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Study of the volcano-sedimentary nature of the Serro formations – Silurian terranes of Serra de Arga – Minho (Northern Portugal)

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ABSTRACT: Petrography and paragenetic analysis of some phyllitic Silurian formations from the North of Serra de Arga (Minho – Northern Portugal) revealed an abnormal modal percentage of iron sulfides in a complex set of lithologies that include amphibolic members and tourmaline-garnet rich horizons as well. Excluding the geochemical influence and expression of superposed metamorphism and metasomatism, whole rock analysis shows conspicuous high Fe and Al percentages and low contents of incompatible elements in some facies. Significant Zn, Mn, Sc, Ba and Sr may be related to the presence of accessory minerals suggesting an exhalitic affinity. Pyrrotite and pyrite are the main sulfides but sphalerite, galena and molybdenite are also present in low quantities. These petrographic and geochemical characteristics and the presence of textural aspects such as clastic and/or porphyric relict geometries support the establishment of some correspondences between the observed rock types and few possible volcano-sedimentary or exhalitic ancestors.
Whole rock geochemistry also suggests the manifestation of a protolithic polimodal volcanism with a main expression in the felsitic domain with several complex primordial textures indicating that the primitive rock types could be tuffaceous/volcanoclastic to porphyric.

KEYWORDS: metavolcanic rocks, exhalites, Silurian Terranes, iron sulfides, polimodal volcanism.

1. INTRODUCTION

The metasedimentary terranes that surround the Serra de Arga massif (Minho, Portugal) are considered parautochthonous and Silurian (Pereira et al, 1989). In the compartment located between Orbacém thrust and Vigo-Régua shear, regional mapping (Pereira et al., 1989 and Teixeira et al., 1961) shows a very marked lithological homogeneity, composed of andalusite-schists (fig. 1a). Yet there is significant compositional and textural diversity along some alignments of competent formations, essentially psammitic, that mark the D3 Variscan megafolds and induce prominent reliefs in the Serra de Arga counters.

These are complex petrographic suites that include: quartzites; quartz-phyllites; lidites with phosphatic nodules; black schists with basic metals sulfides; amphibolites of uncertain protolithic nature, metacarbonates, rocks of psammo-pelitic appearance occasionally enriched in sulfides (with possible volcanoclastic to tuffaceous nature), argillic rocks with inherited textures that suggest a felsophyric primary character (Braga et al., 1999); almost monomineralic garnet rocks composed of spessartine to Mn-almandine or grossular; polygenic tourmalinites with several textural expressions of schorl-dravite that switch to meta-phosphorites, suggesting a primitive evaporitic and/or exhalitic nature (Leal Gomes et al., 1997).

In the thematic structural mapping dedicated to the Variscan ductile to ductile-fragile deformation of the Serra de Arga aplite-pegmatite field, Leal Gomes (1994) considered this suites as “reference formations”(fig. 1b).

Beyond these formations, in particular in the North of the Serra de Arga massif, sets up an important D3 antiform mega-structure, known as "Domo de Covas", which in the past supported intense extractive activity dedicated to tungsten in calc-silicate rocks rich in sulfides (Coelho, 1993). The corresponding mineral deposits were considered metasomatic: tungstifferous skarns. In the 70 and the beginning of the 80 of the last century these deposits have been subjected to exploration geophysics (magnetic methods) by the Serviço de Fomento Mineiro (SFM) using as magnetic guidance the anomalous high magnetic susceptibility of some stratiform horizons of iron sulfides (particularly pyrrotite) that have economic contents of W ores. The SFM detected then several magnetic anomalies not only in Domo de Covas but also in adjacent areas.

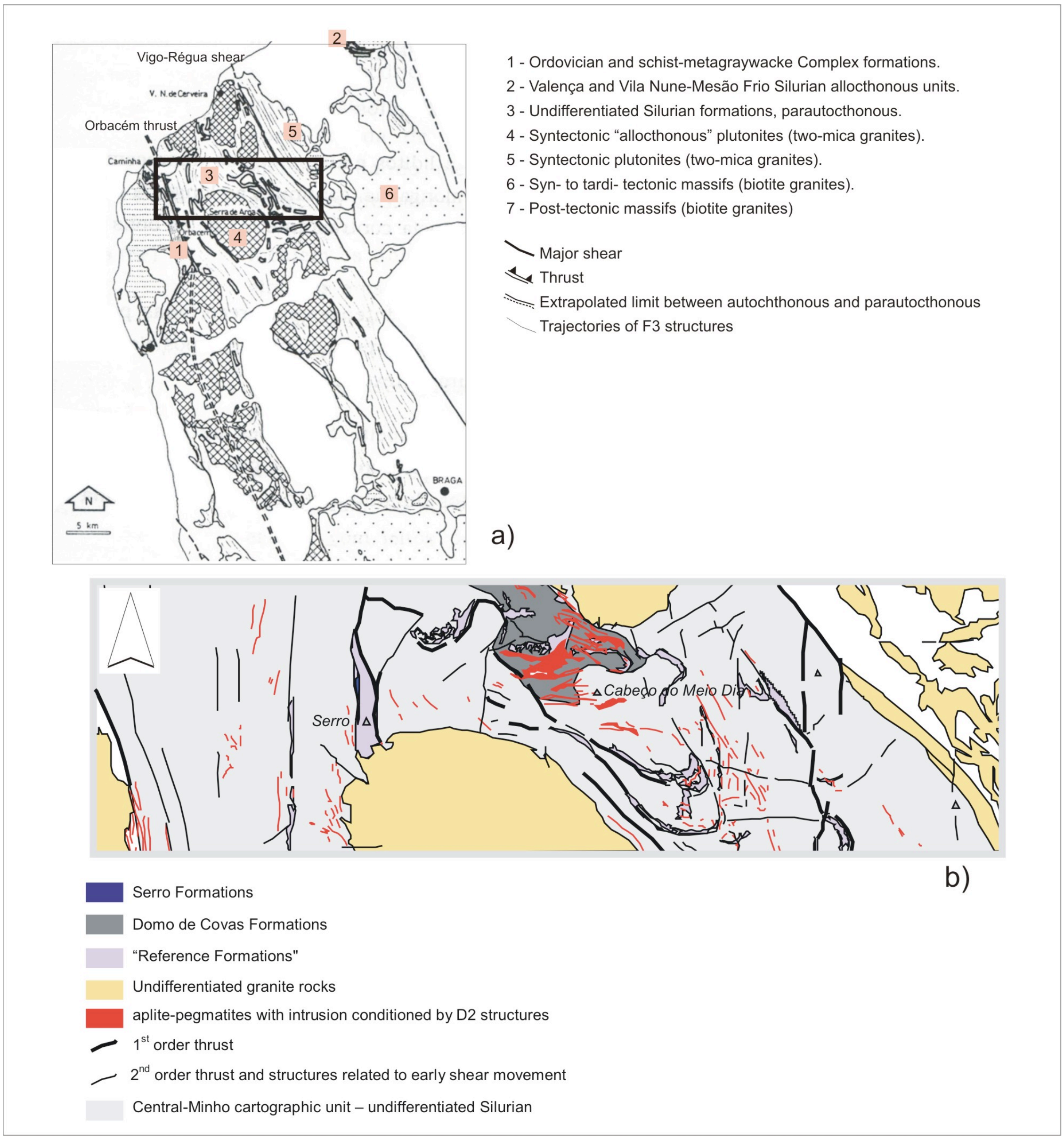

Figure 1 – a) Lithological and structural cartographic configuration of the Minho sector of the Central Iberian Variscan Zone. The information refers to the 1:200000 geological map (Pereira et al., 1989) and has been extracted from Leal Gomes (1994). The rectangle covers roughly the area of b).
b) Location of the areas of Serro, Domo de Covas and "reference formations", in the area assigned to undifferentiated Silurian, in the surroundings of the northern Serra de Arga massif granite, within the limits established by the Orbacém thrust (to the west) and the Vigo-Régua shear (to the East).

One of these anomalies is situated near Serro (A. Rocha Gomes, personal communication, 1981), on terranes separated from the Covas antiform structure by important reverse faults (azimuth N-S to NW-SE) (fig. 1b). Following this anomaly, the SFM in 1987, located three exploration drill holes, which intersected formations with a typology and lithological organization distinct from that observed in Covas stratigraphic sequence. Recently, the topographic regularisation and excavations related to water supplying and the installation of a wind field led to the outcropping of some formations with quartz-phyllitic appearance and high sulfides contents. These formations, although heterogeneous with many unusual textural aspects, have low percentages of calc-silicate minerals and abundance of sulfides. Occasionally they are enriched in amphibole, garnet and/or tourmaline, and may be similar to those which had already been identified in the "reference formations". The knowledge of its possible protolithic nature is essential to achieve the establishment of a primitive lithostratigraphic diversity characterizing the terranes surrounding the Serra de Arga massif. The recognition of a volcanogenic-exhalitic affinity, related or not with the succession expressed in Domo de Covas and prior to granite related metasomatism is the main purpose of this study. However a limitation of the study results from the fact that these formations correspond to metamorphits submitted to the main Variscan thermotectonic evolution culminating with the generation of a S3 highly penetrative cleavage followed by cordierite blastesis.

2. METHODOLOGY

A program of mapping with detailed structural analysis supported the petrological discrimination of the main sub-units with anomalous texture and composition, and suggested their spatial organization (fig. 2).

Whole-rock chemical analyses were performed on seven samples of more homogeneous and lithological persistent terms of Serro sequence and specially those with less petrographic evidences of metasomatism. As shown in table 2, 51 constituents were determined using methods of X-ray fluorescence spectrometry (SiO_2, Al_2O_3, Fe_2O_3, MnO, CaO, MgO, Na_2O, K_2O, TiO_2, P_2O_5, Rb, Sr, Y, Zr, Nb, Ba, Ta, Sn, W, Th, Hf, U, Ni, Cu, Zn, Pb, V, Cr, Co, Ga, Ge, As), inductive plasma mass spectrometry (R.E.E.), atomic absorption spectrometry (Li), potentiometry (F), anodic redissolution potentiometry (Au) and gravimetry (H_2O^+, H_2O^-). Paragenetic analysis relied on the observation in transmitted light and reflected light in polarising microscope and in phase contrasting in scanning electron microscopy (back scattered electron images with qualitative compositions determined in energy dispersive mode).

The study of the geochemistry of rocks combined with the paragenetic analysis aims to establish the fundaments to the deduction of a protolithic nature for the more exotic lithological types and contributes to the knowledge of the polygenic nature of the Central-Minho cartographic unit.

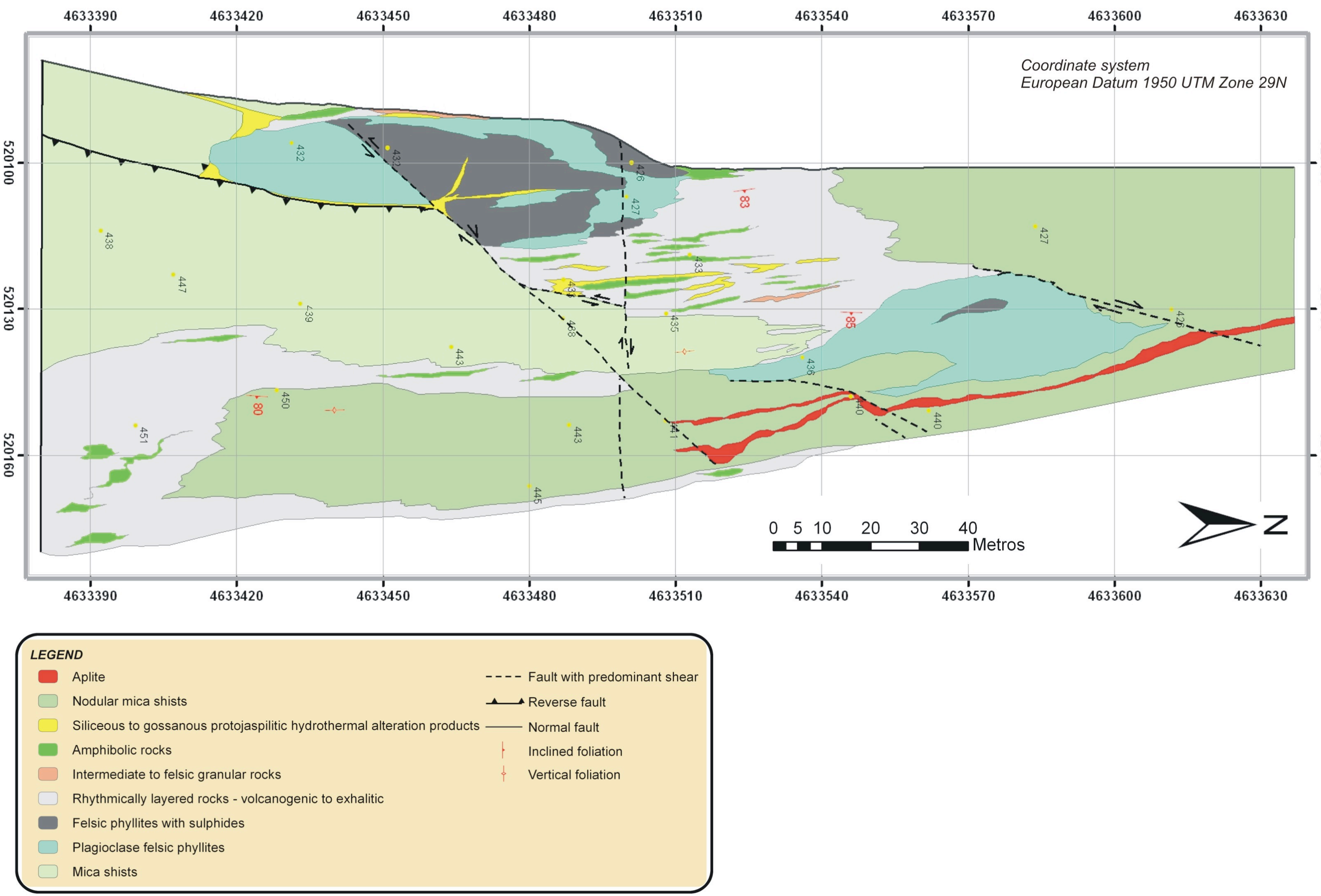

Figure 2 – Detailed geological and structural mapping of the Serro area. In this sector the main contours of abnormal lithologies are related to D2 tangential displacement and are affected by D3 Variscan folding and flattening.

3. PETROGRAPHIC, PARAGENETIC AND GEOCHEMICAL DISCRIMINATION OF ANOMALOUS LITHOTYPES

The most abundant metasedimentary formations throughout the Serro succession exhibit a psammo-pelitic nature – andalusitic mica schists and biotite quartz-phyllites. These are clearly distinct from the main sub-units with anomalous texture and composition shown on table 1. The same table 1 summarizes the most relevant hypotheses for the primitive nature of these rock types based on petrographic and geochemical criteria.

The establishment of a volcanogenic/exhalitic affinity is supported by the identification of relic porphyroid and volcanoclastic textures, the presence of high amounts of modal Fe-sulfides, albite phenocrysts and unusual Sc, Zn and Mn minerals. Thus, facies displaying the characteristics above mentioned are considered to be the result of metamorphism of predominantly felsic volcanites.

The occurrence of tourmaline phyllites with schorl-dravite and Mn-almandine and lithotypes of jaspilitic trend may also indicate a protolithic exhalitic nature.

Table 2 shows representative chemical analysis of the preponderant lithological members. In some samples impoverished in silica the content of Fe and Al is high. The incompatible elements appear in unusual low contents. Some high Sr and Ba may not be strictly dependent on the presence of feldspars and phyllosilicates but related to accessory peculiar minerals especially phosphates what could be another sign of an exhalitic nature.

The distribution of projections of chemical constituents normally characterized by a lower mobility in Nb/Y - Zr/TiO_2 diagram (fig. 3a) shows the following lithological correspondences: amphibolic rocks and felsic granular rocks - rhyodacite / dacite; metavolcanic rock with sulfides - andesite; amphibolite with felsic segregations - basalt. The attribution of a basaltic composition to a sample of amphibolite with felsic segregations is consistent with the compositional pattern found for REE (Eu / Eu *≈ 1; (La / Yb) N = 2.18) (table 1; fig. 3b) revealing a lower differentiation of restitic amphibolic facies.

In tourmaline phyllites, some accessory sulfides expressing Zn and Pb, are consistent with the exhalitic character attributed to at least some of these formations (Slack, 1996; Leal Gomes et al., 1997).

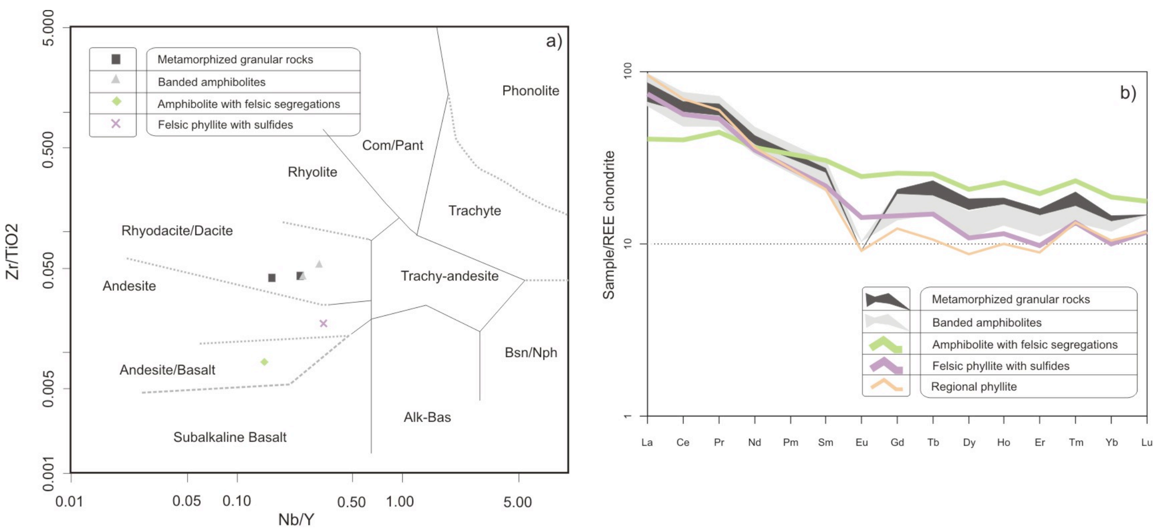

Figure 3 – a) Compositional areas of Winchester and Floyd (1977) (bilogarithmic projections of Nb/Y-Zr/TiO2 relations) for different sets of facies to which was assigned, in petrographic and paragenetic approach, a possible volcanogenic filiation. The set of projections, suggests the existence of felsic to mafic precursors, which should characterize a polimodal type volcanism.
b) REE variation trends obtained for all facies analyzed (reference values from Nakamura, 1974). Establishment of the fractionation trend of equivalent volcanites – amphibolites with plagioclase segregations lack Eu anomaly and have less differentiated restitic compositions.

Petrographic type - metamorphite	Geochemical indications for a non phyllitic nature	Typomorphic minerals and textures	Possible protolithic nature
Amphibolites with plagioclasic segregations	TiO_2=1,91% Fe_2O_3= 8% Eu/Eu*= 0.88 $(La/Yb)_N$= 2.18 P_2O_5=0,27%	scheelite	Late metamorphic segregation to metasomatic terms
Nodular mica schists		andalusite and/or corundum	Metasedimentary pelitic
Quartz-phyllites		ilmenite, REE phosphates., tourmaline	Metasedimentary psammopelitic-exhalitic
Plagioclase felsic phyllites	Ti=407ppm	thorthveitite, REE phosphates.	felsite
Felsic phyllites with sulfides	S = 7,19%; Fe = 8%	pyrrotite>pyrite>>arsenopyrite	felsite, tuff (?) or felsophyry – volcanite (porphyry)
Clastic quartz-phyllites occasionally enriched in sulfides		pyrrotite>pyrite	Volcanoclastic facies
Gossan siliceous rocks		Rare Fe-oxides and sulfides (pyrite, sphalerite, chalcopyrite, galena)	Facies of jaspilitic appearance
Metamorphized granular rocks	Eu/Eu* = 0.39 $(La/Yb)_N$= 4.60-6.36	molybdenite (?)	Primordial porphyry rocks (?) – intermediate composition
Layered amphibolites	SiO_2=72,7 – 74,1	zircon, ilmenite, Ti-spinel, sphene	Hybridized volcanogenic lithologies
Phyllitic facies with argillic alteration	Zn = 502 ppm Pb = 162 ppm	Fe and Ti oxides; secondary Fe, Zn, Pb and Cu sulfates and phosphates	Late argillic alteration products
Brecciated felsic facies		pyrrotite>pyrite>>arsenopyrite	Venular and silicified products
Garnet-tourmaline phyllites		spinel, Mn-almandine, dravite	exhalites
Tourmaline phyllites with sulfides		pyrite>>pyrrotite, arsenopyrite, sphalerite, galena, molybdenite, schorl-dravite	Late hydrothermalized exhalite
Mica schists		andalusite-sillimanite	Metasedimentary pelitic

Table 1 – Discrimination of lithotypes ordered according to their space configuration.

	FFS	ASF	AB		RG		FLR
SiO_2	50,51	49,85	74,09	72,70	73,8	73,51	70,63
Al_2O_3	21,47	15,54	11,98	12,5	13,75	13,8	16,56
Fe_2O_3	8,04	12,29	2,94	4,14	2,27	2,27	2,13
MnO	0,06	0,73	0,3	0,07	0,34	0,41	0,04
CaO	1,73	9,53	6,6	0,85	1,85	2,15	0,54
MgO	1,81	6,33	2,33	3,19	1,47	1,72	1,37
Na_2O	5,95	2,1	0,35	1,79	2,6	3,23	2,04
K_2O	1,76	0,24	0,05	1,15	1,94	1,56	2,62
TiO_2	0,79	1,91	0,41	0,28	0,34	0,35	0,22
P_2O_5	0,07	0,27	0,15	0,06	0,08	0,07	0,03
F	0,07	0,2	0,06	0,11	0,06	0,06	0,13
$H2O^-$	1,84	0,9	0,3	2,49	1,13	0,79	2,79
$H2O^+$	0,63	0,17	0,09	0,35	0,21	0,14	0,47
Total	94,7	100,1	99,7	99,7	99,8	100,1	99,6
P.F.	7,60	0,89	0,50	3,00	1,31	0,84	3,68
mg-no	0,18	0,34	0,44	0,44	0,39	0,43	0,39
Rb	75	7	<3	47	79	70	99
Sr	256	253	86	111	126	146	65
Y	18	40	22	24	29	36	18
Zr	138	157	218	117	145	139	140
Nb	6	6	7	6	7	6	6
Ba	575	31	18	543	606	374	653
Ta	<5	<5	<5	<5	<5	<5	<5
Sn	<6	28	<6	<6	<6	<6	<6
W	9	<6	10	<6	<6	<6	<6
Th	6	<5	9	10	9	8	10
Hf	<5	<5	<5	<5	<5	<5	<5
U	4	<4	<4	<4	<4	4	<4
La	24,7	13,4	21	32,5	28,6	22,1	31,8
Ce	49	35	42	66	58	51	60
Pr	6	5	5,4	8,1	7,3	6,3	6,7
Nd	22	23	21	30	27	24	23
Sm	4,4	6,2	4,1	6,2	5,6	5,3	4,2
Eu	1,1	1,9	0,8	0,8	0,7	0,7	0,7
Gd	4	7,1	3,8	5,6	5,4	5,7	3,4
Tb	0,7	1,2	0,7	0,9	0,9	1,1	0,5
Dy	3,7	7,1	3,7	5,3	5,4	6,3	3
Ho	0,8	1,6	0,9	1,2	1,2	1,3	0,7
Er	2,2	4,4	2,5	3,3	3,3	3,6	2
Tm	0,4	0,7	0,4	0,5	0,5	0,6	0,4
Yb	2,2	4,1	2,6	3,2	3	3,2	2,3
Lu	0,4	0,6	0,5	0,5	0,5	0,5	0,4
Ni	88	50	15	<7	<7	<7	<7
Cu	45	37	19	<6	6	<6	9
Zn	25	104	35	63	53	52	32
Pb	23	11	11	20	21	21	26
V	319	356	40	22	25	28	29
Cr	687	225	42	16	24	20	71
Co	39	35	11	<5	5	<5	<5
Ga	23	21	14	15	13	15	20
Ge	<5	5	<5	<5	<5	<5	<5
As	7	37	<6	<6	<6	<6	<6
Li	125	46	12	125	75	78	68
Au (ppb)	<20	51	<20	<20	<20	100	<20
Σ REE	121,6	111,3	109,4	164,1	147,4	131,7	139,1
$(Eu/Eu^*)_N$	0,81	0,88	0,62	0,42	0,39	0,39	0,57
$(La/Yb)_N$	7,48	2,18	5,38	6,77	6,36	4,6	9,22

FFS - Felsic phyllite with sulfides
ASF - Amphibolite with felsic segregations
AB - Banded amphibolites
RG - Metamorphized granular rocks
FLR - Regional phyllite

Table 2 – Chemical composition of some lithologies present in abnormal sub-units. Oxide and F at %, minor elements at ppm (except Au).

4. CONCLUSIONS

The set of available data supports a hypothetical approach to the primitive nature - volcanogenic to exhalitic - of some lithologies with anomalous petrographic and geochemical signatures, enlarging the context of heterogeneity and polygenesis of Silurian rocks around Serra de Arga (Minho Central Unit). The detection of mineralogical and textural aspects outside the psammo-pelitic main trends, the cartographic distribution and structural analyses of abnormal metamorphits, supported this approach. The geochemical studies provided analytical data with petrogenetic consistence and geochemical signatures of elements with less mobility, contributing to a more accurate identification and discrimination of the studied metamorphits, enhancing the expression of a polimodal volcanism, predominantly felsic, with metalogenic potential, capable of producing the high percentage of sulphides observed in metamorphits.

In this sector of the Centro-Iberian Variscan structure (Central Minho Unit), the area of Serro, in the north of Serra de Arga, seems to represent the best expression of Silurian volcanism.

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