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Physical properties and petrographic characteristics of some Bateig stone varieties

Propriétés physiques et pétrographiques de quelques variétés de 'Pierre Bateig'

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ABSTRACT: Bateig stone is an allochemical calcareous rock (mainly biosparite - biomicrite) worked in Novelda, named Novelda stone too (Alicante province, Spain) that belongs to a transgressive unit of Middle - Late Miocene age. This stone is a highly workable material that often was used in monumental Spanish architecture. Using criterium publising by the M.I.T., Bateig stone may be classified as a Medium to Low Limestone. Data from Mercury Porosimeter has been used to stimate a DDS (Durability Dimensional Stimation). The DDS equation is supported on the calculus of the pressure of salt crystallization in porous mediums. The DDS values obtained, for different varieties of Bateig stone let us establish that the microporosity, size pores less than 0,1 μm, is the main factor responsible for durability of materials.

RESUMÉ: La "Pierre Bateig" est une roche carbonatée à allochèmes (biosparite-biomicrite) extraite en Novelda, elle est appellée aussi "Pierre de Novelda" (Province de Alicante, Espagne); elle appartient à une unité transgresive du Miocène Moyen- Supérieur. Cette roche est très facile à travailler et souvent a été utilisée dans la architecture monumentale espagnole. En utilisant le critérium publié par le M.I.T. la "Pierre Bateig" peut être classifiée comme "Moyen à Low Limestone". Les données du Porosimètre de Mercure ont été utilisées à la fin d'établir une DDS (Durability Dimensional Stimation). L'équation de la DDS est basée dans le calcule de la pression de cristallisation des sels dans un moyen poreux. Les valeurs obtenues pour les différentes varietés de la Pierre Bateig permettent d'établir que la microporosité, pores plus petits de 0,1 μm, est le principal facteur responsable de la durabilité des matériaux.

1 INTRODUCTION

Bateig stone is an allochemical calcareous rock (mainly biosparite - biomicrite) extracted in Elda municipal district (Alicante) from the early XX century, however is knew in scientifical literature as Novelda stone too (Alicante), because the manufacture is located in Novelda. Bateig is the name of hill where the stone are mined. Similar stones were mined in the past in other geographical location in Novelda municipal district, Casas del Señor,...

The Bateig stone is a highly workable material that often was used in monumental Spanish architecture since XIXth-XXth century, mainly in Madrid (Linares Palace, Príncipe Pío Railway Station, Ministry of Agriculture, Palace of Comunications, Almudena Cathedral, Central Telephone Company Office...) and Valencia (General Post Office, some elements of City Hall...), and Alicante (some modernist houses,) ; in Novelda we find monuments in Bateig stone since XIIIth century: La Mola Castle (XIIIth century), San Pedro Church (XVIth century), City Hall (XVIIth century) and Modernist Museum-House (1904). To day this stone is used in modern building and restoration of monuments (Almudena Cathedral of Madrid, Leon Cathedral, Salamanca monuments,...) too. This stone was used in the restoration of the Old Facade of the University of Alcalá de Henares (Madrid province) dated in 1925 (García de Miguel at al, 1992)

The present day commercial varieties of Bateig stone are:
Bateig Blanco (White Bateig), Bateig Azul (Bleu Bateig), Bateig Llano (Layer Bateig), Bateig Diamante (Diamond Bateig) and Bateig Fantasia (Fantasy Bateig).

The active quarries of Bateig stone are located in the west part of Bateig hill (551 m a.s.l.). There are two main zones of quarries, one zone just located in the side of the hill, from there are extracted White Bateig, Diamond Bateig, Bleu Bateig and locally Fantasy Bateig; and another located in the foot of the hill, from there are extracted Layer Bateig. At the moment, geological relations among diferents varieties are not well understood. The production of commercial products are 9.000 cubic meters per year, and the annual extracted material are up to 30.000 cubic meters. Dimension stone are extracted using diamond wire cutting machines. The total lengt of active faces are more than 2 km, and the average heigh less than 10 m, sometimes with benches dipping in agree stratification. The potencial resources are up to 13 millions of cubic meters. The indentified reseves are probably less than 5 millions of cubic meters.

2 GEOLOGY

Bateig stone outcrop belongs to a transgressive unit of Middle - Late Miocene age in the Betic - Balearic domain (External Zone of Betic Cordillera- Prebetic Zone), that represents a north-eastern prolongation of the external part of the Betic thrust and fold belt. This transgresive unit is developed in a basin formed during the Early and Middle Miocene, coetaneously with the westward drift of the Internal Zone of the Betic Cordillera. This foreland basin , with an active sector (foredeep), located in front of the new formed reliefs, received huge olistostromic masses. (Sanz de Galdeano & Vera, 1991). The Trias (Keuper facies) has played an important role. The diapiric processes affect the Bateig stone and condition their outcrops and folds.

From sedimentological point of view Bateig stone primary sediments belong to a continetal shelf with no continous deposition marked by erosional unconformities, strongly agitated waters that are ideals for benthic, nektonic and plantonic organismes at the same time causing strong reworking and movement of sediments. Sediments displays abundant organic shells (mainly foraminifera), detrital quartz and neoformed silicates (attapulgite, glauconite and cristobalite). Sedimentary structures such as extensive bioturbation, burrows and flaser bedding are abundant, mainly in the variety named "Fantasy".

3. PETROGRAPHY

The original sediments of Bateig stone displays laminated primary structures, however was deeply bioturbated and primary structures are destroyed, only some varieties as Layer Bateig preserve primary laminations. The characteristic features of Fantasy Bateig, as pointed out before, may be related with burrowed laminated sediments, while other varieties display homogeneous aspec probably related with deepest reworking and burrowing of sediments. In the outcrops the "Blue Bateig" variety display a sharp contact with "White Bateig" variety that apparently cut bedding planes, and probably may be interpreted as conected with a later diagenetic process of oxidant water infiltration that flux trough primary and secondary (faults and extensional joints) high permeability layers, and flux the moderate reduced formation waters. The "Diamond Bateig" layers are allways located in the lower part of stratigraphic section just under "Blue Bateig" outcrops.

Some textural and mineralogical microscopical features may be used as differential character of the five varieties studied in this paper (table 1).

The White Bateig (W), and the Diamond Bateig (D) varieties have up to 5 % of siliceous cement and authigenic layered silicates: smectites and palligorskite. Fantasy Bateig (F) has mainly detritic layered silicates: micas. Glauconite is widespread in Bateig stone varities: small grains and internal moulds of carbonate microfossil test mainly Foraminifera.(García del Cura et al. 1994).

The **White Bateig** is a biomicrite that consist mainly of a 15 % of terrigenous components, mainly angular microcrystalline quartz, dolostone extraclast and minor feldspars, muscovite, tourmaline,.. Two modes (0.06 - 0.12 & 0,12 - 025 mm) has been identified in terrigenous fraction. The 56 % of components are **fossils** (foraminifera: *Rotalidae, Textularidae, Globigerinidae,...* ; mollusca and briozoa). The 19% are orthochems (15% micrite matrix and 4% sparite cement). As authigenic constituents has been identified opalo C, phylosilicates and glauconite. Some sparite cements and even fossils display a grain disminution type of recrystallization. The under optic microscopy porosity (inter- & intra granular) is up to 10%.

The **Blue Bateig** is a biomicrite that consist mainly of a 15 % of terrigenous components, mainly monocrystalline and polycrystalline quartz, dolostone extraclasts, K- Feldspar, phyllosilicates, opaque minerals, tourmaline, muscovite, rock fragments (metacuarcite and slates). It has been identified clay galls and also clay filling shells. The 60% of components are fossils (foraminifera: *Textularidae, Rotalidae, Globigerina s.p., Globigerinoides s.p., Globorotalia s.p.,...* briozoa, echinodermata). The 15 % are orthochems (10 % micritic matrix and 5 % sparry cement). Also has been identified locally a siliceous fibrous cement. The under optic microscopy porosity is lower than the 10 %.

The **Layer Bateig** is a sandy biosparite with

Table 1. Summary of petrographical features of the Bateig stone.

Components	W	B	L	D	F
% Terrigen.	15	15	20	6	15
% Fossils	56	60	55	69	65
% Ortochems	19(m)	15(m)	5(s)	20(m)	12
% Porosity	10	10	20	5	8
% Calcite	85	86	78	78	85
% Quartz	7	8	12	5	6
% Philosil.	5	2	3	5	6
% Dolomite	2	2	2	2	2
% K Felds.	1	2(w)	5 (w)	1	1
Accesor.	mu, t	t, mu	t, mu	t, mu	mu, z

m = micrite; s = sparite; mu = muscovite; t = turmaline; w = weathered; z = zircon.

Table 2. Physical properties of bateig stone.

CHARACT.	W	B	L	D	F
Type (MIA)	Medium	Medium	Low	Medium	Low
Porosity 7-0,005μm	18,32	12,57	14,60	17,79	
Porosity 200-7μm	0,35	0,17	1,33	17,79	
Mineral.	cal, q,	cal, q,	cal, q,	cal, q,	cal, q,
Chemistry $CaCO_3$ $MgCO_3$	 >85 >1	 >86 >1	 >78 >1	 >87 >1	 >85 >1
Density	2,26	2,31	2,13	2,20	2,10
W. absort.	4,86	4,32	6,60	5,79	6,10
Compress. strength	35,0	31,27	22,05	35,41	30,07
Modulus rupture	6,08	5,00	*	*	*
Sonic velocity	3392	3545	3328	3569	*

some laminations that consist of 20 % of terrigenous components, mainly monocrystalline quartz with anhydrite inclusions, probably derived from idiomorphic authigenic quartz of Keuper facies (Trias), besides wheatered K - Feldspar, schist and clay balls. The 55 % of components are fossils (foraminifera: *Rotalidae, Textularidae, Globigerina s.p.,..*; briozoa fragments, mollusc shells, echinoderma plates. The 5 % are ortochems, mainly sparite cement, sometimes has been identified some calcitic rim cements and locally some grain disminution processes over skeletic carbonates. Besides siliceous interparticula and intraparticula cements has been described too.

The **Diamond Bateig** is a biomicrite that consist of 6 % of terrigenous components mainly monocrystalline quartz, K - Feldspar, schist and clay balls. Terrigenous components display bimodal size distribution. The fossils components size display low sorting distribution: *Rotalidae, Globigerina s.p., Turborotalia s.p. and Heterostegina s.p.* has been identified. The main ortochem component is micrite. The under optic microscopy porosity is lower than 5 %.

The **Fantasy Bateig** is a biomicrite - biosparite that display a highest variability in the micrite/sparite ratio and percent of terrigenous, from one thin section to another. It is difficult to define the average of components, but may described as a mix of the previous described varieties.

Amphistegina s.p. and scarce *Globigerinidae* are present.

4 MECHANICAL PROPERTIES AND CHARACTERISTICS OF STONES.

A summary of physical properties and characteristics of Bateig varieties using criterium published by the Masonry Institute of America (M.I.T.), see Harbem & Purdy (1991), is contained in the table 2. The White, Blue and Diamond Bateig varieties may be classified as Medium Density Limestones, and Layer and Fantasy Bateig belong to Low Density Limestone type.

The sonic velocity of Bateig stone varieties is also contained in table 2. We tested using Lineal Regresion Analysis to compare sonic velocity (m/sec) values of Bateig stones varieties with compressive strength (Mpa) ones. The equation of the line is:

$$UCS(Mpa)=0,0262V(m/sec)-57,56$$

, the correlation coefficient, r = 0,71, and data number is up to 24.

The color measured using L*a*b* color system, recommended by CIE, over unpulished samples has been listed in the table 3. Color values reflected there are the average of 36 measures obtained from three samples for each Bateig type.

5. PORE SIZE DISTRIBUTION AND DURABILITY.

Pore size and pore volume distribution was obtained by Mercury Porosimeter data, Autoscan - 60. Mercury Porosimentry offers the possiblity to obtain data about porosity, pore size (from 213 μm to 0,0018 μm) and normalized volume vs diameter.

Table 3. Color measured using l*a*b* color system.

	W	B	L	D	F
L*	83,9	79,9	81,8	85,5	-
a*	,5	-0,1	1,3	0,7	-
b*	8,0	5,7	12,0	9,1	-

L* Black to White.
a* - green + red.
b* - blue + yellow

The data from Mercury Porosimeter may be used to stimate the stone durability. Thus may predict the behaviour of a stone during salts crystallization an/or hydratation and frost weathering.

The theoretic problem of the pressures of crystallization of salts in porous mediums was studied by Fittzer and Shethlage (1982) by analogy with the thermodynamics of the freezing of dissolutions in porous mediums, developed by Everet (1961). According to these authors the crystals of the saline phases show a preference to grow in large pores. When the crystallization of the saline phases in the large pores ceases, for having filled the available space, crystallization will then continue in the connected small pores.

When the phase minerals precipitate in the pore, the pressure of crystallization can be expressed, according to Fittzer and Shethlage (1982), as:

$$p=2\sigma\left(\frac{1}{r}-\frac{1}{R}\right)$$

, where p, is the pressure of crystallization; σ is the ionic interfacial tension salt-solution ; r and R are the radia of the coarse and small pores considered, respectively.

Following the method employed by Rossi-Manaresi and Tucci (1989), we may estimate the pressures of crystallization that can develope in the rocky materials. For this we have considered five intervals, or classes, of pores in function of the radius expressed in μm : class 1, r < 0.01; class 2, 0.01 < r < 0.1; class 3, 0.1 < r < 1; class 4, 1 < r < 10; class 5, 10 < r < 100. As centers of the classes of distribution we have considered respectively the values , 0.003, 0.03, 0.32, 3.16, and 31.6 μm.

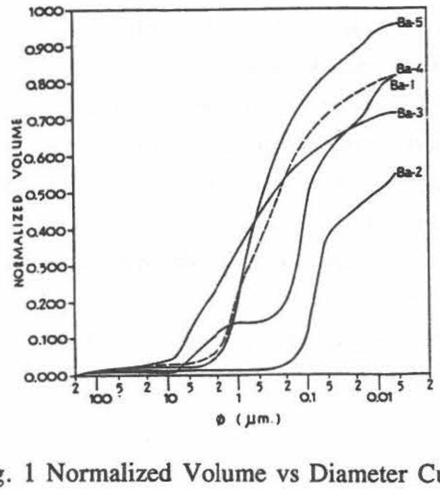
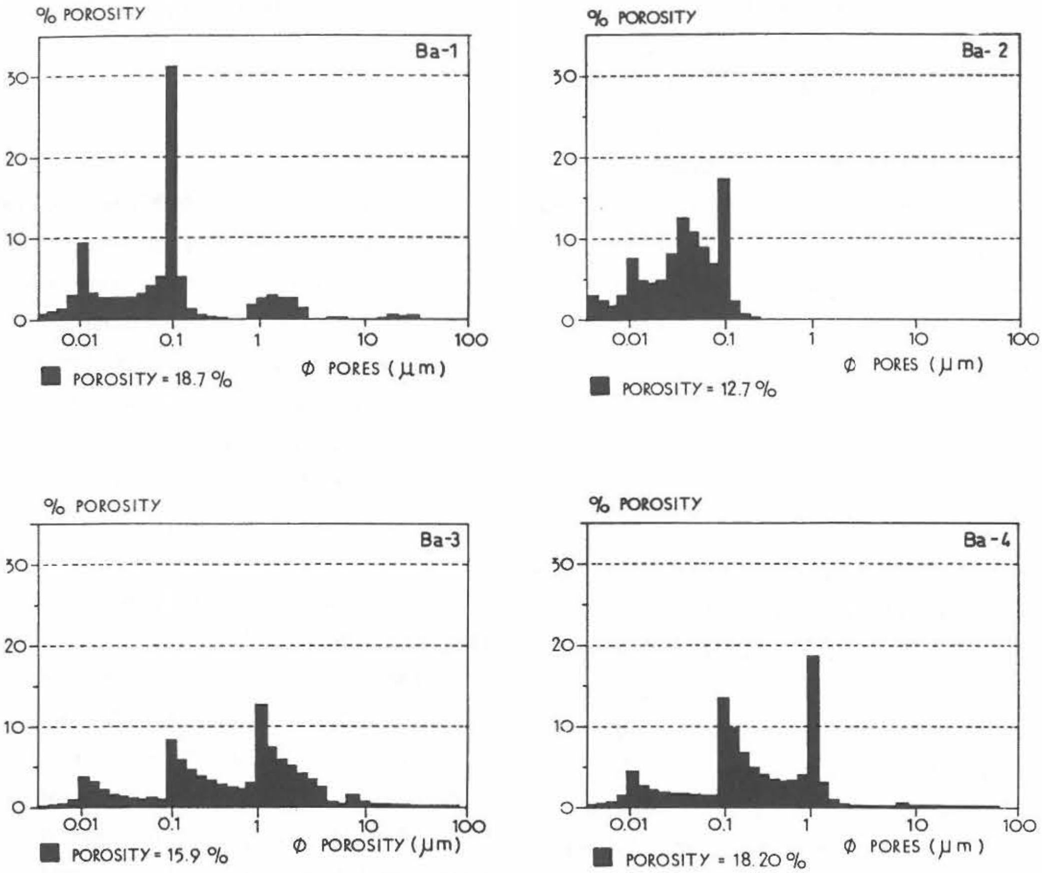


Fig. 1 Normalized Volume vs Diameter Curves of Bateig Stones varieties. Ba-1, White Bateig; Ba-2, Blue Bateig; Ba-3, Layer Bateig; Ba-4, Diamond Bateig; Ba-5, Fantasy Bateig.



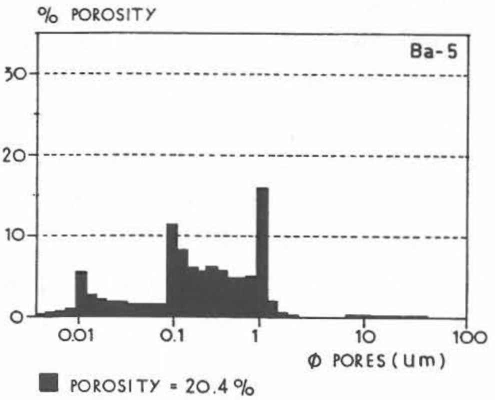


Fig. 2 Histograms of pore size diameter of Bateig stones.

Using the curve of the distribution of porosity in function of pore size (fig. 1), we can estimate the volume percentage of correspondant pores for each class or interval, La Iglesia & others (1992).

The sum of the effective pressures of all the classes will give us a total effective pressure that the material will support. From the above considerations we may define a Durability Dimensional Stimator, that may expresed as follow:

$$DDS=\Sigma\,[4\,(\frac{1}{d}-\frac{1}{D})\,\%V_d]$$

, $\%V_d$, is the percent of porosity of the class which center of class is the value d. The DDS values obtained, table 2, for different varieties of Bateig stone let us stablish that the microporosity, size pores less than 0,1 μm, is the main factor resposible for durability of materials, fig. 2. As a consecuence the treatments of material for improve the natural properties ought to diminish the microporosity. The necrosis of microporosity may obtained also with natural climatic conditions exposure during long time, as has been point out by La Iglesia & others (1991). The DDS values obtained for samples studied in this paper is contained in the table 4.

Table 4

1	2	3	4
W	64,64	18,7	35.0
B	85,82	12,16	31,27
L	62,88	15,90	22,05
D	51,05	18,20	35,41
F	22,10	20,40	30,07

(1)Durability Dimensional Stimation (m^{-1}).
(2)Percent of porosity.
(3)Uniaxial comprenssive strength (Mpa)

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