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Limestone Weathering and Deterioration in the Tebessa Roman Wall N E Algeria

A. Boumezbeur, H. Hmaidia, and B. Belhocine

Abstract

Tebessa city is first build on what remained of an ancient Roman city called Thevest. It is surrounded by a famous wall of more than seven meters high and three meters thick. The stone used for building the wall comes from Turonian limestone from nearby quarries. It is a clear pinkish limestone containing small grains of calcite and bioclasts with micritic cement. On the wall, the stone material show varying signs of deterioration such as powdering, flaking, pitting, cracking and discoloration. On top of the observations made in the field, several other experimental techniques have been used to investigate the weathering intensity of the limestone in the laboratory. The first technique is the microscopic examination of thin sections made from weathered and sound limestones. Then density, specific gravity and ultrasonic velocity have been measured for a set of samples taken from both sound material from three quarries and weathered ones from different parts of the wall. Schmidt rebound test has also been undertaken to assess the resilience of both fresh and weathered materials. Geochemical analysis has also been carried out. The results show that the limestone of the wall is moderately to highly weathered with a loss of strength and resilience due mainly to the micropores and cracks which have been developed upon weathering. The salts (sulfates and chlorides) revealed by geochemical analysis explain the reason of flaking, spalling, pitting and discoloration observed on the stone. In order to take the appropriate preservation and restoration measures we have shown the mechanisms by which salts arrive inside the stone and crack it.

Keywords

Salt weathering • Tébessa • Limestone • Dimension stone

27.1 Introduction

Tebessa is a city that has known the succession of several civilizations. It has been conquered by the Romans, Vandales, Byzantins and the Muslims. It was known by Thebes, Theves, Thevest and then Tebessa. The name Thevest was the name by which it was called at the arrival of the Muslims. Thevest city is build after the erection of the Hycatempyle in what is known today by Tebessa Al khalia. The Hycatempyle is constructed eight centuries before the Christ by the Phoenician.

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G. Lollino et al. (eds.), *Engineering Geology for Society and Territory – Volume 8*,
DOI: 10.1007/978-3-319-09408-3_27,

Thevest or the actual Tebessa hosts several historical monuments, the most distinguished one being the Wall that surrounds the city. It forms a rectangle of 180 m × 160 m with 14 surveillance tours. It has three main gates: Caracalla, Solomon and Cirta (Fig. 27.1). It is three meters wide and seven to ten meters height. Other monuments such as the roman theater and the basilica are of a paramount importance.

An important part of the history of the city and its surroundings is getting erased. Unfortunately, when these traces are lost, it is forever. Vandalisme on one hand, natural weathering processes on the other and the lack of maintenance are speeding the loss of the traces of the past human history and civilization in the area. We know that stones or rocks under the attack of the different environmental factor changes their mineralogical content as well as their textural integrity and consequently get decayed. This study comes to investigate the geology, mineralogy, the origin as well as the state of weathering and degradation of the stone of the Thevest Roman wall.

27.2 Geological Setting

Tebessa area belongs to the autochthonous structure of the northern Aures mountain belt of the Saharan Atlas (Durozoy 1956; Villa 1969; Kowalski et al. 1997). It is a rift valley like structure bordered by high grounds and mountains of different altitudes. Geologically, the formations constituting the area are dominantly carbonates. The carbonate formations in the area extend from the Albian up to the Eocene. Older formation which can be found is the Triasic outcrops, they occurs as elongated bodies of diapirs which consist of multicolored clay, dolomite gypsum and halite. They generally come to surface along deep tectonic accident at the borders of the depression (trough). Albian limestone outcrops in very limited area around Hamimet. It is a dark gray vacuolar dolomitized limestone. The vraconian is mainly composed of marl with few passages of limestone and argillite. On top of the vraconian comes the cenomanian which consist entirely of marl. The basin continues to receive sediments that alternate between marl and limestone. At the base of the upper Turonian, a well developed recifal facies was found in many part of the area where limestones are highly crystalline and highly fossiliferous. Turonian limestone outcrops in many areas in Tebessa. The Maestrichtian, which also outcrops over large areas, is constituted of a succession of fine beds of marl and limestone at its lower part and continues upward with mainly fine chalky limestone sediments. Eocene is mainly marl at its lower part and limestone with silex at its upper part.

27.3 Geological and Petrographical Characteristics of the Stone of the Wall

It is obvious that the stones used for the construction of the wall and the other monuments come from nearby quarries. Many references state that the building stone used for the wall comes from different places such as Djebel Ozmor,

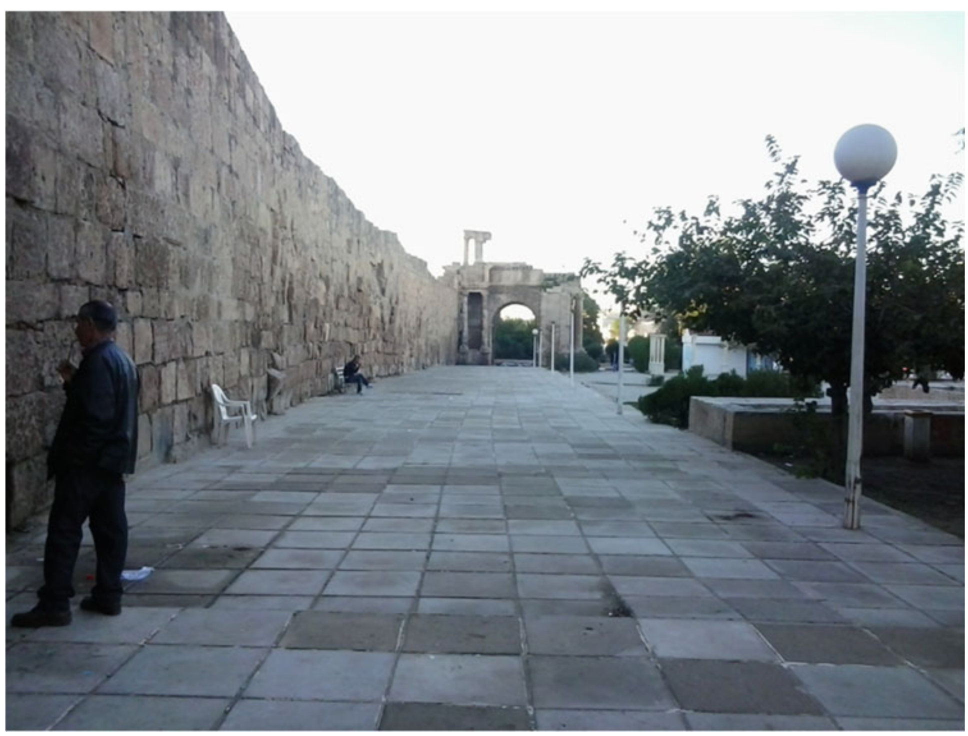

Fig. 27.1 The northern part of the wall and Karakalla Gate

Djebel Mizeb and from Tnoukla. The rapid examination of Tebessa geological map reveals an important deposit of hard and massive Turonian limestone at the vicinity of the city. The macroscopic and microscopic examination of the stone wall reveals the existence of more than one type of limestone. Travertine can be found scattered throughout the wall, it is a highly porous limestone. It shows the most advanced state of weathering of the stones of the wall. Its origin is not known yet (Fig. 27.2). Claire pinkish well crystalline and highly fossiliferous limestone building materials constitute an important part of the wall and mainly Caracalla Gate. This material is distinguished by its attractive appearance due to its color and its content of rudiste remains (genre Hippurites). This later material is comparable to the Turonian limestone of Al Gaaga localité. Beige Claire fine micritic limestone is also used in the construction of the wall. This later looks similar to the Turonian limestone of the outcrops surrounding the city such as Mizeb, Ozmor and Tebessa Al Khalia. Whitish chalky hard micritique limestone has also been used in the construction of the wall. It probably comes from the Maestrichtian carbonates that are widespread in the area.

In thin section, turonian limestone are biomicritic to biosparitic, fine to coarse grained, with varying pore sizes and geometry. Section cut from material of the lower part of the wall are highly discolored and porous. Voids can be seen throughout the section. The purity of the limestone is tested by calcimetry using Bernard calcimeter. For the stones of the wall, the amount of insoluble residue which consists of clay and salts vary from 30 to 14 %. This figure is about 10 % for Ozmor and 25 % for Mizeb. Chemical analysis by XRF method shows that the stones of the wall contain along with the calcium carbonates which is the main component, other secondary constituents such as aluminum silicates and several types of salts (Table 27.1). Aluminum silicates are chiefly clay minerals. Among the salts present one can note magnesium and calcium sulfates, sodium chlorite, sodium sulfate, sodium carbonates, potassium chlorite…etc.

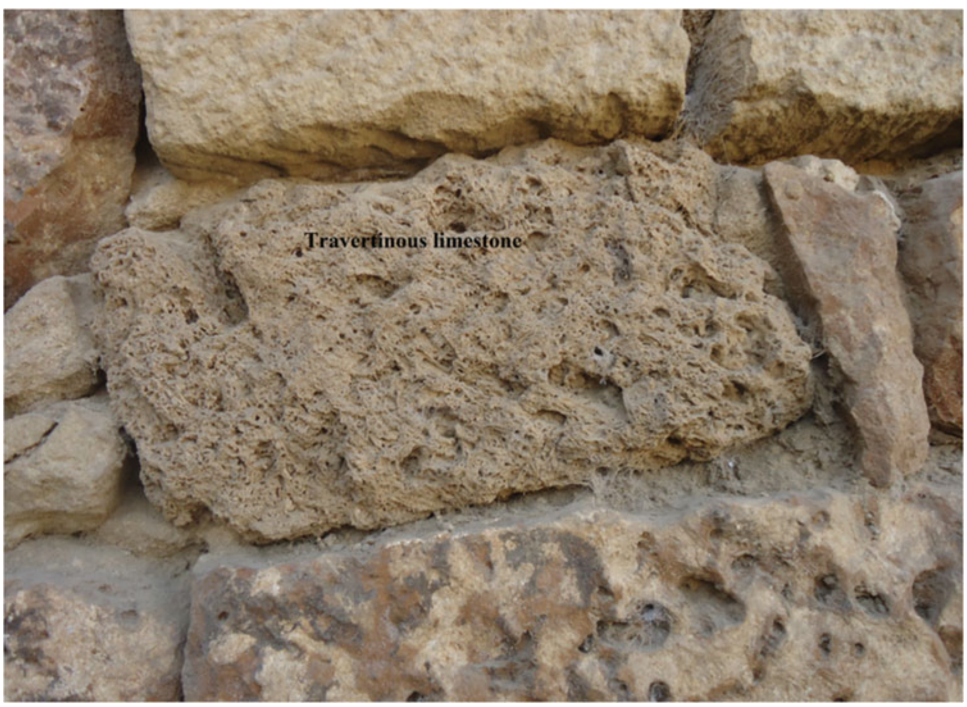

Fig. 27.2 Travertinous highly porous limestone

Table 27.1 Chemical analysis of the stone of the wall and Ozmor turonian limestone

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	Cl
Stone wall	3.42	2.052	1.01	91.72	0.76	0.04	0.16	0.096	0.004
Ozmor	3.54	2.26	1	91.33	1.23	0.06	0.14	0.27	0.05

Fig. 27.3 Limestone showing an advanced state of weathering: **a** Alveolar weathering, **b** light colored crust tracing the surface, **c** loss of scales, efflorescence, subflorescence and cracking

27.4 State of Degradation of the Stone

From a quick look at the wall one can distinguish that the stones display a varying degree of stain. Completely discolored and covered by a thin black soft and silky film of probably oxidized sulfate material are found in the lower part of the wall. Stone displaying vacuoles of different dimensions are widespread. Efflorescent salt like material are also found on the stone surface. In some parts whitish powder like material are seen to cover the stone surface. Thin slivers parallel to the stone surface are easily detached (Fig. 27.3). Relief form of weathering, Fitzner and Heinrichs (2002) and Heinrichs and Fitzner (2002), where differential alteration displays nodes of iron ore like material can also be seen throughout the wall materials. The upper parts of the wall are slightly stained and less weathered.

Along with these observations, some test indices have been carried out in order to shed light on the effect of weathering on the physical properties of the stone. Specific gravity has been used to assess weathering grades by several authors (Irfan and Dearman 1978; Dobreiner and de Freitas 1986). For the same rock type, the weathered stone has a lower density than the fresh one as weathering is usually accompanied by loss of matter and replacement by lower density minerals.

Specific gravity values obtained for the wall stones vary from 1.01 to 2.22 while those of the presumed source rock vary between 2.3 and 2.7, Table (27.2). The values of the specific gravity for the other limestone rocks such Aptian, Maestrichtian and Eocene are all in the range of 2.15 and 2.6. It is clear that the specific gravity values of the stones of the wall are lower than those obtained for the rocks of Ozmor and Mizeb localities.

Table 27.2 Specific gravity values of the studied materials

Samples	Wall stones	Ozmor	Mizeb
1	1.53	2.52	2.65
2	1.63	2.45	2.71
3	1.10	2.30	2.67
4	1.01	2.35	/
5	2.22	2.48	/

Table 27.3 The porosity values of the studied materials

Samples	Wall stones (%)	Ozmor (%)	Mizeb (%)
1	2.80	2.13	2.00
2	3.00	3.08	2.10
3	3.80	2.80	1.90
4	2.90	4.90	/

Table 27.4 Schmidt Hammer rebound number of the studied materials

Ech	Wall stones	Ozmor	Mizeb
1	25	30	38
2	27	32	42
3	30	34	36
4	32	31	44
5	22	36	32
6	14	32	30
7	16	29	39
8	34	31	28
9	12	26	50

The other test index used to assess weathering is the porosity (Irfan and Dearman 1978; Fookes et al. 1988). The porosity values of the stones of the wall are in the range of 1.8–3.8 %, those of Ozmor in the range of 1.13–9.8 % and Mizeb in the range of 1.9–2.3 % (Table 27.3). The porosity values do not seem to vary much between the stone of the wall and the limestone coming from Ozmor and Mizeb.

Schmidt Hammer which is used worldwide to estimate the compressive strength of the concrete is also used by the rock mechanic community as a tool to estimate the compressive strength of rocks (Deere and Miller 1966). It is a good and rapid tool for the assessment of weathered material. The rebound numbers obtained on different parts of the wall are in the range of 12–32. Samples of the rocks of Ozmar display a rebound of 26–36 and those of Mizeb 30–44 (Table 27.4). The lower values of the stones of the wall reflect that they have lost some of their hardness and strength upon weathering.

Another test index was also used for the diagnosis of weathering. It is the pulse ultrasonic velocity. This test is widely used to evaluate weathering of porous materials, the transit time is inversely proportional to the weathering state. Thus velocity values are greater for sound material than for weathered ones. As weathering goes by, voids, fissures, lesser density neoformed minerals become more and more abundant and hence the velocity through the material decreases. In our case, the lower velocity values obtained were for the stone wall about 3,000 m/s. Mizeb and Ozmor limestones display relatively higher values (Table 27.5).

27.5 Degradation Mechanism

The degradation of the stone of the wall is in fact caused by the interplay of several agents (Cardell et al. 2008). Salts, clays, relative humidity and wetting—drying are the main factors that lead to deterioration. Salt weathering is a well known phenomenon, the humidity carried soluble salt crystallize just under the surface when water becomes a vapor. These salt crystals exert a pressure and wedge small pieces of the surface. The repeated cycles of crystallization–hydration results in the formation of flakes parallel to the surface. The movement of the water in the porous material causes the appearance of a whitish crust on top of a weak powder like material; this phenomenon is known by powdering. The attack by aerosols containing salts in an appropriate relative humidity causes vacuolar weathering, well seen on the wall. It is much like the effect of sea spray on rocks. Clay minerals that are originally contained in the limestone, upon wetting—drying cycles, expand, shrink and exert pressure on the material forming what is known by scaling. The disrupting work of the clays is usually enhanced by the presence of salts. By being part of the absorbed layer of the clay it helps in absorbing more water and consequently more expansion.

27.6 Conclusion

The stones of the wall of the Roman wall of Thevest are brought from nearby quarries. They are mainly from the Turonian formation that surrounds the Antic City. The tones come more probably from tree localities Mizeb, Ozmor and Gaagaa. The stones display varying degree of weathering. The lower parts are the more affected. Weathering is displayed by discoloration, alveolar weathering, spalling, efflorescence, pitting and cracking. It is accompanied by an increase in porosity and water absorption and a decrease in the specific gravity, strength and ultrasonic velocity. The most important agent of weathering is salt crystallization and clay minerals expansion upon water and humidity migration throughout the stones.

Table 27.5 Velocity values for the studied materials

Samples	Stones of the wall		Ozmor		Mizeb	
	Velocity dry (m/s)	Velocity humid (m/s)	Velocity dry (m/s)	Velocity humid (m/s)	Velocity dry (m/s)	Velocity humid (m/s)
1	4,226	3,000	3,642	4,611	5,531	5,090
2	4,883	3,408	4,500	4,435	6,891	6,000
3	5,184	4,775	5,250	6,060	5,313	6,164

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