PROSPEG PROJECT-PEGMATITE

REMOTE SENSING AND MAPPING FINAL REPORT
Synopsis

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By combining those processing procedures with indications of productive slips and masses obtained from the analysis on the regional distribution of bodies in the considered areas, and using the empiric geological-structural and morphological criteria, it was possible to select a set of more restricted areas on which was done geological investigation. In a first phase, the geological investigation comprised cartography on 1:5000 scale, as a way for identifying sectors with pegmatitic bodies in potentially economic situations to be investigated through drillings.

From these surveys were also discriminated some structural and lithological guides conditioning the presence of pegmatites in an aproposocratic context. The late Variscan direction NS/NE seems to strictly condition the installation of bodies with higher volume in the North and Center of Portuguese territory. On the other hand, it is also noticeable that the pegmatite distribution reveals a character coincident with sectors of higher lithological diversification and heterogeneity, with the following facies tending to pegmatites fine grained leucogranites with nodular biotites, yellowed by supergene leaching influence, facies with leucocratic tendency with diffuse pegmatitic differentiation, rhyolomorphic facies with flow evidence, microlastic facies punctuated by pegmatitic bubbles, leucogranites corners of corundum and garnet; biotites established on the contact surface between granitic faces and porphyrid granites reddened by hydrothermal and supergene hematization.

The punctual prospecting program with drillings was, in some cases, well succeeded, having been intersected a pegmatic body in depth, with considerable dimension. In other cases it was possible to delimit the development of known bodies in depth, subjected to exploitation in the past, and increase the amount of potential reserves. In the cases where destructive drilling methods were used, it was adopted, in an innovative way, the filming of boreholes combined with mineralogic cutting analysis, as a way to obtain correspondent drilling columns.

As a result of the drilling program is also referred the optimization of geometric and conceptual pegmatites models which can represent paradigmatic conjectures amenable to be extrapolated to the Portuguese fields and, this way support subsequent punctual prospecting programs.

Also from the drilling logs, here perceived as granitic columns productive in pegmatites, it was possible to infer fractionation, segregation and flow tendencies, capable of fostering the appearance of transitional leucogranitic and pegmatitic magmas that may then evolve in situ or be mobilized and re-leached to structural corridors. The trends seem oscillatory in some cases, with well-defined histograms in others organization.

From the remote sensing viewpoint the resulting facies are perceptible as they represent extreme and contrasting chromatic with more extensive cartographic expression than the pegmatitic bodies.

As a line of investigative research capable of supporting pegmatites prospecting through remote sensing, were also obtained reflectance measures of lithologic pegmatitic products and their productive enclosures. The correspondent survey was done through the using of spectroradiometers and the spectra obtained were organized in a specific database. These can be correlated with some spectral oscillations in the satellite images, creating this way an useful acquis to be used in image processing, namely multi and hyperspectral. From the analysis of the spectra it was found that the quartz masses spectra are more distinct. It was also possible to separate from a spectral viewpoint leucogranitic endpoints and test the influence of the substratum exhumed by leaching cover. It was found that with percentages of coating of as 35% the spectral signal is effectively homogenized, turning impossible the lithological discrimination.

Considering the increasing strategic, economic and technological value attributed to pegmatitic resources and considering the inadequacy of many other prospecting methods, the methodologies here explored are effectively applicable.
For their contribution to this project the PROSPEG technical team shows its gratitude to some people, institutions and companies:

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- Dr. Miguel Potes
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- Junta de Freguesia de Vila Boas
- Junta de Freguesia de Funchal
- Junta de Freguesia de Maçães
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- Laboratório Nacional de Energia e Geologia (LNEG)
- Felmica - Minerais Industriais SA
- José Aldeia Lagoa & Filhos SA
- Aldeia & Irmãos SA
- Areias e Britas da Barca Lda.

Introduction
Introduction

Interest and framework of the project

Within the framework of R & D activities of the company Sinergeo Ltd., the project PROSPEG, dedicated to the investigation through prospecting and research of pegmatitic granites, co-funded by ‘ON2 - O Novo Norte’ and QREN through the European Regional Development Fund (ERDF), results from a co-promotion with University of Minho (Centro de Investigação Geológica, Ordenamento e Valorização de Recursos) and the company Geotecnia Consultores, Lda., as consultant.

The overall objective of this project is the development of research activities supported by articulated methodologies and conventional geological prospecting interface, based on lithological and structural mapping, combined with remote mapping analysis, understood as the domain that brings together photogeology and remote sensing by satellite imaging and conventional geological prospecting interface, based on lithological and structural mapping, combined with remote mapping analysis, understood as the domain that brings together photogeology and remote sensing by satellite imaging (Figure I.1).

The integration of these methodologies follows the functional structure of mineral deposit exploration; it is mainly based on scalar manipulation and seeks to have predictive character for outcropping and suboutcropping pegmatitic occurrences with useful economic masses, aiming at situations of potential interest from the innergranite to the outergranite context.

The target deposits include ceramic resources and rare metal mineralization. The selected study areas correspond to Iberian Variscan Chain sectors, in the Portuguese territory.

The receptors of the remote mapping analysis and the remote sensing in strategic prospecting phases of pegmatites may be advantageous in terms of cost/benefit, given the difficulties in implementing other geophysical and geochemical methods; due to the poor contrast between deposit and host rocks.

Considering the increasing strategic, economic and technological value of the pegmatitic resources, one glimpses some effective applicability for the methodologies explored.

Methods of soil geochemistry are described, for example, in Galeschuk and Vanstone (2007) as appropriate for the prospecting of rare metal pegmatites.

Minerometery programs applied in strategic phases provide, according to Trueman and Černý (1982), the most consistent supports of technical decision regarding the continuance of exploration activity. The utilization of research areas uses the quantitative evaluation of oxides and pegmatitic dense silicates (cassiterite, Nb-tantalates, tourmaline, beryl and spodumene), recovered from the bed sediment, as criteria.

There are not known, however, formalized examples and routine procedures for the approach to pegmatite prospecting and exploration. The discovery of deposits continues to rely mainly on geological and structural mapping programs and, at term, target testing by drillings.

In this perspective, and as a mean for the lithological and structural discrimination capable of revealing useful indicators for prospecting, photogeology (aerial photographs and satellite images) is generally used. Its terms and concepts, established for example in Scanvic (1996), are still widely used at regional scales.

As a reference, the work of Ray (1960) presents the fundamentals of photogrammetry and defines the criteria for images assessment that can be used in the definition of lithological and structural attributes. The terms of assessment and classification are the tone (as a qualitative measure of reflectance), the color, texture, pattern, shape and size usually used in conjunction.

Photointerpretation is used in a diffuse manner in pegmatite prospecting (e.g. Pereira, 2009; Minnaar, 2006), using the research and qualification of patterns, colors and textures particularly in regions with good visibility of contours and pegmatite / host rock contrast.

Lately remote sensing through automatic image classification methods is beginning to be explored as a means of consistent physical and chemical contrasts with regard to host rocks hinders the geophysical and geochemical prospecting and exploration. The deterrents to the use of these methods are the low percentage of components with magnetic response and the low density and volume of their masses.

Nevertheless, the scope of their contributions may be greater in deposits with higher volumes. Trueman and Černý (1982) consider, for example, gravimetry as an efficient method for the delineation of the Tanco pegmatite (Bernic Lake, Manitoba). Regarding the regional fund, they found positive gravity anomalies on the internal lithineous units of this body and negative anomalies on the surface contact with the host rhyolites (Figure I.2-A).

Some procedures that make use of geophysical methods on punctual exploration phases are also described. Patterson and Cook (2002) consider, for instance, the use of the radar very useful for the detection of open cavities in mafic volcanic pegmatites.

The chemistry of the enclosing rocks affected by hydrothermal alteration phenomena during the formation of the deposits is discussed, for example, in Beus et al. (1969). In this work, developed on the pegmatic district of Bernic Lake (Manitoba, Canada), they resort to lithogeochemistry to delineate pegmatite related facies of metasomatic influence, manifested by high contents of Li, Nb and Cs (Figure I.2-B). They consider that its development is more pronounced in the dependence of evolved to Na mineralized pegmatites and towards meta sedimentary enclosing rocks.
for prospecting outcropping bodies (Silva, 2009). The mineralogical rips of the residual magmatic composites make feasible its detection in hyperspectral images (e.g. Hyperion). In this sense, it is possible to distinguish alteration parageneses including internal pegmatitic replacement units in bodies with large volumes and outcropping extensions. Peng et al. (2011) propose the combined use of these images with radar images for the definition of pegmatitic targets in regions with significant vegetation cover.

This approach still remains, however, little explored in the sense of finding remote signals with intrinsic coherence, and convertible into application protocols used in programs for research of geographical prospecting. However, by generalizing its use, spectral signatures research alluding to minerals and associations of pegmatic materials and its productive enclosing gains emphasis. The corresponding reflectance measurements collected using spectroradiometers (for in field and in laboratory use), accrédit elements of image classification and target validation. Some recent studies claim this line of investigation applied to pegmatite prospecting (e.g. Peng et al., 2011; Silva, 2009; Fair et al., 2012).

1.1.2 Conceptualization of the distant approach to pegmatite research

The pegmatitic deposits are organized in swarms (Cerny, 1982) - sets of bodies structurally and/or petrogenetically related - which have at regional scales:

- a spatial organization more or less regular within the structure of the host granitic plutons and towards the parental granitic source;
- a more favorable host rock - lithological masses corresponding to granitic fractionation terms that may tend to pegmatites or metasedimentary benches with theological behavior more conducive to the hosting functionality they are considered productive units.

These attributes, resulting from the analysis of genetic and interpretative conceptual models, provide clues for the prospecting and discovery of research targets which are likely to set up deposits with practicable production, after test through drilling. As so, they are seen as exploration guides or indicators.

Conceptually, it is predictable that in some cases their objects can be observed in the remote imagery by providing a set of specific signals, with a certain level of response. These signals are, in principle, susceptible of discrimination using a methodical and systematic exploration of the images (Figure 1.3).

Some signals can be seen as vectors, pointing in the direction of the targets; others express a simple variation of the magnitude of the indicator underlying a target. They have scalar behavior, independent of the direction. These signals can be decomposed into textural, chromatic, morphological and spectral responses that not only describe the information that proceeds from the exploration guides, but also represent the interfering influence of vegetation and meteorization products, resulting from different water-rock and mineral-rock interactions (chromating halos, clay and oxides with different degrees of moisture).

Hence, under functional criteria, intrinsic and extrinsic signals are separated from the indicators. The latter may functionally they are considered productive units.

Thus, under functional criteria, intrinsic and extrinsic signals are separated from the indicators. The latter may present as the most difficult to understand, and even allocate the inefficiency of remote sensing methods. The tools for image enhancement can be combined in order to make them more noticeable. Remote mapping analysis should thus be oriented towards the research for signals that are both reliable and clear evidences of pegmatite presence, at a regional scale.

1.1.3 General objectives

The following objectives were hierarchized by the scope of their contributions to the usefulness of the project:

1. conversion of prospecting guides or indicators to remote signals of morphologic, chromatic, textual and spectral response that are reliable and clear evidence of the presence of pegmatites, to be seen as tools for prospecting of pegmatitic bodies, in a strategic phase;
2. definition and introduction of detail to the prospecting criteria - geological, geomorphological and structural - of pegmatites in the Portuguese territory through research for structures of favorable enclosing, and geometric configurations suggestive of credible granite pegmatite relations;
3. obtaining of spectral data identifying pegmatites and fertile lithologies or indicators of the presence of pegmatites;
4. deduction of 3D conceptual models about the organization and morphology of bodies from detailed geological surveys and drillings, which are representative of the tectonic-inorganic conditioning of pegmatites within the Iberian Variscan Chain.

5. intersection of deposits by drillings on the range of the most shallower 50 m - the ultimate goal of the prospecting program.

12 Framework of the prospecting and extraction of pegmatitic resources in Portugal

The mining industry investment in prospecting, research and exploration of pegmatitic granites had the production of quartz, feldspar and mineral masses of ceramic-appetence (undifferentiated spilitic pegmatite mixtures with Li) as its main objective.

The market receptors of the raw materials are fundamentally national, regarding the supply of the glass and ceramic industries and the production of metallic silicon and ferrosilicon. In some cases reserves of beryl that came to purvey external metallurgical industries were declared.

Tables 11, 12 and Figure I.14-A provide a perspective on the pegmatitic deposits with current production in the Portuguese territory. According to data from DGEG (Direção Geral de Energia e Geologia), for the period of 2011, are counted 15 concessions with active mining and 21 with suspended mining. The productions reported by dealers are relatively low. DGEG organizes them into two productive components - producing less than 50,000 tons/year (Class A) and more than 50,000 tons/year (Class B). Specifically, the concession of Vila Seca, in Viseu, is the only type B deposit with production exceeding 50,000 tons/year and record of underground workings. The type of extraction adopted is usually on open pit, and from the production point of view are generalized operations of manual selection for ascertaining of useful fractions of the deposit (quartz, potassic feldspar and sodium feldspar), in the quarry front, after fragmentation/reduction of the caliber. Optic separation equipments are lately used in the improvement phase.

Table I.13 lists up contracts and requests for prospecting and exploration, with the intention to exploit pegmatitic mineral resources. Their cartographic distribution is represented on the map of Figure I.14-B.

The exploration, prospecting and research follows the regime established by the Basic Law on Natural Resources (DL 90/90), and the legal procedures framed by law DL 88/90 - Basic Law on Natural Resources - legal regulation and use of natural resources - mineral deposits, hydromineral resources, and geothermal resources in the public domain.

- DL 88/90 - laws concerning prospecting, research and exploration of natural mineral deposits.

In Portugal the potential use of metallic Li from Li minerals in pegmatites has been equated (e.g. in 2011 it was devoted to this topic the Symposium Benelux). The proven occurrence of petalite, spodumene, lepidolite and Li phosphates, which have been seen as ceramics materials benefiting the industrial flux process, arises the intention of its use, which, although with no current competitive price relatively to the production of Li carbonate from precipitated salines, hydrothermal hectorite and volcanicogenic-exhalative jadarite, is justified by the increased demand of Li phosphates.
### Table 1

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<tr>
<th>Cadastre</th>
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<th>Concessionaire</th>
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<td>Feldspar, Pegmatite</td>
<td>Guarda</td>
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<td>C-105</td>
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### Table 2

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<th>Substance</th>
<th>Actual situation</th>
<th>District</th>
<th>County</th>
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<td>C-108</td>
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<td>Feldspar, Pegmatite</td>
<td>Guarda</td>
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### Table 5

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<th>Actual situation</th>
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<td>C-111</td>
<td>GONÇALO</td>
<td>SABLES S. A.</td>
<td>Li,Sn</td>
<td>Feldspar, Pegmatite</td>
<td>Guarda</td>
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### Table 6

<table>
<thead>
<tr>
<th>Cadastre</th>
<th>Holder</th>
<th>Area</th>
<th>Substance</th>
<th>Actual situation</th>
<th>District</th>
<th>County</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-112</td>
<td>GONÇALO</td>
<td>SABLES S. A.</td>
<td>Li,Sn</td>
<td>Feldspar, Pegmatite</td>
<td>Guarda</td>
<td></td>
</tr>
</tbody>
</table>


| Inventory of contracts and requests for prospecting and exploration to date 05-05-2013. Source: DGEG |
1.3 Selection and framework of study areas for strategic prospecting actions

In photointerpretation and remote sensing methodologies testing for pegmatite research, in a strategic prospecting phase, the first approach to the targets is regional, and should focus on a number of broad areas in a territorial coverage point of view, which are recognized as or hypothetically fertile in pegmatites with proven economic interest.

This way, the preliminary approaches have focused on the prospecting work in areas with numerous traces of mining activity for the production of quartz and ceramic feldspar. These are considered to be the most promising, concerning the possible detection of bodies with large surface and sub-surface dimensions.

It was defined an initial set of intervention areas distributed in the north, center and south regions of the country that were designated by A (Pontes da Barca-Terras de Bouro), B1 (Chaves), B2 (Tâmega), B3 (Murça), C (Penedono-Armamar), D (Viseu-Cabeceiras de Basto), E (Guarda-Belmonte), F (Idanha-a-nova), G (Torrão-Montemor).

This way, the preliminary approaches have focused on the prospecting work in areas with numerous traces of mining activity for the production of quartz and ceramic feldspar. These are considered to be the most promising, concerning the possible detection of bodies with large surface and sub-surface dimensions.

The delimitation of areas seeks to represent the widest possible diversity of enclosing pegmatite intrusion and filiation relationships, granite-pegmatite, expressing different levels of exhumation and structures of placement of swarms and bo-

1.3.1 Elements of geographical, geomorphological and vegetation framing

The areas selected for the study have their geographical coordinates identified in Table 1.4. From the administrative point of view they cover the districts of Viana do Castelo, Braga, Vila Real, Viseu, Guarda, Castelo Branco, Évora and Santarém.

The size of the areas is between 179 km² and 397 km² (Table 1.5), considering these, the most appropriate comprehensive coverage for the prospecting supported by remote mapping analysis. Its geographical position is given on the map of Figure 13.
Lineaments of NE-SW azimuth in the areas A and B2, and with guidelines NNE-SSW and straight tracks in the areas B1, D and E are determinants of each area's physiography. These directions and the domes of the massifs appear truncated by E-W fractures. The direction NW-SE seems to influence most strictly the remaining "Beiras" areas.

Trends in spatial planning, including land use, were weighted by the need to find superficial exhumation indexes - parameter that qualifies the % of the lithologic substrate coating. The suitability maps and land uses according to the map of land use of the Environment Atlas 1980, are shown in Figure I. These urban fabric is included in complex uses (areas of human intervention) and occupies a major part of the areas in a discontinuous way. In particular the areas B1 and G manifest extraordinarily high occupation percentages of this kind. Areas A, B2, D and E are distinguished by lower spatial definition of the complex occupation. Here, and in most areas distributed throughout the north and central regions, agricultural uses are organized in a small scale farming environment, with predominating forest spaces (with pine and eucalyptus) or non-forested (bare rock). The occupation percentages are described in Table I.6.

In Area G, Montemor, with lower slopes and transition to Mediterranean climate with subtropical influence, the presence of evolved altered mantles is reflected in the effective coating of the lithologic substrate, which implies a lower probability of success on the approach supported by remote mapping analysis and sensing. The altered mantles are polychromatic, with ochre colors predominance.

In Table 16 the superficial exhumation qualitative classes weighted from the percentages of occupation and land use are defined, which allow to predict better conditions for the development of more successful operations of remote sensing in the areas A, B2 and E.

The analysis had not, however, accounted for the covering by lichens and mosses that can be extended on the exhumed rocks; these, by producing the homogenization of the remote signal also decrease the possibilities of discrimination of the substrate in distant approach (e.g. Riaza Garcia, 1994; Robaça, 2001).

When a deposit is recognized, its exploitability is also function of the constraints that introduce the spatial planning instruments.

Figure I.8 shows the conservation areas in Portugal (according to the records of 1980 and 1991 of the Environment Atlas). The legal protection of these spaces prevents mining activities and includes restrictions on prospecting and exploration activities that underlie land movements and drilling.

Through cartographic information overlap (Fig. I.8 A) it can be recognized the overlay of Peneda-Gerês National Park in the area of Ponte da Barca (A) and Serra da Estrela Natural Park in Guarda (E).

The distribution of special protection areas for birds and CORINE biotopes has the same geographic reach and includes a larger number of spaces (Fig I.8 B). The areas B1, D and F are conditioned by these protecting statutes, without, however, known impediments to prospecting, exploration and resource use.
and B3), the Central Iberian zone (ITCz) (areas C, D, E and F) bed in the Galicia Trás-os-Montes zone (z GT) (areas A, B1, B2 and Farias et al. (1987) defines the framing level of 1st order. Proposed by Lotze (1945) and revised in Julivert et al. (1974) differentiated paleogeographic structure and context, with limits Devonian and Permian) imposes its structure on them. The Variscan Orogeny (between the Upper Proterozoic to the Carboniferous and granitoid rocks that intrude them. The Variscan Orogeny (between the Devonian and Permian) imposes its structure on them. The partitioning of the Iberian Massif in areas with differentiated paleogeographic structure and context, with limits proposed by Lotze (1945) and revised in Julivert et al. (1974) and Farias et al. (1987) defines the framing level of 1st order. According to these divisions the studied areas are inscribed in the Galicia Trás-os-Montes zone (ZGT) (areas A, B1, B2 and B3) the Central Iberian Zone (ITC) (areas C, D, E and F) and Ossa Morena zone (ZOM) (area G), as shown in Figure I.9. The following fundamental characteristics of the compartmentalized terrain portions (e.g. Ribeiro, 2013) are recognized:


- ZOM - comprises polygenetic formations of the Upper Proterozoic to Paleozone and the south Portuguese ophiolitic complexes. Its structural organization results from the deformation of three deformation phases in the Variscan Orogeny, as proposed by Ribeiro (2013):
  - 1st Phase (D1) - compressive, originates folds with NW-SE axis with vertical axial plan in ZCL and differentiated vertical axes in the parasitic structures of the Variscan Orogeny. In ZOM are attributed thrusts to this subhorizontal phase related to the obduction of ophiolite complexes of the south Portuguese sector (with N to NE direction).
  - 2nd Phase (D2) - tangential, induces subhorizontal displacement with mantle-fold formation in the parasitic ophiolite complexes of central Trás-os-Montes. In ZOM it causes lying flat folds and thrusts with transportation from N to SW.
  - 3rd Phase (D3) - covers all the zones developing, in its dependences, folds with subvertical axial planes. Concurrently with the D3 phase are defined at a megascale level, corridors and ductile-fragile and fragile shear zones, with vertical plan and NNE-SSW azimuth (e.g. Pego-Verm fault). At this stage are still retained, in a transparent regime, previous structures possibly formed in D1 or D2 (e.g. shearing zone Vigo-Régua).

The crustal thickening associated with the Variscan collision resulted in the production of granitic magmas by anatexia. It follows, in the 3rd phase, the installation of the main granites and related pegmatites, hosted or intruded on its periphery. Ferreira et al. (1987) classifies them according to their installation period relatively to stage D3 in granites prior- syn- and late to post-D3. The geographical distribution, adapted from Ribeiro and Coke (2006), is given in Figure I.10. In Table I.7 are provided some petrographic references and chronological ages.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Common facies</th>
<th>Ages U-Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granitoids late to post-D3</td>
<td>biotite granites, biotite-muscovite and two-mica sometimes porphyroid</td>
<td>300-290 Ma</td>
</tr>
<tr>
<td>Granitoids syn-D3</td>
<td>leucogranites and two-mica granites with variable deformation, granodiorites and biotitic granites with variable deformation</td>
<td>320-310 Ma</td>
</tr>
<tr>
<td>Granitoids prior-Variscan</td>
<td>granitoids of the Upper Proterozoic to Lower Paleozoic (orthogneisses)</td>
<td>-</td>
</tr>
</tbody>
</table>

Adapting recent papers on the typology and petrogenesis of granites in northern and central Portugal (Azevedo and Aguado, 2001; and Noronha et al., 2013), are referred the following key features:

- Syn-D3 granites (or syntectonics) - are contemporary to the formulation of the D3 foldings, occupying their hinge zones with NW-SE azimuth, include biotite granites and granodiorites, volumetrically minor, and predominant two mica facies, S-type, peraluminous, attributed to the partial hydrated melting of mesocrustal levels.
- Late to post-D3 granites (or late-tectonics) - intrusive in the syn-D3 plutons, include granodiorites and biotitic non-zonitic granites, usually porphyroidic, bearers of mafic microgranular enclaves, with low peraluminosity and without evident deformation. Represent type I or transitional I-S magmas produced by crustal magmas hybridization with basic magmas from the lower crust and mantle, a process that in the Variscan Chain tended to be favored, in a context
of orogenic collapse, by deformation of the asthenosphere. Also include later biotic-muscovitic granites with more marked crustal affinity, hypothetically attributed to fractionation processes developed from these.

- Post-D3 granites (or post-tectonics) - generally correspond to biotic faces, usually porphyroid, sub-alkaline, I-type, organizing concentrically zoned plutons, discordant to regional structures and late granites. Represent magmas from the lower crust, with contribution from the mantle, installed in higher structural levels (6-7 km). An analysis of the distribution of relatively large Variscan structures from the north and centre of Portugal can be found in Dias and Coke (2006). The authors propose the following megastuctures and fundamental axes, viewing them as crustal anastomoses formulated during extensional phases of the lower Paleozoic, and suggest their fundamental role on the Variscan granites implantation coordinates:

- Shear zone of Vigo-Amarante-Régua – with NW-SE orientation, controls the installation of syntectonic circumscribed plutons and hard-tectonic massifs;
- Axis Monção-Mondim-Murça-Moncorvo – representing the installation and extension of syntectonic two-mica massifs in Trás-os-Montes;
- Axis Porto-Viseu-Guarda and Chaves-Miranda do Douro – smaller alignments indicated by syntectonic two-mica granites;
- Régua-Verín fault – megascalar late-D3 structure with polyphase reactivation, NNE-SSW orientation, which controls the post-tectonic granites installation from the massif of Vila Pouca de Aguiar.

13.2.2 Geological context

The geological mapping on 1:500 000 scale from Oliveira et al. (1992) establishes the necessary geological setting from the selected areas, supporting the discrimination of granitic facies in the considered domains and developing the lithostratigraphy of the terrains from zCI, zGTM and zOM covered by the delimitation of the areas.

In the north and central Portugal are recognized contact syn, late and post-tectonic granites. In the areas A, B2 and B3 the syntectonic granites are those with greater representation and correspond to two-mica facies. Are also recognized in the area A sets of granites and granodiorites syn to late-tectonic and monzonitic porphyroid late-D3 granites (Figures I.11 and I.12-B, C).

Other granites spatially associated with these areas are post-tectonic, mainly biotic and generally porphyroid. They have greater representation in the geological mapping of areas B1 (Chaves), emplaced according to the Régua-Verín fault (Figure I.12-A).

The late to post-tectonic granites, comprising biotic faces with porphyritic tendency, and muscovitic biotic granites, predominate in the Iberian areas (C, D, E and F). In the areas D and F are also recognized spatially related quartzdiorite and coeval biotic granodiorites (Figures I.12, 14).

In the Area G are represented diorites, gabbron tonalites and syntectonic porphyroid biotic granites in contact with granodiorites and late-tectonic tonalites (Figure I.15). In this sector the granites have adakitic chemism (Lima et al., 2012).

In any of the considered areas numerous veins of basic rocks intersect the granites. In particular, in the mapping of areas A and E, are even represented some thick dykes (Figures I.11 and 13). They correspond to dolerite albitic rocks, quartziferous calc-alkaline microgranites, lamprophyres with diotric composition and amphiobic microdiorites.

Ages were obtained by K/Ar method between 189 ± 9 Ma and 226 ± 2 Ma. According to Tena (1981), in a study on the petrology and geochronology of this type of dykes in the Iberian region, they attribute their emplacement to the Mesozoic, relating them to the volcanic activity driven by the Atlantic Ocean opening. Ages were obtained by K/Ar method between 189 ± 9 Ma and 226 ± 2 Ma.

The paratourchonic lithostratigraphic units of the ZGTM are polygenic; they are represented in the areas B1, B2 and B3 by the Structural Domain of Carnaxide (Silurian), described in mapping 1:500 000 as upper and lower schists, quartzites and acid tuffs (Figure I.12).

In the ZCI are located, regarding the areas C, D, E and F, the formations of the Armorican Quartzite of Valongo, Ordovician, and the formations embedded in the shale-greywacke complex. Cambrian of Excomugadela, Desejosa and Santa Justa, Neoproterozoic of Bateiras and undifferentiated formations of the Iberian Group. They correspond to sequences essentially detrital, with turbidite affinity.

In the area F are even discriminated sandy and conglomeratic deposits distributed according to Cenozoic tectonic depressions (Figure I.14). In the organization of area G, the enclosing formations of granitoid include basic volcanites, schists and phylites from the Volcano-sedimentary Complex of Moura - Santo Aleixo, old-Ordovician Silurian and sets of granite rocks and Proterozoic migmatites.
I. Introduction

Figure 1.2
Geological maps from Chaves (B1), Vimeiro (B2) and Marão (B3) sectors - adapted from the geological map of Portugal, northern sheet, 1:500,000 scale (Oliveira et al., 1992)

Figure 1.3
Geological maps from Penedono-Armamar (C), Viseu-Satão (D) and Guarda (E) sectors - adapted from the geological map of Portugal, northern sheet, 1:500,000 scale (Oliveira et al., 1992)
I. Introduction

3.2.3 Regional divisions of pegmatites

In northern and central Portugal, most pegmatites arise in a cartographic space more or less coincident with the limits proposed for the Central Iberian Zone of the Iberian Variscan Chain. In this sense, Leal Gomes (1994) and Leal Gomes and Nunes (2003) introduced for the regional organization of pegmatites in the north and center of Portugal the divisions Variscan Pegmatitic Province and Central Iberian Pegmatite Belt (CIPB), adapted from the layout of subdivisions advanced by Černý (1982). The remaining divisions considered by that author are also retained, with the inherent adjustments to the peculiar character of the structures and compositions found in pegmatites. They are presented as follows:

- **Variscan Pegmatitic Province** - corresponds to the broadest division, and includes all pegmatites distributed in the Iberian massif, somehow related to the metamorphism and the Variscan granitoid installations.

- **Central Iberian Pegmatite Belt (CIPB)** - covers the pegmatites mainly distributed in the ZCI and the outcrops situated in the parautochthonous grounds of ZGT, considering, however, that the pegmatites are allochthonous in ZGT, depending more strictly on the granitization and Variscan heat dissipation, more extensive in the ZCI. The orientation of its cartographic stretching follows the Ibero-Armoric Arc and also the stretching of the Syn and late-tectonic granitic masses (Figure I.16).

- **Pegmatite or pegmatite field** - designates pegmatic groups occurring in spatial proximity, genetically related or not with a common granitic intrusion but structurally conditioned by it. Covers pegmatites and aplite-pegmatite as well as other potentially pegmatoid veins and dykes, with diverse genesis - hyperaluminous metamorphic segregations, quartz veins, masses or bodies formed by deuteritic alteration, microgranitic hypabyssal dykes and porphyries. The fields are predominantly inner or (perigranitic) outergranitic with installation within the granitic masses or enclosed in metasedimentary formations. Due to the complex evolution of the generator plutonite, they include one or more pegmatic swarms.

Pegmatic or aplite-pegmatic swarms describe a set of cogenetic pegmatites which emplacement is related to a well-defined evolutionary step of the parental plutonite and/or with the local stress field well-delimited in the Variscan chronology. This division defines a pegmatic group, most recently used (e.g. Trabulo et al. 1995; Leal Gomes et al., 2009; Dias et al. 2009) to describe innergranitic coupled pegmatites. Very often, in these cases, one of the bodies represents a more advanced state of group fractionation.

- **Pegmatic or aplite-pegmatic body** - refers to a lithological portion with residual granitic composition with primary quartz, feldspar and muscovite minerals. They may present great diversity of facies and accessory parageneses. They look more or less homogeneous in the case of bodies with existence of aplitic and pegmatic facies. Other bodies are heterogenous and hetero-granuland zoned, established by centrifugal fractionation, and organized according to the diagrams of Figure I.17 in the border zone, wall zone, intermediate zone and core (mainly quartzose). The morphology, paragenesis and mineralization are attributes of a body. Are separate from the morphological point of view irregular bodies, referred as pockets and tabular or vein bodies (all late bodies). Regarding specific mineralization they adjust to types LCT (with Li, Cs, Ta) or NYF (Nb, Y and F), as proposed by Černý (1982).
The focus areas of this project can be seen as compartments of the Variscan Pegmatitic Province and Central Iberian Pegmatite Belt, representing sectors from pegmatite fields where each body is distinct from a structural and paragenetic point of view within the larger outcropping areas. These areas have common characteristics such as a large structural, morphometric, mineralogical and economic diversity.

In the Portuguese context, the installation of syn and late-tectonic granites is responsible for the diversity of pegmatitic bodies that result from the fractionation of those granitic magmas. Generally, the ones hosted in granites correspond, predominantly, to large dimension pegmatites with ceramic potential and no significant enrichment in rare metals. They relate more closely to biotite porphyroid granites, late to post-tectonic, regarding the third phase of Variscan deformation, emplaced in dome portions. They correspond to bodies lightly to strongly zoned, locally mafic with bulky replacement units that comprise phosphates and sulphides. Mostly the innergranitic pegmatite bodies acquire irregular shapes. Geometries like sill/vein bodies are less prevalent.

In an outergranitic context, installed around circumscribed syntectonic two-mica granitic plutons, predominates aplite-pegmatites organized in vein or sill swarms. The aplite-pegmatites emplaced in this context, with greatly evolved textures, manifest marked LCT specialization and are enriched in rare metals. Li minerals with proven occurrence are petalite, spodumene and lepidolite. The Sn, Nb and Ta are the dominant mineralization.

The extraction cycle dedicated to Sn and W in the 2nd half of the 20th century, led to an increase of research in the areas covered by the project. This is the main reason for the extensive bibliography to be presented in this paper. In the remaining areas - B2, B3, C, F and G - the prospects for detecting deposits are predictably lower. As so, they were prospected by the Junta de Energia Nuclear in the 70s also result, in some cases, from late hydrothermal reactivation of pegmatitic dykes, occurring in these the precipitation of autunite and tourmaline.

### I.3.2.4 Mining provinces and strips

To the Variscan Pegmatitic Province, other regional divisions established for the deposits represented in Portuguese Mining Charter of the 1960s overlay. Resuming the mineralization axes advanced in Nervo (1944), this author proposes the Metallogenic Septentrional Tin-wolframite division, which covers the pegmatitic and aplite-pegmatitic dykes and outergranitic greisens mineralized with Sn-Nb-Ta. It is also included here W mineralized quartz veins resulting from the trans current reactivation of pegmatitic bodies during the late Variscan period.

The extractive cycle dedicated to Sn and W in the 2nd half of the 20th century, guided the research of these veins in northern and central Portugal.

That author also classifies the Portuguese Uraniferous Province and its divisions in the Beira regions (uraniferous Sub-province of Benel) in Viseu-Tondela-Gouveia strip (mining district of Urgaçã), Monções - Trancoso-Celanova da Beira strip (mining district of Guarda), and Guarda-Belmonte-Sabugal strip (mining district of Guarda). The mineralized veins, prospected by the Junta de Energia Nuclear in the 70s also result, in some cases, from late hydrothermal reactivation of pegmatitic dykes, occurring in these the precipitation of autunite and tourmaline.

### I.3.3 Selection of areas for implementation of prospecting routines

If on one hand the current state of knowledge about each of the selected areas is very different, on the other hand, as seen in Table I.6, the corresponding outcrops obtained for each area, anticipate differentiated options or response possibilities in remote mapping analysis of signals which identify the presence of pegmatites. The combination of these constrains motivated the election as major areas of study the areas A, B1, D and E, in which were undertaken geological prospecting programs with field surveys. It was also considered to find in these areas larger concentration of exploitations in pegmatites and bodies with higher reserve quantity, keeping presently the mining interest (view Figure I.4).

In the remaining areas - B2, B3, C, F and G - the prospects for detecting deposits are predictably lower. As so, they were destined to a test of exploited analytical remote methods to carry out forward in the project.

### I.4 Data typology and methodological protocols

The mining prospecting articulated by valences at the level of remote sensing techniques and geological exploration, proposed as a less conventional approach to the research of pegmatitic deposits, involved a wide range of data, methods and analysis techniques.

The data are described here - starting and acquired - that used in conjunction and submitted with an order query, and analysis according to the diagram in Figure I.18, allowed the delimitation of research areas and the establishment of prospecting programs from strategic to punctual scales. These involved geological mapping on 1:5000 and 1:10000 scales, topographic surveys and drillings, overlocking the intersection of deposits.

The collection of reflective data (spectroscopy) of pegmatitic materials and productive enclosing facies, detected by geological mapping and drillings in the research areas, appears as a line of investigation developed to term the project, which had as its main objective the establishment of a spectral database.
concept of index or occurrence is adopted by Siorminp, referring to any mineralization or mineral concentration suitable or not for economic exploitation. Most occurrences were exploration targets in the past, representing abandoned mining concessions. They are registered in the corresponding database by substance or substances which constitute the useful mineralization of the deposit.

These elements were extracted, subjected to georeferencing and vectorization conversion with pGisG software (free access, Anguix et al., 2008), gathering in SIG documents to enable manipulation. The coordinate system used was the datum WGS 84.

I.4.2 Acquired data

It was acquired the following set of satellite images:
- Images available from Google Earth Pro;
- Images from sensor Landsat (available for free on NASA's website);
- SPOT satellite images (acquired from the company SPOTIMAGE);
- Geoscience satellite images (acquired from the company GeoEye).

The images have the characteristics presented in Tables I.8 and I.9 and map coverage of Figure I.19.

For the handling and implementation of image processing operations was used the software SPRInG (free access, Câmara et al., 1996 and Santos et al., 2010). The procedures used resume the methodological foundations established in multiple specialty references (e.g. Gupta, 2001; Sabins, 2007; Chuvieco, 1996).

The collection of spectral measurements was made by outsourcing services, contracted with the University of Évora. It was used the portable equipment FieldSpec-UV/VNIR from Analytical Spectral Devices (ASD), for obtaining reflectance and transmission measurements calculated by comparison with a white reference.

The spectroradiometer used has a spectral resolution of 3nm to 700nm and an integration time, manually adjustable, of 17ms to several minutes. When used without any additional accessory, the light is captured with an observation angle of 25°.

This angle may be increased or decreased according to the size of the sample to be analyzed, the observation angle and the specific referrals (e.g. Gupta, 2003; Sabins, 2007; Chuvieco, 1996).

Technical adjustments of the equipment are described in Table I.10.

I.4.1 Previous data

The relevant starting data came from cartographic, geological and topographical databases and mining data. From these, and by the review of conceptual emplacement models of pegmatites and data published regarding pegmatitic fields, settles the first strategic approach to pegmatite productive corridors and massifs in the selected areas.

The geological information, responsibility of the Portugal Geological Survey (Laboratório nacional de Energia e Geologia), is published in the Geological Map of Portugal 1:50 000.

The topographic registry was consulted from military maps on 1:25 000 scale published by the Instituto Geográfico do Exército (IGeoE).

The knowledge about the distribution of pegmatitic occurrences was done by consulting the Siorminp database. The knowledge of the distribution of pegmatitic occurrences was done by consulting the Siorminp database.

The geological information, responsibility of the Portugal Geological Survey (Laboratório nacional de Energia e Geologia), is published in the Geological Map of Portugal 1:50 000.
I. Introduction

Spectrum domain

<table>
<thead>
<tr>
<th>Spectrum domain</th>
<th>ETM+ (Landsat 7)</th>
<th>HRVIR (SPOT 5)</th>
<th>Geoeye</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible</td>
<td>Blue</td>
<td>B1 - 0.45 - 0.515 um</td>
<td>B1 - 0.45 - 0.515 um</td>
</tr>
<tr>
<td></td>
<td>Green</td>
<td>B2 - 0.525 - 0.605 um</td>
<td>B2 - 0.52 - 0.68 um</td>
</tr>
<tr>
<td></td>
<td>Red</td>
<td>B3 - 0.63 - 0.69 um</td>
<td>B3 - 0.58 - 0.75 um</td>
</tr>
<tr>
<td>Infrared</td>
<td>Neat-infrared</td>
<td>B4 - 0.79 - 0.90 um</td>
<td>B4 - 0.79 - 0.90 um</td>
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<td></td>
<td>Mid-infrared</td>
<td>B5 - 1.59 - 1.75 um</td>
<td>B5 - 1.59 - 1.75 um</td>
</tr>
<tr>
<td></td>
<td>Thermal-infrared</td>
<td>B6 - 2.09 - 2.25 um</td>
<td>B6 - 2.09 - 2.25 um</td>
</tr>
<tr>
<td></td>
<td>Mid-infrared</td>
<td>B7 - 2.09 - 2.25 um</td>
<td>B7 - 2.09 - 2.25 um</td>
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<tr>
<td>Panchromatic</td>
<td>Panchromatic</td>
<td>B8 (PAN) - 0.52 - 0.90 um</td>
<td>M (PAN) - 0.64 - 0.68 um</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Features of the portable spectroradiometer FieldSpec UV/VNIR</th>
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<tbody>
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<td>Spectral domain: 450 - 1000 nm</td>
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<tr>
<td>Spectral resolution: 1 to 3 nm (35 nm to 700 nm)</td>
</tr>
<tr>
<td>Integration time: 17 ms to several seconds</td>
</tr>
<tr>
<td>Collection rate: 0.7 spectra/second (solar illumination)</td>
</tr>
<tr>
<td>Noise (radiance): 5.0 x 10^-8 W/cm²/nm/sr at 700 nm</td>
</tr>
<tr>
<td>Precision: 5% at 400 - 900 nm</td>
</tr>
<tr>
<td>Observation angle: 130° and 180°</td>
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<td>Weight: 12 Kg</td>
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</tbody>
</table>

Orogenic pegmatite setting
Orogenic pegmatite setting

In this chapter the conceptual models on pegmatites emplacement are established. These gather occurrence cri-
teria and provide an insight on pegmatite bodies and swarms organization, which can be used as a basis for setting
organizational paradigms and conspicuous bi-dimensional sections of pegmatite - enclosing rock relations, which
can be glimpsed by observation of remote images. With this perspective the indicators and their specific signals are
discussed, under the scope of remote mapping and sensing.

The conceptual models that have been proposed to explain the emplacement of pegmatite sets and distribution
explore kinematic relations - stress fields that influence the geometries of the bodies - or petrogenetic relations - of
granite-pegmatite affiliation. By possessing intrinsic coherence and reproducibility they convert into indicators of
great efficiency and application in prospecting programs. As stated by Trueman and Černý (1982), this level of un-
explored kinematic relations - stress fields that influence the geometries of the bodies - or petrogenetic relations – of
terria and provide an insight on pegmatite bodies and swarms organization, which can be used as a basis for setting
the demarcation of strips and productive massifs to be aware of in the satellite images processing.

II.1 Models of pegmatite emplacement

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From the main trends of fractionation of the pegmatites, regarding parental granitic stocks and using as indicators
specific mineralogical associations and the minerchemistry of key and accessory stages, the model of Černý (1982)
proposes that the location of the pegmatite sets and the cartographic disposal of the fields obey to a zonography
conditioned by the distance to the parental granite source. The pegmatites located in the apical portions of the plu-
tonic and perigranitic domes are little evolved. The possibilities of enrichment in rare metals and textural and para-
genetic diversification (increase in the number of internal primary zones and diversity and extent of late metamor-
sic units) are incremented by the distance to the granite generator in the spread of magmas into the enclosing. The
irregularities imposed on this distribution occur under the effect of the local anisotropy influence and surrounding
structural context. The granite - pegmatite field transition is gradual, spread in vertical to subhorizontal directions,
defined according to Figure II.1.A. The greater differentiation of bodies in distal positions is explained by fractionation
and volatile enrichment in conditions of lower crystallization temperature.

The Černý (1986) kinematic model of pegmatitic intrusions-consolidation suggests the influence of the lithostatic
pressure (depth-sensitive), the configuration of the local stress fields and the surrounding metamorphic context, on
the forms, dimensions and strikes of pegmatites. In the upper crust, in environments subject to low confining pres-


In the context of the Iberian Variscan Chain, with various phases of deformation and syntectonic polyphase ins-
tililation of granitic bodies, with local directed constrictions and interfering on the opening of distalional hosting
spaces, the acquisition of morphologies does not strictly follow the Černý model (Leal Gomes and Nunes, 2003).

This model applies more strictly to outergranitic bodies and is best understood when the intrusion of pegmati-
tic magmas occurs in a well-defined compressional orogenic episode, without interference from prior deformation
structures that may modify the tension relations. It also does not take into account the structures polyphasic reacti-


Regarding the pegmatic magma generation potential in the interior of the granitic columns subject to differen-
tation, authors like Silva (2000) and Leal Gomes and Nunes (2000), invoke the role of mixing mingling processes -
hybridization of pegmatic magmas by a mixture with more basic magmas - to explain the distribution of pegmatite
bodies with conditioned alignment to certain proliferation corridors of mafic granomgranulatic envelopes. The cor-
responding enclave swarms can assume a megascalar expression, defining patterns that are coherent with the injection
trajectories of pegmatic differentiates. Regarding the pegmatic productivity is concerned the content transference
of depressors elements of liquids and mineralizers - higranogranophile and volatile - to the felsic magmas, rising its
potential as a generator of pegmatites (Leal Gomes and Nunes, 2003).

The production of pegmatite that cross the granitoid contact with the enclosing metasedimentary formations. These assume
the configuration of subparallel silts to the granite contact, being subhorizontal at distal locations (furthest from the
plutonite) and inclined towards the granite when rooted therein (crown sheet type) or granite marginal. The most
preponderant influence of the granitic magma displacement, near the massal, and the regional stress field in distal
locations (creating distalional hosting spaces) helps to understand this setting. In Figure II. C is presented the con-
ceptual framework adapted from the work of Leal Gomes and Nunes (2003). In this scheme, the placement of the
horizontal tabular pegmatic bodies above the granitic domes is dependent on the internal relaxation of granitic
stocks deployed in uplifted, according to the Brünn and Pones (1988) model, for installations in fragile conditions.

In contrast to previous models of pegmatite emplacement, the bodies installations organization is less known in an
inserirangenic context. Nevertheless, some recent work by Leal Gomes and Nunes (2003), Leal Gomes (2003) and
Guimarães (2002) gather aspects that may indicate acquisition of form and internal structure trends in pegmatites.
By using notions of morphocopy and morphometry referring to the three-dimensional sections and by analyzing
mesoscalar structuring devices (independent of the size of the body and therefore invariant in a scalar point of view)
observed in pegmatites of the CPB, they propose trends of placement and sequencing of shapes and dimensions sta-
bilized in the granitic domes organization, supporting its usefulness for defining levels of pegmatite emplacement.
In these studies, they invoke the Brünn and Pones (1988) kinematic model about the evolution of granitoid installations
by ballooning in shearing zones, to explain the rise of pegmatite differentiates according to tendentially diapiric
shapes. They presuppose the possibility of a persistent and polyyclic mobilization of magmas with more acidic com-
position (bolder), towards the core of the plutonic chambers, which may suffer lateral expansion due to a process
of gravitational origin (floatability stress or buoyancy) or due to the cessation of vertical displacement, after being detai-

develop into a rigid interface. From these, and by differentiation, they can evolve to pegmatic bodies. The displacement in
the granitic chambers occurs by density and viscosity contrast between the felsic or pegmatic acidic magmas and the
granitic magma with higher level of crystallization and, therefore, denser and more viscous. The geometries of the
pegmatic bodies that result from ascension mobilizations are classified as a type of pegmatic bubble (embryonic
geometries). Bouglass, inverted droplet or turnup and dumbbell. The latter, observed in morphologically matured
bodies, simulates the lateral expansion to which the parental plutonite is subjected to. These geometries can contain
pyramidal and hemispheric protuberant devices, indicators of ascensional displacement. The conceptual model
presented in Guimarães (2012) can be viewed in Figures II.1D and E.

Regarding the pegmatic magma generation potential in the interior of the granitic columns subject to differen-
tation, authors like Silva (2000) and Leal Gomes and Nunes (2000), invoke the role of mixing mingling processes -
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the demarcation of strips and productive massifs to be aware of in the satellite images processing.
II. Orogenic pegmatite setting

The possibility of magma portions enriched in fluids being enclosed in the vicinity of the plutonic chambers apical zones is also pointed in Guimarães (2012) as a determinant of the pegmatitic potential. The enrichment process in volatiles tending to exceed the lithostatic pressure and temperature (when the pressure of volatile components in the magma exceeds the lithostatic pressure). The decompression is more efficient in terms of volatile components release, triggering fluid immiscibility during primary exsolution. Other part of the fluid is released after crystallization during the secondary exsolution. The fluid bubbles can be preserved during the fast cooling of the magmatic chamber, converting into cavities, coated or not by minerals. The hydraulic stress resulting from the release of the volatile content is responsible for the bubbles ascendant displacements and translates into the development of hydraulic decompression fractures, orthogonal to the displacement (Dias et al., 2003).

A study about the geometric analysis and kinematic reconstitution of the residual magmatic composites collecting structures in pegmatite fields of northern Portugal can be found in Leal Gomes (2010). Seen as polycyclic systems of magma feeding they are capable of conducting the pegmatitic magmas installation, which evolves by fractionation, gradual or direct, in situ or flow.

In the Iberian Variscan Chain, the draining and hosting environments are fundamentally originated by the spread of the stress field in the late-Variscan episodes, during the beginning of the uplifting. They correspond to transtensive, ductile-fragile structures, developed during the magma consolidation or resulting from the reactivation of prior structures, precocious in the structuring of the Iberian Variscan Chain. The larger pegmatitic volumes are situated in triple junctions and dilatational knots of shearing nets. If these alignments certainly affect most part of the pegmatites dykes, they may, however, not affect the more or less isodiametric innergranite bodies.

The morphologies of the bodies and geometries of the internal interfaces observed in innergranitic environment are established in the typology of Figure II.1, as proposed by Leal Gomes (1995).

II.2 Expected entities in remote mapping analysis

For innergranitic contexts, the previous models establish a kinematic placing essentially dependent on the low viscosity flow in dome portions of the granitic plutons subjected to an enrichment in volatiles. This way, the research and evidence of exhumed granitic domes should guide the prospecting intentions through remote mapping analysis.

The distribution of pegmatites according to a dome positioning in relation to the parental granites, can be revealed by the presence of roof-pendants and stopped blocks – portions of enclosing rocks incorporated by collapse of the chamber’s ceilings. The proximity of the dome is also revealed, for instance, by the contact between two or more granites.

Admitting that the pegmatitic productivity is related to contamination processes produced through the interaction of different types of magma during the ascension in chambers, it will also be sought by remote mapping analysis.
the research of magma mixture corridors capable of being revealed by ranges of concentration and enclave prolifera-
tion. On the other hand, it is also expected that near structural levels of swarms placing, the granitic fractionation re-
mains expressed in the acquisition of lithological heterogeneities within the plutons. Thus, the granitoids can be atyp-
ical near the differentiation spots. As supported by Cameron et al. (1949), quoted by Silva (2002), in an innergranitic con-
text the granite-pegmatite transitions tend to be gradational expressed, for instance, in the loss of the porphyroid char-
ter of the granite, in a transition range to the pegmatitic mural zone.

The research of facies shifts and other irregularities in plutonic hosting bodies, for example, foliations that express con-
ditions of magmatic flow, can, thus way, allow to establish sectors of higher productivity. These may be perceptible
in remote analysis by having a more extensive cartographic expression than the pegmatitic bodies.

The number of bodies, the type of morphologies and dimensions susceptible of being found in each sector depend-
s on the structural levels of placing in the exhumed and exposed masses due to erosion. The possibility of displace-
cements and adjustments, related to large accidents with vertical slip (horst-graben type) allows more than a level of
these models to be represented in the compartmentalization of the areas. It is also a goal of the prospecting program, in its remote mapping assessment, the research of brittle directions that match preferential hosting structures. The late Variscan NE-SW strike developed during the consolidation of the granitic parental magmas should be representative of the hosting of major pegmatitic groups in the considered areas.

Some of the geometric expressions, typical of the pegmatites hosting, can be relatable with the bi-dimensional
sections and arrangements of Figure II.3.

In tactic prospecting, the prediction on the morphology of the bodies, as well as the movement of masses in depth,
depends on the recognition of three-dimensional trends. In Figure II.4 is shown, as an example, the geometric reconsti-
tution of a pegmatite exploited in Ponte da Barca region, from which are deduced bi-dimensional sections or plants. These
depend on the identification of three-dimensional trends. In Figure II.4 is shown, as an example, the geometric reconsti-
tution of a pegmatite exploited in Ponte da Barca region, from which are deduced bi-dimensional sections or plants. These identify the superficial expression of the bodies in satellite images.

From the satellite images, the possibilities of discriminating the referred prospecting guides and bi-dimensional sec-
tions depend on the identification of the following signals, explicit in Ray (1960):

- **Color** - natural or artificial, obtained through the conjuncture of spectral bands, which provide better contrast resolu-
tion in photointerpretation;

- **Texture** - frequency of tonality variation in the image. Evaluation based on gray shades granulometry, it is produced
  by sets of very small objects, difficult to distinguish individually in the images. The texture results from the conjunction of
tone, shape, size and pattern parameters. For instance, the space between waterlines results in a textural effect.

- **Pattern** - orderly spatial arrangement (bi-dimensional) of geological, topographic or vegetation characteristics. Some
  patterns, expressed as curved or straight lines in images, represent faults, schistosities, dykes and stratification surfaces.

- **Shape** - defined by Ray (1960) as a “spatial form in relation to a contour or constant periphery”

- **Conjunction of the previous elements** - some criteria indicators are identified in the images, for more than one attribute.

The diagram of Figure II.5 explains the criteria useful in pegmatite prospecting, indicating, for each case, the attributes
and distant ways to evidence them. Due to their leucocratic tendency, outcropping pegmatites, fertile leucogranites and granite-pegmatite transition facies
manifest light tones in the images, expressing high values of reflectance. In the same way, overburdens with pegmati-
tic floating and pegmatitic colluviums may also manifest the same signal.

The research of alteration halos affecting the enclosing volumes, resulting from the mobility of lithophile elements can
also be done by tone research, light in case of albitizations, and pervasive muscovitizations or darker, in case of tourmali-
nizations.

The main structural directions for which occurred the pegmatites hosting come up by identification of linear patterns
in the images.
In this approach the following aspects are pointed out:

- **False positives** - objects that provide a remote signal similar to the one that identifies pegmatite outcrops and their indicators - for example, antropic action in granitic grounds and kaolinized zones of the massifs, with leucocratic tendency.
- **Specific masks** - pegmatites and their indicators, without distant evidence due to being disguised by covered grounds that provide non identifiable signals (for instance, vegetation).

**II. Orogenic pegmatite setting**

**II.3 Geological framing and structure of the pegmatitic fields in selected areas**

The geological mapping of the study area can be found on sheet 5B – Ponte da Barca – on 1:50 000 scale, from Teixeira et al. (1974).

There are represented syn to late-tectonic two-mica granites, predominantly biotitic, inferred as calc-alkalines, that include sets of dominantly porphyroid facies and syntectonic granites, non porphyroid, referred as alkalines.

The distribution of contrasting faces patches, as observed in map 5B, is presented by decal and vector conversion in Figure II.6.

The coarse or medium grained porphyroid granite (Y1) is predominant in the south. On a petrographic point of view it presents white color alkaline feldspar phenocrysts with coarse dimension and patterns of concentric zonality. The biotite contents are variable. The hydrothermal and supergene alteration generates sericitization and argi-
ization of the feldspars and occasionally epidotization. The biotite presents exudation of ilmenite, magnetite and pyrrhotite manifesting replacement by chlorite (Teixeira et al., 1975). Several microgranular enclaves with intermediate composition, dioritic to tonalitic, are related to these faces. In its outcropping area can also be noticed sectors of great concentration of basic dykes equivalent to lamprophyres and microdiorites (Teixeira et al., 1975). The dykes are organized in families of anazmuths ENE-SSW, NE-SW and NW-SE.

Still in Figure II.6, in the north, non porphyroid granites with significant petrographic variability outcrop. Importantly, modifications in the granulometry lead to separate medium to coarse grained facies (X/Y) from the medium to fine grained facies (Y/Z). There are also recognized strips of metasedimentary rock enclaves, represented near to the core bodies the quartz has fine composition, dioritic to tonalitic, are related to these facies. In its outcropping area can also be noticed sectors pyrrhotite manifesting replacement by chlorite (Teixeira et al., 1975). Several microgranular enclaves with intermediate composition, dioritic to tonalitic, are related to these facies. In its outcropping area can also be noticed sectors

II.3.2 Typology and distribution of the pegmatites

In the Ponte da Barca area, numerous disabled exploitations on pegmatitic bodies for consistent quartz production are mentioned. Some of these exploitations were recently converted for the production of aggregates, from host granites. Others are active deposits – Pedro da Moura and Mata da Galantierra. In Figure II.7 partial views of these quarries can be seen. In Figure II.6 their distribution is presented.

In Table II.1 the occurrences are discriminated, and the corresponding geographic coordinates given.

In Silva (2002) data about the morphology, internal structure and paragenesis of some bodies are treated, which was considered in the preparation of Table II.1 by establishing morphologic and mineralogical analogies for sets of bodies, this author separates the following pegmatic groups: Sexas type, Pedro da Moura type and Penacova type.

<table>
<thead>
<tr>
<th>Concession</th>
<th>Concession n°</th>
<th>Location</th>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedro da Moura</td>
<td>2907</td>
<td>Vila Chã (S. João Baptista)</td>
<td>554697</td>
<td>4628329</td>
</tr>
<tr>
<td>Vouga, Sousel, Branco, Entre Agua, Galoio and Penedo do Pinto/Goiana</td>
<td>1847/p, 3100</td>
<td>Vila Chã (S. João Baptista)</td>
<td>553730</td>
<td>4626890</td>
</tr>
<tr>
<td>Mata de Galantierra</td>
<td>3637/p, 400</td>
<td>Vila Chã (S. João Baptista)</td>
<td>553669</td>
<td>4629650</td>
</tr>
<tr>
<td>Monção do Carvalho</td>
<td>2434/p, 400</td>
<td>Vila Chã (S. João Baptista)</td>
<td>554900</td>
<td>4628109</td>
</tr>
<tr>
<td>Alto da Baracinha</td>
<td>1357/p, 400</td>
<td>Vila Chã (S. João Baptista)</td>
<td>557900</td>
<td>4624892</td>
</tr>
<tr>
<td>Penedo Redondo</td>
<td>3504</td>
<td>Germin</td>
<td>557250</td>
<td>4624076</td>
</tr>
<tr>
<td>Cruz</td>
<td>3042</td>
<td>Atal</td>
<td>553667</td>
<td>4625024</td>
</tr>
<tr>
<td>Fonte Fino / Fonte de Sousa</td>
<td>1240/p, 400</td>
<td>Abreu da Nogueira</td>
<td>552762</td>
<td>4627604</td>
</tr>
<tr>
<td>Lameira Velha</td>
<td>3687/p</td>
<td>Maltax</td>
<td>554637</td>
<td>4620666</td>
</tr>
<tr>
<td>Carvalha</td>
<td>1034/p</td>
<td>Seurimi</td>
<td>551613</td>
<td>4628095</td>
</tr>
<tr>
<td>Coja da Fontes</td>
<td>300/p, 400</td>
<td>Coja and Brinde</td>
<td>552791</td>
<td>4625041</td>
</tr>
<tr>
<td>Trava</td>
<td>3500</td>
<td>Vila</td>
<td>554205</td>
<td>4627856</td>
</tr>
</tbody>
</table>

**TABLE II.1**

List of concession for exploration of quartz and feldspar in the pegmatites of the Ponte da Barca – Pedro da Moura areas (silicification – Contribution to mining).
Orogenic pegmatite setting

The Pedra da Moura type pegmatites are fundamentally irregular bodies distributed in the interior of the coarse-grained two-mica granite (e.g. Mata da Galinheira), or in dome zones of contact with biotitic perphyry granite (e.g. Pedra da Moura and Castro de Pena). The morphology is variable from hourglass to inverted drop. It has a complex mineralogy of miarolitic nuclear cavities with great volume, coated by druses of quartz gigacrystals; the late units are composed by Fe precipitated in cleavage planes of micas. The units filled with quartz follow a subhorizontal structure, suggesting the presence of concentric zoning.

The Seixas type pegmatites have tendentially arachnid shape morphologies and are characterized by the existence of micaose nuclear cavities with great volume, coated by druses of quartz gazycrystals, the late units are composed by Fe and Mn phosphates, apatite and sulphides. The Seixas pegmatites are located at lower elevations (250-350m) in contact zones between two micaic granite (Y1 and Y2). The Pedra da Moura type pegmatites are fundamentally areniticoic bodies essentially quartzose, with conditioned structure and affected by the regional late-Vanguard tectonic. The existence of albitic and micaose replacement units with sulphides is characteristic. They are installed according to NE-SW shear corridors in the interior of the porphyry biotite granite (e.g. Travaços) or in pericupular hosting ruptures of two mica granites (e.g. Pedrido Redondo).

**Table 1.3 describes in detail on a paragenetic, morphological and structural perspective the grouped pegmatites.** The structural location, type of hosting granite faces and altitude are also included as attributes.

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**Orogenic pegmatite setting**

**Table 1.3**

<table>
<thead>
<tr>
<th>Occurrence</th>
<th>Morphology</th>
<th>Mineral comp. (accessory minerals)</th>
<th>Internal structure</th>
<th>Structural location</th>
<th>Hosting granitic facies</th>
<th>Altitude (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedra da Moura</td>
<td>Hourglass</td>
<td>Pegmatite with concentric zoning</td>
<td>Irregular</td>
<td>Prismatic, late</td>
<td>Coarse-grained</td>
<td>150</td>
</tr>
<tr>
<td>Mata da Galinheira</td>
<td>Inverted drop (hanging)</td>
<td>Pyrite, apatite</td>
<td>Zoned pegmatite</td>
<td>Interior of the granite mass</td>
<td>Coarse-grained</td>
<td>450</td>
</tr>
<tr>
<td>Montes de Castro de Pena</td>
<td>Granite</td>
<td>Zoned pegmatite</td>
<td>Zoned pegmatite</td>
<td>Coarse-grained</td>
<td>Coarse-grained two-mica granite</td>
<td>650</td>
</tr>
<tr>
<td>Alto de Barcelos</td>
<td>Anhedral shape</td>
<td>Cassiterite</td>
<td>Cassiterite</td>
<td>Intermedium</td>
<td>Coarse-grained</td>
<td>590</td>
</tr>
<tr>
<td>Vale de Sado, Breixo, Aguias, Gato e Parada do Pico</td>
<td>Anhedral shape</td>
<td>Anhedral shape</td>
<td>Cassiterite</td>
<td>Cassiterite</td>
<td>Coarse-grained</td>
<td>250-350</td>
</tr>
<tr>
<td>Parada</td>
<td>Anhedral shape</td>
<td>Anhedral shape</td>
<td>Zoned pegmatite</td>
<td>Coarse-grained</td>
<td>Coarse-grained</td>
<td>800</td>
</tr>
</tbody>
</table>

**Note:** The Seixas type pegmatite setting comprises a number of the Seixas type pegmatites located between different lithologies zones. The Seixas type pegmatite setting comprises a number of the Seixas type pegmatites located between different lithologies zones. The Seixas type pegmatite setting comprises a number of the Seixas type pegmatites located between different lithologies zones.

**II.3.2 Geological and mining framing of area BI – Chaves**

In the region of Chaves, the decasgi pegmatite in Pedra de Sado that corresponds to a large body explored for production of quartz and lead-zirconium-tantalum, is paradigmatic. Mining began in 1968 and was maintained until 2000.

Reference works on the paragenetic, structure and installation mechanism of the pegmatite can be found in Pereira et al. (1998) and Pereira (2005).

**II.3.2.1 Geological framing on 150 000 scale**

The area BI is inscribed in 68 of Tenera and Medões (1969) and 60 of Noronha et al. (1998) sheets from the geological map of Portugal on 150 000 scale.
According to these publications, are separated, in the study area, granitoid rocks, Paleozoic metamorphics and recent sedimentary deposits, with discriminated outcrops in Figure II.8.

The north outcropping granites are medium to coarse grained two-mica syntectonic facies, tending porphyroid. The coarse grained Santa Bárbara granite and the medium grained Minho Lagoa granite, with faces richer in muscovite, are distinguished (e.g. in São Pedro de Agostém).

In the south, are represented in the interior of the post-tectonic: Vila Pouca de Aguaru ma basaltic granite; facies correspondent to terms with medium to coarse grained porphyroids (Pedras Salgadas and Vila Pouca de Aguaru granite) and fine grained two-mica facies (Sabroso granite).

The enclosing metasedimentary sequences described in Teixeira and Medeiros (1969) as schist-granitic complexes are characterized by migmatization and silicification appear in the most recent cartographic revisions of Noronha et al. (1998) attributed to the Três Minas structural domains (Curros unit, Devonian age) and Carrazedo (units of Santa Maria de Émeiras and Varzíeiras). According to these publications are separated, in the study area, granitoid rocks, Paleozoic metasediments and recent sedimentary deposits, with discriminated outcrops in Figure II.8. There are small thickness bodies with variable directions, with past exploitation, in some cases focused on adjacent alluvial.

**Table II.4**

<table>
<thead>
<tr>
<th>Concession</th>
<th>Concession n°</th>
<th>Location</th>
<th>X</th>
<th>Y</th>
<th>Deposit</th>
<th>Thickness of Dykes (m)</th>
<th>Attitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seixigal</td>
<td></td>
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<td>40 081</td>
<td>g</td>
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<td>E-W, vertical</td>
</tr>
<tr>
<td>Carqueijal</td>
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<td>40 081</td>
<td>g</td>
<td>0.30 10</td>
<td>N-SW vertical</td>
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<tr>
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<td>Falgueiras</td>
<td>622 015</td>
<td>40 081</td>
<td>g</td>
<td>0.1 04</td>
<td>N 75 W</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>a</td>
<td>0.2 9</td>
<td>N-SW, vertical</td>
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</table>

**Table II.5**

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<td>1847, 2462</td>
<td>S João da Carra de</td>
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<td>46 025</td>
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<td>0.1 04</td>
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<td>Sn W</td>
<td>Estanheiro and Palhuno</td>
<td>1445, 1736</td>
<td>S João da Carra de</td>
<td>633 023</td>
<td>46 025</td>
<td>i</td>
<td>0.2 9</td>
<td>N-SW, vertical</td>
</tr>
<tr>
<td>Sn Ti</td>
<td>Jogoeador and Vareiros</td>
<td>2249, 2259</td>
<td>S João da Carra de</td>
<td>627 028</td>
<td>46 025</td>
<td>i</td>
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<td>N-SW, vertical</td>
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<tr>
<td>Sn</td>
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<td>55 58, 55 59, 56 00</td>
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<td>46 025</td>
<td>i</td>
<td>0.2 9</td>
<td>N-SW, vertical</td>
</tr>
</tbody>
</table>

According to Pereira (2005), the Senegal pegmatite corresponds to a tabular body with subhorizontal strike and stocklopping geometry type. It is located in a sector subject to dome collapse in intermediate position between Santa Bárbara granite (outergrainite) and a post-tectonic biotitic granite, non-outcropping, that limits it inferiorly (innergrainite, intersected by drilling). The contact of the pegmatite with the inner granite is gradational, with interfaces typical of fractionation, leaching and residual differentiation.

The rising of post-tectonic magmas might have happened in the last stadiums of the Variscan transcurrent deformation. The Régua-Verin corridor, delimited in Figure II.8, possibly represents the first-order feeding zone from which the post-tectonic magmas had access, capable of issuing residual differentiates. The occurrence of Sn, Nb, Ta in pegmatitic dykes, aplite-pegmatitic and greisens with outergrainite installation are more numerous (Table II.5 and Figure II.8). There is a clear syntectonic relationship with the Sn, Nb, Ta deposits, with discriminated outcrops in Figure II.8. The approaches that describe the geometry and paragenesis of the Seixigal pegmatite are gathered in Table II.6, according to Pereira (2005). According to Siorminp there are only 3 concessions attributed for quartz and feldspar exploration in the Chaves sector (Siorminp).

According to Pereira (2005), the Seixigal pegmatite corresponds to a tabular body with subhorizontal strike and stocklopping geometry type. It is located in a sector subject to dome collapse in intermediate position between Santa Bárbara granite (outergrainite) and a post-tectonic biotitic granite, non-outcropping, that limits it inferiorly (innergrainite, intersected by drilling). The contact of the pegmatite with the inner granite is gradational, with interfaces typical of fractionation, leaching and residual differentiation.

The aspects that describe the geometry and paragenesis of the Seixigal pegmatite are gathered in Table II.6, according to indications collected from Pereira (2005).
II.3.3 Geological and mining framing of area D – Viseu-Sátão

In the area referenced as D (Viseu-Sátão) several intra and peri-granitic pegmatitic bodies with ceramic resources and mineralization in rare materials are recognizable.

Lebote (01/0) presents a reference work on the use conditions of quartz, feldspar and beryl, and correspondent beneficiation diagrams from Beiras pegmatitic deposits and especially larger pegmatite (Senhora da Assunção pegmatite). The definition of the Alto Vouga pegmatitic field is due to Trabulo et al. (1995) that proposes elements for the compartmentalization of groups and swarms.

II.3.3.1 Geological cartography on 1:50 000 scale

Sheet 14 of the Geological Map of Portugal on 1:50 000 scale from Teixeira et al. (1972) establishes the geological framing of the study area.

In this compartment, late-tectonic granites are preferentially distributed, which intrude formations of the Schist-greywacke Cambrian and Ordovician Complex, occupying the SW quadrant of the area.

The enclosing metasediments are distributed according to general NWW direction outcrops on the extreme SE of the Carbonaceous Dourao-Bento granite shear zone (Galeas e Ribas, 1988; Rodrigues, 1997). From the stratigraphic standpoint they comprise metapelites, metagreywacke and conglomerates of the Doura group (CQG, Cambriico) Ordovician quartzites and schists and intraconformal dol Carbonaceous schists (carbonaceous schists and metagreywacke) (Figure II-9).

The most represented granitic facies, inserted in the Aguiar da Beira late-tectonic massif, comprise porphyroid biotitic granites with granularity varying from medium to coarse and medium grained two-mica facies. The Ferreira de Aves granite, central in relation to the delimitation of the area, corresponds to a two-mica facies with abundant biotite, medium grained and porphyroblastic character, biotite-granitic micas and quartz porphyroblasts. It is defined as an arch that matches the oriental side of the massif. Sheet 14-E recovers ‘zones of dykes and aplite-pegmatic masses’ and small flaps formed by fine grained granite in their interior.

The north delimitation of the area covers the post-tectonic Pera Velha mafic and syntectonic two-mica granites. The petrologic discrimination of these granites can be found in Costa (2006).

Intersecting the granites are outcrop dykes of basic rocks with more frequent direction N 0°, NE 5W and NW SE (Figure II-10).
IL3.2 Typology and distribution of the pegmatites

In this compartment pegmatites can occur in two essential positions: innergranitic and peri-granitic.

The distribution of pegmatic mineral occurrences can be found on Figure II.10. In Table II.7 these are discriminated by target substance, location, concessionaire and topographic level.

The main swarms and most representative groups (isolated, coupled or as a rosary) are innergranitic and inserted in medium to coarse grained two mica porphyroid facies of the Aguiar da Beira massif. In this situation, for instance, the Senhora da Assunção and Pestarenga pegmatites, with installed extractive units for production of quartz, feldspar and beryl.

The Senhora da Assunção pegmatitic group comprises two zoned lenticular bodies, exposed in two quarries that are 50m distant from each other (Trabulo et al., 1995). Due to the volume and size of useful masses it assumes a key character in the context of the Alto Vouga innergranitic field. Being considered representative of the framing of other ceramic pegmatites of the region, it can be used as a model of mineralogical characterization. By combining the classifications of Ginsburg et al. (1979) and Cerný (1982) they can be referred as marnolitic hybrids with beryl, phosphate and columbite-tantalite.

According to Trabulo et al. (1995) the Senhora da Assunção pegmatites and, generally, the pegmatites hosted in medium grained two mica facies (Pereira de Aves granite) present deeper location in the context of the massif structuring, scattered or in coupled sets. They contrast with an swarm distribution with higher number of pegmatites, predominant in the south massif, in coarse grained facies - Sezures-Dornelas and Trancozelos-Travanca de Tavares swarms.

According to the same authors the disposal of bodies of the Assunção group following an axis orientation n25°E, is consistent with the fluid trajectories in the sector, which follows roughly the massif contour. The pegmatites are heterogeneous, strongly zoned with abundant quartzose nuclear masses and frequent manganese-ferrous and lithium-phosphorus replacement masses that occur in the later internal fractionation units, located in the intermediate transition zone and the quartz core (Leal Gomes, 1999). The recognized independent units are discriminated in Table II.6.

They present Be, Nb-Ta (Nb-Ta) Li, Mo and Ti specialization which translates into a parageneses represented by beryl (gigacrystals in the intermediate-core zone interface), bertrandite, fenacite, OH-herderite, columbite-tantalite, and molybdenite and limerite. This is expressed in phosphate units. The south pegmatite is the one that presents greater mineralogical diversity, regarding phosphate phases, discriminating the primary phosphates triple-meteoricite, OH-berdeite, trihalit lithium phosphate and F-apatite and the following descending associations by evolution in liqunulite, sulfur and in supergene: rockbridgeite, yaymynite, rocherite, chilenidite, amblygonite-montellite, brasilinite, augeite, lazulite, scorzalite, hexasilte, vivianite, sicklitte, hutenite, purpurite and OH-apatite (Leal Gomes and Azevedo, 2003).

Sulphides can also be abundant. Besides molybdenite are also referred pyrite, arsenopyrite, chalcopyrite and blende (Leal Gomes and Azevedo, 2003).

The morphology of the dumbbell bodies suggest final terms of kinematic evolution in the emplacement of pegmatites, subject of lateral expansion in a terminal stage of the ascensional course (Guimarães, 2012). The dome proximity is revealed by the presence of a roof pendant and stoped blocks at top of the main mass (Guimarães, 2012).

The pen-granitic pegmatites located on the SE side of the Carboniferous Dúrico-Benafarès shear zone groove include sill rooted in the medium grained porphyroclastic granite and stanniferous dykes or exotaxotropic swarms of the Lagos mining district (Nerha 1944).

The Quenza pegmatitic group is represented also called Lagos de Estarrosa or Minas de Rebenção in the documents of the mining accounts. The main body of this group has N20°W-E subline and dip of 45° medium thickness (Paroupols, 2003). It is classified by the criteria of Cerný and Erict (2003), as LCT petatitic type. Econometrically it manifests ceramic aptitude and mineralizations ordered by abundance of Li=Be/Nb-Ta/Nb=W+R.

The Lagos mining field is characterized by pen-granitic and oligo pegmatites stricking E-W to N-S and NW-SE, variable dips and medium thickness between 10 and 15 m. In the Minas Velhas sector the mining units refer the occurrence of quartz dykes, which in more recent works of Dasset al. (2000), and by the recognition of important contents of topaz in its paragenesis, are described as topazites, mineralized with cassiterite, columbite-tantalite, wolframite, rutile, rhenopyroxyne, gold, electrum and bismuth. According to the same authors they have enclosing tourmalinizes with topaz parapyroxyphilitized interstitials in the Antas Formation.

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<td>Located in the Rosary of the medium grained porphyroclastic granite</td>
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<td>Course-grained porphyrogranite</td>
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</tbody>
</table>

The pen-granitic pegmatites are characterized by innergranitic and peri-granitic deposit that stricking E-W to N-S and NW-SE, variable dips and medium thickness between 10 and 15 m. The Minas Velhas sector the mining units refer the occurrence of quartz dykes, which in more recent works of Dasset al. (2000), and by the recognition of important contents of topaz in its paragenesis, are described as topazites, mineralized with cassiterite, columbite-tantalite, wolframite, rutile, rhenopyroxyne, gold, electrum and bismuth. According to the same authors they have enclosing tourmalinizes with topaz parapyroxyphilitized interstitials in the Antas Formation.
II.3.4.1 Geological mapping on 150 000 scale

In 1:50 000 sheets of the Geological map of Portugal on 1:50 000 scale, the following late-tectonic granitic facies are divided (Figure II.11):

- Muscovitic-biotitic granites – define the outcropping circumscribed massif in the central part of the area – Fatuque-Pena Lobo massif
- Monzonitic porphyroid granites – occupy the remaining space around that massif – Belmonte-Pega massif
- Monzonitic porphyroid granites – define the outcropping circumscribed massif in the interior of the Belmonte-Pega monzonitic granite, belonging to the Schist-greywacke Complex of the Beiras group.

II.3.4.2 Typology and distribution of the pegmatites

In Figure II.11 is represented the distribution of pegmatitic mineral occurrences with former and current mining activity, for the production of ceramic quartz and feldspars and productive in Li and Sn mineralizations. They are also discriminated by substance type in Table II.9.

The more representative sets of this field, object of previous studies, outcrop in the Gonçalo-Seixo Amarelo areas (Ramos, 1998; Ramos et al., 2006), Cabeço dos Poupos (Silva et al., 2003; Silva et al., 2006) and Bendada (Correia Neves, 1960). These dykes have high potential for the production of Li phyllosilicates, quartz and feldspars. The Gonçalo pegmatite stands out due to its importance and representativeness, peculiar due to its abundance of blue and greenish topaz.

The pegmatites are mainly intrusive in the late-tectonic porphyroid biotitic Belmonte-Pega granite. They have tabular morphology and evolved parageneses. Includes subhorizontal and inclined dykes with associated apatite and pegmatic structures (Table II.10). The most outstanding LCT specialization can be lithinipherous, with lepidolite or amblygonite, or berylipherous, exceptional with columbite and phosphates.

The models of Brisbin (1986) for epizonal pegmatitic intrusions in uplifting conditions, and exhumation in environments subject to low confining pressures, explain the generation of pegmatites. In these conditions, in superior levels of the crust, the prevalence of fragile conditions promotes the installation of tabular pegmatites.
petalite, zinnwaldite, topaz, apatite, cassiterite, columbite-tantalite, micaite, and zircon. The same author refers the presence of metasomatic halos affecting the enclosing granite in the contact surface with the pegmatite (configuration parallel to the dyke’s strike) which have the most common size 7 to 8 cm, not exceeding 20 cm in expression. Albitization, tourmalization, recrystallization of quartz, feldspars muscovitization and biotite replacing by zinnwaldite.

In the Pêga-Sahal region the most outstanding specialization is berylipherous and dykes mineralized with lepidolite are less frequent. The swarms observed in Cabeço dos Pousos Silva et al., 2006) are organized according to variable strike, the dykes with subvertical inclination have average orientation E-W to NW-SE and their subhorizontal are distributed around the average strikes N/10°E, 20°SE. The vertical bodies have variable thickness between 10 cm and 15 m and horizontal development that can reach 700 m. The silts have thickness till 2.5 m and outcrop extension that can reach 200 m. The pegmatites have generally internal zoning and banded organization of apatic and pegmatitic facies. They are predominant in the apatic facies contact surfaces typically pegmatitic structures develop mainly in nuclear positions at top. Rhythmic style apitic and pegmatitic alternations can develop in the internal zone of the dykes subject to minor dilatation. The less thick dykes do not normally evidence zoned organization corresponding to apitic and pegmatitic facies imbrication with comb-structure potassic feldspar gacysytals. The mineralogical reference association discriminated in Silva et al., 2006 includes quartz, orthoclase, perthitic microcline, albite, muscovite, lithiophilous muscovite, tourmaline, beryl, zircon, columbite-tantalite, ferrocolumbite, ferrotantalite, cassiterite, apatite and Fe-Mn phosphates (triptile, heterosite and eosphorite). Centimetric halos with metasomatic zinnwaldite are also typical.

The geochemical modeling of Ramos (1996) suggest an affiliation relation between Gonçalo-Sexo Amarelo field with the bioticous-muscovite Pêna Lobo granite. Silva et al., 2006) proposes a fractionation of the Pêga granite to generate the compositions observed in the Cabeço dos Pousos swarms.

In the bendada pegmatites, the diversity of Pe-Mn and Li phosphates is remarkable, especially in late replacement units distributed in the intermediate core zoned interface (Correia Neves, 1960). The dykes and outcropping masses on this sector and the Seixeira and Quinta da Ribeira pegmatites, with beryl and lepidolite and mineralized with cassiterite and columbite-tantalite, present tritite-lithistite and tritite as primary phosphate phases and secondary associations with purpurite, managanosiderite, stearite, phosphosiderite, huzelite, hermanite, rockbudite, vivanite, strunite and wavelite. The sulphides identified include arsenopyrite, molybdenite, pyrite, and chalcopyrite.

The uranium minerals - uraninite, sabugalite, torbernite, autunite, matolitebermeite and phosphuranopyrite - occur mainly in late quartzose fillings.

**TABLE II.**

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**TABLE III.**

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<td>Vila</td>
<td>641931</td>
<td>447035</td>
<td>Unidentified</td>
<td>Unidentified</td>
</tr>
</tbody>
</table>

In the Gonçalo-Sexo Amarelo sector, Ramos (1996) and Ramos (2010) describe apatic-pegmatitic subhorizontal silts with about 5.3 m thickness installed in fractures systems NW-WSSW consistent with the late Variscan stress field. They describe 3 fundamental silt types - stanniferous, mixed and lithiophilous. The first appear in inferior structural and topographic levels presenting simple structure, homogeneous, and minor paragenetic diversity. The lithiophilous bodies present lepidolite or ambykolite montebrasite as specialization typomorpho-minerals. A mineralogical inventory of the swarms contemplates the following accessory phases:
In Table II.11 were selected:

- criteria of pegmatite occurrence, extracted from geological maps and topographic bases. The following criteria, identified
  - the Perda da Moura pegmatites occur close to a mixing-mingling corridor established near that apical contact.
  - some pegmatites with arachnid shape geometries seem to be controlled by NE-SW shear zones corridors.

II.4.2 Delimitation of research areas by integration of geological-structural and geomorphological elements

The first approach to the research areas resulted from using some empiric geological-structural and geomorphological

- the cartographic concentration of pegmatic indexes is more consistent along the interface established between
two mica granites and porphyroidic bostonic granites, which seems to be equivalent to an emplacement corridor of two

cornaginatic granites with a posterior granite

- the Pedra da Moura pegmatites occur close to a mixing-mingling corridor established near that apical contact.
- some pegmatites with arachnid shape geometries seem to be controlled by NE-SW shear zones corridors.

a) Area A
- the cartographic concentration of pegmatic indexes is more consistent along the interface established between
two mica granites and porphyroidic bostonic granites, which seems to be equivalent to an emplacement corridor of two
cornaginatic granites with a posterior granite

- the Pedra da Moura pegmatites occur close to a mixing-mingling corridor established near that apical contact.
- some pegmatites with arachnid shape geometries seem to be controlled by NE-SW shear zones corridors.

b) Area B1
- the main pegmatic bodies are distributed in the interior of the Ferreira de Aves granite, which can manifest faces
  heterogeneities, suggested by the existence of small flaps formed by fine grained granite as represented in the published
  geological map.

- the existence of a roof-pendant ceiling on the Senhora da Assunção pegmatites suggests that the exhumed surface of
  the Ferreira de Aves granite corresponds to a dome zone.

c) Area D
- the main pegmatic bodies are distributed in the interior of the Ferreira de Aves granite, which can manifest faces
  heterogeneities, suggested by the existence of small flaps formed by fine grained granite as represented in the published
  geological map.

- the existence of a roof-pendant ceiling on the Senhora da Assunção pegmatites suggests that the exhumed surface of
  the Ferreira de Aves granite corresponds to a dome zone.

d) Area E
- from the bibliographic research, are established as potential pegmatites in this sector dyke-like bodies with
  beryllipherous or lithinipherous specialization, mainly oriented according to NNE-SSW and E-W structural strikes.
- the Belmonte-Pêga granite seems more fertile, presenting higher cartographic concentration of pegmatic bodies.
3 chapter

Satellite imaging processing
Satellite imaging processing

Once explained the orogenic tectonic conditioning of bodies and swarms in the considered pegmatitic fields, the signals underlying their indicators in satellite images will now be identified.

As discussed previously and using the attributes on the diagram of Figure II.5 (chapter II), chromatic and textural contrasts, shape parameters, reflectance indexes expressed in shades of gray and geometric patterns resulting from ruptures are searched in the images, which represent remote signals identifying pegmatite bodies and prospecting guides.

The most fertile strips and massifs from the considered study areas were also previously identified through the analysis of the distribution of pegmatitic bodies, in relation to main cartographic sets and regional structures. The systematic observation of images focuses on these. The useful contrasts here detected conducted to the selection of images and guided the digital processing tasks of Landsat and Spot images, presented in this chapter.

The goal of the photointerpretation and image processing was to identify targets and select the research areas for geological investigation and punctual prospecting. The processing techniques used were the ones that provided better results in identifying meaningful remote signals for pegmatite prospecting and, as so, is proposed a more generalized use of it in remote mapping analysis, equilibrated here as via to pegmatites prospecting.

III.1 Digital image processing

The digital processing used on Landsat and Spot images included the following techniques:
- **Highlighting of individual bands by contrast broadening** - it was generally applied the linear expansion of histograms in initial Landsat and Spot bands for contrast broadening.
- **RGB combination of spectral bands** - natural color and false color images were obtained by the combination of bands 1, 2, and 3, respectively, which contain data from the electromagnetic spectrum visible domain. The combination will be RGB31.
- **Analysis of main components** - images of main components (MC) were obtained from the bands 1, 2, 3, 4, 5, 7 of satellite Landsat and from bands 1, 2, 3, and 4 of satellite Spot.
- **Supervised spectral classification of images** - applied to the cases in which it was expected the repetition of pegmatitic spectral patterns, or relevant to the identification of their indicators, their identification pixels were selected and the reflectance ranges categorized. It was elected the Maximum classification - maximum likelihood algorithm.

The maximum likelihood algorithm evaluates the variance and covariance of spectral response patterns categories, when classifying an unknown pixel. For this, it is assumed that the point cloud distribution that forms the training data category is Gaussian (normal distribution). As so, the distribution of a category spectral response pattern can be completely described by an average value and covariance matrix. With these parameters, it is possible to estimate the likelihood of a pixel belonging to a given class. As a result, it is obtained an image in which every single pixel assumes the value of the class where it is inserted.

III.2 Image selection and photointerpretation

From the application of the described operations resulted a numerous set of images. The images in this set were selected having as criteria the existence of more credible evident signal relations between pegmatite and enclosing.

The results of this selection are presented with a descriptive analysis and comment, on its utility, on each image.

### III.2.1 Area A - Ponte da Barca

In the Ponte da Barca area, a belt with higher concentration of pegmatites, considered fertile, was deduced through the analysis of the distribution of pegmatitic bodies. This range corresponds to the lithological contact established in published mapping on 1:50000 scale, between syn to late-tectonic porphyroid granites and syntectonic fine- to medium grained non porphyroid granites. (View Fig.16, chapter II).

The identification of a mixing-mingling corridor established near that apical contact, on Pedra da Moura pit, led to consider it as useful criteria for prospecting, proposing its research in image analysis.

It was also found important the hosting of bodies with anchiolite shape morphologies near the structural corridors and rupture junctions.

The image selection and interpretations done pursued the research of those guiding criteria.

On Google Earth's image (Figure III.1) is perceptible two compartments, or sector, with differentiated aspect (a and b), with contrasts coming from minor vegetable coverage in the granitic patch at north. Pedra da Moura and Sêxas mining pits are visible, and correspond to the larger mining pits in the region. The fertile contact established between porphyroid granites and medium to coarse grained granites (c) is defined with good resolution in the images. Its design is segmented in the west through a megascale structure N30°E (d).

The most relevant structural patterns are well seen in the image correspondent to band 8, panchromatic, from satellite Landsat. (Fig.

In this image, the compartment designated by the letter A seems to be a junction sector of a NE-SW shear corridor with NW-SE and WWNW-ESSE ruptures, that matches the location of the Cruz pegmatite (b). The density and pattern of the ruptures found here explains the interest in this sector, which was already demarcated in the previous analysis that matched geological-structural and geomorphologic criteria (view Figure II.13).

Through the RGB combination of bands 1, 2 and 3 - natural color image on Figure III.3 - it is possible to see the curvilinear alignments located on the most fertile interface strip. These correspond to limits or chromatic and textural variation lines of the objects on the surface, with concentric design, observing vicinity between these configurations and the distribution of the pegmatites explored in Mata da Gaiñheira (a) and Monte do Castelo da Pena (b).

On the image corresponding to the 2nd main component (MC, Figure III.4) are also in evidence those configurations. The curvilinear alignments evidenced this way have geometry, by hypohenxiv, related to ballooning type emplacement, due to the density and viscosity contrasts of the intrusive granitic magmas. These alignments seem to control the pegmatitic bodies emplacement, determining their location on the periphery of the alignments sets.

The 3rd main component (Figure III.5) evidences heterogeneous patches distribution represented by variations in the gray intensities in the same sector, which can express lithological contrasts produced by different reflectance facies in the granite interior. Because it hosts the Mata da Gaiñheira, Castelo de Pêra and Sêxas pegmatites, the granite is thought to be fertile. The existence of chromatic patterns can eventually be explained by compositional heterogeneities and/or presence of enclaves and roof pendants in the exhaustion granitic facies.
III. Satellite imaging processing

**Figure III.1**
Google Earth image of area A – Ponte de Barca/Terre de Bouro.

**Figure III.2**
Image correspondent to the panchromatic band of satellite Landsat/area A.

**Figure III.3**
Natural color image obtained by RGB combination of bands 3, 2 and 1 (RGB321) for area A.

**Figure III.4**
Image correspondent to the 2nd main component obtained through bands 1, 3, 4, 5 and 7 of satellite Landsat/area A.
III. Satellite imaging processing

III.2.2 Area B1 – Chaves

Through the revision of the tectonic conditioning of the Senegal pegmatite emplacement, and using as reference the work of Pereira (2005), it was put into evidence the genetic relation of this body with the post-tectonic granites that intrude according to the Régua-Verin megastucture, with NNE-SSW azimuth. The proximity to the Santa Bárbara pluton also seems to condition the location of the body on the periphery of this granite (view Figure II.8).

This geotectonic context was considered in the satellite images analysis.

On Google Earth’s image (Figure III-6-A) the urban occupation which has already appeared prominently in the territorial statutes analysis made in Chapter I (Table I.6), is perceived.

Notwithstanding, some Landsat images selected, presented below, show reasonable contrasts for some lithological and structural elements.

Band 8 of satellite Landsat enhanced by contrast increase (Figure III.6-B) shows good resolution for structure design. The NE-SW Régua-Verin megastucture is defined with good resolution and is segmented by structures with N-S azimuth. This fracturing pattern is repeated in the surroundings of the Senegal pegmatite, whose pit is visible in the image, and its location can be observed on the intersection of two N30ºE and N-S structures.

The image correspondent to band 6 of satellite Landsat (Figure III.6-C) also shows the Régua-Verin megastucture design and reproduces, to some extent, the design of formations represented on geological maps 6B and 6D (view Figure II.8). Using gray intensity variations, are highlighted the following compartments represented with light tones in the image, correlated with the following formations represented on geological map:
- Post-tectonic granites (a);
- Undifferentiated structural domain metasediments of Três Minas and Carrazedo (b);
- Metasediments of the Carrazedo superior subdomian (c).

The 3rd main component (Figure III.6-D) improves the discrimination of metasedimentary formations represented at south and separates them from the Minheu-Lagoa syntectonic two-mica granite. The cartographic design is correlated with the geological maps the following way:
- Minheu-Lagoa syntectonic granite (a);
- Curros unit of the Três Minas Structural Domain and Rancho subunit of the Carrazedo inferior subdomian (b);
- Cubo unit of the Carrazedo inferior subdomian (c);
- Santa Maria de Émeres unit of the Carrazedo superior subdomian (d) – the corresponding patch, represented east of the Minheu-Lagoa granite, manifests, however, in the image, compartmentalization in structurally limited blocks, which can mean a higher heterogeneity of the facies represented in published maps.
III.2.3 Area D - Viseu-Satão

Using as reference the indications from analysis on the distribution of pegmatites from the Viseu sector (chapter II), it was sought to value through the images analysis the Ferreira de Aves granite. The main pegmatitic bodies are distributed in the interior of this massif which manifests also in published mapping small dimension flakes formed by fine grained granite (view Figure II.10). These facies represent conceptually productive units that can be more embracing, and potentially appear discriminated on images available on Google Earth, Landsat and Spot.

On Google Earth images (Figure III.7) are separated in the Viseu area, 3 compartments with granitic outcrops less subjected to the influence of vegetable coverage (1, 2 and 3). The central sector corresponds roughly to the limits defined on geological mapping for the Ferreira de Aves massif (1). In this image it is also visible the pit of the Senhora da Assunção pegmatite (a) and the main NNE/SSW tectonic accident, that compartmentalizes the massif and conditions the course of Vouga river (b).

The 3 granitic domains expressed on Google Earth’s image are also well discriminated in the image corresponding to the 1st band of satellite Landsat (Figure III.8). Here is observed that the main tectonic accidents that compartmentalize the Ferreira de Aves massif have N00E to NNE/SSW and NW-SE direction.

In the same Figure III.8 other apparent division corresponds to a 1st order structure NW-SE (a) that separates two sectors, NE and SW, with distinct rupture patterns. It can be observed greater rupture density at NE, according to NE-SSW and NE-SW directions. At SW the granitic spots have a more homogeneous appearance, minor granulometry of gray levels and faded fragile structures. These kind of contrasts can indict compositional variations in granitic facies represented in both sectors of the Ferreira de Aves massif.

In the image correspondent to band 6 (Figure III.9) the SW compartment manifests light tones, reflective in the thermal infrared. On the high reflectance patches are distinguished circular internal organizations that may suggest a concentric zoning of the plutonic facies. The peripheral circular ranges marked in the figure are lighter.

These compartments are well demarked, with dark shades of gray in the image correspond to the 3rd main component (Figure III.10).

One of the sectors covers the Salgueiro area (a) previously delimited on Figure II.14 (chapter II) by geological-structural and geos. Other compartment spreads to the south of the Senhora da Assunção pegmatite (0).
III. Satellite imaging processing

III.2.4 Area E - Guarda

From bibliographic research were established as potential targets in the Guarda sector berylliferous and lithiiferous aplite-pegmatite NNE-SSW and E-W directed dykes, subhorizontal and subvertical, with higher cartographic concentration of deposits in the interior of the Belmonte-Pega granite.

The continuity of the deposits on the outcrop surface is a relevant aspect of the pegmatitic field, increasing the possibility of distantly detecting outcropping bodies using shape and tone criteria. This way, the heterogeneous textures and high reflectance chromatic patterns in the visible spectra bands can be considered useful indicators of pegmatites presence.

In this study area, the remote detection of pegmatitic dykes also benefits from the scarce vegetable coverage, that allows a good outcrop observation.

The main structures that compartment the area are well represented on the Google Earth’s image (Figure III.11). They are NNE-SSW and WNW-SSE directed.

In the image correspondent to the RGB combination of Landsat 751 bands (Figure III.12) is demarked a sector designated by the letter A, that presents a distinct chromatic and textural pattern on the surrounding masses. It is colored in red and blue tones, meaning higher reflectance on the materials underlying bands 7 and 1. The correspondent leucocratic character of the outcrops is seen on Google Earth’s image. On the other hand, this sector covers an area called Cabeço dos Poupos (b) in mapping from Silva et al. (2006) correspondent to an area of great density of aplite-pegmatitic dykes outcrops.

Taking advantage of the higher spatial resolution of the images captured by satellite Spot, is perceived that the heterogeneous pattern seems to result from the intersection of linear objects exposed in the images and, as so, it is credible to believe that they are related to outcrops of dyke-like bodies. In the event that they correspond to swarms, it is well seen in the images that they result from the combination of RGB bands 1, 2 and 4 of satellite Spot (RGB124) (Figure III.13).
III. Satellite imaging processing

Satellite imaging processing

III.3  Image classification

The possibility of pegmatitic spectral bands repetition in area E, and geometric configurations suggestive of ballooning type emplacement in area A led to the using of Maxver classification in these sectors.

III.3.1  Area A

The photointerpretation of the image obtained by combination of RGB bands 3, 2 and 1 revealed, in area A, curvilinear alignment patterns located on the productive granitic strip, which through the circular design seems to show contrasts related to magmatic ascending by ballooning.

In figures III.3 and III.4 exists a spatial correlation between the location of the pegmatites and the more peripheral wrappings of the alignments sets.

Applying the Maxver classification to the image resulting from RGB321 combination and using as guides for the attribution of pixels the photointerpretation indications, was obtained the artificial colors image of Fig. III.14-A (scenario 1).

The extraction of lineaments through the image obtained by classification, highlights the curvilinear alignments noted in previous observations, allowing to deduce other situations with the same geometric expression that weren't visible in the untreated image.

In order to obtain a 3D scenario for the organization of ballooning plumes and its structuring against the current erosional surfaces, was done a manipulation on Google Earth Pro with distortion of scenario 2 for a 3D context presented in Fig. III.15. The simulation of intrusion relations suggest the tectonic conditioning responsible for the dislocation of flow trajectories, according to an alignment generated in N-E-S-W ductile regime. This hypothesis is supported by Silva (2002) to explain the lateral extrusion to S of inverted droplet pegmatitic bodies in Mata da Galinha and Monte do Castelo da Pena, seems also to control the emplacement and conformation of innergranitic ballooning plumes.

The curvilinear alignments organizations observed on a manipulation level of satellite images are not spurious and may eventually be recognized in a mesoscale context. If the scalar invariance is considered valid, Guimarães and Leal Gomes (2010) document an outcropping deposit also in Ponte da Barca, in which the curvilinear limit geometries that separate differentiated phenocrysts clustering domains can have the same genetic type of the ones observed in remote mapping analysis (Fig. III.16).

Thus, the existence of flow trajectories, more or less convulsive, related with models of installation by ballooning, and the possibility of their detection in remote mapping analysis can be a via for remote detection of pegmatitic bodies.

The Galínheira (A) and Germil (B) areas, marked on Figure III.14, were selected for geological investigation because they correspond to sectors where the referred alignment patterns are more evident.
III.3.2 Area E

In the Guarda area, the photointerpretation on Landsat and Spot images allowed to identify textural and chromatic patterns eventually related to aplite-pegmatitic dyke swarms. This idea proves itself when compared to mapping published in Silva et al. (2003) for the Cabeço dos Pousos sector, with patterns detected in the images (Figure III.17). The light tones that are identified in the Spot image correspond with close approximation to the mapped dykes.

This way, and through the possibility of showing accurately representative pixels of spectral pegmatitic patterns, was used the Maxver classification as a way to detect relatable patterns in other sectors of the study area.

The samples used in classification have spectral values close to the ones characteristic of the pegmatites marked in Figure III.17-B.

Figure III.17-C shows the classification results for correlation thresholds greater than 90%. It is perceived the cartographic distribution of patches classified mainly around the Frágas massif and especially according to a transversal WSW-ENE corridor. The signal obtained this way can be decomposed into two typologies – linear, related to the structure and diffused, induced by coverage, eventually compositional.

The selection of the Águas Belas and Quinta Cimeira research areas, to allocate for geological study for prospecting useful pegmatitic dykes, came from this analysis, recognizing in these spots high dispersion of remote aplite-pegmatitic patterns (Figure III.18). An analysis on the typology of the signal here obtained is available in Table III.1.
III. Satellite imaging processing

Evidence of remote agile pegmatite patterns and the distribution of patches resulting from Maxver classification is shown in the Águas Belas and Quinta Cimeira sectors.

Table III.1

<table>
<thead>
<tr>
<th>Research Area</th>
<th>Typology of the Signal Obtained Through Maxver Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quinta Cimeira</td>
<td>NP4: linear pattern truncated by zones more or less heterogeneous elongated patches corresponding to leucite outcrops, delimited by 2nd order truncations</td>
</tr>
<tr>
<td>Águas Belas</td>
<td>Linear patterns, very dense similar to heterogeneous and low density magmatic agglomerate</td>
</tr>
</tbody>
</table>

Typology of the signal obtained by Maxver classification in the Quinta Cimeira and Águas Belas areas – referable to Fig. III.18

Chapter

Geological investigation in research areas – substantiation of borehole location
Geological investigation in research areas - substantiation of borehole location

IV. Selection of extensive areas of research

From the matrices and analysis procedures developed in the previous chapters, by using structural-geological-geomorphological criteria and the results of their combination by buffering in GvSIG (schematized approach in Figure II.3, chapter II) and by texture, structure and alignment photointerpretation, in direct and filtered remote images, combined with automatic procedures for pixels evidence established by Maxver classification (chapter III) which could be indicative of pegmatite presence, a selection of favorable areas was made. The aspects of the area selection are recapitulated in Table IV.1.

Geological surveys on 1:5000 scale were carried out on these compartments, which came to support the selection of research spots. Within these, geological maps at greater detail scales (1:1000) were developed, with supporting topographical survey. These maps allowed the acquisition of predictive 3D conceptual models indicative of the pegmatite masses distribution in depth, to be investigated through drilling.

### Table IV.1

<table>
<thead>
<tr>
<th>Extensive areas of research</th>
<th>Criteria for the areas selection</th>
<th>Valency of the program</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong> AZAS</td>
<td>Near contact and their respective diastatic environments; Local in the interaction of NNW-SE and N-S shear zones, with NNW 45° E captured favorable to the occurrence of acaulid shaped bodies; Proximity to an explored pegmatitic body</td>
<td>Photointerpretation of Landsat images; Buffering GvSIG</td>
</tr>
<tr>
<td><strong>B</strong> GERMIL</td>
<td>Pegmatite contacts between syenitic rocks for a garnet and syn to late tectonic porphyroblast biotite granites; Zones with curvilinear lineaments; concentric, correspond to the outcrop of ascending magmatic plumes differentiated by ballooning</td>
<td>Photointerpretation and Maxver classification</td>
</tr>
<tr>
<td><strong>C</strong> MAIA DA GALINHEIRA /CASTELO DA PENA</td>
<td>Zone with curvilinear lineaments; concentric; Explored pegmatitic bodies from Mata da Galinheira and Monte do Castelo da Pena</td>
<td>Photointerpretation/ MAXVER classification</td>
</tr>
<tr>
<td><strong>D</strong> PESNEIRA DE SELAO</td>
<td>Local in the interior of a Late Variscan NE-SW shear corridor, associated with dilational environments able to convey post-tectonic magmas; Proximity to Senegal pegmatite (stockbreaker type large body); Spot located in NO/EN-S structure intersection</td>
<td>Photointerpretation; conditioning of the Senegal pegmatite; employment and photointerpretation</td>
</tr>
<tr>
<td><strong>E</strong> SULGUEIRO</td>
<td>Geological-geotectonic and geological criteria of proximity to the acaulid pegmatitic index, included in the Ferreira da Aves productive massif; basic rock dykes delimitation and proximity to elongated ridge adjoins to continuous lineament, interrupted by oblique lineament; Chromatic/natural contrast within the granite mass with general circular guidance, revealed by band 6 and main component 3 of Landsat image</td>
<td>Buffering criteria; Photointerpretation of Landsat images</td>
</tr>
<tr>
<td><strong>F</strong> ASSUNCAO SOUTH</td>
<td>Chromatic/natural contrast within the productive granite mass with general circular guidance, revealed by band 6 and main component 3 of Landsat image; Proximity to the Senhora da Assuncao pegmatite</td>
<td>Photointerpretation of Landsat images</td>
</tr>
<tr>
<td><strong>G</strong> QUINTA CINHA</td>
<td>Spectral continuity; Areas with high dispersion of albite pegmatitic pattern in MAXVER classification (90%) of sets of pixels corresponding to outcrops of albite pegmatites from the sector of Cabeço dos Poupos; Proximity to other minor pegmatitic indexes</td>
<td>MAXVER classification of Landsat image; Photointerpretation of Landsat images</td>
</tr>
<tr>
<td><strong>H</strong> AGUAS BIRAS</td>
<td>Spectral continuity; Areas with high dispersion of albite pegmatitic pattern in MAXVER classification (90%) of sets of pixels corresponding to outcrops of albite pegmatites from the sector of Cabeço dos Poupos; Geological structural and geomorphological criteria; proximity to the Cabeço dos Poupos swarm, proximity to an elongated ridge contiguous to a continuous lineament and differentiation by basic rock dykes</td>
<td>MAXVER classification of Landsat image; Photointerpretation of Landsat images; Buffering GvSIG</td>
</tr>
</tbody>
</table>

The planning and geological substantiation of the drilling program (for sub-outcropping pegmatite deposit intersection) is reported in this chapter. It shows the corresponding locations and depths reached in each case.

It was pre-stipulated 40 to 50 m maximum drilling depths, considering these the limits of feasibility for potential exploitation. Case by case, the drillholes reached depths determined by geological monitoring.

IV.2 Geological investigation in the Area A – Ponte da Barca

In the Ponte da Barca area, the research work was concentrated in 3 restricted areas: Azas, Germil and Mata da Galinheira/Castele da Pena.

The selected blocks are represented on the map of Figure IV.1, emplaced on the geological basis, with legend reported to Figure II.6.
IV.2.1 Azias research area

Within the Azias research sector, one glimpses a favorable tectonic conditioning by the occurrence of a previously exploited pegmatitic body (Cruz pegmatite), hosted in a porphyroid coarse grained granite, near to the junction of a sin-D3 NNW-SSE shear corridor (alignment parallel to the Vigo-Régua shear zone) with late-(D3-D4) structures oriented 30°E and WNW-ESE, noticeable in the filtered Landsat image photointerpretation (view fig. III.2, chapter III).

Under tectonic conditioning the pegmatite emplacement leverages the shear and their conjunctions, favoring the development of arachnid shape geometries.

In this research sector the approach criteria mentioned in Figure II.13 are also combined.

Geological surveys on 1:5000 and 1:1000 scales (Figure IV.2) in the surroundings of the exploited pegmatite body, revealed the existence of aplitic dykes and bit thick pegmatites close to enclave concentration strips, also suggesting that contamination processes as a result of mixing and mingling can be favorable for the pegmatite productivity in these structural corridors.

The predominant enclaves are metasedimentary and ultramafic xenoliths, rounded heterogeneous ellipsoidal enclaves tending to be meso to melanocratic with fine grain, and also fine- to medium grained leucogranite facies (Figure IV.3-E). Corresponds to them a distribution that roughly parallels the topography at higher altitudes and 22°W fracture directions. On its periphery, the enclosing granite presents typical alteration phenomena manifested by the megacrysts and matrix pervasive reddening (Figure IV.3-D).

The aplitic dykes (Figure IV.3-C) occur according to 30°E fracture direction.

A three-dimensional predictive model regarding the organization of pegmatitic bodies, relatively to the main deformation structures and mingling ranges, is presented in Figure IV.4.
By combining the marked productivity criteria, 3 boreholes with core recovery and 4 destructive holes with cuttings recovery were located in the Azias sector. The selected spots coordinates are shown in Table IV.2 and represented on the map of Figure IV.2. The drillholes reached the depths shown in Table IV.2.

### Table IV.2

<table>
<thead>
<tr>
<th>Study area</th>
<th>Research sectors</th>
<th>Assignment</th>
<th>M</th>
<th>P</th>
<th>Depth (m)</th>
<th>Drilling type</th>
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<td>233660.66</td>
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<td>A#AZ4</td>
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<td>Germil</td>
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<td>234479.92</td>
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<tr>
<td>Galinhaira/ Castelo da Pena</td>
<td>A#CP1</td>
<td>-15480.89</td>
<td>233546.66</td>
<td>50</td>
<td>R</td>
<td></td>
</tr>
</tbody>
</table>

In Table IV.3 the reasons that led to the selection of the Azias drilling spots are detailed.

### Table IV.3

<table>
<thead>
<tr>
<th>Assignment</th>
<th>A#AZ1, A#AZ2, A#AZ4, A#AZ5, A#AZ6, A#AZ7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Located in the periphery of the Cruz pegmatite, in the following of an elongated strip of enclaves proliferation with intermediate mafic composition parallel to N22°W alignments to where N30°E structures converge, with accommodation of aplite dykes and structures N70°E, indicating dykes of basic rocks.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Assignment</th>
<th>A#AZ2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Placed on the development of a N22°W oriented megascopic structure with quartz filled the alignment with the Cruz pegmatite, at south, predicts some continuity between pegmatite bodies located in a common structural level in this corridor and according to a range of 70 m are recognized in continuity strips of metasedimentary rocks enclaves (possible roof pendant), enclaves of mafic rocks, to the expression of minor pegmatitic bodies which can evolve by coalescence, in the range of the more superficial 40 meters.</td>
</tr>
</tbody>
</table>

### IV.2.2 Germil research sector

The Germil research sector is located near the granitic interface considered productive for the pegmatite bodies distribution in the Ponte da Barca sector (view chapter II), characterized by the contact of porphyritic granites and fine to medium grained granites (Figure IV.6-A).

The geological mapping on 1:5000 scale (Figure IV.5) revealed various minor pegmatitic outcrops within fine to medium grained facies. Some thicker bodies have a very marked hyperalumunious character, with abundant andalusite in their paragenesis (Figure IV.6-B). Others match aplite-pegmatitic subvertical dykes with thicknesses reaching up to 1 meter maximum (Figure IV.6-E).
Contacts between the porphyroid granite and the fine grained facies are gradual, being locally observed the presence of enclave strips of fine grained facies within the porphyroid granite interior (Figure IV.6-C).

Filter pressing phenomena are also typical of the contact between the porphyroid granite and the fine to medium grained facies; they are expressed through biotite progressive enrichment in the porphyroid facies from the range of contact, and manifest a segregational aspect, schlierenitic, showing, at times, a banded tendency (Fig. IV.6-D); the biotite contents here located can reach modal values close to 70%.

In line with the hyperaluminous character of the pegmatites, the fine grained host granite is locally a carrier of cordierite and garnet (Figure IV.6-F). The biotite is typically colorless and chloritized (Figure IV.6-G) and trends of yellowing of the granitic mass, caused by hydrothermal alteration and leaching with supergene influence of Fe from biotite crystals, and the late fixation of the Fe in the form of vacuolar fills are typical (Figure IV.6-H).

In the selected compartment for geological mapping on 1:1000 scale (Figure IV.7), 3 spots with pegmatite coverage debris were detected, putting up the hypothesis that they match buried mining works. Within this sector, outcrops of a leucogranite pegmatoid facies constitute an innominate belt established in the contact with the porphyroid granite, circumscribing those earthworks. These facies enriched in muscovite and graphic pegmatite (Figure IV.6-I e J) may be transitional towards the pegmatite bodies, from which they develop by in situ fractionation, gradual and direct.

According to these criteria, a borehole was proposed, which is likely to intersect a pegmatitic body in the range of the more superficial 30 m (Fig. IV.7, Tab IV.2).
IV.2.3 Mata da Galinheira/Castelo da Pena research area

In this sector it is observed the gradual transition between the medium grained granite and a porphyroid facies, with small potassic feldspar phenocrysts that come to define a penetrative lineation and which cartographic arrangement, approximately aureolar and dome-like relatively to surrounding granites, seems to relate to some geometries established by remote mapping analysis (view cap III). In this linear facies (Figure IV.7 A, B and C), the geometric arrangement of the Fk phenocrysts expresses linear and planar fluidities, established at low viscosity, with sufficient continuity to establish components of magmatic flow, which should be parallel to the rise of magmas and the propagation of pegmatitic sets.

On the map of Figure IV.8 it is verified that the pegmatites explored from Mata da Galinheira (A) and Monte Castelo da Pena (B) seem to have a clear relationship with this granitic interface.

In the same figure, it is delimited at south, a sector of low dip outcropping dykes (Figure IV.7 D), hosted in microporphyroid granite near the apical productive contact, which may correspond to converging corridors of preferential percolation of differentiates, apical to a pegmatite body in depth. A dyke intersected in the trail, with 50° to E dip, ma-
IV. Geological investigation in research areas – substantiation of borehole location

IV.3 Geological investigation in the Area B1 – Chaves

The possibility of detecting pegmatites with analogous setting to the Seixigal body appears as the main objective of the prospecting program. The prospecting program and the approach, supported by detailed mapping of the late Variscan shear corridor direction N30°E in Figure IV.10 and the proximity to the Santa Bárbara plutonite, was based on this assumption.

The program of geological mapping carried out here (Fig. IV.11) allowed the discrimination of the limits between granite and metasediments and the marking of the major ductile-brittle structures. It also provided access to some outcropping pegmatitic bodies. On the Redial site, there is a tabular subhorizontal body in a peri-granitic strip, next to the contact with the enclosing metasedimentary formations, which manifests collapse banded structures and internal units filled by the resurgent biotite granite. The possibility of being a stocksheider type pegmatite with post-tectonic inner granite/outer granite analogous to the Seixigal pegmatite, led to focus here the mapping and topographic surveys at greater detail scales (1:1000) capable of supporting the marking of drilling sites (Fig.IV.12).

Some of the most striking aspects of the Redial pegmatitic outcrops, that suggest similarities with the Seixigal body, are:

- proximity to the contact with metasedimentary enclosing rocks;
- the pegmatite hosting, in the form of a tabular subhorizontal body;
- the presence of planar faulting parallel to the contacts, more intensely developed in the border areas;
- internal banded structure, typical of dome collapse with open filling (Figure IV.13-C);
- internal units with interstitial inner granite (Figure IV.13-D);
- venular tourmalinization in the granite contact.

The coordinates of the locations determined for drilling are shown in Table IV.6 and are represented in the map of Figure IV.12. A forecast on the three-dimensional disposition of the Redial pegmatitic body, that is expected to be intersected in the drillholes, is presented in Figure IV.12.

Other compartments with subhorizontal pegmatitic outcropping masses detected in the geological mapping program also appear to be promising (view Fig. IV.11). Namely, the periphery of the Seixigal mining pit manifests a dispersion of minor outcrops that are included in the same N30°E structural corridor, propagated between the Seixigal and Redial pegmatites, which have tabular morphology and possible spread in depth.
IV. Geological investigation in research areas – substantiation of borehole location

IV.4 Geological investigation in the Area D – Satão-Aguiar da Beira

In this study area, the selection of research spots was based on geomorphological and structural criteria, considering situations intended as more favorable to the occurrence of pegmatitic bodies, locations close to elongated domes contiguous to continuous lineaments and interrupted by oblique lineaments, simultaneously near known pegmatitic outcrops and dykes of basic rocks.

After surveying these criteria indicators by decal from topographic and geological mapping, its intersection space (“buffering”) was operated in gvSIG software, obtaining polygons corresponding more or less to restricted sectors that came to correspond to key study areas.

The Salgueiro spot comes from a program with this approach.

The area that was conventionally designated south Assunção, neighboring the more representative pegmatitic group with the same name, resulted from the remote observation of contrasting chromatic and textural patterns, with roughly circular design in that sector.

In Figure IV.14 the two sectors submitted to geological research are identified.
IV.4.1 Salgueiro research area

In Salgueiro, the outcropping granite is medium to coarse grained porphyroid. The geological mapping on 1:5000 scale allowed the discrimination of clustering phenomena of phenocrysts in granites, leading to the definition of granitic inhomogeneous facies (Figure IV.15), which show some proximity to the distribution of swarms of small pegmatitic dykes.

The fluidal lineations marked by the concentration of FK megacrysts manifest a vertical tendency (Figure IV.16-A and B) and are subparallel to the strike of some shears, suggesting the influence of the D3 stress field regarding the granite emplacement.

Within the porphyroid facies, small outcrops of fine grained granite are also observed. On the south of the area, one compartment with at least 4 pegmatitic minor outcrops subjected to research in the past, was detected. The existing small pits not referenced in the Siorminp database (Figures IV.15 and IV.16-C) revealed a paragenesis very rich in quartz (including gigacrystals of smoky quartz) and brecciated hydrothermal beryl, typical of the final evolution of pegmatitic differentiates. The detailed geological survey of this sector is presented in Figure IV.17-A; the coordinates of the pits suggest the existence of an E-W alignment of pegmatite bodies near an interface between the porphyroid granite and a fine grained granite (contact tilting 50° to north), in a band with detrital cover, while suggesting a greater alteration rate of the outcropping materials.

This organization, to investigate through drilling (holes with the assignments D#S2, D#S3, D#S4 and D#S5; Tab.IV.8) admits two possible situations (Figure IV.17-B):

- eventual pegmatitic band (tabular body), from which emerge convex protruding structures, fundamentally quartzo-feldspathic, that crystallize at the ceiling of the pegmatitic strip, set upon a band of granite with subhorizontal fine grain.
- set of individualized and evolved bodies from a paragenetic viewpoint, with approximately spherical morphology, that might, by coalescence, propagate laterally. This organization is assumed in the three-dimensional conjecture of Figure IV.17c.

Inside the surrounding porphyroid granite, subvertical and subhorizontal pegmatitic dykes are common, according to an organization that foretells the repetition and extension of the tabular structures in depth. The host in horizontal bodies seems to be thicker on the east side of the charted sector (Fig. IV.17-A and IV.16-D and E) which led to set a borehole in that location (D#S1, Fig. IV.17-C and Tab. IV.4).
IV. Geological investigation in research areas – substantiation of borehole location

Illustrative photographs of outcrops with key petrographic aspects and dyke organizations commented in the text.

Figure IV.16

Legend
- Coarse-grained porphyry granitic
- Fine-grained porphyry
- Annular veins
- Dyke and intrusion
- Pegmatite
- Quartz
- Phonoclyosites
- Deformed and deformed fractures
- Jointed and deformed with petrographic textures
- Outcrop of intermediate and pegmatitic tonalites
- Quartz concretion
- Bright contours obtained for interpretation from a survey carried out with differential GPS
- Pegmatites with cavities
- Drilling with diamond drill core recovery
- Pegmatitic pockets
- Dyke with optical anisotropies

Figure IV.17

Tabular pegmatitic body from which emerges protruding convex structures, mostly quartz rich

Set of individualized and evolved pockets with roughly spherical morphology

Geological map corresponding to the Salgueiro sector – survey at scale 1:10000
IV.4.2 South Assunção Research area

As can be seen in the map of Figure IV.19 the interest area covers an elongated dome (NNW-SSE) with a maximum altitude of 770m and covers coarse grained porphyroid granite facies and fine grained facies mainly leucocratic. The sector is compartmentalized by a complex tectonic expressed in NOE/EW and N45°W ruptures. These ruptures can be filled by dykes of basic rocks and seem to delimit sectors dominated by pegmatite with different geometries and internal organizations, from tabular in São Matias to irregular bodies in Carrasqueira, and even the spread of numerous small spherical bodies- pegmatitic bubbles- in Fraga.

Putting up with the hypothesis that the morphologies of the bodies may be related to the emplacement depth in the magma chamber occurring according to a defined organization in the lithological heterogeneity of the granitic domes (view Figure III.6; Guimarães, 2012) in south Assunção it is credible to assume the coexistence, in the same current topographic surface, of distinguished levels of structural settings.

This scenario would result, by hypothesis, from vertical displacements motivated by a latest distensive tectonic, according to NW-SE directions.

### TABLE IV.3

<table>
<thead>
<tr>
<th>Study area</th>
<th>Research sector</th>
<th>Assignment</th>
<th>M</th>
<th>P</th>
<th>Depth (m)</th>
<th>Drilling type</th>
</tr>
</thead>
<tbody>
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<tr>
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<td></td>
<td>D#S2</td>
<td>42992.43</td>
<td>124443.02</td>
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<td>D</td>
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<tr>
<td></td>
<td></td>
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<td>126209.77</td>
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<td>D#C4</td>
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<td>D#S1</td>
<td>39888.23</td>
<td>126322.79</td>
<td>60</td>
<td>R</td>
</tr>
</tbody>
</table>

In the Fraga sector (delimited in Fig. IV.19) an unusual bubbling phenomena is recognized within the fine grained granite, manifested by the occurrence of numerous miaroles coated with pegmatitic minerals (Figure IV.20-A and B).

The structural control of these granites outcrop is well defined, featuring in strips oriented n35°E (with several gaps regarding continuity), parallel to the main regional shearing structures and subparallel to the configuration of the plutonic dome. The contact of the fine grained granite with the porphyroid granite is abrupt (Figures IV.20-C and D).

The potassic feldspar, quartz and muscovite can be considered the essential minerals of the bubbles, which have dimensions between 5cm³ and 1dm³. They are most often lenticular or elliptical (trimetric, prolates and oblates) as -

The potassic feldspar, quartz and muscovite can be considered the essential minerals of the bubbles, which have dimensions between 5cm³ and 1dm³. They are most often lenticular or elliptical (trimetric, prolates and oblates) as well as characterized by a pronounced deformation by shear. In the peripheries of most bubbles, and with areolar disposal, is typical the enrichment in feldspar with corresponding depletion in quartz and ferromagnesian constituents (Figure IV.20-B), which means, by hypothesis, primary crystalization or fractionation in primary equilibrium or late metasomatism.

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IV.4 Geological investigation in research areas – substantiation of borehole location

<table>
<thead>
<tr>
<th><strong>Research area</strong></th>
<th><strong>Assignment</strong></th>
<th><strong>M</strong></th>
<th><strong>P</strong></th>
<th><strong>Depth (m)</strong></th>
<th><strong>Drilling type</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>D</strong> Salgueiro</td>
<td>D#S1</td>
<td>42900.02</td>
<td>124914.91</td>
<td>36</td>
<td>D</td>
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<td>42941.41</td>
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<tr>
<td></td>
<td>D#S5</td>
<td>42896.10</td>
<td>124412.97</td>
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<td>D</td>
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<td></td>
<td>D#S6</td>
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<td>124456.00</td>
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<td>R</td>
</tr>
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<td>D#C1</td>
<td>40506.96</td>
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<td></td>
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<td>40035.00</td>
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<tr>
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<td>41887.80</td>
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In the peripheries of most bubbles, and with areolar disposal, is typical the enrichment in feldspar with corresponding depletion in quartz and ferromagnesian constituents (Figure IV.20-B), which means, by hypothesis, primary crystallization or fractionation in primary equilibrium or late metasomatism.

In the peripheries of most bubbles, and with areolar disposal, is typical the enrichment in feldspar with corresponding depletion in quartz and ferromagnesian constituents (Figure IV.20-B), which means, by hypothesis, primary crystallization or fractionation in primary equilibrium or late metasomatism.
These pegmatitic devices represent the rise in the granitic magmas domes greatly enriched in volatiles and are explained by fluid immiscibility triggered mainly by decompression phenomena (first boiling, Candela, 1997). In the south Assunção sector, the kinematics prosecutor of decompression and enhancer of immiscible fluid, is transcurrent with direction N30°-45°E, as simulated in the model of Figure IV.21-A.

The volatile enclosing and the preservation of the bubbles inside the granitic column benefit from conditions of relatively rapid cooling, of which are testimony fine grained host facies.

The drilling coordinates in Table IV.8 has as its main objective the structural and paragenetic analysis of the bubbles along the granitic column, expecting that the results provide important input for pegmatite emplacement modeling. The interpretation and survey work is in progress.

The Carrasqueira sector covers an old mine of quartz and feldspar, where were left three small mining pits (Fig. IV.19).

The exploited deposits have inverted drop morphology with apical dilation and extravasation (Figure IV.22-A and B), seemed to be rooted in N30°E shear structures, plunging to east. This direction, which also affects the bubble formation at north, is truncated by E-W shear structure which also influences the pegmatite emplacement.

On the top side of the bodies there are flaps of small fine grained granite with subhorizontal relaxation structures (Figure IV.22-B).

In Carrasqueira three spots were selected for drilling at east of the main N30ºE alignment, looking for intersecting in depth the fluidal corridors that seem to control the installation of pegmatitic bodies (Tab. IV.8 and Fig. IV.21-B).
IV. Geological investigation in research areas – substantiation of borehole location

In Guarda region the selection of areas of interest relied on image classification methodologies. The selection of Águas Belas and Quinta Cimeira research areas, in order to prospect useful pegmatitic dykes, ran from the geology analysis, recognizing in these spots high dispersion of remote aplite-pegmatitic patterns (view Figure III).

The locations are reproduced in Figure IV.23.

IV.5 Geological investigation in the area E – Guarda

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The locations are reproduced in Figure IV.23.

IV.5.1 Quinta Cimeira research area

In the sector of Quinta Cimeira are represented coarse grained porphyroid granitic facies and lithologies with inhomogeneous character which include facies with drop-like quartz with coarse granulometry and transitional leucogranites with pegmatoidal differentiations (Fig. IV.24). The thicker pegmatites detected are tabular dykes more or less irregular with subhorizontal development and variable orientation between NNE-SSW and NNW-SEE. Other dykes are distributed according to the NE-SW, ENE-WSW and NW-SE azimuths presenting variable thickness and dip.

The thicker pegmatites are represented on the map of Figure IV.26-A. In the pegmatitic units is observed paragenesis that includes phases as sulphides (loellingite) and secondary phosphates (siderotil, rockbridgeite and sarcopside) located in the intermediate zone - quartz-core transition.

The possibility of existing a single mass covering all the bodies, intersected in the two cutting pits is considered. The drilling surveys E#QC(S)1 and E#QC(S)2 seek to determine the lateral and depth continuity of the pegmatite body Fig. IV.26 and 27 and Tab IV.9.

The observation of fragile downward collapse structures in intra-pegmatite position with gapping and horizontal elongation of the quartz suggests their deeper rooting, as illustrated in Figure IV.25-C.

In north Quinta Cimeira outcrop subhorizontal aplite-pegmatitic dykes, with aplite in wall, segmented by N30°E fragile structures (Fig. IV.26-B).

The bodies are highly fractionated, rich in quartz and with abundant disseminated beryl in the micaeous units (Figure IV.26 A). The thicker vein, with about 4m, dips 20° to E. The possibility of having a more irregular development in depth, as is simulated in Figure IV.27, motivated the research with drilling on the locations marked in Figure IV.26-B. The corresponding coordinates are in Table IV.9.

In this sector the geological detailed survey also revealed a peculiar occurrence of radial aggregates of beryl located in the granitic mass close to the contact with an aplitic vein (view Fig. IV.28-A). The possibility of being a hydrothermal growth from fluids very rich in Be, collected on a surface near the contact between granite and pegmatite, seems more credible.
IV.5.2 Águas Belas research sector

In the Águas Belas sector the outcropping granite is coarse grained porphyroid. It is cut by numerous aplite-pegmatitic dykes with variable thickness, strike and dip represented on the map of Figure IV.29 A and illustrated in Figure IV.30 A and B.

In a more restricted area of this sector (Feiteira, Fig. IV.29-B) were detected aplite pegmatitic dykes with greater outcropping extension which have raised particular interest due to the dissemination of coarse tantalite and occurrence of zinnwaldite very differentiated in the cavities filling (Fig. IV.30-C and D).

The greater paragenetic differentiation is observed in the thicker pegmatitic masses that may match thick joints of vertical systems of magmas channeling.

The corresponding detailed geological survey with the location of the drillings and prediction on the development of the pegmatitic mass in depth is presented on Figures IV.29-B and C.
IV. Geological investigation in research areas – substantiation of borehole location

**Figure IV.26**
Geological maps on 1:1000 scale of the north and south Quinta Cimeira research areas.

**Figure IV.27**
3D simulation of the pegmatite bodies to be prospected in Quinta Cimeira.

**Figure IV.28**
Thicker aplite-pegmatite in north Quinta Cimeira with illustration of the spread of beryl in their micaceous units and in the enclosing granite.
IV.6 Implications of the drilling program

The prospecting developed in the different areas of the project revealed a number of promising sites to be investigated through drilling. It should be noted, however, that the determination of these locations results from an optimistic forecast on the development of useful masses in depth, not existing in any case guarantees that it will identify a deposit.

The forecast on the intersection of pegmatitic masses follows the order towards an increase probability: Azias/Galinheira – Salgueiro/Carrasqueira/Germil - Quinta Cimeira (n) – Redial – Quinta Cimeira (S)/São Matias.

In any case the drillings should provide access to granitic columns representative of pegmatite implant levels, providing indications on the functioning of the domes and its potential to generate pegmatites.

IV.7 Structural and lithological guides for pegmatites prospecting – generalization resulting from geological survey in research areas

In the sectors mapped on 1:5000 and 1:1000 scales, beyond the regional lithotypes described in published 1:5000 mapping, were identified other granitic facies, tendentially abnormal and interpenetrated, which gradually pass into the regional facies, noting that the distribution of pegmatites reveals a character coincident with sectors of greater lithological diversification and heterogeneity.

These sectors represent, hypothetically, petrographic signatures of trends of fractionation in granitic domes, productive in pegmatites, verifying also in relation to some of them, specific patterns of hydrothermal and supergene alteration.
Based on the granulometry, fundamental paragenesis, microstructure and alteration mineralogy, are distinguished the following facies:

- Fine grained leucogranite with nodular biotites, discolored and chloritized (yellowing tendency by leaching with supergene influence).
- Facies tending leucocratic, carriers of diffuse pegmatitic differentiations or carriers of radial mica and plume structure feldspar (pegmatoid granite).
- Micro porphyroid facies with penetrative lineation marked by the alignment of potassic feldspar phenocrysts caused by flow at low viscosity.
- Granite carriers of agglomerations or clustering of potassic megafeldspars, with vertical tendency.
- Dark biotitic segregations, schlierenitic, established on the surface of contact between granitic facies.
- Fine grained miarolitic facies punctuated by pegmatitic bubbles representing phenomena of fluid immiscibility of volatile-rich magmas below the levels of greater volume pegmatite emplacement.
- Granite with drop-like quartz.
- Leucogranites carriers of cordierite and garnet (facies in transition to hyperaluminous pegmatites).
- Porphyroid granites differentially reddened by feldspar hematization of the matrix and/or megacrystals.

Regarding the preferential structures hosting pegmatitic magmas, it is deduced from the study carried out that the direction N30°E, late-Variscan, seems to condition the installation of the bodies with higher volume in the sectors of Chaves, Salão and Ponte da Barca. They are aligned according to this direction:

- the pegmatites of Senhora da Assunção group;
- the patches with bubbling and the average lineation of bubbles stretch;
- Carrasqueira pegmatites;
- the structural corridor where the pegmatites of Seixal and Redial are distributed;
- the aplastic dykes in the Azias sector.

This direction is orthogonal to the elongation of granitic massifs in northern and Beiras regions, occupying NW-SE structures parallel to the shearing zone of Vigo-Regua. Hypothetically, the magmas that intruded those structures were affected by late stretch according to N30°E, which is the preferential direction for pegmatites installation resulting from fractionation of those magmas. The directions NNE-SSW and ENE-WSW have greater influence on the emplacement of the pegmatites in the Guarda region.
Drillings and 3D modeling

In this chapter are presented the results from the drilling survey on the locations identified in the previous chapter. Of all the expected boreholes, only the drilling in Águas Belas (area E) was not done, due to lack of authorization from the owner of the terrains.

The survey done with diamond drilling with core recovery included the identification of intersected pegmatite ranges and the macroscopic petrographic description of the enclosing granites.

In the case of the destructive drillings with cuttings recovery, the indications about the intersection of pegmatite came from a recording of the boreholes with a “video inspection camera” (model RCAM1000® from Laval Underground). The material recovered from the productive holes was subjected to panning concentration and stereo macroscope observation. It was done a diagnostic of the dense pegmatitic fraction and the identification of nodal biotite contents in enclosing granites.

The information gathered through drilling was used as an attempt for three-dimensional modeling of pegmatitic masses intersected in depth, using software “Voxler®”. The obtained results are also addressed in this chapter, discussing the adjustment of the models, relatively to the conceptual previsions presented in chapter IV.

V.1 Drilling logs - results

The diamond drilling logs are shown in Figure V.1. The correspondent logs of the drilling made in Azias, Germil and Quinta Cimeira north were not included in this set due to low recovery percentages induced by the greater changeability of the terrains crossed. The drilling logs from Chaves and Fuga areas are also not presented here.

The composition of the lithological columns was done using software Strater®, locating on the correspondent logs to pegmatitic ranges and discriminating the intersected granitic facies. In the describing petrographic analysis of the logs, the distribution of mineralogical constituents, the granulometry of the facies and the abundance and location of the potassic feldspar phenocrysts was made. It was also associated to the columns the indications of % of phenocrysts, the presence of macroscopic schlieren and the existence of mafic calc-silicate formation. These indications are useful to establish trends of facies variations and anomalous transitions in the granitic column, which seem to tend to pegmatites.

In any of the drillings, thick pegmatitic masses were intersected, but in all of them were recognized three or more pegmatitic or aplitic ranges with 0.5 meters of average thickness, organized as more or less regular alternations in the granitic columns.

Only the drilling D#C2 intersected a pegmatite over a range of 3 meters, close to the surface, identifying in this particular case internal zonality, representative of an edge zone, intermediate zone and quartz core (2 meters thick).

The drilling E#QC(S)1 also revealed a thicker pegmatitic range intersected 3m in depth, essentially constituted by quartz (1.5 meters).

In Table V.1 are given the total thicknesses of pegmatitic ranges, crossed in the several drillings.

In the case of destructive drillings only the drilling D652, in Salgueiro, provided an intersection of a pegmatitic mass between 18 and 26 meters depth, via video combined with the mineralometric test, and was identified in this range a nuclear quartz mass 4 meters thick. About this range the mineralometric test leads to the identification of anatase present in amounts close to 7% of the corresponding concentrate (view Figure V.2).

The pegmatitic body intersected in Salgueiro may have dimensions that justify an industrial use.

<table>
<thead>
<tr>
<th>Drilling</th>
<th>Sum of the thicknesses of pegmatites or aplitic-pegmatite intersected in each case (in meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area A</td>
<td>15</td>
</tr>
<tr>
<td>Area B1</td>
<td>2.5</td>
</tr>
<tr>
<td>Area D1</td>
<td>0.4</td>
</tr>
<tr>
<td>D6C1</td>
<td>2.18</td>
</tr>
<tr>
<td>D6C2</td>
<td>2.3</td>
</tr>
<tr>
<td>D6C3</td>
<td>0.2</td>
</tr>
<tr>
<td>D6N1</td>
<td>9.7</td>
</tr>
<tr>
<td>D6S1 (destructive)</td>
<td>8.0</td>
</tr>
<tr>
<td>Area E</td>
<td>15</td>
</tr>
<tr>
<td>E6QC(S)1</td>
<td>1.5</td>
</tr>
<tr>
<td>E6QC(S)2</td>
<td>3.0</td>
</tr>
<tr>
<td>E6QC(S)3</td>
<td>1.74</td>
</tr>
</tbody>
</table>

In Table V.1: Total thicknesses of pegmatites and/or aplitic-pegmatite intersected by boreholes.

Note: In the São Matias drilling were accounted granitic pegmatoid facies.
V.2 Productive pegmatitic granitic columns

From the drilling holes with core recovery, some transition granitic facies near the pegmatitic masses were distinguished.

Through the identification of lithological granitic interfaces it is intended to inscribe the major evolutionary trends of granitic magmas which seem dependent of fractionation and segregation processes that seem tendent to pegmatites.

Although the test on fractionation should use geochemical data, the approach done here is defensible due to being indicated by gradual transitions between distinct granitic terms.

This way, the corresponding logs can be considered as granitic columns of productive pegmatitization and the approach of its organization provides a contribute useful for prospecting mineral pegmatitic deposits.

V.2.1 Analysis of granite-pegmatite transitions

The structuring processes of granitic domes leading to the appearing of petrographic anomalies with variable modal compositions and configurations, and specific fluidal compositions, rely on the fractionation, segregation and mobility of liquids after some percentage of crystallization, below the creep barrier (e.g. Pupier et al., 2008).

In petrographic terms, the segregation processes are indicated by the anomalous concentration of biotite, with schlierenitic organization. The responsible mechanisms usually appointed to the separation magma crystals, are hydrodynamic and gravitational by compression (Barbey, 2009) or filter pressing, explaining the expulsion of magmas through the granitic column by flow deformation (according to Weinberget al., 2001). According to these authors, the possibilities of segregation are mostly viable at a low crystallization rate (approximately 50% of crystallization).
On the other hand, it is accepted that the pervasive magmas migration zones should be coherent with fluid trajectories, marked by phenocrysts.

In the granitic columns referable to the logs on Figure V.1, the homogeneous granitic volumes represented correspond to poophysiod two-mica faces and medium to fine grained granites with shortage of phenocrysts. These may transt to the following anomalous horizons:

A - ranges of fine grained leucogranites, sometimes muzonic, with diffuse pegmatic segregations;
B - ranges with leucic composites of granite and graphic pegmatite with coarse muzonic intergrowth, radial, and banded structures with feathery feldspars (pegmatitic granite);
C - enrichment ranges culminating in biotite, and more penetrative schlierenistic bands;
D - phenocrysts clustering domains;
E - penetrative lineations - convolutes and with horizontal and vertical tendency - marked by the fluidal alignment of potaslic feldspar megacrysts;
F - ranges with pegmaticic bubbles carries of mafic cushions, with a few centimeters volume.

Type A and B horizons represent transitional terms of fractionation. They can evolve to banded pegmatites (incipient manifestations of thermogravity differentiation panels) and suffer internal fractionation, potentially generator of zonality.

Transitional granites and graphic - pegmaticic ranges reveal an emplacement, usually above the panels with fluidal lineations (type E horizons), and enrichment in ferromagnesian constituents (type C horizons), suggesting continuity between the magmas released by segregation and the following segregant evolution by fractionation of separated felsic magmas.

The schlierenistic organizations and some increments of the biotite content along the drillholes also manifest oscillatory tendency. These interfaces between these configurations and the presence of flow lineaments in the enclosing granite-masses.

Observations like these lead to the hypothesis of the segregation possibilities being strongly influenced by liquid’s mobility, idea that is coherent with the work of Weinberg et al. (2001) and Zak and Klimkinsky (2007).

From Figure V.2 it can also be perceived the oscillatory variation of the biotite contents along the borehole, and it’s more significant increment on the wall zone of the pegmatitic range.

The type D horizons - ranges with potaslic feldspar megacrysts clustering affecting porphyroid granites - are possibly determined by a higher crystallization rate of the granitic mass; and by a relatively higher viscosity. According to Weinberg et al. (2001) and Peterson et al. (2005) they result from mechanical instabilities, produced by thermal and compositional convection.

Bubble type pegmatites and miarolitic cavities within the granitic mass (type F horizons) can result from the enclosure of magma portions enriched in volatiles. The enclosure and immiscibility conditions depend on the increase of volatile pressure and temperature decrease (e.g. Candela, 1997), observed with consistent distribution of bubbles near the transitions with granulometry contrasting ranges.

V.2.2 Implications

Although the main constraints of the deposits location are structural, with the higher pegmaticic volumes situated in the triple junctions and dilatational knfs in shear nets, the internal dome fractionation is expressed in the acquisition of lithological heterogeneities, in the pluton interior. These seem to correspond to oscillatory fractionation and segregation tendencies with well-defined rhythms in the domes organization.

From these horizons can be released and mobilized differentiates, collected from structural corridors.

The segmentation processes seem to favor fractionation and have the ability to increase the appearance of transitional and pegmaticic leucogranitic magmas that may then evolve in situ. The segregation possibilities seem strongly influenced by liquid’s mobility.

Thus, in the approach to the massifs, the geological prospecting of pegmatites should privilege a combined structural analysis with the detection of these targets, preserved in granitic columns. These are useful for the definition of pegmatites emplacement levels, and from the remote detection viewpoint are usable, as they represent extreme and contrasting chromatic types with continuity on the surface (extension and width).

V.3 Three-dimensional modeling

V.3.1 Introduction

The type of data used (input) in a three-dimensional modeling project are quite diverse and can include field observations, interpretative maps, and geological sections, data from remote detection and remote mapping analysis, and mechanical drilling data according to Bellian et al. (2005). Each of these types of data have particular aspects, which integration and the way that it is done, will affect the quality of the geological model obtained. According to Gaumon et al. (2009), the spatial resolution of the data used will affect the construction of the three-dimensional model.

The underground three-dimensional modeling described next comes directly from the results obtained through the drilling program done previously. The software VOSTER was used for the software modeling.

The comprehension of the pegmatitic bodies shape and depth is one of the biggest challenges in its prospecting and characterization. The pegmatitic body’s morphology is generally extremely irregular, due to the petrogenesis of these kinds of rocks.

The first step to the study was the creation of a digital terrain model (DTM) for each of the study areas. The digital model was created from the topographic surveys. This model allows the integral spatial referentiation of the data (X, Y, Z - Latitude, Longitude and height). On the digital models created, it is possible to construct models to which variables can be assigned (C - Variable).

The creation and improvement of a pegmatitic body’s 3D geological model (3DGM) requires the increase of direct information, using data from the surface geological prospecting, followed by mechanical drilling campaigns (Ferreira and Cunha, 2011).

A 3DGM constructed this way allows the approach to shape and volume of pegmatitic bodies, in depth.

PROSPROG, given the specificity of the pegmatitic bodies to be modeled, it became necessary to make generalizations and use previous modeling from the known data about pegmatitic bodies, already described in bibliography and from the data collected in the field, in the course of the project tasks.

The methodological sequence used in the acquisition of the data used for obtaining the 3DGM within PROSPROG, is presented in a simple way in Figure V.3.

Within the methodological sequence described in Figure V.3, the edition of drilling logs (binary pegmatite/null) describes special mention.

The insertion of data in the modeling software implies the creation of three-dimensional matrices (attaches) X, Y, Z in which C corresponds to a numerical data (value) in a given spatial position. Due to the complexity of the data collected and observed in the drilling cores, the values of C are hard to distribute, not being possible a consistent numerical weighting. In order to overcome this situation, the value of C was given the binary value: 0 (absence of pegmatite); 1 (presence of pegmatite).

The use of locking points that correspond to the insertion of data from geological cartography, obeying the same logic, also contributed for obtaining 3DGM with a closer approach to reality, according to the sequence in Figure V.4.

V.3.2 Preparation, interpretation and modeling on PROSPROG

The 3DGM is derived from the obliteration of volumes of the geological model (GGM) by means of a set of techniques by the software PROSPROG. The GGM is a three-dimensional volume-surface model, transformed from data collected in the field, in the course of the project tasks.
V. Drillings and 3D modeling

The following sequence of images (data from Quinta Cimeira south area) represent the overlap of drillings and locking points on the topographic base and geological mapping 1:1000 previously georeferenced.

In creating the 3DGM it was used the generation of isosurfaces that correspond to volumes produced from alphanumeric matrices previously generated (crossing of drillings data, geological mapping and topographic survey), in which all surface points have the same numeric values.

V.3.2 Results

Area A - Ponte da Barca

In the area A, modeling 3DGM was done using drilling data and detailed cartography. The previous geological model that supported the implementation of the drilling program and that is now compared with the results obtained in the 3DGM with the aid of software VOXLER®, can be seen in Figure IV.21.

In Figure V.7 is presented the 3DGM obtained for the Azias area using software VOXLER® on a generated topographic base (SW view).
Drillings and 3D modeling

Figure V.8 represents a perspective of the 3DGM generated for the Azias area on geological mapping 1:1000.

The agreement of the 3DGM created with cartographic structures can be observed in Figure V.9. Despite being intersected aplite pegmatitic levels as well as levels with evidence of magmas mixing and mixing/mingling phenomena it was not possible to confirm either the continuity of the Azias pegmatitic body (previously explored), either the intersection of a new body. However, the 3DGM created can be used as a work base in posterior studies on this area.

Area B1 - Chaves
In B1 area a drilling campaign was done, based on the previous geological model presented in Figure IV.7 in the Referal study zone. However, in B1 area it was not possible to carry out a coherent three-dimensional modeling because the mechanic drillings results do not match to the previous model, as it wasn’t intersected any relevant pegmatic level.

Area D - Vouga
In D area - Vouga a modeling (3DMG) was done using drillings data and detailed mapping. The previous three-dimensional geological models that supported the implementation of the drilling program and that can be compared to the results obtained in the 3DMGs, with the aid of software VOXLER®, can be seen in Figure IV.21.

In this area were selected four spots for detailed work: Salgueiro, Fraga, Carrasqueira and S. Matias. Relatively to the S. Matias and Fraga spots it was done a drilling in each one, which results complement the previous geological modeling (view respective drilling logs).

The agreement of the 3DGM created with cartographic structures can be observed in Figure V.9.

Despite being intersected aplite pegmatitic levels as well as levels with evidence of magmas mixing and mixing/mingling phenomena it was not possible to confirm either the continuity of the Azias pegmatitic body (previously explored), either the intersection of a new body. However, the 3DGM created can be used as a work base in posterior studies on this area.
V. Drillings and 3D modeling

Area E

On area E - Guarda a modeling (3DGM) was done using drillings data and detailed mapping. The previous geological model that supported the implementation of the drillings program and that is now compared to the results obtained on the 3DGM can be seen in Figure IV.27. In this area was selected the Quinta Cimeira south area for research work.

Figure V.12 illustrates the 3DGM obtained for the Quinta Cimeira area, on the respective topographic base. Figure V.13 represents the 3DGM obtained for Quanta Cimeira south area, on geological background on 1:1000 scale with respective topographic base.

The 3DGM obtained against the existent data, is approximated to the shape expected in the previous three-dimensional simulation.
V.3.3 Conclusions
The geological modeling, namely the creation of 3D models, was possible due to the implementation of auxiliary points that resulted in a simplification of the data to be treated. Due to the high complexity of the intercepted pegmatitic bodies, it is considered that the approach obtained is suitable, even if grossly, to the geometry of the existing pegmatitic bodies, being considered credible in methodological terms. One of the main advantages of using the 3DGMs with the aid of specific software is the possibility of spatial manipulation of the data. This manipulation allows seeing the models obtained from multiple viewpoints, which provide a better three-dimensional understanding of the studied objects.

With the exception of area B1 it was possible to reconstitute the shapes and volumes of existent pegmatitic bodies in each one of the studied areas.

The suitability of isosurface using can be improved through a higher number of drillings, the integration of cartographic data and the obtaining of specific qualifiers. The drillings mesh should be equated according to the scale of bodies to characterize.

The investigation of shape and volume qualifiers likely to be used in three-dimensional geological modeling is foreseeable as a future investigation domain in pegmatites prospecting programs.

Spectral characterization of pegmatitic masses and enclosing lithologies spatially related
VI. Spectral characterization of pegmatitic masses and enclosing lithologies spatially related

In order to obtain spectral signatures that could be used as diagnostic property, under a context of remote mapping analysis, it was proceeded the spectral characterization of pegmatitic masses and enclosing lithologies, spatially and genetically related to the pegmatites.

VI.1 Introduction

The field tasks undertaken under PROSPEG allowed the selection of restricted areas of research that configure multiple conditions for the occurrence of pegmatites. However, given the size of the pegmatites identified and the chromatic diversity of rocks spatially related, the direct application of aerial/satellite imagery for its proper identification requires a higher individual spectral resolution for each lithology considered.

VI.1.1 Spectral reflectance

The geological materials (rocks and minerals) have spectral reflectance variations that result from their different physicochemical properties (especially those depending on light). In different wavelength intervals of the electromagnetic spectrum, the reflectance varies according to the chromatic properties of the objects.

The reflectance of an object corresponds to the ratio between the amount of reflected light and the amount of light received from a light source. The reflectance varies between 0 and 1, corresponding to an absence of reflection and maximum reflection, respectively.

The electromagnetic spectrum of an object corresponds to the division of electromagnetic radiation, according to its wavelengths, as shown in Figure 1. In satellite imaging, the spectral bands represent defined ranges of the electromagnetic spectrum. The denomination and amplitude of the spectral bands vary according to the authors. However, the most common terminology, as proposed by Chuvieco (2000) (in Alonso et al., 2005), comprises the following division of bands:

- a) band of the visible spectrum (0.4 to 0.7 μm) - the only electromagnetic radiation that can be perceived by the human visual system, coinciding with the wavelengths where the solar radiation is maximum. Usually are distinguished three elementary bands designated blue (0.4 to 0.5 μm), green (0.5 to 0.6 μm) and red (0.6 to 0.7 μm). These three bands are the primary colors perceptible to the human eye.
- b) near-infrared (0.7 to 1.3 μm) - also often called reflectance or photographic infrared, as part of it can be removed from photographic film endowed with special emulsions. It has special interest due to its ability to discriminate vegetation and moisture concentrations.
- c) mid-infrared (1.3 to 9 μm) - in this band the processes of sunlight reflection and land-surface emissivity are mixed up. It is widely used for estimating the moisture content in the vegetation and for the detection of high-temperature focus.
- d) far or thermal infrared (8 to 14 μm) - includes the portion of the terrestrial spectrum emission were the heat from the most part of the coverage of the earth can be detected.
- e) Microwave (as of 1000 μm) - type of energy quite transparent to nebulosity and that minimizes the presence and impact of small objects in the atmosphere and in the land surface.

The spectral signature of each material corresponds to the reflectance value exhibited by the material, in response to a stimulus (light), for defined and calibrated wavelengths, and that is similar for the same kind of material.

VI.1.2 Spatial resolution

The spatial resolution designates the smallest object that can be distinguished on a given image. In a photographic system, usually it is measured as the minimum separation at which objects appear distinct and separated in the picture. It is measured in millimeters on the pictures, or meters on the ground, and depends on the focal length of the chamber and its height above the surface, according to Chuvieco (2000) (in Alonso et al., 2005).

The spatial resolution is dependent on the scale effect, because, according to the graphic scale used, the distance on the field, as well as the objects observed, can vary for the same spatial resolution. The spatial resolution of the satellite images used only allowed the direct identification of macro and megascale geological bodies, so it became necessary to study the spectral properties of geological materials related to the presence of pegmatites. The increased spatial resolution of the different geological materials considered will allow an increase in the discriminating power of the data extracted from satellite images (Pereira, 2009).

VI.1.3 Color as an indicator

The manifestation of the outcrop pegmatitic sections chromatic properties depends on the chromatic properties of the minerals that constitute them. The cardinal minerals of the granitic pegmatites that are functional for this application are: feldspar, quartz and white mica.

Hypothetically and in application, the felsic nature of the cardinal minerals from the granitic pegmatites will confer a leucocratic character to the outcrop sections, creating a contrast of color relatively to the granitic enclosing.

This leucocratic character will tend to be diffuse on the interface of the contour of the outcrop pegmatitic section with the enclosing granite, being such widespread expected due to the frequent gradual nature of the geological contact between the pegmatites and their respective enclosing granites.

VI.2 Purpose

The main purpose of the spectral characterization of pegmatitic masses and spatially related enclosing lithologies is to obtain a spectral signature for each geological material present in the different study areas. It was intended, therefore, to constitute a spectral data base, through which it would be possible to study the individual spectral characteristics of each lithology so that this information can be integrated in the analysis of satellite images.


The optimal use of automatic classification procedures on these type of images requires the prior knowledge of the spectral reflectance relationships between the different geological objects to be identified in the field. Plus, according to Weston (1992), there must be a prior determination of spectrum regions on which it is possible to distinguish the different lithologies.

**FIGURE VI.1.1**

Spectrum of electromagnetic radiation (Alonso et al., 2005)
VI. Spectral characterization of pegmatitic masses and enclosing lithologies spatially related

The spectral measurements obtained under PROSEPR were done on geological materials that could be related to the presence of pegmatites in each of the study areas, in order to constitute a comprehensive set of spectral signatures for lithologic indicators.

VI.3 Methods and materials used

The methodological sequence adopted is synthesized in the flowchart of Figure 2.

![Flowchart](image)

**VI.3.1 Data collection**

In this stage, for the selection of sampling points, previously performed remote geological mapping was used, together with the data collected in the materialographic study phase of support to prospecting tactics.

Together with the spectral measurements in outcrop was also made a laboratory measurement campaign on samples from drill core and hand samples collected in the field, cutted into splinters with defined structural orientation (lithologic "chips").

Each point sampled was properly georeferenced, identified by an individual file, and photographed.

For the elaboration of individual files were used descriptors that allow the distinction between the main types of lithologies associated with the presence of pegmatites, as well as the observation of particular aspects of outcropping in each target. The selected descriptors are described in Table 1.

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Considered properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>Identification of the target of measurement and distinction between outcrop and artifact (occasionally, distinction between heap and quarry)</td>
</tr>
<tr>
<td>Lithology</td>
<td>Description according to detailed mapping carried out previously and after petrography</td>
</tr>
<tr>
<td>Petrographic description</td>
<td>Mineralogic identification and modal composition indication. Characterization of the size and frequency of phenocrysts and alteration products observed, capable of influencing the spectral measurement results.</td>
</tr>
<tr>
<td>Intensity of the reddening</td>
<td>Indication of the reddening intensity variation by microcyclization and hematization of feldspars, when observed, capable of affecting the measurement results.</td>
</tr>
<tr>
<td>Particular aspects</td>
<td>Indication of the presence of penetrative structures and vanations, other textural aspects, capable of altering the spectral measurement results.</td>
</tr>
<tr>
<td>Coating by lichens</td>
<td>Indication of the percentage of coverage by lichens for later comparison with the spectral curves obtained on not covered rock.</td>
</tr>
<tr>
<td>Munsell color</td>
<td>Display of Munsell color of the measured target, represented in outcrop element sample, for later comparison. Verification of the persistent relations between color (usage of Rock Color Chart) and spectrum.</td>
</tr>
</tbody>
</table>

One of the descriptors considered in the fieldwork was the color, expressed in several levels of organization of the study targets. Since the perceived color is itself distinct from individual to individual, causing a high degree of subjectivity in the descriptions, procedures to minimize that subjectivity should be adopted.

To classify the color, the visual comparison with Munsell® Color chips from Rock Color Chart was adopted. The color chips are standardized according to the Munsell® color abacus. The Rock Color Chart used in this work was produced under the supervision of the Geological Society of America (GSA) (2011).

The chips are classified by color: R (red), Y (yellow), G (green), B (blue), P (purple) and N (neutral - black and white). The photographic record of the measured targets is exemplified in Figure 3. It supports the interpretation of spectral data and the correlations between lithologies.
VI. Spectral characterization of pegmatitic masses and enclosing lithologies spatially related

For the execution of the materials reflectance measuring on the ground it was used a portable spectroradiometer FieldSpec UV/VNIR from Analytical Spectral Devices (ASD).

This spectroradiometer has a spectral resolution of 3 to 700 nm and an adjustable integration time, manually, of 17 milliseconds to several minutes. When used without any additional accessory, the light is captured with an observation angle of 25°. This angle can be reduced or increased according to the size of the sample to be analyzed, the viewing angle and the distance.

VI.3.2 Data processing

With this equipment it is possible to obtain multiple punctual measurements, in order to minimize random measurement errors. The spectral curves obtained are here presented as average curves, resulting from ten continued measurements on each sample, which treatment was done by software View Spec Pro®, from ASD.

Since the Field Spec Pro file generates an enormous amount of alphanumeric files, these were processed with the software Grapher®, from Golden Software Inc., which allows simultaneously the management of large amounts of alphanumeric data and graphics, generating, this way, the tables and spectral data files of the samples.

VI.3.3 Results

Once all the spectral measurement data were generated, collected and treated in the earlier stages, its statistical treatment was proceeded:

i) creation of data correlation tables, using the statistical open-source software “R” (2013),

ii) calculation of the average spectra by lithology and by areas, using simple Excel® spreadsheets,

iii) observation and comparison of the spectral curves, so as to be generated spectral signatures.

The spectral curves obtained were initially grouped according to the geographic areas of study, without defining classes of observation. This methodology allowed the assessment of merely numerical relationships between the different spectra, registering any possible groups of spectra relatable to the lithologies.

Figure 4 illustrates the methodology adopted in the statistical treatment and description of the reflectance results.

It was sought to isolate the factors that determine the variations observed considering their lithology and color as well as other aspects taken as descriptors, in order to obtain spectral signatures. In parallel, was studied the reflectance correlations between samples and spots.

It were determined classes of spectra based on:

i) lithology of the studied targets

ii) percentage of coverage by lichens

iii) colors N, registered in the field

The analysis of these classes of spectra allowed the lithologically similar spectral groupings.

VI.4 Results processing

With the development of this work were obtained, as results, 229 reflectance spectra, relative to the 229 samples analyzed in the different sectors and areas of study, distributed as shown in Table 2.

<table>
<thead>
<tr>
<th>Area</th>
<th>Sector</th>
<th>Spectra obtained</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Aziás</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Galinhense</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Germãos</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Pedra da Moura</td>
<td>17</td>
</tr>
<tr>
<td>B1</td>
<td>Monteados</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>Assunção</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Carrapiqueira</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Fraça</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Salgueiro</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>São Matias</td>
<td>12</td>
</tr>
<tr>
<td>E</td>
<td>Minas Norte</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Aguas Belas</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Pedras Alvas</td>
<td>5</td>
</tr>
</tbody>
</table>

Table VI.2

Table identification of the number of spectra obtained for the different geographic areas and sampling sectors.
VI. Spectral characterization of pegmatitic masses and enclosing lithologies spatially related

VI.4.1 Spectral results

As an illustration of the results obtained and subject of statistical analysis, the spectra graphic is presented in Figure 5.

The spectra shown are the result of the average reflectance measured in the targets for a wavelength interval, 325-1075 nm. From 980 nm, approximately, there is an oscillation in the spectra that is due to “noise” of the measurement method.

It can be observed a large variation in the spectral response of each type of lithology, either in terms of relative reflectance values, either in the form of individual spectral curves. Indeed, there is a difficulty in establishing a spectral signature for a given lithology that is easily distinguishable from the others. This is explained by the compositional similarity and, therefore, also chromatic of the pegmatite lithologies, light granites and aplite, not discriminable in many applications of this type.

It also happens that similar lithologies can present distinct spectral curves. Here, it will have to be considered other factors that influence the results, such as the own granularity of the constituent minerals of the targets under observation. In any case, the best discrimination between spectral curves seems to be associated to the specific geometry and slopes of the segments of curves.

Based on the defined spectra classes and eliminating potential outliers, this is, results of targets that deviate too much from a predetermined lithological pattern, it is possible to define spectral lithology signatures based on the average or most recurrent pattern.

The laboratorial results obtained for the drill core and lithological chips were inconclusive, presenting dispersion and spectra geometry values that have not yet been clarified, considering mainly that these were obtained in an apparent higher control of the luminosity.

VI.4.2 Correlation tables

The statistical analysis of numerical data collected in the field and that graphically constitute the spectral curves was proceeded. In order to verify the linear relationship between the data were performed Pearson correlation tests between the different samples and were generated correlation tables for each of the sectors under study.

As observed in Figure 6, similar lithologies can present large discrepancies in global reflectance values. Similarly, to targets with high correlations (0.99) may correspond different lithologies, as shown in Figure 7. However, from a genetic and pegmatitic productivity standpoint these two lithologies are very similar or, in other words, manifest petrographic equivalence. This is of some interest for the evidence of pegmatitic precursors (genetic) in potentially productive granitic systems.
VI.4.3 Environment classes and related lithologies

Table 3 shows the number of spectra considered in each area according to the environment classes and materials observed.

<table>
<thead>
<tr>
<th>Lichens (&gt;35%)</th>
<th>A</th>
<th>B1</th>
<th>D</th>
<th>E</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colors N</td>
<td>10</td>
<td>5</td>
<td>6</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Quartz</td>
<td>11</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pegmatite</td>
<td>12</td>
<td>4</td>
<td>7</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Undifferentiated pegmatite material</td>
<td>6</td>
<td>2</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pegmatic bubble</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aplite</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Porphyroid granite</td>
<td>14</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Coarse granite</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Medium granite</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Fine granite</td>
<td>8</td>
<td>-</td>
<td>8</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Fine grained porphyroid granite</td>
<td>6</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basic rock</td>
<td>1</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

VI.4.4 Munsell color

The obtained results did not allow a consistent grouping of the samples according to the color recorded in the field, since the dichotomy of spectral behavior versus color was extremely uneven. Exceptionally, the colors N (neutral) could be clustered, always representing low reflectance spectra, quite consistent with the class of coverage by lichens, being these, mainly, the ones responsible for inducing colors N.

VI.4.5 Influence of lichen coverage

The coverage of lichens can mask the spectral reflectance of rocks in outcrop. Spectral measurements made by Satterwhite et al. (1985) on granites revealed that a dense cover of lichens can mask the spectral response of the underlying rock outcrops, causing incorrect classifications of rocks when based exclusively on the spectral reflectance data.

Through the field forms registry, concerning the presence of lichens and their relative amount on the surfaces sampled, it was found that the spectral behavior presented a homogenization in the samples in which the percentage of coverage by lichens was greater than 35% of the measured area, being the coverage diffuse or dispersed.

VI.5 Analysis of spectral signatures

Figure 8 shows the spectral signatures for each defined class, obtained using the average for each area under study, in order to obtain patterns and allow the deduction of particular spectral behaviors, susceptible of diagnostic use in remote mapping analysis context.

It is possible to verify, through the observation of Figure 8, that there are inflections in 500µm and 680µm, in most of the signatures observed. There is a great similarity between the slopes of quartz of the samples with lichens and colors N, despite the differences in reflectance. This might be due to the fact that they are materials with very typical primary color, allowing its spectral distinction.

The high reflectance observed in the aplite samples can be explained by the strong leucocratic character of the facies.

The granites present quite similar spectral curves, with regard to their shape, with a well-defined order of their reflectance: coarse grained granite > medium grained granite > fine grained granite > porphyroid granite. The higher spectral curve of the coarse grained granite, compared to the other granites, might be due to fairly widespread kaolinitization observed in this facies.

The mingling corridors, the basic rock and the targets with lichens coating with >35% present the lower reflectance values from all lithologies observed, with the most notable differences in the initial portion of the spectrum presented (from 325 to 510µm). The rose quartz has a particular spectral signature with several variations on the same portion of the spectrum considered.

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VI.5.1 Analysis of the average spectral curves of pegmatitic samples

From the observation of the different signatures is notorious a large variability in the response of both pegmatite and undifferentiated pegmatitic material for the studied areas, obtaining an average spectral signature, as observable in Figure 9.
VI. Spectral characterization of pegmatitic masses and enclosing lithologies spatially related

VI.5.2 Analysis of the average spectral curves by study area

Given the homogeneity observed in global averages, in Figure 10 are shown the average spectral curves obtained for each lithology by study area (A, B1, D, E and G) where the particular spectral behaviors of similar lithologies (pegmatites, granites and quartz) in the considered study areas, are evidenced.

With this approach it is possible to verify a reflectance gradation in the different areas, maintaining, however, the geometric shape of the individual spectral curves for each lithology observed.

When comparing the spectral behavior of the different lithologies grouped by study area, it acquires local characteristics differing from the standard average behavior. This means that the spectral patterns should be considered independently for each study area and not through the global average, since it masks the characteristic features of geological context carrier of pegmatites. However, the common points of inflection among the pegmatite signatures and undifferentiated pegmatite material are maintained.

Within the granites, those which possess more characteristic signatures are the fine grained granites. The other granites have signatures very similar to each other, as to spectral trajectories (inflections and slopes).
More than the curves singly, for each area, the observable differences in the spectral curves of the different lithologies (and their combination) may be used as pointers in the context of remote mapping analysis. In order to obtain spectral signatures that reflect the singularities of each particular geologic context, the results were grouped by geographic area, and the outcome can be seen in Figure 11, Figure 12 and Figure 13.

In area A, the pegmatite, the undifferentiated pegmatitic material and the medium grained granite stand out from the other lithologies, for exhibiting high reflectance curves. The distinction of the pegmatite against all other lithologies occurs from 600 μm up to the end of the measured spectrum.

In area B1, the quartz stands out with reflectances superior to the other lithologies in the whole spectrum considered. The pegmatite is not discernible from the surrounding granites and aplites.

In area D, the pegmatite has higher reflectance values up to 550 μm, from which it becomes less reflective than the coarse grained granite. The undifferentiated pegmatitic material has higher reflectance than the granites for the whole spectrum considered.

In area E, other than the aplite, which has the highest reflectances, and the fine grained granite, which has the lowest reflectances, it is not possible to discern further lithologies. However, the pegmatite has a higher reflectance than the other lithologies in the 600 - 760 μm interval.

In area G, quartz stands out with higher reflectances for the whole spectrum considered. For the pegmatite, its spectral behavior resembles the fine grained granite, except in the range 425-590 μm. The medium grained granite exhibits the smallest reflectances of the whole sample.

Looking at the mean values of the areas, the quartz signature is highlighted, which has a different behavior, characterized by low slope in the initial region of the measured spectrum.

For each area individually, undifferentiated pegmatite, aplite and leucogranites exhibit at least some geometric domains which are distinguishable from surrounding rocks, both in outcrop and remote mapping analysis.

Once again, it is confirmed the induced homogenization when considering the overall average areas of different lithologies.

VI.6 Conclusions

With this study it was possible to conclude that, for lithologies of the same type, there is a variation of the spectral response, depending on the studied area.

This variation might be due to a joint action of several factors, including:

- The genesis conditions of each area;
- The different types and degrees of meteoric alteration (e.g. kaolinitization);
- Very localized hydrothermal alteration phenomena and with less spatial expression (e.g. reddening, epidotization, zinwalditization).
VI. Spectral characterization of pegmatitic masses and enclosing lithologies spatially related

Although there is variability in the average reflectances spectrum in the different lithologies, it is possible to define typical spectra for each area. It was also concluded that the reflectance has a direct relation with the leucocratic character of the observed targets, being possible to isolate different intervals of maximum relative reflectance, which will allow equating the distinction of spectral characterizations.

The lichen coating, from 35% in outcrop area, acquires a mask effect that obliterates spectral relations, creating spectral curvature.

Isolated Munssiell colors are entities themselves with respect to spectral signatures, characterized by low reflectances and flattened spectral curves. The results obtained from the drilling samples and lithological “chips”, although not conclusive, may be useful in future spectral characterizations.
http://www.dgeg.pt/

http://sniamb.apambiente.pt/webatlas/

http://geoportal.lneg.pt/geoportal/egeo/bds/siorminp/

http://www.gvsig.org/web/

References


