Portuguese ornamental stones

Jorge M. F. Carvalho[1, a], Cristina I. Carvalho[1, b], José V. Lisboa[1, c], António Casal Moura[1,d] & Mário M. Leite[1, e]

1 – Laboratório Nacional de Energia e Geologia, Apartado 7586 – Alfragide, 2610-999 Amadora, Portugal
a – jorge.carvalho@lneg.pt, b – cristina.carvalho@lneg.pt, c – vitor.lisboa@lneg.pt, d – casal.moura@lneg.pt, e – machado.leite@lneg.pt

Abstract

Portugal produces a great diversity of ornamental stones. Besides the internationally known white and pink marbles, also light cream limestones are produced, as well as grey, yellow and pink granites, and dark grey slates. From these, limestones are the most request variety today, especially by the Chinese market.

Key-words: *Ornamental stones; Portugal.*

Resumo

Portugal é produtor de uma grande variedade de rochas ornamentais. Para além das variedades de mármore branco e rosado que são, desde há muito, internacionalmente conhecidas, também se produzem calcários de cor creme, granitos cinzentos, amarelos e rosados, bem como xistos cinzento escuros. Atualmente, a produção nacional centra-se nas variedades de calcário, as quais são muito requisitadas pelo mercado chinês.

Palavras-chave: Rochas Ornamentais; Portugal.

Introduction

The Portuguese territory has a great geological diversity (Fig. 1): Neoproterozoic phyllites, schists and gneisses; Paleozoic meta-pelites, meta-psamites, marbles, meta-volcanics and granites; Mesozoic limestones, clays and sands; and Cenozoic sands and clays. From this diversity, Portugal also presents a wide variety of geological resources, notably in ornamental stones, which are also known as natural stones or dimension stones (Carvalho, 2007).

The inventory and characterization of the Portuguese ornamental stones is one of the missions of the Portuguese Geological Survey (LNEG – Laboratório Nacional de Energia e Geologia). This systematic work resulted in the preparation of the Portuguese Catalogue of Ornamental Stones, which is continuously updated and is available online at the Geological Survey *Geoportal* (http://geoportal.lneg.pt/).

This work presents a synthesis of the Portuguese Ornamental Stones and its main technical properties. The most important mining districts are presented here (Fig. 1), whose selection, especially for most of the granite type rocks, was based on the existence of more than a quarry in each of the considered districts. Presented are also, some of the most typical ornamental varieties.

The ornamental stones here considered, correspond to granites, marbles, limestones and slates. These terms should be understood according to the nomenclature commonly used in the commercial transactions of these raw materials (Langer, 2001).

Granites

The North and Centre of the Portuguese territory are characterized by extensive areas of granitic outcrops of Paleozoic age (Fig. 1), to which several mining districts

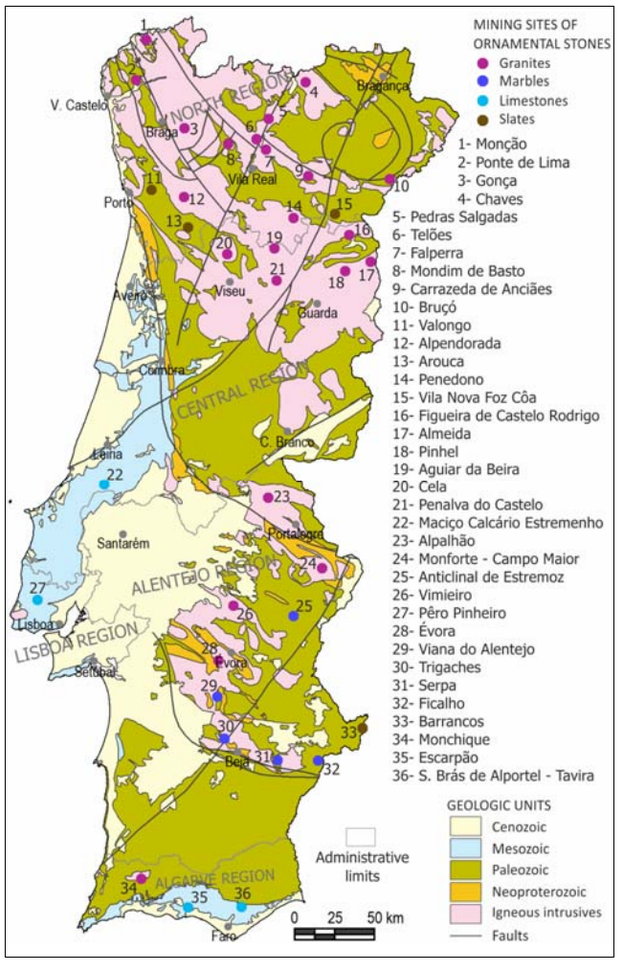

Figure 1 – Location of the main Portuguese ornamental stones mining sites.

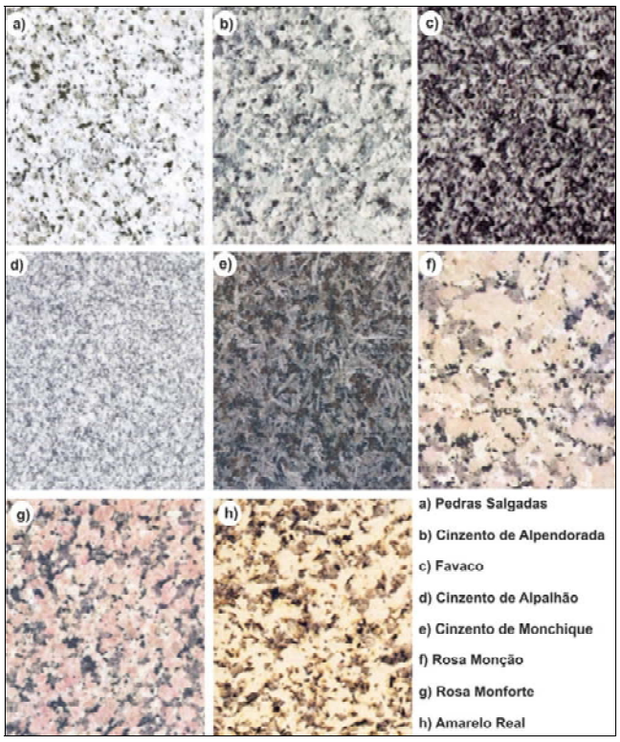

Figure 2 – Examples of some of the granite ornamental varieties produced in Portugal.

of ornamental stones are associated. However, in the Alentejo and Algarve regions, the mining of these resources for ornamental purposes also takes place. The ornamental rocks potentialities are mainly associated to granites of pós-Variscan Orogeny times (Casal Moura, 2000, 2001; Casal Moura *et al.*, 1995, 1997; González-Clavijo & Valadares, 2003; Lisboa, 1998; Lisboa & Oliveira, 2005; Moreira, 1992, 1994, 1999; Ramos *et al.*, 2000; Sardinha *et al.*, 2010; Sousa, 2006).

Portuguese granites show a wide variety of colours and textures. Nevertheless, the vast majority have grey to bluish grey colours and fine to coarse granular textures, sometimes porphyroid. These kinds of granites are exploited in most of the mining sites marked on the map in figure 1. At Pedras Salgadas and Alpendorada sites are produced the well-known commercial varieties *Pedras Salgadas* and *Cinzento de Alpendorada* (Fig. 2).

By its peculiarities regarding colour and/or texture, other varieties worth emphasizing: the *Favaco* variety due to its dark grey colour, which is exploited in a restrict place of the Monforte – Campo Maior mining district, the *Cinzento de Alpalhão* that is mined at Alpalhão and deserves to be pointed out for its homogeneous fine-grained texture, and the *Cinzento de Monchique* that comes from an igneous massif, in the Algarve region. This variety, is actually a medium to coarse grain nepheline syenite with a greyish general colour that is here highlighted for its somewhat acicular texture from which reddish-brown grains of nepheline stands out.

Greyish granites are actually very common in the international market of ornamental stones. Thus, the best quarrying conditions are required in order to maximize the exploitation efficiency of this type of granites in Portugal. The depth of the quarries is quite variable, often exceeding 30 m and, at Alpalhão, reaching almost 70 m in depth. Nevertheless, some of the most profitable quarries are those engaged in the mining operation of large balls of granite.

From the varieties with higher economic value, nowadays stands out those with pinkish or yellowish colours. The pinkish varieties occur in the Monção and Monforte – Campo Maior mining districts, where the quarries often exceed 30 m in depth, as seen in the greyish granite quarries. The varieties exploited present a coarse to very coarse grain size and are known as *Rosa Monção* and *Rosa Monforte*, respectively (Fig. 2).

Yellowish varieties are intensively exploited at several sites but the most active are those of Ponte de Lima, Mondim de Basto and Falperra regions. Their colour results of shallow weathering phenomena, affecting the grey underlying granites and, therefore, the exploitable thickness only sporadically exceeds 10 to 15 m depth. This particular genetics of the yellow granites, justifies the values obtained for its physical-mechanical properties, when compared with those of other granite varieties (Table 1).

***Table 1* – Representative technical values of the Portuguese ornamental granites.**

	Mean Values — Variation range	
	Yellow Granites	**White, Grey, Dark and Pink Granites and other silicate stones ***
Compressive strength [MPa]	79 — 246	131 — 262
Flexural strength under concentrated load [MPa]	3.1 — 20.1	9.4 — 29.4
Apparent density [kg/m^3]	2530 — 2660	2610 — 2870
Open porosity [%]	0.7 — 4.2	0.1 — 1.2
Water absorption at atmospheric pressure [%]	0.3 — 1.7	0.1 — 0.4
Linear thermal expansion coefficient [10^{-6}/ºC]	5.9 — 9.2	6.5 — 10.7
Rupture energy [Joules]	6 — 11	4 — 11
Abrasion resistance — Wide Wheel Abrasion Test [mm]	13.0 — 20.5	11.5 — 20.5

***** Sienite, serpentinite, gabrodiorite, etc..

Marbles

Although there are some well-known marble occurrences in the northern Portuguese territory, whose economic interest is very low, these ornamental stones occur mainly in the Alentejo region, being the Anticlinal de Estremoz the main production centre (Fig. 1). The earliest evidence for exploitation of this resource in this region dates back to the year of 370 BC (Martins & Lopes, 2011). Later, in the Roman Period, it has been widely used for structural and decorative purposes. Because of this historical relevance and because some of the present day open-pits are very deep, reaching almost 150 m in depth, being like windows to the earth's interior, they are considered in the context of the Portuguese geological heritage (Brilha *et al.*, 2005).

In the last few decades, several research studies have been undertaken to valuate marbles from this region, namely, those of Carvalho (2008), Carvalho *et al.* (2008), Casal Moura (2007), Henriques *et al.* (2006, 2008), Lopes & Gonçalves (1997) and Vintém *et al.* (2003).

The marble unit is of Lower Paleozoic age and has a total thickness that ranges from 100 to 250 m. As they were affected by the two main deformation phases of the Variscan Orogeny in the Portuguese territory, they are arranged in a very complex geological structure that strongly affects its exploitability. Nevertheless, the importance of the Anticlinal de Estremoz production

Figure 3 – Examples of the Portuguese marble varieties.

centre is translated by the 150 active reported quarries on the year 2009. These are distributed over 5 mining districts: Estremoz, Borba, Vigária, Lagoa and Pardais, being these last three, part of the Vila Viçosa municipality. As mentioned earlier, some of them are very deep but typically they have a depth of about 50 m.

The marbles are characterized by a fine to medium-grained texture and they present a wide range of colours, from white to dark grey. Although, the most common are the white and light cream varieties, with more or less abundant greyish to reddish stripes, they are known by different commercial names, according to the quarry owner. Table 2 presents the figures obtained for the main physical-mechanical properties of these marbles. The most valuable are the pure white and the pinkish varieties (Fig. 3).

***Table 2* – Representative physical-mechanical features of the Portuguese ornamental marbles.**

	Mean Values — Variation range
Compressive strength [MPa]	52 — 141
Flexural strength under concentrated load [MPa]	4.9 — 19.3
Apparent density [kg/m^3]	2710 — 2790
Open porosity [%]	0.2 — 0.5
Water absorption at atmospheric pressure [%]	0.0 — 0.2
Linear thermal expansion coefficient [10^{-6}/ºC]	4.1 — 14.0
Rupture energy [Joules]	5 — 11
Abrasion resistance — Wide Wheel Abrasion Test [mm]	15.5 — 26.5

Viana do Alentejo, Trigaches, Serpa and Ficalho are small mining sites where the potentialities for the production of marbles are relatively small because of the high fracturing degree. Particularly, marbles from Viana do Alentejo and Trigaches that present some textural and chromatic peculiarities (Fig. 3), have an interesting commercial market. Those from Viana do Alentejo show a medium to coarse-grained texture and are green coloured with typical well marked dark green to brownish stripes (Henriques, 2001). The Trigaches marbles are grey in colour but present a very coarse-grain texture.

Limestones

In Portugal they occur mainly near the shore, to the north of Lisbon and in the Algarve region, in the south (Fig. 1). The main mining district of ornamental limestones is the Maciço Calcário Estremenho (MCE), located north of Lisbon (Carvalho, 2005; Carvalho *et al.*, 2003; Casal Moura, 2007). It is a limestone massif with a well-known lithostratigraphy that is made up of a thick sequence of Mesozoic carbonated rocks tectonically elevated (Manuppella *et al.*, 2000; 2006). The productive lithostratigraphic units of the main ornamental varieties date from Middle-Jurassic (Carvalho, 1997).

Mining is carried out by more than 50 quarries in 6 main mining districts: Pé da Pedreira (municipality of Santarém), Moleanos (municipality of Alcobaça), Codaçal, Cabeça Veada and Salgueiras (Porto de Mós) and Fátima (Ourém). The limestone's exploitation in MCE is relatively recent, having started in the early eighties of the last century. However, approximately since 10 years ago, these rocks are the most requested Portuguese ornamental stone, especially by the Chinese market.

The lithostratigraphic units have thicknesses of about 40 m to more than 150 m and the strata thickness spans from 2 to more than 20 m. As the geological structure is very simple, the strata being sub horizontal, exploitability conditions are very favourable.

Most of the MCE limestones are fine to coarse-grained calciclastic sparitic rocks (rudstones and grainstones), that is, formed by grains cemented by small amounts of translucid calcite; corresponding the grains to skeletal fossil fragments of marine organisms and to other carbonate particles as intraclasts, oncholiths and ooliths. They are cream coloured with a texture marked by thin laminations, which are visible or not, depending on the way the blocks are cut. The most traditional ornamental stones from MCE are represented in figure 4, being referenced by their most common commercial names. The variation range of their technical properties is listed in table 3.

The region of Pêro Pinheiro, North of Lisbon, is one of the most traditional production centres of ornamental stones of Portugal. Quarrying in this region

should have been started in Roman times, as testified by the discovery of a roman quarry located about 10 km to the south (Coelho, 2002). However, their intensive exploitation has only begun in the 18th century, for the reconstruction of Lisbon, after the big earthquake of 1755. Because of nowadays major urban spread in the region, the availability of the resource is threatened and most of the quarries are currently inactive. From one hundred quarries registered, only 27 remain occasionally active.

***Table 3* – Main physical-mechanical features of the Portuguese limestones.**

	Mean Values — Variation range
Compressive strength [MPa]	44 — 246
Flexural strength under concentrated load [MPa]	4.4 — 23.4
Apparent density [kg/m^3]	2190 — 2710
Open porosity [%]	0.1 — 16.5
Water absorption at atmospheric pressure [%]	0.1 — 8.9
Linear thermal expansion coefficient [10^{-6}/ºC]	2.7 — 5.1
Rupture energy [Joules]	2 — 5
Abrasion resistance — Wide Wheel Abrasion Test [mm]	17.5 — 28.0

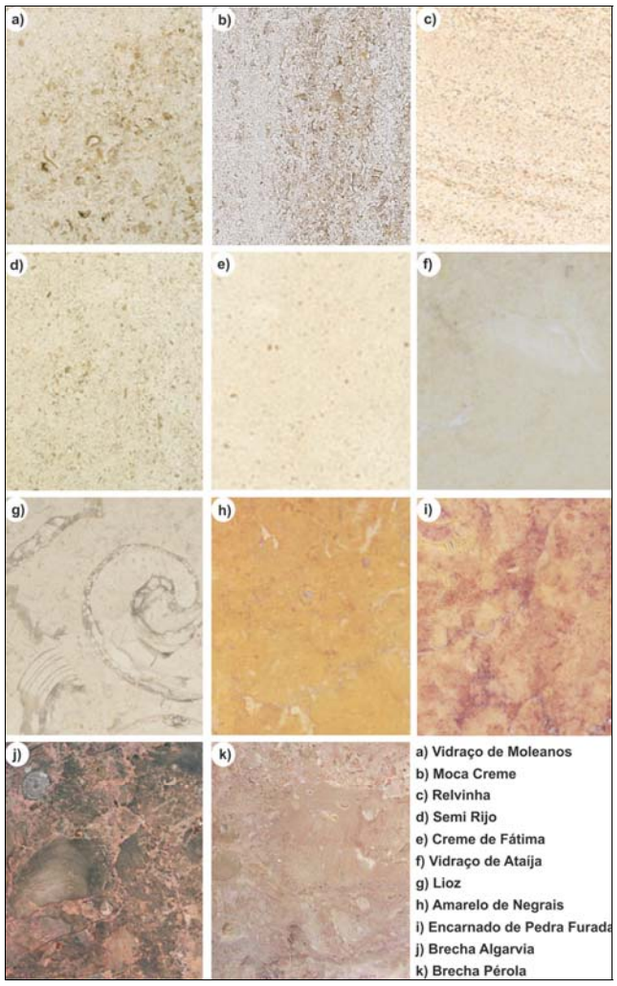

Figure 4 – Examples of the most common Portuguese ornamental varieties of limestones.

Ornamental limestones from Pêro Pinheiro are dated Cretaceous in age. In general terms they correspond to bioclastic and bio-edified rocks characterized by more or less abundant fossil remains of rudists which give a aesthetics peculiarity to the ornamental varieties (Martins, 1991). From these, the so called *Lioz,* is the most traditional (Fig. 4). Although, nowadays are much appreciated the varieties with vivid yellowish or reddish colours.

In the Algarve region, ornamental stones are exploited near the localities of Escarpão (municipality of Albufeira), Mesquita (municipality of S. Brás de Alportel) and Santo Estêvão (municipality of Tavira) (Fig. 1).

Escarpão is a very small mining site of Upper Jurassic bluish grey limestone, that is mainly exploited for aggregates. As some of the strata shows less fractured, they are also used for ornamental purposes.

In the S. Brás de Alportel – Tavira production centre, exploitation takes place in 8 relatively deep quarries, showing very limited activity nowadays. The ornamental variety of this production center, is known as *Brecha Algarvia* (or *Brecha de Tavira*). As reported by Henriques *et al.* (2003), it is part of a thick lithostratigraphic productive unit, up to 150 m, that corresponds to a bioclastic and partially bio-edified limestone of Upper Jurassic age, whose coarse elements and reddish and greyish colours variations suggests a breccia appearance (Fig. 4).

Slates

The outcropping areas of slates in Portugal are quite extensive (Fig. 1). However, the production of ornamental slates is relatively small. The main mining

sites are located in Valongo, Arouca and Vila Nova de Foz Côa regions, in the North of Portugal, and in Barrancos region, in the Alentejo.

In Valongo, slates are exploited in a very narrow land band, constrained by urban households. The slates present a dark gray colour and a very fine granularity (Fig. 5). Their superior textural homogeneity and the very well defined slaty cleavage, improves the quality, being currently used for the production of billiard tables. Nevertheless, the production is mainly directed for the tile industry. The productive unit of Valongo is known as *Xistos de Valongo*, of Paleozoic age (Ordovician) and the same unit is exploited at Arouca.

Figure 5 – Examples of Portuguese slates.

In Vila Nova de Foz Côa, the so called *Xistos do Poio* are mined since 200 years ago for building construction as dry set mansory and tiles, as well as vineyards support masts (Búrcio, 2004). They are part of a thick lithostratigraphic unit known as *Desejosa Formation*, of Cambrian age, and are made up of alternating fine levels of light colored psamites and dark colored pelites, but the irregular cleavage surfaces present a dark grey color (Aires *et al.*, 2011). It is a deposit strongly conditioned by the geologic structure. In fold-hinge zones, where the cleavage intersects perpendicularly the stratification, long and narrow pieces are produced – the so called *Esteios* that still are used as support masts for vineyeards.

In Barrancos an Ordovician unit, the *Xistos com Phyllodocites* Formation is exploited seasonally in a single large quarry - the Mestre André quarry (Carvalho & Falé, 2002). The rock corresponds to a fine-grain micaceous shale characterized by regular cleavage surfaces. These are highly aesthetically appealing as they are multicoloured, from yellow to pink and green, and commonly present meandering bioturbations.

In Table 4 are presented the main technological characteristics of the Portuguese ornamental slates.

***Table 4* – Main physical-mechanical properties of the Portuguese slates.**

	Mean Values — Variation range
Compressive strength [MPa]	114 — 217
Flexural strength under concentrated load * [MPa]	29.5 — 69.6
Apparent density [kg/m^3]	2700 — 2830
Open porosity [%]	0.4 — 1.2
Water absorption at atmospheric pressure [%]	0.2 — 0.5
Linear thermal expansion coefficient [10^{-6}/ºC]	7.1 — 8.1
Rupture energy [Joules]	9 — 10
Abrasion resistance — Wide Wheel Abrasion Test [mm]	20.0 — 36.0

* Load applied perpendicular to the foliation planes.

Conclusions

As a result of the geological diversity that characterizes its territory, Portugal produces a large chromatic and textural variety of granites and marbles for ornamental purposes. However, regarding granites, the most abundant varieties are the greyish coloured with relatively low economic value, due to the strong pricing competition for this kind of stones in the global market. The most common varieties of marbles are the light cream coloured with more or less abundant dark stripes.

Concerning limestones, MCE is the main production centre. The homogeneous cream coloured varieties produced in that region are strongly requested nowadays, especially by the Chinese market. Finally, with respect to slates, the Portuguese production is relatively low.

From the physical-mechanical point of view, Portuguese ornamental stones can be used in a wide range of applications. Stone suitability should be evaluated both on the stone properties and on the technical specifications for each application.

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