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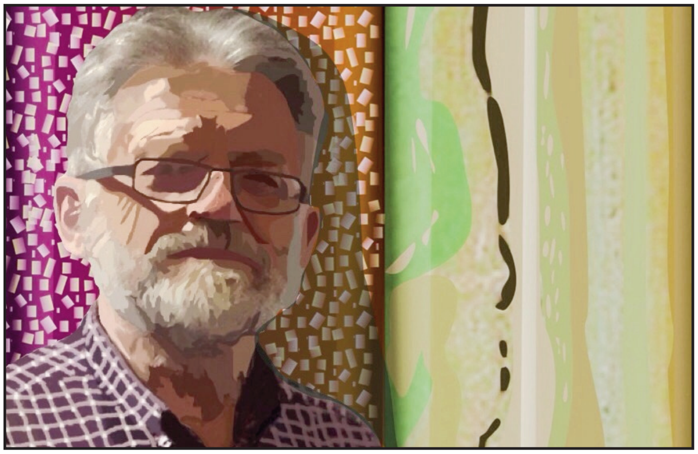

Heritage Stone 4. The Piedra Berroqueña Region: Candidacy for Global Heritage Stone Province Status*

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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 preserve 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 important 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 preservation to the stone's petrophysical characteristics and durability. The granite is also found in most of the city's housing and streets, as well as in modern buildings the world over, such as the airport terminals at Athens and Cork, and the British consulate at Hong Kong.

Four major types of monzogranite occur including: biotitic monzogranites containing some cordierite, biotitic monzogranites containing some amphibole, biotitic monzogranites having no cordierite or amphibole, and leucogranites. The petrological, petrophysical and chemical properties of Piedra Berroqueña, which afford it great durability, vary little from one variety to another and depend on the degree of alteration. Physical and chemical characteristics were determined for five granites representative of historic or active quarries in the Piedra Berroqueña region: Alpedrete (monzogranite containing cordierite); Cadalso de los Vidrios (leucogranite); La Cabrera (monzogranite containing amphibole); Colmenar Viejo (monzogranites containing cordierite); and Zarzalejo (monzogranites having no cordierite or amphibole).

The Piedra Berroqueña region meets the requirements of a Global Heritage Stone Province, and this paper supports the Piedra Berroqueña region's application for recognition as such. This distinction would enhance public awareness of an area committed to quarrying and working the local stone.

RÉSUMÉ

La région de Piedra Berroqueña dans les monts de Guadarrama, qui fait partie de la chaine centrale d'Espagne, est la principale source du granite de construction utilisé à Madrid et dans les provinces environnantes. Les agglomérations de la région qui exploitent une carrière conservent leur tradition d'extraction et de taille du granite. Les anciennes carrières font maintenant partie du paysage, comme les sites d'extraction actuels avec d'énormes réserves ce qui garantit un approvisionnement rapide en pierre de taille de fini varié. Le granite de *Piedra Berroqueña* a été utilisé comme matériau de construction bien avant l'époque romaine. De nombreux monuments importants, y compris le monastère royal de San Lorenzo à l'Escurial (1563–1584), le palais royal de Madrid (1738–1764), la porte d'Alcalá (1770–1778), le musée du Prado (1785–1808) et la Puerta del Sol (une des principales places de Madrid), doivent leur bon état de conservation aux caractéristiques

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pétrophysiques et à la durabilité de la pierre. Ce granite se retrouve également dans la plupart des habitations et des rues de la ville, ainsi que dans des bâtiments modernes du monde entier, tels que les terminaux de l'aéroport d'Athènes et de Cork, et le consulat britannique à Hong Kong. Il est constitué de quatre grandes classes de monzogranite : des monzogranites à biotite contenant un peu de cordiérite, des monzogranites à biotite contenant un peu d'amphibole, des monzogranites à biotite ne contenant ni cordiérite ni amphibole, et les leucogranites. Les propriétés pétrographiques, pétrophysiques et chimiques des granites de Piedra Berroqueña qui leur assurent une grande durabilité, varient peu d'une variété à l'autre et dépendent du degré d'altération. Les caractéristiques physiques et chimiques ont été déterminées sur cinq granites représentatifs des carrières historiques et actives de la région de Piedra Berroqueña : Alpedrete (monzogranite à cordiérite); Cadalso de los Vidrios (leucogranite); La Cabrera (monzogranite à amphibole); Colmenar Viejo (monzogranite à cordiérite); et Zarzalejo (monzogranite sans cordiérite ni amphibole). La région Piedra Berroqueña répond aux critères d'une Province pétrologique du patrimoine mondial, et le présent article documente la candidature de la région de Piedra Berroqueña à cet effet. Cette distinction permettrait d'améliorer la sensibilisation du public concernant une région spécialisée dans l'extraction et à la taille de la pierre locale.

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INTRODUCTION

The Piedra Berroqueña region occupies an area of about 100 km by 40 km, and lies partly in the Guadarrama Mountains National Park, in the eastern branch of Spain's Central Range. The region is oriented southwest–northeast across the provinces of Madrid, Segovia and Ávila. 'Berroqueña' stone, a name that comes from the Spanish word 'berrueco' or 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 these towns forms part of the province of Madrid's intangible heritage, as attested by the many festivals honouring Saint Peter, the monuments to and courses on the stone trade, and quarrymen's competitions (Fig. 1). Most of the 2000 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 to 1.5 m). Whereas quarrying in the past consisted of removing only small whale-back formations (Fig. 2a), the gradual depletion of the latter has led to larger operations and quarrying at greater depths (Fig. 2b). Today, traditional family-run quarries co-exist with the mechanized variety (Fig. 2c, d).

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 culturally significant buildings the world over (Tables 1, 2). This stone, along with other materials (Fort 2008), was used in 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 in pavement, 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 on Piedra Berroqueña have discussed 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, b, c); and the buildings for which it has been used (López de Azcona et al. 2002; Fort González et al. 2004; Pérez Monserrat and Fort 2004; Menduiña and Fort 2005; Fort et al. 2010).

The granitoid plutons of the Piedra Berroqueña region (Brandebourger 1984) consist of Carboniferous to lower Permian, late- to post-orogenic monzogranite (De Vicente et al. 2007). Four major types of monzogranite occur: biotitic monzogranites containing some cordierite, biotitic monzogranites containing some amphibole, biotitic monzogranites with no cordierite or amphibole, and leucogranites. Monzogranite normally generates flat, braided, landscapes featuring boulders or tors. Leucogranites, having a smaller grain size, form more rugged landscapes characterized by subvertical fracturing, resulting in greater topographic relief. Piedra Berroqueña monzogranites have mafic inclusions of 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. This paper provides appropriate detail for GHSP assessment, including petrophysical and chemical descriptions of the granite, and the economic and cultural importance of quarrying this stone throughout history.

METHODOLOGY

Petrophysical data were compiled for five granites that are representative of historic or active quarries in the Piedra Berroqueña region and have been widely used in Madrid (Fort et al. 2013b). This includes granites from Alpedrete (monzogranites containing cordierite; Freire-Lista et al. 2015b), which has been proposed as a Global Heritage Stone Resource (Cooper 2010, 2013a, b; Hughes et al. 2013); Cadalso de los Vidrios (leucogranite); La Cabrera (monzogranite containing amphibole); Colmenar Viejo (monzogranite containing cordierite); and Zarzalejo (monzogranite having no cordierite or amphibole; Freire-Lista et al. 2015d) (Fig. 3), which was also proposed as a Global Heritage Stone Resource. To quantify the deterioration in the physical properties and strength of these granites, they were exposed to 280 freeze-thaw cycles (see

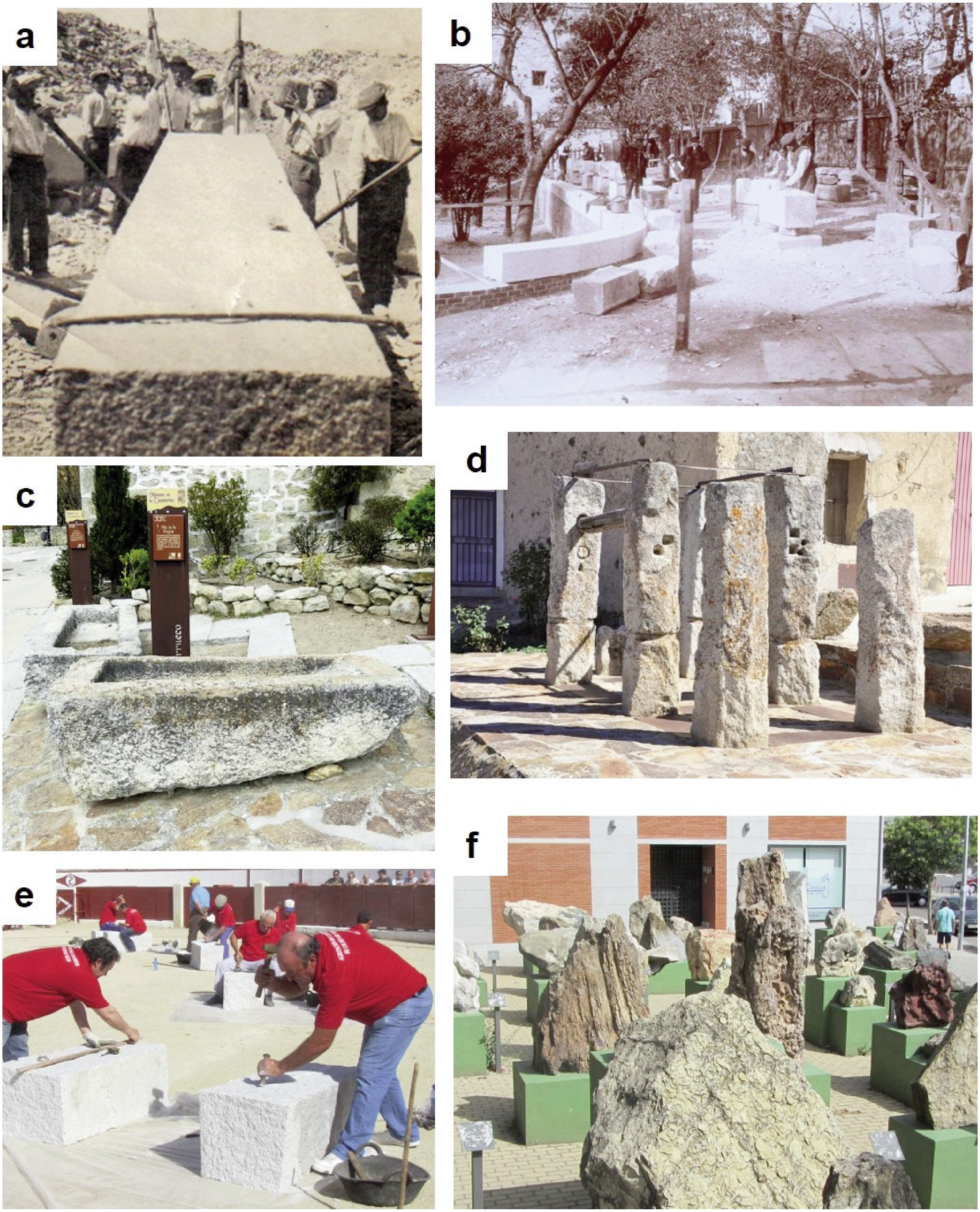

Figure 1. a) Lintel in historic quarry at Alpedrete; b) laying of Piedra Berroqueña at Madrid's Santo Domingo Square; c) outdoor Quarry Museum at El Berrueco; d) shoeing pen at Villavieja de Lozoya; e) quarrymen's competition at Colmenar Viejo; f) Geology Museum at Colmenar Viejo.

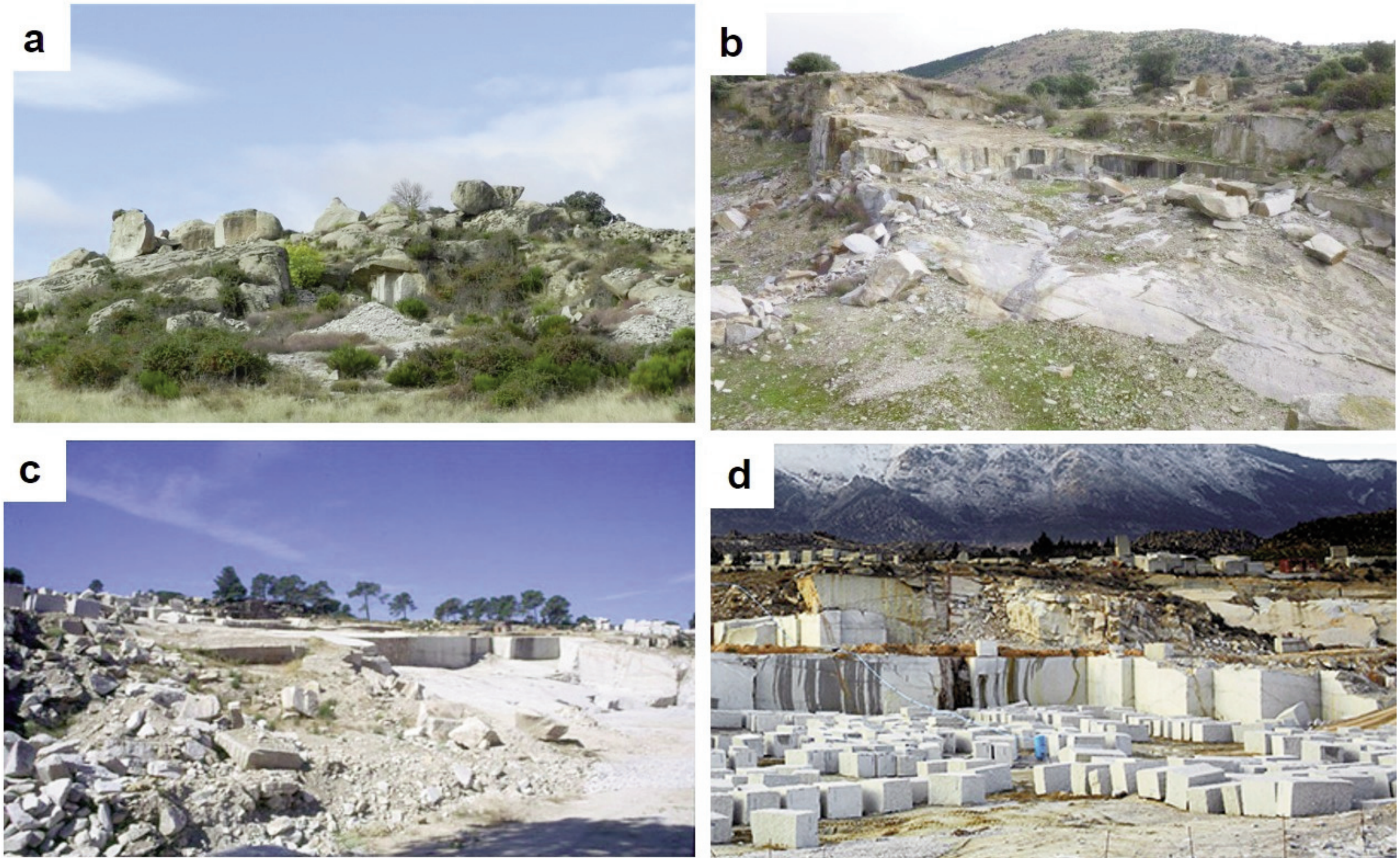

Figure 2. a) Historic quarry at Zarzalejo; b) historic quarry at Alpedrete; c) quarry in operation at Cadalso de los Vidrios; d) quarry in operation at La Cabrera.

below), as specified in European standard 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 cave (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 preserved, 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 (4th to 8th 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 (Moorish) kingdoms to the north and south, respectively. 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, and 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 (7th through 15th 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) using 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 newly paved road from the Guadarrama Mountains to Madrid. This improvement in communications increased the volume of granite shipments to the city. In the 18th 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, which was approved in 1761, that called for paving the streets of Madrid with Piedra Berroqueña. The 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 that was built on the battlefield with Piedra Berroqueña has been conserved and today is a cultural heritage asset. During and after the reign of Joseph (Bonaparte) I (1808−1813), a town planning ordinance required all

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

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 González 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	Blokdegal, S.A. Granite production company
Addition to the Reina Sofía Museum	2001–2005	Blokdegal, S.A. Granite production company
Addition to the Bank of Spain	2003	Blokdegal, S.A. Granite production company

buildings to have a dado (the lower part of a wall) consisting of three rows of Piedra Berroqueña ashlars, or finely dressed stone masonry (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-19th 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

Table 2. New buildings in other countries.

Atatürk Airport, at Istanbul, Turkey
Enfidha International Airport (Zine El Abidine Ben Ali Airport), Tunisia
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

*Source: Granite production company: http://www.ingemargroup.com/.

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 as late as the 20th century, albeit less and less commonly, as the use of trains and trucks started in the 19th century. 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, the 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 1000 quarrymen. The economic importance of the Piedra Berroqueña region was symbolized 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 constructed with Piedra Berroqueña between 1931 and 1942 (Maure 1985). Although building construction, and therefore 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), paving, and funerary art, and for export, restoration and rehabilitation works in the region of Madrid. The key production centres are La Cabrera, which markets its stone under the trade name Blanco Perla, and Cadalso de los Vidrios, the home of Blanco Cristal. The granite is also quarried at Zarzalejo 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 Institucion Ferial de Madrid (IFEMA) fairgrounds and erect the Queen Sofia Museum, among others. Historic Piedra Berroqueña quarries at Alpedrete and Zarzalejo supplied the granites used in many heritage buildings (Tables 1, 2).

HERITAGE ISSUES

Piedra Berroqueña has not only been used in art and building construction, but since the Middle Ages has also been cited in literature 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 19th and first quarter of the 20th 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).

Piedra Berroqueña has also been the subject of painters, e.g., 'Valle en la Sierra de Guadarrama' by Carlos de Haes (1826−1898), 'Arroyo de la Sierra de Guadarrama' by Martín Rico (1833−1908), 'Guadarrama, Picos de la Najarra' by Jaime Morera (1858−1927), and 'Tormenta sobre Peñalara' by Joaquín Sorolla (1863−1923). Guided tours have now been instituted (Perez-Monserrat et al. 2013) to enhance public awareness and to showcase significant 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

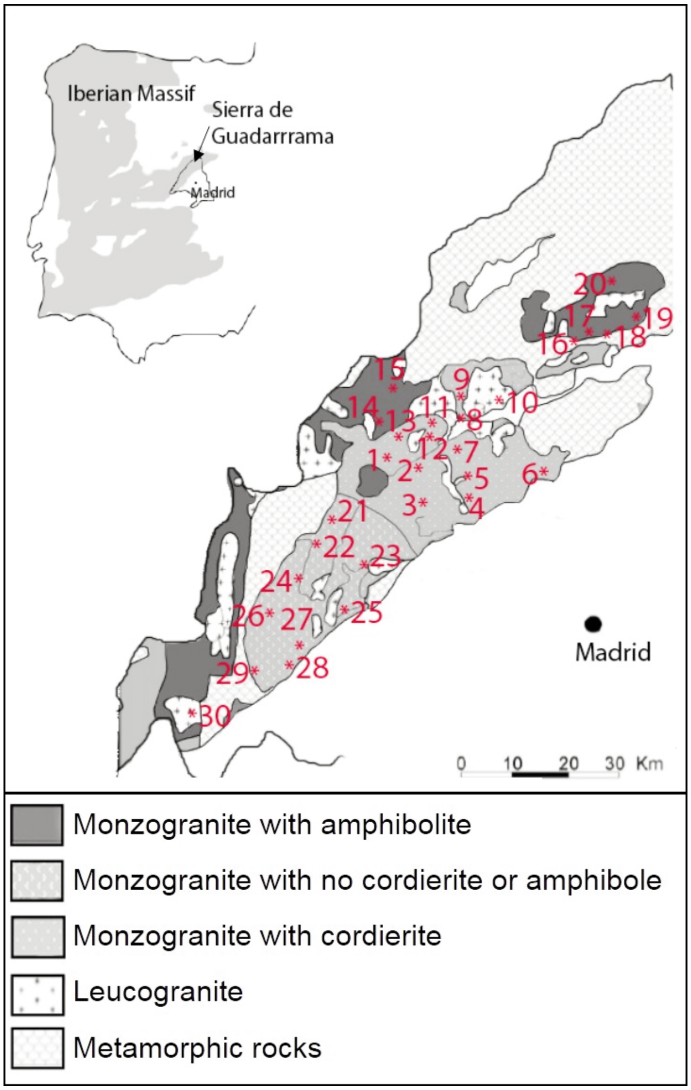

Figure 3. Towns with the highest density of historic quarries in the Piedra Berroqueña región. *Monzogranites with cordierite:* (1) Alpedrete, (2) Moralzarzal, (3) Galapagar, (4) Torrelodones, (5) Hoyo de Manzanares, (6) Colmenar Viejo, (7) Cerceda, (8) El Boalo, (9) Mataelpino, (11) Becerril de la Sierra, (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.

(Tables 3, 4). These characteristics are largely determined by a linear crack density (Wang et al. 1989; Sousa et al. 2005; Ismael and Hassan 2008; Vázquez 2010) that ranges from a high of 1.8 microcracks per millimetre in Zarzalejo granite to a low of 0.9 microcracks per millimetre in Colmenar Viejo granite (Freire-Lista et al. 2015a). The increase in linear crack density after exposing the Alpedrete, Cadalso de los Vidrios, Colmenar Viejo and Zarzalejo stones to 280 freeze-thaw cycles was similar in all the granites studied (Table 5).

Piedra Berroqueña has resisted weathering for centuries. Its low anisotropy, capillary absorption, 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

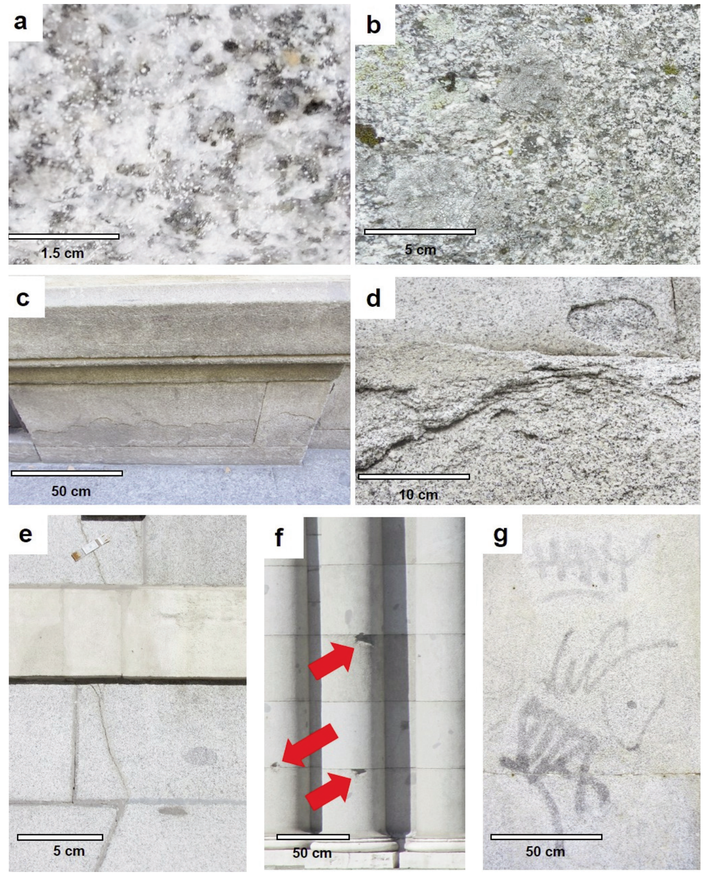

Figure 4. Decay in Piedra Berroqueña: a) salt efflorescence, indoor columns on Conde Duque Palace, Madrid; b) biodecay, Nuestra Señora de la Asunción church, Colmenar Viejo; c) scaling, Madrid; d) scaling and flaking, San Andrés Church, Madrid; e) cracking, Chamber of Deputies, Spanish Parliament, Madrid; f) bullet impact, Alcalá Gate, Madrid; g) graffiti, Madrid.

decay in the form of salt efflorescence (Fig. 4a), biodecay (Fig. 4b), and surface scaling (Fig. 4c) or cracking (Fig. 4d), with a concomitant loss of volume. These forms of decay are primarily the result of climate, air pollution, and 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 cordierite-bearing stone, which contains smaller crystals. Pre-quarrying decay, gloss (micro-roughness), finish, location on or within a building, and type of decay determine the type of maintenance or cleaning required; the methods used must not roughen the stone (Vazquez-Calvo et al. 2012). Old ashlars that have been quarried at the surface may contain altered feldspars and 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 had a heavy impact on the conservation of heritage buildings in historic urban cores. Action to reverse this trend is needed on

Table 3. Physical properties of five representative samples of Piedra Berroqueña.

Property	**AL**	**CA**	**CO**	**LA**	**ZA**
Impact strength (cm)	68±14 (2)68±14 (2)	-	-	44 (5)44 (5)	58.8 (1)58.8 (1)
Compressive strength (MPa)	136.9±41 (2)136.9±41 (2)	-	-	203 (5)203 (5)	160.0±49.0 (1)160.0±49.0 (1)
Bending strength (MPa)	8.88±3.69 (2)8.88±3.69 (2)	-	-	11.06 (5)11.06 (5)	8.21±2.25 (1)8.21±2.25 (1)
Bulk density (Kg/m^3)	2 636±18 (4)2 636±18 (4)	2 602±16 (4)2 602±16 (4)	2 629±13 (4)2 629±13 (4)	-	2 657±15 (4)2 657±15 (4)
Young's Modulus (MPa)	33 275 (4)33 275 (4)	35 377 (4)35 377 (4)	66 838 (4)66 838 (4)	-	26 882 (4)26 882 (4)
Water absorption (%)	0.29 to 0.31 (3)0.29 to 0.31 (3)	0.41 to 0.49 (3)0.41 to 0.49 (3)	0.28 to 0.41 (3)0.28 to 0.41 (3)	0.2 (5)0.2 (5)	0.54 to 58 (3)0.54 to 58 (3)
Water saturation (%)	0.5±0.2 (1)0.5±0.2 (1)	-	-	-	1.24 (1)1.24 (1)
Capillary absorption coefficient ($g \cdot m^{-2} \cdot s^{-0.5}$)	1.523 to 3.983 (3)1.523 to 3.983 (3)	3.502 to 4.706 (3)3.502 to 4.706(3)	0.969 to 1.437 (3)0.969 to 1.437 (3)	-	4.238 to 4.796 (3)4.238 to 4.796 (3)
Porosity accessible to water (%)	0.8±0.1 (4)0.8±0.1 (4)	1.2±0.2 (4)1.2±0.2 (4)	0.7±0.1 (4)0.7±0.1 (4)	-	1.7±0.06 (4)1.7±0.06 (4)
Porosity measured by HG intrusion (%)	0.44 (4)0.44 (4)	0.95 (4)0.95 (4)	0.59 (4)0.59 (4)	-	1.4 (4)1.4 (4)
Frost resistance (%)	0.01 (2)0.01 (2)	-	-	0.07 (5)0.07 (5)	0.005 (1)0.005 (1)
Ultrasonic P-wave velocity (m/s)	4 625±163 (4)4 625±163 (4)	3 687±300 (4)3 687±300 (4)	5 051±349 (4)5 051±349 (4)	-	3 219±204 (4)3 219±204 (4)
Ultrasonic S-wave velocity (m/s)	3 812±92 (4)3 812±92 (4)	2 596±110 (4)2 596±110 (4)	3 494±94 (4)3 494±94 (4)	-	2 2116±89 (4)2 2116±89 (4)
Total anisotropy (%)	5.8 (3)5.8 (3)	15.3 (3)15.3 (3)	3.5 (3)3.5 (3)	-	12.7 (3)12.7 (3)
LCD (microcracks per mm)	1.1 (5)	1.8 (5)	0.9 (5)	-	1.2 (5)

AL: Alpedrete; CA: Cadalso de los Vidrios; CO: Colmenar Viejo; LA: La Cabrera; ZA: Zarzalejo.
Sources: (1) Bernabéu et al. 2004; (2) Menduiña and Fort 2005; (3) Fort et al. 2011;
(4) Freire-Lista et al. 2015a; (5) ROC Máquina 2009.

Table 4. Chemical analyses for Alpedrete (AL), Cadalso de los Vidrios (CA), Colmenar Viejo (CO), La Cabrera (LA) and Zarzalejo (ZA) granites.

	Chemical analysis				
Major elements	**AL wt%** (1)wt% (1)	**CA wt%** (2)wt% (2)	**CO wt%** (3)wt% (3)	**LA wt%** (4)wt% (4)	**ZA wt%** (5)wt% (5)
SiO_2	69.6	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	13.5	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	0.9	2.47
Na_2O	3.32	3.4	3.32	3.3	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

Sources: (1) Villaseca et al. 1998; (2) Martín-Serrano 2007; (3) Rodriquez-Fernández 2000; (4) Bellido 1979; (5) López de Azcona et al. 2002.

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/). 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 newly published history book for the general public 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 Global Heritage Stone Province (GHSP) would help rally all 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.

Table 5. Linear crack density test results for Alpedrete, Cadalso de los Vidrios, Colmenar Viejo and Zarzalejo granites in freeze-thaw cycles 0 and 280.

Granite	Cycle 0	Cycle 280	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

CONCLUSIONS

Piedra Berroqueña, which forms part of the Region of Madrid's tangible and intangible heritage, is exported worldwide. 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 future supply of manually hewn Piedra Berroqueña in the homonymous region is not in doubt. 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 paving and cobblestones. Although the properties of these granites are similar, the crystal size is larger in Zarzalejo granite. Although Cadalso de los Vidrios and La Cabrera granites were used as building materials in the villages near their respective quarries from before Roman times until the mid-late 20th 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 mechanized quarries ensures that the demand for restoration and construction works can be met.

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. 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 eligible for designation as a Global Heritage Stone Province (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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