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Iberian roofing slate as a Global Heritage Stone Province Resource

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The Iberian Peninsula is, nowadays, the main producer of roofing slate of the world. Most of the outcrops are located in the NW of the Iberian Peninsula, in the regions of Galicia, Leon, and in Portugal. The technique of working and roofing with slate was brought from Flanders by King Felipe II by the second half of the XVI century. The most representative building from this period is the Monastery of El Escorial, N Madrid. However, the Spanish slate industry remained incipient until the 1960s, when Galicia and Leon suffered an accelerated industrialization process which greatly enhanced the volume of production. Additionally, the Portuguese slate industry was well developed by the second half of the XIX century. Most of the Portuguese production was exported, mainly to the United Kingdom. By the second half of the XX century, the Spanish, and in a lesser extent, the Portuguese roofing slate spread all over Europe, forcing most of the existing European quarries to close. Nowadays, different varieties of roofing slates are quarried, mainly in Spain, being used indistinctly in new residential construction and for restoration of historical buildings. The main importing countries are France, Germany and the United Kingdom. This work presents an overview of the history and main varieties of the Iberian roofing slate, in order to propose its inclusion as a Global Heritage Stone Province.

Introduction

Roofing slate is the commercial term for a wide variety of rocks that have in common their ability to be split into thin, large and plane tiles. The metamorphic degree of the Iberian roofing slates ranges from the greenschist to the amphibolite facies. Nowadays, the largest roofing slate outcrops over the world are located in the Iberian Peninsula, which produces about 60% of the slate tiles sold in the world (Fig. 1). However, there are also other countries with important slate outcrops like Brazil and China.

Most of the Spanish slates come from the Ordovician terrains of the Truchas Syncline (Martínez Catalán et al., 1992), a macro structure located between Valdeorras, La Baña and El Bierzo, located in the South-East of Orense and the North-West of Leon, in the NW of Spain. However, there are other important outcrops outside this area which played an important role as slate source areas in the past, creating a local economic motor for the population. Thus, Iberian slate lithotects can be divided into 12 districts, following historical and geographic criteria (Fig. 2). This division is widely used today in the slate sector (Cárdenes et al., 2008).

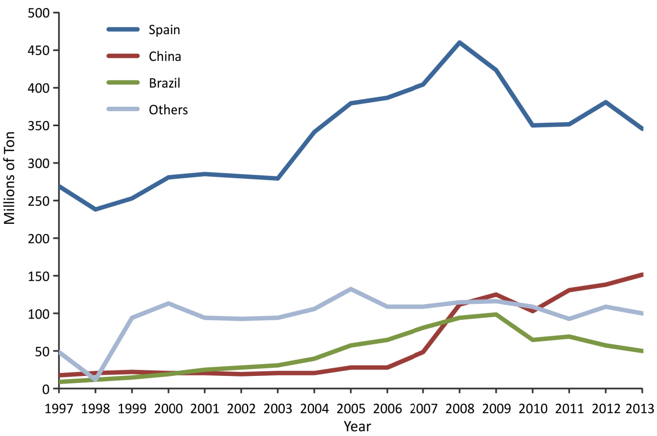

Figure 1. World's exportations of roofing slate for the period 1967-2013. Data: UNSTATS, United Nations Comtrade

Checklist for Global Heritage Stone Province (GHSP) citation

Historic use and geography

The first uses of slate in the Iberian Peninsula can be found during the Chalcolithic period, as material for making arrow heads and similar tools (Fabregas, 2008) at the archeological outcrop of Trabazos de Aliste (Zamora). Later, during the VI-VII centuries, slate is used as a writing base for the so-called "Visigothic numeral slates" (Cordero and Martin, 2012) in the area of Montijo, Badajoz. In both archeological sites, the slates documented come from actual roofing slate districts. Slate was used over the centuries by the inhabitants from settlements close to the outcrops. However, the modern slate industry in the Iberian Peninsula begins during the XIX century.

Portugal

Historically Portugal had a good relationship with the UK. The

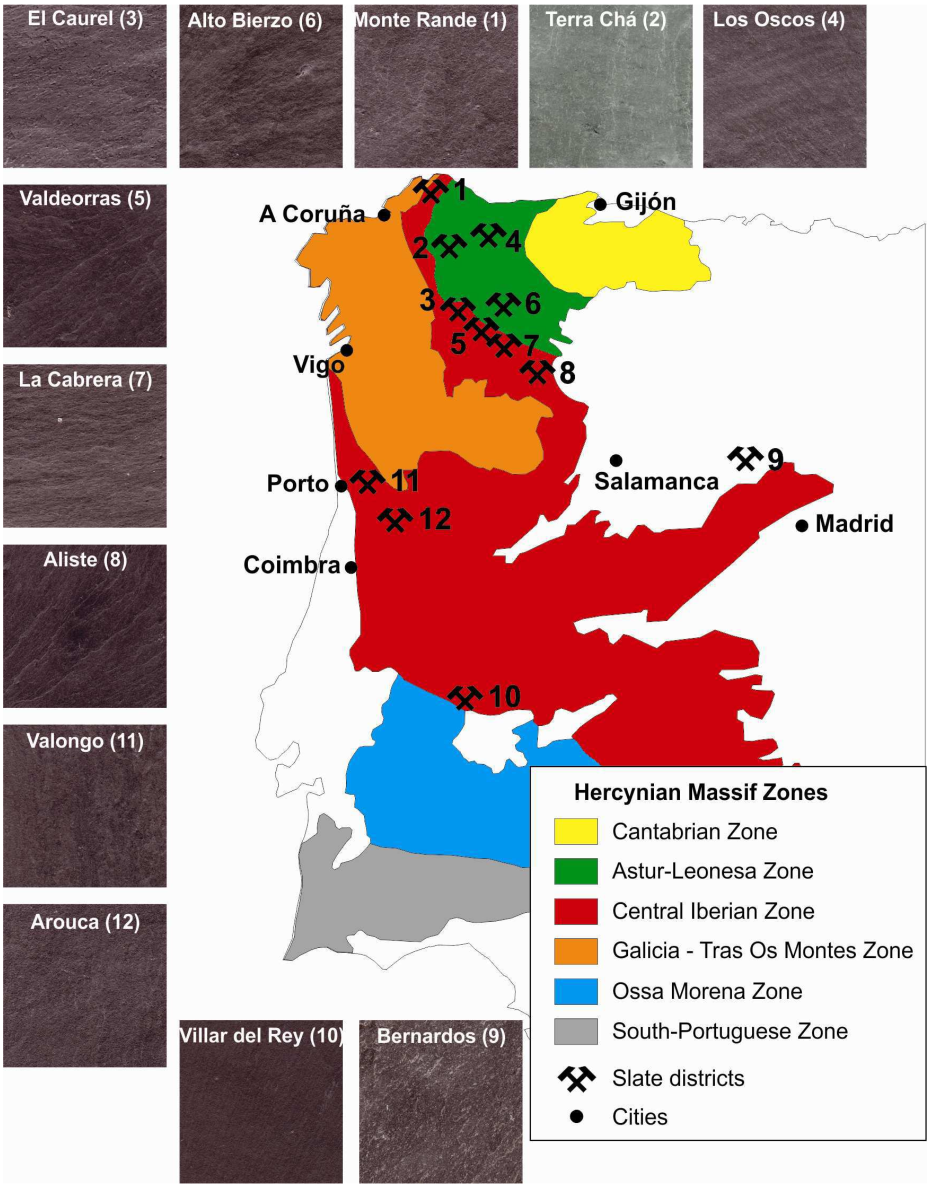

Figure 2. Location of the slate quarries on the Iberian Peninsula and districts classification.

development of the slate industry was done on their first stages by Englishmen. The modern slate mining began in 1865, with the foundation in the region of Valongo of the English company *The Vallongo Slate & Marble Quarries* (Santos de Oliveira, 1997). The English company owned the mines in Galinheiro, Cardósias, Valle de Amores and Susão.In 1874, these slates were appointed as the main supplier of the Royal House. At the end of the 19thcentury the company exported over 40 tons of slate todifferent countries such as Brazil, Russia, and Denmark and mostly to Great Britain, and it employedover 500 workers. As new applications (billiard tables, pavements, chimneys, etc.) for the slate were created, the industry increased. In 1930, *The Vallongo Slate & Marble Quarries* is absorbed by the new company *Empresa das Lousas de Valongo S.A.* The new company reached up to 1.600 workers, but in 1939, the beginning of WWII marks a negative point of inflexion for the slate business (Santos de Oliveira, 1997). During the years of the war, the business decreased dramatically, since most of the production was exported to the UK. Neither after the war the exportations recovered, since national governments protected their local industries. Thus, UK consumed only its own slate. In the 50's, the slate business suffered a deep restructuration, diversifying the offer and focusing in other slate products. Nowadays, the Portuguese slate industry, led by the company *Pereira Gomes & Carvalho, Lda.*, is highly mechanized, with an average production of 7.000 ton/year, of which 80% is exported. East of Valongothe slate district of Aroucacan be found. The quarries, reopened in 1990, are much smaller, with a reduced production. However, the great value for these quarries is not the slate itself, but the exceptional trilobite outcrop (Gutiérrez-Marco et al., 2009).

Spain

During the Spanish Renaissance, the urban architecture experienced a growth that brought an extensive use of roofing slate. The milestone for this slate development was 1559, when King Felipe II ordered to build "*with slate covers and in the same way as in Flanders*" (Nieto et al., 2001). King Felipe II was very influenced by the architecture of Central Europe, since his father, Emperor Carlos V, abdicated several territories to him, among which were the Netherlands. Qualified Flemish slate roofers were sent to Spain to teach the slate roofing techniques. The maximum exponent was obtained with the construction in the 16th century of the Royal Monastery of San Lorenzo de El Escorial (known as El Escorial), about 45 km North of Madrid, one of the most important buildings in the Spanish Heritage and sepulcher of the Spanish Kings. The slate supplied for this construction was quarried at Bernardos (Segovia), located about 75 kilometers North of San Lorenzo de El Escorial. The outcrops were seized by order of the King in order to secure the supply of slates. During the Spanish Baroque period, the use of slate consolidated.

At the same time, the mining industry developed in order to satisfy the demands of the building industry. Bernardos quarries provided most of the slates needed for the construction, since the Valdeorras and Villar del Rey outcrops were still not exploited to their fullest potential. At that time, in the second half of the 16th century, Valdeorras was rather isolated from the rest of Spain. The first mentioning of slate quarrying in Valdeorras is found in the 18th century (García Tato, 1994). The first Valdeorras slate quarries were located along the valley of the Casaio river. These quarries were worked only by locals. There was no machinery, and the mining labors had to be done only using *blood power*, or the strength of men and animals. This task was especially hard since most of the outcrops were located in mountain areas, with altitudes over 1800 m.

The slate from Valdeorras was only used locally until the beginning of the 20th century, when an English company, Cantabrian Slate

Figure 3. The beginning of the modern slate industry in Valdeorras. (A) Splitting of a slate block just in the middle of the mountai, Valley of Casaio. Photograph courtesy of Manuel Fernandez, Casaio. (B) Load of tiles directly in a truck. Photograph courtesy of Pizarras SAMACA, S.A.. This method caused many tiles to broke before arriving to destiny.

Quarries Ltd, opened a quarry in Congosto, located in El Bierzo, the neighboring region to Valdeorras, also located in the Truchas Syncline. However, the lack of experience made this company to exploit one of the poorest outcrops of Northern Spain and finally they were forced to close in 1931 (The London Gazete, 07/31/1931). It took several years before they tried again to exploit slates from these areas. At thistime French technicians prospected the area and discovered the high resources potential. In the 60's, an accelerated industrialization process took place in these areas. French, and later Germans, used their know-how in the manufacturing of slate tiles, especially in dimensioning the tiles following their own templates. Before that, slates were cut without following any normalized template, so each piece had different dimensions. With the introduction of hand dies that could dimension the tile into regular shapes in seconds, the production increased in quality and quantity. This industrialization process was also favored by the rupture of the agrarian communities due to the emigration (San Román Rodriguez, 2000). However, the new promising slate industry reverted the emigration tendency in some areas (Fig. 3A). Tools used at that time were the same as for agriculture.

In 1962, an engine of a dismantled truck was the first compressor to be working in the Valdeorras slate industry and the first mechanical shovel arrived at the end of that decade. Black gunpowder cardtriges were stuck by hand in order to pull out the big blocks of slate(García Tato, 1994). This process caused a high number of cracks in the blocks, but continued to be used until the early 90's, when the Italian technology of diamond wire saw allowed to increase enormeously the explotation ratio of the slate outcrops. This technology brought also a secondary advantage for geologists and engineers. Because now it became possible to clearly see the relationships between the main structures in the slate, sedimentation S_0 versus slaty cleavage S_1 and they better understood the regional geology.

Transportation was done by lorries to the port or directly to the warehouses. The slates were stuck inside two types of crates, *road crates* or *ship crates*, depending on the method of transportation. Sometimes tiles were directly stuck on the truck (Fig. 3B). Nowadays, only *ship crates* are used, because they are more solid and appropiate for the sucessive changes of transportation, up to 12 times a crate might suffer before arriving to its destination. In these years, the slate industry in Villar del Rey (Badajoz, Fig 1-10) and Terra Cha (Lugo, Fig 1-2) took its first steps. In Villar del Rey slates had been used for construction for at least 300 years. Due to its proximity with the Portugal border, some British-Portuguese investors saw the potential of the outcrops and opened the first quarries. On the other hand, the green phyllites from Terra Cha never had been quarried since a slate company with Italian and Spanish founding (*IPISA*) opened the first quarries during the 60's.

During the 70's, the sector consolidated and the first cooperative societies were formed (*Pizarras SAMACA* and *Cupire Padesa*, nowadays named *CUPA PIZARRAS*). Today, these two companies are still the leading companies of the world slate production. The Spanish slate irrupted in the European market, especially in France helped by the strikes of the French slate workers of the late 70's.

In the 80's, first pneumatic cuters were introduced and the legislation of the dumps began. Before that they were dumped without governmental criteria, only using the quarrymen criteria. In the 90's, the sector was shaken by numerous strikes that lasted for several months, making the situation very hard for both workers and owners. During the second half of this decade and the first half of the 21st century, the exportations increased continuosly year after year. This period was the most profitful for the slate industry. Finally, in 2008 the global crisis began to hit hard in the sector, leading many companies to close and putting the rest in a very difficult situation. Nowadays, several slate districts have closed their quarries (Villar del Rey, Terra Cha, Aliste, El Caurel, La Cabrera) and many others are threatened by the current economicalcrisis.

Compared to Portugal, the Spanish slate industry was developed much later, and with a considerably lower degree of industrialization. However, the Spanish outcrops are much bigger than the Portuguese, so nowadays Spain is leading the slate sector, but with some challenges needed to face urgently, like the competition with the emerging countries such as Brazil and China, and the neccesary restructuring of the sector, that still suffers from some handicaps inherited from the past.

Formal Name for this proposed GHSP

Iberian slate province

Origin of name

Roofing slates from the Iberian Peninsula

Other names

None

Area of occurrence

Spanish Provinces of A Coruña, Lugo, Ourense and Leon, in NW Spain, Segovia, center of Spain, and Badajoz, SW Spain. Portuguese provinces of Arouca and Valong, N Portugal.

List of constituent GHSP designations that are included within this designated Province

As pointed before, there are 12 slate districts in the Iberian Peninsula (Fig. 2):

1. Monte Rande slate, Ortigueira, in A Coruña. Dark-grey slate. Two active quarries at this moment.
2. Terra Cha phyllite, Pol, in Lugo. Light-green phyllite with abundant pyrite cubes. No active quarry at this moment.
3. El Caurel, Quiroga, in Ourense. Light-grey slate with characteristic crystals of chloritoid. Not working at this moment.
4. Los Oscos, Fonsagrada, in Lugo. Light-grey slate. One active quarry.
5. Valdeorras, in Ourense. This district is the largest one,of all, with more than 50 quarries. Slates from Valdeorras range from dark to light grey colors. Several varieties can be recognized (IGME, 1991):
    a. Casaio
    b. Castañeiro
    c. Mormeau
    d. Rozadais
    e. Los Molinos
    f. Domiz
    g. Vianzola
    h. PenedoRayado
    i. San Vicente
    j. Forna
6. Alto Bierzo, Laciana, in Leon. Light-grey slates, no quarry working at this time.
7. La Cabrera, in Leon. This is the second district in order of importance, with about 20 quarries working. These slates are mainly greyish. As for Valdeorras, there are several varieties:
    a. San Pedro de Trones
    b. Benuza
    c. La Baña
    d. Odollo
8. Aliste, Bercianos de Aliste, in Leon. Dark-grey slate, no quarry working at this time.
9. Bernardos, in Segovia, N Madrid. Light grey phyllites. There are two quarries, owned by the same company, that are still working.
10. Villar del Rey, in Badajoz. Dark slate with abundant iron sulphides and organic matter, no quarry working at this time.
11. Valongo, Portugal. Light grey slate, two active mines.
12. Arouca, Portugal. Dark slate, one active quarry.

List of other known constituent heritage stone types

No other significative heritage stones are quarried in this proposed GHSP.

Geological setting

The proposed GHSP is located at the Hercynian terrains of the Iberian Peninsula (Fig. 2). Most of the slate outcrops can be found on Ordovician terrains (Table 1, Fig. 4).

Table 1. Geological settings of the slate districts from the Iberian Peninsula

	Slate districts	Formations / Geological structure / Age
1	Monte Rande	Luarca slates / W of the Ollo de Sapo Anticlinorium / Upper Ordovician
2	Terra Cha	Cándana slates / Mondoñedo Thrust / Lower Cambrian
3	Caurel	Luarca slates / Truchas Syncline / Middle Ordovician
4	Los Oscos	Luarca slates / Mondoñedo Thrust and Narcea Anticlinorium / Middle Ordovician
5	Valdeorras	Luarca slates, Casaio, Rozadais and Losadilla formations / Truchas Syncline / Ordovician
6	Alto Bierzo	Luarca slates / Truchas Syncline / Ordovician
7	La Cabrera - La Baña	Luarca slates, Casaio, Rozadais and Losadilla formations / Truchas Syncline / Ordovician
8	Riofrio	Luarca slates / Alcañices Syncline
9	Bernardos	Santa MariaBeds / Santa María la Real Massif / Precambrian
10	Villar del Rey	GevoraUnit / San Mamed - La Codosera Synclinorium / Devonian
11	Valongo	Valongo slates / Valongo Syncline / Middle Ordovician
12	Arouca	Valongo slates / Valongo Syncline / Middle Ordovician

From a stratigraphic point of view, the productive formations are as follows (Cárdenes et al., 2013):

- Santa María Beds, from the Santa María la Real Massif (Álvarez, 1982), belonging in turn to the Schists Greywacke Complex. Quarries are located to the North of Madrid, in the province of Segovia. The slates are slightly sandy, greenish-grey colored, with numerous sandstone and quartzite levels, more abundant to the top and bottom of the stratigraphic section. These are the roofing slates of the Iberian Peninsula which present the highest metamorphic grade, reaching the biotite isograde.
- Formation Cándana Green Slates (Compte, 1959), from the Group Middle Cándana. These are green slates and schists with abundant carbonates and centimetric cubic crystals of pyrite. The characteristic mineral for these slates is clinochlore, which gives them the green color. Outcrops are located in the province of Lugo, N Spain, in MondoñedoThrust Domain. These slates have a low fissility grade, being used mostly for flooring.
- Luarca Slates Formation (Barrois, 1882) is the largest roofing slate lithotect in the Iberian Peninsula. Main outcrops are found in the Truchas Synclinorium (Fig. 5)and El Caurel Domain (Marcos, 1973), covering the provinces of Lugo, Orense and León. It consists of a monotonous sequence of black slates with thin sandy levels. To the bottom and top of the stratigraphic section there are volcano-sedimentary levels, and to the middle part there is an iron nodule level, which in some localities have been quarried. The slate is black, fine grained, with abundant iron sulfides to the top. In the slates from El Caurel Domain is usual to find chloritoid well developed, visible with naked eye. In N Portugal, the equivalent lithotect is the Valongo Slates Formation (Romano and Diggens, 1974).

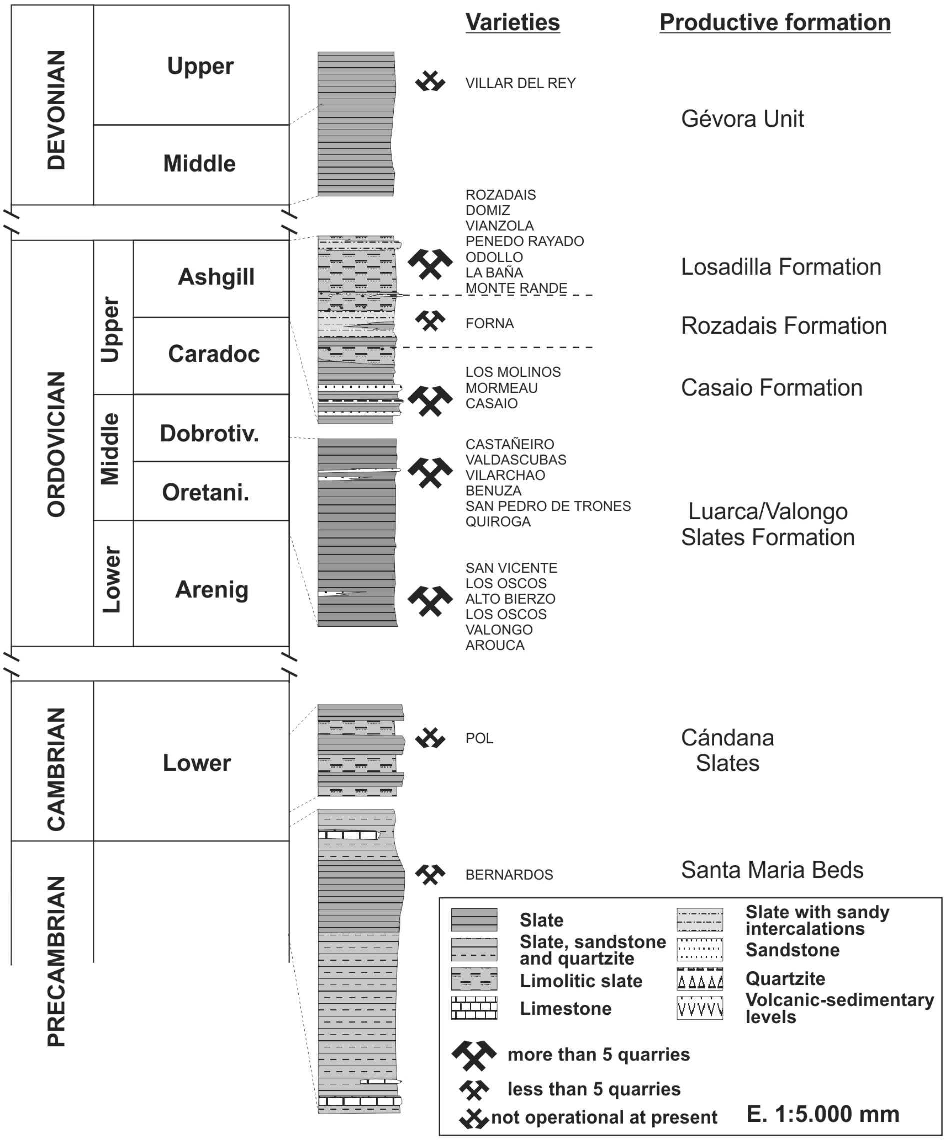

Figure 4. Stratigraphic column for the Iberian Peninsula slate varieties.

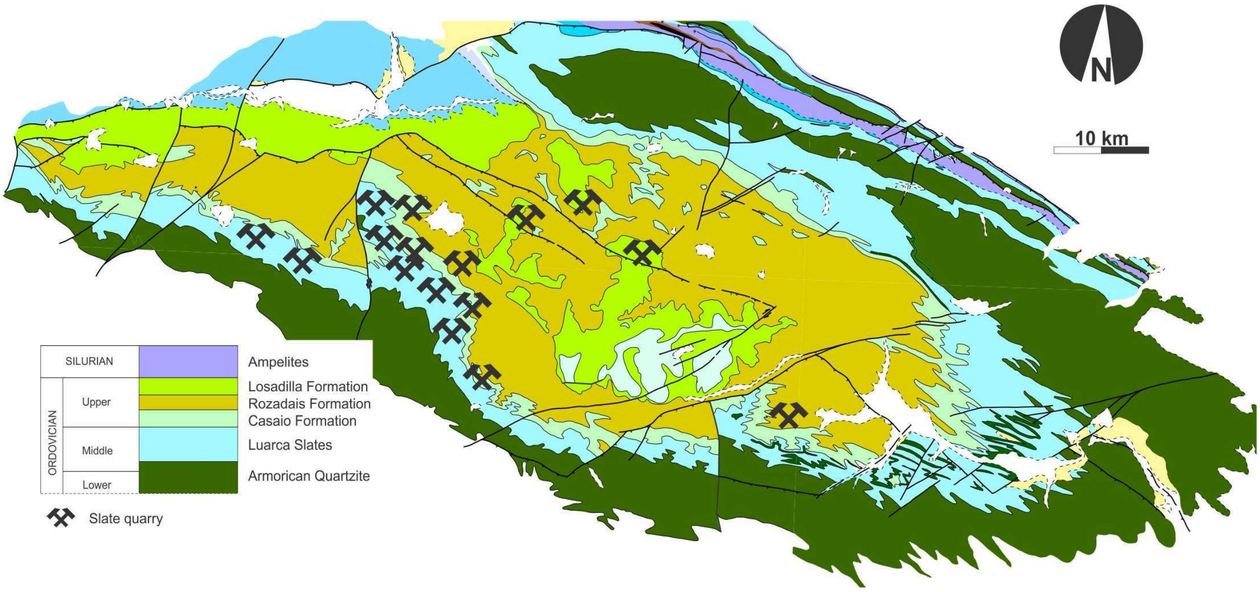

Figure 5. Geological map of the Truchas Syncline, with the main slate outcrops represented. Modified from Heredia et al., unpublished.

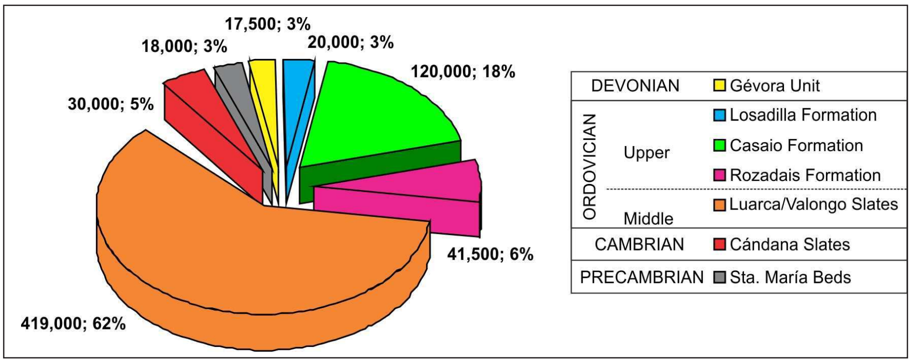

Figure 6. Slate production by Formations. Data from UNSTATS, United Nations Comtrade, 2009.

- Casaio, Rozadais and Losadilla formations (Barros, 1989) for the Truchas Syncline Domain, and Agüeira Formation (Marcos, 1973), outside the Syncline. Casaio Formation consists of light grey slate, with coarse detritic lithologies and iron sulfides. Most of the quarries are placed in this formation. Rozadais Formation has predominance of slaty terms, with some quartzite intercalations, and fragments of limestone and sandstone to the top. These pelite fragments (pelítes à fragments) can be recognized in other localities of the European Hercynian chain. Finally, Losadilla Formation, the less productive, is represented by light grey slates with sandy laminations, with high quartz content.
- Gévora Unit (Santos-García and Casas, 1979), in the southern area of the Central Iberian Zone, in the province of Badajoz. The outcrops are located in the La Codosera-Puebla de Obando Synclinorium. These slates are black, medium grained, homogeneous, with abundant inclusions of cubic pyrite and organic matter.

The main, by far, productive formation is the Luarca Slates, from Middle Ordovician (Barrois, 1882), mainly quarried at the Truchas Syncline (Catalan et al., 1992). Other Ordovician formations (Casaio, Rozadais and Losadilla) are quarried at the Truchas Syncline, with a considerable volume of production (Fig. 6).

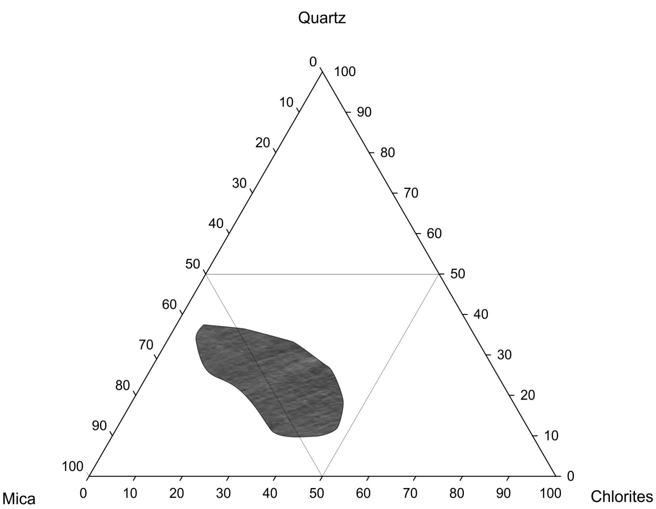

Figure 7. Triangular diagram for the three main mineral components. The shadowed area represents the average values for Iberian roofing slates.

Unifying characteristics of this province

The proposed GHSP comprises the roofing slates from the Iberian Peninsula. By definition, roofing slates are a fine grained group of stones which have the ability to be split into thin, plane and large tiles. In the Iberian Peninsula two types of rocks agree with these conditions, slates *s.s.* and phyllites (Arkai et al., 2007). Technical characteristics of these rocks are very similar. As a general condition, they fulfill the requirements of the European Norm for roofing slates EN 12326 (AEN/CTN_22, 2011). The main characteristics that together form a good slate tile are mineralogy and geochemistry (weatherability) and petrographic texture (fissility).

Iberian roofing slates are very uniform in mineralogy, with three main minerals (quartz, mica and chlorites, Fig. 7) and some accessories like chloritoid, iron sulphides, carbonates, organic matter, rutile and tourmaline.

Regarding to the geochemistry, the elemental composition of the Iberian slates is rather homogeneous (Fig. 8). The average values and standard deviation (in brackets) for the major elements are SiO_2: 56.03(3.35), Al_2O_3: 22.09 (1.97), Fe_2O_3: 8.06 (1.33), MnO: 0.09 (0.03), MgO: 2.37 (0.52), CaO: 0.44 (0.23), Na_2O: 1.29 (0.73), K_2O: 4.05 (0.73), TiO_2:1.15 (0.22), P_2O_5: 0.16 (0.16).

From a petrographic point of view, the texture of the slates is very characteristic, lepidoblastic or porfiro-lepidoblastic (Fig. 9). This texture always shows a penetrative slaty cleavage, with clear alignments of the clasts. There is a special requirement of the EN 12326 for roofing slates regarding to petrography, that is the calculation of the Mica Stacking Index (MSI). This index calculates the density and thickness of the mica levels that form the slaty cleavage planes, and it is related with the fissility(Cárdenes et al., 2010).

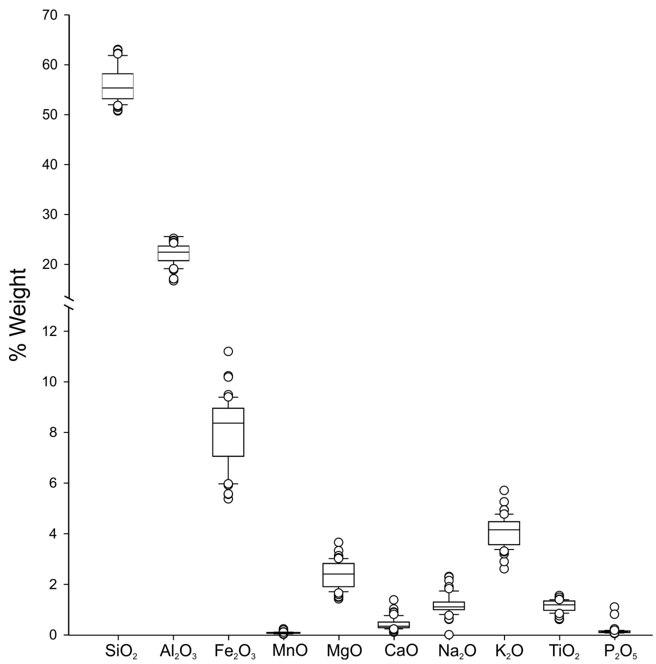

Figure 8. Major elements composition for Iberian roofing slates.

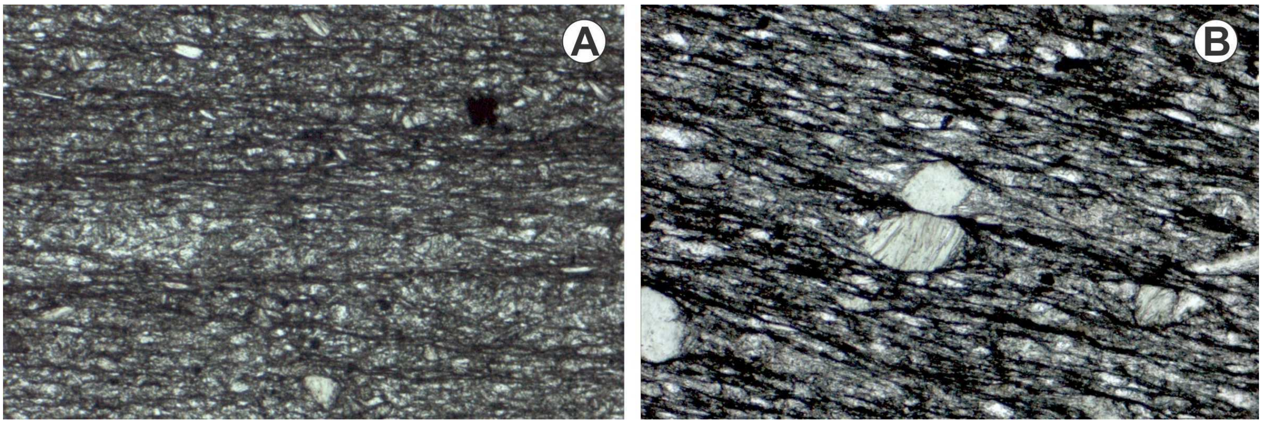

Figure 9. The two characteristic microscopic textures for Iberian roofing slates. (A) Lepidoblastic texture, Luarca Slates Formation, Valdeorras. (B) Porphyro-lepidoblastic texture, Rozadais Formation, Valdeorras. Both microphotographs taken with parallel nichols, 200x magnification.

Natural variation of geology within this province

The geology of the different areas that form the proposed province falls within the Hercynian of the Iberian Peninsula. However, all these areas have some important geological features in common. All of them are located in the Hercynian terrains of the Iberian Peninsula, showing none or very slight deformation; otherwise it would be impossible to obtain regular tiles. The metamorphic range is rather short, from 200 to 400 °C of temperature and 20 to 40 MPa of pressure. The original sediments were in all cases pelites (Cárdenes et al., 2013).

Vulnerability

There are enough reservoirs in all the districts, with the exception of the district of Bernardos. This district has been quarried from more than 500 years, and now it is close to its exhaustion. However, there is always the possibility to continue the works by opening a mine, like in other countries (France, Germany) that have been quarrying slate for hundreds of years. This option has been taken into account by several companies in Bernardos but also in other districts, such as Valdeorras and La Baña. In case there would be needed substituting slate from a heritage building with a different source slate, a protocol of acting has been developed (Cárdenes et al., 2014; Prieto et al., 2011), taking into account the mineralogy and aesthetics of the slate.

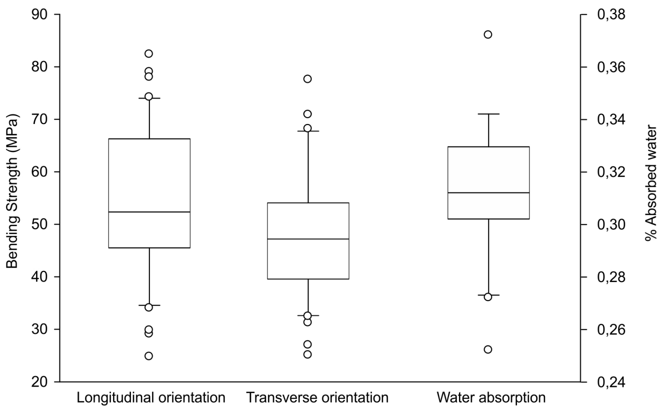

Figure 10. Average values for bending strength (right) for both longitudinal and transverse orientations. On the left, average values for water absorption. Data from the Technological Center of Slate, Sobradelo de Valdeorras, Spain.

Construction

Nowadays, about 80% of recent buildings in Europe with slate covershave Iberian slate. Also, many buildings from the European heritage have been restored with Iberian slate, or still keep the original slate, as in the case for El Escorial Palace in Spain.

Technical and aesthetic characteristics for Iberian roofing slates are very similar. The tests needed for commercializing, according to EN 12326, are bending strength (calculated in both longitudinal and transverse orientations respect of the tile), water absorption (Fig. 10), freeze-thaw resistance, oxidizability by thermal cycling and petrographic characterization. This set of tests is focused on the requirements of a roofing material. From a durability point of view, roofing slates can be affected by two main pathologies, oxidation and gypsification. The oxidation is the result of the weathering of the iron sulphides (mainly pyrite and pyrrhotite) that the slate may content, while gypsification is the transformation of the carbonates to gypsum. The relative abundances of the potentially harmful minerals are between 0 and 4% for iron

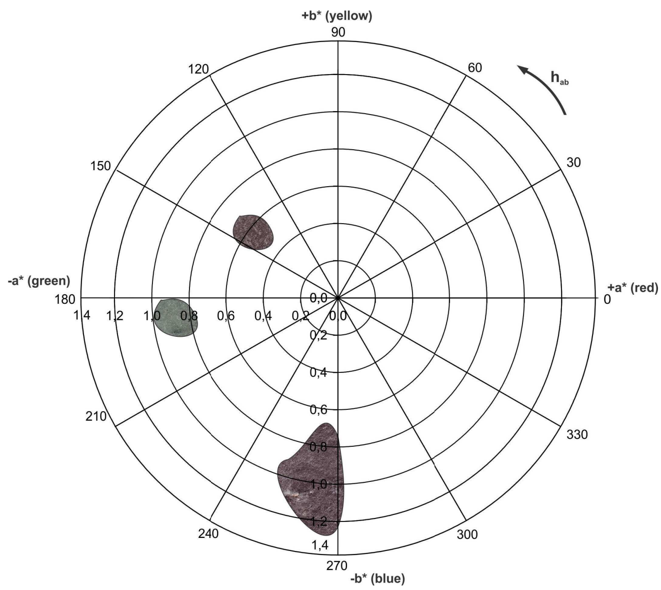

Figure 11.CIELAB color space: representation of the area in which the chromatic parameters: a*, b*, C*ab and hab of the slates studied are included. Shaded area corresponds to the average coordinates for Spanish roofing slates.

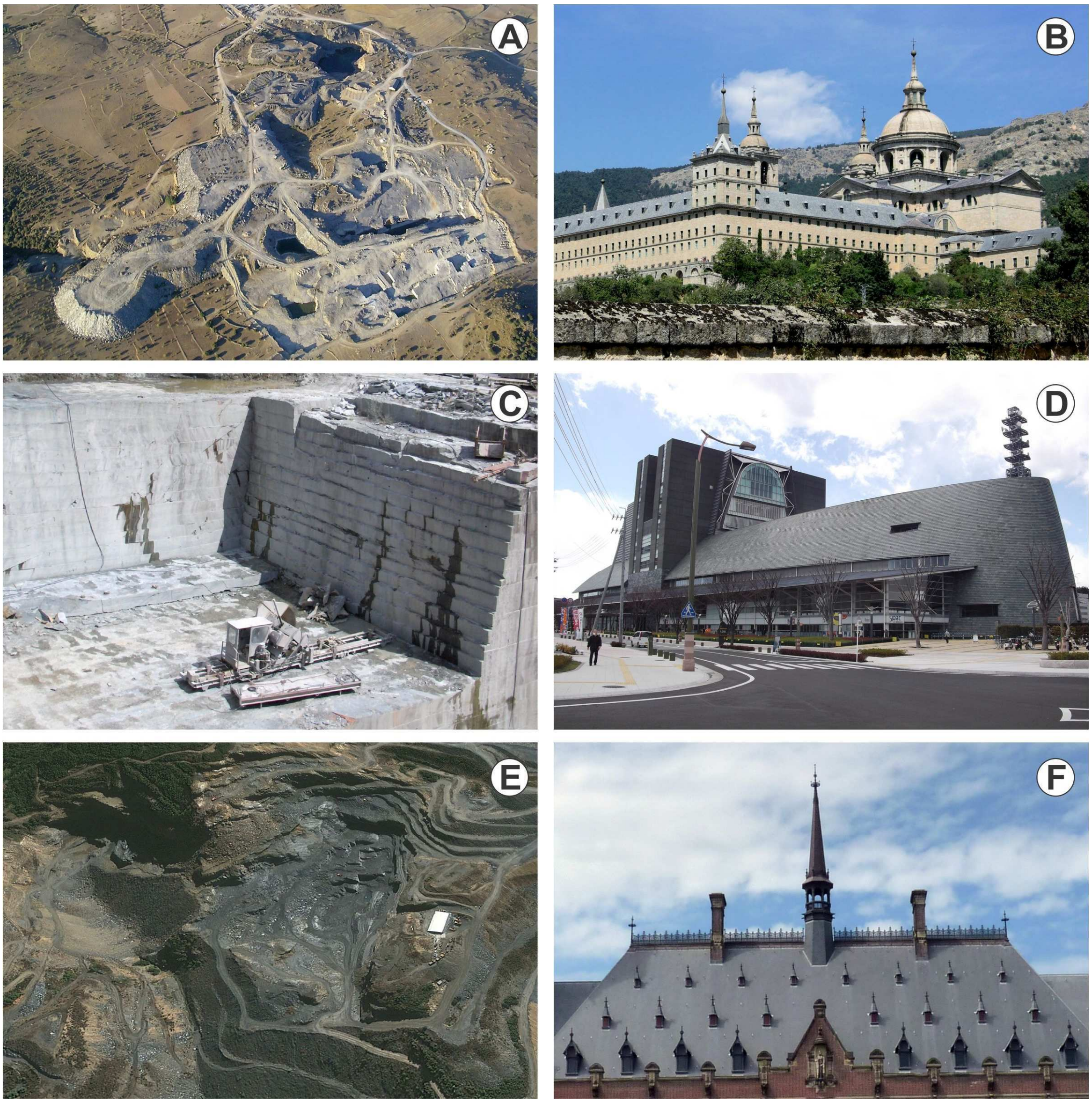

Figure 12. Some of the most important representative Iberian slate quarries, together with emblematic buildings made with their slate: A. Quarry from Bernardos, Segovia, Spain.Image: Pizarras J. Bernardos. B. Royal Monastery of San Lorenzo de El Escorial (1563-1584), Spain, one of the most important buildings in Spanish Heritage constructed by and for King Felipe II, originally covered with slate from Bernardos. C. Quarry for the variety Verde Pol, in Lugo, Spain. D. Shizouka Convention and Arts Center (1999), Shizouka, Japan, made with Verde Pol Photo: IPISA. E. Quarry from Los Molinos, Ourense, Spain. Image: Google maps. F. Peace Palace (1907 – 1913), The Hague, The Netherlands, place for the International Court of Justice, slate from Los Molinos quarry.Image: CUPA Pizarras.

sulphides and between 0 and 2% for carbonates.

Regarding to aesthetics, slates have colors ranging from black dark to light grey, with the exception of the phyllites from Lugo, that are light green (Fig. 11).

Some examples of representative buildings (Fig. 12) made with Iberian roofing slate are:

- The Peace Palace (1907-1913), The Hague, The Netherlands.
- Merlemont Castle (17^{th} century), Val d'Hermeton, Philippeville, Belgium.
- Baelen Castle (17^{th} century), Welkenraedt, Belgium.
- Mitsubishi Ichigokan Museum of Arts (1864), Tokyo, Japan.
- Church Notre Dame, Laeken, Brussels, Belgium (1854).
- Kerfily Castle (1858-1863), Elven, Morbihan, France.
- Pontevedra Auditorium, Spain.
- Shizouka Convention and Arts Center (1999), Japan.
- Royal Monastery of San Lorenzo de El Escorial (1584), Madrid, Spain.
- Royal Mint House (1580), Segovia, Spain.
- Palace of Cardenal Espinosa (1572), Segovia.
- Santa Cruz Palace (1629-1643), Madrid, Spain.
- Parish church of Santa Bárbara (former Royal Monastery of La Visitación, 1757), Madrid, Spain.

Conclusions

The Iberian Peninsula is, nowadays, the main producer of roofing slates of the world. As pointed before, about 80% of the world's production comes from the Iberian Peninsula. Roofing slates from the Iberian Peninsula are rather homogeneous both from constructive and petrological points of view, with only some differences among them in color and mechanical performance. They are present in many of the European building heritage and also in actual buildings. These facts give sense to the proposal of a *Global Heritage Stone Province* for the Iberian roofing slate.

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