may indicate a terraced mound (pers. comm., H. S. Chafetz [9] Department of Geosciences, University of Houston), these deposits lack the shallow pools and raised rims characteristics of mound complex. The height of the waterfall deposits may reach 20m in vertical thickness. Dry stream beds towering above the accumulations appear to be the ancestors of the present sulfur springs at the toe of the deposits.

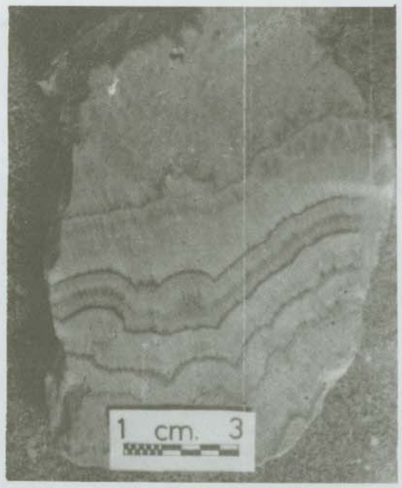

Fig. 3. Laminated travertine crusts showing alternate light and dark laminae. Layering is uniform and undulatory reflecting the morphology of the substrate

Most crusts are moderatly dense to porous and consist of alternating light and dark laminae paralleling the substrate (Fig. 3). Light laminae are the dominant with thicknesses ranging from 0.5mm to 4cm, whereas, dark layers are 0.5mm to 3cm thick. Aggregate crusts are also common and are indicating periods of drought or non-precipitation. Individual crusts range in thickness from a few millimeters to 20cm. Layering is normally uniform and undulatory, reflecting the morphology of the substrate. Laminae are consistent within a single crust. However, thicknesses vary considerably between crusts and correlation of laminae becomes extremely difficult.

Highly porous to friable crusts also are common in the vicinity of the waterfall deposits (Figs 4 and 5). These accumulations are believed to have been formed in cavities within the waterfalls [4].

Origin of Travertines

Travertines are considered a form of fresh-water carbonates. Analyses of travertines from many sites in the United States and Italy showed that they consist of low-magnesian calcite [4].

Fig. 4. Porous and crudely laminated travertine crusts possibly forming in isolated cavities within large waterfall precipitates

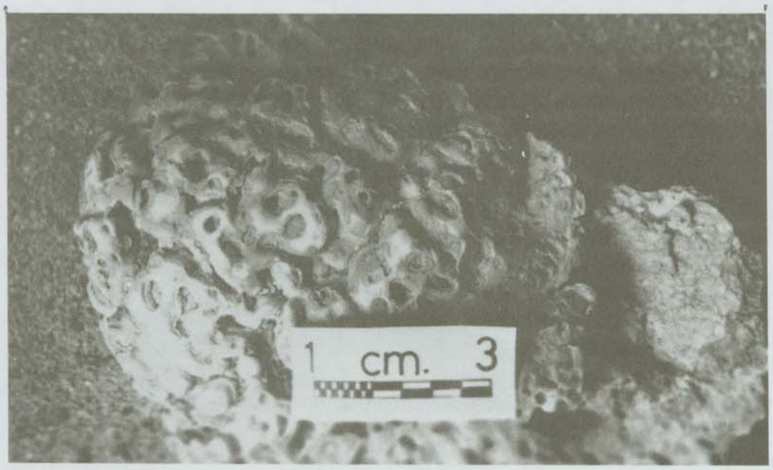

Fig. 5. Porous travertine showing swirled calcite laminae, probably having the same origin as the sample in Fig. 4.

Water percolating through subsurface formations attains the necessary limits of CO_2 and Ca^{++} for the precipitation of $CaCO_3$. The movement of water most likelv takes place along a subsurface fault in the study area. Agitation of water, photosynthesis, and water temperature greatly influence the concentration of CO_2. Precipitation of carbonate occurs when the amount of CO_2 in water has been lowered. Brock [10] remarked that water temperature, pH, salinity, and light intensity significantly influence the relative amount of organically-precipitated carbonate. The narrow range of these environmental controls determine the taxa that will grow. It has also been recognized that, in many cases, water chemistry is more important than temperature in controlling the kindof organisms that grow in spring water [4].

Generally, physicochemical precipitation dominates areas adjacent to spring orifices where organisms, such as blue-green algae, cannot tolerate the harsh environmental conditions, whereas, biochemical processes become increasingly important downstream [4]. However, in light of the work of Love and Chafetz [5] utmost care is warranted before ascribing an inorganic origin for travertines, especially waterfall travertine crusts.

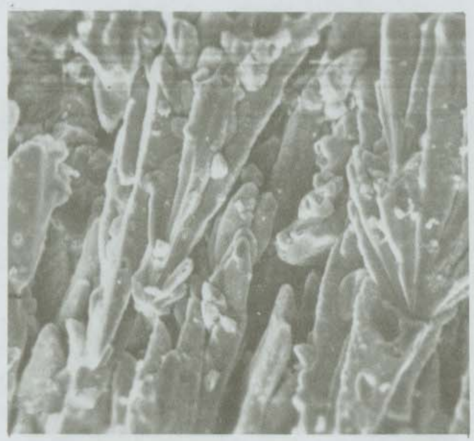

Fig. 6. SEM photomicrograph of a light layer revealing the "bushy" nature of fibrous calcite crystals. Scale equals 50 μm

Petrography of Crusts

Petrographic examinations of travertine crusts show that the longest axis of the calcite crystals are oriented nearly vertical but maintain the "bushy" texture characteristic of the slightly altered crusts (Fig. 6). Calcite crystals normally cross laminae boundaries where laminae spacing ranges from 0.03 to 1.0mm. Crusts consist of alternating undulatory light and dark layers. Light laminae are more abundant and relatively thicker than the dark crusts. Individual calcite fibres crystals, in the light layers, may reach up to 1.0mm in length and 0.1mm in width. On the other hand, calcite fibres crystals in the dark laminae are smaller and predominantly composite in character, though maintaining the general "bushy" appearance.

Further examination of thin sections show that cyanophyte occur in the micritic portions located between the calcite spar crystals. The blue-green algae, upon gentle etching of thin section in dilute HC1, exhibit a radiating structure with individual filaments approximately 80 μm long. However, upon dissolution in dilute HC1 of small fragments of crusts (both light and dark), blue-green algae become more evident and abundant in the solution. Blue-green algal filaments obtained from the light layers are predominantly cylindrical, unbranched with 6-10 μm in diameters. This blue-green algae probably belongs to the genus *Phormidium* as suggested by Love and Chafetz [5]. On the other hand, the alga recovered from the dark crusts, which most probably belongs to the genus *Schizothrix,* is smaller in diameter (approximately 3 μm).

In addition to the blue-green algae obtained from dissolution of travertine layers, gypsum crystals were also observed in the solution. These crystals are euhedral, 80 μm in size, and occur more frequently in the dark laminae. X-ray diffraction analyses of several light and dark crusts supported this finding.

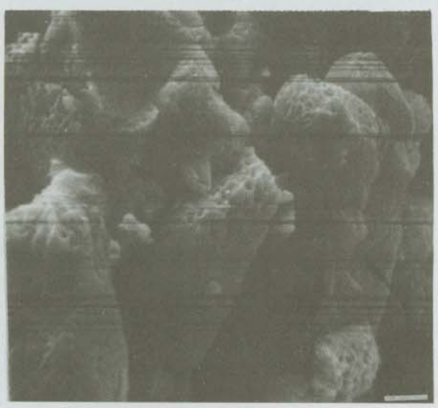

Fig. 7. SEM view of gently etched dark crust revealing microtube-loaded clumps. Sample is slightly altered as it lacks calcite cement. Bacterial rods are the precursers of these microtubes. Scale equals 10 μm

SEM analyses, on the other hand, of samples of travertine crusts (prepared by gentle etching in dilute HCl) revealed moldic microtubes (micropores of Chafetz and Folk [4]) with circular openings approximately 0.3 μm in diameter (Fig. 7). These microtubes normally exists in bulb-shaped calcite crystals (clumps) which are more abundant in the dark crusts.

Discussion

It is evident that these travertine crusts have undergone a moderate stage of diagenesis. Aggrading neomorphism is primarily responsible for transforming the microcrystalline calcite into coarse, elongate calcite fibres crystals. This process has been described by Schmalz [11] (in Bathurst [12]) and has also been documented in the Oklahoma waterfall travertine crusts by Love and Chafetz [5]. The presence of organic matter in the dark laminae of Al-Fat'ha travertines probably influenced the degree of neomorphism and resulted in the formation of smaller calcite crystals. However, Golubic and Fischer [13] related the difference in crystal size to the isolation of the microenvironment from the ambient water.

Since the average length of the spar crystals of Al-Fat'ha travertines is approximately one-tenth of that of the Oklahoma deposits; the authors believe this discrepancy is probably directly related to the low degree of neomorphism in the former. The slow rate of neomorphism in Al-Fat'ha travertines is mose likely ascribed to the presence of abundant sulfide-rich waters in the area which tended to slow down diagenesis.

Identification of blue-green algae in thin sections was quite difficult; however, upon dissolution in dilute HCl, blue-green algal sheaths became readily visible. The reason as to why the blue-green algae were identifiable after treatment with dilute HCl is probably due to the fact that calcite-filled blue-green algal sheaths are in optical continuity with the large calcite fibres crystals. Calcite, most likely, precipitated around the blue-green algal filaments and eventually encasing the latter. The precipitated calcite usually exhibits the barrel-shape nature of the blue-green algae (Fig. 8). The occurrence of two types of algae (*Phormidium* and *Schizothrix*) probably indicates changes in the chemistry of spring water. Chafetz and Folk [4] stated that "chemistry is probably the most important variable." We believe that the chemistry of the spring-fed water in Al-Fat'ha area has evolved from slightly sulfide-rich water in earlier times to highly rich in H_2S more recently. The chemistry of this water is directly related to the thick evaporite deposits underlying the travertine accumulations. This probably explains the presence of gypsum crystals in travertine crusts; though they are more abundant in the darker laminae. Changing chemistry of spring-fed water largely accounts for the uneven distribution of gypsum in the travertine layers.

Fig. 8. SEM photograph of a slightly etched light laminae showing calcite crystals encasing blue-green algal fibres of filaments. Scale equals 50 μm

The microtubes revealed by SEM photographs (see Fig. 7) most likely represent remnants of bacterial rods. The pore opennings have undergone enlargement both due to the decay of bacteria and the effect of the HC1 acid during the preparation of the SEM sample. Chafetz and Folk [4] reported that "the bacteria, in general, are poorly preserved; they readily decay, leaving moldic microporosity." They, also, were the first to demonstrate the importance of bacteria in constructing textures and structures in travertine deposits. The presence of both bacteria and blue-green algae in the Al-Fat'ha travertines may be due to the association of waterfall travertine crusts with the terraced mound deposits. Therefore, in light of the present findings, blue-green algae as well as bacteria can positively influence travertine crust formation. In addition, since more bacterial microtubes occur in dark crusts, then, the alga *Schizothrix,* which dominate such crusts, must have become adaptable to living in such environments. Finally, we suggest that the varying H_2S content in water may significantly favor the precipitation of either light and/dark travertine layers.

Conclusions

Waterfall travertines of Al-Fat'ha, Iraq, share some petrographic and morphological features with travertine crusts from other localities, particularly those in

Oklahoma, U.S.A. However, the former deposits are unique as both blue-green algae and bacteria influenced the precipitation of low-magnesian calcite layers. These findings have essentially expanded the realm of formation of travertine cursts to include streams fed by sulfur-rich springs.

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ترسبات ترافرتين العصر الرباعي، منطقة الفتحة، العراق

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ملخص البحث. توجد ترسبات الترافرتين في منطقة الفتحة الجبلية والناشطة تكتونيًّا حيث تقع الترسبات فوق فالق سطحي رئيس. تبين هذه الترسبات خواص بتروغرافية، وأشكالاً تشبه مثيلاتها الموصوفة من أمريكا الشمالية. تتكون الغالبية العظمى من هذه التراكمات من بلورات الكالسايت السباري. هذه البلورات تتميز بالاستطالة الناتجة عن العمليات التحويرية.

تعود خيوط الطحالب المتحصلة من هذه الترسبات إلى جنسين منفصلين هما *Phormidium* و *Schizothrix*، تتميز صخور الترافرتين هذه بوجود بللورات الكالسايت الغنية بالأنابيب الدقيقة، والتي توجد أساسًا في الطبقات الداكنة، إن مصاحبة البكتيريا والطحلب *Schizothrix* في الطبقات الداكنة تدل على أن الأخيرة قد تكيفت للعيش في ماء غني بالكبريت. لهذا السبب فإن ترسبات الترافرتين لا يقتصر تكوينها في المياه الاعتيادية، كما افترض سابقًا، بل يمكن أن تتكون في بيئات المياه الكبريتية القاسية. إضافة إلى ذلك، فإن ترسب كل من الطبقات الفاتحة والداكنة ربما يكون قد نتج عن تغاير كمية غاز ثاني كبريتيد الهيدروجين في الماء.