The Piedra Berroqueña region: candidacy for Global Heritage Stone Province status

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SUMMARY

The Piedra Berroqueña region in the Guadarrama Mountains, part of Spain's Central Range, supplies most of the construction granite used in Madrid and surrounding provinces. The region's quarrying towns conserve their granite extraction and hewing traditions. Historic quarries form part of the landscape, as do current extraction sites with huge reserves that guarantee a speedy supply of variously finished dimension stone.

Piedra Berroqueña granite has been in use as a construction material since long before Roman times. Many emblematic monuments, including San Lorenzo Royal Monastery at El Escorial (1563-1584), Madrid's Royal Palace (1738-1764), the Alcalá Gate (1770-1778), the Prado Museum (1785-1808) and Puerta del Sol (one of Madrid's main squares) owe their good state of conservation to the stone's petrophysical characteristics and durability. This granite is also found on most of the city's housing and streets, as well as modern buildings the world over, such as the airport terminals at Athens and Cork and the British consulate at Hong Kong.

This paper supports the Piedra Berroqueña region's application for nomination as a Global Heritage Stone Province. It also discusses the petrographic and petrophysical properties of five representative granites that share many characteristics, including their

grey tones and the presence of approximately spheroid nodules. The location of historic quarries is shown for possible future use of the material in restoration works.

The Piedra Berroqueña region meets the requirements for nomination as a Global Heritage Stone Province, a distinction that would enhance public awareness of an area committed to quarrying and working the local stone.

INTRODUCTION

The Piedra Berroqueña region occupies an area of about 100 km long by 40 km wide, part of which lies in the Guadarrama Mountains National Park, in the eastern branch of Spain's Central Range. It runs southwest-northeast across the provinces of Madrid, Segovia and Ávila.

"Berroqueña" stone, a name that comes from the Spanish word "berrueco" or an outcrop of granite boulders, is the granite traditionally used in regional construction.
Many towns in the Guadarrama Mountains, particularly in the province of Madrid, engage in quarrying, hewing and shipping granite. The mainstay of the area's economy for centuries, its importance is mirrored in the stone-related etymology of some of the local place names: such as Alpedrete (stone in Spanish is *piedra*), Berrocal (in Spanish, a place where granite boulders outcrop) (Llorente, 2011), Moralzarzal and Valdemorillo (based on the pre-Roman roots "mor(r)" or "mur(r)", meaning a pile of stones).

Traditional quarrying in the towns forms part of the province of Madrid's intangible heritage, as attested to by the many festivals honouring St Peter, the monuments to and courses on the trade and quarrymen's competitions (Fig. 1).

Most of the 2 000 historic quarries in the province of Madrid are small and shallow because the stone was traditionally removed manually from the top of the outcrops (to depths of approximately 1-1.5 m). Whereas in the past, quarrying consisted of removing only whale-back formations (granite boulders) (Fig. 2a), more recently, with their gradual depletion, extraction has involved quarrying at greater depths (Fig. 2b). Today traditional family-run quarries co-exist with the mechanised variety (Fig. 2b). Piedra Berroqueña began to be used internationally in the twentieth century. By mid-century, approximately 21 000 000 tonnes of Piedra Berroqueña had been removed from historic quarries and used as a construction material in Madrid (Martín, 1994). In 2011, 5 573 450 tonnes were exported (AIDICO, 2012). Cadalso de los Vidrios and Bustarviejo – La Cabrera are the two main quarrying areas presently in use. Their granite has been used in emblematic buildings the world over (Table 1). This stone, along with other materials (Fort, 2008), was used on key heritage buildings in the centre of the province (Table 1) and in nearly all the residential buildings in the capital city's historic quarters, as well as to make pavers, cobblestones, manhole lids and urban furniture (Martín, 1994).

Since Casiano de Prado y Vallo published his *Descripción Física y Geológica de la provincia de Madrid* (physical and geological description of the province of Madrid) in 1864, many scientific articles have appeared on Piedra Berroqueña: on its origin (Villaseca et al., 1998, 2009, 2012; Villaseca and Herreros, 2000), petrological (Gómez-Heras et al., 2008) and petrophysical (Fort et al., 2011, 2013a) characteristics; durability (Gómez-Heras, 2005; Fort et al., 2011; Freire-Lista et al., 2015a, 2015b, 2015c); and on the buildings for which it was used (López de Azcona et al., 2002; Fort González et al., 2004, Fort et al., 2010; Menduiña and Fort, 2005; Pérez Monserrat and Fort González., 2004).

The granitoid plutons of the Piedra Berroqueña region (Brandebourger, 1984) consist of Carboniferous-lower Permian, late- to post-orogenic monzogranite (De Vicente et al., 2007). Four major types of monzogranite occur: biotitic monzogranites with some cordierite, biotitic monzogranites with some amphibole, biotitic monzogranites with no cordierite or amphibole and leucogranites.

Monzogranite normally generates flat, braided, landscapes with boulders or tors. Leucogranites, with smaller grain size, form more rugged landscapes with subvertical fracturing, resulting in greater topographic relief.

Piedra Berroqueña monzogranites have mafic inclusions of essentially two types: xenoliths unrelated to granite magma (such as orthogneiss, metapelite or schist fragments) and igneous mafic microgranular nodules (Villaseca et al., 1998), for which the region's quarrymen have a number of terms: *gabarros, negrones* or *manchones* (smooth-edged nodules, black spots, or stains).

Global Heritage Stone Province (GHSP) status for the Piedra Berroqueña region is proposed in light of its quarrying tradition and history and the use of its stone. It provides appropriate detail for GHSP assessment, describing the petrophysical and chemical properties of granite and the economic and cultural importance of quarrying this stone throughout history.

METHODOLOGY

Petrophysical data were compiled on five granites representative of historic or active quarries in the Piedra Berroqueña region that have been widely used in Madrid (Fort et al., 2013b). These included granites from Alpedrete (monzogranites with cordierite, Freire-Lista et al., 2015b), proposed as a Global Heritage Stone Resource (Cooper, 2010, 2013a, 2013b, Hughes et al., 2013); Cadalso de los Vidrios (leucogranite); La Cabrera (monzogranite with amphibole); Colmenar Viejo and Zarzalejo (monzogranites with no cordierite or amphibiotite) (Freire-Lista et al., 2015d), also it was proposed as a Global Heritage Stone Resource.

To quantify the decline in their petrophysical and strength values, they were exposed to freeze-thaw testing as specified in European standard (with 280 cycles) (UNE-EN 12371, 2001, Freire-Lista et al., 2015a).

HISTORIC USE OF PIEDRA BERROQUEÑA

The earliest artistic expressions in the Piedra Berroqueña region are found in a nook in the Aljibes caves (Priego, 1991), where granite walls serve as a substrate for paintings that date from 1500-1200 BCE. The Neolithic dolmen at Entretérminos (Losada, 1976) and the burial mound at Las Vegas de Samburiel (Gil, 2013) are other examples of the pre-Roman use of Piedra Berroqueña. The Romans used it to build a road from Cercedilla to Segovia, remains of which have been conserved, as well as bridges at Colmenar Viejo and a building at Collado Mediano, now an archaeological site. The

Colmenar Viejo Municipal District (Colmenarejo et al., 2005) hosts remains from the Visigoth period (fourth to eighth centuries).

The mountains in the Piedra Berroqueña region form a natural barrier that has been the site of a number of important battles. For centuries, it was a frontier that divided the Christian and Muslim kingdoms, respectively, to the north and south. In Muslim times, watchtowers were built in places such as El Berrueco and Buitrago de Lozoya. The latter town's historic centre was listed as a historic-artistic compound and its castle as a cultural heritage asset, both in 1993, while its walled enclosure has had national monument status since 1931.

It was not until the permanent conquest of Toledo by the Christians in 1085 that monastery-fortresses, churches and castles were built with Piedra Berroqueña. In the Middle Ages (seventh through fifteenth centuries), the materials used were the ones closest to population centres. In 1475, work began on the Manzanares el Real castle (listed as a historic-artistic monument in 1931) with local leucogranite. Pedraza's historic core, built with Piedra Berroqueña, has had monumental compound status since 1951. Madrid's designation as the capital of the Kingdom of Spain in 1561 and the construction of the Royal Monastery at El Escorial between 1563 and 1584 marked the beginning of the widespread use of Piedra Berroqueña throughout the region of Madrid (Fort et al., 2011).

In 1749 work was completed on a new paved road from the Guadarrama Mountains to Madrid. This improvement in communications increased the volume of granite shipments to the city. In the eighteenth century nearly all the inhabitants of the Piedra Berroqueña region engaged in quarrying or shipping the stone (Marqués de la Ensenada, 1752).

Royal architect Francisco Sabatini drafted a code that called for paving the streets of Madrid with Piedra Berroqueña, which was approved in 1761. The respective municipal ordinance enacted that same year generated a growing demand for this dimension stone. After the city's Plaza Mayor (main square) burned down for the third time in 1790, it was reconstructed with Piedra Berroqueña, which was also used to build the Prado Museum (1785-1808). The Battle of Somosierra, fought and lost in 1808 during the War of Independence against the French, cleared the way for Napoleon's troops to enter Madrid. A small fort built with Piedra Berroqueña on the battlefield has been conserved and today is a cultural heritage asset. During the reign of Joseph (Bonaparte) I (1808-1813), and later, a town planning ordinance required all buildings to have a dado consisting of three rows of Piedra Berroqueña ashlars (Cabello y Lapiedra, 1901). The stone was also one of the materials used to build the network of optical telegraphic communication towers between Madrid and Burgos, undertaken in 1836 (Olivé, 1990).

A substantial number of Piedra Berroqueña quarries were opened in the mid-nineteenth century to build the Isabel II Canal that carries water from the Guadarrama Mountains to the city of Madrid. That project entailed the construction of a host of hydraulic infrastructures, such as the Amaniel aqueduct, a neo-Gothic tower, the reservoir at Manzanares el Real (Unceta and Echenagusía, 2005) and bridges. Improvement works were also conducted on the road between the quarries and the capital city.

Oxen were used to carry construction granite from the Piedra Berroqueña region through to the twentieth century, albeit less and less commonly, for trains and later lorries were used starting in the nineteenth. To meet such high demand, an 11-km railway line operated for 73 years (1883-1956), exclusively to ship Alpedrete granite from the quarry to Collado Villalba station (Aranguren and Lópes, 1990). Railways lowered the cost of shipping the material, just at the time when most of Madrid's quarters were being built and summer homes were going up in the mountains. The dados on Madrid's municipal slaughterhouse (1910-25) and bullfighting ring (1920-29) are made of Piedra Berroqueña.

When the Sociedad de Sacadores de Piedra de la Sierra (society of stone extractors) and the Sociedad Construcciones Hidráulicas y Civiles (hydraulic and civil construction society) were founded in 1914, Alpedrete region became the area's leading producer of Piedra Berroqueña. The harsh working conditions, in conjunction with the large number of workers engaging in quarrying Piedra Berroqueña, led to a strike in 1930 backed by over 1 000 quarrymen. The prevalence acquired by the Piedra Berroqueña region was symbolised by the 1932 unveiling of the Fountain of the Geologists, made of Piedra Berroqueña. The monument was a tribute to geologists Casiano del Prado, José Macpherson, Salvador Calderón and Francisco Quiroga, who had pioneered the study of this stone, fostered scientific research in the Guadarrama Mountains and placed the region on the cultural map.

The building christened as “los Nuevos Ministerios” (new ministries), one of Madrid’s largest, was erected with Piedra Berroqueña from 1931 to 1942 (Maure, 1985). While building construction, and with it work in the quarries, waned during the Spanish Civil War (1936-1939), the war itself left a considerable heritage of trenches, shelters, observatories and forts scattered across the region. Alpedrete granite resisted the ravages of war, although bullet holes are still visible on the ashlars in some of Madrid’s heritage buildings (Pérez-Monserrat et al., 2013) (Fig. 4f).

The granite quarried in 1940-50 was used to rebuild Madrid and erect the “Valle de los Caídos” (Valley of the Fallen) monument (Méndez, 2009). Beginning in 1960 output rose substantially to meet the city’s huge demand for granite for buildings such as the National Mint, finished in 1964.

The stone quarried today is used primarily in flooring (García del Cura et al., 2008), pavers and funerary art and for export and restoration and rehabilitation works in the region of Madrid. The key production centres are La Cabrera (LA), which markets its stone under the trade name Blanco Perla, and Cadalso de los Vidrios (CA), the home of Blanco Cristal.

The granite is also quarried at Zarzalejo (ZA) and trades under the name Blanco Rafaela, although output is much smaller. This stone was used to reconstruct Moncloa Palace (residence and office of the President of the Spanish Government), renovate the Royal Palace, build the entrance and buildings in the IFEMA fairgrounds and erect the Queen Sofia Museum, among others.

Historic Piedra Berroqueña quarries at Alpedrete (AL) and Zarzalejo (ZA) supplied the granites used in many heritage buildings (Table 1).

HERITAGE ISSUES:

Piedra Berroqueña has not only been used in art and building construction, but has also been cited in literature since the Middle Ages by travellers crossing the Guadarrama Mountains. Pinciano Hernán Núñez’s 1555 compilation of sayings includes one on the durability of Piedra Berroqueña. The Piedra Berroqueña region was mentioned in the second half of the nineteenth and first quarter of the twentieth centuries by authors such as Francisco Giner de los Ríos (1839-1915), Miguel de Unamuno (1864-1936), Pío Baroja (1872-1956), Antonio Machado (1872-1956) and José Ortega y Gasset (1883-1955).

Carlos de Haes (1826-1898) painted “Valle en la Sierra de Guadarrama”, Martín Rico (1833-1908) “Arroyo de la Sierra de Guadarrama”, Jaime Morera (1858-1927) “Guadarrama, Picos de la Najarra” and Joaquín Sorolla (1863-1923) “Tormenta sobre Peñalara”.

Guided tours have now been instituted (Perez-Monserrat et al., 2013) to enhance public awareness of and spotlight emblematic buildings bearing Piedra Berroqueña.

PETROPHYSICAL PROPERTIES, CHEMICAL ANALYSIS AND DURABILITY OF PIEDRA BERROQUEÑA

The tectonic, petrological, petrophysical and chemical characteristics of Piedra Berroqueña are similar across the region (Tables 2-3).

These characteristics are largely conditioned by a linear crack density (LCD) (Wang et al., 1989; Sousa et al., 2005; Ismael and Hassan, 2008; Vázquez, 2010) that ranges from the highest (1.8 microcracks per millimetre) in Zarzalejo granite to the lowest (0.9 microcracks per millimetre) in Colmenar Viejo granite (Freire-Lista et al., 2015a).

The increase in LCD after exposing the AL, CA, CO and ZA stones to 280 freeze/thaw cycles was similar in all the granites studied (Table 4).

Piedra Berroqueña has resisted weathering for centuries. Its low anisotropy, capillary absorption and porosity and high mechanical strength and durability protect it from damp and capillary rise. Ashlars hewn from this stone were traditionally used as pedestals for statues and on dados and building façades.
Despite its resistance to alteration, it may be subject to decay (Fig. 4) in the form of salt efflorescence (Fig. 4a), biodecay (Fig. 4b), surface scaling (Fig. 4c) or cracking (Fig. 4d), with the concomitant loss of volume. These forms of decay are primarily the result of climate, air pollution or the presence of salts (Pérez-Monserrat et al., 2013), in conjunction with other factors. The occurrence of microgranular nodules in these

granites may also expedite weathering resulting from the differential thermal behaviour associated with these inhomogeneities (Gómez-Heras et al., 2008). Stone with larger feldspar crystals, more biotite and no cordierite or amphibole is more vulnerable to decay than stone containing cordierite, whose crystals are smaller.

Pre-quarrying decay, gloss (micro-roughness), finish and position on buildings and type of decay condition the type of maintenance or cleaning required. The methods used must not roughen the stone (Vazquez-Calvo et al., 2012): old ashlars quarried at the surface, with feldspars that may consequently be altered, must be treated with particular care.

NEED FOR GHSP STATUS FOR THE PIEDRA BERROQUEÑA REGION

Towns in the province of Madrid are losing their traditional identity because of the increased use of stone from other regions as replacement or building stone. This change has a heavy impact on the conservation of heritage buildings in historic urban cores.

Action to reverse this trend is needed on the local, regional, national and even international scale. Moreover, society at large should be made aware of the importance of construction materials in the local heritage and economy.

To that end, the Group for Petrology Applied to Heritage Conservation, in conjunction with local quarries, conducts activities such as guided tourist routes to enhance public awareness of Piedra Berroqueña (http://www.madrimasd.org/English/Science-Society/scientific-heritage/Geomonumental-Routes/default.asp). Popular cultural outings such as the tour of the "Valle de los caídos" have been conducted in recent years under the umbrella of Madrid's Science Week.

Another initiative, jointly backed by one municipality and the Region of Madrid, has led to the creation of a regional archaeological and geological interpretation centre (http://www.igeo.ucm-csic.es/en/igeo/noticias/588-risco). Similarly, a history book for the general public now in print contains a chapter dealing with quarries and their contribution to the construction of one of Madrid's historic quarters.

Designation of the Piedra Berroqueña region as a GHSP would help rally all the stakeholders around a set of shared interests: to train local quarrymen, to further the use of traditional building stone, and to secure greater national and international visibility for Piedra Berroqueña.

CONCLUSIONS

Piedra Berroqueña, which forms part of the Region of Madrid's tangible and intangible heritage, is exported world-wide. Heritage buildings bearing this stone form part of Spain's history and culture, and as such must be conserved for future generations. Their restoration with material from the Piedra Berroqueña region will ensure more effective conservation of the tangible and intangible heritage.

The supply of manually hewn Piedra Berroqueña is guaranteed in the homonymous region.

The physical properties of Piedra Berroqueña, which afford it great durability, vary little from one variety to another and depend on the degree of alteration.

Traditionally, Alpedrete and Zarzalejo monzogranites were the stones most widely used in heritage buildings in the city of Madrid, whereas Colmenar Viejo monzogranite was used primarily for its pavers and cobblestones. Although the properties of these granites are similar, the crystal size is larger in Zarzalejo granite.

Whilst Cadalso de los Vidrios and La Cabrera granites were used as building materials in the villages near their respective quarries from Roman times and earlier until the mid-late twentieth century, neither was deployed in Spain's capital city.

Today, however, output at Cadalso de los Vidrios and La Cabrera is greater than at Alpedrete, Zarzalejo or Colmenar Viejo. The existence of a considerable number of historical as well as mechanised quarries ensures that the demand for restoration and construction works can be met.

The petrographic, petrophysical, mechanical and aesthetic properties of Piedra Berroqueña, along with its durability and the large number of quarries still in operation, make the region where it outcrops eligible for designation as a Global Heritage Stone Province (GHSP) (Pereira and Cooper, 2015).

Such a designation will enhance public awareness of the past and present of this cultural asset and the features that are vital to its conservation, while ensuring fuller use of Piedra Berroqueña as a construction material.

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Figure 1.

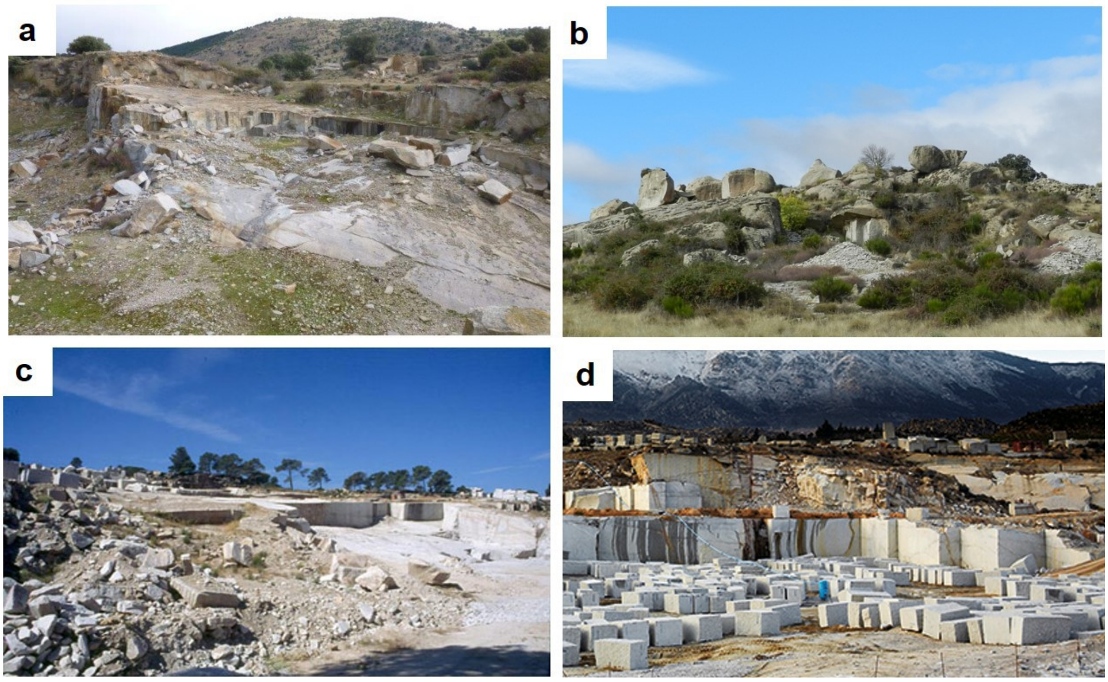

Figure 2.

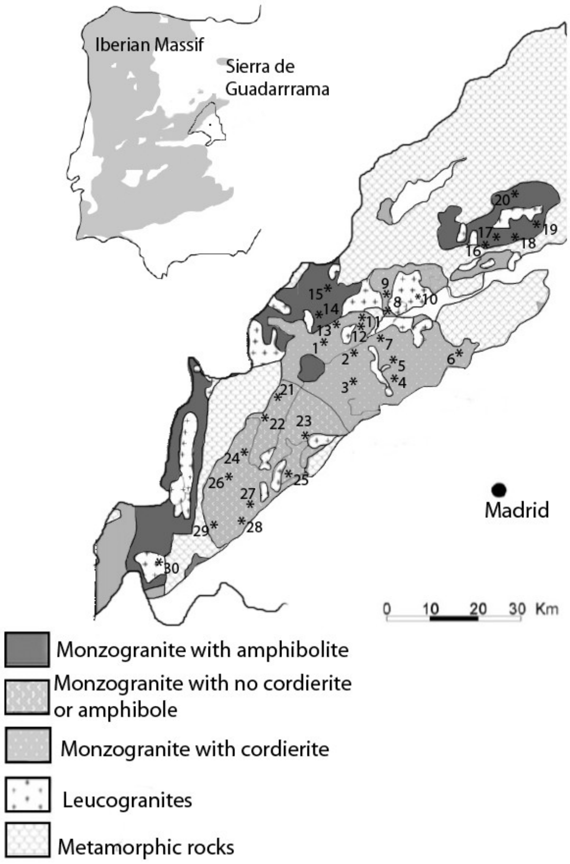

Figure 3.

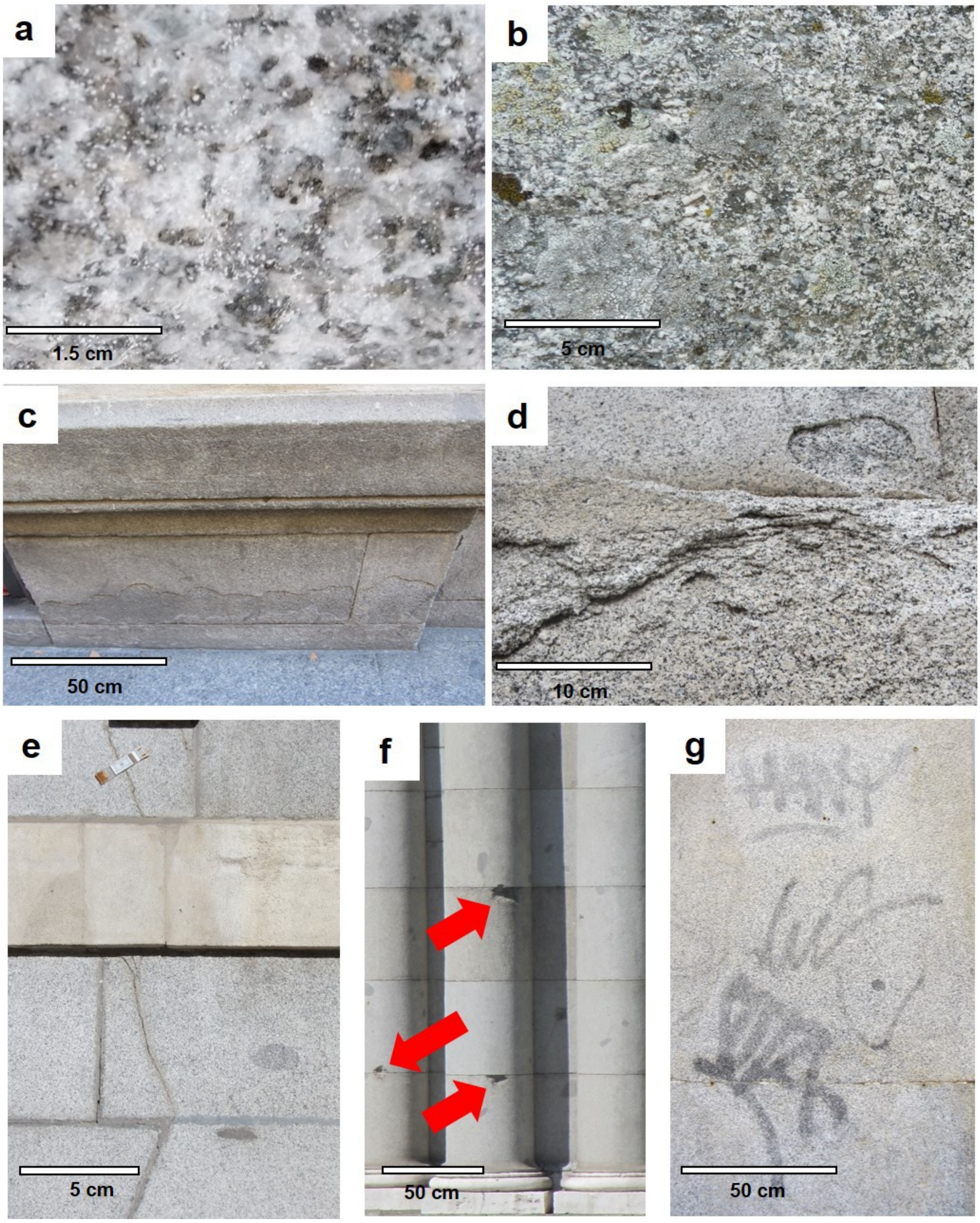

Figure 4

Table 1.

Works	Year built	References
Roman road, Caratrava, Cercedilla and Zarzalejo	Before 3rd century	Martín, 1994
Batán and Grajal Roman bridges at Colmenar Viejo	Before 3rd century	Colmenarejo, 1986
Archaeological site at Navalvillar	6th-7th centuries	López Sáez et al., 2015
Fuente del Moro archaeological site	6th-7th centuries	Colmenarejo, 1986
"Remedios" necropolis	After 7th century	Colmenarejo et al., 2005
El Paular monastery	1086	López-Arce et al., 2011
Nuestra Señora de la Asunción Church at Alpedrete	12th-13th centuries	Menduiña and Fort, 2005
Bernardos Monastery	12th century	Calero, 1992
Church at Fuente el Saz del Jarama	13th century	Menduiña and Fort, 2005
Castle at Manzanares el Real	1247	Menduiña and Fort, 2005
El Paular Monastery (intervention)	1440–1486	López-Arce et al., 2011
Bishos Chapel	1520-1535	Guerra and Zapata, 2010
Las Descalzas Reales Monastery	1559-1564	Martín, 1994
San Lorenzo Royal Monastery at Escorial	1563-1584	Fort et al., 2013a
Segovia Bridge	1582-1584	Martín, 1994
Plaza Mayor (main square)	1590, later reconstructions	Martín, 1994
Agustinas Recoletas de la Encarnación Monastery	1611-1616	Bernabéu et al., 2004
Nuestra Señora del Carmen y San Luis Church	1611-1638	Menduiña and Fort, 2005
Agustinas Recoletas de Santa Isabel Monastery	1640-1667	Tovar, 1983
San Ginés Church	1641-1645	Martín, 1994
San Andrés Church	1657-1669	Martín, 1994
Concepción Real de Calatrava Church	1670-1678	Menduiña and Fort, 2005
San Isidro Collegiate Church	1673-1675	Menduiña and Fort, 2005
San Ildefonso de Trinitarias Descalzas Convent	1673-1688	Tovar, 1983
Toledo Bridge	1719-1724	Menduiña and Fort, 2005
Royal Palace at Madrid	1738-1764	Fort et al., 2004
Palace of Prince Luis de Borbón	1763-1765	Fort et al., 1996
Prado Musesum	1785-1808	Martín, 1994
Alcalá Gate	1770-1778	Martín, 1994
Botanical Garden winter shelters	1779-1781	Martín, 1994
Royal Theatre	1830-1850	Menduiña and Fort, 2005
National Library	1862-1892	Martín, 1994
Dam at El Villar	1870-1873	Unceta and Echenagusía, 2005
San José Homeopathic Hospital	1874-1878	Merlos, 2005
Veterinary School - Former Casino de la Reina	1877-1881	Del Corral, 1972
Niño Jesús Hospital	1879-1881	Navascués, 1993
Bank of Spain	1884-1891	Navascués, 1993
Ministry of Agriculture, Fisheries and Food	1893-1897	Navascués, 1993
Milagrosa Church	1900-1904	Menduiña and Fort, 2005
La Concepción Church	1902-1914	Menduiña and Fort, 2005
Former Maudes Street Workers' Hospital in Madrid	1909-1916	López-Urrutia, L. 1926
El Águila beer factory	1912-1914	Gutiérrez, 1997

San Francisco de Sales Church	1926-1931	Martín, 1994
Nuevos Ministerios	1933-1942	Maure, 1985
Valle de los caídos monument	1940-1958	Méndez, 2009
Moncloa Palace reconstruction	1953	Menduiña and Fort, 2005
IFEMA	1980	Source: Granite production compay
Addition to the Reina Sofía Museum	2001-2005	Source: Granite production compay
Addition to the Bank of Spain	2003	Source: Granite production compay
New buildings.Other countries (Source: Granite production compay)		
Atatürk Airport, at Istanbul, Turkey		
Zine El Abidine Ben Ali Airport (New Enfidha International Airport)		
Singapore Post Center		
Mall Boulevard - Las Vegas, Nevada, USA		
Cathedral Place - Vancouver ,Canada		
Sam Jung Building, Seoul, Korea		
Cork Airport, Ireland		
Magit Palace - Budapest, Hungary		
Migdalot Tower - Tel Aviv, Isreal		
Terra Park - Budapest, Hungary		
Federal Deposit Insurance Corporation building - Washington, D.C., USA		
Yayasan Sultan Hassanal Bolkiah - Brunei		
Capval - Nouveau Berci - Paris, France		
Istambul Airport, Turkey		
Capitol East End Complex - Sacramento, California, USA		
Granite Castle, English Channel Island, UK		
US Embassy at Abidjan, Ivory Coast		
Opera Tower, Tel Aviv, Israel		
Zamert Tower, Tel Aviv, Israel		
Platinum/Milenyom Towers, Tel Aviv, Israel		
Great America Plaza, San Diego, California, USA		
Migdalot Tower, Tel Aviv, Israel		
Oceanus, Herzlelia, Israel		
Herzelia Square, Herzklia, Israel		

Table 2.

Property	AL	CA	CO	LA	ZA
Impact strength (cm)	68±14 (2)	-	-	44 (5)	58.8 (1)
Compressive strength (MPa)	136.9±41 (2)	-	-	203 (5)	160.0±49.0 (1)
Bending strength (MPa)	8.88±3.69 (2)	-	-	11.06 (5)	8.21±2.25 (1)
Bulk density (Kg/m^3)	2 636±18 (4)	2 602±16 (4)	2 629±13 (4)	-	2 657±15 (4)
Young's Modulus (MPa)	33 275 (4)	35 377 (4)	66 838 (4)	-	26 882 (4)
Water absorption (%)	0.29 to 0.31 (3)	0.41 to 0.49 (3)	0.28 to 0.41 (3)	0.2 (5)	0.54 to 58 (3)
Water saturation (%)	0.5±0.2 (1)	-	-	-	1.24 (1)
Capillary absorption coefficient ($g\cdot m^{-2}\cdot s^{-0.5}$)	1.523 to 3.983 (3)	3.502 to 4.706(3)	0.969 to 1.437 (3)	-	4.238 to 4.796 (3)

Porosity accessible to water (%)	0.8±0.1 (4)	1.2±0.2 (4)	0.7±0.1 (4)	-	1.7±0.06 (4)
Porosity measured by HG intrusion (%)	0.44 (4)	0.95 (4)	0.59 (4)	-	1.4 (4)
Frost resistance (%)	0.01 (2)	-	-	0.07 (5)	0.005 (1)
Ultrasonic P-wave velocity (m/s)	4 625±163 (4)	3 687±300 (4)	5 051±349 (4)	-	3 219±204 (4)
Ultrasonic S-wave velocity (m/s)	3 812±92 (4)	2 596±110 (4)	3 494±94 (4)	-	2 2116±89 (4)
Total anisotropy (%)	5.8 (3)	15.3 (3)	3.5 (3)	-	12.7 (3)
LCD (microcracks per mm)	1.1 (5)	1.8 (5)	0.9 (5)	-	1.2 (5)

Table 3.

Chemical analysis					
Major elements	**AL** wt% (1)	**CA** wt% (2)	**CO** wt% (3)	**LA** wt% (4)	**ZA** wt% (5)
SiO_2	69.60	76.94	74.15	76.02	68.97
TiO_2	0.4	0.08	0.14		0.55
Al_2O_3	15.02	12.83	13.50	12.99	15.17
Fe_2O_3	2.97	1.07	0.23	0.29	3.26
FeO	1.54		1.15	0.72	1.11
MnO	0.05	0.04	0.05	0.03	0.06
MgO	0.96	0.16	0.56	0.22	1.19
CaO	2.45	0.78	0.93	0.90	2.47
Na_2O	3.32	3.4	3.32	3.30	3.21
K_2O	3.89	4.48	4.79	4.58	4.07
P_2O_5	0.16	0.04	0.06	0.03	0.13

Table 4.

	LCD: FT test results		
Granite	**Cycle 0**	**Cycle280**	**Δ 0 to 280 (%)**
Alpedrete	1.1	3.2	193
Cadalso de los Vidrios	1.8	3.7	107
Colmenar Viejo	0.9	2.3	150
Zarzalejo	1.2	3.9	228

List figure captions:

Figure 1. a: lintel in historic quarry at Alpedrete; b: laying of Piedra Berroqueña at Madrid's Santo Domingo Square; c: outdoor Quarry Museum at El Berrueco; d: shoeing pen at Villavieja de Lozoya; e: quarrymen's competition at Colmenar Viejo; f: Geology Museum at Colmenar Viejo.

Figure 2. a: historic quarry at Alpedrete; b: historic quarry at Zarzalejo; c: quarry in operation at Cadalso de los Vidrios; d: quarry in operation at La Cabrera.

Figure 3. Towns with the highest density of historic quarries in the Piedra Berroqueña región. *Monzogranites with cordierite:* (1) Alpedrete, (2) Moralzarzal, (3) Galapagar, (4) Torrelodones, (5) Hoyo de Manzanares, (6) Colmenar Viejo, (7) Cerceda, (8) El Boalo, (9) Mataelpino, (11) Becerril de la Sierra, (12) El Berrocal, (13) Collado Mediano. *Monzogranites with amphibole:* (14) Los Molinos, (15) Cercedilla, (16) Bustarviejo, (17) Valdemanco, (18) La Cabrera, (19) El Berrueco, (20) Lozoyuela-Navas-Sieteiglesias. *Monzogranites with no cordierite or amphibole:* (21) San Lorenzo del Escorial, (22) Zarzalejo, (23) Valdemorillo, (24) Robledo de Chavela, (25) Navalagamella (26) Fresnedilla de la Oliva, (27) Colmenar de Arroyo, (28) Chapinería, (29) Navas del Rey. *Leucogranite:* (10) Manzanares el Real, (30) Cadalso de los Vidrios.

Figure 4. Decay in Piedra Berroqueña: A: salt efflorescence, indoor columns on Conde Duque Palace, Madrid; B: biodecay, Nuestra Señora de la Asunción church, Colmenar Viejo; C: scaling; Madrid; D: scaling and flaking; San Andrés Church, Madrid; E: cracking; Chamber of Deputies, Spanish Parliament, Madrid; F: Bullet impact, Alcalá Gate, Madrid; G: graffiti, Madrid.

List table captions:

Table 1. Emblematic monuments in the region of Madrid built with Piedra Berroqueña and other types of stone.

Table 2. Physical properties of Piedra Berroqueña (1) Bernabéu et al., 2004; (2) Mendiuña and Fort., 2005; (3) Fort et al., 2011; (4) Freire-Lista et al., 2015a; (5) ROC Máquina, 2009.

Table 3. Chemical analysis for Alpedrete, Cadalso de los Vidrios, Colmenar Viejo, La Cabrera and Zarzalejo granites. (1) Villaseca et al., 1998; (2) Martín-Serrano, 2007; (3) Rodriguez-Fernández, 2000; (4) Bellido, 1979; (5) López de Azcona et al., 2002.

Table 4. Linear crack density (LCD) for Alpedrete, Cadalso de los Vidrios, Colmenar Viejo and Zarzalejo granites in freeze-thaw (FT) cycles 0 and 280.