International Journal of Design & Nature and Ecodynamics
Vol. 19, No. 4, August, 2024, pp. 1447-1455
Journal homepage: http://iieta.org/journals/ijdne

Quaternary Travertine Facies and Paleo-Environments in Jordan's Mashara and Panorama Regions

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https://doi.org/10.18280/ijdne.190437

Received: 3 April 2024
Revised: 12 May 2024
Accepted: 20 May 2024
Available online: 28 August 2024

Keywords:
travertine, quaternary, paleoenvironments, Jordan Valley, dead sea, paleoclimate, paleoaquatic bodies

ABSTRACT

This study investigates terrestrial freshwater carbonate deposits from the Panorama (Dead Sea area) and Mashara sites (northern Jordan Valley), describing their facies and the paleoenvironments in which they formed. At the Panorama site, five distinct facies of travertine have been identified through field and laboratory investigations, namely: Phytoherm framestone, Shallow Lake fills in travertine, Lenses spherical pisoids, Paper-thin raft, and Iron rich travertine with paleosol facies. These facies are interpreted as lake fill travertine deposited in lake terrace environments from thermal mineralized water resembling Ma'in thermal springs. This is supported by the macro- and microscopic characteristics of the travertine and its fossil content. Additionally, the absence of typical freshwater fauna like gastropods or bivalves, which are common around normal water springs in Jordan, Furthermore, the travertine exposed at the Mashara site is primarily represented by two facies, Paludal travertine and Lithoclast travertine facies, with fossilized remains of organisms, including coated reed (*Phragmites sp.*), trees (*Tamarix sp.*), and shells of *Melanopsis sp*. These results suggested that the Mashara travertine was deposited in a well-vegetated marsh wetland with normal freshwater conditions. The presence of these travertine deposits and their fossil contents at both sites indicates formation during the Quaternary period, when the climate was wetter than today. This study highlights that Quaternary travertine deposits are valuable for reconstructing past environments and climatic conditions, providing insights into the paleo-environments and the hydrological history of the region.

1. INTRODUCTION

Travertine ($CaCO_3$) are non-marine calcareous sedimentary rocks, found deposited around calcium rich -springs, ponds, rivers, streams, and lakes [1, 2]. They are formed by chemical and/or biochemical carbon under wide range of natural conditions [3]. Travertines can be classified into two groups are meteogene travertines and thermogene (thermal) travertines [4, 5]. Meteogene travertines, also known as calcareous tufa are non-marine carbonate rich in plant remains of stems, leaves, woody remains and highly porous or spongy form, which are formed in cold water shallow environments (e.g., fluvial, lacustrine) by organic activities [4, 6, 7], while thermal travertine result from de-carbonation or magmatic degassing processes, when hot rocks react with carbon dioxide gas fluids leading to rapid precipitation of fabric travertine [8-12]. The tufa is often less cemented than thermal travertine. In addition, travertine deposits have various morphologies, includes spring mounds (sloping or terraced), fissure ridges (travertine deposited along faults or joints, dam deposits, cascades (waterfalls), Paludal (marsh wetland), lake-fill, and speleothems form which is travertine deposits accumulated in caves such as stalactites and stalagmites [13-15].

In Jordan, travertine deposits have been subject of several studies concentrating on their mineralogy, isotopes, geochemistry, commercial uses, material properties and microfacies. Such studies were useful also for the study of paleoenviroments, paleoclimate, paleohydrological systems and others. The petrographical and mineralogical properties of the Travertine in northwest Jordan at Deir Abu Said area were studied and identified to five facies of travertine which was formed by thermal fresh water springs [16]. The studied travertine consists mainly of plant impressions and microbiological remains with low Mg-calcite, K and low concentration of trace elements (Sr, Mn) and is enriched in Zn, Pb, Cu, and Mo component. Same researchers worked on the travertine rocks in Wadi Haufa, Wadi El-Arab areas [16]. They found that the investigated travertine has terraced-mound appearances with columnar-tube- like shapes, spherical-lobate, cylindrical structures and irregular bodies morphology. They also concluded that the travertine consists of CaO (35-39 wt%) and $CaCO_3$ around 71.2wt%, based on the geochemical analyses [16].

Moh'D and Abu-Hamatteh [17] studied the mineralogical and geochemical characteristics of travertine in Siwaqa area, and they concluded that the travertine is differentiated by occurrences of trace element components as a result of the chemical composition of the thermal springs, diagenetic processes and alteration of oil shale and marble. Later, Alhejoj et al. [18] studied the formation of Pleistocene travertine in

Siwaqa area, central Jordan, that originated from thermal spring water. Transportation of molted chaotic fragments in well stratified travertine beds has been interpreted as explosive geyser.

In addition, Ibrahim et al. [19] studied the mineralogy, stable isotopes and geochemistry characteristics of travertine deposits, that formed during Late Pleistocene from the three locations of Deir Alla, Suweima, and Az Zara area. The study results showed that the investigated travertines are mainly low Mg-calcite and minor quartz composition as dated by radiocarbon method. They concluded that the geochemistry and Isotopes results reflected dependence on the water temperature and water/rock isotopic exchange which is indicated by variable isotope (δ 13C and δ 18O). Recently, Makhlouf et al. [20] have continue the work on the same locations and deposits investigating microfacies of travertine deposits. They recognized the microfacies of Deir Alla travertines are micrite and spar groundmass, shrubs, crystalline crusts, a stromatolite-like structure, peloids, and cements while in the Suweima and Az Zara travertines include crystalline calcite rhombs and other composite scalenohedral crystals microfacies. Deposits of travertine and associated fossilized organisms observed at the Panorama and Mashara sites have not been studied by researchers. The objective of this work is to study travertine deposits in two locations of the Jordan Valley and the Dead Sea areas, specifically the Panorama and Mashara sites. Identify and describe the facies in these sites to clarify their depositional environments. Additionally, compare the studied fossils with their currently living equivalents to derive more about their environmental conditions.

1.1 Geological and tectonic setting

In the Jordan Valley and Dead Sea area different geological Formation are exposed from Cambrian to recent alluvial deposits. Within Cambrian, Jordan was part of Gowndwana, where the northern part was a shelf area. Colorful Paleozoic sandstone of Umm Ishrin sandstone Formation deposits was formed at early Cambrian time, which has been interpreted as fluvial environment with Trilobite [21, 22]. Deposits of Devonian, Carboniferous deposits and early Permian are not documented in Jordan but they could have been eroded due the sea level fluctuation and tectonic activities. As a result of the dramatic lifting tectonic activities during Late Eocene-Oligocene periods and after that the last regression of the Tethys within Eocene, Jordan became land and terrestrial erosion and deposition took place [23]. The Dead Sea Transform Fault created a large accommodation to accumulate sediments and water bodies mostly belonging to the Tertiary-Quaternary period. A series of lakes or shallow marine ecosystems most likely occupied the resultant depression. Alluvial deposits of gravel and conglomerate originating from weathered Cretaceous deposits from the Jordan rift mountain shoulders were laid down. Exposure of significant aquatic deposits of Miocene to Quaternary time, were deposited along the Dead Sea and Jordan Valley depression such as Tayba Formation, Al Qarn Formation, Samra Formation, and Lisan Formation [21, 24, 25].

Jordan is posited in the north-western area of the Arabian Plate that separated from the African Plate with the Dead Sea Transform fault system (DSTF) or also known as Dead Sea Rift along wadi Araba-Dead Sea-Jordan Valley in between. The study area is affected by the major structure of the Dead Sea extensional basin with its N-S sinistral strike slip movement of supposedly 107km. This structure has been interpreted as a normal tensional graben [26]. Along the faults associated with the main Jordan Valley Transform fault, water courses developed draining surface and ground water, where cold and thermal springs issued and are still issuing either along wadis to find their way to the bottom lakes of the Jordan Rift Valley or to form local travertine deposits. The Panorama area formed during the existence of Lake Lisan times the shore of the lake where springs directly issued in the lake depositing travertine. In Mashara it was another lake within the Rift valley along which shores the travertine was deposited.

In the Panorama area located East of the Dead Sea and north of Wadi Zarqa Ma'in lies at an elevation of about 180 below sea level and forms a part of the shoulder of DSTF shows major tectonic and structural features that affected the eastern side of the Dead Sea, where a branch of the Dead Sea major fault can be seen with flexure structures of the strata of Upper Cretaceous age. Mashara travertine deposits were also deposited on the shoulder of the northern Jordan Valley, connected to the Jordan Transform Fault along which series of ancient lakes formed. Mashara Travertines were deposited during the existence of the ancient Lisan Lake, the ancestral lake of the Dead Sea during Pleistocene time Ca. 80.000 to about 10.500 years ago [22-25].

2. METHODOLOGY

This study is to describe the morphology, depositional environment and fossils and trace fossils of faunal and floral species found in Quaternary travertine deposits of the study area, according to field, macro and micro-observations. Facies identification based on microscopic and outcrop characteristics of physical, chemical and biological contents. studied travertines by comparing the fossilized remains of organisms with their living relatives to identify the environment conditions which governed their formation. The collected travertine from the study sites were prepared for thin sections, X-ray diffraction (XRD) and XRF (X-ray fluorescence) in order to identify the microscopic characteristics and the elemental composition of the materials. All laboratory analyses were performed in the laboratories of the University of Jordan. The prepared thin sections from the travertine and associated sediments have been studied by using a S6 D Leica stereomicroscope (with magnification of 6.3x-40x) connected to a digital camera and Leica DM750 microscope to evaluate the texture, the microbial components, the chemical compositions and fossil content under cross-polarized (XPL) or plane-polarized (PPL).

The studied travertine outcrops are found exposed on the Dead Sea shoulders at the Panorama site (Figure 1). The Panorama site is located north of Zarqa Ma'in spa on the eastern side of the Dead Sea, just south of the Panorama Road (at around 600m). The Panorama site lies to the northwest of Zarqa Ma'in thermal springs site at an elevation of about -170 m below sea level. The other studied calcareous deposits are located in the northern Jordan Valley near Mashara Village.

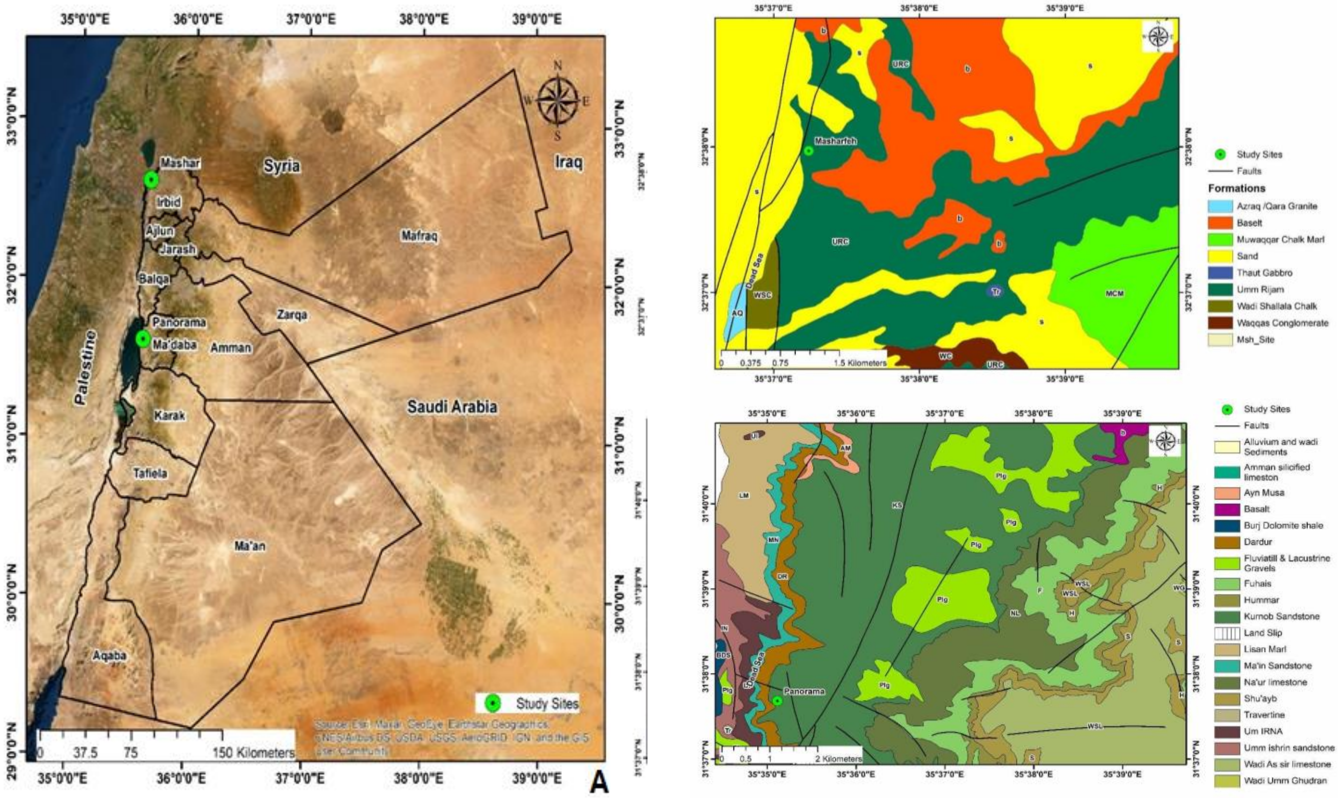

Figure 1. Location and geologic maps. A. Location map of the study; B. Map of Mashara site in the northern Jordan Valley showing geologic and structural features (Study site at Panorama, Dead Sea area)

3. FACIES DESCRIPTION AND INTERPRETATION

The investigated travertines in the course of this study are those from the Panorama site and from the northern Jordan Valley, Mashara area. Travertine was deposited alongside the Dead Sea Transform Fault in Wadi Arab, the Dead Sea, and the Jordan Valley areas during Quaternary times. Along the Dead Sea Transform Fault huge basins were created and were occupied by different water bodies such as lakes, rivers, streams and springs. In this chapter field outcrops description and the microscopic characteristics of the travertine from the study area are described and discussed.

3.1 Panorama travertine facies

The studied travertine from the Panorama area is characterized by its irregular appearances with high porosity and dense fossilized plant remains with about 3m thickness. The travertines are brown to tan-rusty colored, especially when weathered. Biological traces are preserved in travertine deposits, which belong to different groups including algae, cyanobacteria, lower and higher plants and specially, plant imprints of trees and shrubs containing trunks, twigs, and leaves impression. In this site four types of travertine facies are defined that include, Phytoherm framestone, shallow lake fills in travertine, lenses pisoids facies, paper-thin raft facies, and Paleosols facies as describe below:

3.1.1 Phytoherm frame stone facies

Description: This facies is composed of fossilized plant-dominated travertines. It is a dense, irregular, creamy to rusty colored facies with fenestral porosity (Figure 2(a)). It is autochthonous facies containing thick deposits of travertine of about 3m in height and rich in stromatolitic laminations and calcified gas bubbles (Figure 2(b)). The weathered travertine of the top layer processes conical domed like morphology.

The trees and shrubs recognized in the field are based on their trunk, leaves, and twigs (Figures 2(c-d)). Coated reed travertines occur very commonly in these deposits (Figure 2(e)). Rhizoliths traces varying in appearances such as cylindrical or irregular, empty, solid, vertical are present in this location. Casts of roots of grassy-like plants, trunks, and branches are common in the Panorama travertine (Figure 2(f)). Moss remains encrusted by travertine are shown in (Figure 2(h)). In addition, plant molds are found such as stem and root hollows infilled by carbonate sediments (Figure 2(i)).

Dense Fossilized microbial mates or Stromatolitic laminations with tabular, wavy and dome-like shapes and fenestral porosity, are found within the studied travertine and surrounding plant remains (Figure 2(j)). Microscopic characteristics of these travertine are fossilized filamentous algae mate with laminated and conical shaped are defined by alternating micritic and lighter sparitic calcite layers (Figure 3(a, b)). Also, precipitating-type of stromatolite showing laminae of radiating crystal fans with large porous travertine and microbial remains surrounded by aragonite fibrous (Figure 2(c-f)).

Discussion: Aphytoherm indicates an autochthonous travertine facies as defined by Pedley [27], are carbonate freshwater reefs made by autochthonous petrification of organisms such as fungi, bryophytes, cyanobacteria, fungi, and algae. Leaf molds of higher plants coated with travertine are also found. They are similar to recent trees as observed to grow around springs in Jordan. In modern springs in Jordan willows (*Salix sp*.), Poplar trees (*Populus euphratica*), coniferous (pinacae), eucalyptus (*Eucalyptus globulus*), palm-tree (*Phoenix dactylifera*), and Tamarix (*Tamarix jordanensis*) were found [28-30]. On other hand, dense occurrences of coated reed within the travertine indicate that reeds were common in this environment. They occurred at the margin of this shallow lake filled with travertine as indicated by the presences of reeds, trees and grass which usually grow at the margin of water bodies. In the present time, reeds grow around springs such as *Arundo donax* grow near freshwater, cold or hot water springs [31, 32]. Also, *Juncus arabicus, Polypogon monspeliensis, Cyperus laevigatus, Schoenus nigricans* are documented to grow around water bodies in Jordan [30], especially *Cyperus laevigatus* reeds grown in thermal water (with up to 60°C) found in Zarq Ma'in thermal springs [30]. Rhizoliths are fossilized root traces of plants found in the sediments. Klappa [33] described different types of rhizoliths: Casts (infilling of voids), moulds (voids), tubules (cemented cylinders around roots), petrification (mineral impregnation of plant tissue) and rhizocretions ('pedodiagenetic' mineral accumulation und roots). Rhizoliths are formed in the travertine.

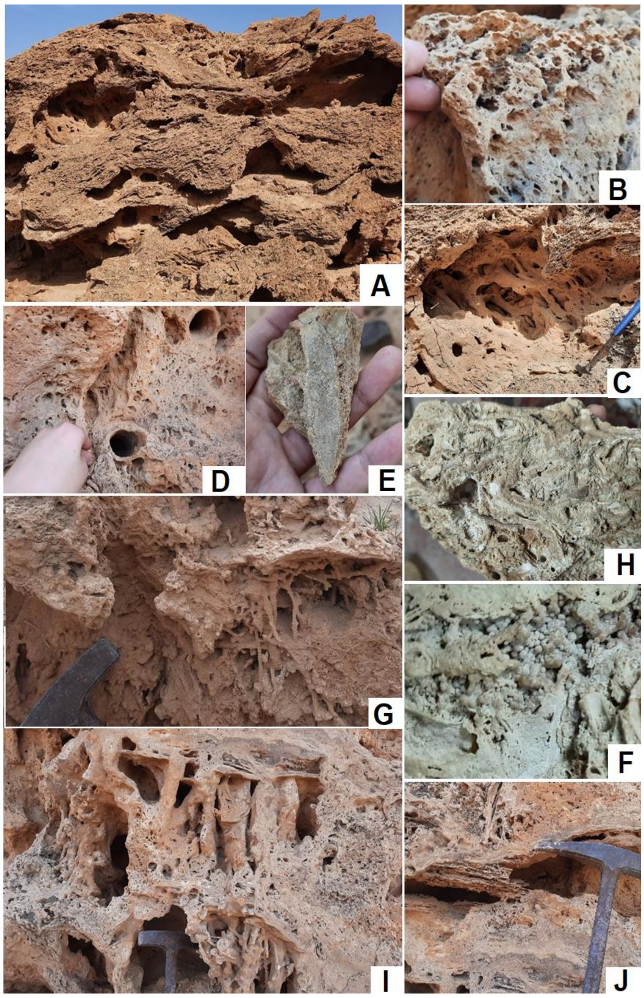

Figure 2. Macromorphologic features of aphytoherm travertine in the Panorama area. A. Field view of the irregular travertine morphology in the Panorama area; B. Abundant lithified gas bubbles in the travertine rocks at the same location; C. Travertine coated plants remains with fenestral porosity. D. Rounded reed casts associated with coated gas bubbles; E. Field specimen showing a calcified leaf F. Moss remains coated by travertine; G. Branched root terraces encrusted by travertine; H. Travertine rich organic remains with fossilized cyanobacterial crust; I. Crowded travertines rich in plant remains; J. Outcrop photos showing the plant remains with microbial mate crust

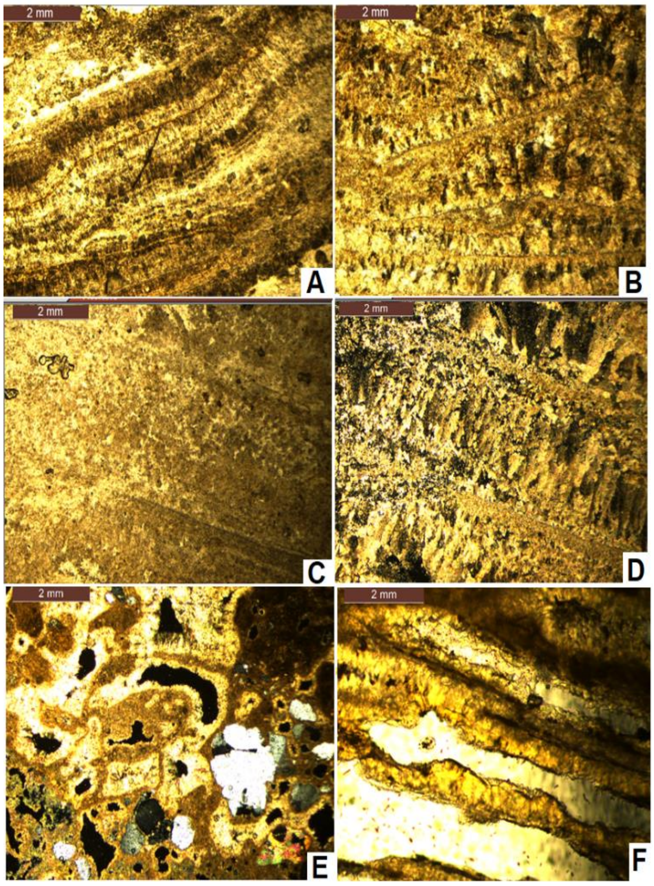

Figure 3. Characteristics of the microscopic aphytoherm facies at Panoroma site. A. Thin-section photomicrograph of laminated (Stratomatolites) and filamentous algae mate, (under cross-polarized (XPL); B. Thin-section photomicrograph of domal stromatolites with lamination defined by alternating micritic, darker and lighter sparitic calcite layers (PPL); C. Microscopic characteristics of precipitating-type stromatolite showing laminae of radiating crystal fans under plane-polarized (PPL) light; D. under cross-polarized (XPL)); E. Thin-section photomicrograph of porous travertine with microbial remains surrounded by aragonite (sparit: coarse carbonate) fibrous. (Cross-polarized (XPL) view); F. Thin-section photomicrograph of travertine with fenestral porosity (white color), cross-polarized (XPL)

Lithified gas bubbles formed by microbial activities are found on the top of cyanobacteria surface which are supposed to result from photosynthesis process but also can be found between plant remains or as result of rapid precipitation of travertine in hot spring areas. Laminated crust of cyanobacteria with planar and dome form also recognized in the active thermal springs of Zarqa Ma'in. Also cone or dome shaped travertine were observed in Zarqa Ma'in. This indicates that the fossil travertine was deposited in similar conditions from thermal springs.

3.1.2 Shallow lake fills in travertine facies

Description: This facies is characterized by dense thin layers of carbonate mud with about 10cm in thickness. Shrub-like travertine, a few millimeters to a few centimeters thick are found associated with polygonal cracks of desiccation marks (Figures 4(a-d)).

Discussion: Shrubs are bounded by the micritic layer. The shrubs, identified by Chafetz and Folk [34] started as branches that radiated upward to form colonies. Guo and Riding [7] also described shrubs as little bush-like structures that are mainly common precipitations on parallel to subparallel surfaces and later, Chafetz and Guidry [35] divided shrubs into "bacterial shrubs", showing very irregular forms, "crystal shrubs" and "ray-crystal crusts" displaying regular geometric patterns. The contact between algal remain and clastic deposits is clearly observed as shown in Figure 4(e). These facies are autochthonous and indicate shallow lake fill with travertine where, during summer time the water level drops and the shrinkage of the sediments left behinds the mud crack marks. Shurp-like travertine with desiccation marks represent the former shoreline of shallow lake travertine. During the winter season with increasing lake level and fluvial detritus input led to the deposition of carbonate mud, which cracks in the dry season.

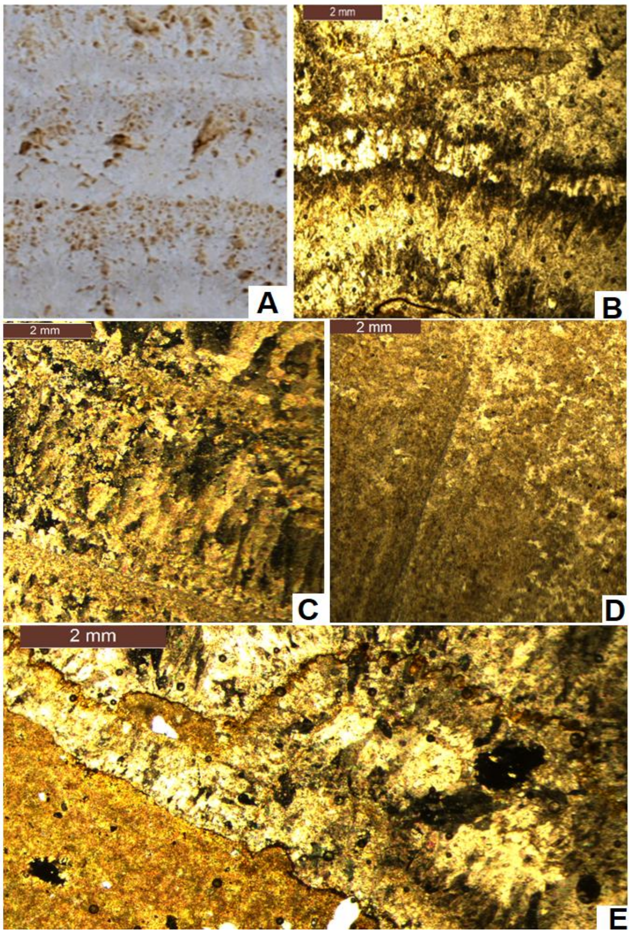

Figure 4. Main characteristics of the shallow lake fills in travertine facies in the Panorama site. A. Field photo showing luster of small stromatolites with bush-like appearances; B. Petrographic thin sections of Sharb-like stromatoltic travertine bounded by the micritic layers (XPL view); C. (XPL view); D. Thin-section photomicrograph of stromatolite showing laminae of radiating calcite crystal fans (PPL); E. Thin section photo showing the contact between algal mate and intra-clastic (micrite)

Notes: It is typical that algae cover the micrite fenestral porosity under cross-polarized (XPL).

3.1.3 Lenses spherules pisoids facies

Description: This facies is defined by coated spherical grains of pisoids within the travertine deposits (Figure 5(a)). They are milky brown colored, rounded, irregular and concentrically laminated with knobby external surface morphology, 3 to 6mm in diameter, containing micrite (Figure 5(b)).

Discussion: Pisoids are small concretionary grains of calcium carbonate that are common in travertine deposits, but some contains iron or quartz [7, 34, 36-38]. Concentrically laminated pisoids are formed under turbulent water flux and high energy environment [7, 34, 39]. Pisoids coated grains are originated from bubbling hot or thermal waters in carbonate-saturated and fast CO_2 degassing [40]. The presence of concentrically laminated pisoids suggests that such travertines are deposited at the terraces of small lake under low water turbulence and high energy. Also, the amicrobial origin of pisoids is indicated by the knobby surface appearance. The mineralogical composition of the pisoids is quartz and calcite, based on the XRD measurements.

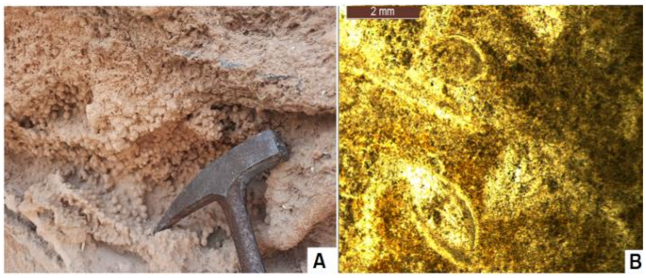

Figure 5. Weathered lenses spherical of the pisoids facies at Panorama location, east of the Dead Sea area. A. Selected field photos showing the rounded small pisoid grains with ball like shaped; B. Photo of thin section showing microbialite microstructures in the pisoid (PPL view)

3.1.4 Paper-thin raft facies

Description: This facies is characterized by the occurrence of sheet-like travertine covering lithified gas bubbles found in the Panorama area (Figures 6(a, b)). These deposits have rusty colors with thin laminated travertine, ranging from a few cm to 50cm in thickness. It's mainly composed of calcite.

Discussion: Raft travertine is autochthonous facies that can be deposited in stagnant pools, around spring orifices and fissure spaces filled by hot waters and cave pools [3, 10, 40, 41].

These facies indicate at still water bodies with quiet and low energy that allowed the precipitation of carbonates from the water because of CO_2 outgassing causing increases in the carbonate saturation of the spring water. Degassing process produced gas bubbles that later on become calcified and covered by carbonates that can be originated by the action of a biotic component in the environment. Lithified gas bubbles are found below the sheet like travertine deposits in the Panorama sites.

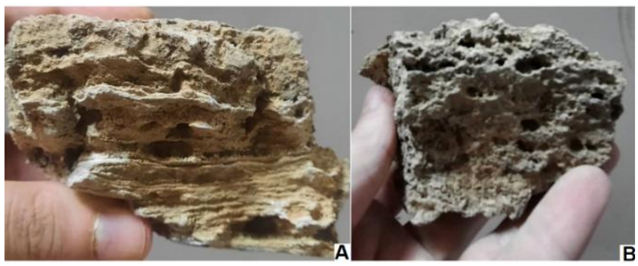

Figure 6. Paper-thin raft facies at the Panorama site. A. Paper-like travertine associated with fossilized gas bubble; B. Calcified gas bubbles travertine below the paper-thin raft

3.1.5 Facies of iron-rich travertine and Paleosols

Description: This facies is composed of black colored travertine with orange to reddish colored Paleosols containing mud carbonate detrital. Travertines show porous laminae texture (Figure 7(a)). Traces of long microbial activity are preserved on the surface of the travertine with small, rounded bubbles like structure. The layers are mainly composed of calcium carbonate (calcite and aragonite) and Iron based on XRD measurements.

Discussion: Iron rich travertine observed in the Panorama location seems to have resulted from depositions from the mineralized thermal water (Figure 7(b)). Paleosols are ancient soils that formed during weathering process. The orange and red colored Paleosols reflect subaerial conditions of atmospheric redox conditions. Palaeosol formation is generally encouraged by desiccation and biological activities [7, 34, 41, 42].

The small rounded structures are formed by microbial activities.

The absence of freshwater fauna such as gastropods or bivalves which are common around normal water spring in Jordan supports the above interpretation. Comparison fossils remain associated within Panorama travertine with modern living organisms provides information about their environmental conditions, for examples thick crust of cyanobacteria occur Zarqa Ma'in resembles fossilized laminated algae mate or stratomatolites in the Panorama site (Figure 8(a)). The trees and shrubs recognition in the field area based upon leaves, twigs, and branches reveal the presence of palm, tamarix and reeds. Regarding reeds, large colonies of *Cyperus laevigatus* occur near Zarqa Ma'in mineralized thermal spring which are similar to preserved reeds observed in Panorama travertines (Figure 8(b)). Coated leave remains have similar appearances to Willow leaves *Salix sp.* (Salicaceae family) with narrow lance-shaped (Figure 9(a, b)).

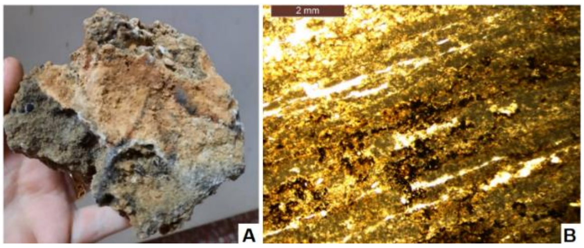

Figure 7. Facies of Iron-rich travertine and Paleosols. A. Field hand specimen showing Iron-rich travertine with orange Paleosols at the Panorama site; B. Petrographic thin sections of the porous laminae texture showing stratomilite with elongated pores and black reddish iron oxides deposits in the Panorama sites (XPL)

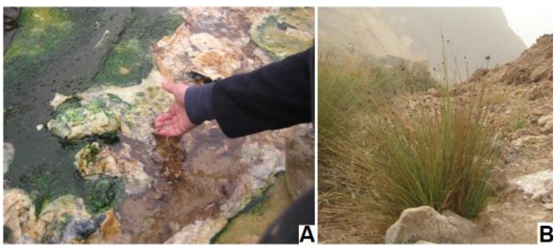

Figure 8. Modern organisms living in or near Jordanian thermal springs. A. Thick crust of Cyanobacteria from Zarqa Ma'in; B. Large colonies of Cyperus laevigates herb occur near Ma'in mineralized hot spring

Figure 9. Comparison of living plants and the fossilized remains. A. *Salix sp.* tree leaves found around freshwater springs in Jordan; B. coated leaf with narrow lance-shaped found in Panorama travertine

3.2 Mashara travertine facies

The largest travertine deposits are found on the hilly land near Mashara Village in the northern Jordan Valley. In the field, we defined and described facies as follows:

3.2.1 Paludal travertine facies

Description: The facies is mostly composed of carbonate mud with stromatolitic coated tree branches and reeds, as well as shells which are consolidated to form these facies (Figure 10(a)). It is autochthonous facies abundant with lithified reeds and trees' remains which are branched and extend vertically upwards to reach about 20cm (Figure 10(b)). Wavy form of stromatolite is found within Mashara travertine (Figures 11(a, b)). Stromatolite lamination under microscope is defined by the alternations of clay-rich laminae and calcite laminae (Figures 11(c, d)). Also fresh water mollusca *melanopsis* are observed in this facies. These facies consist of calcite based on XRD measurements.

Discussion: The plant stems and branches upward in the travertine precipitations are generally studied as "reed" type travertines [7]. Fossilized stems and roots are similar to the reeds *Phragmites* and *Tamarix* which are common around normal spring water in Jordan. Living gastropod *melanopsis* are found in or around fresh water bodies with normal water conditions in Jordan which are also observed within paludal travertine (Figures 12(a, b)). These facies are well vegetated, clam, normal water and fresh water wetland drainage that indicates marshes environment. The presences of carbonate mud, coated reed lithified tree branches, and *melanopsis* fossils provide further evidence for fresh water marshes' environment.

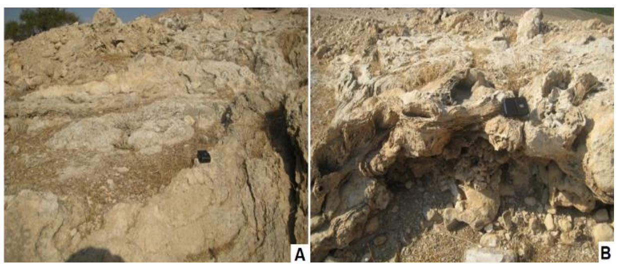

Figure 10. General view of Mashra travertine deposits. A. Exposed travertine of marshes' deposits in Mashara area, Jordan Valley; B. Field photo showing crowded reed *Phragmites* cast encrusted by wavy stromatolitic travertine, Mashara, Jordan Valley

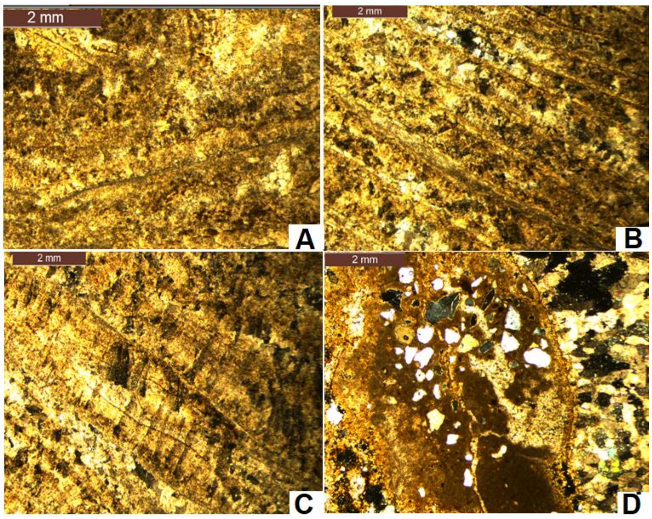

Figure 11. Thin-section photomicrograph of Mashara travertine, all photos under PPL. A. Thin-section photomicrograph showing wavy shaped stromatolitic structure. B. Microscopic laminated structures of the stromatolites. C. Thin-section photomicrograph of representative stromatolite lamination, defined by the alternations of finer, more clay-rich laminae (dark layers), and lighter calcite laminae. D. Thin-section photomicrograph of clastics in micrite (fine grains of calcite indicate low energy and quite water) that later changed into calcite cement deposits (right hand)

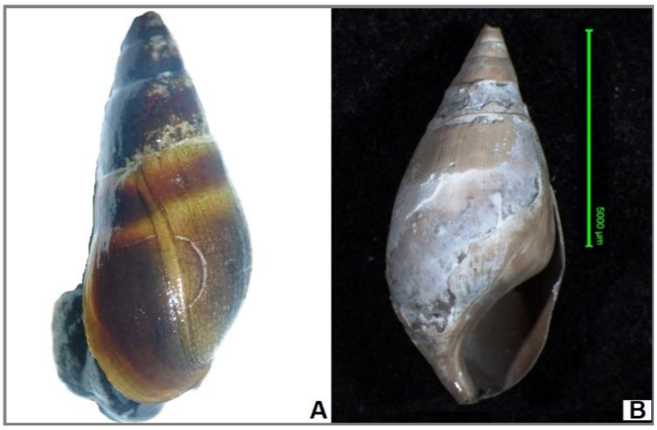

Figure 12. Comparison of Living molluscan and the fossilized gastropods in Mashara travertine. A. Modern Melanopsis found around Hisban spring; B. Melanopsis fossils from Mashara travertine deposits

3.2.2 Lithoclast travertine facies

Description: The facies is dominated by travertine clasts associated with poorly sorted pebble, gravels, conglomerates and clay. The lithoclast travertines facies is brown to light gray colored and rich in skeletal grains including calcified branches and roots of reeds and trees fragments (Figure 13 (a)). Also shells of mollusca fossils belonging to *melanopsis* of class gastropod are observed. Layered coated grains of oncoid deposited by coating microbes which are composed of lithoclastic nucleus are recognized within these facies.

The Oncoid size reach 1mm in diameter with elongated shapes. The microscopic characteristics of this facies are of poorly sorted clastic sediments consisting of feldspar with cleavage and quartz with cyclic or graded bedding which reflect the water energy and depositional environment (Figure 13(b)). The depositions show that during the warm climate aragonite and algae were deposited while during rainy wet conditions clastic grains are observed. The monocrystalline quartz grains with wavy and non-wavy extinction and the feldspar with cleavage may indicate the source rock is an alkaline granitic orthoclase. The cements between clast grains contains calcite with dolomite which indicate secondary diageneses resulted from groundwater rich in Mg and Ca ions. The rock is highly porous as a result of dissolution processes.

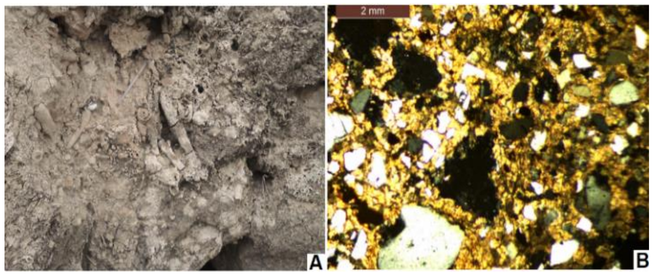

Figure 13. Facies of Lithoclasts travertine in Mashara. A. Lithoclasts travertine with bioclasts of cylindrical mold reed travertine fragments, Mashara, Jordan Valley; B. Thin-section photomicrograph of clastic, poorly sorted clastic grains, feldspar and quartz (XPL view) from Mashara site

Discussion: These facies formed as a result of strong erosion by flood water during the rainy winter seasons, when pieces of upstream travertine deposits were eroded and accumulated downstream in the marsh areas. Lithoclast derived from the carbonate rocks from around the study site. The lithoclasts and biotic fragments are eroded and deposited in marsh and subsequently cemented together by carbonate water to form the lithoclastic facies.

4. CONCLUSIONS

In conclusion, studying terrestrial limestone deposited in water bodies can be an excellent tool to assist in understanding the paleo-environment, paleo-hydrogeology, and paleo-climate that prevailed in ancient times. By examining the travertine deposits and their fossil content, as well as comparing them with modern living organismes (flora and fauna) found around springs provides a historic record for paleo-environmental conditions. Calcified plant remains in the studied travertine such as coated leaves that was observed in the Panorama travertine deposits are similar to willow leaves *Salix sp.* (Salicaceae family) with narrow lance-shaped leaves that are still growing around spring water in Jordan so that the lithified leaves can give accurate information about the type of bushes or trees that were present in Pleistocene times.

Also, the coated reed travertine that was found in the Panorama site could represent *Cyperus laevigatus* reeds that grow in thermal (with up to 60°C) mineral alkaline environments which are found in Zarqa Ma'in thermal springs. In Mashara, cylindrical reed traces are similar to reed *Phragmites* and bushes *Tamarix* which is common in the travertine present on the edges of the normal water springs. Moullsca *melanopsis* observed in Mashara travertine indicate normal freshwater deposits when compared with the living *melanopsis* which lives in cool, fresh, and active water bodies in Jordan.

Five facies of land freshwater limestone are documented from the Panorama site containing Phytoherm framestone, Shallow lake-fills in travertine, Lens spherical pisoids facies, Paper-thin raft facies, and Iron rich travertine with Paleosols facies. These facies are suggested lake-fill travertine deposited in a lake terrace environment from thermal mineralized water resembling that of Zarqa Ma'in springs. The absence of freshwater fauna such as gastropods or bivalves which are common around normal water spring in Jordan supports the above interpretation.

In Mashara site, outcrops are mostly represented by Paludal travertine Facies and Lithoclast travertine facies. Mashara Travertines are dominated by coated reed remains and shells of gastropods fossils. Field observations show that these facies were deposited in water well-vegetated march wetland with quiet normal fresh water environment.

Pervious works on the area document that ancient humans (e.g., *Homo sapiens*) had lived around water bodies along the Jordan Valley during Pleistocene time so that studying travertine deposits can give information about the ancient human migration and Quaternary water bodies relationships. The studied travertine had been deposited during Quaternary based on fossils remains in the travertine deposits of the two sites. The travertine deposits distributed along the area of the Dead Sea Transform Fault as found in Mashara, Deir Alla, Aramisha, Suweimau, Panorama, Zara and others are the result of freshwater bodies fed by groundwater originating from the Highland aquifers during Quaternary time when the weather was wetter than today.

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