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Research Paper

The travertines of Irdi of Ziz wadi (south east of Morocco): An example of hydrothermal process- Facies of bioconstructed carbonates

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ABSTRACT

The outcrop of the travertines of Oued Ziz is located about 10 km from Erfoud on the national road number 13 in the South-East of Morocco. It extends along the Wadi Ziz, it appears as a sedimentary complex, which consists of conglomerates and calcareous sandstones as mature travertine deposits. Travertines interested in this study were mentioned by Margat (1962) in the hydrogeological map of tafilalet among the Quaternary lake limestones. In 1971, Chamayou and Ruhard signaled them as markers of the southernmost quaternary alignment of neotectonic deformations, in relation to the tectonic of the southern Atlas furrow. But these travertines have never been the subject of a detailed study as regards their internal structures and their mode of genesis. The genesis of this travertine is controlled by the carbonate inlays with hydrothermal processes of water in a continental environment. The main objective is to highlight the genetic processes responsible for the construction of travertines (Source & Chemistry of water, nature of encrusting biological species) and their interpretation as indicators of neotectonics associated with the circulation of hydrothermal fluids. Generally, this travertine always shows a laminar structure with a double vision: clear and dark. The stratifications are planar, slightly wavy. Fieldwork and microscopic studies of travertines suggest that it is a sedimentological facies with a biological-type construction in which the combination of algal action and bacteria is evident with a precipitation of calcium carbonate in a favorable hydrothermal circulation environment. In addition, these travertines prove to be interesting as ornamental rocks, given their very sought after facies in decoration in the building sector, in a region with particularly poor economic resources.

Key words: Travertines of the Ziz Wadi, hydrothermal processes, continental environment, biological type.

INTRODUCTION

The Travertines of the Ziz wadi represents one of the various landscapes of Tafilalet. It appears in the north of Erfoud, in the sector of the Radier of Ziz, located on the road between the cities: Errachidia and Erfoud (Figures 1 and 2), in the South East territory of Morocco, called pre-Saharan region.

The area studied belongs to the northern of the plain of Tafilalet, which takes part in the southern flank of the Cretaceous basin of Errachidia-Boudnib, the widest domain of the South Atlas furrow, whose average altitude is between 1000 and 1100 m, constituting thus a good geomorphological landscape (Figure 3).

The region is subject to a presaharan climate, it is one of the most continental regions of Morocco by its position, as it is surrounded in the North by the High Atlas and in the West and the South by the Anti Atlas.

The annual rainfall regime is characterized by two wet seasons of autumn and spring, separated by a brief dry

Figure 1: The situation of travertines of Ziz wadi (Satellite image, Source: https://www.bing.com/maps).

Figure 2: Exposure of travertine deposits on both sides of the road linking Errachidia-Erfoud.

Figure 3: Panoramic view of the site of the decorative rocks.

winter and a long summer season marked by drought.

Travertines are continental formations limestones formed under various conditions starting from sources of water which vary considerably according to the natural conditions (Rousseau et al., 2008).

Travertines are formed with room temperature (Saltlik Spring, California; Amundson and Kelly, 1987) and others starting from a hot spring (various Japanese sources; Kitano, 1963). The CO_2 pressure can be very low (Westeroff, Germany; Jacobsonet and Usdavski, 1975) or very high (Saltlik Spring, California, Amundson and Kelly, 1987). The majority of travertines shows an alternation of clear and dark bands, and has a calcitic composition with aragonite.

Travertines have a great interest on the knowledge of the climatic hydrological and vegetable old environments as that of the morphodynamic, structural and even neotectonic evolution (Macklin et al., 2002). In the arid areas, according to their modes of formation (Freytet and Verrechia, 1989), they are regarded as witnesses of phases wet (Butzer et al., 1978 ; Nicod, 2000), the U/Th datings were carried out by classical spectrometry alpha, in the series of Irdi, which were treated by mass spectrometry with thermal ionization (TIMS) (Boudad et al., 2003).

There are travertines of hydrothermal origin related to water increase of deep tablecloths due to fracturing. The travertine formation currently continues in the bed of the Ziz wadi in Irdi, which does not imply however that these constructions can reflect the current climatic conditions of piedmont atlasic, where precipitations annual averages are only of 130 mm with Errachidia.

Certain bacteries were searched such as the species recognized in the precipitation of fresh water carbonates: species of the *Bacillus*, *Brevibacillus*, and *Flaviobacterium*.

GEOLOGY

The study site corresponds, in part, at average to Ziz wadi, also called intermediate Basin. It is part of the central depressed zone of Errachidia-Boudnib Basin, of mainly cretaceous sedimentary infilling of tabular form, often surmounted by quaternary desert pavements (Figure 4). The altitude varies between 1200 m in the North and 740 m in the South, giving the valley of Ziz its profile as slightly sloped towards the South.

The stratigraphy of the study area in the outcrop seems simpler: it is a paleozoic basement composed of sandstones and green schists in Cambrian intercalations, surmounted by Micaceous sandstones of Ordovician age, the Silurian is lacking in the study area, the Devonian consists of limestones constructed from a reef platform, surmounted by shales with Trilobites, the whole is covered by green schists and sandstone schists of the Transgressive Visean.

The covers begins with the argillites with purplish red evaporites of the Triassic intercalated of tholetic basaltic complex, and then arrive from limestones to anhydrite of Lias, with sandy passes towards the top with continental seal and which are arranged in the Infra-Cenomanian. The Cenomanian is made of clay sandstone with developed levels of gypsum surmounted by epicontinental red clay sands. The Neogene is frankly lacustrine with marly and conglomeratic facies, sealed by pebbles. It should be noted that the travertine facies, which this time presents an undulating stratification, is difficult to observe, because of the mobility of the sandy dunes which invade the bed of Ziz wadi region.

The structure of the area of Errachidia-Boudnib studied shows a vast syncline, whose southern flank is largely inclined towards the north. It occupies an intermediate position between two major geotectonic units: the High Atlas in the North and the Anti-Atlas in the South.

The structural evolution of the region is characterized by two major compressive periods related to the Hercynian and Alpine cycles: Hercynian and Atlasic (Oligocene). Those two orogens are separated by the triasico-lisasic atlas rifting (Costagliola and Belkhir, 1981).

Structural architecture continues to the present (Lavilel, 1978), numerous studies have revealed neotectonic activities accompanied by a very significant seismic activity (Ambroggi, Choubert, Gauthier and Hindermeyer, 1935, Margat, 1953 Du Dresnay, 1954). These neotectonic activities date from the Saletian-Amirian.

Quaternary deformations have been at the origin of the individualization of the South atlas staked by the sedimentation of the travertines which extend from the Radier du Ziz to the north of Erfoud (Lacustre limestone at Onyx) (Chamayou and Ruchard, 1971).

On the scale of the outcrop, the travertines of Ziz wadi are in the form of often sub-tabular slabs packed in the detritic and calcareous rocks of the Quaternary old. This travertine system is more developed at the level of the Ziz Bridge, which is the downstream part of the Ziz Valley, and forms a table perched in relation to the bed of the wadi, reaching in places up to 20 m high.

Karstification is important, with many resurgences, the most important being called "Ain El Ati" located about 4 km north from the Ziz Bridge. The flow results from a rainfall regime and partly underground (artesian water table, Amharraf, 1996).

The karstified limestones of the Turonian developed in the limestones massif of the Cretaceous basin form the upstream of these formations with travertines. These extend superficially for about 8 km^2, over an infra-cenomanian substratum formed of red sandstones with intercalations of gypsiferous marls. (Note that the presence of gypsum in karstified or crossed formations increases Ca^{2+} in the water system, and therefore the travertine potential).

The flaky limestones are crystalline, often tufted (spongy and porous). Their mesostructures show many features of karstification and diagenesis.

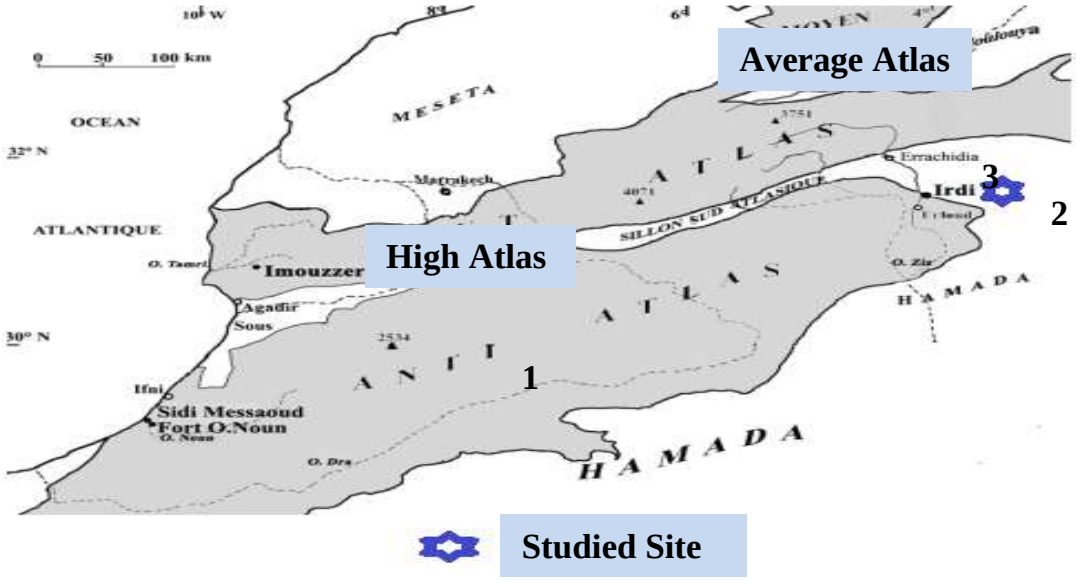

Figure 4: Place of travertine studied formations in local geology and location of mountains and studied site.1: mountain; 2: studied site; 3: main town.

In the absence of other karstification indices (subvertical fissures, macro-microscopic cavities, sometimes stalactic, indicative of active dissolution-precipitation), the basin shape of the karstic cavities with travertines can be confused with the chenalised and lenticular form Alluvial travertines complexes.

It should be noted that the travertines behave like a mass which gnaws in sandstone limestones of very high porosity, and seems to be organized as well in horizontal, vertical, subvertical and inclined structures. We also observed the bulging of certain travertine masses that appear as mounds on the surface.

These observations were the starting point for a hypothesis of travertinisation by warm waters of deep origin very mineralized, not to mention the striking character of this facies which is laminar most likely corresponding to pulsating crusts or an influence of the biotope (Encrusting species, influences of the physico-chemical factors of the environment, seasonality ...), or the combination of the two?

In any case, the spatial arrangement of these travertines indicates that most of the deposit was made by a ground water circulating in the rock in place, in particular in the existing cavities and in the zones of weakness (fault, interbanks, cracks, pores ..) of this rock.

MORPHOLOGY

From a morphological point of view, the study site corresponds, in part, to the average course of the Ziz wadi, also called intermediate basin. It is part of the central depressed zone of the Errachidia-Boudnib basin, with mainly cretaceous sedimentary filling, of tabular form, often topped by quaternary regs. The altitude varies between 1200 m in the North and 740 m in the South, giving the valley of the Ziz its profile slightly sloped towards the South (Akdim and Julia, 2005).

In its northern part, the Ziz flows in its wide spread alluvium from the site of the Hassan Addakhil dam upstream of Ain Meski, Downstream from Ain Meski, in the central part of its course, the Ziz cut the Cenomano-Turonian limestones by deep valleys, thus determining trays, and at the bottom of Wadis of the plains.

The broad Ziz valley extends to the south in the plain of Tafilalet, corresponding to a gutter dug in the Palaeozoic massifs of the Anti-Atlas, and filled with alluvial deposits in divergent cones downstream.

The perimeter of outcrops of the travertines interested in this study, straddles the central part and the southern part of the valley of the Ziz in the broad sense.

HYDROLOGY

The hydrology of the region that is synthesized from geology and geophysical data clearly shows levels that are likely to play a major role in the storage and flow of groundwater.

Within the Cretaceous basin of Errachidia-Boudnib, hydrostratigraphic levels separated by impermeable screens have been identified, distinguishing from top to bottom:

1). The continental series formed of coarse-grained sandstones, cretaceous sands and clays;

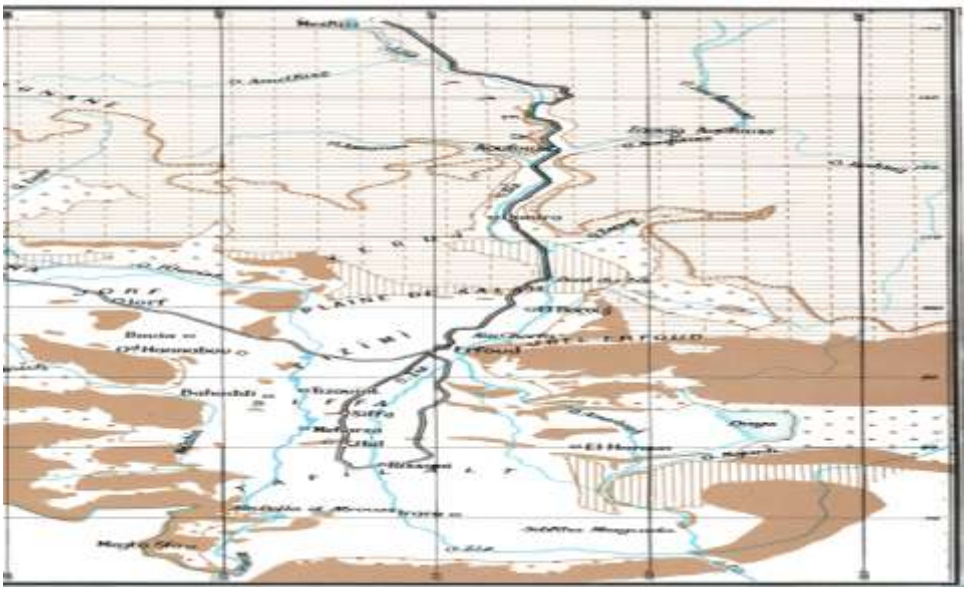

Figure 5: Hydrographic network of study area.

Figure 6: Current encrustment of Ain El Ati mineralized water cascades.

2). Being more or less fissured and very porous locally, the Turonian limestones constitute a permeable level of the karstic type which plays a major role in the hydrography of the whole Basin;
3). The intermediate marl of the Cenomanian forms impermeable basis ensuring perfect watertight bedrock (substratum) at the upper level;
4). The Infra-Cenomanian composed of sandstones of basic level as well as the sandstones of the superior unit constitute an important permeable basis (Rousseau et al., 2006);
5). The heavily cracked limestones and dolomites of the Jurassic (Domerian -Aalenian) appear on the northern edge of the Basin and constitute potential aquifers.

The hydrographic network consists mainly of Ziz wadi (Figure 5).

HYDROCHIMY

The Hydrochimy deduced from some analyzes for each layer identified on the Scholler diagram shows the following results:

1). The Jurassic aquifer is characterized by a calcium and bicarbonate chloride facies;
2). The Cenomanian aquifer shows chlorinated sodium water, the source of Ain El Ati (Figure 6), Artesian and saline constitutes one of the exits of this aquifer;
3). The Senonian aquifer presents a large variety of chemical facies (Nicod, 2000), thus reflecting the heterogeneity of its lithology (chloride-sodium facies, magnesium sulphate facies, calcium chloride and bicarbonate facies);
4). The Quaternary aquifer is characterized by a chloride-

Figure 7: Laminate travertine develops in a karstic cavity.

Figure 8: Desired levels of ornamental rocks for craft industry near the foundation raft of Ziz.

sodium and bicarbonate facies, but with a much greater mineralization towards the downstream (Tafilalet).

DESCRIPTION OF TRAVERTINES

The photographs taken from the site (Figures 7 and 8) provide important information concerning outcrops, sedimentology, beds structures with different lithologies, ribbons, sedimentary discontinuities and granulometries , Etc.

The greater thickness in the middle of the cavity is observed (Figures 7 and 8), and the travertinization by dissolution precipitates the edges of the cavity.

It should be noted initially the presence of "dendrites of manganese" which are similar to floral forms (Figure 9), they develop centripetally towards the opening surface.

The lamination is characterized by alternating light/ dark (Figures 10 and 11). Here, the white calcitic levels alternate with black levels rich in manganese. We note also the undulating appearance of laminates and Slightly undulating Litho-facies of hydrothermal origin of the various facies of Ziz wadi travertines.

EQUIPMENT AND METHODS

The methodology is based initially on the field of work using the equipment and techniques of sampling, at the laboratory for the mineralogical preparation of the thin blades of travertine rock and finally observation using the polarizing microscope which remains the essential work tools of petrographes for the precise recognition of the various components.

Figure 12 shows that some lamines are clear, and sparitic and others are darkish. Light Lamines shows diagenesis criteria, each doublet of laminates has two different zones:

1). A dark zone, stromatholitic structure, porous and rich in

Figure 9: Photograph shows the symmetry of travertine constructions, developed in a network that includes very often secant fractures.

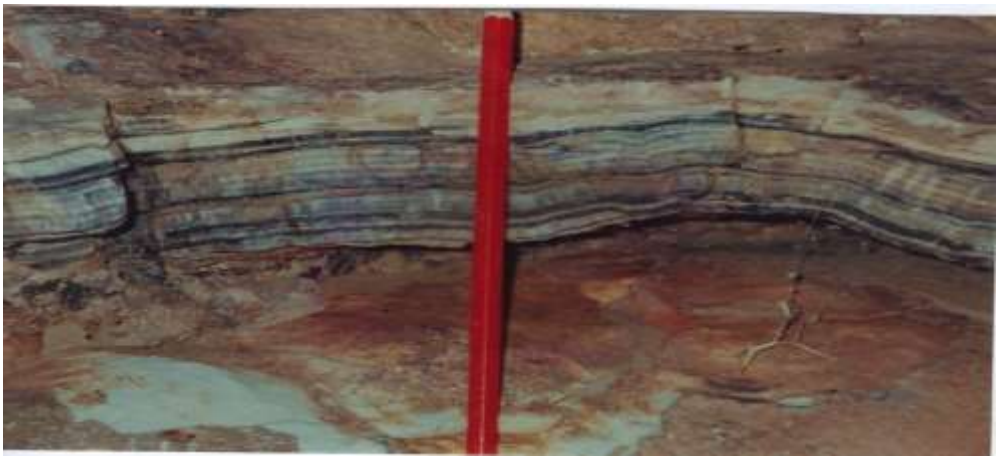

Figure 10: Travertine bench in a few centimeters, showing lamination and alternation of the clear and dark bands and various lithography-facies of travertines of Ziz.

Figure 11: Significant karstification in lithic conglomerates with travertine cement and even in travertine levels.

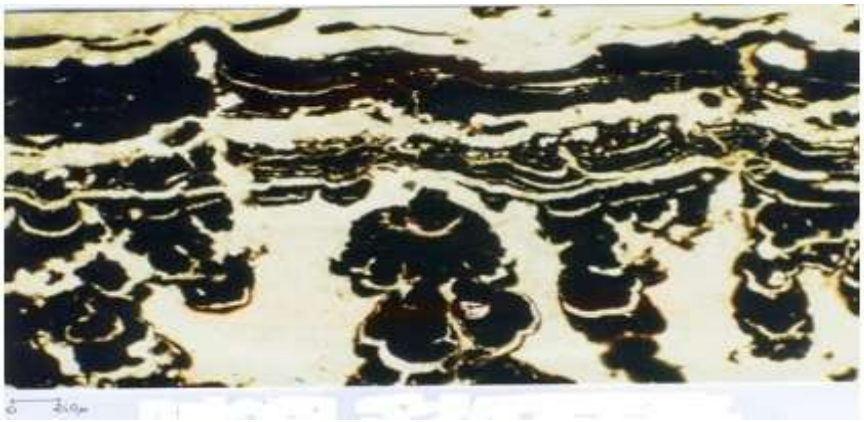

Figure 12: Microphotography showing the development of manganese dendrites from open areas (Sample collected on the right bank, south of the Ziz bridge).

Figure 13: Crystals of increase isodiametric calcites from jagged edges in micritic limestone.

Figure 14: Laminar microfacies with detrital dark levels and light calcitic levels.

algal forms (and in organic matter, iron oxides and sometimes manganese oxides);

2). A more ordered zone has a nucleus at the centre on which a radial and laminated sparite develops.

The manganese dendrites are developed from dark laminar levels. Figure 13 shows the genesis of travertines thorough a hydrothermal atmosphere in which the bacterial activity is very active and constructive according to the reactions of

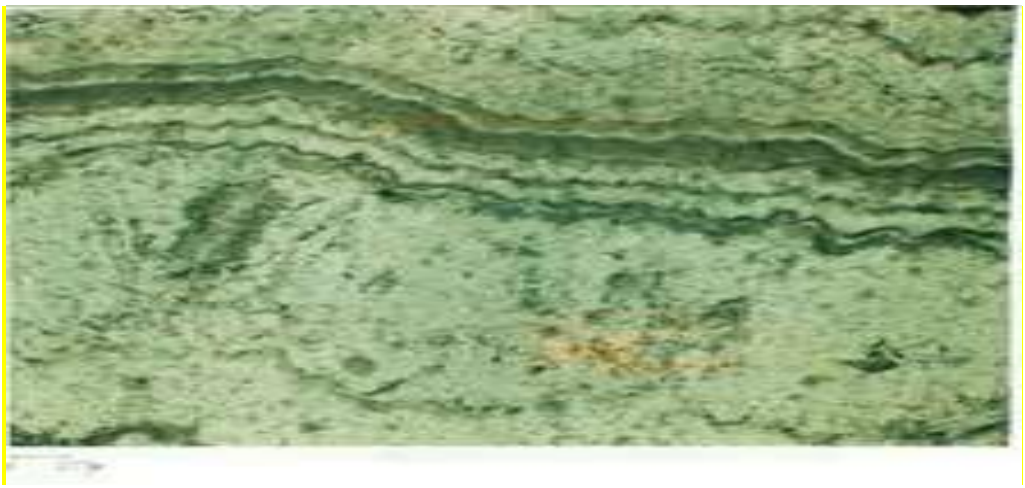

Figure 15: Polarized microscopic view of laminar structure.

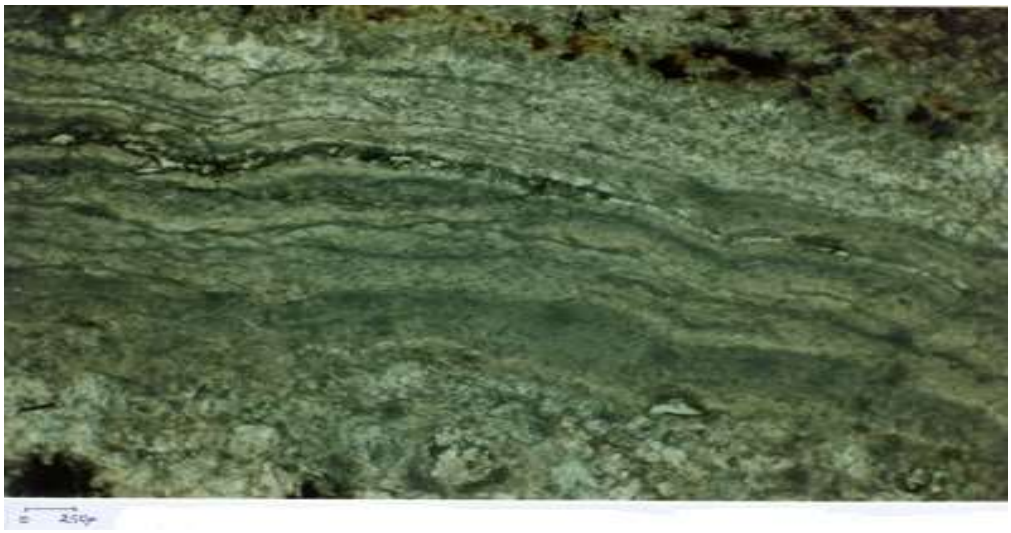

Figure 16: Microphotography of laminar microfacies with dark lamine stromatholitic structure, and light sparite lamine.

carbonation and precipitation that is most often striped.

The latter is apparently more affected by the diagenesis generating both sparite crystals and a radial structure (Figures 14, 15 and 16).

CONCLUSION

The discussion of the results is marked in two following essential points:

1) The hydrothermal character:

a). Morphological indicators in favor: Ziz travertine is a local deposit; it is not a general spreading like the quaternary terraces;

b). Deposits of travertines show evident tectonic manifestations, decimetric and metric faults with sometimes recent rejections;

c). The visible vertical orientation on the megascopic and microscopic level, with a generally vertical tendency of the primary pores, manganese oxides and calcitic filaments;

d). A source of gaseous emanations (Ain El Ati) currently functional and encrusting is also an argument in favor of the hydrothermal hypothesis.

2) Additional factors:

The microscopic study of these travertines reveals the association with thermalism of other factors that build up these travertine structures. Indicators of the role of biogenesis of physico-chemical and hydrological factors are

manifested to different degrees; it is difficult to separate them, for they act simultaneously, associates, at different intensities.

Biogenetic traces, such as algal filaments, are distinguished, and can orient crystallization. In addition, hydrothermalism is not unfavorable to biological action, quite the contrary. It is an activator.

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