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GEOLOGICAL STUDIES ON VOLCANIC TUFFS USED AS NATURAL BUILDING STONES IN THE HISTORICAL CENTER OF SAN LUIS POTOSI, MEXICO

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Abstract

The use of volcanic tuffs as building elements in historical monuments built during the 17th, 18th and 19th century are an important part of the cultural heritage in the city of San Luis Potosi, Mexico. For the constructions of the historical buildings pink-colored volcanic tuff rocks of the region were used, geologically defined as units of the "Cantera Ignimbrite". This rock, locally also known as "Cantera Rosa" shows very different appearances and colors which can vary from pink to dark pink, grey, brown and orange. However these building rocks have significant variations in texture, compositions and mechanical properties and these properties determine the resistance to weathering and deterioration, because they show a wide range of deterioration types, e.g. scaling, flacking, sanding, back weathering and coloration/discoloration. Geological, petrophysical, geochemical and mechanical studies were realized on these rocks to understand the causes of their weathering and deterioration.

Keywords: tuff, Mexico, deterioration, porosity, pore distribution

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1. Introduction

The old mining city of San Luis Potosí in middle Mexico was founded in the year 1592 (Villar Rubio, 2000). Due its important mining activities San Luis Potosí was one of the richest cities of the Nueva España, which was clearly demonstrated in the impressive colonial (Baroque) architecture of the old downtown. For the constructions of these buildings were used volcanic tuff rocks of the surroundings. These tuff rocks are utilized until today for the construction of modern buildings in the city. The uses of the volcanic tuff rock as building element in royal houses, government buildings and religious settlements as chapels and temples build in the 17th, 18th and 19th century are an important part of the cultural heritage in the city of San Luis Potosi, Mexico (Fig. 1).

Fig. 1: Some of the principal buildings and monuments build with the Cantera Rosa. Left to right: Tower and facade of the San Agustín Church, facade of the El Carmen Church, fountain in the Santuario and Santuario del Desierto Church.

For the construction of the historical buildings in San Luis Potosi were used impressive pink-like colored volcanic tuff rocks of the region, geologically defined as units of the "Cantera Ignimbrite", which belongs to the Tertiary acid volcanism of the San Luis Potosí-Volcanic Field (SLPVF) (Labarthe *et al.* 1982). These rocks locally grouped and known as "Cantera Rosa" show some variations in color from pink to dark pink, grey, brown and orange (Fig. 2). Although physical appearance of the rocks seems to be not very different, observing nearly and in detail, these building rocks have significant variations in texture, compositions and mechanical properties and these properties determine the resistance to weathering and deterioration, because they show a wide range of deterioration types, that include scaling (Fig. 3c), flacking (Fig. 3d), sanding, back weathering and coloration/discoloration (Fig. 3a and Fig. 3b; González-Sámano, 2012). Geological, petrophysical, geochemical, physical and mechanical studies were realized to know the causes of their weathering and deterioration and thereby to contribute to the care, preservation and if necessary restoration of buildings constructed with these rocks.

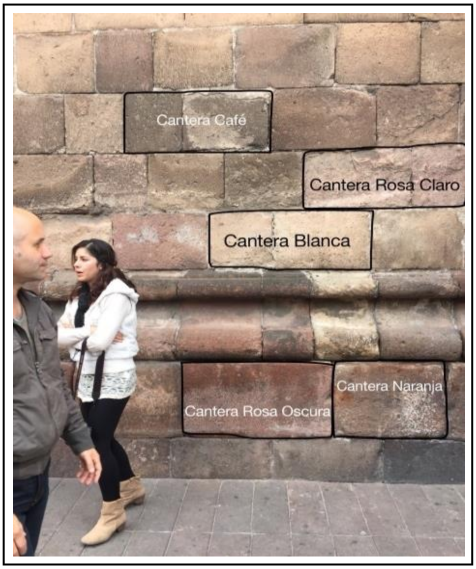

Fig. 2: North wall of the Templo del Carmen. Five variations of the Cantera Rosa can be distinguished here. Cantera Café (brown), Cantera Rosa Claro (light pink), Cantera Rosa Oscura (dark pink), Cantera Naranja (orange) Cantera Blanca (white).

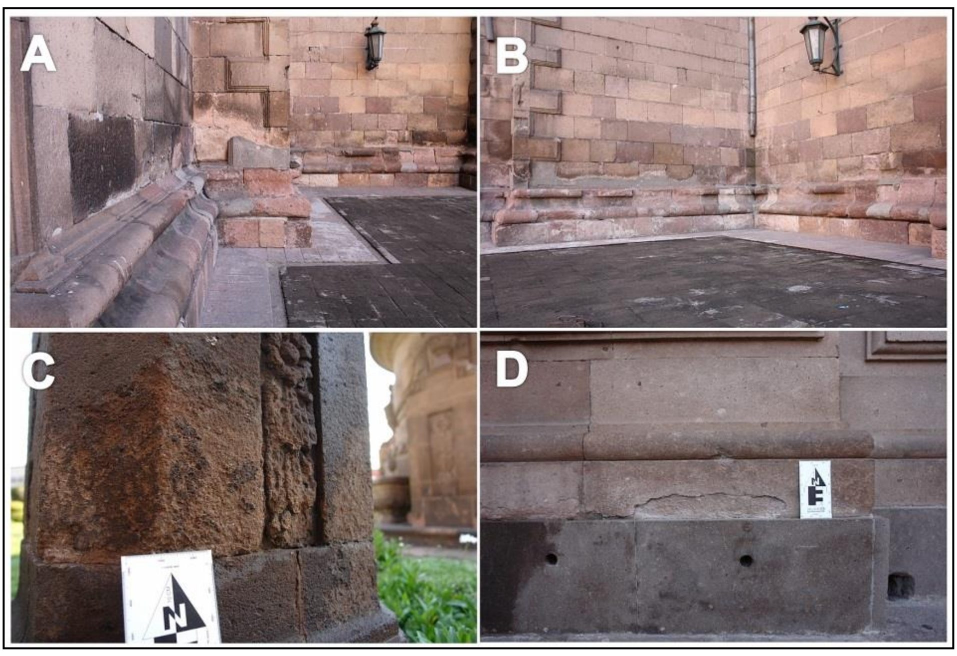

Fig. 3: Appearance of the different damage and deterioration types observed in the Cantera Tuff; a and b) Sanding, back weathering and coloration/discoloration in the San Carmen Church; c) Scaling and lost material in the Caja de Agua monument; d) Extensive flacking in lower parts of the south wall of the cathedral of San Luis Potosí.

2. Materials and methods

Five different types of Cantera tuff rocks of San Luis Potosí were analyzed petrographically, geochemically and geomechanically in laboratory. The analyzed tuff rocks are (Fig. 4): Cantera Rosa Clara, Cantera Rosa Oscura, Cantera Blanca, Cantera Café and Cantera Naranja. The petrographic analyses were performed on oriented thin sections and studied under a polarizing microscope. The percentage of minerals and matrix was measured using the point counting method. Mineralogical and geochemical analyses were performed using XRD, elemental carbon and sulphur analysis, and CEC analyses. Hydrostatic weighing was carried out to acquire the absolute and apparent density as well as the porosity of each Cantera of San Luis Potosí. The pore radii distribution was determined using mercury injection porosimetry. The hydric and hygric expansion of each rock was measured on cylindrical samples (diameter 15 mm, length 100 mm). For hydric expansion measurements the cylinders were completely immersed in distilled water. The compressive strength load was realized on cylinders with 40 mm in diameter and 20 mm in length using a servo-hydraulic testing machine with a stiff testing frame (3,000 kN/mm^2) and a load range up to 300 kN. The tensile strength measurements were determined by means of the ‘‘Brazilian test’. Finally to assess the salt weathering resistance of the five investigated tuffs, a salt-crystallization test was performed. For this test the samples were cut into cubes (6.5×6.5 cm) and were soaked in a 10% Na_2SO_4 solution. The samples stayed about 4 hours in the salt solution and then they were dried in an oven at 60°C - 70°C for 48 hours. This process was repeated as often as the sample allows. After each cycle, the samples are weighed to determine the loss of material. Photos documented the result of each cycle.

3. Results

3.1. Petrography

The Cantera Rosa in all their types has rhyolitic composition. The percentage of crystals and matrix vary of 35% - 65% in Cantera Rosa Clara, and Cantera Naranja, 30% - 70% in Cantera Rosa Oscura and Cantera Café and < 30% - >70% in Cantera Blanca respectively (Fig. 4). The main crystals are quartz with 45% in the Cantera Rosa Claro and Cantera Naranja, 35% - 40% in the Cantera Rosa Oscura and 30% in the Cantera Café. Alkali feldspar (mostly sanidine) is present in some samples but their amount vary of 35% - 40% in the Cantera Blanca, 30% in the Cantera Café (most as orthoclase) and < 30% in the Cantera Naranja Rosa Oscura and Rosa Claro. Cantera Naranja shows the highest content on plagioclase (microcline and anortite) crystals with more than 30%. The types Cantera Rosa Clara and Oscura show euhedral crystals (Fig. 4a and b) and Cantera Blanca, Café and Naranja have mostly anhedral crystals (Fig. 4c, 4d and 4e). Cantera Rosa Clara, Cantera Café and Cantera Naranja show a porphyritic hypocrystalline texture and Cantera Rosa Clara and Cantera Blanca have a vitrophyric texture (Fig. 4).

XRD analysis (Fig. 5) demonstrates that most of the samples are quartz-rich and they show in general a clearly acid composition. Cantera Naranja is the only sample containing additionally microcline and Cantera Rosa Oscura is the only having halloysite. Alkali feldspar (sanidine) is almost exclusively in the Cantera Blanca and the Cantera Café has practically only orthoclase (Fig. 4).

3.2. Petrophysical and moisture properties

Analyses for the five studied volcanic rocks were performed, in order to determine their density and porosity. The results of the determination of the porosity and density are presented in Tab. 1. As shown in the Tab. 1, the Cantera Café has a greater density than the others tuffs with an average of 2.611 and the lightest is the Cantera Rosa Oscura with 2.331 g/cm^3 respectively.

Tab. 1: Porosity, density and average pore radius of the studied rocks (López Doncel et al. 2016).

Sample	Porosity (%)	Density (g/cm^3)	Average pore radius (µm)
Cantera Rosa Clara	21.14	2.500	0.148
Cantera Rosa Oscura	17.88	2.331	0.476
Cantera Blanca	36.14	2.447	1.080
Cantera Café	25.45	2.611	4.029
Cantera Naranja	23.8	2.500	0.275

The Cantera Blanca has the highest porosity with 36.14% and the Cantera Rosa Oscura shows only 17.88% of porosity. A very interesting result is that the heaviest tuff (Cantera Café) has the biggest pore radius with an average of 4.029 µm

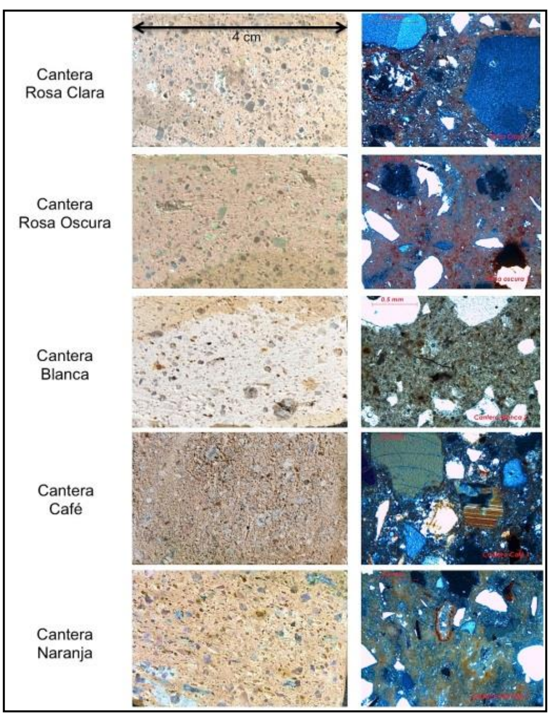

Fig. 4: Macroscopical photographs and thin section photomicrographs of the studied rocks (explanation in Text, obj. ×5, crossed nicols, except Cantera Blanca parallel nicols)

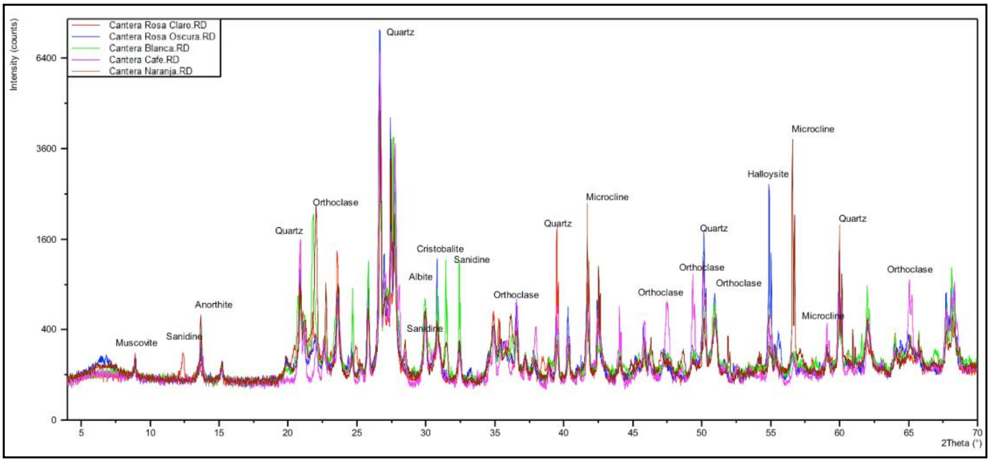

Fig. 5: XRD-diffractograms of the five analyzed volcanic tuff rocks of San Luis Potosí.

The distribution of the pore size in the analyzed volcanic rocks is unimodal by the Cantera Rosa Oscura, Cantera Blanca and Cantera Café (Fig. 6). These three samples rocks are dominated by macropores with pore sizes ranging from 1.0 to 10 µm (Fig. 6). As seen in Tab. 1 the Cantera Café has the biggest pores and it consists practically only of macropores. Cantera Rosa Clara and Cantera Naranja show a bimodal pore size distribution with a very similar porosity (Fig. 6, compare with Tab. 1).

All five samples were tested about the hydric expansion and all of them did not show any expansion and by the Cantera Rosa Claro and Cantera Naranja occur even contraction with values around -0,03 mm/m. The practically non-existent hydric expansion is securely associated to the poor content on clay mineral with average values of 0.3 meq/100 gr after CEC-analysis.

Tensile strength tests under dry and wet conditions were realized on four of the five selected samples and they show values that range from 1.28 MPa (wet) by the Cantera Blanca to 7.05 MPa (dry) by the Cantera Rosa Clara (Tab. 2). The results show that the Cantera Café with a tensile strength average value of 1.83 MPa under dry conditions and the Cantera Blanca with an average value of 1.44 MPa under wet conditions are the less resistant to the strength (Tab. 2). Under dry and wet conditions Cantera Rosa Clara was with values around the 5 MPa the hardest tuff.

Tab. 2: Tensile strength under dry and water-saturated conditions

Dry samples		**Tensile strength**, MPa		**Average**
Direction	X-axis	Y-axis	Z-axis	
Cantera Rosa Clara	7.05	4.86	4.13	5.34
Cantera Rosa Oscura	2.94	4.16	3.93	3.67
Cantera Blanca	2.51	2.11	2.16	2.26
Cantera Café	1.43	1.58	2.48	1.83
Wet samples		**Tensile strength**, MPa		**Average**
Direction	X-axis	Y-axis	Z-axis	
Cantera Rosa Clara	4.31	5.71	5.62	5.21
Cantera Rosa Oscura	1.97	1.79	2.72	2.16
Cantera Blanca	1.52	1.28	1.54	1.44
Cantera Café	1.62	1.33	1.99	1.64

The conducted salt bursting tests (Fig. 7) show that after 7 cycles Cantera Blanca lost 20% of its weight and Cantera Café and Cantera Rosa Oscura lost 10 % of their weight. After 14 cycles Cantera Blanca tuff was total destroyed and Cantera Café and Cantera Rosa Oscura had lost around 30% of their weight. Cantera Rosa Clara and Cantera Naranja showed after 14 cycles less than 5% of lost material and have resisted at the end of the test 47 and 48 cycles respectively (Fig. 7).

4. Discussion

The data from the conducted experiments on the natural building rocks show that the tuff with the highest absolute density is the Cantera Café (2.611 g/cm^3), and it has also the largest pore radii (4.029 µm with 78% of the pores between 1-10 µm), but contrary to expected. it is the rock with the lowest tensile strength (1.83 MPa by dry conditions), therefore the large pores may be the cause that this rock has a poor cohesion and likely poor resistance against weathering.

The tuff rock with the greatest porosity is the Cantera Blanca tuff (36.14%) and it was the less resistant against salt bursting. Laboratory experiments realized with rocks with similar values of porosity showed that these conditions favoured the water uptake by capillarity and with that increase the deterioration (López-Doncel *et al.* 2012, 2013).

The Cantera Rosa Clara tuff with a density of 2.5 g/cm^3, porosity of 21.14%, tensile strength values of 5.3 MPa and with the smallest pores (0.148 µm with 94% micropores) is the least-damaged rock under our test (salt bursting and strength). Under wet conditions all the samples were less resistant against strength and e.g. Cantera Café and Cantera Blanca reached values comparable to very soft rocks. As our experiments and tests show, Cantera Café and Cantera Blanca are the most sensitive rocks against salt bursting and tensile strength and under wet conditions both tuff rocks reach critical values of resistance. However, the moderate annual rain fall in this area of Mexico, located in a semi-arid region, seems to be the cause for just an incipient deterioration of this tuff rock after more than 400 years exposure. Recently, the historic center of San Luis Potosi was declared world heritage site and plans to carry out extensive restoration work in different buildings and historical monuments have been initiated. It is precisely for this reason that the study of geological, geochemical and geomechanical properties of the rocks used play a predominant role in the care and restoration works.

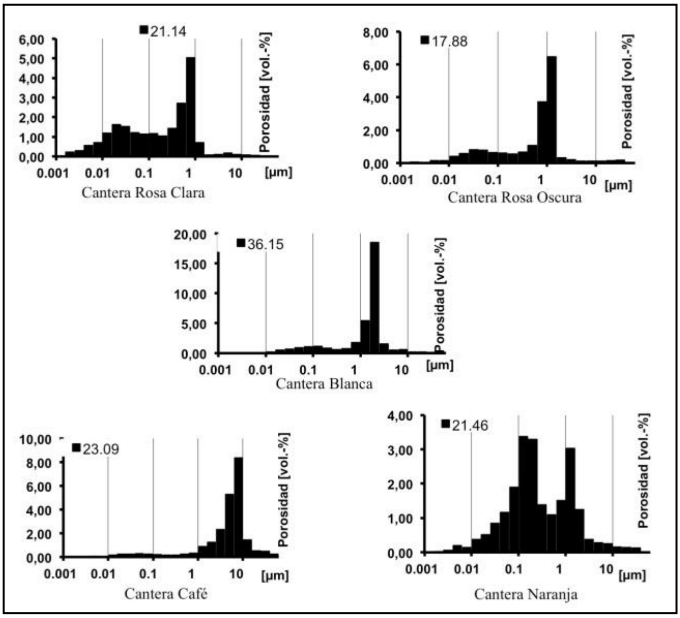

Fig. 6: Pore size distribution (MIP) of the five studied tuffs (López Doncel et al. 2016).

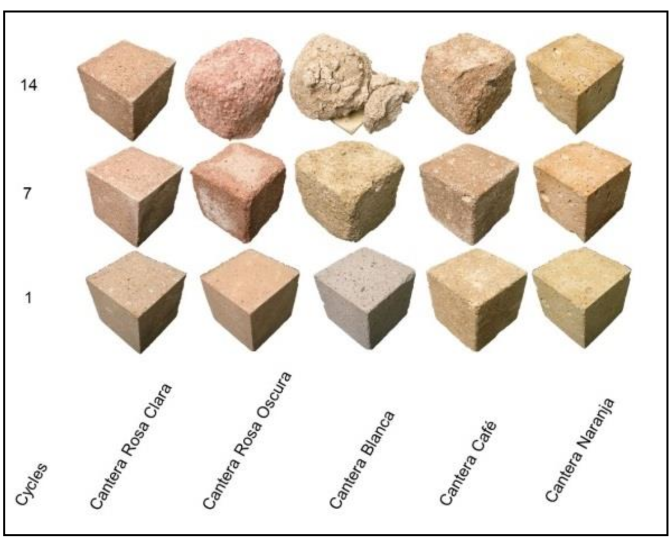

Fig. 7: Salt bursting test conducted on the analyzed tuff rocks of San Luis Potosí. Comparison between the five selected samples after 1. 7 and 14 cycles (López Doncel et al. 2016).

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