

# Evaluation of the Portuguese Ornamental Stone Resources

Jorge M. F. Carvalho<sup>1, a</sup>, José V. Lisboa<sup>1, b</sup>, António Casal Moura<sup>1, c</sup>,  
Cristina I. Carvalho<sup>1, d</sup>, Luís M. O. Sousa<sup>2, e</sup> and Mário M. Leite<sup>1, f</sup>

<sup>1</sup>Portuguese Energy and Geology Laboratory, Apartado 7586 – Alfragide, 2610-999  
Amadora, Portugal

<sup>2</sup>Departamento de Geologia, Universidade de Trás-os-Montes e Alto Douro, Apartado  
1013, 5001-801 Vila Real, Portugal

<sup>a</sup>jorge.carvalho@lneg.pt, <sup>b</sup>vitor.lisboa@lneg.pt, <sup>c</sup>casal.moura@lneg.pt,  
<sup>d</sup>cristina.carvalho@lneg.pt, <sup>e</sup>lsousa@utad.pt, <sup>f</sup>machado.leite@lneg.pt

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**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.

A first exercise is presented on the evaluation of the available resources of ornamental stones in the whole Portuguese territory. The results show a total availability of 410 million cubic meters, of which 274 million refer to granite, 76 million to limestone, 51 million to marble, and 9 million to slate.

## Introduction

Portugal is one of the world's leading producers of ornamental stones. It has a rich variety of this kind of mineral resources, which are exploited all over the country in several mining sites. As a result of the systematic inventory of those mining sites, carried out by the Portuguese Geological Survey since long time ago, most of the ornamental varieties produced are known and have been technically characterized.

Granite type ornamental stones are mainly exploited in the central and northern regions of the country's territory. The most abundant present greyish colours and a great diversity of textures but there are also pink and yellow varieties, which are the most valuable [1]. Marbles are exploited in the Alentejo region, notably in the so-called Anticlinal de Estremoz [2]. They present a large spectrum of colours, from white to dark grey, but the most common are the light-cream coloured with streaks of different tonalities. Pale to deep pink varieties are the most valuable. With respect to limestones, the largest mining district is the Maciço Calcário Estremenho (MCE), located 150 km north of Lisbon [2]. They are cream coloured and, depending on the way the blocks are cut, they may show a texture marked by thin sedimentary laminations. Nowadays, these limestones are the most required Portuguese ornamental stones, especially by the Chinese market. Portugal also produces slates but in limited quantities in small mining sites.

The terms employed here to refer the main groups of ornamental stones should be understood according to the nomenclature commonly used in the commercial transactions of these raw materials [3].

Despite the thorough knowledge concerning the characteristics of the Portuguese ornamental stones and some resource measurements in restricted places, there is no concrete knowledge about the overall amount of available resources. This work presents a first attempt on the quantification of the available ornamental stone resources in Portugal.

## Data and methodology

The data that form the basis of this work results from the systematic inventory of ornamental stone resources developed by the Portuguese Geological Survey. It is supported on field works at various levels. From simple recognition studies of the mining sites and ornamental varieties therein exploited, to detailed geological studies aiming the definition of areas with better ability for the exploitation of such resources. The respective results are set out in technical reports that are part of the Geological Survey's scientific repository and were the support for some reference works and papers [1, 2, 4-9]. As will be referred further on, data from other authors, obtained outside the scope of the Portuguese Geological Survey systematic activity, was also used.

The applied methodology focused on the delimiting of potential areas around the known mining sites, that is, geologically suitable areas for the expansion of the mining industry. Even those mining sites temporarily inactive due to constraints of the current market for this type of raw materials were considered because we judge the existence of suitable rock deposits for ornamental stone production, despite their present day commercial value. However, those sites represented by a single quarry and whose potential area turned out to be very small, were not considered here.

Evaluated resources are here distinguished from estimated resources. The first ones result from detailed geological studies that allowed the resources quantification in some restrict areas of the considered extractive centres, namely in the Maciço Calcário Estremenho (MCE), in Pêro Pinheiro, in Alpalhão, in Anticlinal de Estremoz, in Barrancos and in São Brás de Alportel – Tavira. The results obtained and the respective authors are referred on Table 1.

In what concerns the estimated resources, their assessment was carried out according to the size of the potential area associated with each mining site, to the thickness of the deposit and to the usual yields.

Regarding the size of the potential areas, its delineation was based on the extent of the geologic unit that is subject to operation. In the case of granites, these units match with specific granitic facies, and in the case of marbles, limestones and slates, they have correspondence with lithostratigraphic units. However, for the majority of the cases here considered, the full extent of the geologic unit in question was not respected. It was truncated according to the level of geological knowledge concerning each area.

In some of the mining districts geological reconnaissance studies were conducted that allowed a delineation of their specific potential areas. These were the adopted ones for the estimation of the available resources, as is the case of the Monção, Pedras Salgadas, Serra da Falperra, Penalva do Castelo, MCE, Monforte – Campo Maior, Anticlinal de Estremoz, Viana do Alentejo, Monchique and S. Brás de Alportel – Tavira mining districts. For those about which the existing geological knowledge is very limited, the respective potential areas have been truncated according to geological or topographical major accidents, and also as a function of large urban areas.

As there is a large discrepancy between the quality of information that was used to support the delineation of the potential areas, a correction factor was applied to the lower quality ones. In a first instance were considered the mining districts for which there is hard evidence concerning the size of the respective potential areas, but are constrained to a specific granitic facies or lithostratigraphic unit. For each case it was verified the ratio between the size of the outcrop area of those units and the potential areas marked on the basis of geological studies. It was established as Correction Factor the mean of the ratio values obtained.

To estimate the volume of available resources in each area, two main hypotheses were regarded for the thickness to be considered: the total thickness of the productive unit or the usual open-pit depths in each area. If the first hypothesis is plausible for the metamorphic and sedimentary units, it is not for the granitic units. Further, both assume that the overall extent of the potential areas is suitable for the production of ornamental rocks, which hardly will happen. Thus, bearing this in mind, it was decided to consider a minimum thickness that could justify a standard economic viability of the exploitations. Apart from a shallow bench on which the rocks commonly are weathered and fractured, it was found that the above mentioned minimum thickness would be equivalent to the vertical extension of a regular bench, that is, 5 m. However, even taking into account that this is a value to be applied to the full extent of the potential areas, it seemed to us an amount not representative of the reality, because on those locations that may prove to be suitable for mining, the thickness will be significantly greater, particularly in granites and marbles. Thus, depending on the rock type and on the usual quarry depths for each potential area, it was decided to consider what we call the Minimum Efficiency Thickness, which respective figures are listed in Table 1. Finally, the figures were corrected for the yields that characterize the operations in each production centre. These yields are reported in some of the papers published by the mentioned above authors but also in numerous Environmental Impact Studies that were carried out to the quarries, and can be viewed online at the Portuguese Agency for the Environment [10].

## Results and discussion

The data and methodology outlined above led to the estimated ornamental stones' resources presented in Table 1. The figures therein hold a relatively high degree of subjectivity that results from the assumptions governing the demarcation of potential areas and the exploitable thickness. Nevertheless, as a result of this exercise, it is obvious that the smaller estimated resources have a general match with the smaller areas, because major variations for the remaining variables were not considered.

The most important exceptions to this relation are referred to Mondim de Basto, Falperra, S. Brás de Alportel – Tavira, Alpalhão and Penalva do Castelo. The low volume estimated for Mondim de Basto and Falperra arises from the low resource thickness considered, as therein are exploited shallow yellow granite facies. For S. Brás de Alportel – Tavira the reason lies on the high degree of fracturing affecting limestones of this area, which is translated on the adopted low yield. Regarding Alpalhão and Penalva do Castelo, for their small potential areas the estimated resources are relatively high. This is because the Correction Factor was not applied to these areas, as they were delimited on the basis of fieldwork.

Table 1- Estimated and evaluated ornamental stone resources in Portugal

AREA NAME	AREA [km <sup>2</sup> ]	BIBLIOG. REFERENCE	MINIMUM EFFICIENCY THICKNESS [m]	CORRECTION FACTOR	YIELD	ESTIMATED RESOURCES [m <sup>3</sup> x 10 <sup>6</sup> ]	EVALUATED RESOURCES [m <sup>3</sup> x 10 <sup>6</sup> ]	BIBLIOG. REFERENCE
Aguiar da Beira	19.9		10	0.3	0.4	23.9	-	
Almeida	9.0		10	0.3	0.4	10.8	-	
Alpalhão	2.2	[11]	10	1	0.4	8.6	0.3	[11]
Alpendorada	32.5		10	0.3	0.4	39.0	-	

Anticlinal de Estremoz	26.7	[12]	30	0.3	0.2	48.0	51.5	Adapted from [5]
Barrancos	1.4	[13]	5	0.3	0.7	1.5	0.2	[13]
Bruçó	9.0	9	10	0.3	0.4	10.8	0.3	[14]
Carrazeda de Ansiães	3.3		5	0.3	0.3	1.5	0.02	[15]
Falperra	19.8	[16]	5	0.3	0.3	8.9	-	
Figueira de Castelo Rodrigo	5.5		5	0.3	0.3	2.5		
Gonça	11.0	11	10	0.3	0.4	13.2		
MCE	76.9	[17]	5	0.3	0.5	57.7	25.0	[18-21]
Monção	8.7	[22]	10	1	0.4	34.9	-	
Monchique	4.2		10	0.3	0.4	5.1	-	
Mondim de Basto	16.6		5	0.3	0.3	7.5	-	
Monforte - C. Maior	11.3	[23]	10	1	0.2	22.6		
Pedras Salgadas	9.2	[24]	10	1	0.4	36.7	-	
Penalva do Castelo	3.1	[25]	10	1	0.4	12.4		
Penedono	3.7		5	0.3	0.3	1.7		
Pêro Pinheiro	6.9		10	0.3	0.5	10.3	1.7	[26]
Pinhel	15.9		10	0.3	0.4	19.1	-	
Ponte de Lima	5.1		5	0.3	0.3	2.3	-	
S. B. Alportel - Tavira	12.9	[27]	10	0.3	0.2	7.7	12.8	[28]
Trigaches	3.4		10	0.3	0.2	2.0	-	
V. Alentejo	2.1	[29]	10	0.3	0.2	1.3	-	
V. N. Foz Côa	3.2		5	0.3	0.6	2.9	-	
Valongo	4.2		5	0.3	0.7	4.4	-	
Vimieiro	10.4		10	0.3	0.4	12.5	-	
<b>TOTAL</b>	<b>337.9</b>					<b>409.5</b>	<b>91.8</b>	

It is also important to stress out two discrepancies which comply with the S. Brás de Alportel – Tavira and Anticlinal de Estremoz areas because the estimated resources are less than the volume assessed by geological research performed in those areas.

In what respects to the area of S. Brás de Alportel – Tavira, the assessed  $12,8 \times 10^6 \text{ m}^3$  available resources refer to two small areas that make up  $1,3 \text{ km}^2$  [28]. The reason why this value is higher than the right now estimated relates to the fact that it has been calculated for a total operation up to 50 m deep, whereas the present exercise only has considered 30% of the potential area and a depth of 10 m. Indeed, taking into account the specific constraints known to the Algarve region in terms of land use planning, the quarries hardly will reach great depths. So, the estimated value should be closer to reality.

Regarding the Anticlinal de Estremoz area [5], and according to detailed field research therein carried out, it presents  $103 \times 10^6 \text{ m}^3$  of available resources [30-32]. That volume was evaluated for an area of  $9 \text{ km}^2$  considering a yield of 20%. It performs more than the double of the now estimated volume for an area of  $26,7 \text{ km}^2$ . The mentioned  $9 \text{ km}^2$  regards marble outcrops in 5 locations where intensive mining takes place, having the resources been calculated by applying the total thickness of the marble unit on these

locations, which varies between 100 to 250 m, but sometimes reaching up to 400 m. Even bearing in mind that over the long term the future of the mining activity in the Anticlinal de Estremoz has to evolve for underground mining, we adopted in this work only half of the resources presented by [5], as it seems a more realistic option. That means that the estimated and the evaluated resources have the same figures of about  $50 \times 10^6 \text{ m}^3$ .

A qualitative evaluation of the resources was also performed (Fig. 2). Three classes of ornamental stone deposits were considered: small deposits (estimated resources lower than  $10 \times 10^6 \text{ m}^3$ ), medium deposits ( $10 - 20 \times 10^6 \text{ m}^3$ ) and big deposits (more than  $20 \times 10^6 \text{ m}^3$ ). However, on the basis of the specific knowledge of some of the deposits, some order changes were made:

- S. Brás de Alportel - Tavira, first estimated as a small deposit, should be considered as a medium one because the potential area is large and the productive unit is very thick.
- Pêro Pinheiro, first considered as a medium deposit, should be considered as a small deposit because it is affected by a dense urban area.

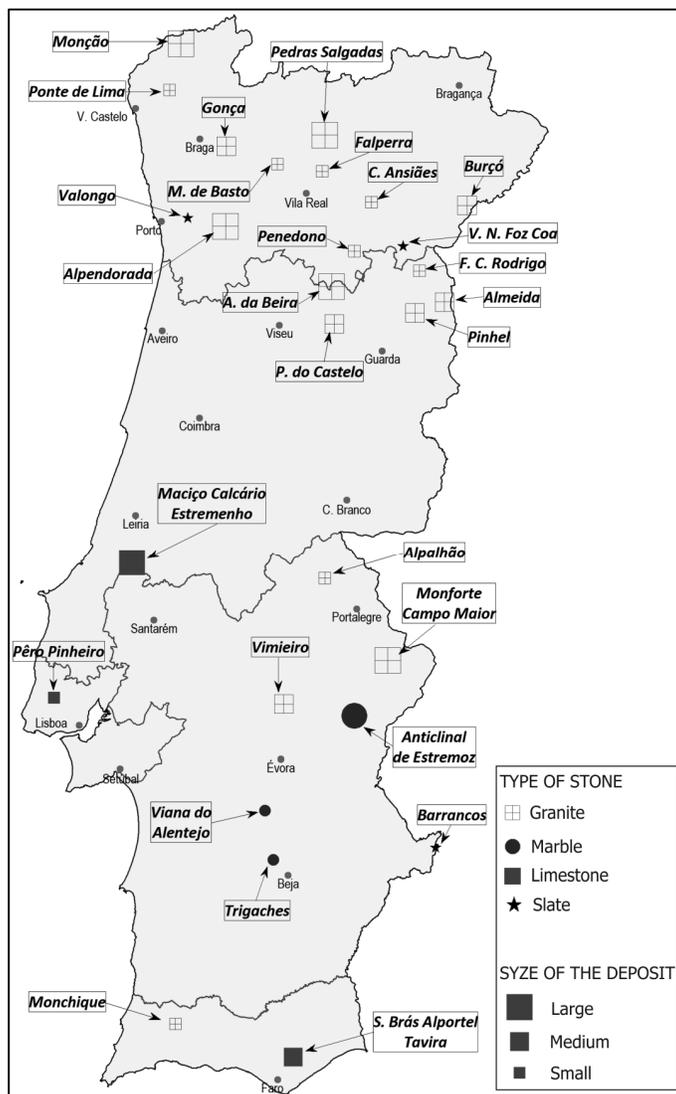


Figure 1- Qualitative assessment of the Portuguese ornamental stone deposits.

The major difficulties encountered for the resource's estimation presented here concerns the delimitation of the potentially favourable areas for mining. In some cases that delimitation was based on fieldworks for that specific purpose, but for most of the country that task is still to be done. For this reason, caution must be taken when reading the presented results. Future work to increase the accuracy of the obtained figures will have to go through geological reconnaissance studies of the several mining districts in order to better delimit their potential areas, and to better understand the ideal exploitable thickness, bearing in mind the total thickness of the deposit and the exploitability conditions.

## Conclusions

The Portuguese industry of the ornamental stones sector is well skilled with exploitation and transformation units incorporating the most modern technologies. Thus assures its competitiveness and the generation of important profits, useful to the regional development and the national economy. As a result of the systematic inventory and evaluation of the country's mineral resources, Portugal has good qualitative information about this type of resources. However, regarding the resource's availability, current knowledge is still very limited.

In this paper we presented a first exercise for the global assessment of the available ornamental stone resources in Portugal. The estimated total volume is 410 million cubic meters. Of these, 274 million refers to granites, 76 million to limestones, 51 million to marbles, and 9 million to slates.

We believe that this first exercise can be a starting point for more precise works involving geological reconnaissance studies, which would lead to more accurate results.

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