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Technological applications for Neoproterozoic-Cambrian limestones from northwest Argentina

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Abstract

Some rocks have been used as ornamental stones without knowledge of the natural material or its characteristics when included in agglomerates, or even those acquired during the benefit process. This study shows that prospection for ornamental stones should include studies of physical, chemical and mechanic properties that allow determination of its application to industrial merchant.

The Neoproterozoic-Cambrian limestones from Northwest Argentina extend along a wide area, with interesting sectors of low fracturation, being lack of oxidation and karst morphologies. High compression and bending strength values of this micrites, good engraved qualities, polished surfaces and cut facilities generate an important industrial interest for exploration and quarry development evaluation at Sierra de Castillejo.

Limestones abrasive and weather resistance, along with very fine-grain and porosity reduction due to cementation by the calcite veins framework, make them suitable for covers of high performance furniture and ornamentations in architectural designs. If fractured, they are suitable for paving tiles, sculptures, small ornamental stones, adornments, ordinary jewels, arids and lime formation.

Reserves at Sierra de Castillejo are equivalent to 20 year-production of the San Juan limestones and 11 year-production of the Córdoba marbles.

Keywords: Neoproterozoic-Cambrian limestones, Northwest Argentina, Prospection and quarry development evaluation, High-performance ornamental stones, Paving tiles and lime.

Introduction

The Neoproterozoic-Cambrian basement from Northwest Argentina is composed by clastic turbiditic sequences and carbonate subordinate successions, extending across Cordillera Oriental and Puna regions (Fig. 1). Carbonate sequences are exposed in diverse localities of Cordillera Oriental region, such as Sierra de Castillejo, Lerma Valley and Humahuaca Creek (Fig. 1). Ortiz (1962) and Salfity *et al*. (1976) defined them as Las Tienditas and Volcán Formations, indicating deposition on a carbonate platform environment. Oxygen and Carbon isotope analyses in these primary carbonates registered the Precambrian-Cambrian transition (Sial *et al*., 2001; Toselli *et al*., 2005).

These Proterozoic-Cambrian limestones and dolomites were exploded by lime, despite being less important than the Cretaceous due to lower extension. Rarely, they had been used in altar pieces of the San Alfonso Church, as interior coating in Alhambra V building both in Salta city (Argentina), and adornments for occasional commerce.

Intermediate to high compression, flexure and impact values of limestones, as well as good engraved qualities, polished surfaces and cut facilities due to their low abrasive characteristics, have generated an increasing industrial interest on these rocks. Durability in prestigious constructions, such as Burgos Cathedral (Spain), and its utilization as concrete aggregates and for lime and cement fabrication, open a wide field for prospection and extraction of these rocks. Then exploration of Neoproterozoic-Cambrian limestones for other technological applications than lime would be relevant.

In Sierra de Castillejo, the black limestones bring a mirrorlike polished surface (Fig. 2a) crossed by fine white veins, which make them very attractive for ornamental use. Tapia Viedma (1998) made reference to the economical importance of its ornamental and industrial use, estimating reserves in 28.608.331,414 tn. Considering this value equivalent to 20 years of limestones production of the San Juan Formation and equivalents (San Juan province) and 11 years of the Córdoba marbles, Neoproterozoic-Cambrian

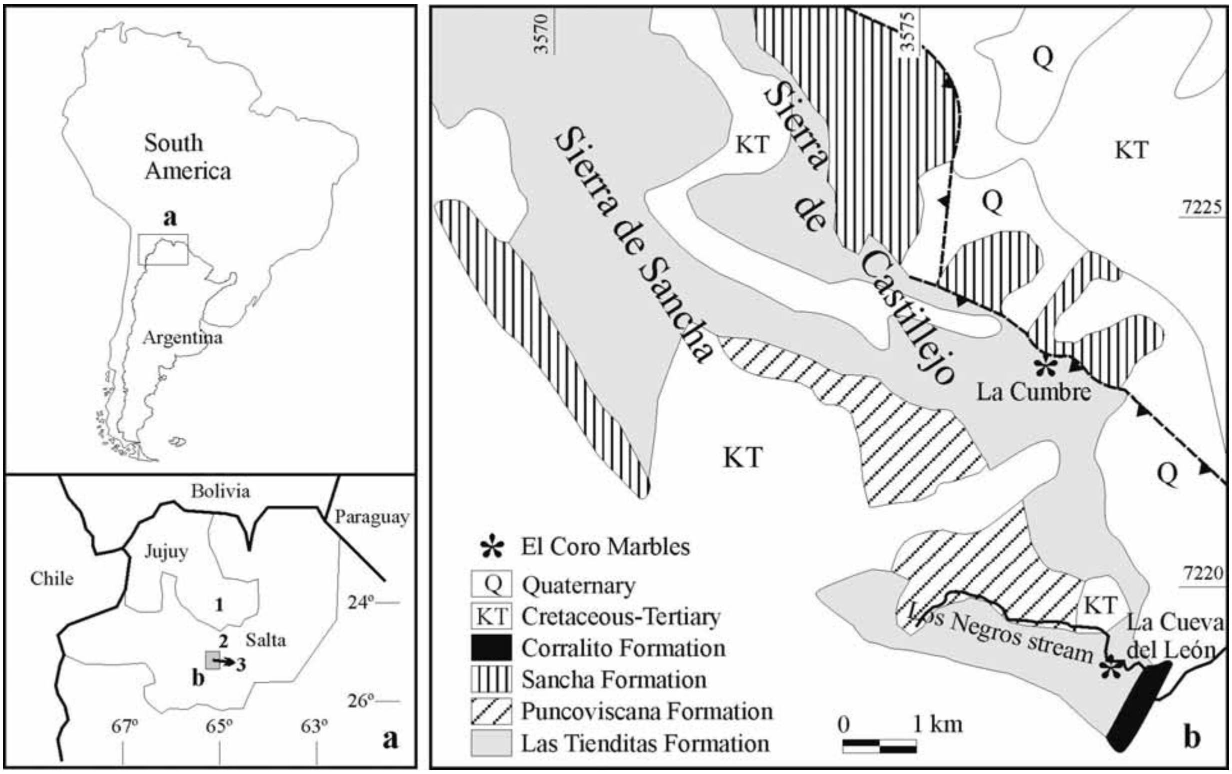

Fig 1 - a) Distribution of Precambrian-Cambrian facies of Northwest Argentina, at Cordillera Oriental region. 1: Humahuaca Creek, 2: Lerma Valley, 3: Sierra de Castillejo. b) Study area (modified from Tapia Viedma and Gorustovich, 2001).

carbonates of Sierra de Castillejo have a relevant interest for quarrying. Juri (1999) analyzed the development pre-feasibility of these calcareous banks, known commercially as 'El Coro Marbles' ('Mármoles El Coro'), but no other studies have been carried out.

The present contribution analyzes physical, chemical and mechanical characteristics of the Neoproterozoic-Cambrian limestones in order to determine its potential use as ornamentation stones that would help to continue prospection and exploitation stages. Investigation is set in Arroyo Los Negros area (Fig. 1b), localized in the eastern flank of the Sierra de Castillejo (Salta province, Argentina).

Methodology

Samples were taken from selected points over the outcropping carbonate sequence, based on exposure front and structural qualities, where a quarry would be developed. Stone properties were analyzed by three major points of view: i) physical, ii) chemical, iii) mechanical. Physical properties were studied on thin sections, under a Leitz Wetzlar ORTHOPLAN polarized-light microscope, equipped with a Leitz Wetzlar ORTHOMAP camera. Also an 11x11 cm paving tile was prepared for studying brightness and polishing properties, and ornamental qualities of the rock.

Chemical analyses were carried out at Laboratorio de Geoquímica – Universidad Nacional de Salta (Argentina), with X Ray Fluorescence equipment. Insoluble constituents were analyzed under a Wild Heerbrugg binocular lens, after treated with ClH [50] at room temperature.

Mechanical properties analyses were carried out in rocks from El Coro Marbles as detailed below; results are shown in Table 1.

Density

The density of the stone, expressed in mass per unit volume (gr/cm^3), was calculated using the I.S.R.M. norm (International Society of Rock Mechanics) at Instituto de Tecnología Minera (INTEMIN) - SEGEMAR (Córdoba, Argentina) from dry weight and volume of samples N^o 3306-

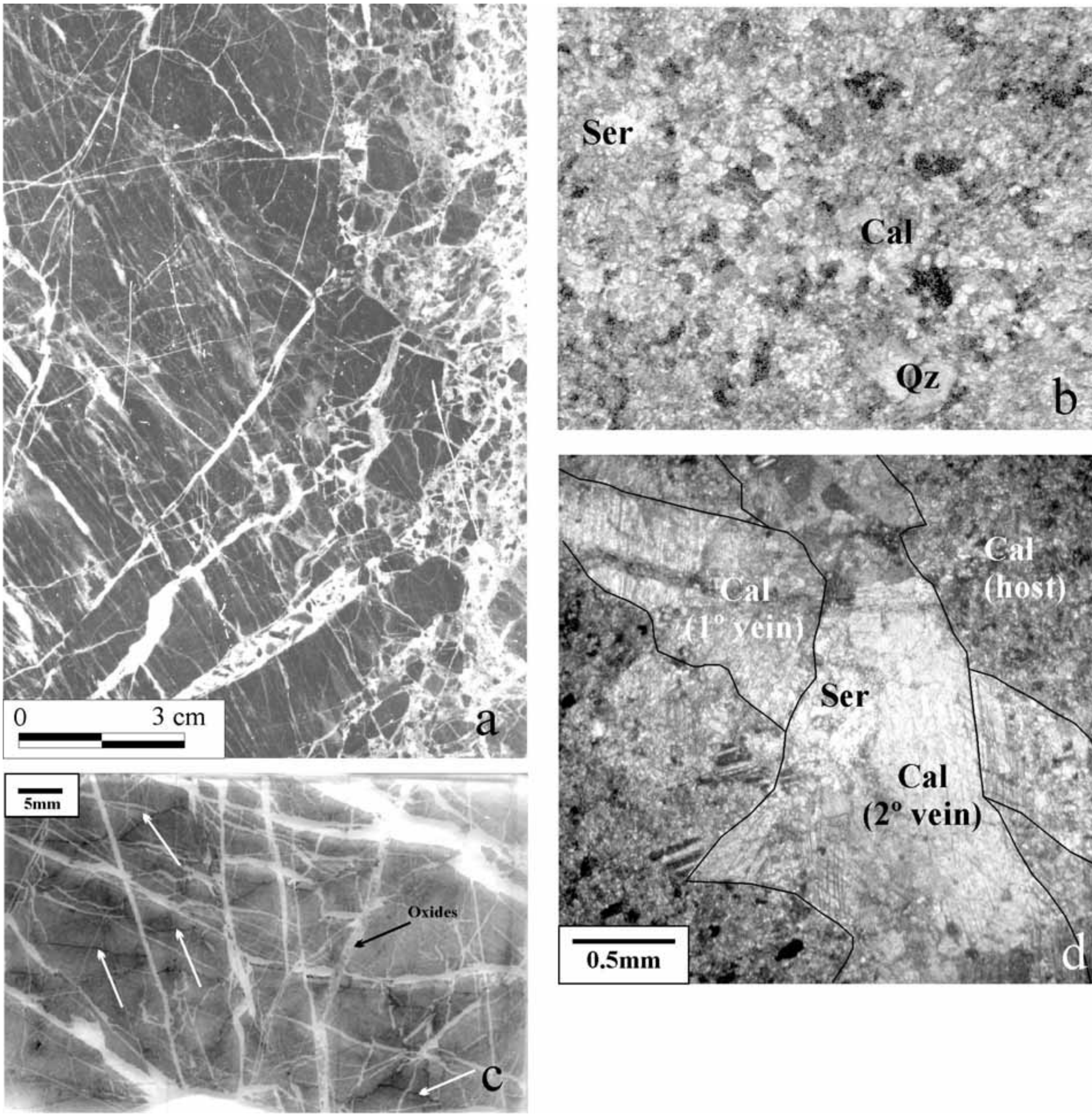

Fig. 2 - a) Polished surface of Las Tienditas Formation in Arroyo Los Negros area. b) Microscopic view of micritic texture. c-d) Calcite veins (white) and estilolites (black), cutting micrite.

319 (Table 1). It represents the density of the bulk rock, not of a crashed sample, and constitutes a quality control parameter, as an indicator of changes in a quarry, for example to more weathered (weaker) zones (Smith, 1999). Dry density, as well as water absorption, is considered a vital parameter for designing armourstone projects, giving information on volume filling and weight relations for the execution-induced properties of an armour layer (Smith, 1999). This method allows estimation of rock‘s behaviour outdoors and/or under water action, constituting the first appreciation of its quality.

Water absorption

This parameter was obtained at Instituto de Tecnología Minera (INTEMIN) - SEGEMAR

Relative natural density (I.S.R.M.)-Sample Nº 3306-319			
Subsample	Weight (gr)	Volume (cm^3)	Density (gr/cm^3)
TL 319-01	998.06	371.63	2.69
TL 319-02	985.39	371.49	2.65
TL 319-03	981.94	371.37	2.64
TL 319-04	1014.36	379.87	2.67
TL 319-05	983.33	369.10	2.66
TL 319-06	357.89	135.00	2.65
TL 319-07	421.85	161.00	2.62
TL 319-08	427.64	160.00	2.67
TL 319-09	327.70	122.00	2.69
TL 319-10	173.19	67.00	2.58
TL 319-11	1012.87	381.00	2.66
Average density (gr/cm^3): 2.65		Standard deviation (δ): 0.03	
* Brazilian marbles (gr/cm^3): 2.60-3.03 (Almeida Mendes and Hollanda Vidal, 2002).			

Water absorption (I.S.R.M.)-Sample Nº 3306-320			
Subsample	Massive limestones	Subsample	Fractured limestones
TL 320-01	0.197	TL 320-06	0.404
TL 320-02	0.198	TL 320-07	0.413
TL 320-03	0.242	TL 320-08	0.427
TL 320-04	0.256	TL 320-09	0.456
TL 320-05	0.265	TL 320-10	0.462
Absorption (%)	**0.231**	Absorption (%)	**0.433**
Average water absorption (%): 0.332		Standard deviation (δ): 0.11	
* Brazilian marbles (%): 0.01-1.01 (Almeida Mendes and Hollanda Vidal, 2002).			

Compression breaking load (Uniaxial Compression, ASTM C170-94)-Sample Nº 3306-317				
Subsample	Longitude (mm)	Wide (mm)	Thick (mm)	Tension (MPa)
TL 317-01	7.63	7.10	6.86	59.26
TL 317-02	7.56	6.97	7.05	62.93
TL 317-03	7.69	6.85	7.05	72.97
TL 317-04	7.60	7.03	7.11	75.89
TL 317-05	7.59	6.83	7.12	84.33
Average σc (MPa): 71.07			Standard deviation (δ): 10.11	
* Brazilian marbles (MPa): 37-214 (Almeida Mendes and Hollanda Vidal, 2002).				

Bending Strength (Flexure, ASTM C880-85)-Sample Nº 3306-318				
Subsample	Longitude (cm)	Wide (cm)	Thick (cm)	Tension (MPa)
TL 318-01	29.50	4.05	2.67	5.72
TL 318-02	30.00	4.07	2.62	4.43
TL 318-03	30.00	4.07	2.63	8.06
TL 318-04	30.00	4.09	2.66	4.45
TL 318-05	30.00	3.86	2.57	3.43
TL 318-06	30.00	3.85	2.61	2.10
Average σc (MPa): 4.36			Standard deviation (δ): 1.46	
* Brazilian marbles (MPa): 6-28.5 (Almeida Mendes and Hollanda Vidal, 2002).				

Abrasion resistance (IRAM 1539) -Sample Nº 1-4			
Subsample	Hardness coefficient D	Subsample	Hardness coefficient D
1	18.8	3	19
2	18.9	4	19
Average D: 18.9		Standard deviation (δ): 0.10	
* Concrete and asphalt rock aggregate D ≥ 18			

Tenacity (IRAM 1538) -Sample Nº 5-7	
Subsample	Tenacity T (cm)
5	13
6	13
7	11
Average T (cm): 12.3	Standard deviation (δ): 1.16
* Concrete and asphalt rock aggregate T (cm) ≥ 12	

Water absorption under ebullition (IRAM 1522, 11569 and 11571 modified)- Sample Nº 8			
Subsample (polished)	Longitude (mm)	Wide (mm)	Thick (mm)
8	135	110	20
Absorption (%)	**0.07**	Absorption under ebullition (%)	**0.07**

Table 1 - Index properties.

(Córdoba, Argentina) from samples N° 3306-320 (Table 1) following I.S.R.M. norm. The water absorption coefficient is the percentage of water absorbed in relation to dry weight of the sample under atmospheric pressure. This technique determines the quantity of water that rock could absorb when immerse, allowing estimation of its behaviour outdoors and/or under water action. For armourstone, water absorption is often used as a simple indicator of resistance to weathering, with stones usually being classed as less than 2-6 % (Smith, 1999). High absorption values indicate lower durability.

Compressive strength

Uniaxial compressive strength was carried out at Instituto de Tecnología Minera (INTEMIN) - SEGEMAR (Córdoba, Argentina) on dry square prisms samples N° 3306-317 (Table 1) following ASTM C170-94 norm. This parameter represents the measure of the load applied on a single axis that a stone can withstand without being crushed. Results of the compressive strength tests could be compared directly to the structural requirement of the application; for example, the load to be supported plus an acceptable safety margin (Smith, 1999).

Bending (flexural) strength

Norm ASTM C880-85 was applied on the dry samples N° 3306-318 (Table 1) at Instituto de Tecnología Minera (INTEMIN) - SEGEMAR (Córdoba, Argentina). This four-point bending test with two loading points is a measure of the strength that a rectangular sample supports at its ends and loaded at right-angles to its plane. Results of this test can be compared with the bending stress induced by the lateral loads on the proposed element, e.g. a cladding panel plus an acceptable safety margin (Smith, 1999).

Abrasion resistance

Dorry test was carried out at Laboratorio de Estudio y Ensayo de Materiales - Universidad Nacional del Sur (Bahía Blanca, Argentina) according to IRAM 1539 norm. Dry samples were subject to abrasion on a spinning disc with sand and water for 1000 turns each side (Dorry machine). Hardness coefficient is determined based on weight loss of dry sample.

Hardness coefficient D was calculated from initial dry weight (grs) and final dry weight (grs) through formula: D= 20- (wi-wf)/3. Although abrasion is usually negligible in vertical surfaces, it is an important factor to be considered in stone selection for flooring and paving (Shadmon, 2004). The results can give a relative value for the rate of wear during foot traffic compared to different stones. It is difficult to interpret the results in absolute terms, e.g. mm per year per million people (Smith, 1999).

Tenacity

This parameter indicates rock resistance to impact and was evaluated following IRAM 1538 norm at Laboratorio de Estudio y Ensayo de Materiales - Universidad Nacional del Sur (Bahía Blanca, Argentina). Dry samples were tested until appearance of the first fissure under the impact of 2 kg steel hammer (Page machine) released from increasing height with 1 cm intervals.

Absorption under ebullition

Laboratorio de Estudio y Ensayo de Materiales - Universidad Nacional del Sur (Bahía Blanca, Argentina) according to norm IRAM 1522, 11569 and 11571 modified evaluated water absorption of the polished sample by immersion into 20° C water and after 3 hours immersion into boiling water. Result of this assay allows prediction of stone marking during wear and is related with stone absorption. Since most common oils can be absorbed through porous surface, stone cleanability increases when polished finish is applied.

Geological setting

The Neoproterozoic-Cambrian basement from Cordillera Oriental (Northwest Argentina) was defined as the Lerma Group (Salfity *et al*., 1976), and is constituted by sedimentary and meta-sedimentary rocks, occasionally intruded by Proterozoic-Cambrian granitoids. It conforms a marine psamo-pelitic succession, intercalated to polimictic conglomerates and limestones, intruded in basal sections by alkaline ultra-potassic dykes and volcanic flows interpreted as the initial intraplate rifting (Omarini *et al*., 1999).

Conglomerates of Corralito Formation (Salfity *et al*., 1976) are commonly associated to the bottom of the sequence. The clastic sequences of the Puncoviscana Formation include turbidite to shoreface successions containing Neoproterozoic-Cambrian trace fossils (Aceñolaza, 1973; Durand and Aceñolaza, 1990; Jêzek, 1990; Buatois and Mángano, 2004), whereas zircons of silicic volcanic provenance indicate 530 Ma for sedimentation times (Lork *et al*., 1990).

Carbonate successions are concordant over diamictites or interbeded within the clastic sequences, and were assigned to Las Tienditas and Volcán Formations (Ortiz, 1962). They are dark blue to black limestones, locally dolomitic, brachiated, which include carbonaceous material and are cut by fine carbonate and quartz veins. In Sierra de Castillejo (Fig. 1), where the present study was developed, the calcareous basement is represented by Las Tienditas Formation, which integrates limestones interbedded with thin pelitic levels that transitionally pass to black organogenic limestones (Iturriza, 1981; Seggiaro, 1980). Lithostratigraphic framework allowed Toselli *et al*. (2005) to assigned these to "cap carbonates" sequences related to the post-Marinoan glaciation period.

Metamorphism occurred only in the clastic sequences by 575-521 Ma and was accompanied by granites intrusions (Bachman *et al*., 1987), both related to continental collision during the Middle Cambrian (Rapela *et al*., 1998). Thermodynamics recorded maximum P-T of 400-450 ^{o}C and 5-7 kb (Do Campo, 1999), whereas sometimes they show no-metamorphism (Turner, 1960).

In clear discordance over this basement, Cretaceous- Tertiary basin was developed (Salta and Orán Groups) being lately deformed during the Neogene. Quaternary sediments covered the whole stratigraphic sequence with alluvial fan facies and fluvial deposits. Sierra de Castillejo has the structure of an East-vergent fold-and-thrust sheet, in which Las Tienditas and Puncoviscana Formations lie over Tertiary and Quaternary sediments (Fig. 1).

Physical and chemical properties

Black microcrystalline limestone (Las Tienditas Formation)

It is formed by medium to fine grain calcite, accompanied by 0.5 mm-size plagioclase (polisinthetic twined albite), quartz and fine sericite (Fig. 2b). Calcite conforms 95 % of the rock, leaving an insoluble residue (< 4.5 %) when treated with ClH [50]. It consists of clay minerals (sericite), bipiramidal quartz, plagioclase with oxide inclusions, minor gypsum and a colloidal material of possible organic nature.

Calcite develops a microcrystalline texture with occasionally esferulitic granules of micritic calcite at the nucleous, surrounded by radial calcite and Fe-oxide-bearing out borders. Some irregular levels of Fe-oxides showing dentate morphologies are found cutting the rock as estilolites (Fig. 2c). This feature indicates compaction and pressure-solution process during diagenesis. Metamorphism episodes are discarded in order to textures observed. According with clastic fragments content and calcite textures the rock is classified as mudstone or microcrystalline limestone - micrite (Dunham, 1962; Folk, 1959, respectively).

An important net of calcite veins acts like a tight cementation for original micrite, as well as brachiated calcite-cemented veins, as shows Figure 2a (right).

The carbonate fraction of Las Tienditas Formation is mainly $CaCO_3$ with minor $MgCO_3$ (CaO > 50 %, MgO: 1-3 %, calcinations' loose-PPC > 40 %), with trace elements pointing to a passive margin environment (López de Azarevich *et al*., 2006).

Low MgO and SiO_2 make these rocks appropriate for lime and cement fabrication. Excess of those components can make the rock react with cement-derived alkali during or even after a paving tile preparation. Consequent crystallization of brucite would produce expansion and blistering. Fortunately, this is not the case of El Coro Marbles.

Calcite veins

The microcrystalline limestone is cut around 4 mm thick by an important vein framework, whose cutting angle varies widely (Figs. 2a and d). Veins are composed by coarse- pseudopoligonal calcite, polisinthetic partially sericitized plagioclase, anhedral undulose quartz and fine sericite patches. Occasionally, Fe-oxides are associated to these veins (Fig. 2c).

Deformational stress and kinking are recognized within calcite crystals, perpendicular to the vein walls, suggesting syn-kinematic crystallization. Structural and sequential arrangement suggests a first diagenetic event that produced a first episode of vein development cut by estilolites (Fig. 2c). A second event of vein intrusion related to hydrothermal process accompanied by brachiated micrite cemented with fine calcite (Fig. 2a, right) occurred nearby shear structures.

As veins are as hard as micrite they do not represent polishment disparities, giving a unique and smooth mirror-like surface.

Mechanical properties

Fracture framework

According to published data of the structural setting at Sierra de Castillejo (Seggiaro, 1980; Tapia Viedma and Gorustovich, 2001) and field works, industrial qualities of the Neoproterozoic-Cambrian limestones can be measured in terms of fracturation patterns.

Microfracturation is evident on meso- and micro-scale analysis (Fig. 2). This interpenetrating pattern is filled by diagenetic-derived carbonate veinlets (López de Azarevich *et al*., 2006), thus cohesion is enhanced to initial carbonate properties.

Structural restrictions consist in relatively short fracture intervals of 0.1 to 0.5 m, occasionally 1.5-3 m, especially nearby the shear zones (N295^o to N337^o; Fig. 1). Geometric patterns arise from orthogonal to 45^o cut-angles of joint pairs, giving good perspectives for its exploration as ornamental and industrial stones.

Density

Density oscillates from 2.62 to 2.69 gr/cm^3, between usual range for compact limestones and marbles (2.4-2.8 gr/cm^3), and equivalent to other fine to very fine grain Cambro-Ordovician or Devonian limestones and dolostones, and the Carrara Marble (2.71 gr/cm^3; Fredrich *et al*., 1989). Constant density along the calcareous bank makes these rocks appropriate for a preferential industrial use in terms of homogeneity.

Water absorption

These tests give values of 0.231 % for massive limestone and 0.433 % for samples with partially cemented discontinuities. Obtained values are higher than marbles's average and much lower than limestones's average (0.2 and 0.9 %, respectively). In spite of this, they are highly below the maximum 10 % accepted for calcareous tile pavement (IRAM 11560, 1970), and the < 3-12 % specified for low to high density limestones by the ASTM norm.

Compression breaking load

This parameter is 71.07 MPa in average, similar to Silurian, Carboniferous and Miocene limestones from U.S.A. (Carr *et al*., 1994), which are fine grained or fossileferous, and to Precambrian marbles and siliceous limestones. Obtained values are also comparable to some granites from Protugal (Casal Moura, 2000), characterized by foliation or oriented megacrysts.

El Coro Marbles compression breaking load shows values below of that of the Carrara Marbles (95 MPa; Fredrich *et al*., 1989) but much above the specific minimum limit for calcareous rocks used for ornamentation informed by ASTM norm (52 MPa for marbles and 55 MPa for high density limestones). This fact is due to its chemical and mineralogical characteristics, cohesion, deformation conditions and granulometry.

Bending strength

Variability of bending strength values (2.10 to 8.06 MPa) is notable influenced by microstructural condition of the samples: weakness is in association with more porous zones, which coincide with partially cemented discontinuities. Maximum values are equivalent to those obtained for foliated feldspar-megacrysts bearing granitoids and non foliated granites from Portugal that show values of 6.47-9.71 MPa and 10–25 MPa, respectively (Casal Moura, 2000). All of them are used as application stones, and together with the cubication made by Tapia Viedma (1998) in Sierra de Castillejo, carbonates of Las Tienditas Formation have very good perspectives for commercialization. Minimum flexure of 3 MPa is accepted by IRAM 11560 (1970) for calcareous tile pavement, which is below calculated average (4.36 MPa).

Abrasion resistance

Values obtained for D coefficient, above 18, imply that El Coro Marbles have excellent resistance to foot traffic being especially apt for paving tiles since they would maintain their original appearance for a larger period of time. This attribute in conjunction with uniform behavior of different tested samples ensure an optimum performance for flooring and coating. Abrasion characteristics of these rocks are also comparable to those required for concrete and asphalt rock aggregates what make small rock pieces from the exploitation front viable for construction industry commercialization.

Tenacity

Average tenacity of samples results higher than 12, indicating high resistance to impact of falling elements over paving tiles. Along with abrasion resistance, tenacity values make El Coro Marbles qualify for construction industry.

Water absorption under ebullition

Tested polished samples give identical levels of 0.07 % for water absorption at room temperature and under ebullition reflecting that absorption conditions are not affected by aggressive uses. Observed differences with water absorption of massive samples are due to the surface treatment. In the other hand, polished marbles offer good cleanability qualities for paving and flooring applications.

Industrial aptitude and commercialization

The studied lithological unit shows a black matrix with white veins inherent to the coloration of calcite and amber and ochre-coloured veins with a touch of oxide-orange due to pigmenting elements.

Polished surface of El Coro Marbles appears pleasant to the eye, very soft to the sense of tact and transmits the feeling of warmth, elegance and sophistication.

The industrial quality of El Coro Marbles (Las Tienditas Formation) allows establishing the following categories, according to dimensions of the obtained blocks:

1. First quality: high-value ornamental rock in huge blocks (3-5 m^3).
2. Second quality: industrial limestone in ornamental blocks ($\sim$1 m^3).
3. Third quality: rock for building, with small volumes as consequence of fracturation.
4. Fourth quality: rock for small scale adornments for artisan use.
5. Fifth quality: aggregates used for concrete and reconstructed paving tiles, and lime.

Commercial system for Precambrian-Cambrian limestones depends on their destiny. If they are used as ornamental stones, then could be merchantable as first and second quality blocks: i) Blocks of 3.00x1.50x1.00 m with three faces that allow plates cut (Tourn and Castro, 2003); ii) Irregular blocks that occasionally show two planes, which are destined for paving tiles, sculptures, small ornamental stones, ash holes, adornments and paper weights. Three meters-long plates could be used for covering of high performance furniture or as ornamentations in architectural designs (Fig. 3).

Plates are sold in different sizes (Tourn and Castro, 2003) and with different specifications: i) With a polished 0.02 m-thick face and rustic borders; ii) With a polished 0.02 m-thick face and a cut border; iii) Polished and cut by order form, 1.20 to 3.00 m-long, 1.00-1.50 m-wide and 0.0015-0.002 m-thick; iv) Polished and cut by order form, for especial works such as false joints, rounded borders, anchor or stopcock holes, between others. When destined for paving tiles, they are sold with a polished face, beveled and calibrated, cut by order form between 0.30x0.30x0.01 m and 0.61x0.61x0.127 m.

Third and fourth quality blocks are irregular and could be obtained from the exploitation front, especially when highly fractured, or during the cutting and trimming. They are used in cement agglomerated paving tiles, small adornments (ashtrays) and ordinary jewels (rings, earrings, key rings).

When destination for arids and lime, blocks are transported from the quarry to the treatment plant to be processed and reimbursed for its commercialization.

Discussion and conclusions

El Coro Marbles are equigranular very fine grain limestones with homogeneous chemical and mineralogical composition. Despite no metamorphism affected Las Tienditas Formation, it is very fine-grained and notably cemented, which made porosity reduced. White calcite veins cross cut this rock, whose hardness is equivalent to micrite. Then they do not generate polishment

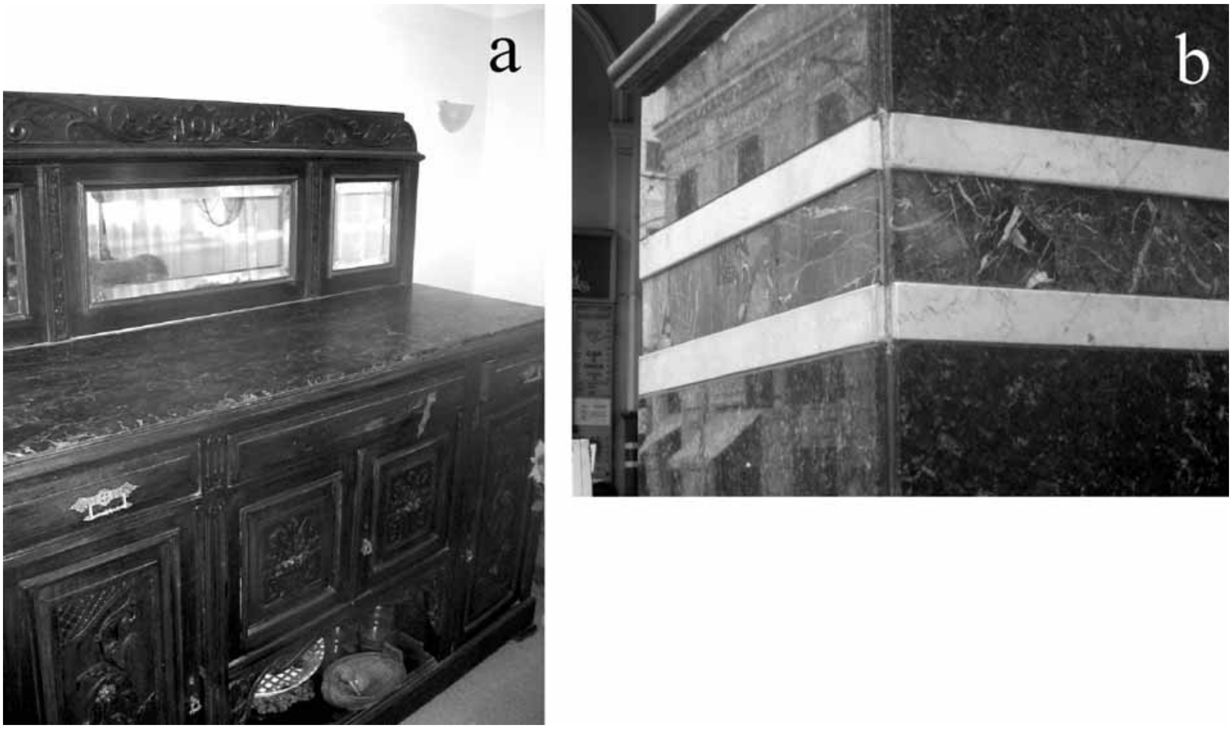

Fig. 3 - a) High performance furniture. See calcareous rock as cover. b) Ornamentations in architectural designs. See calcareous rock in the middle column.

disparities, giving a unique and smooth mirror-like surface of sophisticate ornamental stone. Such qualities of cementation and packing of natural structure give high intrinsic cohesion that makes it apt for construction and ornamental use, with high durability rates.

Products derived from exploitation of El Coro Marbles will be suitable for merchant in terms of huge areas with relatively low fracturation, and lack of oxidation and karst morphologies.

Chemical, physical and mechanical properties of El Coro Marbles suggest these rocks are adequate for many industrial, architectural and artisan use, with widely more range of application options than lime.

Application for flooring would be one of the most sophisticated uses, together with coating in special designs for buildings. Stone requirements for flooring depends on its resistance to stress, abrasion, impact and environmental chemical agents; flexural strength is particularly important for paving that take the eccentric loads especially of heavy traffic.

Polished surface is adequate to human traffic, especially in entrance halls and star-rooms of buildings which need an elegant environment for people.

Although limestones and marbles are used mainly for interiors, their application in outdoor (exterior) paving is increasing due to its lower cost and architectural preferences. For example, travertines have been used in recent sidewalk in 45th Avenue in New York. Other varieties used for flooring or paving internationally include Carrara Marble, Trani Chiaro, Botticino and Tennessee Limestone.

Technological aptitudes are comparable to medium grain granites from Portugal (Casal Moura, 2000), being better than those calibrated by IRAM system for paving tiles, better than ASTM norm and equivalent to Brazilian ornamental marbles (see Table 1). Then a wide merchant for calcareous products derived from quarry development is open.

Blocks of 3-5 m^3, 1 m^3 and plates of 3 m long have very good aptitudes for covers of high performance furniture or as ornamentations in architectural designs. Smaller irregular plates and blocks could be destined for paving tiles, steps, sculptures, small ornamental stones and adornments. If destined for paving tiles, a polished face of 0.30x0.30x0.01 m to 0.61x0.61x0.127 m is needed. When highly fractured, micrite is used in cement agglomerated paving tiles, small adornments, ordinary jewels, arids and lime formation.

Durability of the stone is dependent on its location as regards exposure in architectural structures, and mainly due to its hydraulic behaviour in terms of such properties as water absorption. Microcrystalline texture and cementation by calcite veins give these rocks additional compaction that diminishes porosity and hydraulic problems associated.

With respect to uses in exterior paving or coating in urban centers affected by high grade of pollution, application of malonato ions would protect limestone and marbles from weather conditions, closing the microscopic porosity that could make them sensible to acid rain (Salinas-Nolasco *et al*., 2004). Authors affirm that presence of a malonate adsorptive layer on calcite generates an interface interaction potential that may influence the reaction and transport mechanisms within the medium.

Absence of environmental protected zones and natural reserves, good accessibility and distance from villages and cities make Sierra de Castillejo Precambrian-Cambrian limestones suitable for quarry development. This would constitute one of the most important industrial activities for local citizen, since no other industry but limited animal farm are emplaced in the area.

Reserves at Sierra de Castillejo are equivalent to 20 year-production of the San Juan limestones and 11 year-production of the Córdoba marbles (Herrman and Menoyo, 2000), ensuring at least 10 years of high ornamental and industrial limestone production.

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