“Schist” as a geological resource of “Trás-os-Montes e Alto Douro” (NE Portugal)

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Abstract. The main purpose of this contribution is to increase the knowledge of the geological resources of “Trás-os-Montes e Alto Douro” (TMAD) region, in particular of it “Schist” (slate, phyllite, Schist and quartzite), considering its economic and social impact. The target area is characterized by the abundant occurrence of different types of “Schist”, from the Hercynian basement, belonging to Galiza Trás-os-Montes Zone (GTMZ) and to the Central Iberian Zone (CIZ).

The main outcome of this work was to improve the knowledge about mineralogy, fabric, chemistry and technology of the “Schist”, which can promote their exploitation and use as a natural stone. It was possible to identify the main factors that have an influence on the mechanical behaviour of the schists, conditioning their use as natural stone. This work also contributed to increase the knowledge about lithology and it allowed to show how the relationship between the metamorphic grade and the deformation intensity have a great influence on the stone properties and consequently on the type and size of the exploration site.

Introduction

“Trás-os-Montes e Alto Douro” (TMAD) is located in the NW sector of the Hesperian Massif and in terms of lithology it consists essentially of two types of rocks: granite and metasediments. These ones are abundant and occur in geological formations ranging from the Precambrian to Devonian in age. These rocks were mainly formed from pre-existing sediments that were deformed and affected by orogenic metamorphism.

Particular attention was given to the metasediments and, among these, the ones exhibiting slate cleavage or fissility. The facility with which these rocks have to divide into sheets or plates has been the reason for its widespread use by humans since ancient times to the present day.

“Schist” formations are frequent but only a small part can be used as a natural stone. The geological structure, the intensity of deformation, the degree of metamorphism and the state of fracturing of the rock mass are important to determine exploitability and profitability of quarrying operations.

With this study we proceeded to an inventory and characterization of the main occurrences and the study of physical and chemical characteristics of the present metasedimentary rocks contributing to the knowledge of TMAD potential in terms of "Schist" usable as ornamental stone.

Geology

The Hesperian Massif (HM) is a morpho-structural unit that has been divided into several areas with different geological, petrological and structural data, separated by major tectonic structures in: Cantabrian Zone, West Asturian-Lyonese Zone, Galiza Tras-os-Montes Zone, Central Iberian Zone, Ossa Morena Zone and South Portuguese Zone [1].

The studied cases are geographically located in the former province of Trás-os-Montes and Alto Douro (TMAD), which is geologically located in the inner part of the Variscan orogen being distributed by the Central Iberian Zone (CIZ) and Galiza –Tras-os-Montes Zone (GTMZ). The boundary between these two geotectonic zones is marked by the "Main Trás-os-Montes Thrust" (MTMT) [2].

An outer and an inner zone relatively to MTMT whose facies are grouped in "Lower Douro Domain", in the CIZ, and "Transmontano Domain", in GTMZ respectively characterized TMAD stratigraphically. The "Transmontano Domain was subdivided in "Centrotransmontano" and "Peritransmontano" [3].

The dominant rocks are phyllites and quartzphyllites but other rock types are present. They exhibit a well-marked foliation, generally parallel to the stratification, and a low grade of metamorphism.

Outcroping metamorphic rocks can be distributed into three structural domains: (i) "Autochthonous", when they outcrop in places where they are rooted; (ii) "Parauchthonous", if they suffered only minor movement from the root zone to where outcrop and (iii) "Allochthonous" when are provided by the stacking of lithologic units whose root zone is too far from where they occur (more than 100 km) during Variscan orogeny [4,5].

Particularly, the "Lower Douro Domain" corresponds to the "Schist-greywacke Complex"-Douro Group; pre-Ordovician in age (Precambrian to Lower Cambrian) is composed by metasedimentary formations characteristic of the "Autochthonous". The "Peritransmontano" correspond to "Parauchthonous" and "Sub-autochthonous" terrains and the "Centrotransmontano" to "Allochthonous" terrains.

Tectonic

The Variscan orogeny played a key role in the geology of Northwest Peninsular. The GTMZ and CIZ are structured by a succession of three phases of Variscan deformation: D1, D2 and D3 [3,6]. D1 is contemporary of the upper Devonian "flysch"; D2 with an age ranging from Upper Devonian to Namurian and D3 intraWestefalian [3]. D2 is represented mainly in the allochthonous and sometimes in upper parautochthonous and sub-autochthonous. S2 is mainly observed in allochthonous complexes and often transposes S1. D3 covered the autochthonous, allochthonous and parauthochtonous, giving folds with low-amplitude and vertical axial planes. During Late-and post-D3 many ductile-brittle and fragile conjugate fracture systems occur: the main is NNE-SSW (like Verin- Régua- Penacova fault-VRPF) conjugated with NNW-SSE.

Metamorphism

The tectonometamorphic evolution of the NW of Hesperian Massif is characterized by a syn-D2 peak of P and an orogenic metamorphism of Barrovian type, which evolves into conditions of HT-LP between D2 and D3 phases [7,8].

TMAD geology is strongly associated with the occurrence of major accident NNE-SSW, the Verin-

Régua-Penacova fault. Due to this geological accident we can now observe two distinct crustal levels, a deeper level that corresponds to it West block and a shallower level corresponding to East block, characterised by a low grade of metamorphism (greenschist facies), where are situated all the studied outcrops [9].

Methods

We proceed to the recognition of metamorphic formations already defined in the published and available geological mapping (1:200 000 and 1:50 000), giving priority to sites explored in recent years through traditional methods. Resulting from this task, sites were selected for more detailed study, considering their representativeness in terms of the different outcrops of metamorphic terrains split into the three major structural domains, such as the various metasedimentary formations. In the map of Fig. 1 are shown the locations of selected sites.

The geological and structural mapping of the selected sites was realised with identification of major ductile and brittle structures with possible influence on the mechanical behaviour of "Schist" that can restrict its use as an ornamental stone. The maps contain essentially structural and lithological information. For each site an inventory sheet was drawn up, containing information on the characterization of the exploration and data concerning stratification and also existing anisotropies and frequency diagrams for the main fracture systems.

Considering the potential economic interest that may have a delimitation of the sectors with small deformation and low-grade metamorphism, specific studies were carried out.

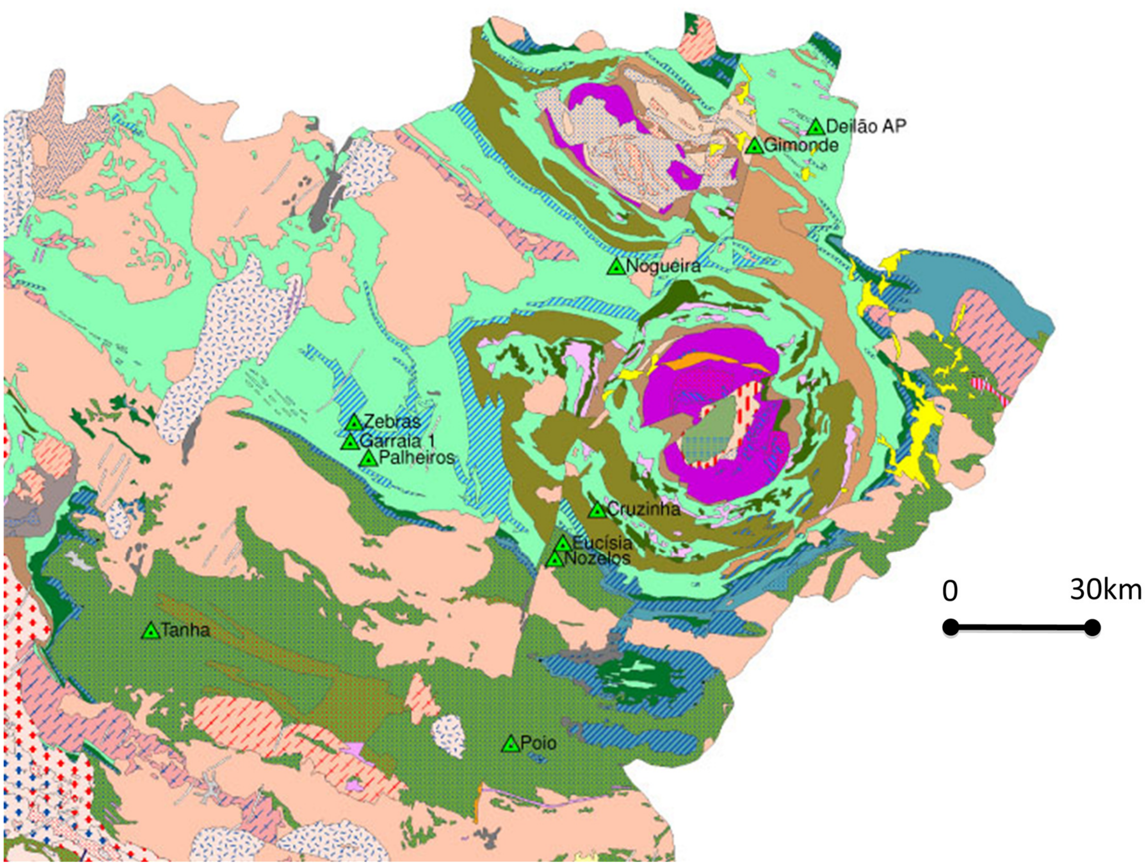

Fig. 1- Location of studied sites. After Sheet 2 1:200 000 from IGM- (after [10] simplified).

In the laboratory we proceeded to petrographic, chemical and technological studies of the different types of samples. The petrographic and mineralogical characterization, based on the macroscopic description and petrographic observations on thin sections using polarized light microscopy (PLM). Chemical analyzes of major and some trace elements, performed by XRF complemented the petrographic studies in order to get a better classification of different lithologies.

Knowledge of the characteristics and behaviour of the rocks is required to give each one the most appropriate use. It is necessary to predict the behaviour once the stone is placed in the work and when subjected to stresses, action of atmospheric agents and human activity over time. The evaluation of the physical-mechanical characteristics was obtained by subjecting the rock samples to a series of tests directly related to their mechanical behaviour in use. The selection of tests, to run on a particular natural stone, should always take into account: (i) the type of natural stone; (ii) the type of application (there are currently several natural stone products subject to CE marking, regulated in their product standards, in its Annex ZA; (iii) the environmental conditions of the place where the natural stone will be applied [11].

Results and Discussion

The geological, petrographic, mineralogical and chemical characteristics are described in specific files elaborated for each case studied [12].

It was important to determine the relationship between deformation and metamorphism, including its intensity and degree, respectively, because its implications on the exploitability of the natural stones can be determinant.

All the studied cases correspond to examples where the degree of metamorphism was low (greenschist facies) and where the deformation of the metassediment implies a slate cleavage.

The results of chemical analyses of major elements and minor elements are shown in Tables 1 and 2 respectively.

Table 1- Chemical analysis – major elements (%)

		SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	Na_2O	K_2O	TiO_2	P_2O_5	P.R.	Total
Autochthonous	Eucísia 1	59.2	19.66	7.38	0.08	0.21	2.61	1.79	3.77	0.98	0.12	4.07	99.87
	Eucísia 2	60.68	18.9	7.2	0.06	0.22	2.41	1.51	3.66	0.91	0.12	4.11	99.78
	Nozelos	58.97	20.59	6.64	0.08	0.33	2.24	1.71	4.43	0.98	0.11	3.94	100.02
	Tanha	60.78	18.5	7.55	0.07	0.36	2.78	1.51	3.82	0.95	0.15	3.44	99.91
	Poio Am	69.29	13.81	3.94	0.06	1.55	1.41	2.99	2.87	0.79	0.14	3.05	99.9
	Poio Az	66.38	15.49	5.7	0.05	0.89	2.09	2.19	3.67	0.74	0.13	2.6	99.93
Parautochthonous	Garraia 1	95.08	2.4	0.96	< 0.02	< 0.04	0.03	< 0.20	0.69	0.06	0.04	0.59	99.85
	Garraia 2	94.6	2.73	0.72	< 0.02	0.07	0.09	< 0.20	0.87	0.15	< 0.03	0.66	99.89
	Zebras 1	80.02	10.51	2.85	< 0.02	< 0.04	0.41	< 0.20	3.45	0.54	0.06	1.92	99.76
	Zebras 2	91.3	4.84	0.68	< 0.02	< 0.04	0.06	< 0.20	1.65	0.19	< 0.03	0.87	99.59
	Nogueira	85.09	7.89	1.07	< 0.02	0.12	0.49	< 0.20	3.52	0.3	< 0.03	1.19	99.67
	Palheiros	76.44	12.27	2.67	0.02	0.14	0.84	2.81	2.82	0.47	0.07	1.35	99.9
Subautochthonous	Gimonde	67.6	15.19	4.97	0.04	0.25	1.89	3.52	2.02	0.7	0.15	3.51	99.84
	Aveleda	73.58	12.01	5.24	0.03	0.12	0.99	0.76	2.64	0.81	0.09	3.64	99.91
	Deilão- A.P.	66.32	17.5	5.91	0.07	0.04	0.63	0.2	4.18	0.83	0.11	4.26	100.05
Allochthonous	Cruzinha-AF	45.04	16.16	14.46	0.23	7.36	6.38	2.88	0.26	2.45	0.29	4.28	99.79

The geochemical studies are an important tool in the classification of the studied rocks because usually they have a very fine grain size.

The contents on major elements (Table 1), particularly in SiO_2 and Al_2O_3 and trace elements (Table 2) such as V and Zr, can discriminate the relative abundance of pelitic and psammitic components on the rock. Higher values of Al_2O_3 and V correspond to more important involvement of a clay matrix. On the contrary, SiO_2 and Zr are higher when the psammitic component is more abundant.

The classification of the different studied lithologies taking into account the petrographic and geochemical studies is as follows:

Autochthonous

Poio - "Schist-greywacke Complex"- Douro Group- Desejosa Formation – Phyllite and Metaquartz wacke (Lower Cambrian).

Tanha - "Schist-greywacke Complex"-Douro Group, CXG) - Pinhão Formation – Phyllite with silt quartz layers (Precambrian to Lower Cambrian).

Eucísia and Nozelos - "Schist-greywacke Complex"- Douro Group - Desejosa (?) Formation- Phyllite with chlorite.

Parautochthonous

Garraia and Zebras – Upper Quartzite Formation. Quartzite and Quartzphyllite (Upper Silurian).

Nogueira- Upper Quartzite Formation. Quartzphyllite (Upper Silurian).

Palheiros- Pelite-Greywacke Formation. Feldspathique Quartzphyllite (Middle to Upper Silurian).

Sub-autochthonous

Gimonde- Gimonde Formation – Metagreywacke (Upper Devonian).

Aveleda- Gimonde Formation – Metaquartzwacke (Upper Devonian).

Deilão- Supraquartzite Formation –Quartzphyllite (Middle Silurian).

Allochthonous.

Cruzinha- Alfândega da Fé– Lower Allochtonous – Basic metavolcanite with schistosity (Silurian)

Table 2- Chemical analyses – trace elements (ppm)

		Rb	Sr	Y	Zr	Ba	Th	U	La	Ce	Nd	Ni	Cu	Zn	Pb	Sc	V	Cr	Ga
Autochthonous	Eucisia 1	175	120	28	180	664	20	< 6	51	96	42	34	22	103	15	16	105	104	25
	Eucísia 2	167	110	26	160	606	18	< 6	27	55	24	31	25	94	17	15	95	92	24
	Nozelos	197	112	28	185	907	20	< 6	51	105	41	42	9	96	24	17	103	129	26
	Tanha	168	93	27	186	708	18	< 6	39	71	33	42	23	120	26	16	92	110	23
	Poio Amarelo	118	250	27	362	627	18	< 6	36	90	40	21	14	60	22	11	58	53	16
	Poio Azul	149	184	34	215	814	16	< 6	57	105	45	29	18	85	25	13	70	59	19
Parautochthonous	Garraia 1	24	43	5	46	138	< 5	< 6	11	26	11	8	< 6	6	11	< 7	7	185	< 5
	Garraia 2	30	20	5	155	202	< 5	< 6	5	16	7	11	< 6	< 6	14	< 7	9	128	< 5
	Zebras 1	128	53	18	299	632	13	< 6	27	58	25	11	< 6	28	20	7	37	37	12
	Zebras 2	51	35	7	174	305	5	< 6	10	35	11	< 7	< 6	8	12	< 7	9	12	5
	Nogueira	121	30	10	225	626	8	< 6	16	36	13	10	< 6	9	15	< 7	15	20	8
	Palheiros	96	108	15	214	822	11	< 6	29	52	22	15	11	45	22	7	38	34	13
Subautochthonous	Gimonde	71	88	24	182	590	11	< 6	29	61	29	38	27	66	12	12	68	67	18
	Aveleda	108	41	32	534	348	18	< 6	35	84	34	29	9	63	13	11	63	88	14
	Deilão- A.P.	151	36	26	224	775	15	< 6	31	86	32	44	26	84	26	15	89	73	21
Allochthonous	Cruzinha- Af. Fé	6	263	45	179	87	< 5	< 6	7	28	23	74	38	148	8	39	351	187	21

As an example, we can report the comparative geochemistry of phyllites from "Schist-greywacke Complex"- Douro Group – but attributed to different formations. At "Pinhão Formation" on Tanha and Poio [13,14], and to "Desejosa Formation" at Eucísia and Nozelos [10]. However, the chemical composition of the phyllites of Tanha is identical to that of phyllites of Eucísia and Nozelos and diferent from that of Poio shale, these ones undoubtedly considered as belonging to the "Desejosa Formation" so we are led to believe that the set (Tanha+Eucisia+Nozelos) belongs to the top of the "Pinhão Formation" and Poio to the base of "Desejosa Formation" near the limit with "Pinhão Formation".

On the phyllites of Poio, we can differentiate "Poio amarelado" (Yellowish Schist) and "Poio Azulado" (Bluish Schist), being richer in SiO_2 (69.29 and 68.38 respectively) than the phyllites of Tanha (60.78), Eucísia (59.2 to 60.68) and Nozelos (58.97) phyllites. The latter are the ones that show higher levels of Al_2O_3 (20.59), suggesting a greater contribution from pelitic component against the lower levels on "Yellow Schist" (13.81), which more siliceous and therefore richer on psammitic composant.

The contents on Fe_2O_3 are important when we compare different stones coming from the same formation namely on what concerns the occurrence of brownish colours, at Zebras 2 (10.51), and/or brown spots at "Poio Azulado" [11,12].

Deformation is also a very important aspect to consider. For example, we have the deformation of the "Schist-greywacke Complex"- Douro Group" giving the significant representation on surface on TMAD. It is characterized by the action of a single phase of deformation, which is common at CIZ. The deformation is associated with D1 and presents a rather homogeneous behaviour in the wider Northern sector of the CIZ. As regards the intensity of deformation, it appears that D1 has a very heterogeneous distribution. This heterogeneity leads to sectors with tight folds and others with large folds [15]. The coexistence of slightly deformed bands alternating with bands where deformation is more intense, is extremely important at the regional level since the more important exploitation of "Schist" from CXG is located in a band slightly deformed at Poio (Vila Nova de Foz Côa). A study in Tanha region showed a similar structure to that identified in the work done at Poio [16], which suggests an important axis ENE-WSW where the regional structure is favourable to new sites for natural stone exploitation.

Conclusion

The mining industry gradually lost its importance in the economy of Northern Portugal mainly from the 70s of last century. Among the factors that contributed to the decline in the sector, we include: the increasing impoverishment affecting the sector, the rate of inadequate mechanization, poor economic performance and small size of holdings. The exploitation of industrial rock, which had a growth due to the impetus given by aggregate "inert" for the construction has slowed in the same way.

The future of the mining industry in TMAD and Portugal goes through the natural stone. The natural stone sector has acquired a great dynamism in recent years.

With this Project we acquired an increase of knowledge about the structural, mineralogical, petrographic, chemical and technological characteristics of "Schist" from northern Portugal that can help to promote its exploitation and use for construction.

The main results that were achieved by this work are: a better understanding of an abundant material in TMAD: the "Schist"; a rediscovery of a potential resource, on a regional level; the possibility to generate added value in an economically deprived area of inland Portugal.

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References

[1] M. Julivert, J. M. Fontbote, A. Ribeiro and L. E. Nabais Conde: Mapa Tectonico de la Peninsula Ibtrica y Baleares E. 1: 1.000.000. Inst. Geol. Min. Esp. Madrid. (1972)

[2] A.Ribeiro, E. Pereira and R. Dias, in Pre-Mesozoic Geology of Iberia edited by R.D. Dallmeyer and E. Martinez-Garcia, Berlin Heidelberg: Springer-Verlag. (1990).

[3] A. Ribeiro: Mem.Serv.Geol.Portugal, N.S., 24: 168 pp. (1974)

[4] E. Pereira, in: E. Pereira, coord. Carta Geológica de Portugal. Notícia Explicativa da Folha 2. (2006)

[5] E. Pereira, A. Ribeiro, in: E. Pereira, coord. Carta Geológica de Portugal. Notícia Explicativa da Folha 2. (2006).

[6] F. Noronha, , J. M. F. Ramos, J. A. Rebelo, A. Ribeiro and M. L. Ribeiro: Bol. Soc. Geol. Portg., 21, 2/3: 227-237 (1979)

[7] M.A.M. Ribeiro: PhD Thesis, Faculdade de Ciências da Universidade do Porto, 231 pp. (1998). [8] R. Arenas, and J.R.M. Catalán: Tectonophysics, 365: 143-164 (2003).

[9] F. Noronha, M.A. Ribeiro, A. Almeida, A. Dória, A. Guedes, A. Lima, H.C. Martins, H. Sant'Ovaia, P. Nogueira, T. Martins, R. Ramos, R. Vieira, in: Geologia de Portugal no contexto da Ibéria edited by R. Dias, A. Araújo, P. Terrinha and J. Kulberg. Univ. Évora, Évora, (2006).

[10] E. Pereira (Coord): Carta Geológica de Portugal 1:200 000, Folha 2, Instituto Geológico e Mineiro, Portugal (2000).

[11] C. Carvalho, S. Aires, F. Noronha, A. Casal Moura and J.Farinha Ramos: submitted to "Globalstone 2012".

[12] S. Aires, C. Carvalho, F. Noronha, A. Casal Moura and J.Farinha Ramos: submitted to "Globalstone 2012".

[13] M.B. Sousa, PhD Thesis. Universidade de Coimbra, 222 pp. (1982).

[14] M.B. Sousa, A.D Sequeira, J. Cotelo Neiva, A. Neiva and M. Azevedo: Folha 10-D (Alijó), Carta Geológica de Portugal 1:50 000 (1987).

[15] R. Dias, C. Coke and A. Ribeiro, in: Geologia de Portugal no contexto da Ibéria edited by R. Dias, A. Araújo, P. Terrinha and J. Kulberg. Univ. Évora. Évora, (2006).

[16] N. Moreira, M. Burcio, R. Dias, R. Coke: Com. Geológicas, 97 (2010).