ISSN 0871 – 1607

UNIVERSIDADE DO PORTO – FACULDADE DE CIÊNCIAS

DEPARTAMENTO DE GEOLOGIA

MEMÓRIAS N.º 9

GRANITIC PEGMATITES: THE STATE OF THE ART

INTERNATIONAL SYMPOSIUM

FIELD TRIP GUIDEBOOK

EDITED BY ALEXANDRE LIMA & ENCARNACIÓN RODA ROBLES

PORTO – PORTUGAL

6TH – 12TH MAY, 2007

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MEMÓRIAS, Nº. 8 – GRANITIC PEGMATITES: THE STATE OF THE ART – BOOK OF ABSTRACTS (PORTO, 2007).

TITLE: GRANITIC PEGMATITES: THE STATE OF THE ART – FIELD TRIP GUIDEBOOK
PUBLICATION SERIES: MEMÓRIAS N. º 9, UNIV. DO PORTO, FACULDADE DE CIÊNCIAS, DEPARTAMENTO DE GEOLOGIA
AUTHORS: SEVERAL
DATE: MAY 2007

ISSN 0871 – 1607
ISBN 978 – 989 – 20 – 0624 – 6

PRINTER: ORGANIGRÁFICA, ARTES GRÁFICAS. RUA PASSOS MANUEL, 251;4760-375 CALENDÁRIO, V. N. FAMALICÃO
PRINTED UNITS: 200

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CONSTRUÇÃO CIVIL E OBRAS PÚBLICAS

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FOREWORD

Organising this field trip and symposium about granitic pegmatites from the Iberian Peninsula didn't come out from nothing. The idea was born three years ago in a field trip during which the first contacts between the Porto research group and the Bilbao research group were made. Researchers from other countries, also taking part of that field trip, considered it a very interesting idea and encouraged us to bring it to reality. Their interest made us realise that our case studies were worth to be seen by others.

Motivated by these friends from France, Belgium, Germany, the Czech Republic and the Popular Republic of China, organizing this scientific meeting in the Iberian Peninsula became a goal to achieve.

For that reason, we are in debt with all them and we want to thank them for their support.

Pegmatites from the Iberian Peninsula have been known and studied during several decades by researchers from both, Portugal and Spain. However, not all of them are widely known amongst the scientific community. Some of them are even more "famous" among the mineral collectors. This does not mean that they have no interest for science, though. On the contrary, it is our believe that these pegmatite bodies still have many features to look into and require intensive hours of lab and field study.

From these lines we invite you to learn something more about a small part of this natural treasure that outcrops in the north and centre of Portugal and in the central-west of Spain.

The aim of this excursion is to provide an overview of the main different pegmatite types that can be found in the NW Iberia. After a brief introduction to the geological setting of the Galicia Tras-os-Montes Zone and the Central Iberian Zone, this Field Trip Guidebook presents condensed descriptions of five localities of granitic pegmatites. There is also some detailed information about each pegmatite field that we are going to visit: Barroso-Alvão, Fregeneda-Almendra and Gonçalo.

Each stop description includes several bibliographic references which correspond to the most important information about the general geology, mineralogy, petrology and geochemistry studies of the visited outcrops and their respective pegmatitic field.

We hope this Symposium will be a great opportunity for discussion on different topics related to the geology of pegmatites. We also hope this exchange of ideas will promote and reinforce the co-operation between pegmatite researchers from all over the world.

We sincerely thank you for coming and wish you a nice and interesting stay here.

Welcome to Iberia!

The Organizing Committee

May 2007

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FIELD TRIP PROGRAM

Field trip officially begins in the 9th May, Wednesday, at 16.30h in room -120. During this period we are going to deliver some documentation regarding it, and briefly introduce the places that are going to be visited.
The field trip takes place during the following three days, through which several outcrops will be visited. It is very important that the follow schedule is completely accomplished, in order to allow us to visit all the places that we have programmed.

Thursday, 10th of May

08.30 – Departure from Porto, Faculty of Sciences building.

10.00 – Arrival at Venda Nova. Quick stop for refreshments.

11.00 – Arrival at Boticas. **1st LOCALITY**: Lousas outcrop.

13.30 – Lunch in Boticas.

15.00 – Departure from Boticas.

16.30 – Arrival at Mirandela. Quick stop for refreshments.

18.00 – Arrival at Vila Nova Foz Côa.

19.00 – Dinner.

20.30 – Departure from Vila Nova Foz Côa to Castelo Melhor (facultative - visit to PAVC).

23.30 – Estimated arrival to the hotel.

Friday, 11th of May

09.00 – Departure from Vila Nova de Foz Côa – Bajoca Mine: 25 km

09.30 – Arrival at Almendra**. 2nd LOCALITY**: Bajoca Mine.

12.00 – Lunch in Almendra.

13.00 – Departure from Almendra.

14.00 – Arrival at Barca d'Alva. Quick stop for refreshments.

15.30 – Arrival at La Fregeneda. **3rd LOCALITY**: Feli open pit.

17.00 – Departure from Feli quarry.

17.40 – Arrival at La Fregeneda. Quick stop for refreshments.

18.00 – Departure from La Fregeneda.

19.30 – Arrival at Canãda. **4th LOCALITY**: Cañada quarry.

20.30 – Departure from Cañada quarry.

21.00 – Arrival at Ciudad Rodrigo.

22.00 – Dinner.

Saturday, 12th of May

10.00 – Departure from Ciudad Rodrigo.

10.30 – Arrival at Gonçalo. **5th LOCALITY**: Gonçalo quarry.

12.30 – Departure from Gonçalo Mine.

13.00 – Arrival at Folgosinho. Closing lunch.

15.00 – Estimated departure from Folgosinho.

18.30 – Estimated arrival in Porto, Faculty of Sciences Building.

The itineraries to be accomplished are schematically represented in figure 1. Figure 2 is a simplified map of the regional geology. The detailed excursion agenda is presented in table 1.

TABLE 1. – Program

Date	Place / activity	Distance (km) (1 km ≈ 0.62 miles)	Duration
Thursday, 10th of May	Trip from Porto to Boticas. **Stop 1** - Barroso-Alvão pegmatitic field. Pegmatite mined for tin and Lousas outcrop: petalite subtype vein.	130 km **by bus** plus 3 km of **easy walking.**	**Porto→Boticas**: 2.5 hours (includes a 15 minutes stop in Venda Nova for refreshments).
	Lunch break: 90 minutes at "Albergaria do Beça", Boticas		
	Trip from Boticas to Vila Nova de Foz Côa.	170 km **by bus** (110 km until Mirandela + 60 km until V. N. F. Côa).	**Boticas→V. N. F. Côa**: 3 hours (includes a 20 minutes stop in Mirandela for refreshments).
	Dinner: 60 minutes at Albergaria Foz Côa, Vila Nova de Foz Côa (limited time for those who are going to the "Archaeological park").		
	Trip from Vila Nova Foz Côa to Castelo Melhor (facultative).	15 km **by bus**.	**V. N. F. Côa→Cast. Melhor**: 15 minutes. (*We estimate be back to the Hotel around **23.30**, though it depends on the archaeological visit.)*
Friday, 11th of May	Trip from Vila Nova de Foz Côa to Almendra. **Stop 2** - Bajoca mine.	25 km **by bus**.	**V. N. F. Côa→Almendra**: 10 minutes.
	Lunch break: 50 minutes at Almendra		
	Trip from Almendra to La Fregeneda. **Stop 3** - Feli open pit. Ancient tin mine and lepidolite and spodumene bearing pegmatite)	65 km **by bus** (60 km until Barca d'Alva plus 15 km until La Fregeneda) plus 5 km **on foot** (difficult slope).	**Almendra→La Fregeneda**: 80 minutes (includes a 15 minutes stop at Barca d'Alva for refreshments).
	Trip from La Fregeneda to Aldehuela de la Bóveda **Stop 4 –** Cañada pegmatite.	70 km **by bus** plus 5 km of **easy walking**.	**La Fregeneda → Aldehuela de la Bóveda**: 2 hours (includes a 20 minutes stop at La Fregeneda for refreshments).
	Trip from Aldehuela de la Bóveda to Ciudad Rodrigo.	50 km **by bus**.	**Aldehuela de la Bóveda → Ciudad Rodrigo**: 30 minutes.
	Dinner: 90 min at Restaurante "La Artesa" at Ciudad Rodrigo		
Saturday, 12th of May	Trip from Ciudad Rodrigo to Gonçalo. **Stop 5** - Gonçalo quarry.	95 km **by bus** plus 3 km of **walking** (moderate slope).	**Ciudad Rodrigo→Gonçalo**: 90 minutes.
	Trip from Gonçalo to Folgosinho.	40 km by bus	**Gonçalo →Folgosinho**: 40 minutes.
	Closing lunch: 120 min at Restaurante "O Albertino" at Folgosinho.		
	Trip from Folgosinho to Porto.	175 km by bus	**Folgosinho→Porto**: 2,5 hours **Arriving time – 18.30h**

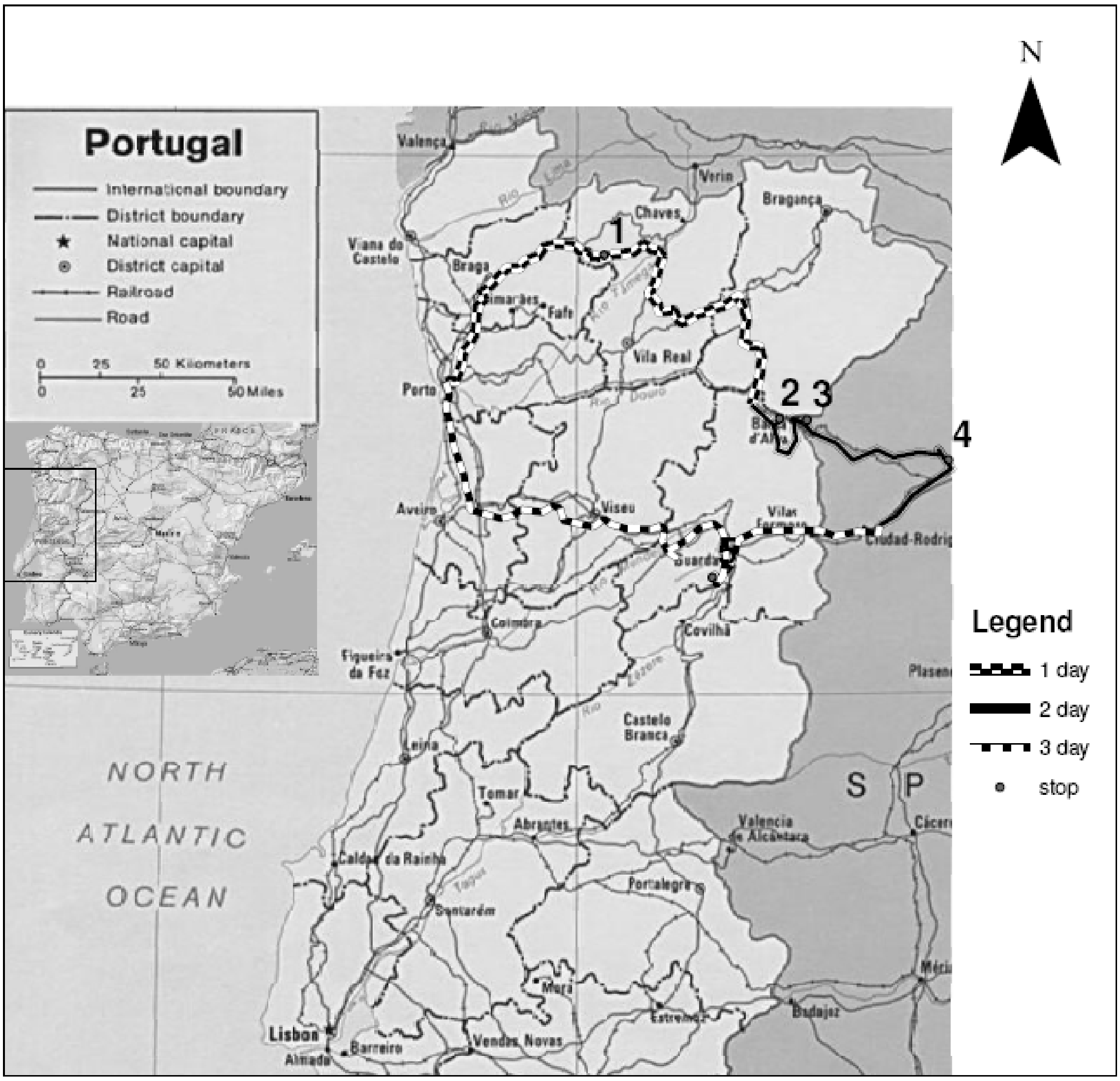

FIGURE 1. General location of the proposed itineraries and localities (adapted from www.mapasmurais.com).

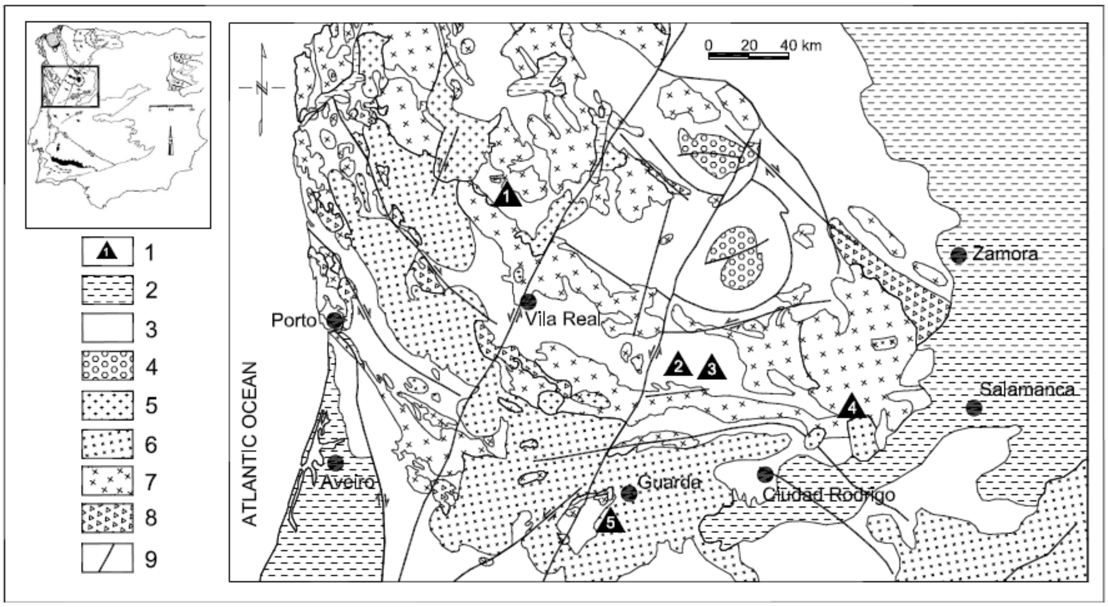

FIGURE 2. Simplified Geological map of the field trip localities. 1 - Field-trip geological stops; 2 - Post-Paleozoic; 3 - Paleozoic metasediments; 4 - Ultrabasic Complex; 5 - Post-tectonic biotite granite; 6 - Late-tectonic biotite granite; 7 - Syn-tectonic two-mica granite; 8 - Syn-tectonic biotite granite; 9 - Faults.

INVITED LECTURES

THE HERCYNIAN OROGENY IN THE NW OF IBERIAN PENINSULA

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The Hercynian (Variscan) Orogeny has a main role on the geology of Western Europe. The Hercynian belt is characterised by several, roughly E-W trending geotectectonic zones with specific and peculiar paleogeographic, tectonic, metamorphic and magmatic characteristics. These zones define structural lineaments in the chain namely defining the Ibero-Armorican virgation (Matte and Ribeiro, 1975; Dias and Ribeiro, 1995) (Fig. 1).

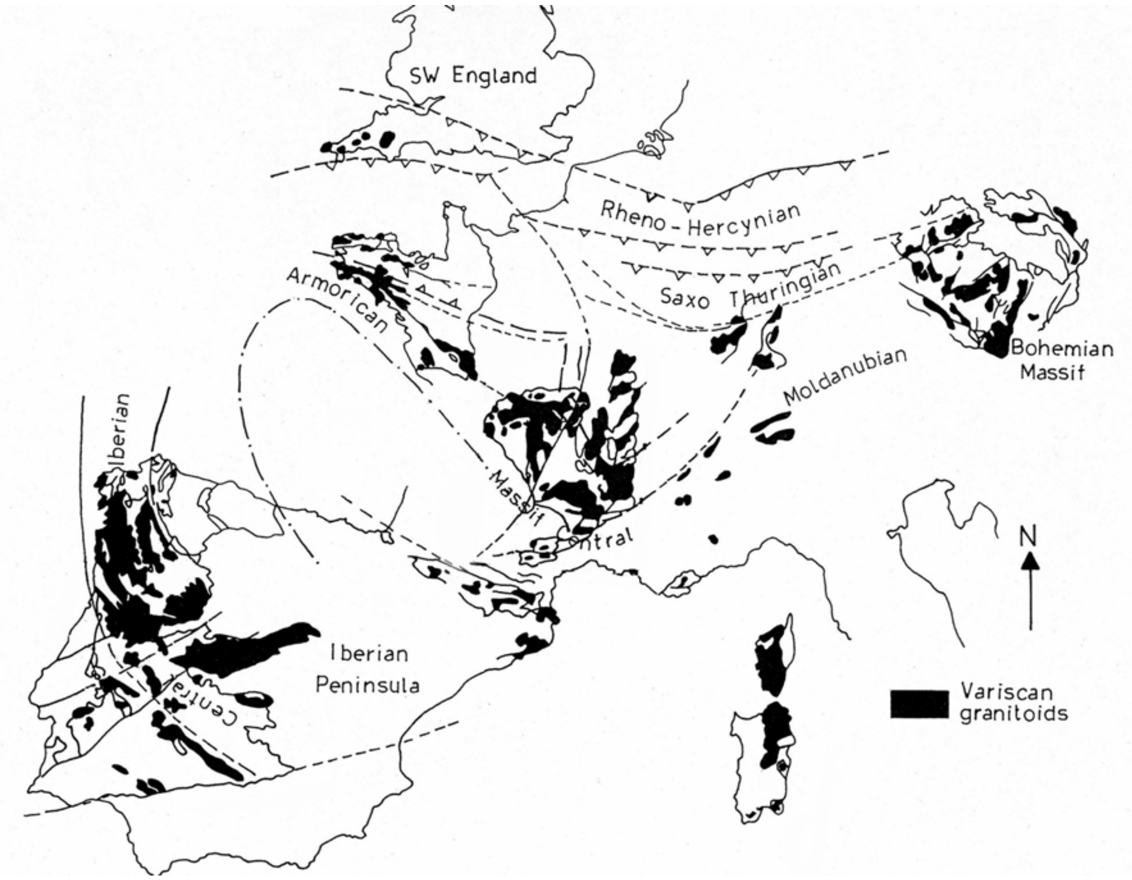

FIGURE 1. Geotectonic zones from Western Europe (Matte 1986).

From numerous modern structural, petrological, geochemical, geophysical and geochronological studies, it is now possible to reconstruct a relatively continuous Hercynian belt (3000 km long and 700 to 800 km wide), which extends from Morocco to North Bohemia (Matte, 1986, 1991). The southern part of the belt was more or less obliterated by younger Alpine deformations. The tectono-metamorphic records in Massif Central and Iberian Peninsula shows that the geological history must involve significant crustal thickening explained by the overthrusting of thick nappes.

Tectonic characteristics of the European Hercynides are those of a classical obduction-collision belt and it is described as a stacking of large-scale thrust crustal nappes, between 380 and 320 Ma. The arcuate belt originates with the convergence, obduction, subduction and collision of the North Laurentia and the Gondwana continents, with minor intermediate blocks. The orogen has a fan-like configuration with megafolds and overthrusts facing towards the external devono-carboniferous basins not or less implicated in the continental collision. The overthrust is mainly southward in the inner zones of the orogen (Matte and Ribeiro, 1975; Dias and Ribeiro, 1995). These inner zones are represented by the "Central Iberian Zone" (CIZ) in the Iberian Peninsula and by the South Armorican Zone and Massif Central in France (figure 1 and 2).

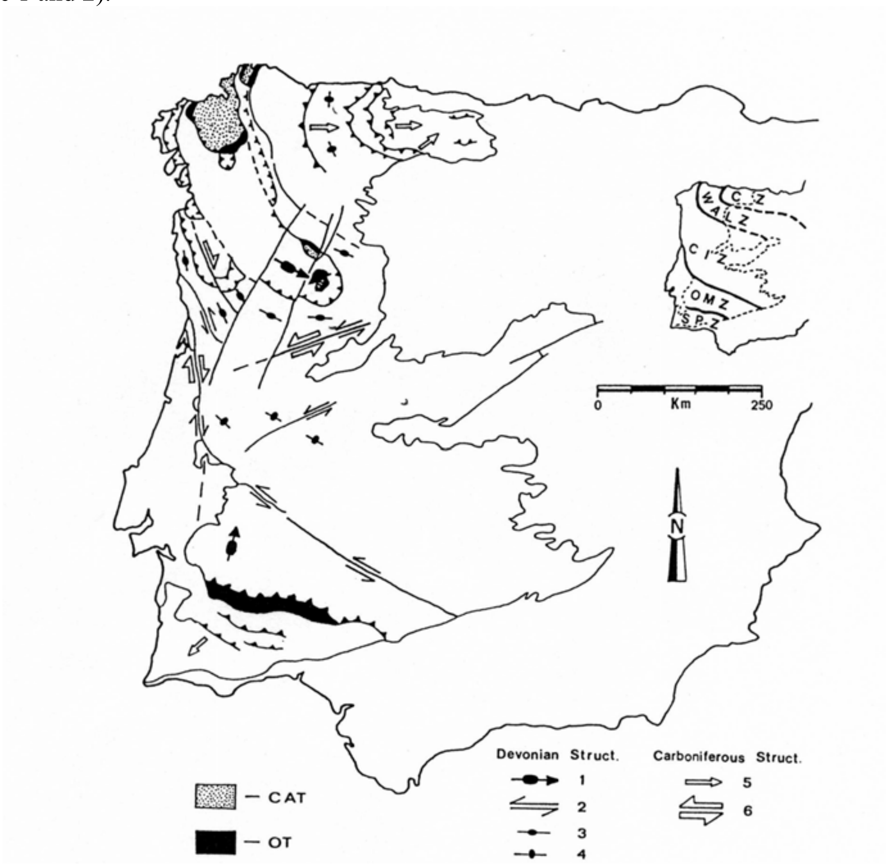

FIGURE 2. Major Variscan structures in the Iberian Peninsula. CZ=Cantabrian Zone; WALZ=West Asturian-Leonese Zone; CIZ=Central Iberian Zone; OMZ=Ossa-Morena Zone; SPZ=South Portuguese Zone; CAT=Continental Allochthonous terrane; OT=northern and southern ophiolitic terranes; 1=Devonian shear sense; 2=Devonian shear zone; 3=stretching in b; 4= stretching in a: 5=Carboniferous shear sense; 6= Carboniferous shear zone (Dias & Ribeiro 1995).

Most of the pre-Mesozoic basement of Western Europe is composed of Neoproterozoic to Carboniferous terranes which were highly deformed, metamorphosed and intruded by numerous granitoids of various types and sizes before the Permian, during the Hercynian orogeny.

Radiometric data show that there is an almost continuous magmatic activity from Upper Devonian to Upper Carboniferous. A voluminous magmatism (mainly granitic in composition) was associated with all phases of plate convergence and collision. Magmatic diversity and granitoid distribution imply the involvement of variable crustal sources. Those granitoids are markers of the crustal deformations indicating their geometrical and cinematical characteristics. Three main stages of granitoid genesis and settings were recognised: the first stage is coeval with the syncollisional thickening of the lithospheric crust through thrusting (compressive style); the second (the most important in volume) corresponds to the thermal relaxation, crustal thinning and wrench faulting; the third stage (late orogenic magmatism) corresponds to the adiabatic decompression in an extensional regime (Ferreira et al. 1987; Stussi, 1989; Lagarde et al., 1992).

In the NW of the Iberian Peninsula, three main phases of deformation D1, D2 and D3 are usually considered responsible for the structuration of this part of the Hercynian belt, the last one being intra-Westphalian in age (Noronha et al., 1981; Dias and Ribeiro, 1995) (Figure 3). One of the most significant features of the NW Iberian segment is the strong curved structures, related with a succession of the three penetrative deformation phases defining the Ibero-Armorican Arc (Jegouzo, 1980).

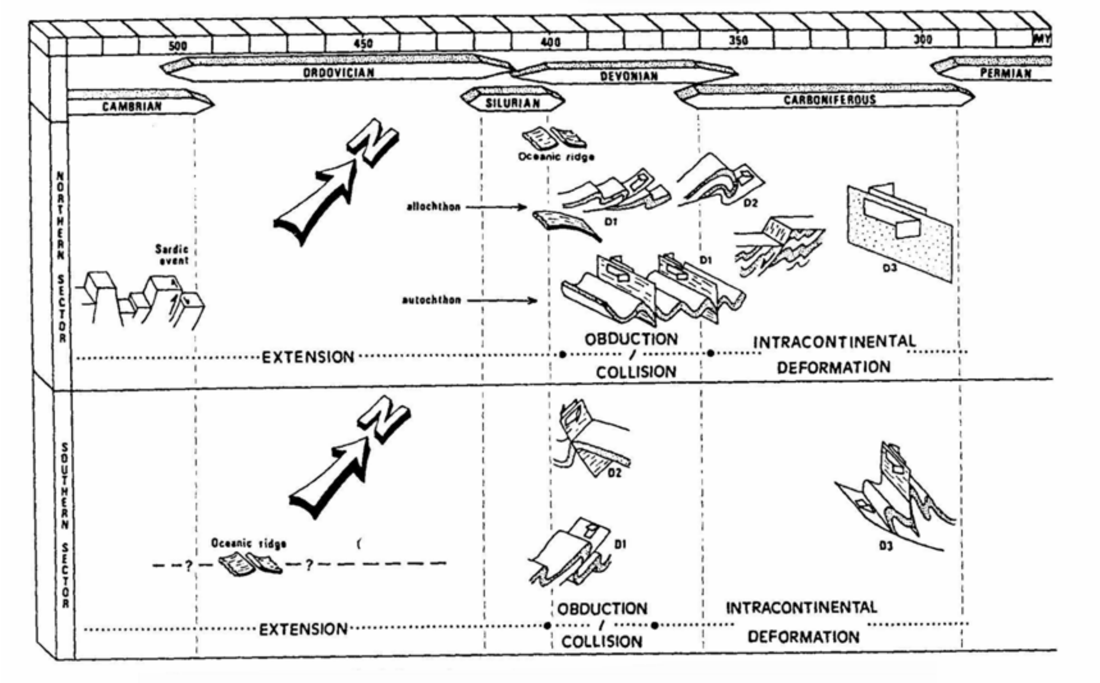

FIGURE 3. Timing of the main deformation events in the Iberian Peninsula during the Variscan cycle (Dias & Ribeiro 1995).

Several structural levels and metamorphic domains are represented from the more external zone, "Cantabrian Zone" (CZ), to more internal zones the "Central Iberian Zone" (CIZ) and its subzone "Galicia-Tras-os-Montes Subzone" (GTMSZ) as defined by Julivert and col. (1974). The CIZ is the most important zone and the spine of the Hesperic Massif. It is characterised by the presence of autochthonous metamorphic formations, Neoproterozoic in age. The GTMSZ, now considered as a zone "Galicia Tras-os-Montes Zone" (GTMZ) (Farias et al. 1987) is characterised by Precambrian allochthonous predominantly mafic and ultramafic massifs, surrounded by parautochthonous metasedimentary sequences mostly from Ordovician-Silurian including an important volcano-sedimentary complex and organic rich lithologies, the "Peritransmontano domain" (Ribeiro 1974) (Figures 2 and 4). At the higher levels the D1 structures are well preserved; at lower levels, the D1 structures were transposed by D2 giving rise to the regional schistosity (S2) namely at GTMZ. In the latter domains a peak of regional metamorphism, of low-pressure type (T 650 to 700 oC at P< 5 kb) is reached during or just after D2 and is Namurian in age. Regional ductile shears acting symmetrically in the basement has induced thrust systems on surface; the latest stage of ductile deformation of the basement correspond to D3 (Iglesias and Choukroune, 1980). The Malpica-Vigo-Braga-Amarante dextral shear zone is an example of this ductile deformation; its orientation varies from N30oE in the north (Malpica) to N100ºE at southest (Amarante) passing by N170oE (Vigo) and N140ºE (Braga) (Iglesias and Choukroune, 1980, Iglesias and Ribeiro, 1981).

The metasediments of both zones are intruded by Hercynian granites. In GTMZ and CIZ plutonic magmatism is essentially represented by important Hercynian synorogenic granites and is the marker of the main deformation.

Based on their geological, petrographical and geochemical characteristics, these granites are broadly divided into two main groups: two-mica granites and biotite granites (Ferreira et al., 1987).

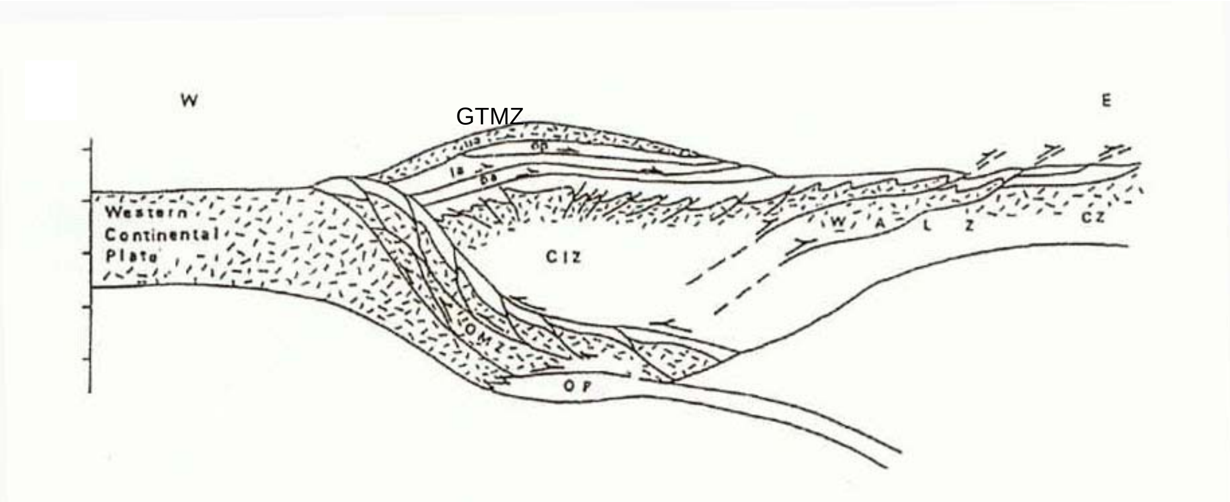

FIGURE 4. Schematic interpretation of geotraverse along the Central-Iberian Zone in northern Portugal in terms of flake tectonics: GTMZ=Galicia Tras-os Montes Zone with ua=upper allochthonous; op=ophiolite; la=lower allochthonous; pa=parautochthonous; CIZ=Central Iberian Zone (autochtonous); WALZ=West Asturian-Leonese Zone; CZ=cantabrian Zone; OMZ=Ossa Morena Zone (Ribeiro et al. 1990).

The two-mica granites could be considered as syncollisional S-type granites, which would be approximately syntectonic (syn-D3) (311Ma) (Almeida et al. 1998). The granites outcrop on the core of thermal domes nearly coinciding with D3 structural antiforms (Noronha et al. 1981; Martinez et al., 1988). They are generally leucocratic granites with primary muscovite and biotite, with modal % muscovite greater than modal % biotite and are considered to result from the crystallisation of wet peraluminous magmas originated at a mesocrustal level (related with metamorphic processes).

The second group of granitoids (biotite granites) are considered as having originated at a deep crustal level and would correspond to relatively dry magmas. The intrusion and distribution of these granites are controlled by the shear zones and by the late-Hercynian fragile fracturation (NS-NNE-SSW). They can be pre- to syn-D3 (313-320 Ma), late-tectonic (306-311Ma), late to post-tectonic (300Ma), or post-tectonic (299-290 Ma) (Dias et al. 1998). These granites can be associated with tonalities and the muscovite, when present, is secondary in origin.

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THE NORTHERN PART OF THE CENTRAL IBERIAN ZONE: PRE VARISCAN AND VARISCAN EVOLUTION

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A few distinctive features characterize the northern part of the Central Iberian Zone (CIZ). Regarding the stratigraphic sequence, these are the thickest Neoproterozoic terrigenous succession known as the Schist-greywacke Complex, the lack of continuity of the Cambrian succession, which is often missing, the abundance of Early Ordovician igneous rocks, and the impressive continuity of the Armorican Quartzite, an indicator of basin stability. Regarding the orogenic evolution, the most important features are the early upright to overturned folds, which are relatively small and regular structures, the emplacement of a huge Variscan nappe stack above the CIZ and presently preserved in the allochthonous complexes, the initial Barrovian metamorphic evolution followed by one of the low pressure type, the late orogenic development of extensional detachments and granite-migmatite domes, and the abundance of syn- to postkinematic granitoids.

The sedimentary succession, the volcanic and plutonic content, and zircon age inheritances can be explained by the CIZ forming part of Gondwana and reflecting Neoproterozoic orogenic activity, Cambro-Ordovician rifting (Díez Montes, 2006), and high stability of the margin from the Arenig onwards. Zircon age populations in Neoproterozoic to Devonian detrital sediments suggest that this part of Iberia remained in the northern, passive margin of Gondwana during the whole Paleozoic and never individualized to form part of the Armorica microplate, whose existence is doubtful (Martínez Catalán et al., 2004).

The position in northern Gondwana conditioned the subsequent evolution during the Variscan collision. Although marginal, the CIZ was not situated at the edge of the continental platform, but in a more landward position that allowed it to escape from early Variscan continental subduction. Deformation on the CIZ is typically collisional and of relatively high intensity. Initial folding and subsequent thrusting of the allochthonous complexes of the Galicia-Trás-os-Montes Zone (GTMZ) represent a significant amount of crustal shortening and thickening. Late orogenic collapse, accompanied by extension and granite generation also suggests that the orogenic crust reached the thickness typical of modern collisional mountain chains.

Modelling the thermal evolution of the orogenic crust throughout the collision has been attempted by Alcock et al. (submitted). The models support the deformation scheme and show that timing, based on published isotopic data, may be correct. Relatively high radiogenic heat production is necessary to explain the metamorphic evolution, but always within the reasonable limits of published present surface heat flow and radiogenic heat production of the Iberian Massif. The modelled P-T-t paths fit the metamorphic evolution of extensional domes when the crust is nearly doubled during the first deformational event, the allochthonous complexes add another 10 km, and large amounts of late-orogenic extension are considered.

The main recognized pulses of granite production are well explained by crustal thickening followed by thermal relaxation and lithospheric extension (see Fig. 1). The mantle contribution recognized in some groups of Variscan granitoids can be explained by partial melting during extension and thermal re-equilibration. Mantle delamination is not necessary to explain the thermal evolution of the crust at any stage of the orogenic evolution.

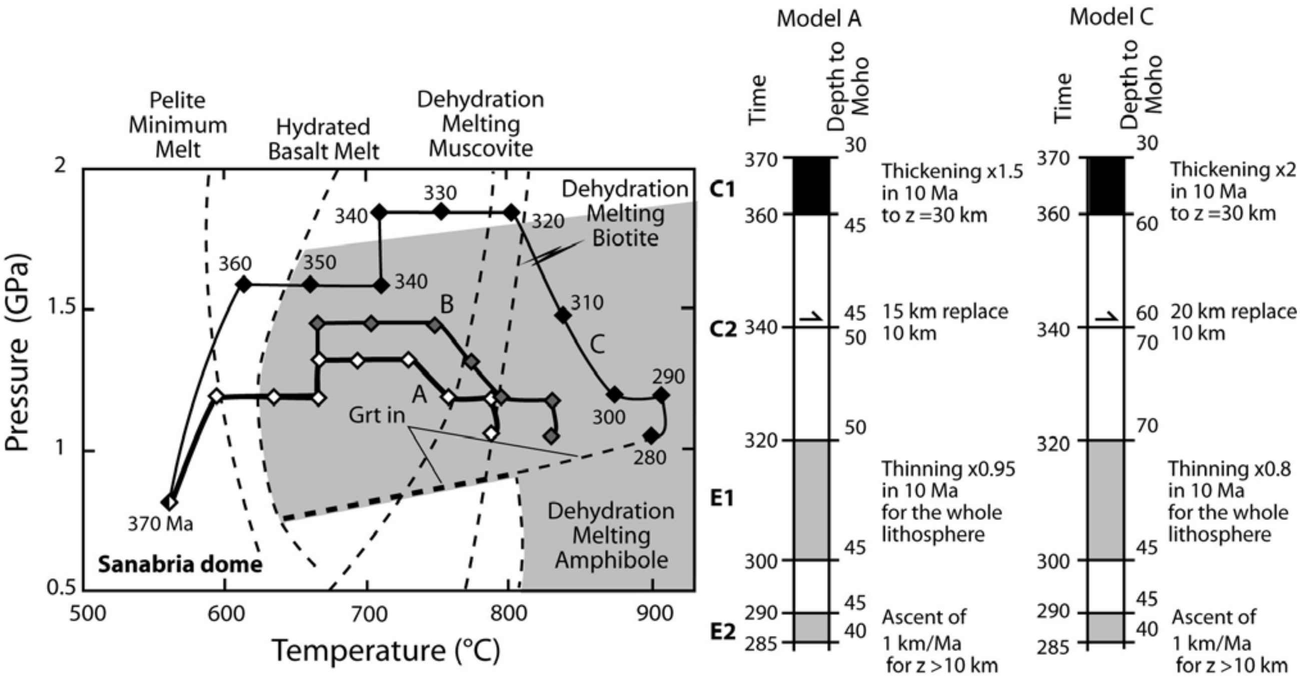

FIGURE 1. Model results for the Sanabria dome showing the P-T-t paths resulting from orogenic thickening and subsequent thinning of the crust at the Moho discontinuity, initially 30 km deep. Logs to the right of the figure represent the structural evolution used in the models as a record of crustal thickness (depth to the Moho in km), timing of orogenic events (age in Ma), and strain rates. C1 and C2 are compressional events, namely recumbent folding (C1) and thrusting of the allochthonous complexes (C2). E1 is the main extensional phase, whereas E2 represents late extension related to doming and normal faulting. Only models A and C are represented. Model A is for initial crustal thickening by a factor of 1.5 and an additional crustal overburden of 5 km due to the emplacement of the allochthonous complexes. Model B is similar to model A but with a 20 km thick allochthon (instead of 15 km) replacing the upper 10 km of crust at its footwall. Model C uses an initial crustal thickening factor of 2. Reaction curves are pelite minimum melt and muscovite dehydration melting (Thompson, 2001), dehydration melting of biotite (Le Breton and Thompson, 1988), basalt melting curve, and dehydration melting field for amphibole and the garnet-in reaction for basaltic amphibolites (Rapp and Watson, 1995). Time is shown in Ma only for the P-T-t path reaching the highest depth. The models are consistent with early production of limited amounts of granodioritic to tonalitic melt in the lower crust at model times between 30 and 60 Ma. Models B and C indicate that more voluminous melting of the lower crust should occur as temperature exceeded that necessary for biotite-dehydration melting and approached 900 °C. After Alcock et al. (submitted).

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BARROSO-ALVÃO AREA

LOCALITY 1

LOCALITY NO. 1 - AN OVERVIEW OF THE BARROSO-ALVÃO APLITE-PEGMATITE FIELD

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INTRODUCTION

Barroso-Alvão aplite-pegmatite field is being studied for more than twenty years and it is recognised for its large number of aplite-pegmatite bodies.

While working on a programme of regional mapping and granite petrology, Fernando Noronha and his team have identified several types of aplite-pegmatite veins in this region. Among them, aplite-pegmatite veins with spodumene, lepidolite and phosphates of the amblygonite series where also recognised and described (Noronha, 1987). The Li-bearing veins population represents a minor fraction of all the aplite-pegmatite occurrences in the field. Despite this fact, mineralogy, geochemistry, petrology and lithogeochemistry studies were undertaken, likewise for veins mineralised in tin previously studied (Ferreira & Noronha, 1987). These studies and a national prospecting campaign carried out by the Portuguese Geological Survey (Pires, 1995) attested the importance of these Li-bearing veins (Charoy *et al*., 1992, 2001, Lima, 2000).

In 2002, during a FCT (Fundação para a Ciência e Tecnologia) research project, Alexandre Lima and co-workers have identified petalite as a dominant phase in aplite-pegmatite veins from the Barroso-Alvão field (Lima *et al*., 2003a, b). Studies focused in veins enriched in petalite were emphasised due to the importance of their use as raw material to the Ceramic and Glass Industries.

During this field-trip not all the types of pegmatites will be seen, but it seems essential to give some information about all of them, in order to a better understanding of the geological context of the area. At this moment, many pegmatites are concessioned for mining industry, and industrial tests (bulk sampling) are being carried out in the Barroso Alvão aplite-pegmatite field.

GEOLOGICAL SETTING

The Barroso-Alvão aplite-pegmatite field is located in the western part of the Iberian Peninsula, in the Hercynian belt, "Galicia-Tras-os-Montes" geotectonic zone.

The dominant rock types hosting this pegmatites are metamorphic rocks, low- to medium-grade, Silurian in age: quartziferous schists and micaceous schists with minor interbedded black schists. Different types of synorogenic granites, all of Hercynian age, are distributed in the area: biotite granites (syn-F3), two mica granites (syn-to late-F3) and post-tectonic biotite granites (post-F3). The two-mica granites (Cabeceiras de Basto Complex) are dominant and define two large NW-trending structures which broadly correspond to the core of a D3 antiform.

In general veins are vertical, flat or with a variable dip. They can appear as lenticular or of elongated shape, in some cases outcropping more than 500 m along strike, like the Lousas pegmatite. They are either concordant or highly discordant and are more or less deformed.

All aplite-pegmatite bodies are spatially associated with the two-mica peraluminous granites and Lima (2000) has considered the syn-to late tectonic two-mica granites from the Cabeceiras de Basto complex, as genetically related with the lithium aplite-pegmatite bodies.

DIFFERENT TYPES OF VEINS

As referred above, several types of veins can be found in Barroso-Alvão pegmatitic field, either intruded in metasedimentary country rocks or in the two-mica granites and more sparsely in the biotite granites (Fig.1). Those intruded in the metasedimentary country rocks are grouped into barren pegmatitic veins, pegmatitic veins with beryl, pegmatitic veins with cassiterite and pegmatitic veins with lithium minerals: spodumene, petalite and lepidolite. According to Černý & Ercit (2005) classification, the Li-bearing veins, belong to the LCT family, Rare element (REL) class, REL-Li subclass, complex type, spodumene subtype, petalite subtype or lepidolite subtype. The available data neither allows the establishment of a regional zoning, where the content in lithophile elements increases with the distance to the parental granite, nor a relationship between the metamorphic degree of the hosting rocks and the mineral assemblages of these veins (Fig. 1).

Intragranite aplite-pegmatite bodies were briefly described in Charoy *et al*., (1992) with muscovite appearing as dominant mica; biotite occurring together with tourmaline (schorl) and spessartine-rich garnet present as minor phases and sometimes outlining a crude layering; beryl is considered as a rare accessory mineral.

MINERAL ASSEMBLAGE OF SPODUMENE AND PETALITE SUBTYPE VEINS

The mineralogical composition of these veins is simple and very similar to granite. They are constituted of a pegmatitic phase very well mixed with a minor saccharoidal aplitic matrix (almost sugar-grained texture) composed by albite, quartz and rare muscovite. This is a typical textural characteristic of these veins.

By hand sight observation the major constituents of the pegmatitic phase are:

1) euhedric K-feldspar crystals (until 50 cm in length). They are uniformly distributed but some times form aggregates, although they never show graphic growing as intragranitic ones;
2) spodumene and petalite appear as clusters or as single crystals;
3) round quartz grains of small dimension.

The most common accessory mineral is muscovite of centimetre dimension although montebrasite and apatite (among other phosphate assemblage of less importance), tourmaline, cassiterite, clay minerals and Mn and Fe oxides might also be present.

In the aplitic matrix, homogeneous grain size is observed although a poorly developed banding can be recognizable in some places. This is interpreted as a depositional and not replacive matrix, in origin. It is mainly composed of albite, with sporadic tapered phenocrysts of turbid K-feldspar. Quartz is an accessory phase as well as rare muscovite that appears as isolated flakes and rarely associated with apatite grains.

PETROGRAPHIC DESCRIPTION

Spodumene subtype

This subtype was well characterized by Charoy *et al*. 1992, Charoy *et al*. 2001 and Lima (2000).

K-feldspar phenocrysts are turbid and have no (or very few) exsolution lamellae of albite, but they do contain albite laths from the matrix as inclusions. They never display cross-hatched twinning, at least at the scale of optical microscopy. The core zone of most of the large crystals of primary albite is decorated with small “droplets” of quartz. These early albite crystals show bent twin lamellae and deformation-induced twinning. Quartz commonly shows undulose extinction. Primary muscovite, scarce in discrete centimetric plates, seems at equilibrium with both primary feldspars. Most of the white mica occurs as small secondary anhedral flakes growing at the expense of the primary Li-aluminosilicate phases or along fractures.

Spodumene is not homogeneous distributed trough each vein: it occurs either as single crystals or as massively aggregates. Their crystals are euhedral to subhedral with a predominant (100) and subordinate (110) development of the prism zone. The simple twin (100) is common. Inclusions of other minerals are rare, suggesting early precipitation in the sequence. Their growing is either randomly or prismatic columnar, and commonly revel embedded texture with K-feldspar megacrysts. Also present are irregularly shaped poikilitic crystals containing sparse blebs of quartz. Spodumene from these veins has characteristically crème colour and reaches 30 cm of maximum length.

In spodumene subtype veins, petalite was only identified in thin section. It follows spodumene as the stable Li-aluminosilicate. Spodumene is in some cases penetrated, but not replaced by petalite along cracks or twin planes. Petalite is partly altered along grain boundaries to a brownish aggregate of microcrystals of eucryptite. In the Veral case study, needles of petalite, together with euhedral quartz, fill angular voids among a meshwork of euhedral laths of spodumene. Such a textural relationship shows that when the main generation of quartz precipitated, the medium was still saturated with Li–Al–silicate-forming components at P–T conditions in the field of stability of petalite. Montebrasite, which seems interstitial, is sporadically encountered as isolated, heavily altered grains with remnants of polysynthetic twinning.

Petalite subtype

Petalite subtype veins were previously characterized in Lima *et al*. (2003a). In this work, the major mineral constituents are Na-rich plagioclase, K-feldspar, petalite and quartz. As accessories, muscovite, montebrasite, apatite, tourmaline, cassiterite, clay minerals (such as montmorillonite) and Fe and Mn oxides were identified. Aplitic matrix is well mixed with the pegmatitic phase, a common feature from the veins of Barroso-Alvão pegmatitic field. K-feldspar phenocrysts, which are described as crystals of big dimensions decorated with small quartz inclusions, are turbid and have few albite exsolutions. Some plagioclase show polysynthetic twinning and mechanical twining, interpreted of primary precipitation. By hand sight observation, petalite is almost colourless or translucent when fresh and pale yellow when altered. It is easily misidentified as albite or K-feldspar, even under the microscope. Exhibits euhedral to subhedral form, perfect cleavage (001) and it can appear either isolated or agglomerated. In the borderline of these petalite crystals it is frequent to observe tourmaline and cassiterite. Round quartz inclusions are common. Quartz commonly shows undulose extinction. Primary muscovite is not easy to find in thin section and when present appears in flakes and seems to be in equilibrium with the feldspars. Spodumene + quartz after petalite, as described by London (1984), is a common aspect that can be observed in these veins either by sight observation or under the microscope. Eucryptite presence in petalite cracks was infer from high-density liquid separation and proved with ultraviolet light observation and micro-Raman microprobe analyses. Electron microprobe analyses are required.

Further petrographic observation allows us to emphasise albite exsolutions as a remarkable feature, especially when petalite and albite co-exist in the same thin section. Subgranulation is also a common aspect either in albite or in petalite crystals, suggesting moderate to high temperature deformation. In some cases it reminds granoblastic texture which mosaic is formed of albite or petalite crystals with the characteristic triple points of approximately 120º. Although this subgranulation is present, it isn’t homogenous. It is possible to interpret this fact as previous heterogeneities before deformation occurred; or as a result of a non constant deformation event; or as a result from a recovery process.

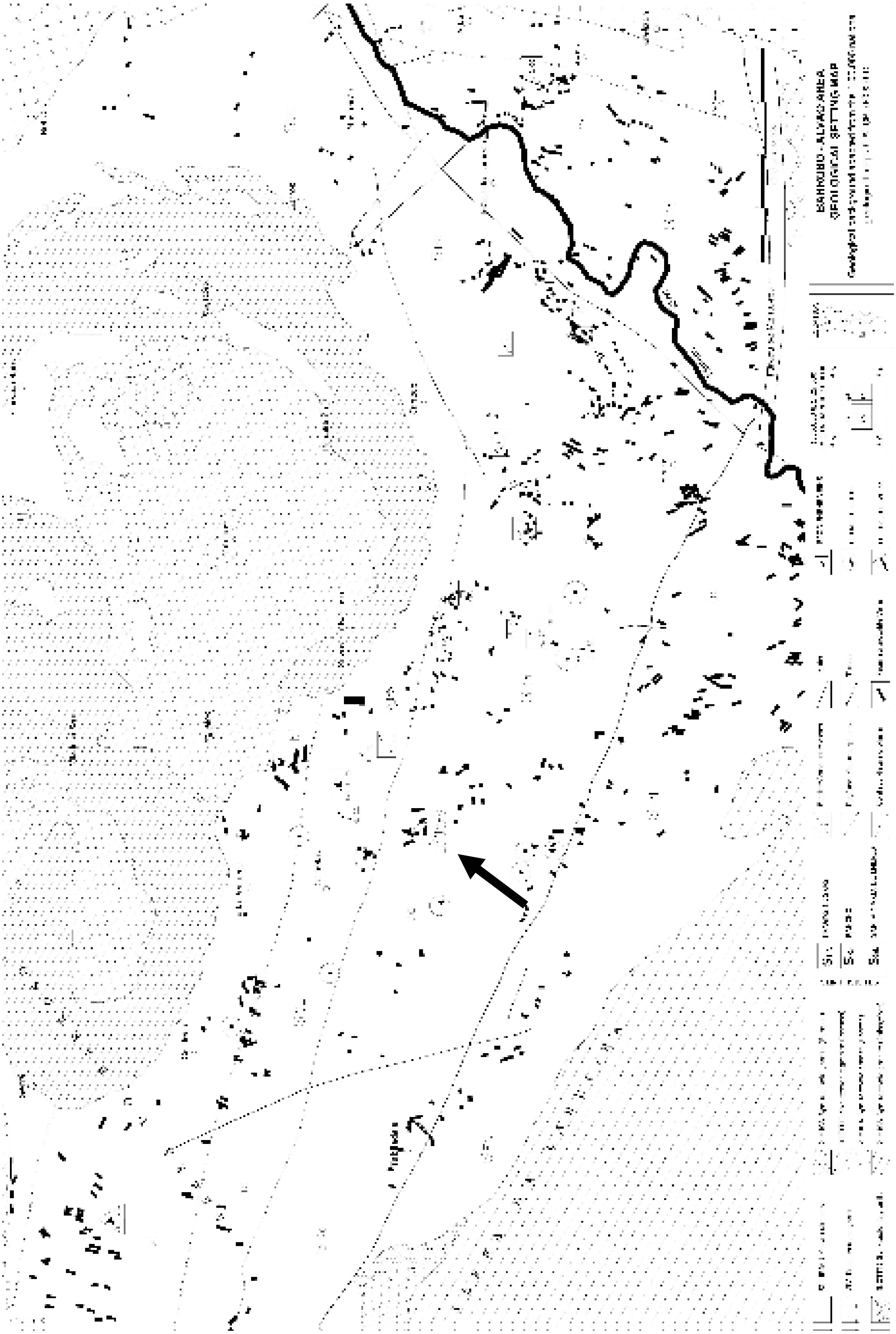

FIGURE 1. Barroso-Alvão Geological Setting

Cassiterite is an important accessory mineral. It appears randomly distributed and based on textural relation with the other mineral phases, it is considered primary. It is deformed, as described by Borges et al. (1979), and fractured (in some cases fractures are filled by aplitic material from the matrix). Cassiterite crystals commonly exhibit typical idiomorphic crystals < 1 cm in length and the familiar "knee" twin. Under the microscope it was possible to identify an internal chromatic oscillatory zoning with strong pleocroism from pale yellow to dark reddish brown and a less coloured area with mineral inclusions from the ferrocolumbite-ferrotantalite series and feldspars crystals. Minerals from the ferrocolumbite-ferrotantalite series were not considered exsolutions because they were also observed in the aplitic matrix and are interpreted of previous precipitation, relatively to cassiterite.

Phosphates are more common in petalite subtype veins than in the spodumene subtype. Besides montebrasite and apatite previously referred, ferrisicklerite was also identified. Pyrite was also observed in the aplitic matrix of these veins.

GEOCHEMISTRY

In table 1 it is possible to compare some of the chemical characteristics of the lithium aplite-pegmatite bodies.

Results indicate that veins classified as spodumene and petalite subtype, basically have the same amounts of major, minor and trace elements. Veins from the petalite and lepidolite subtype have the highest content of tin (Sn) and rubidium (Rb). They also have a lower value of iron (Fe), when compared with the spodumene subtype.

In spodumene and petalite subtype, albite is prevalence over K-feldspar (Na_2O/K_2O>>0,7) especially in the aplitic matrix. Peraluminous index indicate high peraluminous rocks with their (A/CNK)>>1,6.

Regarding fractionation, and using K/Rb ratio (Černý, 1992), lepidolite subtype is the most evolved, followed by petalite subtype and spodumene subtype. Lepidolite subtype is considered the most specialised, as expected, because lepidolite is associated with a hydrothermal post-magmatic signature.

TABLE 1. Comparative bulk composition analysis from lithium bearing veins. nd – non determined; tr – below detection limit.

Wt %	Spodumene subtype	Petalite subtype	Lepidolite subtype
SiO_2	73,39	72,83	70,13
Al_2O_3	16,62	16,95	17,38
Fe (total)	0,72	0,20	0,26
MnO	0,10	0,03	0,08
MgO	0,11	0,06	tr
CaO	0,28	0,08	0,17
Na_2O	4,26	3,76	4,89
K_2O	2,97	2,86	2,85
TiO_2	0,01	tr	tr
P_2O_5	0,34	0,54	0,7
F	nd	nd	0,99
Li (ppm)	3632	6025	3565
Rb (ppm)	562	930	2393
Sn (ppm)	29	665	728
K/Rb	44,06	28,13	9,90
ASI	1,62	1,85	1,56
A/CNK	1,55	1,80	1,52
Na_2O/K_2O	1,43	1,31	1,72

Locality No. 1: Lousas pegmatite outcrop

INTRODUCTION

Lousas outcrop is an example of a petalite subtype vein that can be found in the Barroso-Alvão pegmatitic field. The arrow in the geological map of figure1 localise Lousas pegmatite outcrop. This vein intrudes metamorphic rocks well characterised in Ribeiro *et al.* (this volume) and has variable direction between N-S and N020º pending 70º to west (Fig. 2).

Lousas pegmatite has an extension of approximately 500 meters and a thickness variable from a few meters to more than 10 meters. Detailed geological cartography in 1:1000 scale, allowed the recognition of lateral ramifications attaining several meters of extension (Fig. 2 and 3).

GEOCHEMISTRY CHARACTERISATION

Lousas vein was focus of a detailed geochemical study. In order to understand lithium distribution throughout the vein, Li content of the collected samples was analysed. In the geological map of the figure 2, letter N localise the place where the channel sampling technique was carried out. Results are showed in table 2.

TABLE 2. Li content analyses from AL 103 vein. Collected by channel sampling. Major and trace elements were analysed by atomic absorption in the S. Mamede Infesta IGM laboratory.

Sample nº	Net (Kg)	Thickness (m)	Lithology	Li ppm (IGM)
F103-1	6,5	0,75	Altered pegmatite-aplite vein	478
F103-2	5,5	0,85	“”	358
F103-2A	4,0	0,17	Quartz vein	137
F103-3	5,0	0,3	Altered pegmatite-aplite vein	1600
F103-4	7,0	0,9	“”	810
F103-5	6,5	1,85	Non altered pegmatite-aplite	4200
F103-6	7,0	0,9	“”	3200
F103-7	6,5	1,3	“”	6800
F103-8	9,5	2,45	“”	4700
F103-9	8,0	1,5	“”	3800
F103-10	7,0	1,2	“”	8000

From results showed in table 2, it is possible to verify that the values for the first five samples are impoverished in lithium, interpreted as the result of the leaching out of this element from the vein to the adjacent country rock. This was also observed in previous work (Lima, 2000).

Table 3 exhibits data of several bulk analyses obtained for spodumene subtype veins as well as for the petalite subtype. As summarised above, sodium content is dominant over potassium (Na_2O/K_2O>>0.7) and peraluminous rate is very high (A/CNK)>>1.6. Based in the K/Rb criteria to the fractionation index, defined by Černý (1992), petalite subtype are more evolved than the spodumene subtype. Regarding trace element content, tin is the chemical element that more effectively differentiates these two subtype veins.

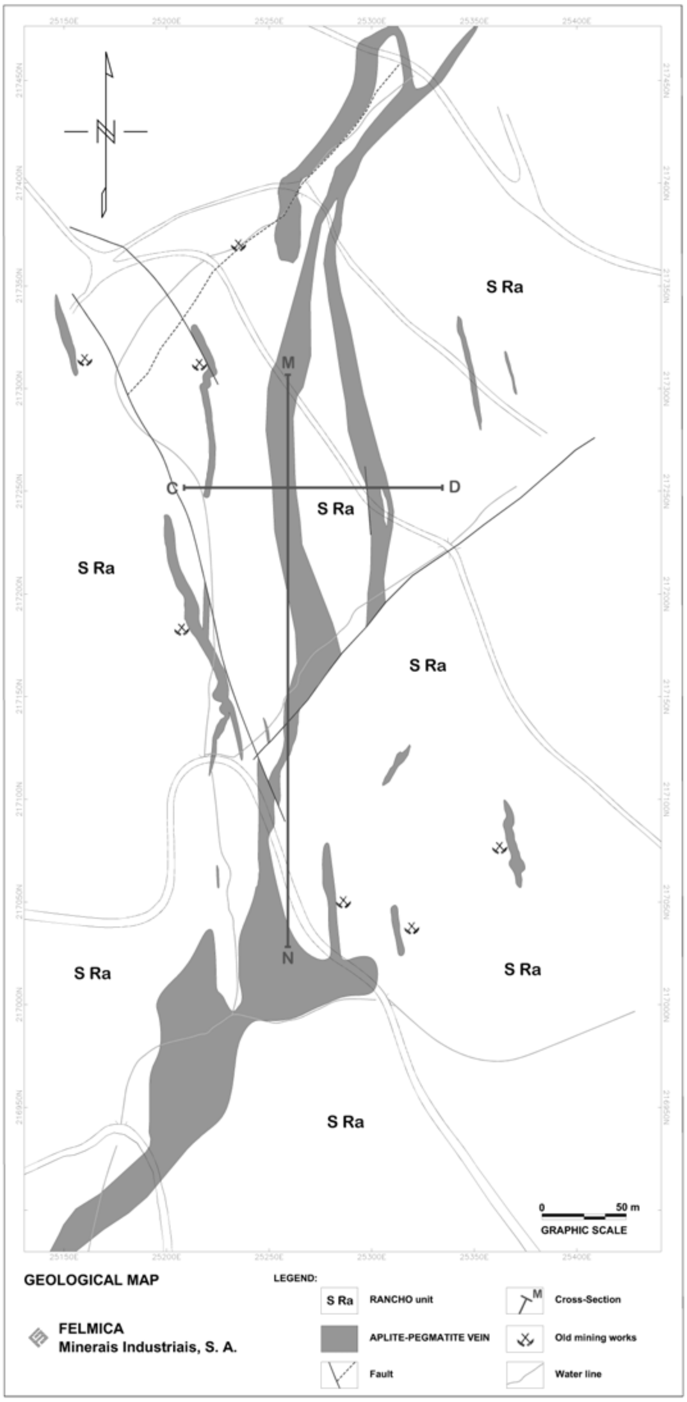

FIGURE 2. 1:1000 geological map of the Lousas pegmatite (Drawings gently ceded by Felmica, S. A.).

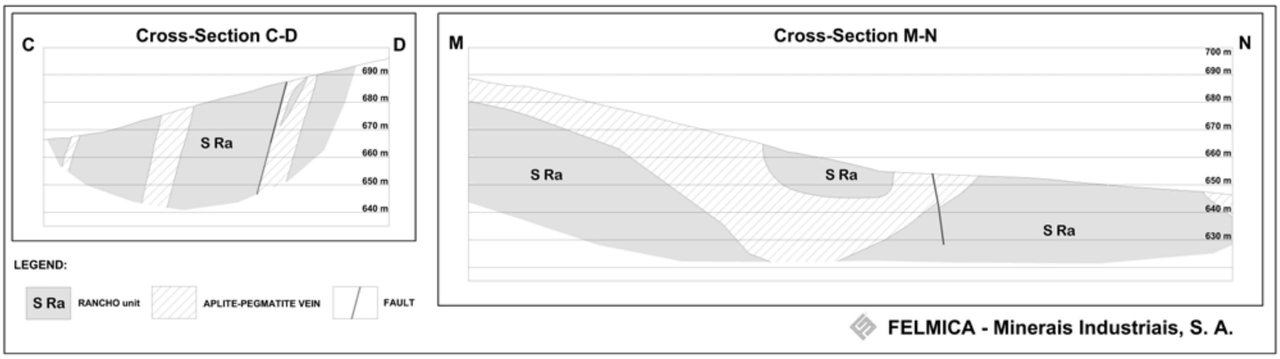

FIGURE 3. Transversal cross-section C-D and longitudinal cross-section M-N of the Lousas pegmatite. (Drawings gently ceded by Felmica, S. A.).

TABLE 3. Bulk analyses of petalite subtype veins (Lima, 2003b) and spodumene subtype veins (Lima, 2000) from the Barroso-Alvão pegmatitic field, compared with bulk analyses obtained from LCT pegmatites Harding (spodumene subtype) and Tanco (petalite subtype) (Černý, 1991).
Sample F103 results from the blending of fresh and altered samples of the AL103 vein (Lousas pegmatite).

Oxide (%)	1	2	Spodumene subtype			Petalite subtype			
			Alijó (average)	Veral (average)	Adagói (average)	AL 91	AL 101	AL 103	F 103
SiO_2	75,24	69,74	73,47	74,07	72,64	71,05	72,69	73,18	74,41
Al_2O_3	14,42	16,50	16,78	16,04	17,03	17,74	16,9	16,67	16,48
Fe (t)	0,65	0,18	0,77	0,71	0,68	0,18	0,2	0,22	0,21
MnO	0,18	0,21	0,12	0,11	0,07	<0,02	0,04	0,03	0,02
MgO	0,01	--	0,10	0,07	0,15	0,02	0,07	0,13	0,02
CaO	0,20	0,89	0,32	0,19	0,33	0,04	0,06	0,1	0,13
Na_2O	4,23	2,69	3,87	4,28	4,63	2,58	4,5	3,69	4,28
K_2O	2,74	4,42	2,67	3,15	3,10	3,58	2,88	2,3	2,68
TiO_2	0,05	0,01	0,01	0,02	0,01	<0,04	<0,04	<0,04	<0,04
P_2O_5	0,13	1,18	0,36	0,34	0,33	0,71	0,93	0,24	0,29
LOI	--	--	1,22	1,18	1,07	1,99	0,26	1,86	1,08
Partial total	97,85	95,82	99,68	100,1	100,02	97,89	98,53	98,42	99,6
ASI	1,45	1,79	1,81	1,53	1,55	2,18	1,61	1,95	1,66
A/CNK	1,54	0,61	1,71	1,49	1,47	2,16	1,59	1,91	1,62
Na2O/ K2O	1,40	1,52	1,45	1,36	1,49	0,72	1,56	1,60	1,60
Li	37-8400		4857	2330	3710	8200	4900	5000	6000
Rb	183-9970		533,17	607	547	1134	970	613	1001,6
Sr			75,27	22,25	49	20	19	31	
Y			1,09	1,2	1,39	3	3	<3	
Zr			13,68	15,55	15,46	9	15	6	
Nb	8-213		19,63	17,95	35,22	34	54	23	
Ba			7	6,55	56,85	14	16	20	
Ta	12-4620		<15	<15	<15	<15	<15	<15	
Sn	12-3170		33,37	26,7	25,55	667	1166	161	
Th			<5	<5	<5	<5	<5	<5	
K/Rb	40-5		41,76	43,18	47,23	26,31	24,74	31,27	22,3
Nb/Ta	1,1-0,3		1,31	1,20	2,35	2,27	3,60	1,53	0,00

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HYDROTHERMAL ALTERATION PROCESSES OF THE LITHIUM BEARING APLITE –PEGMATITE VEINS FROM THE BARROSO-ALVÃO FIELD, PORTUGAL

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INTRODUCTION

Previous studies dedicated to mineralogy and petrography of the aplite-pegmatite dikes have identified several disequilibrium mineralogical reactions during late magmatic to post-magmatic stages (Charoy et al., 2001).
In this short contribution we discuss results of an integrated study dedicated to the evolution of hydrothermal to supergene alteration process in the aplite-pegmatite field from Barroso-Alvão field, northern Portugal.

HYDROTHERMAL ALTERATION STAGES

Early hydrothermal stages

The primary assemblage of rock-forming minerals in Li-bearing aplite pegmatites is constituted by K-feldspar, albite, spodumene, petalite, muscovite, quartz and sporadically phosphates (montebrasite, triphylite, fluor-apatite).
The hydrothermal alteration process has a sporadic development within a given pegmatite dyke, suggesting changes in the chemistry of hydrothermal fluids as thermodynamic conditions modified. Coexistence of heavily transformed and unreacted spodumene crystals at the thin-section scale can be explained either by kinetic barriers, heterogeneity in fluid percolation, or by sealing of fractures and channelways due to the relatively larger molar volume of the alteration assemblage (London & Burt 1982a).
The first stage of subsolidus alteration is usually alkaline (London & Burt 1982b, Burt & London 1982), being followed by a phyllic ("sericitic" alteration) and a weakly acid stage. Assuming a closed system, the total budget of Li in the fluid–mineral system should be constant. More Li went into solution as the progress reaction favoured the replacement of Li-bearing minerals by albite and K-feldspar (Wood & Williams-Jones 1993). Therefore, the K, Na/Li activities in the fluid generally will decrease with falling temperature and pressure.
The widespread replacement of spodumene leading up to complete replacement by albite (± muscovite), and of petalite by K-feldspar and eucryptite are shown in Figure 1. Albite is the major product of the spodumene alteration. Albite may occur in assemblage with secondary K-feldspar, both exhibiting a branching habit. Remnants of spodumene in crystallographic continuity are embedded in medium-grained clear albite, which is surrounded by a fine-grained intergrowth of secondary K-feldspar + muscovite ± eucryptite.
A quite similar sequence of alteration, but at a larger scale, involving the assemblages eucryptite + albite ± K-feldspar and albite + muscovite, has been documented elsewhere (London & Burt 1982a). These subsolidus assemblages correspond to a Na^+-for-Li^+ ion-exchange reaction [spodumene + Na^+ = eucryptite + Ab + Li^+], followed by influx of K^+ (growth of microcline) and H^+ metasomatism (growth of muscovite). Therefore, subsolidus conditions were sufficiently alkaline to stabilize eucryptite + Ab or eucryptite + K-feldspar, and then later, relatively acid to form secondary mica (Montaya & Hemley 1975).

During these episodes of alteration, Li was removed from the primary pegmatite assemblage, partially trapped in secondary eucryptite or leached out of the system and expelled toward the host rocks. Silica is also leached out. A slight increase of Li and Si contents in adjacent micaceous schists confirms this inference (Charoy et al. 2001). The identification of eucryptite in the field, and even at the microscope is very difficult; it being identified just using electron microprobe.

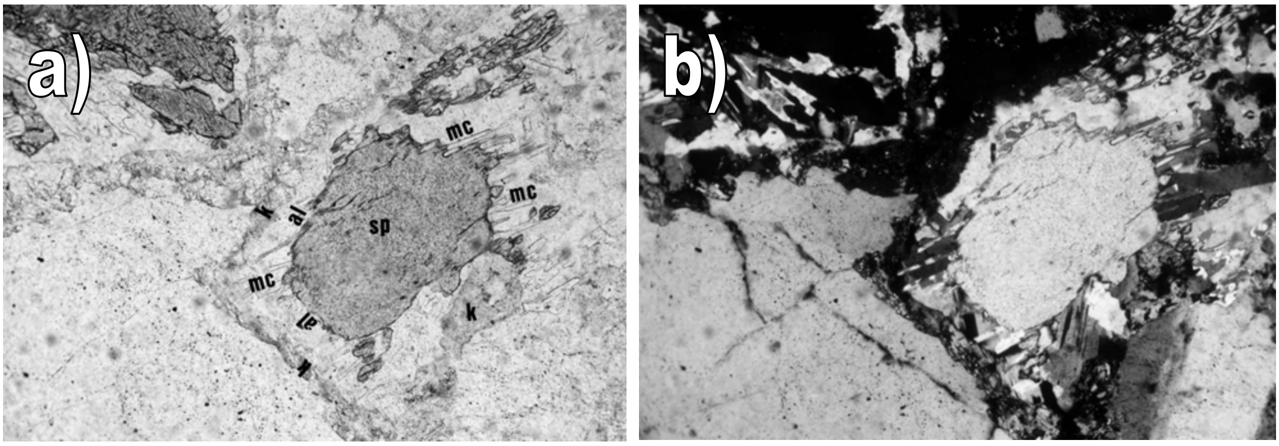

FIGURE 1. Spodumene crystal (sp) substituted by albite (al) and muscovite (mc), surrounded by K-feldspar (k) and eucryptite (detected by electron microprobe), interpreted as the substitution of petalite. Width of field of view: 5 mm. a) parallel nicols b) crossed nicols.

Replacement of spodumene (and eucryptite) by feldspars consumes silica, whereas the replacement of petalite liberates silica. As such, their replacement will not be contemporaneous but complementary (Charoy et al. 2001):

$$\text{Spd} + \text{Na}^+/\text{K}^+ + \text{Qtz} \rightarrow \text{Ab/Kf} + \text{Li}^+$$

$$\text{Pet} + \text{Na}^+/\text{K}^+ \rightarrow \text{Ab/Kf} + \text{Qtz} + \text{Li}^+$$

$$\text{Ecr} + \text{Na}^+/\text{K}^+ + 2\text{Qtz} \rightarrow \text{Ab/Kf} + \text{Li}^+$$

Spodumene and feldspars were also altered in some cases by sericite (which chemical composition confirms a typical muscovite crystal-chemistry) exhibiting radiating thin flakes. In some rare cases, euhedral vuggy prisms of spodumene in a large (decimetres) open cavity have been totally converted to a pale green, soft, waxy pseudomorph of nearly pure fine-grained white mica. This material is very similar to that described as “rotten spodumene” by Graham (1975). Li was nearly completely leached out during this replacement: 7.23 and 0.13 wt% Li_2O remain in spodumene and pseudomorphic white mica, respectively (Charoy et al. 2001).

Also, the formation of secondary mica after spodumene or feldspar alteration is enhanced due to the local increase of H^+ activity, according to the reaction:

$$3\ \text{Spd} + \text{K}^+ + 2\text{H}^+ \rightarrow \text{Ms} + 3\text{Qtz} + 3\text{Li}^+$$

$$\text{Feldspar} + \text{H}^+ + \text{H}_2\text{O} \rightarrow \text{Ms} + 3\text{Qtz} + \text{K}^+(\text{Na}^+)$$

Late hydrothermal stages

An even more evolved alteration of spodumene into clays can be observed in Figure 2. The substitution of spodumene laths by sericite (Fig. 2a) and by cookeite (Fig. 2b).

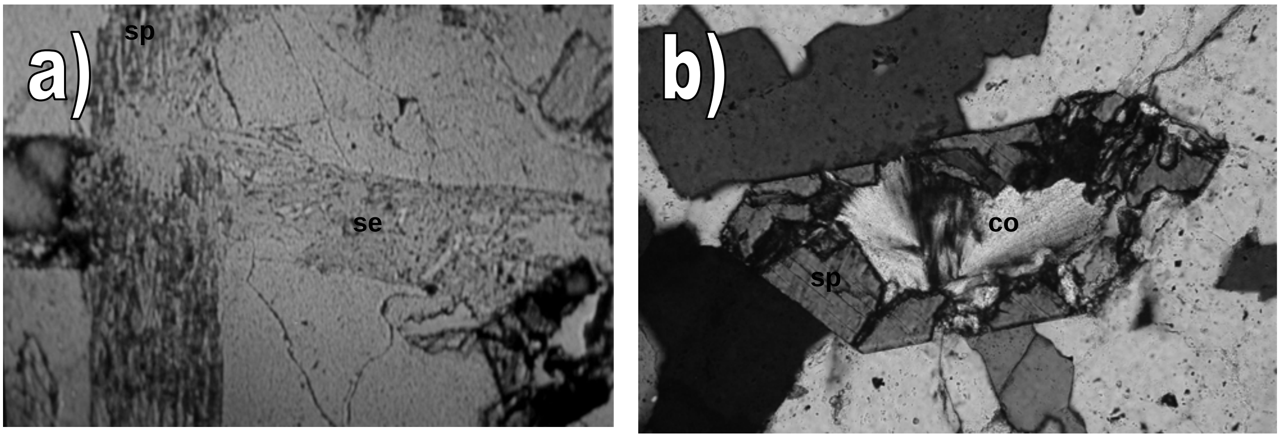

FIGURE 2. Spodumene lath (sp) substituted by sericite (se) and by cookeite (co). Width of field of view: 5 mm.
a) parallel nicols b) crossed nicols.

As observed in figure 2, spodumene may be altered into cookeite as H^+ activity increases in system. The acid solutions dissolved spodumene, cookeite precipitate and silica will be liberated according to the reaction:

$Spd + H^+ + H_2O = Cookeite + SiO_2$

Cookeite, a di-trioctahedral chlorite, was frequently identified at a micrometric scale replacing the spodumene crystals along the fracture cleavages. The susceptibility of aluminous silicates to alter to form sheet silicates was reported also in the eucryptite-to-muscovite alteration where an Al/Si ratio of ~ 1 is maintained (London and Burt, 1982a).

Kaolinite may forms from feldspar, mica, spodumene or cookeite alteration as the water content increases in system. Usually kaolinite was identified to crystallize in hydrothermal conditions just from spodumene or cookeite alterations according to the reaction:

$Spd + H_2O = Kaolinite + SiO_2 + Li^+$

The first evidence of alteration is the ubiquitous presence of micropores in the feldspar (giving them a turbid aspect) that are known as indicative of hydrothermal alteration according to Worden et al. (1990). However, one macroscopic evidences of this kind of alteration recognized in the aplite-pegmatite field is the widespread occurrences of the rose smectite. Smectite occur as the hydrothermal alteration of feldspar produced at low temperature and pressure according to the reaction:
$Feldspar + H^+ = Smectite + SiO_2 + Na^+$

Weathering

Weathering process corresponds to large kaolinization zones in fracture systems of aplite-pegmatite veins. Kaolinization zones correspond to disordered kaolinite and halloysite-7Å. It is characterized also by the almost loss of all content in Li of the Lithium bearing pegmatite.

THERMODYNAMIC STABILITY OF MINERALS DURING THE HYDROTHERMAL ALTERATION

Inferred pressure-temperature paths for the magmatic crystallization Li-Al silicates were discussed by several authors (Holdway, 1971; London, 1984; Jahns, 1982; London and Burt, 1982b). Petalite and spodumene occurrences depend on pressure and temperature (P-T) conditions. According to London (1984), the shallow P-T slope of the univariant reaction signifies that petalite-spodumene stability is more dependent to P than T. Spodumene is stable at P ≥ 1.7 Kbar (quartz + petalite + spodumene + eucryptite invariant assemblage), which precludes its appearance at low P environment. Petalite is stable between 550 – 680°C at 2 Kbar and 635 – 680°C at 4 Kbar, where both T - P signifies a truth magmatic environment. Below these temperatures petalite breakdowns into a fine grained spodumene + quartz assemblage (squi). The stability field of eucryptite + quartz assemblage is limited to low P-T below 320°C and 1.6 Kbar (London 1984).
Wood and Williams-Jones (1993) have drawn the minerals stability previously discussed at a pressure of 1 Kbar (Fig. 3). Log activity (Na,K/Li) vs. temperature at 1 Kbar were computed at 200°C from the equilibrium albite/K-feldspar – eucryptite – quartz.

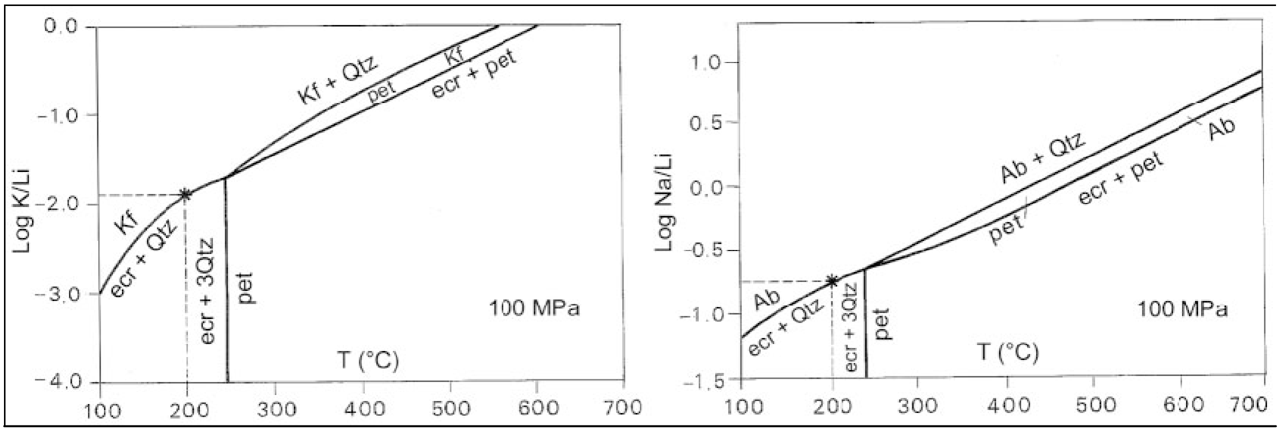

FIGURE 3. Log activity (Na or K/Li) versus temperature at 100 MPa; activities can be computed from the equilibrium albite/(K-feldspar)– eucryptite – quartz at 200 °C (redrawn from Wood &Williams-Jones 1993).

DISCUSSIONS

In the Li-bearing aplite-pegmatite field of Barroso-Alvão, a complete petrogenetic evolution from magmatic to hydrothermal was identified. The hydrothermal history of the Li-bearing aplite–pegmatite field started with the metasomatic replacement of the formed Li-aluminosilicates by albite, K-feldspar and muscovite. Late eucryptite occurs at the expense alteration of petalite during this alkaline stage. Late hydrothermal stage could be related to the opening of fractures which crosscut the metasedimentary host-rocks and it corresponds to the increase of fluid-rock interaction. This stage has generated mineral reactions which produced more hydrated phyllosilicates. The low pH conditions in system favoured intense dissolution of primary minerals and it induced in several places strong kaolinized zones. A supergene alteration characterized by the presence of kaolinite and haloysite-7A assemblage occurs in the fractured zones or in the upper parts of the network dikes.

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ORE SPECIALIZATION OF PERALUMINOUS TWO-MICA GRANITES OF CABECEIRAS DE BASTO COMPLEX (NORTHERN PORTUGAL)

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INTRODUCTION

The voluminous granite occurrence in the northwestern Iberian Peninsula is an expression of the evolution of the Variscan orogeny. The maximum of Hercynian crustal thickening in the NW of Iberia corresponds to the D_1 and D_2 Hercynian deformation phases while D_3, the last ductile deformation phase, marks the end of the collision process. According to their relationship with the D3 tectonic phase and their mineralogy (biotite or two-mica) the syn-orogenic granitic rocks of the Iberian Variscan fold belt can be subdivided into three groups: (1) ante- to syntectonic biotite granites (380-345 Ma); (2) syn- to late-tectonic two-mica granites (330-305 Ma) and (3) late- and post-tectonic biotite granites (290-280 Ma) (Ferreira et al., 1987; Pinto et al., 1987). The biotite granites are calc-alkaline granites of deep crustal origin and the two-mica granites are peraluminous granites of mesocrustal origin (Capdevila et al., 1973). The events related to the D3 tectonic phase were marked by folding and shearing which controlled the granite emplacement (Noronha et al., 1981). Crustal thickening induced by these tectonic events associated with the influence of the underlying mantle has given rise to the generation of various anatectic crustal and hybrid granites (Ortega and Ibarguchi, 1990). In northern Portugal Sn, Li , W and Au mineralizations are spatially linked to acid magmatism and occur almost exclusively sub-parallel to the regional Hercynian structures, associated with shear zones, following the same trend as the granites. Au mineralizations define alignments sub-parallel both to the shear zones and to post-D3 NNE-SSW structures (Noronha, 1988; Noronha and Ramos, 1993). The genetic relationship between the Hercynian acid magmatism and the ore deposits spatially related, in particular Sn, W, Li and, to a lesser extent, Au mineralisations, is one of the most controversial discussion topics in metallogeny (Tischendorf *et al.* 1991). A geochemical study of the behaviour of these elements in the peraluminous two-mica granites of Cabeceiras de Basto complex has been carried out in order to evaluate the metallogenic specialized character of the granites.

GEOLOGICAL SETTING

The Cabeceiras de Basto (CB) granite complex is located in the Central Iberian Zone in the contact with the Galiza Média-Trás-os-Montes domain (Julivert et al., 1974), close to the boundary between the Minho and Trás-os-Montes provinces, about 70 Km NE of Porto. The massif exhibits an elongated NW-SE shape, parallel to the regional structure. It occupies the core of a N130ºE antiform formed during the D_3 Hercynian phase and intrudes Lower Silurian metasediments (mostly schists with subordinate quartzite and metavolcanic rocks) which were affected by the three major Hercynian folding phases (Ramos et al., 1981; Noronha, 1982, 1983; Ferreira et al., 1987). The granites were subsequently affected by shear zones associated with significant late- to post-magmatic alteration processes.

An important Sn and Li vein field crosscutting metasedimentary rocks of Silurian age occurs spatially associated with the two-mica granites, towards NE of the CB complex, in Covas do Barroso area. The Sn mineralization is expressed as cassiterite in aplite-pegmatite veins, most of them controlled by the regional structure, by linear or in "echelon" faults, and are frequently deformed by the third Hercynian deformation tectonic phase (Noronha, 1983; Borges et al., 1979). Charoy et al. (1992) have described for the first time aplite-pegmatite Li-rich bodies in the same area. Li mineralization is expressed under different occurrences: as spodumene and lepidolite crystals dominantly in the pegmatitic phase of the veins, and as a phosphate of the ambligonite series both in the aplite and in the pegmatite veins. Lima et al. (2003) describes in the same area, pegmatitic veins with lithium minerals: spodumene, petalite and rare lepidolite. The veins are syn-tectonic (syn-D3 Hercynian deformation phase) and are spatially associated with the syn-tectonic (syn-D3) two-mica granites of Cabeceiras de Basto.

PETROGRAPHY

The CB pluton is composed of three main petrographic types of two-mica granites: fine-grained granites, G'f (grain size 0.5-1 mm); a medium-grained homogeneous granite, G'm (grain size 2-4 mm) and a coarse-grained locally porphyritic granite, G'g (grain size 5-7 mm). Field observations show that the G'm and G'g granite series crosscut the G'f type, although no clear chronology can be defined for the emplacement of G'm and G'g as the contacts between these units are always transitional (Almeida, 1994). The three granite series present a hypidiomorphic granular texture and a similar mineral association of quartz, plagioclase (An1-An6), perthitic K-feldspar (orthoclase to microcline as anhedral crystals to euhedral megacrysts), biotite and muscovite. Apatite, monazite, zircon, ilmenite, rutile, rare sillimanite and tourmaline occur as accessory minerals. The series may be discriminated according to their structure, grain size and the proportions of their main minerals. An important petrographic feature of these granites is the prevalence of muscovite over biotite, being biotite the only ferromagnesian mineral.
Most of the studied samples exhibit, to various extents, the effects of late- to post-magmatic hydrothermal processes involving essentially sericitization of plagioclase and/or muscovitization of biotite and albitization of K-feldspars.

GEOCHEMISTRY

Whole rock geochemistry

The three granite series are highly evolved rocks, related to leucogranite suites, according to their high silica content (between 70.5 and 75%), total alkalis contents (Na2O+K2O in the range 7.2 to 8.8%) and their low total Fe_2O_3, MgO and CaO values (respectively 1.15-2.01 %, 0.19-0.51% and 0.14-0.64 %). The molar ratio of aluminium over total alkalis and calcium (A/KCN) is, even for almost fresh samples, greater than 1.1. (1.2 < A/KCN <1.4), indicating a highly peraluminous character which is expressed by the abundance of muscovite as a primary phase.
Despite the almost identical compositions the three granite types can be separated according to their K/Na ratios (G'g, 1.9-2.2; G'm, 1.4-1.6; G'f: 1.3-1.5), their total REE contents (G'f: 71-284 ppm; G'm: 43-92 ppm; G'g: 39-126 ppm) and their Zr contents (G'f: 74-195 ppm; G'm: 49-94 ppm; G'g: 46-88 ppm).
Excluding samples significantly affected by hydrothermal alteration (muscovitization and/or albitization), each of the granite suites from the CB complex displays short but well-defined chemical and mineralogical evolution trends for major and trace elements, with increasing Si contents, decrease in Fe, Mg, Ca, REE, Zr and of the Mg/(Mg+Fe) ratios of the biotite and primary muscovite, while alkali contents remain almost constant. Such trends may be related to a crystal fractionation process that occurred within each of the three magmas during their emplacement (Almeida, 1994).

Isotope geochemistry and geochronology

A U-Pb geochronological study was carried out on three zircon fractions and on one fraction of monazite for the CB pluton (Almeida et al., 1998). The U-Pb analytical points define a very good reverse discordia (MSWD=0.15) with a lower intercept at 311±1 Ma, with monazite almost concordant. This age is interpreted as the minimum emplacement age of the CB pluton and is in good agreement with a Middle to Upper Pennsylvanian age (305-316 Ma), suggested for the D3 Hercynian tectonic phase according to the geological setting. The reverse discordia presenting an upper intercept at 1207±8 Ma reveals the presence of an inherited Pb component of Proterozoic age.

$(^{87}Sr/^{86}Sr)_i$ and ε_{Nd} ratios calculated at 311 Ma indicate that the three granite series of the CB massif, despite some variations, are grouped in different ranges, respectively: 0.7101-0.7112 and –8.7 for G'f, 0.7142-0.7152 and –10.6 for G'm and 0.7177-0.7205 and –16.4 for G'g. The different ranges together with the high values of $(^{87}Sr/^{86}Sr)_i$ and the very low negative values of ε_{Nd} suggest that the massif is formed by the association of three independent granite series.

METALLOGENIC SPECIALIZATION

The Sn, Li and W contents of the CB granites fall within the ranges 8-68 ppm, 32-482 ppm and 1.3-16 ppm, respectively (Almeida, 1994). These values are higher than the average values assumed for normal granites (3, 40 and 1.5 ppm, respectively) and can ascribe the CB granite complex as "specialized" if compared with the data proposed by Tischendorf (1974,1977) and Tischendorf *et al*. (1972). Table 1 summarizes the range of variation of Sn, Li, W, F and Au in samples of the three granite types of CB complex, as well as the respective K/Rb and Mg/Ti ratios which are recognized as indicators of metallogenic specialization.

TABLE 1. Content variation of Sn, Li, W, F and Au, as well as the range of K/Rb and Mg/Ti ratios of least altered, albitized (alb) and muscovitized (musc) granite samples of the Cabeceiras de Basto complex

	G'f	G'f alb.	G'f musc.	G'm	G'm alb.	G'm musc.	G'g	G'g alb.	G'g musc.
ppm									
Sn	8 - 38	21 - 51	10 - 66	19 - 40	17 - 46	29 - 47	17 - 68	27 - 44	13 - 16
Li	74 - 482	225 - 322	94 - 220	32 - 345	117 - 267	130 - 395	113 - 433	112 - 442	121 - 195
W	2 - 4	4 - 10	1 - 4	3 - 8	3 - 4	3 - 8	2 - 16	4 - 14	3 - 4
F (%)	0,08 - 0,28	0,17 - 0,30	0,08 - 0,20	0,09 - 0,20	0,13 - 0,17	0,11 - 0,14	0,11 - 0,30	0,20 - 0,29	0,09 - 0,17
Au (ppb)	< 2 - 4	< 2	< 2 - 9	< 2 - 16	5 - 7	5 - 17	< 2 - 16	7	-
K/Rb	88 - 115	67 - 93	96 - 125	88 - 137	84 - 117	76 - 116	64 - 135	59 - 87	99 - 113
Mg/Ti	0,6 - 2,3	1,0 - 6,5	0,7 - 2,5	0,9 - 1,9	1,4 - 3,7	0,4 - 2,1	0,8 - 1,9	1,0 - 2,6	0,7 - 1,5

Li analyses carried out in the biotite of the three granite types, G'f, G'm and G'g, from the CB complex yielded, respectively, the following range of values: 2370-3890 ppm, 780-1360 ppm and 1160-1520 ppm. The behaviour of Li, Sn, W and F in the least altered samples with the differentiation parameter B=Fe+Mg+Ti, proportional to the number of millications in 100 g of rock, illustrates the role of the primary magmatic evolution in the concentration of such elements in the granites from fine to coarse porphyritic granite types, except for Li in G'f granite series (Fig. 1). The behaviour of Li in the fine-grained G'f type, decreasing with B parameter, suggests that biotite is the main carrier for Li in this granite, accordingly with the primary magmatic evolution. The trend exhibited by the primary evolution is affected by the alteration processes (Fig. 1). The albitization of feldspars promotes a more regular correlation with Sn in the three CB granite types, whereas muscovitization seems to induce some dispersion.

Although there are no known gold mineralizations spatially related with the CB two-mica granite complex the Au content, ranging from 2 to 17 ppb, deserve a brief comment. The higher Au contents occur in the medium and coarse-grained granites, but no clear relationship with the magmatic evolution, represented by the decreasing of B parameter for the non-altered samples, or with the F contents, both for non altered and the late-magmatic processes, can be drawn, although there seems to be a slight variation concerning the coarse grain granite type. These observations indicate processes probably independent of the granite evolution, as far as the genesis of gold mineralization is concerned (Almeida *et al*., 2002).

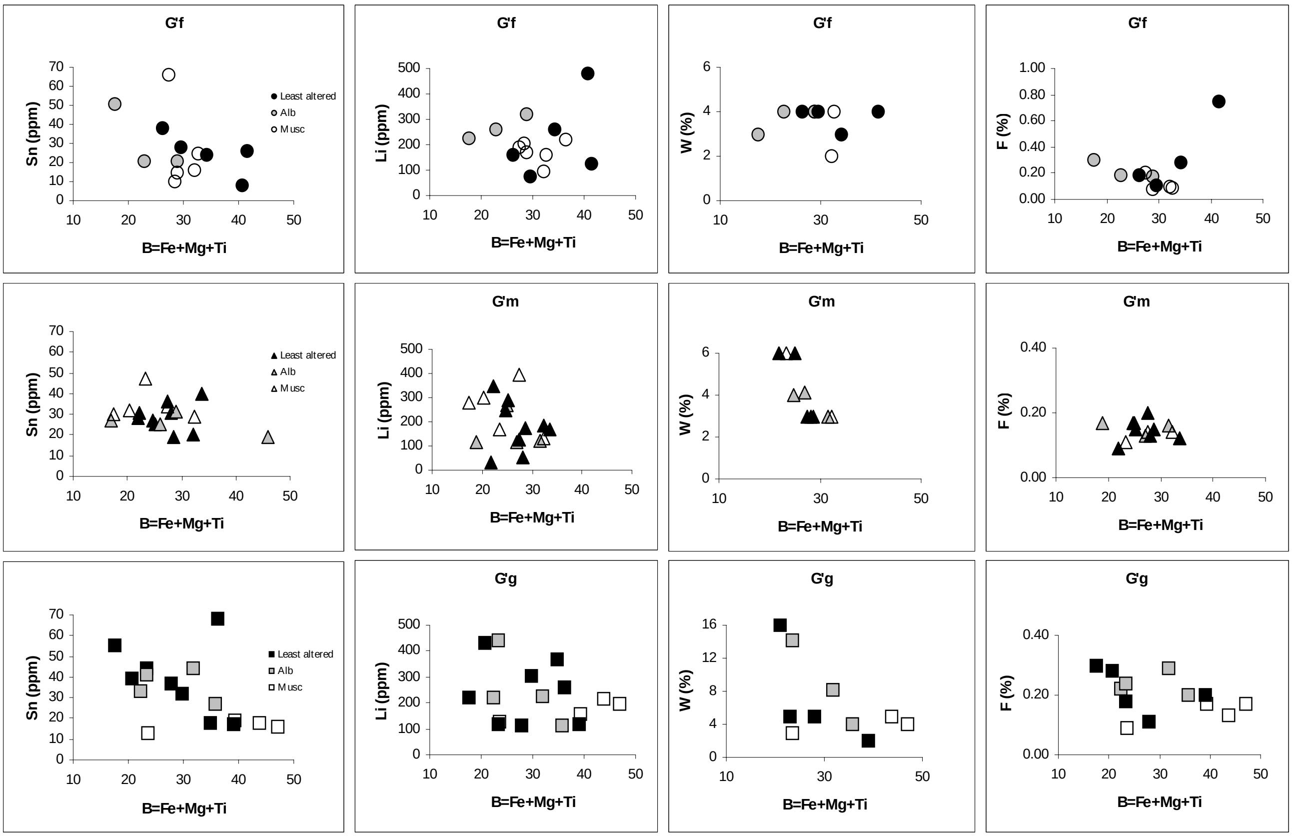

FIGURE 1. Behaviour of Sn, Li, W and F with the B parameter, both in the least altered and in the albitized (Alb) and muscovitized (Musc) samples

The comparative study of the behaviour of Li, Sn and W with F contents shows a positive correlation both in the least altered samples and in those affected by albitization of the feldspars and muscovitization of plagioclase and biotite (Fig. 2). According to the relatively regular behaviour of Sn, Li and W with F it is suggested that F may have been a vehicle for these elements.

Calculations of log fH_2O/fHf and log fO_2 in biotite of the CB two-mica granites yielded respectively 3.5 and –16 (Almeida, 1994), values that are very close to those calculated for similar two-mica granites, associated with Sn,W mineralisations in northern Portugal (*e.g.*, Neiva, 1983; Dias, 1987).

DISCUSSION AND CONCLUSION

The Li, Sn and W contents analysed in the three granite series of the CB complex (G'f, G'm and G'g) confer a specialized character to the massif.

A fractional crystallisation process during the magmatic differentiation seems to have played the main role in the concentration mechanism of the three trace elements (with the exception of Li in the fine grained series).

The positive behaviour of F in relation with Li, Sn and W, both in granites and in lepidolite-bearing pegmatites, suggests that F could have been the vehicle of those elements, particularly of Sn.

The late-magmatic and hydrothermal processes seem to have enhanced the primary evolution performance. The albitization plays an important role in Sn and , to a lesser extent, in Li concentration, whereas the muscovitization of plagioclase seems to promote the W increasing.

Geological and geochemical studies carried out in Barroso-Alvão area suggest that Li-bearing aplites and pegmatites may be spatial and genetically related with the peraluminous two-mica granite complex of Cabeceiras de Basto. The scarce presence of ambligonite and Li-rich micas, in opposition to the abundant spodumene occurrence, puts into evidence the low F activity during fractional crystallisation (Lima, 2000).

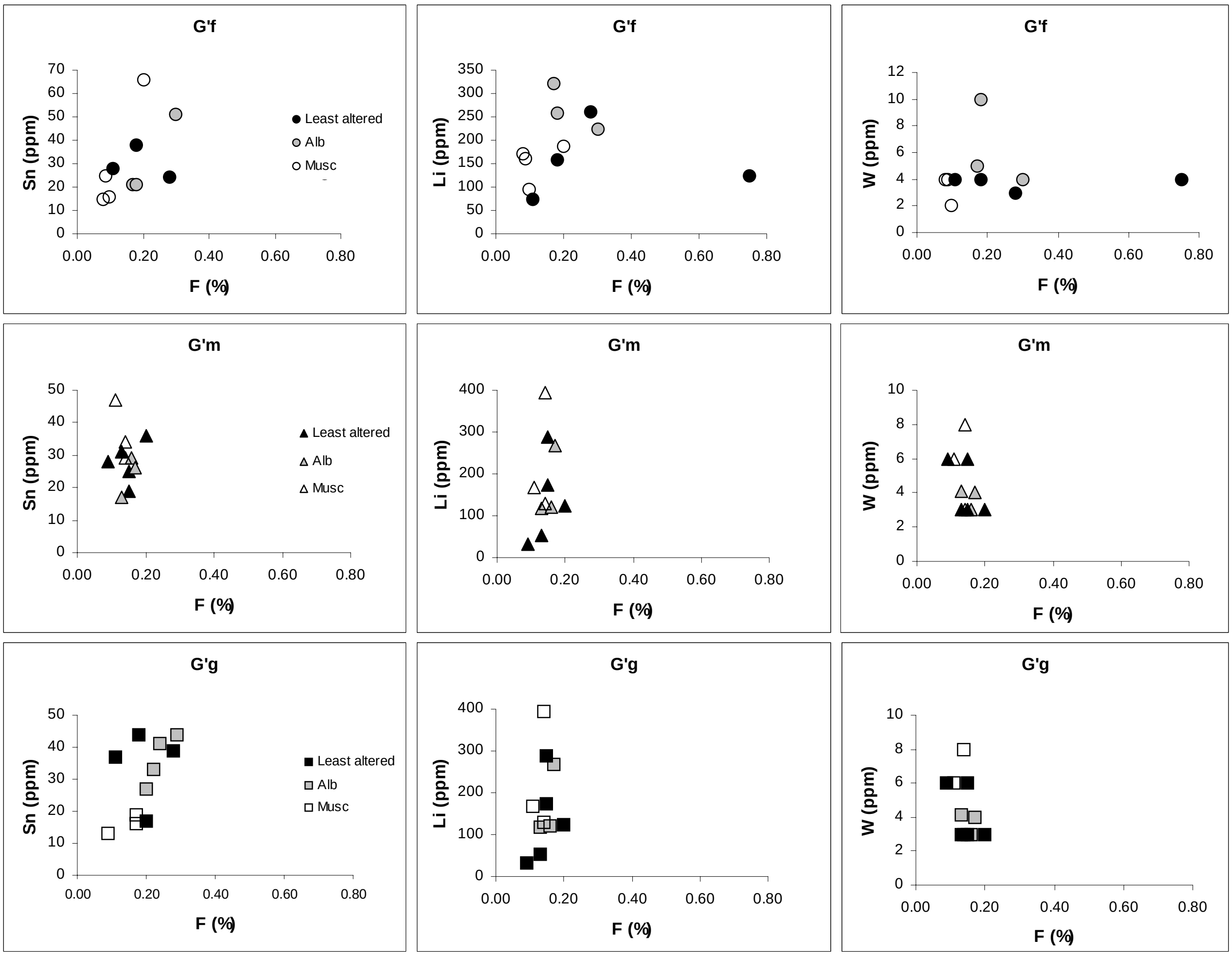

FIGURE 2. Behaviour of Sn, Li and W with F, both in the least altered and in the albitized (Alb) and muscovitized (Musc) samples

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PEGMATITE-APLITE VEINS OF BARROSO-ALVÃO FIELD. LITHOSTRATIGRAPHY AND METAMORPHISM OF HOST ROCKS

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LITHOSTRATIGRAPHY AND STRUCTURE

Regional context

The metasedimentary host-rocks of Barroso-Alvão aplitopegmatitic field (Charoy et al., 1992; Charoy et al., 2001; Lima, A., 2000) are pelitic, semi–pelitic and black-pelitic rocks of upper ordovician to lower devonian age. These rocks are intruded by sin-tectonic, two-micas granites, namely the Cabeceira de Basto Massif and the Barroso Massif, (CBM and BM) (Geological Map of Portugal, scale 1/200 000, sheet 2; Geological Map of Portugal, scale 1/50 000, sheet 6C; Geological Map of Portugal, scale 1/50 000, sheet 6D). In the SE sector of the Barroso-Alvão aplitopegmatitic field the post-tectonic biotitic granitic massif of Vila Pouca de Aguiar (VPAM) outcrops (Fig. 1).

The metasedimentary sequence belongs to the parautochthonous nappe of the Galiza - Trás-os-Montes Zone (GTMZ), a geotectonic zone of the Iberian Variscan Belt, characterized by the overthrust of allochthonous nappes over the parautochthonous sequences, that are similar to the autothonous sequences from the Central Iberian Zone (CIZ), but with an imbricate internal structure, developed during the tangential D_2 phase (Ribeiro, A., 1974).

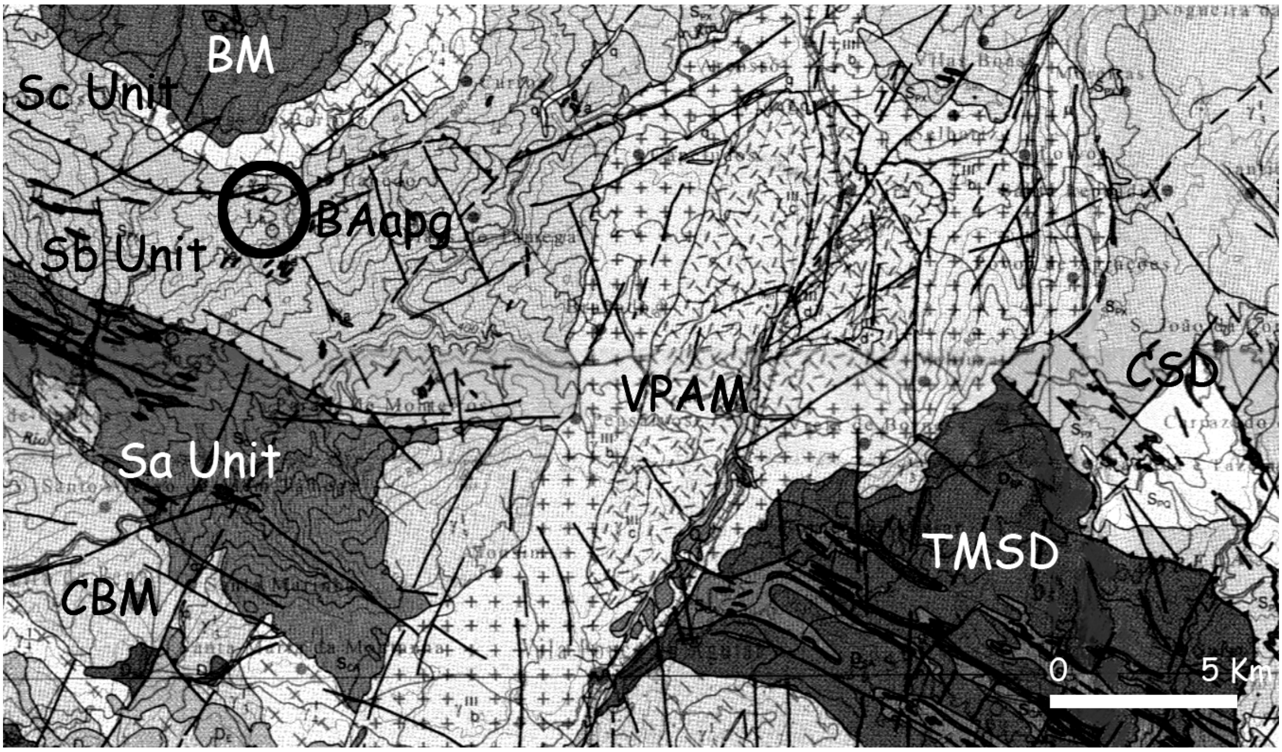

FIGURE 1. Geological map of the Barroso-Alvão sector. Extract of the Geological Map of Portugal, scale 1/200000, sheet 2. (CBM-Cabeceira de Basto Massif; BM-Barroso Massif; VPAM – Vila Pouca de Aguiar Massif; BAapg - Barroso-Alvão aplitopegmatitic field; TMSD - Três Minas Structural Domain; CSD - Carrazedo Structural Domain.

The parautochthonous sequence is subdivided in the Lower Parautochthonous or Três Minas Structural Domain (TMSD) and the Upper Parautochthonous or Carrazedo Structural Domain (CSD) (Ribeiro, M.A., 1998, Rodrigues et al., 2005).

The lithologies of TMSD are similar to the autochthonous Douro Inferior Domain of the Central CIZ, either in lithostratigraphic either in structural feactures (Ribeiro, M.A., & Noronha, 1997; Ribeiro, M.A., 1998; Ribeiro, M.A. et al., 2003). TMSD is composed by two lithostratigraphic units, both well correlated with the autocthonous units. The basal unit, designed as Fragas Negras Unit (SFN), has an organic rich lithology intercalated with black carbonate layers. The upper unit – Unidade de Curros (DCu) has a pelitic lithology. The ensemble of SFN and DCu corresponds to the Sa Unit (fig. 1) (Ribeiro, M.A. & Noronha, 1997; Ribeiro et al., 2000).

The lithologies of CSD are mostly represented by quartz-feldspatic schists, with an internal tectonic imbrication and well correlated with the eastern GTMZ area (Ribeiro, A., 1974, Farias et al., 1987).

The paleogeographic interpretation for the Parautochthonous Domain of the GTMZ points out to a peri-Gondwanic margin deposition, similar to the autochthonous sequence of CIZ (Ábalos et al., 2002), in a continental margin context that has suffered rifting processes during Cambric – Ordovician periods (Martinez Catalán et al., 1997; Raumer & Stampftli, 2000).

Combining paleogeographic and tecnonostratigraphic features with lithogeochemical data, and cross-cutting the correlation between the GTMZ and the CIZ sequences, it is possible to infer that:

(i) - The tectonostratigraphic units of the Douro Inferir and Peritransmontano group correspond to a variscian tectonic pile of sequences deposited on the Gondwanic continental margin, during the Precambric later Arcaic to the Lower Devonic. The Ordovician sequence is characterised by a plataform facies, more distal to the top, and with low grade of maturity. These facies are typical of a transition continental margin context (Ribeiro, M.A. & Noronha, 2001). Silurian sequences point out to an anoxic and confined environment (black shales and lidytes), followed by pelitic lithologies with signatures of basic and acid provenance in more oxygenated contexts, in an active continental margin. The upper parautochthonous domain (CSD) indicates deposition in context of evolution between a passive margin to an active one.

(ii) - The thrust between the sub-autochthonous units (TMSD) and the parautochthonous units (CSD) is the major thrust of the Parautochthonous of GTMZ. This thrust displaced the units of CSD rooted in a vulcanic arc context associated to the enclosure of the marginal ocean (“Rheic-Paleotethys”), over the units of the TMSD. This represents a sequence of more or less deep and confined basin in the Gondwanic margin, in a paleogeographic context closer to the autochthonous (Ribeiro, M.A., et al., 2003).

Local context

Tectonostratigraphic and lithogeochemical characterization of the metasedimentary host-rocks of Barroso-Alvão aplitopegmatitic field (Ribeiro, M.A., et al, 2000) allowed to individualize three lithostratigraphic units in the imbricate metasedimentarv sequence:

- Sa unit belongs to TMSD and is formed by phyllites and micaschists interlayered with black schists, lidytes and some quartzphyllites and calcsilicated rocks;
- Sb unit belongs to CSD and is constituted by quartzites and quartz-phyllites interlayered with phyllites and some lidytes and black schists, but in less proportion than the previous unit;
- Sc unit, also belonging to CSD, is characterized by a relatively monotonous sequence of phyllites, micaschists and quartzgrauvaque with rare calcsilicated rocks. Although rare, these rocks are more abundant than in the previous units.

Structure

The regional structure is mostly characterised by N120º, vertical axial plane folds formed during the last variscan ductil deformation phase (D3).

In the TMSD, with pelitic lithologies, the sub-horizontal shear cleavage S_2 is not present, and the crenulation cleavage S_3 is well marked. The S_1 foliation is parallel to the stratification ($S_1//S_0$). The D_3 phase produced a local strong penetrative crenulation cleavage (S_3), preferentially associated with the ductile shear zones (Noronha et al., 1981).

In the CSD, the foliation S_1 is preserved in microlithons defined by the main foliation S_2, parallel to the stratification ($S_2//S_0$). The S_2 foliation is a sub-horizontal shear cleavage that was locally verticalized during the later D_3 phase. This later phase was responsible for the formation of a local crenulation cleavage S_3, developed only in the more pelitic lithologies.

METAMORPHISM

The geology of Western Trás-os-Montes is marked by a major NNE-SSW variscan fault, known as Verin-Régua-Penacova fault or simply Régua-Verin fault. This fault was nucleated in the D_3 variscan phase and afterwards was reactivated (Baptista, 1998).

As a consequence of this regional fault, two distinguished crustal levels outcrop in Vila Pouca de Aguiar region (Western Trás-os-Montes), with different metamorphic and magmatic feactures: the deep level corresponds to the western block and the shallow level to the eastern block.

Eastern block

In eastern block the orogenic metamorphism was monocíclic and prograde PT clockwise sense, with a sin-D_2 barometric peak, and a later thermal peak, associated with the ascent and instalment of the sintectonic two mica granites, already in uplift and decompression conditions.

In TMSD the isogrades of andalusite and of biotite are parallel and very close to the contact of the sintectonic two mica granite of the Vila Real Massif. In the other sectors of TMSD the metamorphic conditions do not exceed the chlorite zone.

In the full extent of the CSD the biotite zone represents the metamorphic conditions. The relationship between blastesis and deformation confirm that the regional thermal peak is post- D_2 to sin-D_3 in both structural domains.

The thrust between CSD and TMSD is not responsible by the metamorphic leap, because the climax of the thermal conditions was posterior to the tectonic imbrication. Instead, the leap in the the post-cinematic metamorphic features has either a structural either a lithological control.

During the D_1 and D_2 phases the metamorphism occurred in prograde conditions until the barometric peak at T=350 to 450ºC and P= 350 to 400MPa (Ribeiro, M.A., 1998, Ribeiro, M.A. et al, 2000) (Fig. 2). In CSD the D_2 tangential phase was responsible by a strong crustal thickness accompanied by tectonic overpressure, resulting in a well-defined metamorphic differentiation that generated a sub-horizontal regional shear cleavage. In TMSD this barometric peak is not well evident (Ribeiro, M.A., et al, 2000). Castro et al. (2002) refers that in the Moncorvo - Vila Real antiform the Barroviano episode is not represented, due to the absence of sufficient crustal thickness. This interpretation can be applied to the absence of barometric peak in TMSD.

In both domain the thermal peak is ante- to sin-D_3 and occurred in maximum conditions of T = 500 to 550ºC and P=300 to 350MPa.

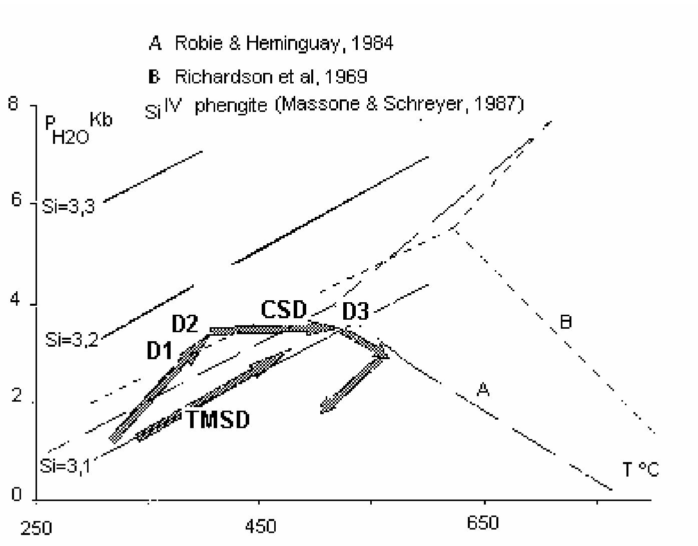

FIGURE 2. PTt metamorphism path in Western Trás-os-Montes.

Western block

This block corresponds to the sector where the Barroso-Alvão field is located. A prograde orogenic metamorphism is marked, in conditions of medium to low pressure and high temperature (MP-HT to LP-HT), resulting in the definition of isogrades parallel to the sintectonic granite massifs (Noronha & Ribeiro, M.L., 1983, Noronha, 1983; Ribeiro, 2000, Ribeiro et al, 2000). Near the CBM, the isogrades of the regional metamorphism are parallel either to igneous contacts either to lithostratigraphics contacts. These isogrades result from the ante- to sin-D_3 regional thermal peak, subsequent to a prograde dinamothermal evolution. This evolution is expressed by the occurrence of staurolite and andalusite I, prior to cordierite and andalusite II. In the western block the petrographic studies were focussed on different lithologies of the metasedimentary host-rocks of the aplitopegmatite fields, such as micaschists, quartzphyllites and phyllites, belonging to the three lithoestratigraphic units: Sa, Sb and Sc units. A special attention was taken on the relationship between the blastesis and the deformation. The following mineralogical associations were defined:

1 - in quartzphyllites and micashists close to aplite-pegmatite veins:

Qz+Ms+Bt ±Staur±And I±Cord±And II±Gr±±Ch Turm

2 – in quartzphyllites and phyllites far from the pegmatite veins:

Qz+Ms+Bt±Ch or Ms+Qz+Bt±Ch.

The microstructures present in the quartzphyllites show a metamorphic compositional layering, with Q and M domains parallel to the S_0 (Ramos, 2003) and corresponding to the S_1/S_2 (Fig. 3A). Sometimes, mostly in the most pelitic lithologies, S_1/S_2 is deformed by D_3 phase, accompanied by the development of an S_3 crenulation cleavage (Fig. 3B). The samples close to the aplitepegmatitic veins or quartz veins show a decussated textural tendency of the phyllossilicates (Fig. 4A) and the development of aluminossilicate porphyroblasts represented by andalusite II (Fig. 4B), and rarely silimanite. The porphyroblast of cordierite, garnet (Fig. 4C) and biotite are also frequent. All of this porphyroblast are sin- a post-D_3 and some are strictly related to the presence of quartz veinlets (Fig.4D). That represents a post-cinematic and local hydrothermal metamorphism. The microstructures present in the quartzphyllites show a metamorphic compositional layering, with Q and M domains parallel to the S_0 (Ramos, 2003) and corresponding to the S_1/S_2 (Fig. 3A). Sometimes, mostly in the most pelitic lithologies, S_1/S_2 is deformed by D_3 phase, accompanied by the development of an S_3 crenulation cleavage (Fig. 3B).

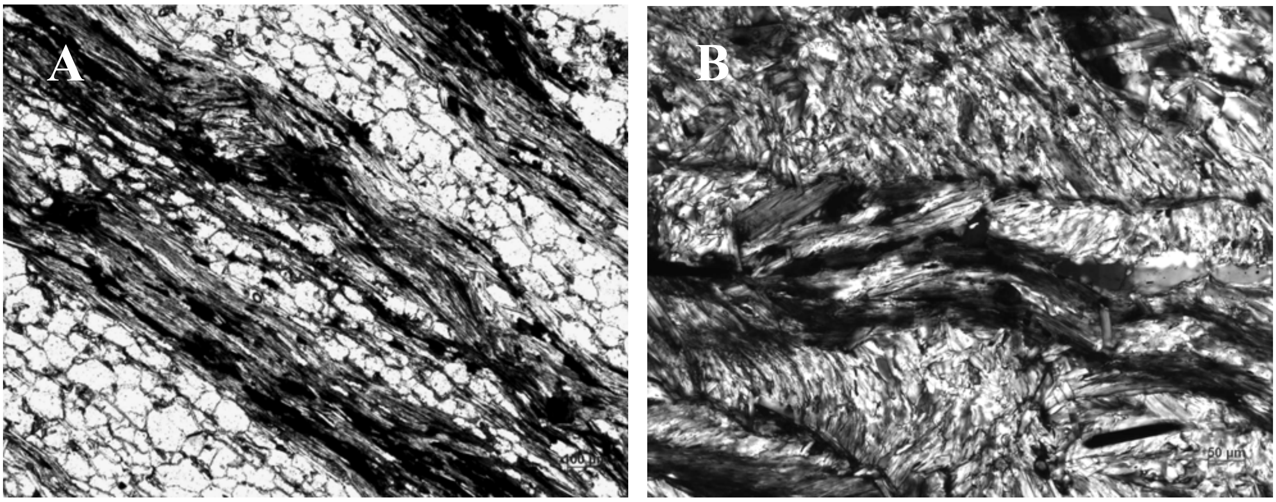

FIGURE 3. A – Metamorphic compositional layering (Q and M domains) parallel to S1/S2. (5×, N//); B – S3 crenulation cleavage.

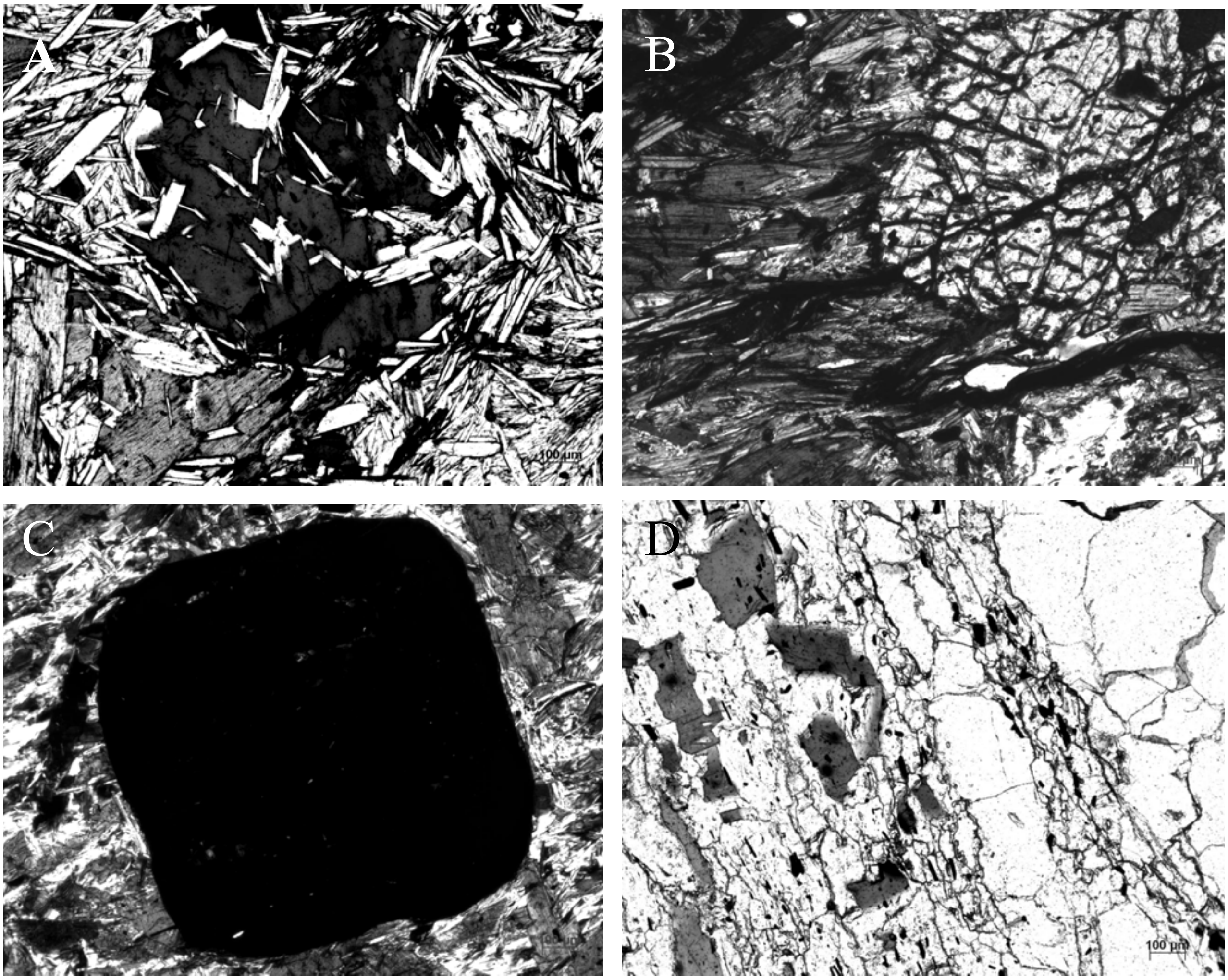

FIGURE 4. A- Decussated texture of phyllossilicates, muscovite associated with a biotite porphyroblast. B - Post-kinematic andalusite. C - Post-kinematic garnet associated with decussated texture of phylossilicates. D - Post-kinematic poicilitic andalusite with Si parallel and continuous with Se (S3). The andalusite has biotite and quartz inclusions and this association is frequent in the contact with the quartz veinlets.

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FREGENEDA-ALMENDRA AREA
LOCALITIES 2 AND 3

LOCALITY NO. 2, BAJOCA MINE, ALMENDRA, PORTUGAL.

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INTRODUCTION

Located 4 Km to the W of Almendra (V. N. de Foz-Côa, Guarda), on the limit of Alto Douro and Beira Alta regions, the Bajoca open-pit mine is actually the biggest feldspatic exploitation, for the ceramic and glass industry. Since 1996, mining rights belong to FELMICA Minerais Industrias, S. A., although mining activity backs to the 50's of the 20^{th} century, with exploitation of cassiterite and columbo-tantalite.

Almendra region is recognised for a great number of geological resources. Sn, W and Li mineralisation are an example of these resources evidencing the metalogenetic potential of this region. Previous studies refer pegmatite-aplite veins with lepidolite as the major source of lithium (Charoy & Noronha, 1999) but further work proved that petalite is also a common mineral (Lima et al., 2003, Almeida, 2003, Vieira et al., 2007) as well as spodumene (Roda et al., 2007, Vieira et al., 2007, submitted).

The area is surrounded by highly evolved granitoids. Favourable metalogenic indicators point out the Hercynian Mêda-Penedono-Lumbrales leucogranitic Complex (Figure 1) (Carnicero, 1981; Ferreira et al., 1987) as a possible source for such mineralisation. A similar situation is described by Roda (1993) and Roda et al. (1999) at the Eastern part of the Fregeneda-Almendra pegmatitic field, in the area of Fregeneda (Salamanca, Spain) with the occurrence of pegmatite veins enriched in rare elements, such as Li, Sn, Rb , Nb>Ta, B and P.

GEOLOGICAL SETTING

Bajoca pegmatite-aplite vein is one of the several bodies that the Fregeneda-Almendra Pegmatitic Field comprises (Roda et al., 2007). This field is located in the western part of the Iberian Peninsula, in the Hercynian Belt, Central-Iberian Zone (Julivert et al., 1974).

The country rock of this region is of Precambrian to Upper Cambrian age and belongs to the low-grade metamorphic "Schist-Metagraywacke Complex" (CXG). CXG consist of an alternation of quartzites, graywackes, schists and pelites, namely the Pinhão (Pi) and Rio Pinhão (Ri) formations, but also in the allochthonous Desejosa (De) formation, and on the autochthonous Bateiras and Ervedosa do Douro formations (Silva & Ribeiro, 1991, 1994) (Figure 1).

As it is possible to see in the Figure 1 geological map, the Almendra region is bordered in the south by the orogenic Mêda-Penedono-Lumbrales Granitic Complex. These are syn-F_3 Hercynian granites, heterogeneous, fine- to medium-grained, two-mica leucogranites (Ferreira et al., 1987; Lopez-Plaza & Carnicero, 1987; Silva & Ribeiro, 1991 & 1994). The Lumbrales granite, according to Rb-Sr isotopic dating, has ages around 300 ± 8 M.a. (Garcia Garzón & Locutura, 1981). They are highly evolved granites and metalogenic specialised, namely with respect to rare-element mineralization, according to criteria defined by Černý (1991). They are peraluminous (ASI and A/CNK>1), with >70% SiO_2, enriched in P_2O_5 (≈ 0,35), Rb, Li, Cs and Sn, and with lowest values of CaO (< 1%), FeO (t), MgO, Sr, Ba, Zr, Y and V (Gaspar, 1997; Vieira & Lima, 2005a, b).

Erro! Ligação inválida.

A first event of regional metamorphism took place prior to the third-Hercynian phase (F_3), generating prograde assemblages with garnet-staurolite-(kyanite). A second thermal metamorphic event, related with the syn-F_3 granite intrusion, generated an isograd overlapping, marked by minerals like andalusite-cordierite-sillimanite (Martinez et al., 1990). In the region, this metamorphism shows an isograd distribution increasing to S, parallel to the Mêda-Penedono-Lumbrales Granitic Complex contact, reaching locally the sillimanite (fibrolite) isograd (Carnicero, 1982; Silva & Ribeiro, 1991, 1994).

The isograds are controlled by tardi-Hercynian tectonic faults, well represented in the area by the NNE-SSW Vilariça fault. This fault divides the region into two unlevelled blocks, with sink of the central block, generating the designated Longroiva graben.

THE BAJOCA VEIN

The main vein, as we can see in the 1:1000 geological cartography (Fig. 2) and in the 1:500 longitudinal (I-J) and transversal (C-D) cross-sections (Fig. 3), has an extension extension of almost 700 meters and a variable thickness, ranging between few meters to more than 35 meters, with some thinner lateral ramifications attaining several meters of extension.

The main body is affected by the Barril Fault along NNE-SSW strike. Occurrence of clay minerals and Fe-oxides give evidence of its action in the pegmatitic body.

It is clearly intrusive in the metassedimentary Schist-Metagraywacke Complex, Pinhão (Pi) formation, showing a general orientation N010º with dip variations between 30º and 45º W. The host country rocks exhibit a turbiditic nature, constituted by metagraywacke and green-schist alternations, with a characteristic decimetric rhythmicity. They are affected by a regional green-schist metamorphism and on the vicinity of the pegmatitic body it is possible to find spotted schist, due to contact metamorphism (Silva & Ribeiro, 1994).

Mineralogy

According to Almeida (2003) and Lima et al., (2003), the main mineralogical association is simple and corresponds to a granitic composition.

The pegmatitic facies is basically: 1) big euhedral to subhedral K-feldspar and Albite crystals, forming occasionally crystalline aggregates; 2) subhedral to anhedral petalite crystalline aggregates; and, 3) small rounded quartz grains, frequently as crystalline aggregates. The muscovite, sometimes in centimetric crystals, is scarce. As accessory minerals it is possible to find montebrasite, Fe-Mn phosphates and apatite. Mineralization of Sn as cassiterite occurs in the greisens zones.

The aplitic mineralogy it is mainly small grains of albite with minor quantities of quartz and muscovite.

By sight observation, petalite is microcrystalline but appears aggregated in big masses, very fresh and white. However, sometimes it is possible to distinguish centimetric crystals, with perfect {001} cleavage. Under the microscope petalite lamellar twin planes (001) are common and polarises in silverplated colours. Petalite occurs as: i) subhedral to anhedral centimetric crystals; and, ii) irregular millimetric crystals, with rounded inclusions of quartz. Until the moment the isochemical passage Petalite to Spodumene+Quartz described by London (1984) was not observed.

Petalite is not homogeneous distributed throughout the body, being barren on the base and having a progressive enrichment in lithium to the top (Almeida, 2003; Lima et al., 2003; Bobos et al., 2004).

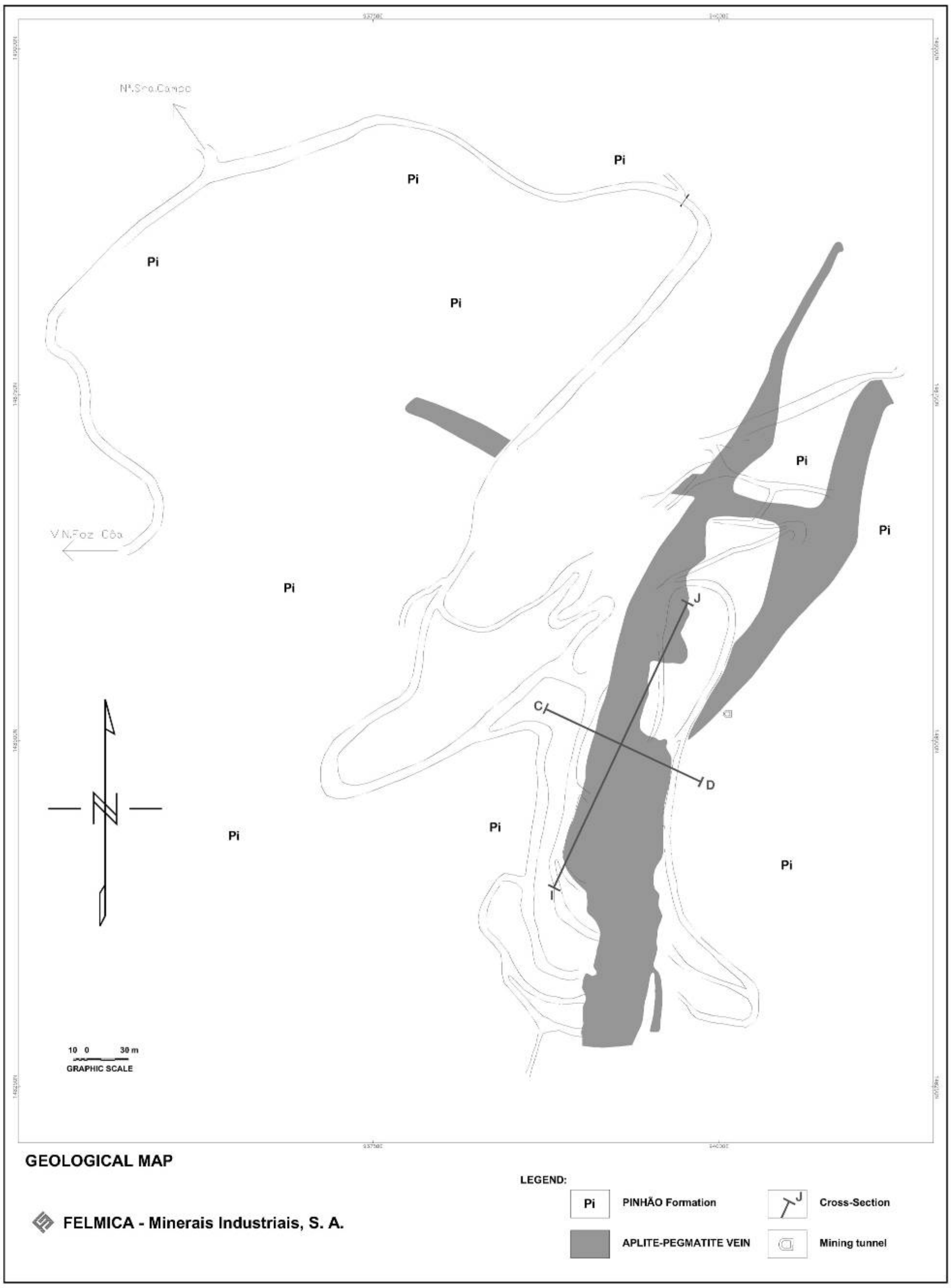

FIGURE 2. Geological Map of the Bajoca- Mine main body (Drawings gently ceded by Felmica, S. A.).

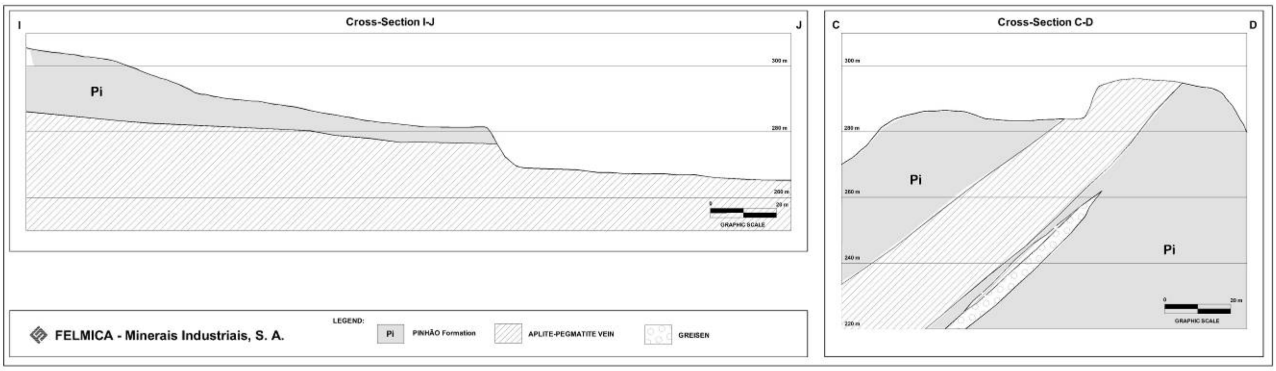

FIGURE 3 I-J longitudinal and C-D transversal cross-sections of the Bajoca Mine main body (Drawings gently ceded by Felmica – Minerais Industriais, S. A.).

Geochemistry

Geochemistry results from channel sampling and drill-cores show that the vein is clearly peraluminous (A/CNK>1), his value of SiO_2 is low and Na_2O content is higher than K_2O, reflecting the albite dominance above K-feldspar, more evident in the aplitic facies (Almeida, 2003; Lima et al., 2004; Vieira & Lima, 2005a, b).

Macro and microscopic observation give evidence of an inverse correlation between the Na_2O and Li values (Almeida, 2003).

Similar data was obtained by Charoy & Noronha (1999) to the lepidolite veins that outcrop to the North of the Bajoca Mine. According to the K/Rb ratio criteria defined by Černý (1992), lepidolite veins were considered more evolved than the Bajoca petalite-bearing vein as it is possible to see in the Table 1 (Lima et al., 2004).

TABLE 1. Bulk analysis average values for major and minor elements from the lepidolite-bearing[1] and petalite-bearing[2,3] Almendra veins.

	SiO_2 (%)	TiO_2	Al_2O_3	FeO (total)	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	F	Total	ASI	A/CNK	Na_2O/ K_2O	Li (ppm)	Rb (ppm)	K/Rb
[1]Lepidolite	69,57	nd	17,35	0,16	0,05	nd	0,3	5,05	3,25	0,73	1,33	97,79	1,47	1,4	1,55	4960	2570	10,51
[2]Petalite	69,56	0,01	16,09	0,13	0	0,04	0,63	5,78	2,93	0,91	0,07	96,15	1,27	1,16	1,97	2050	800	30,38
[3]Petalite	70,95	0,01	16,53	0,14	0	0,06	0,53	7	2,95	0,68	0,07	98,92	1,12	1,05	2,37	nd	nd	-

([1]Charoy & Noronha, 1999; [2],[3] Almeida, 2003); ([2]channel sampling; [3]drill-core); [(ASI=Al2O3/(Na2O+K2O) e A/CNK=Al2O3/ (CaO+Na2O+K2O)]

PETROGENETIC CONSIDERATIONS

According to Černý & Ercit (2005), Bajoca Mine vein can be classified as belonging to the LCT (Li, Cs, Ta) family, Rare-Element (REL) class, REL-Li subclass, Complex-type, Petalite sub-type. This kind of pegmatite-aplite veins points to P-T stability fields around ≈ 200-400 MPa and ≈ 500-600ºC, with the petalite equilibrium conditions ranging within high temperatures, but low-P ≈ 200-300 MPa (London, 1984).

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LOCALITY NO. 3: LEPIDOLITE-SPODUMENE-RICH AND CASSITERITE-RICH PEGMATITES FROM THE FELI OPEN-PIT, (LA FREGENEDA, SALAMANCA, SPAIN)

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INTRODUCTION

Pegmatites of the Fregeneda area, (Salamanca, Spain), show a zonal distribution, from barren to enrichment in Li, Sn, Rb, Nb>Ta, B and P. They intrude pre-Ordovician metasediments which were metamorphosed to sillimanite-zone conditions near the Lumbrales granite. Field, mineralogical and petrographic data show the following zonal sequence from the granite outward: (1) barren pegmatites with quartz, K-feldspar > albite, muscovite, tourmaline ± andalusite ± garnet; (2) intermediate pegmatites, characterized by the occurrence of montebrasite and Fe-Mn-Li phosphates; and (3) fertile pegmatites, with lepidolite, spodumene, cassiterite, columbite, albite > K-feldspar, montebrasite and bluish beryl. This pegmatitic field follows westwards in Portugal, in the Almendra area (Bajoca mine, Locality number 2).

Even if during this field-trip all these types of pegmatites will not be seen, it seems convenient to give some information about all of them, in order to better understand the geological context of the visited pegmatites.

At this moment, two mines remain on activity in the Fregeneda area. First, the old Feli open-pit, that was exploded for tin during several decades of the last century. It was closed in the year 1979 and reopened later, in 1997, this time for feldspars and lepidolite for the ceramic industry. The second mine, the Alberto open-pit, has been recently opened (2003), also for the ceramic industry. In both cases, mineralization is related with different types of rare-element pegmatites.

In the Feli open-pit two pretty different pegmatitic types outcrop. First, several cassiterite-bearing quartz-rich dikes were exploded, which form a stockwork in the hosting metasediments. These Sn-rich bodies are cut by a sub-vertical lepidolite-spodumene-bearing pegmatite, that in the lower zones of the open pit shows a thickness close to 15 m, whereas in the upper parts it branches out in a number of dykes.

GEOLOGICAL SETTING

Deformation and metamorphism

The Fregeneda area is located in the Hesperic Massif, in the western part of a narrow metamorphic belt, with an E-W trend. This belt, situated in northwestern Salamanca, is bordered by the Lumbrales granite to the South, and by the Saucelle granite to the NE (Fig. 1). Both granites and pegmatites intruded pre-Ordovician metasediments of the schist-metagraywacke complex (CEG). In this area, this complex comprises a sequence of quartzites, graywackes, schists and pelites, with abundant thin calc-silicate layers. These materials have undergone two main phases of Hercynian deformation, with late events of less intensity (Martínez Fernández, 1974). The deformation of the Lumbrales granite is attributed to the second phase of deformation, as well as a set of fractures striking N10˚E and dipping 75˚±5˚ to the East. The regional metamorphism is previous to the second phase of Hercynian deformation (Carnicero, 1982), and it is superimposed by a contact metamorphism. In the Fregeneda area, the metamorphism shows an isograd distribution parallel to the Lumbrales granite, locally reaching the sillimanite zone, whereas the biotite zone is the most extensive (Fig. 1).

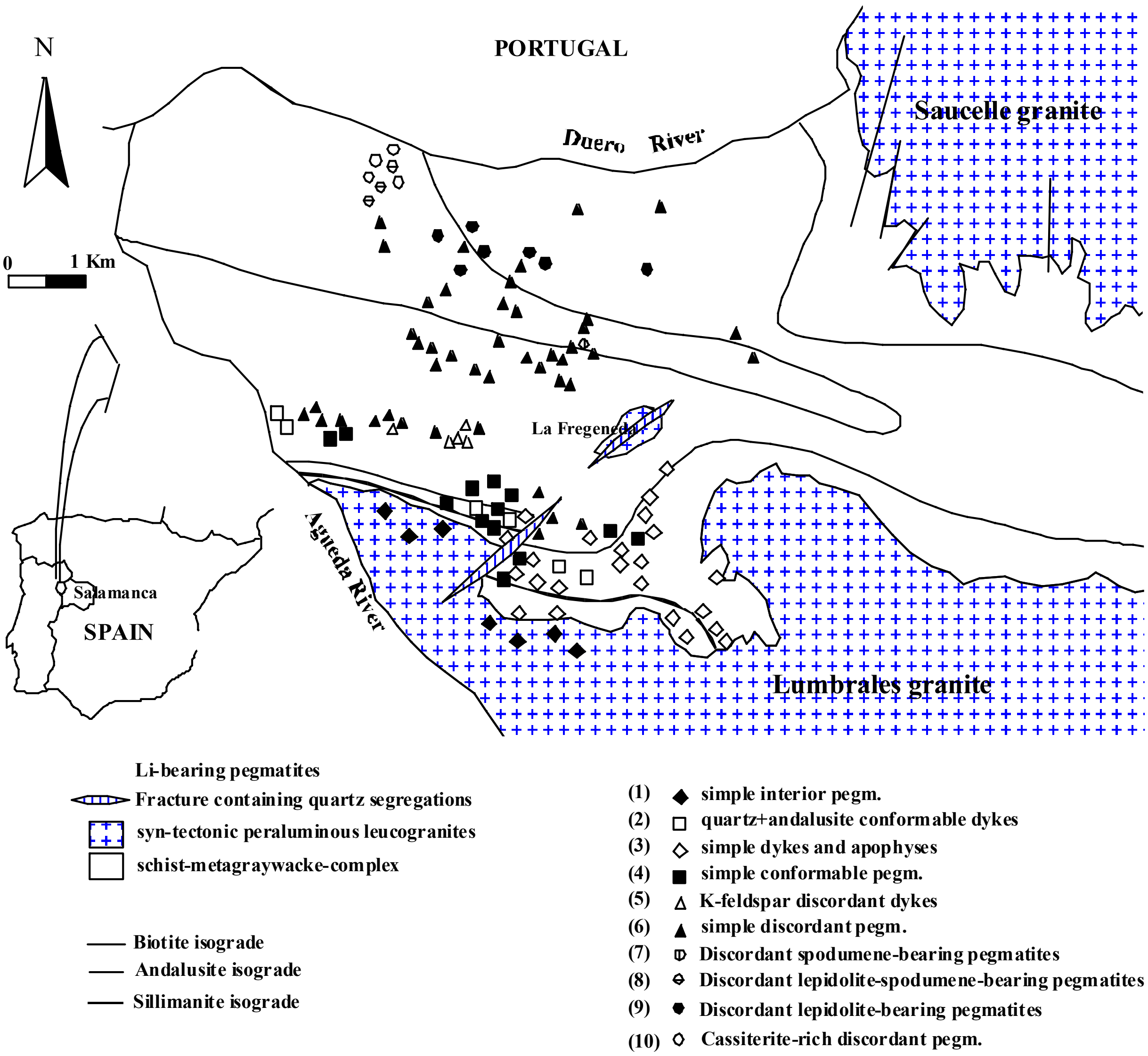


FIGURE 1. Geological map of the Fregeneda area and distribution of the pegmatite groups recognized (modified from Roda et al., 1999). (Pegmatite numbers as in the text).

Igneous rocks

A great diversity of granites crop out in the Fregeneda area. The most common group is that of the peraluminous leucogranites, to which the Lumbrales and the Saucelle granites belong (Fig. 1). Both are parautocthonous, heterogeneous, fine- to medium-grained two-mica granites (Carnicero, 1981) and, with regard to the Hercynian deformation, these plutons are included in the group of syntectonic massifs which have been affected by the third phase of Hercynian deformation (López Plaza and Carnicero, 1988; López Plaza and Martínez Catalán, 1988). The Lumbrales granite is part of the Meda-Penedono-Lumbrales granitic complex (Bea et al., 1988), with a Rb-Sr whole-rock isochron age of 300±8 m.y. (García Garzón and Locutura, 1981). In the border as well as in the inner zones of this body, it is noteworthy the presence of a migmatitic facies, mainly to the east of the Fregeneda area.

GENERAL GEOLOGY OF THE PEGMATITES OF THE FREGENEDA AREA

In the Fregeneda area several hundreds of pegmatitic bodies have been found. On the grounds of factors such as mineralogy, morphology, internal structure, and internal relationships, ten different types of pegmatites have been distinguished. The different pegmatite types display a degree of evolution which increases away from the Lumbrales granite. With increasing distance from this granite the types are (Roda, 1993; Roda et al., 1999, 2007), (Fig. 1) **(in black those visited during this field-trip)**:

i) Barren pegmatites

-(1) Intragranitic pegmatites

These are relatively abundant in the border zones of the Lumbrales granite. They consist of quartz, K-feldspar (orthoclase and microcline), muscovite, albite and schorl. These pegmatite dykes are narrow, and they lay obliquely to the granite lineation. Frequently, these pegmatites show a zoned internal structure, with a core of massive quartz and a border zone consisting of coarse-grained K-feldspar, albite and tourmaline.

-(2) Dykes composed mainly of quartz and andalusite

They include sparse muscovite, K-feldspar (orthoclase and microcline), schorl and chlorite. They show an E-W strike, and different dipping. These dykes conform to their host-rocks, showing a relevant deformation with boudinage structures.

-(3) Dykes and apophyses showing aplitic and pegmatitic facies

They consist of quartz, K-feldspar (orthoclase and microcline), muscovite and minor albite, biotite and schorl. Graphic textures occur locally in these bodies. Their shapes are greatly variable, ranging from irregular and bulbous masses to ellipsoidal, lens-like or turnip-shaped forms. Equally, their size is also variable, being a few square metres at the lower limit, up to 1 km^2 in the maximum observed dimension. The grain size varies abruptly within centimetres from aplitic to pegmatitic facies. They are located S-E of this area, near the Lumbrales granite.

-(4) Simple conformable pegmatites

They are mainly composed of quartz, K-feldspar (orthoclase and microcline), muscovite, albite, schorl and minor andalusite, chlorite, garnet, biotite, apatite and ferrocolumbite. The host rock frequently displays a strong tourmalinisation near the contact. These dykes show an appreciable deformation, with flow textures, boudinage, and "pinch and swell" structures. These pegmatites are located close to the Lumbrales granite.

ii) Intermediate pegmatites

-(5) Pegmatites mainly composed of K-feldspar (orthoclase and microcline)

Other phases that can be present are quartz, muscovite and pyrite. They are discordant to the host-rock, appearing near the contact with the Lumbrales granite. Their shape is clearly dyke-like, striking N170˚ to N10˚E and dipping close to vertical.

-(6) Simple discordant pegmatites

These dykes present the same strike and similar dipping to those of the previous group. In some cases they show a layered internal structure. They consist of quartz, K-feldspar (orthoclase and microcline), albite and muscovite. In the pegmatites nearest from the Lumbrales granite a complex association of Fe-Mn phosphate minerals appears, such as wyllieite, graftonite, ferrisicklerite, sarcopside, alluaudite, triplite and heterosite, whereas in the furthest pegmatites montebrasite may appear. K-feldspar can occur as coarse wedge-shaped crystals that grow perpendicular to the contacts with the host-rock and with their vertex pointing to the walls, which implies an oriented crystallization advancing from the margins of pegmatites inwards and a thermal gradient decreasing in the same direction. Situated in an area between 1 and 4 km to the north of the Lumbrales granite, this group is the most abundant.

iii) Rare-element pegmatites

-(7) Discordant spodumene-bearing pegmatites

Up to now, only one body belonging to this category is known in the Spanish part of this pegmatitic field, which is being mined for the ceramic industry in the Alberto open-pit. As the intermediate pegmatites, this dyke is nearly vertical, with a similar strike. An evident internal zonation is not observed. Thicknesses are variable between 4 m and ≈ 15 m. Mineralogy is simple, with feldspars, quartz and spodumene as main constituents; minor muscovite, montebrasite and petalite; and beryl, Fe-Mn phosphates, blue apatite and cassiterite as accessory minerals. They appear between 1 and 4 km north from the granite, near the biotite/chlorite isograde limit.

-(8) Discordant lepidolite-spodumene-bearing pegmatites,

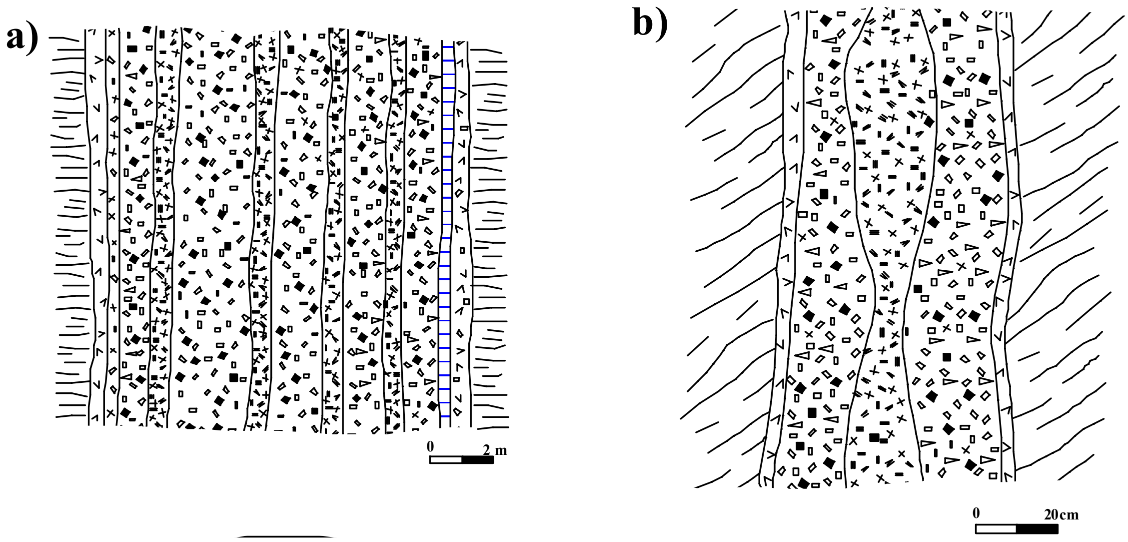
Their shape is clearly dyke-like, also striking N170˚ to N10˚E and dipping close to vertical. Their maximum width is near 15 m, but thicknesses under 3 m are the most common. These bodies frequently display a layered internal structure (Fig. 2), with quartz and Li-mica bands alternating with other bands consisting of albite and K-feldspar. Similarly to the simple discordant pegmatites (6), in these pegmatites K-feldspar can occur as coarse wedge-shaped crystals that grow perpendicular to the contacts with the host-rock, inside the bands. Main minerals are quartz, lepidolite, albite > K-feldspar and spodumene. Montebrasite and cassiterite are minor minerals; whereas bluish beryl, apatite, manganocolumbite, estannite and eucryptite are accessory minerals. Outcrops have only been identified in the Spanish part (Feli open-pit), between 4 and 4,5 km north from the granitic contact, near the chlorite/biotite isograde.

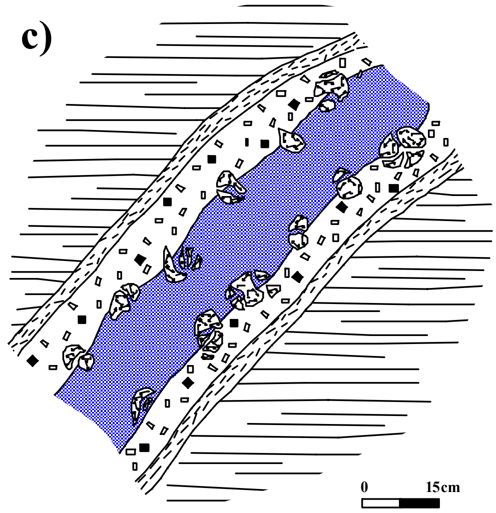
-(9) Discordant lepidolite-bearing pegmatites,

also with a layered internal structure, similar to that of the previous type. Thicknesses are usually < 3 m. Quartz, lepidolite and albite > K-feldspar are the main minerals, with montebrasite and cassiterite as subordinates. They appear between 2 and 4 km north from the granite, in the biotite and chlorite zones.

-(10) Quartz pegmatites with abundant cassiterite

Fine-grained muscovite, microcline, albite and ferrocolumbite are also present. Their shape is clearly dyke-like and, together with the lepidolite-spodumene bearing pegmatite of Feli open-pit, they form a stockwork hosted in the tourmalinized country-rock (Fig. 1). These dykes in some cases show internal zonation (Fig. 3), generally with a border zone mainly composed of muscovite oriented parallel to the contacts; an intermediate zone consisting of microcline and albite, where fine to coarse grains of cassiterite may occur; and a core composed of quartz. Their thickness is usually less than 50 cm, striking similarly to the other evolved pegmatites, but dipping 45˚ to 65˚ to the east. These dykes are folded with an important reduction in the vertical length. They appear in the north zone of the studied area.





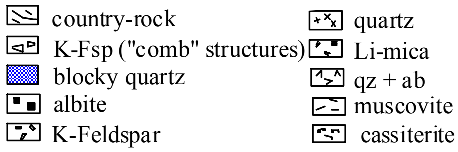


Fig. 2: Schematic section of some of the "evolved" pegmatites: a) lepidolite±spodumene bearing pegmatites (8 and 9 types) with layered internal structure; c) Lepidolite-bearing pegmatite with simple internal structure (9 type); and, d) Cassiterite-rich discordant pegmatite (type 10) (All from Roda et al., 1999).

MINERALOGY

Feldspars

The textures and relative modal proportion of the feldspars vary depending on the pegmatite type. The K-feldspar/plagioclase ratio decreases away from the Lumbrales granite, so that in the more evolved pegmatites albite is more common than K-feldspar. Perthitic intergrowths appear in all pegmatites but they are more abundant in the less evolved pegmatites relative to the Li and Sn-bearing ones. In the simple discordant pegmatites (6) and in the lepidolite-spodumene bodies (8), K-feldspar shows a typical comb-structured growth orientation. Myrmekitic plagioclase-quartz intergrowths are restricted to the most evolved pegmatites. Finally, in the Li-rich pegmatites, K-feldspar mantled by a cluster of plagioclase crystals is sometimes observed.

Although variations in the contents in major elements for K-feldspar have not been detected, there are significant differences in the trace element contents depending on the pegmatitic type. The feldspars associated with the lepidolite-bearing pegmatites exhibit the feldspars richest in Li, among the richest in Rb and Cs, one of the poorest in Ba and with the lowest K/Rb ratios (Roda *et al.*, 1993, Roda, 1999). With regard to the Sn-bearing pegmatites (10), their K/Rb ratio shows intermediate values, whereas their contents of Ba and Sr are the highest .

Micas

Chemical data reveal compositional variations in the micas, also depending on the pegmatite type. The contents of trace elements such as Sn, Li, F, Cs, Rb, etc., seem to increase away from the Lumbrales granite, whereas there is an overall trend of decreasing Ba contents and K/Rb ratio. Nevertheless, it is remarkable that in the case of micas associated with the tin-bearing pegmatites (10), their K/Rb ratio is intermediate, and one of the highest Ba content is found in such mica, as it happens with the K-feldspar associated with these dykes (Roda, 1993; Roda et al., 1995a; 1999).

Tourmaline

No tourmaline is found inside the evolved pegmatites. However, hosting metasediments exhibit frequently an intense tourmalinization, mainly in the proximities of the biggest bodies (Roda 1993, Roda et al., 1995b).

Phosphates

They appear as accesory minerals mainly in the simple discordant pegmatites (6), however, even if they are scarce, they are also present in the Li-rich pegmatites (7, 8 and 9). Ferrisicklerite, alluaudite, graftonite and montebrasite have been observed in the spodumene-rich pegmatites (7); whereas sicklerite, purpurite and montebrasite appear related to the lepidolite-rich pegmatites (8 and 9) (Roda, 1993; Roda et al, 1996).

Nb-Ta-Sn minerals

In the lepidolite-spodumene-rich pegmatites (8) manganocolumbite usually occurs as fine grained subhedral crystals, associated with cassiterite. Less commonly it appears as euhedral crystals (up to 1 cm in length) growing in a fine-grained matrix consisting of muscovite, quartz and plagioclase. In the Sn-rich pegmatites (10) ferrocolumbite is always associated with cassiterite, appearing as sub- to anhedral fine-grained crystals (Roda 1993, Roda et al., 1999).

The main Sn-bearing mineral found in these pegmatites is cassiterite. It appears in the Li-bearing dykes (7, 8 and 9), and mainly in the Sn-bearing pegmatites (10), where it was mined in the Feli open-pit. Cassiterite in Li-bearing pegmatites appears as fine-grained zoned crystals. In some cases it appears as euhedral crystals growing in a fine grained matrix consisting of muscovite, quartz and plagioclase. In other cases, it appears associated with quartz and other oxides and sulfides (manganocolumbite, stannite, sphalerite) showing subhedral habit. In both cases, cassiterite shows a chromatic zonation, being stronger the pleochroism of the crystals associated with other oxides and sulfides than that of the euhedral crystals.

The Sn-bearing dykes (10) are the richest in cassiterite. It appears as fine- to coarse-grained crystals (in some cases up to 7 cm across), associated with other oxides and sulfides (ferrocolumbite, stannite, sphalerite, chalcopyrite, molybdenite, galena). Commonly crystals are sub- to euhedral and frequently they are broken, with a "puzzle" texture. It shows the "knee" twin. A chromatic zonation is observed in many crystals, alternating the dark and pale ribbons.

Similar to the Nb-Ta minerals, there are also compositional differences between the cassiterites from the different types of pegmatites. Those from Sn-rich pegmatites (10) are the poorest in Ta_2O_5 (< 0.82 wt %) and the richest in Nb_22O_5 (up to 2.04 wt %); whereas those from the Li-bearing pegmatites are the richest in SnO_2 (> 97.05 wt %) and show the lowest values in Nb_2O_5+Ta_2O_5 (< 2.63 wt %). TiO_2 values are very low in general (< 0.37 wt %), but an overall trend of increasing TiO_2 from the border to the core has been observed. A relation between composition and color exists, with reddish bands richer in Nb, Ta and Fe, whereas pale bands are richer in Ti (Roda, 1993; Roda et al., 1999).

Beryl

Beautiful bluish crystals of beryl have been observed in the spodumene-bearing pegmatites (7) and in the lepidolite-spodumene-bearing pegmatites (8). Beryl crystals are in general up to six centimeter in length. In both cases, it appears as an accessory mineral.

CONCLUDING REMARKS

(1) In the Fregeneda area a rare-element pegmatite field occurs which shows enrichment in Li, Sn, Rb, Nb>Ta, B and P, and a regional zoning of different types of pegmatites is observed northwards from the Lumbrales granite. The following spatial sequence of pegmatite types can be observed from the granite outward: (1) barren pegmatites (pegmatite types 1, 2, 3 and 4) with a K, Al, Si, Na, B and P enrichment; (2) intermediate pegmatites (types 5 and 6), with a K, Na, Al, Si, P and Li enrichment; and (3) evolved pegmatites (pegmatite types 7, 8, 9 and 10), with a Li, Sn, Nb>Ta, P, and Rb enrichment.

(2) High values of the K/Rb ratio for K-feldspar and micas occur in the barren pegmatites (2 and 4), whereas lower values are characteristic of the more evolved pegmatites (7, 8 and 9). There is a zone with intermediate K/Rb values, where 1, 3, 5 and 6 types overlap. The content of lithophile elements, such as Li and Rb increase with the pegmatite evolution.

(3) The origin of the different pegmatite categories may account for three different paths of fractional crystallization of melts generated by the partial melting of a quartz-feldspathic rock, with a similar composition to that of the CEG. The fractional crystallization of a melt originated by high degrees of partial melting (>50%) would give rise to the Lumbrales granite, the intragranitic pegmatites (1), and the apophyses with aplitic and pegmatitic facies (3). The fractional crystallization of melts generated by lower degrees of partial melting would originate, on the one hand, the K-feldspar dykes (5), the simple discordant pegmatites (6) and the Li-bearing pegmatites (7, 8 and 9) and, on the other hand, the Sn-bearing dykes (10). Finally, the quartz-andalusite dykes (2), and the simple conformable pegmatites (4), would be pegmatitic segregations, earlier or contemporary with the formation of the Lumbrales granite (Roda, 1993, Roda et al., 1999).

(4) Although this model explains the formation of all the pegmatite population outcropping in the Fregeneda area, the influence of other processes cannot be rejected. Partial melting of a heterogeneous source, or equilibrium crystallization intervals, alternating with fractional crystallization, may lead to a similar distribution and characteristics to those shown in the Fregeneda's pegmatitic field. Moreover, studies on the internal evolution of individual lepidolite-bearing pegmatites in this field are in progress since the last year. One of the main aims of these studies is to understand the layered internal structure of such bodies, generally observed in all of them.

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GARCIRREY AREA (SALAMANCA)

LOCALITY 4

LOCALITY NO. 4: THE PHOSPHATES-RICH CAÑADA PEGMATITE (ALDEHUELA DE LA BÓVEDA, SALAMANCA, SPAIN)

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INTRODUCTION

Even if nowadays the outcrop of the Cañada pegmatite is not good anymore, we estimate that the visit to this open-pit is worth, as it is still possible to observe and collect interesting samples from its dumps. Two are the main features of this pegmatite, which made it singular and interesting to be visited. On the one hand, we must underline the unusual enrichment in Mg shown by the (Li)-Fe-Mn phosphates associated with the Cañada pegmatite, probably due to contamination from its hosting gabbro. This way, the Mg-richest ferrisicklerite and alluadite known up to now have been described from this locality (Roda et al., 2004). On the other hand, these phosphates appear in close relation with mafic silicates (such as biotite, garnet or tourmaline), which is not commonly observed in pegmatites. This way, phosphates from the Cañada pegmatite appear in centimeter-sized masses, in samples definitively beautiful under microscope, with different intergrowth textures not only among the phosphate phases themselves, but also among these phosphates and the mafic silicates.

GEOLOGICAL SETTING

The Cañada pegmatite is located in the mid-western part of the province of Salamanca, in the Central Iberian Massif (CIM). Hercynian granites are widespread in this area and can be divided into two main groups: (i) pre- to syntectonic, peraluminous, locally two-mica leucogranites; and (ii) undeformed granitoids, mainly subporphyritic, K-feldspar-rich granodiorites. The leucogranite intruded partly by the Cañada pegmatite, a pre- to syntectonic, two-mica, alkaline leucogranite, belongs to the first group. This leucogranite corresponds to a very evolved facies, containing garnet and tourmaline as common accessory minerals (Martín-Izard et al. 1992). Besides the granitic bodies, small stocks of mafic and ultramafic composition crop out throughout the region, and predate the granitoids with which they are associated spatially (Dpto. of Petrology, University of Salamanca, 1980). The Cañada pegmatite also intrudes partly into one of those pre- to syntectonic biotite-bearing gabbro bodies. The gabbro is rounded in outcrop with a diameter of ≈ 100 m, and is located as a very large enclave within the aforementioned leucogranite (Fig. 1) (Martín-Izard et al. 1992). The gabbro consists of biotite, hornblende, augite, and calcic plagioclase. Near the contact with the pegmatite, the gabbro shows extensive alteration, with albitization of plagioclases, and cloritization of ferromagnesian minerals (Roda et al., 2004).

The granitic plutons and the mafic and ultramafic rocks intruded Precambrian and Cambrian metasedimentary rocks of the Schist-Metagraywacke Complex (CEG). In the studied area, these rocks exhibit medium to high degrees of metamorphism, with assemblages containing biotite, sillimanite, staurolite, cordierite, feldspars, and muscovite (Martin-Izard et al. 1992). According to these authors, all these rocks have undergone two main phases of Hercynian deformation.

General Geology of the Pegmatite

The Cañada pegmatite strikes E-W and dips 60° N. It has a maximum width of 10 m in outcrop and a length of ≈ 70 m (Roda et al. 2004). The pegmatite displays clear deformation effects, e.g. undulatory extinction, subgrains in plagioclase and magniotriplite, bending and kinking in micas, foliated textures where micas wrap around garnet crystals, and granoblastic textures in some phosphates. It was mined for feldspar, and the open pit is located mainly in the gabbro-hosted part of the pegmatite. In this open pit, the pegmatite is apparently fairly homogeneous and unzoned, except for the phosphate phases. The pegmatite consists of quartz, plagioclase, K-feldspar, muscovite, and Fe-Mn-(Li-Mg) phosphates (Tables 1 and 2), with minor tourmaline, garnet, ferrocolumbite, cassiterite, and pyrite. Uraninite, Fe-Mn carbonates, corundum, ilmenite, and zircon occur as accessories (Roda et al., 2004).

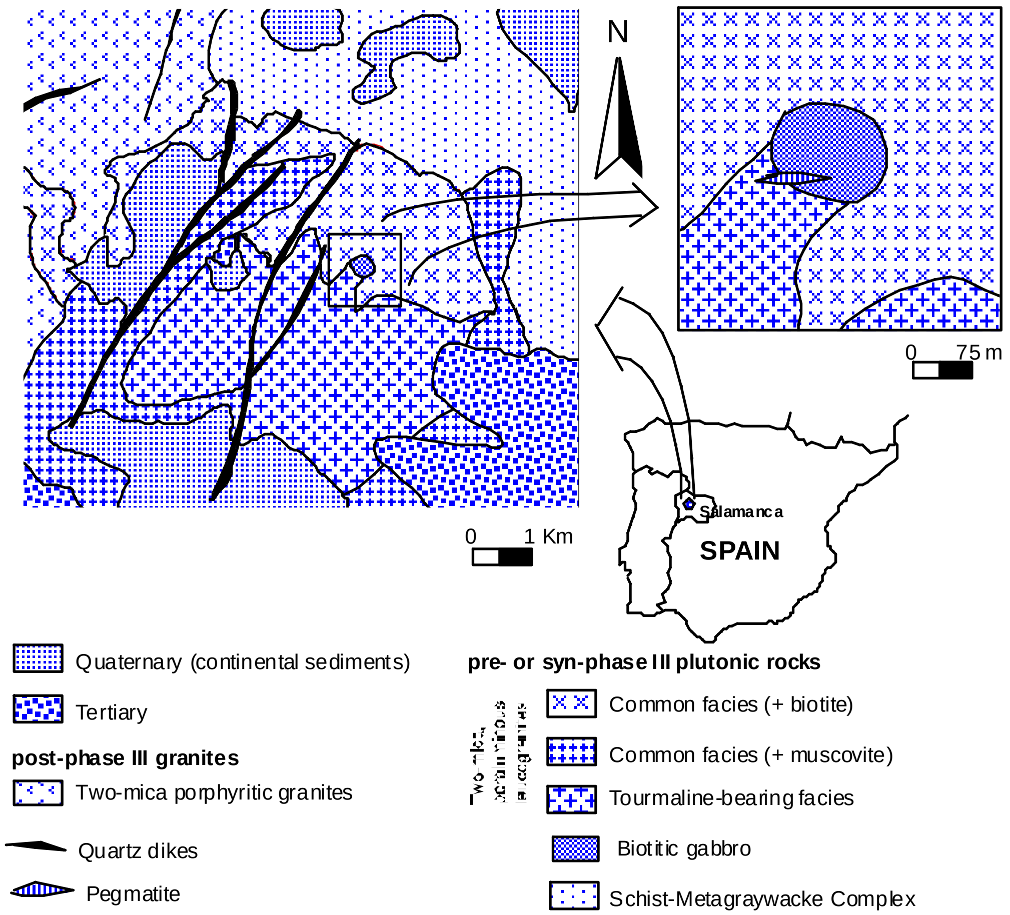

Figure 1. Schematic geological map of the study area (Salamanca, Spain). (In Roda et al., 2004, modified from Martín-Izard et al., 1992).

In the contact zone of the pegmatite, the phosphates are dark in color (mainly brown and black), and they belong to the border zone association (with ferrisicklerite, magniotriplite, johnsomervilleite, manganoan fluorapatite and xenotime-(Y) as the main phosphates) (Fig. 2; Table 1). They appear as decimeter-sized masses, together with K-feldspar, schorl, biotite, muscovite, and garnet. In the inner zone of the pegmatitic body, another association appears. Samples of this association are masses, up to a meter in size, of light gray to gray triphylite and sarcopside, which appear together with plagioclase and muscovite (Fig. 2; Table 1). Finally, the third association appears in a transition zone (with ferrisicklerite and graftonite as main phosphates), between the border and the inner zones (Fig. 2; Table 1).

TABLE 1. Main petrographic characteristics of the minerals from the border zone and the transition zone associations (Roda et al., 2004).

Assoc.	Mineral	Habit and textures	Grain size *	Fe / (Fe+Mg)	Main mineral association
Border Zone	***Primary phosphates***				
	Ferrisicklerite	granoblastic and interlayered textures,	fine to coarse	0.55-0.70	jhsm, mgtr, grft, xnt Mn-apt, allu, stnk,
	Magniotriplite	granoblastic texture an- to subhedral habit	fine to coarse	0.27-0.58	fsck-Mn-apt stnk, rckb, grn, bio, tour
	Johnsomervilleite	granoblastic texture an- to subhedral habit	very fine to fine	0.53-0.66	fsck-grft stnk, grn, bio, tour
	Manganoan fluorapatite	granobl. and interlayered textures, an- to euhedral h.	fine to coarse	>0.65	fsck-xntm
	Xenotime-Y	sub- to euhedral habit	very fine	-	Mn-apt, fsck
	Graftonite	granoblastic texture an- to subhedral habit	very fine to medium	0.0.85-0.89	fsck-jhsm
	Secondary phosphates				
	Alluaudite	skeletal, anhedral habit	very fine to medium	0.54-0.79	fsck, stnk
	Silicates				
	Garnet	sub- to euhedral habit	fine to	0.90-0.98	bio, tour, musc,
	Muscovite	subhedral habit	fine to coarse	0.63	cor, bio, grn, fsck
	Biotite	subhedral habit	fine to medium	0.68	grnt, tour, musc, mgtr, fsck
	Tourmaline	subhedral habit	fine to coarse	0.59	grnt, musc, bio, mgtr,
	Oxides				
	Corundum	rounded to irregular, subhedral habit	very fine	-	musc, bio
Transition Zone	***Primary phosphates***				
	Ferrisicklerite	granoblastic and graphic textures,	fine to coarse	0.72-0.90	grft, allu, hur, stnk,whit,rckb,mtbr ABP2,eosp,grm,lcp,crd,qz,tour,bio
	Graftonite	granoblastic and graphic textures an- to subhedral habit	very fine to medium	0.94-0.96	fsck, stnk qz, tour, bio
	Mn-apatite	granoblastic texture an- to euhedral habit	fine to medium	>0.93	fsck
	Xenotime	sub- to euhedral habit	very fine	-	Mn-apt, fsck
	Secondary phosphates				
	Alluaudite	skeletal, anhedral habit	very fine to medium	0.75-0.91	fsck, stnk
	Stanekite	anhedral habit	very fine	0.88-0.93	fsck, grft
	Silicates				
	Muscovite	subhedral habit	fine to médium	-	tour,bio,fsck,grft,mtbr,eosp
	Biotite	graphic texture an- to subhedral habit	fine to medium	0.86	qz, tour, grft, fsck fsck and grft
	Tourmaline	graphic texture an- to euhedral habit	fine to medium	0.74	bio, qz, grft, fsck

Used abreviations: ferrisicklerite = fsck; alluaudite = allu; montebrasite = mtbr; huréaulite = hur; stanekite = stnk; gormanite-souzalite = grm; manganoan fluorapatite = Mn-apt; xenotime-Y = xntm; magniotriplite = mgtr; johnsomervilleite = jhmv; whiteite = whit; hureaulite = hur; rockbridgeite = rckb; leucophosphite = lcp; crandallite = crd; montebrasite = mtbr; eosphorite = eosp; collinsite = coll; muscovite = musc; biotite = bio; tourmaline = tour; garnet = grn; cassiterite = cass; columbite-tantalite = col; uraninite = ura; corundum = cor; quartz = qz. * grain size: very fine = < 1 mm; fine = 1 to 5 mm; medium = 5 mm to 2.5 cm; coarse = > 2.5 cm.

TABLE 2. Main petrographic characteristics of the minerals from the inner zone association. (Roda et al., 2004)

Mineral	Habit and textures	Grain size *	Fe/(Fe+Mg)	Main mineral association
Primary phosphates				
Triphylite	granoblastic texture anhedral habit	fine to coarse	0.91-0.95	srcp ± wolf, barb, hur, whit viv, allu, fsck, mtbr, grm, musc
Graftonite	granoblastic texture	very fine to fine	0.98	fsck ± srcp
Wolfeite	anhedral habit	very fine	0.92-0.96	trph ± srcp
Montebrasite	subhedral habit, twinning	very fine to fine	-	trph ± srcp, eosp, fsck, allu,
Exsolution phosphates				
Sarcopside	lamellar, twinned	fine to medium	0.96-0.97	trph ± wolf, fsck ± srcp, musc
Secondary phosphates				
Ferrisicklerite	granoblastic texture	fine to medium	0.93-0.96	trph, srcp, allu, stnk, F-apt
Alluaudite	skeletal anhedral habit	very fine to fine	0.88-0.97	trph ± srcp, barb
Barbosalite	anhedral habit, cellular texture	very fine to fine	0.94-0.99	trph, hur, whit, allu
Hureaulite	an- to euhedral habit cellular texture	very fine to fine	0.70-0.99	trph, barb, whit, redd rckb, lpcb, jahn, mtr
ABP1	sub- to anhedral habit	very fine to fine	0.97-0.98	trph, arrj, barb, hur ura, Fe-Mn carb, frf,pyr
Arrojadite	sub- to anhedral habit	very fine to fine	0.88	trph, sml, barb, hur ura, Fe-Mn carb, frf, pyr
Stanekite	anhedral habit	very fine to fine	0.93-0.97	fsck ± srcp
Gormanite-souzalite	anhedral habit	very fine to fine	0.91-0.94	trph, srcp
Silicates				
Plagioclase	subhedral	fine to médium	-	trph±srcp
Muscovite	tabular habit	fine to coarse	0.86	trph±srcp
Biotite	subhedral habit	very fine to fine	-	musc, barb, allu, sml, arrj
Tourmaline	sub- to euhedral habit	fine	0.86	trph±srcp
Oxides				
Cassiterite	subhedral habit	fine to medium	-	trph±srcp, musc, col
Ferrocolumbite	tabular habit	fine to medium	-	trph±srcp, musc, cass
Uraninite	rounded habit	very fine	-	trph, arrj, sml, barb, hur, Fe-Mn carb

The following abreviations have been used: triphylite = trph; sarcopside = srcp; graftonite = grft; wolfeite = wolf; ferrisicklerite = fsck; alluaudite = allu; montebrasite = mtbr; barbosalite = barb; huréaulite = hur; arrojadite = arrj; stanekite = stnk; gormanite-souzalite = grm; lpcb = lipscombite; F-apt = fluorapatite; eosp = eosphorite; whiteite = whit; vivianite = viv; rckb = rockbridgeite; jahn = jahnsite; mtr = mitridatite; frf = fairfieldite; redd = reddingite; plagioclase = plg; muscovite = musc; biotite = bio; tourmaline = tour; cassiterite = cass; columbite-tantalite = col; uraninite = ura; quartz = qz; Fe-Mn carbonates = Fe-Mn carb; pyr = pyrite. * grain size: very fine = < 1 mm; fine = 1 to 5 mm; medium = 5 mm to 2.5 cm; coarse = > 2.5 cm.

All the Fe-Mn phosphate sampling has been done in the part of the pegmatite intruded into the gabbro. Although it is not possible to observe the transition from one association to another, as they do not crop out together, a knowledge of the position of the three associations in the pegmatitic body (contact or inner zone) permitted us to study the evolution of the phosphates through the pegmatite (Fig. 2). In this regard, it is noteworthy that the chemical compositions of the phosphates change dramatically from one association to another, mainly in their Mg-contents (Tables 1 and 2; Fig. 3). This difference is evident not only in the phosphate phases, but also in most of the other phases (e.g., tourmaline and mica). Moreover, some of the minerals only occur together with some of the phosphates: ferrocolumbite, cassiterite, and uraninite are exclusively associated with triphylite, whereas garnet and ilmenite only appear together with magniotriplite and johnsomervilleite (Tables 1 and 2).

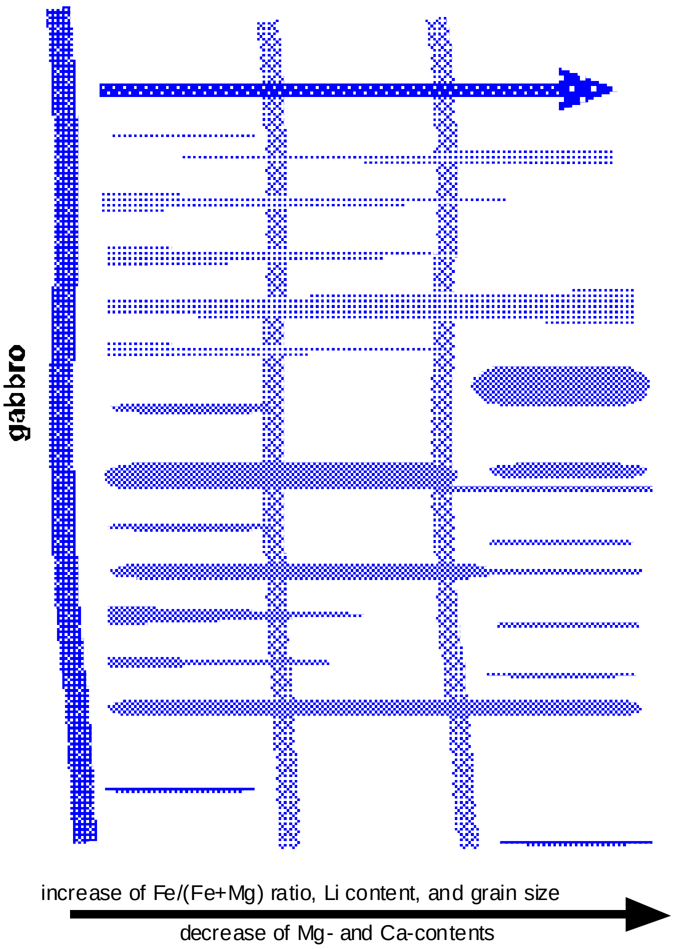

FIGURE 2. Idealized scheme of the phosphate associations distribution in the Cañada pegmatite (Roda et al., 2004).

DISCUSSION

As a result of the decrease of Mg, the Fe/(Fe+Mg) ratios for phosphates, biotite, and tourmaline increase from the border to the inner association (e.g., for ferrisicklerite and graftonite, from 0.67 and 0.85 in the border to 0.94 and 0.98 in the inner association, respectively). This difference is particularly evident for biotite and tourmaline; for example, the Fe/(Fe+Mg) ratios for tourmaline range from 0.59 in the border to 0.86 in the inner zone. These variations seem to reflect contamination of marginal zones of the pegmatite by some type of reaction with the host gabbro. Thus, an evolutionary trend involving inward crystallization from the margins and contamination of fluids from wallrocks into pegmatite-forming melt may be a plausible genetic model. The occurrence of phosphates along with Fe-Mg silicates would indicate that the melt contained on the order of 1.3-2.4 wt % P_2O_5, based on experimental silicate-phosphate equilibria (Roda et al., 2004). Although the Fe/(Fe+Mn) ratio of some Fe-Mn phosphates commonly has been used to assess the degree of evolution of the pegmatites, references to the petrogenetic role of the phosphates in the evolution of pegmatites are scarce.

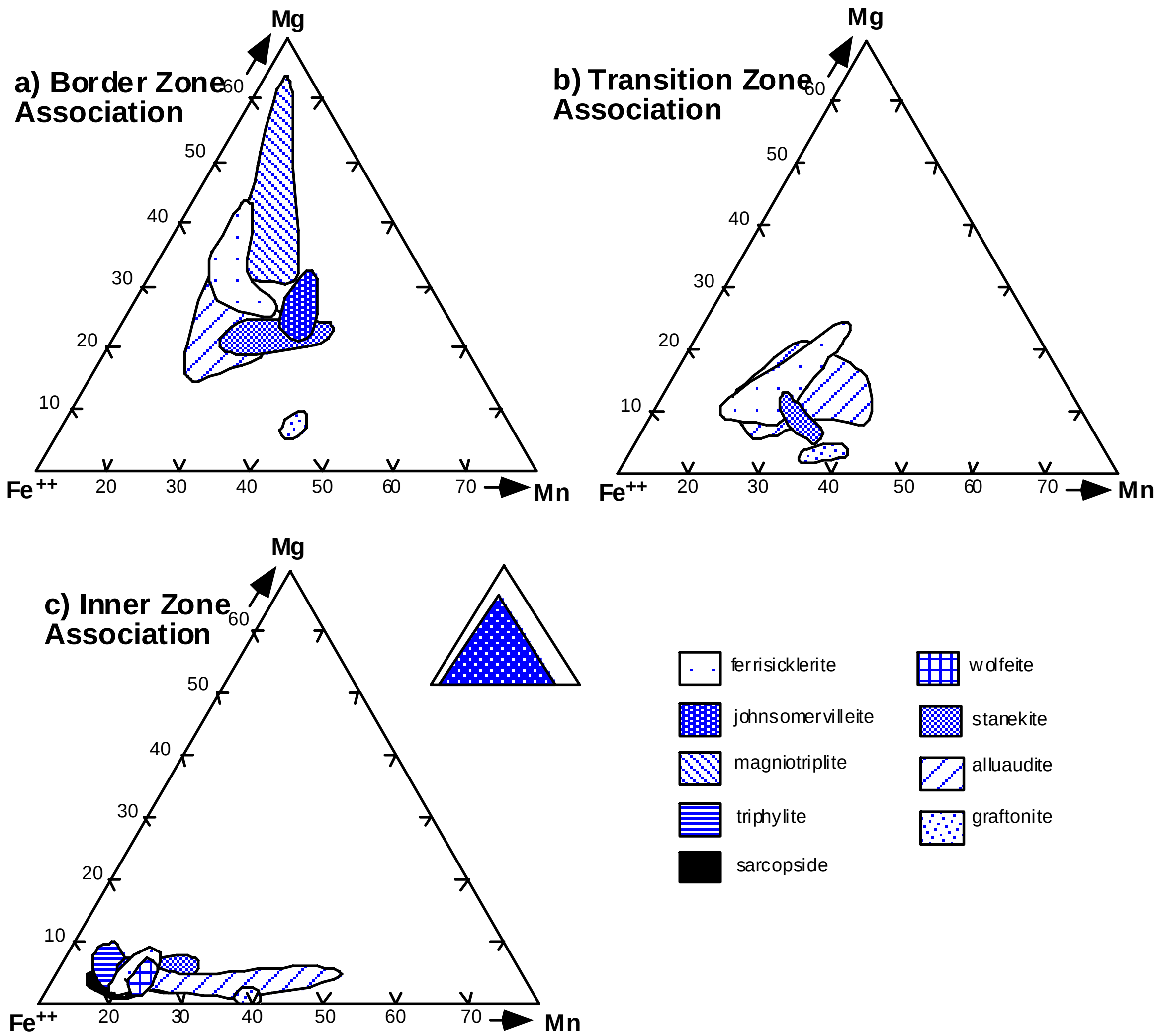

FIGURE 3. Plot of the variation in the contents in Mg, Fe total (as Fe2+), and Mn for the main phosphates of the three associations of the Cañada pegmatite (from Roda et al., 2004).

In the Cañada pegmatite the Fe/(Fe+Mn) ratio remains almost constant throughout the three associations, yet the phosphates and their associated minerals show petrographic and compositional variations that are consistent with crystallization inward from the margins. Different lines of evidence support this interpretation: (1) paragenetic association and distribution; (2) development of graphic and skeletal textures in the border and transition zones that suggest rapid disequilibrium-induced growth due to relatively high degrees of undercooling; (3) the Fe/(Fe+Mg) ratio for mafic phosphates and silicates that increases from the border to the inner zone; and (4) the occurence of minerals relatively rich in Mg, Fe, and/or Ca in the border zone due to possible contamination of the pegmatite system by the mafic host rock (Roda et al., 2004).

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Seixo Amarelo-Gonçalo Area

Locality 5

LOCALITY NO. 5: SEIXO AMARELO-GONÇALO RARE ELEMENT APLITE-PEGMATITE FIELD

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Introduction

A rare element aplite-pegmatite field outcrops in the Central-Eastern region of Portugal, over an area of more than 100 Km^2 that comprises Gouveia-Fornos, de Algodres-Celorico and da Beira-Guarda-Belmonte-Sabugal regions. They are mainly sub-horizontal veins, with thicknesses generally < 3.5 m. This is an interesting region where we can study the result of the gradual evolution of pegmatitic magma from less to more differentiated stages, as we reach higher structural and topographic levels. This evolution became registred not only inside each sill (internal differentiation) but also from one vein to another.

The most important characteristics of this pegmatitic field are (Farinha Ramos, 1998):

- Its extension: The veins outcrop over a wide area (> 100 Km^2). This represents an enormous volume of pegmatitic magma.

- The atitude of the veins: More than 95% of the veins are sub-horizontal.

- The aplite-pegmatite structure: In the same vein we can see very coarse-grained mineral phases coexisting with fine grained aplitic facies.

- The mineralogical composition: Besides the essential minerals (quartz, feldspars and muscovite), Li, Be, Nb, Ta, and Sn minerals occur.

The rare element pegmatitic field is located in a granitic area, where several types of Sin-D3, hercynian, peraluminous, S type granites outcrop. These post tectonic granites where divided into 3 series (early, intermediate and late) that partially overlap in age (Ferreira et al. 1987):

Late serie	Two-micas granites- ***Fráguas granite*** Monzonitic with sparce megacrystals granite Porphyroid Monzonitic granite-***Belmonte granite*** Quartzodioritic and biotitic granodiorite
Intermediate serie	Porphyroid, mainly biotitic granite-***Guarda granite*** Quartzodiorite and biotitic granodiorite.
Early serie	Porphyroid, biotitic granite Two-micas, foliated granite

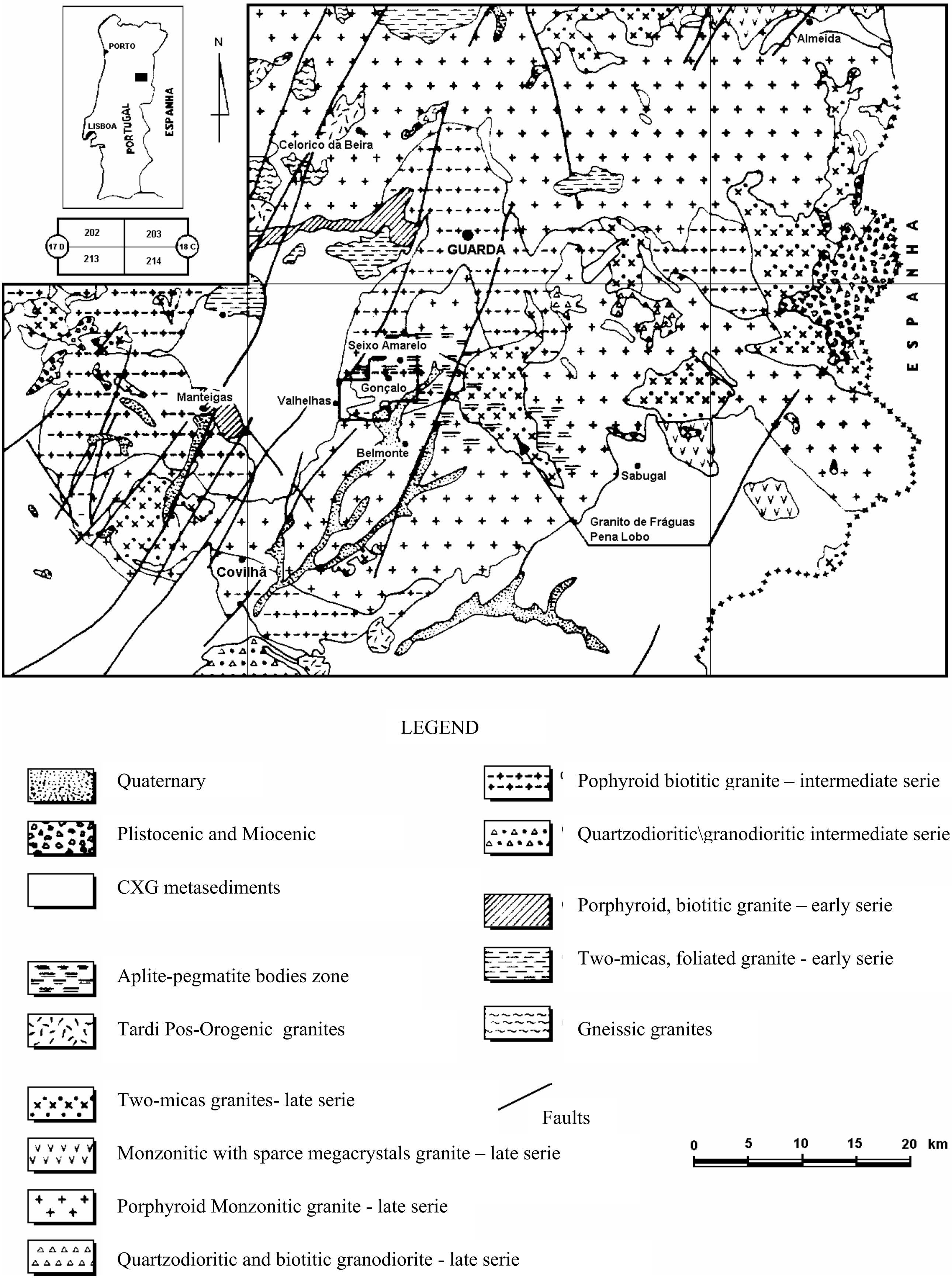

FIGURE 1. Seixo-Amarelo-Gonçalo area represented in a simplified Geologial map of the central-east Portugal (extracted from the 1:500.000 Portuguese Geological Map, (IGM, 1995)).

The granitic type that more widely outcrops in the Central-Eastern region of Portugal is the porphyroid, monzonitic, predominantely biotitic granite of the late serie (Belmonte granite). The latest sin-D3 granites are the two-mica granites (as the Fráguas pluton), that is the most evolved granite in the area. Finally, the most enriched veins occur in the Seixo Amarelo – Gonçalo region, where the Guarda granite (porphyroid, mainly biotitic granite) of the intermediate serie outcrops, as well as small outcroppings of the schist-graywack complex.

The Seixo Amarelo-Gonçalo aplite-pegmatite field outcrops over the slope of the NE border of the Estrela Mountains, between 450 and 850 m altitude. Three types of sills were distinguished in the Seixo Amarelo-Gonçalo Region:

"Lithian" veins: (*Represented by dark grey in the map)* They are pinkish in colour, more evolved than the Sn-rich veins, and generally complex, banded, sometimes zoned, with quartz, albite, K feldspar, muscovite, lithian muscovite, lepidolite, amblygonite-montebrasite, sodic-montebrasite, topaz, cassiterite, manganocolumbite, microlite, Al-phosphates, Mn-oxides, zircon, monazite, torbernite, autunite, etc, as main minerals.
They are enriched in Al_2O_3, MnO, P_2O_5, L.O.I., Li, Rb, Nb, Ta, etc. They outcrop in more distal and topographicly higher regions.

"Stanniferous" veins: (*Represented by light grey in the map)* They are beige coloured, less diferentiated than the Li-rich bodies, generally simple and not banded or zoned. Quartz, K feldspar, albite, muscovite, lithian muscovite, apatite, amblygonite-montebrasite, topaz, cassiterite, columbo-tantalite, hidromuscovite and Mn-oxides are the main minerals of these bodies. They are enriched in SiO_2, K_2O, FeO, Sr, Ba, Sn, etc. They outcrop in more proximal and topographicly lower regions than the Li-rich veins.

"Mixed" sills: intermediate in composition, their aspect is similar to that of the stanniferous veins and intrude in intermediate positions.

In general, the least evolved pegmatitic magma intruded at lower levels, while the more evolved magma intruded at higher levels, but was affected by more intense late to post magmatic effects. These effects determined some aspects as banded structures, rythmical deposition and evolution of mineral compositions. Average of the major, minor and trace elements values for the three types of veins are given in Table. 1. Overall, the more significant enrichments from stannifeous to lithian veins are: Li (3.8x); F (3.4x); Rb (2.0x); Nb (1.4x) and Ta (1.05x).

Episodes of deposition for the Li-rich veins

Episode I- it is represented by narrow aplitic bands (1-2 cm) in the contact with the country rock, Mainly with quartz, albite, K-feldspar, muscovite, apatite, tourmaline, etc.

Episode II – predominantly potassic (lithian-potassic) mainly with K-feldspar, amblygonite-montebrasite, quartz, muscovite, petalite and some topaz.

Episode III – predominantly sodic, with cassiterite columbo-tantalite, albite, muscovite, quartz, topaz and microlite.

Episode IV- predominantly sodo-lithic pegmatitic, with lepidolite, albite, quartz and topaz.

Episode V- predominantly lithian aplitic, with lepidolite, albite, quartz, etc.

Episode VI – the latest, it is characterized by the deposition of sub-microscopic lepidolite, zoned quartz, albite, hidromuscovites, hidrated phosphates, sericite, caolinite, etc.

TABLE 1. Chemical Composition Of The Three Types Of Veins Studied In The Amarelo-Gonçalo Area (Average)

	Sn peg.		**Mixed peg.**		**Li peg.**	
Oxides (%)	**Average**	St. dev.	**Average**	St. dev.	**Average**	St. dev.
SiO2	**71,74**	1,52	**69,35**	2,81	**68,73**	1,47
Al2O3	**15,82**	0,87	**17,39**	1,86	**17,84**	0,56
FeO	**0,99**	0,31	**0,67**	0,22	**0,69**	0,22
MnO	**0,09**	0,06	**0,12**	0,03	**0,16**	0,07
MgO	**0,02**	0,02	**0,03**	0,02	**0,02**	0,02
CaO	**0,20**	0,13	**0,12**	0,12	**0,17**	0,11
Na2O	**4,81**	0,99	**3,74**	1,46	**4,11**	0,76
K2O	**3,41**	0,98	**4,25**	0,45	**3,13**	0,64
TiO2	**0,01**	0,009	**0,02**	0,01	**0,02**	0,01
P2O5	**0,61**	0,45	**0,43**	0,45	**1,07**	1,14
P.R.	**1,60**	0,35	**3,06**	2,43	**2,33**	0,85
Elements	**10 Am.**		**5 Am.**		**46 Am.**	
(ppm)						
F	**4396**				**14977**	
Li	**1484**	1037	**2512**	1465	**5705**	1847
Rb	**1088**	247	**1413**	239	**2169**	573
Sr	**22**	9	**25**	7	**53**	72
Ba	**29**	14	**29**	15	**30**	21
Y	**6**	5	**2**	2	**2**	3
Zr	**26**	9	**25**	5	**37**	34
Nb	**40**	22	**48**	32	**57**	17
Ta	**44**	39	**55**	62	**46**	47
Sn	**319**	154	**426**	375	**310**	260
W	**2**	1	**3**	1	**3**	3
K/Rb	**13,00**		**12,48**		**5,99**	
K/Li	**9,53**		**7,02**		**2,28**	
Mg/Li	**0,08**		**0,07**		**0,03**	
Ta/Nb	**1,10**		**1,15**		**1.32**	

LOCAL GEOLOGY

In the Seixo Amarelo-Gonçalo region the main outcroppings of granites are porphyroid, predominantly biotitic granites of the intermediate serie, as well as some "roof pendants" of schists of the ante-ordivician schist-graywacke complex that enclose the granites. The aspect of the vein field is determined by the sub-horizontal atitude of the veins, on the one hand; and by the late NNE-SSW and NE-SW fractures that divide the vein field in several sectors, on the other hand. In a more detailed view we can see that toward the south-east of the NE-SW Vela-Gonçalo fault, only stanniferous veins outcrop (Fig. 2). We are in a more proximal and structural lower region. North-westwards from this fault, in lower topographic levels, stanniferous veins outcrop. As we go up in the moutain, we find the mixed veins and, finally, the lithian veins appear in the highest levels. This block is depressed.

To the west and to the NNE-SSW of Seixo stream fault, even in the lower topographic levels, only the lithian veins outcrop. In this case we are in a higher structural level. This block is also depressed in comparison to the previous one.

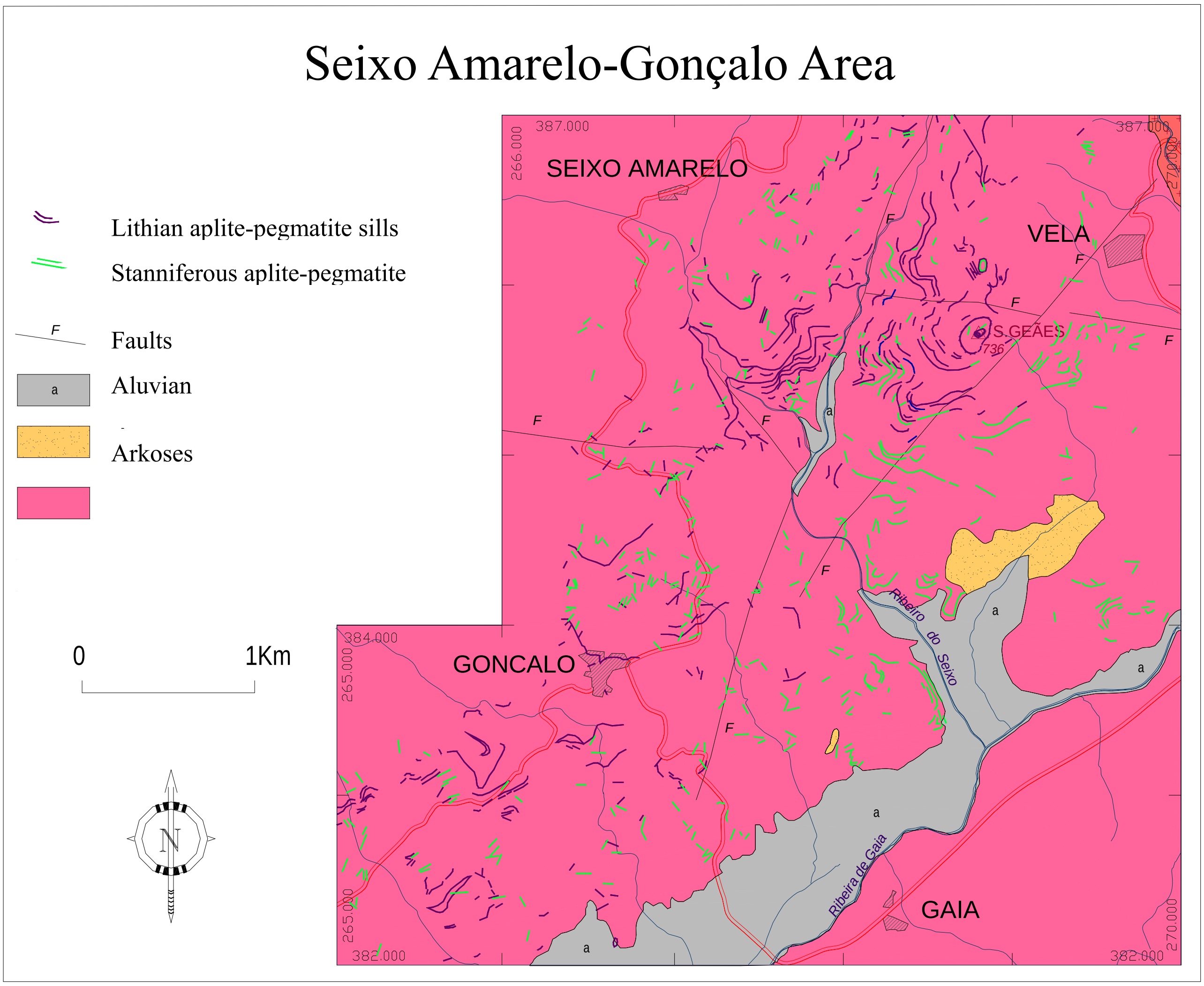

FIGURE 2. Geological map of the Seixo Amarelo- Gonçalo vein field

In figure 3 a structural cross section of the central part of the mineralized zone is shown. This way we can better understand why the more differentiated veins of the rare element vein field occurs in the Seixo-Amarelo Gonçalo region. This is the result of the tendency of the lithian veins to occupy the more distal positions and the action of the NNE-SSW and NE-SW fractures that have preserved from erosion the tectonic blocks that suffered tectonic depression.

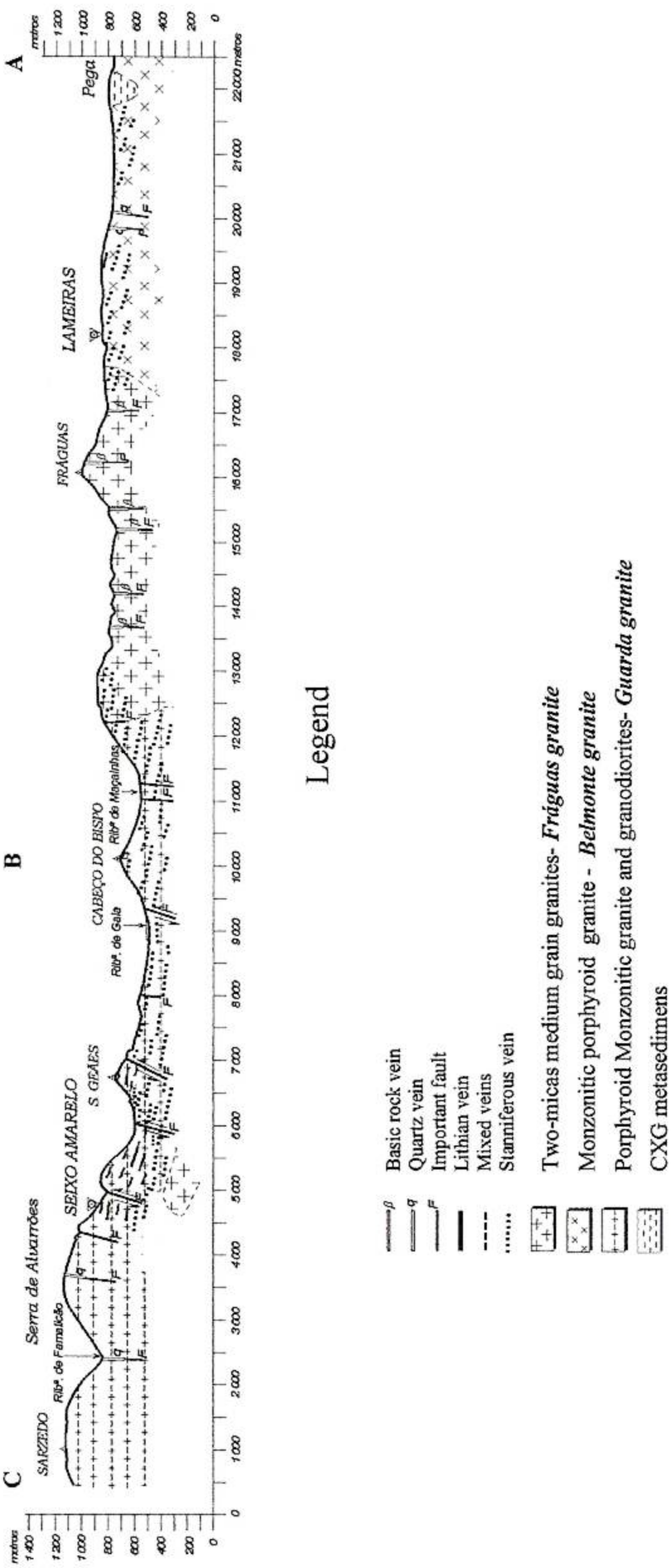

FIGURE 3. Structural cross section in the central part of the mineralized zone

REGIONAL CROSS SECTION

From the east to the west we can see the oucrop of a "roof pendant" of schists belonging to the schist-graywaque complex, and after it, the biotitic Belmonte porphyroid granite of the late serie. There, only stanniferous veins can be observed. Moving westwards, the two-micas Fraguas granite outcrops. It belongs to the late serie and it is the most differentiated outcroping granite in this area. This granite is the result of crystalization of a residual magma, enriched in volatils, that moved up into the crust. In the exo-contact of the Fraguas granite some outcropings of stanniferous veins are observed. We are in a proximal and lower structural level. Westwards from the NW-SE Vela-Gonçalo fault we can see, in the lower levels, the outcropping of the stanniferous veins and when we go up topographicly, the mixed and the lithian veins are observed. Westwards from the NNE-SSW Ribeiro do Seixo fault only lithian veins appear. It is a depressed block. Westwards from Seixo Amarelo, the NNE-SSW and NE-SW faults determine the Estrela Mountains horst.

RELATIONSHIP BETWEEN THE MINERALIZATIONS AND THE GRANITES

In an area where a great number of different types of granites occur, it is not easy to define which kind of granite is genetically related to the rare element mineralizations. We have used several criterions:

-Spatial criterions: the distribution of veins is not homogeneous in the central-eastern region but veins are concentrated in the exocontact of some two-micas granites from the late serie, as the Fráguas granite.

-Geological criterions: the veins cut the schists of the schist-graywack complex, the Guarda granite (intermediate serie), the Belmonte granite and Fráguas granite (late serie). They are cut by the mesozoic basic veins .

-K-Ar Ages: Radiometric ages obtained in lepidolites of the lithian veins give 270-277 Ma.

-Geochemical criterions: the most differentiated and rare elements-enriched granites are the two-micas granites from the late serie (the latest of this serie) (Figs. 4 and 5).

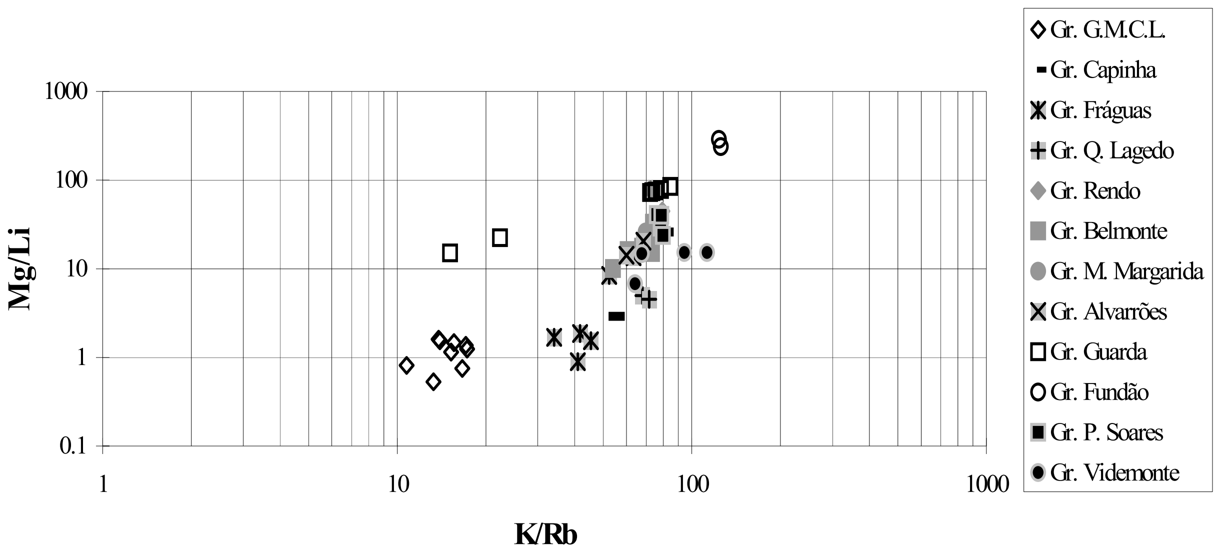

FIGURE 4. K/Rb versus Mg/Li ratios for the studied granites in the Guarda area.

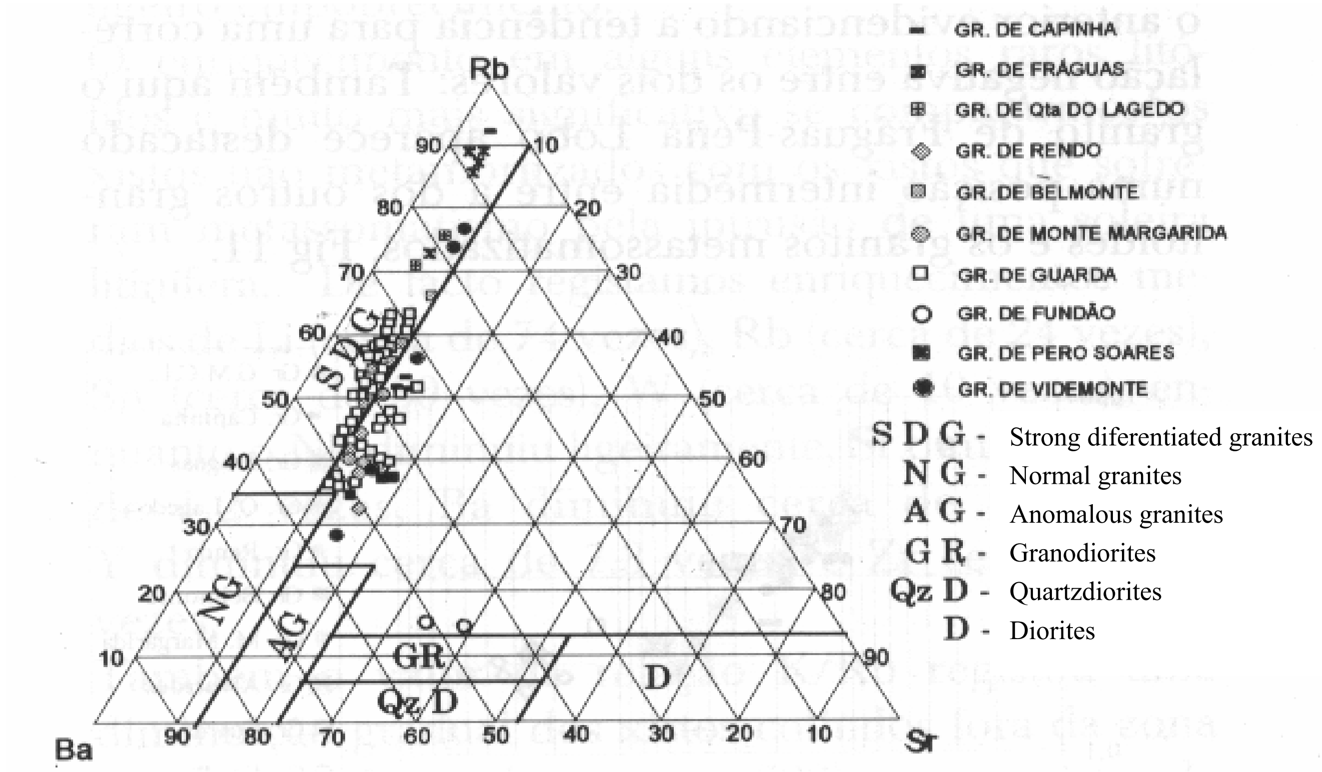

FIGURE 5. Rb-Sr-Ba diagram (El Bouseleily and El Sokkary (1975), for the granites of the Guarda area.

MINERALOGY

The evolution of the pegmatitic magma is also reflected in the chemical composition of minerals:

K-Feldspar

In general, it is more abundant in the pegmatitic than in the aplitic facies, and in the hangingwall than in the footwall. In hand sample it is generally beige, although pinkish crystals are also common. Crystals are commonly fine grained (1 x 2 cm), but tabular crystals, up to 20 cm in length are also observed.

The content in major elements in K-feldspar does not show significative changes. Only the content in P_2O_5 shows some variation (Table 2); whereas we find significative differences in the content of some trace elements (Table 3).

TABLE 2. Average of P_2O_5 content in the K-Feldspar associated with the different types of pegmatites

	Stannifer. veins	Mixed veins	Lithian veins
% P_2O_5 (K-feldspar)	0.4 %	0.3 %	0.6 %

TABLE 3. Content in Li, Rb and Sn in the K-Feldspar associated with the different types of pegmatites

Element	Stanniferous pegm.	Mixed pegm.	Lithian pegm.
Li	67	70	117
Rb	1211	1345	2823
Sn	5	-	11

Albite

It is very abundant. Opposite to the K-feldspar, it mainly occurs in the aplitic facies. It forms withish, rounded crystals, up to 2 or 3 cm in length, sometimes with radial texture (clevelandite habit).

Significative changes in the content of major elements have not been found. Only the P_2O_5 content decreases 0.3 % from the stanniferous to the lithian pegmatites. In the case of Li contents, this is higher in the albite from the Lithian pegmatites (Table 4).

TABLE 4. Content of Li and Rb in albite associated with the different types of pegmatites

Element	Stanniferous pegm.	Mixed pegm.	Lithian pegm.
Li	30	-	124
Rb	9	-	9

Muscovite

It frequently occurs as fine-grained crystal in the aplitic border zones; and also as centimetre sized crystals in zones with pegmatitic texture, associated with lepidolite, quartz and albite. Muscovite is whitish in colour, except for some late, very fine grained, greenish crystals, that usually appear in cavitites of greissen.

Muscovites from the lithian pegmatites are richer in Al_2O_3 but poorer in F than those from the Sn-rich bodies (Table 5). Trace elements in white micas also show differences between the different pegmatite types (Table 6).

TABLE 5. Content in Al_2O_3 and F for muscovite.

Element	Stanniferous pegm.	Mixed pegm.	Lithian pegm.
Al_2O_3	33.8 %	-	37 %
F	1.8 %	-	0.7 %

TABLE 6. Content in some trace elements for white micas.

Element	Stanniferous pegm.	Lithian pegm.	Hidromuscov.
Li (ppm)	17500	-	-
Rb (ppm)	2400	-	1016
Sn (ppm)	5	-	10
W(ppm)	<4		55

Lepidolite

It occurs associated with both, the pegmatitic and the aplitic facies. In the first case, lepidolite appears in crystals up to 2 cm in diameter; whereas in the aplitic facies it frequently gives rise to dense aggregates, in close relation with albite, quartz and topaz. In the pegmatitic lepidolites the 1M polytype is the most common, whereas for the lepidolites with aplitic texture, $2M_2$ and $2M_1$ are more common.

A small increase in the Al_2O_3 content from stanniferous to lithian lepidolites has been observed. The content of different types of lepidolites in some elements is represented in Table 7.

TABLE 7. Content in some elements for lepidolites with different textures.

Element	Pegmatitic lepidolit.	Aplitic. lepidolite	Microscopic lepidolite
F (ppm)	64000	67000	58000
Li (ppm)	23350	25100	3700
Rb (ppm)	3404	2865	1363
Nb (ppm)	47	40	11
Ta (ppm)	24	20	18
Sn (ppm)	96	64	58
W (ppm)	11	8	<4

Topaz

It oocurs associated with quartz, lepidolite and albite. It appears with blue-greeenish or light-greenish colours in up to 5 cm long crystals although, in general, it appears as milimetric rounded crystals. It is more abundant close to the hangingwall.

Al_2O_3 content is slightly higher for the stanniferous pegmatites (56.1% wt) than for the lithian pegmatites (54.9 % wt.).

Cassiterite

Crystals of cassiterite are generally smaller that 1 or 2 mm. Its colour changes from dark brownish to nearly black, but generally it is lighter than the mangano-columbite. It usually appears associated with albite and micas.

The evolution of cassiterites from the stanniferous to the lithian veins is caracterized by the enrichement of the content of Nb+Ta (Table 8). This variation is different to observed in Fregeneda region (Roda-Robles, 1993).

TABLE 8. Content in (Nb_2O_5+Ta_2O_5) for the different types of pegmatites

Oxides (%)	Stanniferous pegm.	Mixed pegm.	Lithian pegm.
Nb_2O_5+Ta_2O_5	1.7 %	2.5 %	5.4 %

Manganocolumbite

It usually appears in elongated or rounded small crystals (1-2 mm), with nearly black or dark brownish colours. T is related to albite and also to the Li-rich micas. The chemical evolution of the manganocolumbite is expressed in Table 9.

TABLE 9. Composition of the manganocolumbite associated with the different types of pegmatites.

Oxides(%)	Stannif. Veins	Stdev	Mixed Veins	Stdev	Lithian Veins	Stdev
SnO_2	**0.2**	0.09	**0.8**	0.50	**0.3**	0.15
FeO	**1.7**	0.41	**2.5**	2.04	**1.4**	0.47
MnO	**17.9**	0.57	**15.7**	2.52	**16.5**	0.67
TiO_2	**1.1**	0.26	**1.8**	0.59	**0.7**	0.14
Ta_2O_5	**21.1**	2.75	**25.3**	2.85	**31.0**	2.12
Nb_2O_5	**56.2**	2.57	**52.8**	2.38	**48.7**	1.88
WO_3	**2.0**	0.79	**0.9**	0.98	**1.2**	0.26
SUM	**100.2**		**99.8**		**99.8**	

Tourmaline

It forms black, fine-grained crystals (1-2 mm). It is frequent in the hosting rocks of pegmatites, close to the contacts, in the zones affected by metasomatism.

The tourmaline from the lithian veins is richer in Al_2O_3 (1.1x) and in MgO (2.2x) than tourmaline from the stanniferous veins.

CONTACT METASOMATSIM

The intrusion of the aplite-pegmatite veins in the country rocks (schists and granite) produced 10-20 cm bands of evident metasomatism. The development of these bands is due to the chemical disequilibrium between the consolidated granite and the intrusive pegmatitic magma.

Metasomatism of the granitic rocks:

These bands of contact metsomatism in the Guarda granite are characterized by some macroscopic aspects:

1- The hardening of the granite that sometimes forms cornices where we can see some albitization, remobilization and redeposition of quartz.

2- Alteration of the colour of the granite determined by the substitution of black biotite by a light brown, ferriferous, lithian mica (zinnwaldite).

3- The deposition of tourmaline (schorlite), that is more abundant at 1 - 2 cm from the contact with the rare element veins. This deposition at 1-2 cm away from the contact with the vein is interesting and results of the fact that the fluids enriched in B, Li, water, and others, expelled by the pegmatite magma do not have Fe and Mg enough to precipitate tourmaline. Only when these fluids penetrated 1-2 cm into the granite, and lixiviated the Fe and the Mg from biotite, the tourmaline precipitated.

4- The texture of the granite does not show important modifications (perhaps the grain is a little bit finer).

5-Sometimes we can see some greisenization of the granite, with recristallization of white mica, quartz, zinnwaldite, topaz, apatite, zircon, rutile and others.

In relation with the chemical characterization of the metasomatic bands, determined in the Guarda granite by the lithian veins, the more significant aspects are:

- An important increase in L.O.I, and some increase in the MgO, FeO, TiO_2 and Al_2O_3 contents, together with a decrease in MnO, SiO_2, CaO and P_2O_5. The increase in FeO, MgO and TiO_2 is determinated by the deposition of tourmaline and, in the case of Ti, also by the recristalization of rutile. The increase in Al_2O_3 can be related with some muscovitization and with the tourmaline deposition. The intense zinwalditization of the biotite can be expressed by some increase of the content in SiO_2, and some decrease of content in Fe, Mg, and Ti. The crystalization of tourmaline compensates this decrease. This increase of content in Fe and Mg is contrary to that proposed by Černý (1995). On the other hand, the decrease in CaO can be explained by the albitization of plagioclase. Similarly, the decrease in SiO_2 is not coherent with the hardening and the formation of cornices. This variation is confirmed by others in the region.

The decrease in MnO and P_2O_5 can be explained by the removilization of apatite in non greissenized zones. Ours results for the variation in P_2O_5 are contrary to others in the same region.

- An increase in Li, Rb, Sn, Nb, Ta, W and Zr; and a decrease in Sr, Ba and Y. Overall, it can be considered normal. The increase in Li and Rb can be related to the crystalization of zinnwaldite. The increase in Nb, Ta, Sn, W can be related to the recristallization of rutile and ilmenite.

Metasomatic effects in the schists

Lithian veins intrude schists of the ante-ordovician schist-graywacke complex, that previously were metamorphized by regional and contact metamorphisms. The samples of schists used to compare the metasomatic effects are essentially:

1-***Schists out from the contact metamorphic zone***: Chloritic-biotititic schists, characterized by the association: quartz + albite + chlorite + muscovite + biotite + rutile + zircon + iron oxides.

2- ***Schists of the contact metamorphic zone***: Biotitic hornfels, with the mineralogical association: quartz + chlorite + muscovite + biotite + plagioclase + ilmenite + rutile + zircon.

3- ***Schists of the contact metasomatic zone***: The contact metasomatized zones are determinated by the intrusion of a lithian vein with 80 cm thickness. These metasomatized zones have a thickness close to 10 cm in the hanging wall and in the footwall.

The mineralogical association is quartz + muscovite + biotite + zinnwaldite + plagioclase + chlorite + tourmaline + ilmenite + rutile +iron oxides + beryl + zircon.

One of the effects of metamorphism, generally considered in schists of similar composition (schist-graywack complex) by some authors, is the decarbonatation of carbonated graywackes and dehydratation with increasing metamorphism. In this case we note some dehydratation, not very extensive, when we pass from the schists out from the contact metamorphic zone, to the contact metamorphized schists. However, when we consider the contact metasomatized schists we expected a significant increase of in L.O.I. that we have not confirmed.

P - T CONDITIONS OF DEPOSITION FOR THE LITHIAN VEINS

The associated study of diagrams P-T of the lithian silicates and the study of fluid inclusions gives us an idea of the evolution of the processes of pegmatitic crystallization, to determine the relative importance of the metassomatic and magmatic processes.

The studies of fluid inclusions in quartz, topaz, lepidolite and albite have pointed out that all of them are rich in water and generally contain 2 phases (rarely a refringent solid phase may also be present).

Independently of the minerals analyzed, **Tmi** is comprised between **--5.5 and -1.1ºC**. This means **aqueous fluids with a very low salinity.** We have not seen the formation of CO_2 clatrates what was confirmed by Raman microprobe and by the jam platine. This means absence of CO_2 in the volatile phase. The determined **Th** is always below 400ºC and the more frequent values are between 160ºC and 260ºC.

Some differences were observed from one mineral to another (Fig. 6):

Topaz and lepidolite - 220ºC-260ºC

Albite – 160 – 240 ºC

Quartz – more variable

The microthermometric results suggests a decrease of temperature and salinity from the Episode III (mainly sodic deposition) to the Episode IV (sodo-lithian pegmatitic). The quartz revels probably the presence of earlier fluids (320º-340ºC) also with low salinity.

Taking into account the presence of petalite and the absence of spodumene and the position of the curves of solidus of the Harding pegmatite (with lepidolite and spodumene), we can say that the deposition of the lithian veins may have begun at T between 650 and 610º C, and under pressures < 3.5 Kb.

As petalite remains stable and the lepidolite deposition is essencialy after topaz, the intersection of the isochor of the topaz with the stability curves of spodumene-petalite-eucryptite allows us to define the limite of the conditions of deposition of lepidolite: P < 2Kb and T < 380ºC. The essencial part of lepidolite deposition happened at temperatures and pressures below these values and from low salinity aqueous fluids.

The deposition of the lithian veins of the rare element vein field was the result of magmatic and post-magmatic processes.

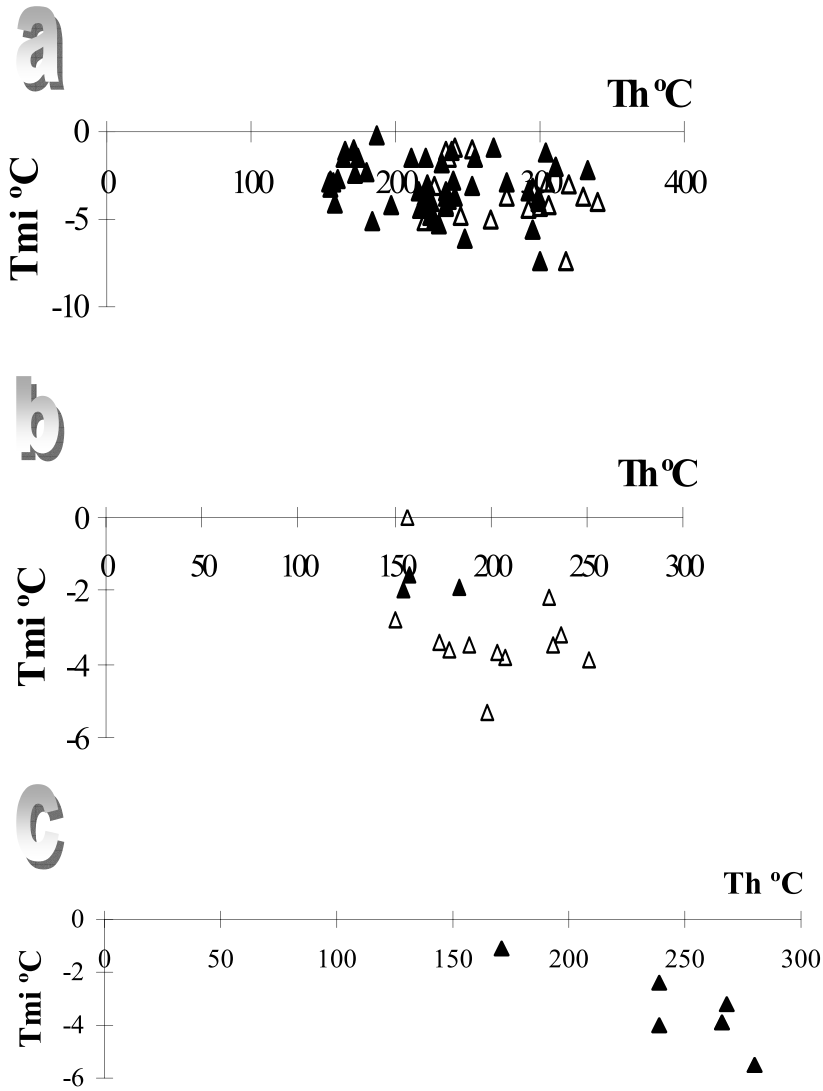

FIGURE 6. Tmi versus Th diagrams for the fluid inclusions studied in a) quartz, b) clevelandite and, c) topaz, from the studied Li-rich pegmatites (filled triangles) and Sn-rich pegmatites (unfilled triangles).

SOME INTERESTING ASPECTS

1-The tabular form and the sub-horizontal atitude of the veins: the narrow thickness is favourable to the formation of complex structures, frequently banded (Černý & Lenton, 1995) (only in lithian veins). The relatively narrow thickness (generaly < 3.5 m) would have determined the rapid cooling of the pegmatitic magma, and of the posmagmatic fluids that originate rapid crystallization.

2-The metasomatic effects in the country rocks and in the pegmatitic magma: with the migration of B, Li, Rb, Nb, Ta and Sn from the pegmatitic magma to the country rock; and the migration of Fe, Mg etc. to the pegmatitic magma. This gives rise to the substitution of biotite by zinnwaldite in granite, and to the deposition of tourmaline near the contact with the country rock.

If the country rock are the schists of the schist-graywaque complex, biotite from the schists is also transformed into zinnwaldite and there is deposition of tourmaline, beryl and, sporadically, gold.

3- The absence of a well defined quartz core: the terminal fluids are not enriched in SiO_2 but in Al_2O_3, P_2O_5, etc.

4- The distribution of the richest zones in lepidolite in the footwall: this is the result of the deposition of centimetric bands of aplitic lepidolite, sub-paralel to the walls of the veins.

5-The nearly absence of sulphides: arsenopyrite, pyrite and sphalerite are sporadic. Probably the structural level of the quartz - sulphides veins was in more distal position and were already eroded.

6- The local ocurrence of gold: a punctual ocurrence of some crystals of native gold (average 98.5 % Au) were observed in the schist metassomatized by the contact of a lithian vein. This ocurrence may be only punctual but can also be related with the presence of traces of gold in lepidolite of Seixo Amarelo-Gonçalo, detected with (SxFR) Xray fluorescence with Syncotran. Some analysis with potenciometry of lithian veins gave 17 - 21 ppb of Au.

7- The abnormal Si-Li correlation in the aplite-pegmatite rare element veins. We expected a strong positive correlation Si-Li, but we have obtained just the contrary, that is, a negative correlation. This is compatible with the final empoverishment in SiO_2 from stanniferous to lithian veins.

8- Also the negative correlation Al-Si is contrary to what we can remark in the evolution in granitic magmas.

9- The abnormal distribution of Sr and Ba that can accompany the final enrichment in Li in lithian veins: we expected an empoverishment in Sr and Ba with the terminal enrichment in Li. This is the result of late redistribution of Sr and Ba with late phosphates.

10-The absence of the effects of termogravitational migration of Li, Rb, W, Sn etc. Li, Rb, etc., that are preferentially concentrated in the footwall of the veins.

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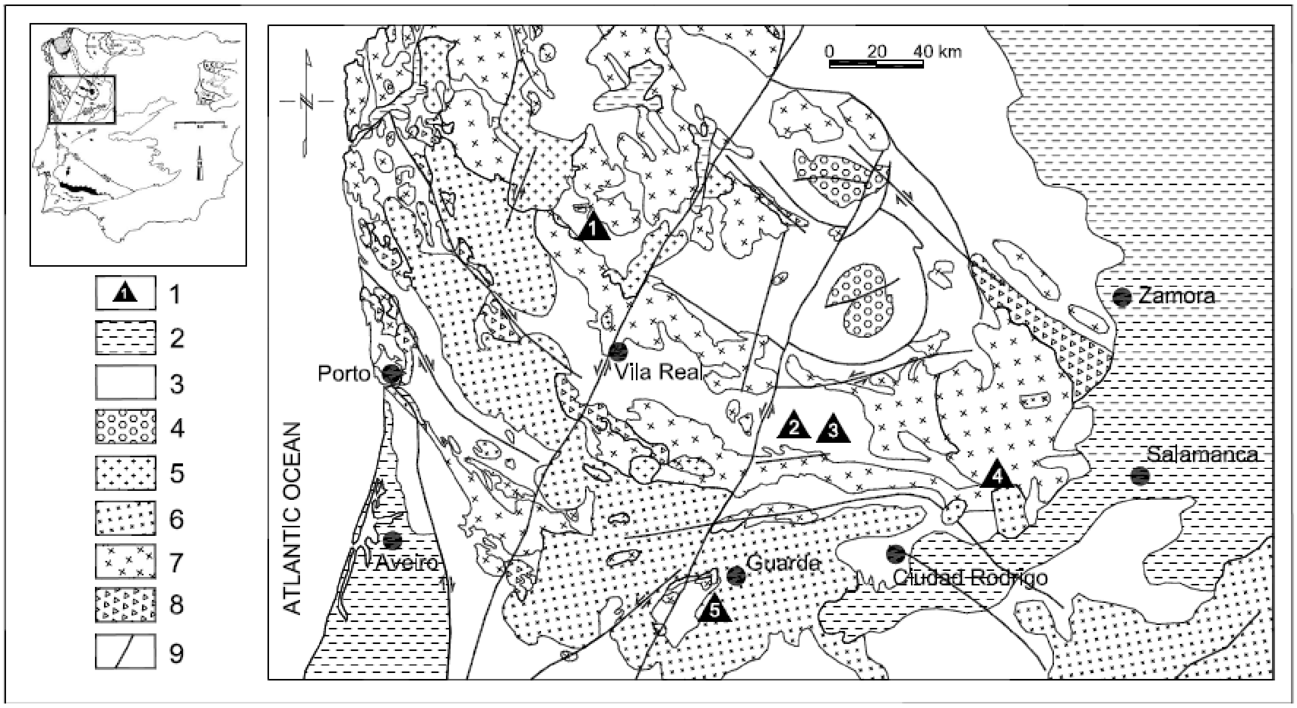
SIMPLIFIED GEOLOGICAL MAP OF THE FIELD TRIP LOCALITIES



LEGEND

1 - Field-trip geological localities (1-Barroso Alvão area;2 and 3 – Fregeneda-Almendra area; 4 - Garcirrey area; 5 – Seixo Amarelo-Gonçalo area);
2 - Post-Paleozoic; 3 - Paleozoic metasediments; 4 - Ultrabasic Complex; 5 - Post-tectonic biotite granite; 6 - Late-tectonic biotite granite; 7 - Syn-tectonic two-mica granite; 8 - Syn-tectonic biotite granite; 9 - Faults.