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PROSPEG PROJECT-PEGMATITE

REMOTE SENSING AND MAPPING FINAL REPORT

PROSPEG

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Final report.

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Summary

Within the framework of the R & D activities of the company Sinergeo Ltd., the project PROSPEG (nº11480), dedicated to the investigation through prospecting and research of pegmatitic granites, co-funded by "ON.2 – O Novo Norte" and QREN, through the European Regional Development Fund (ERDF), resulted from a co-promotion with University of Minho.

The overall objective of this project is the development of pegmatite prospecting and research programs in the Portuguese territory, using as main via for primary approach to the research areas remote mapping analysis and remote sensing methodologies. The investigation in this domain is justified by the difficult implementation of other geophysical and geochemical methods, given the lack of strong contrast between pegmatite and enclosing. On the other hand, the remote mapping analysis and remote sensing inscription in strategic pegmatites prospecting programs is also advantageous in cost/benefit terms and in terms of extension and density of coverage allowed.

In the strategic state the prospecting actions focused a set of areas, known as/or hypothetically fertile for pegmatites with economic interest.

These areas are compartments of the Variscan Pegmatitic Province from the North and Center of Portugal. Here can be found pegmatites with high intrinsic, structural, morphologic, mineralogical and economic diversity, respecting simultaneously different structural levels of placing and exhumation of individual pegmatitic sets and bodies.

The mediums chosen for remote mapping analysis were multispectral images from LANDSAT and SPOT sensors and images from Google Earth Pro. These were treated through digital processes like contrast broadening, RGB combination of spectral bands, analysis of main components and Maxver classification. The conjunction of these techniques turned more evident geometric, chromatic, textural and spectral patterns of the superficial expression of pegmatites and its prospecting indicators.

By combining those processing procedures with indications of productive slips and massifs 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 situation to be investigated through drillings.

From these surveys were also discriminated some structural and lithological guides conditioning the presence of pegmatites in an innergranitic context. The late-Variscan direction N30ºE seems to strictly condition the installation of bodies with higher volume in the North and Center of Portugal. On the other hand, it is also noticeable that the pegmatites 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 differentiations; microporphyroid facies with flow evidence; miarolitic facies punctuated by pegmatitic bubbles; leucogranites carriers of cordierite and garnet; biotites established on the contact surface between granitic facies and porphyroid granites reddened by hydrothermal and supergene hematization.

The punctual prospecting program with drillings was, in some cases, well succeeded, having been intersected a pegmatitic 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 mineralometric 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 fomenting the appearance of transitional leucogranitic and pegmatitic magmas that may then evolve in situ or be mobilized and released to structural corridors. The trends seem oscillatory in some cases, with well-defined rhythms in domes organization. From the remote sensing viewpoint the resulting facies are perceptible as they represent extreme and contrasting chromates with more extensive cartographic expression than the pegmatitic bodies.

As a line of innovative research capable of supporting pegmatites prospecting through remote sensing, were also obtained reflectance measures of lithologic pegmatitic products and their productive enclosings. 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 enclosings and test the influence of the substratum exhumed by lichens cover. It was found that with percentages of coating as of 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.

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1 chapter

Introduction

Introdução

I.1 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 "ON.2 – 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 (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 outcroping 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 inscription of the remote mapping analysis and the remote sensing in strategic prospecting programs 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.

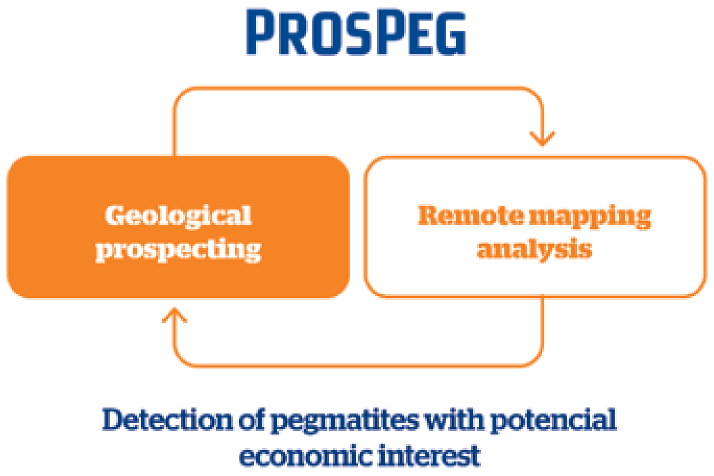


FIGURE I.1

Diagram summarizing the valencies of the project

I.1.1 Geological exploration adjustment to pegmatite research

Mineral deposit prospecting follows systematic methodologies and is defined by phases - strategic, tactical and punctual. Their vectors and functional structure are gathered for example in Chaussier and Morer's book (1992). It aims mineral deposit discovery for exploitation.

In strategic and tactical phases, the approach to the fulcrums of interest is regional and admits the use of geophysical and geochemical methods and photogeology. At punctual scales, after approaching the targets, the better understanding of the deposits and their characteristics requires drilling campaigns.

In the case of the metallic ore deposits the geochemical and geophysical methods are considered useful from strategic to tactical phases, greatly enhancing the access to targets. In the case of the pegmatitic deposits, the absence 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 lithiniferous units of this body, and negative anomalies on the surface contact with the host rocks (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 miarolitic pegmatites.

The chemism of the enclosing rocks affected by hydrothermal alteration phenomenas during the formation of the deposits is discussed, for example, in Beus et al. (1969). In this work, developed on the pegmatitic district of Bernic Lake (Manitoba, Canada), they resort to lithogeochemistry to delimit pegmatite related fulcrums of metasomatic influence, manifested by high contents of Li, Rb and Cs (Figure I.2-B). They consider that its development is more pronounced in the dependence of evolved Ta mineralized pegmatites and towards metasedimentary enclosing rocks.

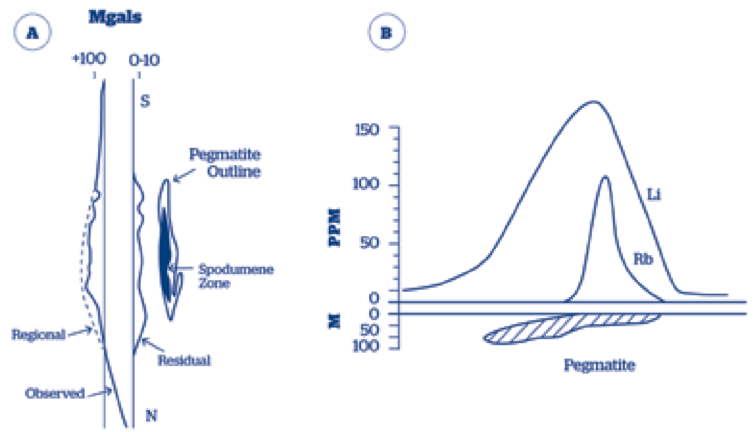


FIGURE I.2

Examples adapted from Trueman and Černý (1982) on the application of geochemical and gravimetric methods for the prospecting of the Tanco pegmatite (Bernic Lake, Manitoba)

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

Mineralometry 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 delimitation 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 (1993), 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 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 paragenesis 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 pegmatite geological prospecting.
However, by generalizing its use, spectral signatures research alluding to minerals and associations of pegmatitic minerals and its productive enclosing gains emphasis. The corresponding reflectance measurements collected using spectroradiometers (for in field and in laboratory use), accredit 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).

I.1.2 Conceptualization of the distant approach to pegmatite research

The pegmatitic deposits are organized in swarms (Černý, 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 rheological behavior more conducive to the hosting; functionally 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, they are, in principle, susceptible of discrimination using a methodical and systematic exploration of the images (Figure I.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.

Signs can be decomposed into textural, chromatic, morphological and spectral responses that not only describe the information that proceeds from the exploration guides, but also they can represent the interfering influence of vegetation and meteorization products, resulting from different water-rock and mineral-rock interactions (chromating halos, clays and oxides with different degrees of moisture).

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, this way, be organized towards the research for signals that are both reliable and clear evidences of pegmatite presence, at a regional scale.

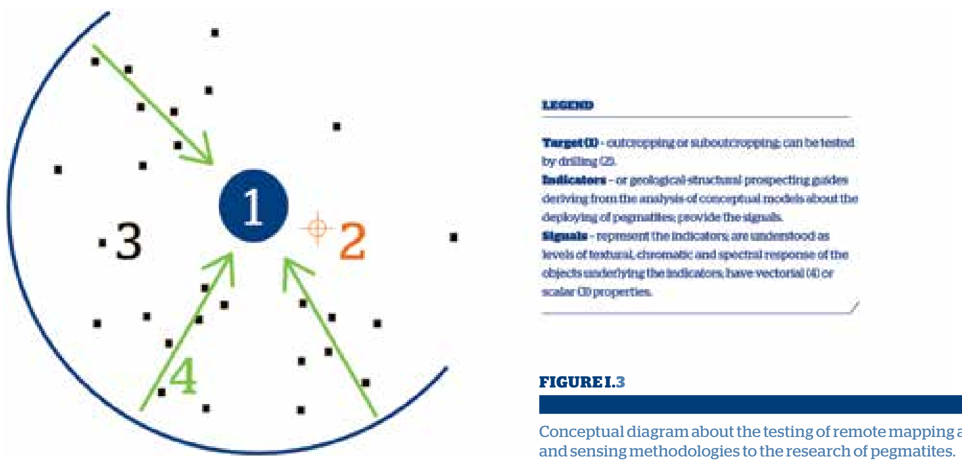


FIGURE I.3

Conceptual diagram about the testing of remote mapping analysis and sensing methodologies to the research of pegmatites.

I.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, textural 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 of structures, favorable enclosing, and geometric configu rations 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-orogenic 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.

I.2 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 aplite-pegmatitic 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 I.1 and I.2 and Figure I.4-A provide a perspective on the pegmatitic deposits with current production in the Portuguese territory. According to data from DGEG (Direcção Geral de Energia e Geologia), for the period of 2011, are counted 35 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 ascertainment 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.3 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.4-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:

DL 90/90 – 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 Iberoeka). 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 volcanogenic-exhalative jadarite, is justified by the increased demand (Leal Gomes, 2011).

According to the same author the prospecting and exploration of pegmatitic resources in the Portuguese territory must also meet the occurrence of significant amounts of metals, namely, Ta, Nb and Sn in pegmatites with reserves of ceramics materials, under the perspective of a full harnessing of the deposit and combined of various substances.

According to data from DGEG only the deposits of Alvarrões, Formigoso, Cubos and Lagares on Tables I.1, I.2 and I.3 consider this harnessing.

Cadastre	Concession	Concessionaire	Deposit	Final product	Location	
					County	Civil Parish
1612	BOQUEIRÃO	SOPRED - SOCIEDADE DE PROTEÇÃO, RECUPERAÇÃO E DESENVOLVIMENTO MINEIRO DO VALE DA GAIA, S.A.	Sn, Feld	Feldspar, Sand	Guarda	Gonçalo
724	TAPADA DOS MORTUORIOS				Guarda	Gonçalo
854	LAMEIRA 2				Guarda	Gonçalo
746	LAMEIRA 1				Guarda	Gonçalo
C-133	ABEGÕES *	FELMICA - MINERAIS INDUSTRIAIS, S.A.	Qz, Feld		Viseu	Real, Germil, Trancoselos, C. de Penalva
C-111	ALIJÓ	JOSÉ ALDEIA LAGOA & FILHOS, S.A.	Qz, Feld	Pegmatite	Ribeira da Pena	Canedo
C-8	ALVARRÕES	MOTAMINERAL - MINERAIS INDUSTRIAIS, S.A.	Li, Sn	Lithium Pegmatite	Guarda	Gonçalo, Seixo Amarelo and Vela
C-117	ATALAIA **	SILICÁLIA PORTUGAL - INDÚSTRIA E COMÉRCIO DE AGLOMERADOS DE PEDRA, S.A	Qz	Feldspar Feldspar	Almeida	Vilar Formoso
C-64	BAJOCA	FELMICA - MINERAIS INDUSTRIAIS, S.A.	Feld, Qz		Vila Nova de Foz Côa	Almenda
C-35	BICHA	SOCIEDADE MINEIRA CAROLINOS, LDA.	Qz	Quartz	Trancoso	Freches
C-98	CABEÇO DA ARGEMELA	UNIZEL - MINERAIS, LDA.	Qz, Feld	Feldspar	Covilhã and Fundão	Barco
C-57	CASTANHO	PEGMATÍTICA - SOCIEDADE MINEIRA DE PEGMATITES, LDA.	Feld	Lithium and Pegmatite	Guarda	Gonçalo
C-101	CASTELO N.º1	FELMICA - MINERAIS INDUSTRIAIS, S.A	Qz, Feld	Feldspar	Mangualde and Penalva do Castelo	Travanca de Tavares
C-15	COVÃO	ALDEIA & IRMÃO, S.A.	Qz, Feld	Feldspar	Guarda	Vela e Benespera
C-51	FONTE DA CAL	FELMICA - MINERAIS INDUSTRIAIS, S.A.	Qz, Feld	Quartz	Sabugal	Bendada
C-123	FORMIGOSO *		Qz, Feld , Li, Ta	Feldspar	Ponte de Lima	Cabração
C-91	FRAGUIÇAS	UNIZEL - MINERAIS, LDA.	Feld, Qz		Celorico de Basto	Agilde
C-70	GONÇALO SUL	JOSÉ ALDEIA LAGOA & FILHOS, S.A.	Qz, Feld	Feldspar and Lithium Pegmatite	Guarda	Gonçalo
C-108	GONDIÃES	FELMICA - MINERAIS INDUSTRIAIS, S.A.	Qz, Feld, Li	and Lithium	Boticas and Cabeceiras de Basto	Gondiães
C-12	GRALHEIRA	GRALMINAS - MINEIRA DA GRALHEIRA, S.A.	Be, Feld, Qz	Feldspar	Sátão and Aguiar da Beira	Vila Longa
C-122	LANCHAIS	FELMICA - MINERAIS INDUSTRIAIS, S.A	Feld, Qz	Kaolin	Sabugal	Aguas Belas e Ombas
C-88	MADALENA		Qz, Feld		Sátão	Ferreira de Aves
C-45	MATA DA GALINHEIRA	ROCÁVIA - ROCHAS DE VIANA, LDA.	Qz, Feld	Quartz	Ponte da Barca	Vila Chã (S.João)
C-100	MINA DO BARROSO	IMERYS CERAMICS PORTUGAL, S.A.	Feld, Qz	Pegmatite Lithium	Boticas	Covas de Barroso
C-32	PESTARENGA	GRALMINAS - MINEIRA DA GRALHEIRA, S.A.	Qz, Feld	Feldspar	Sátão	Ferreira de Aves
C-92	QUINTA DO QUELHAS	FELMICA - MINERAIS INDUSTRIAIS, S.A			Guarda	Benespera
C-82	REAL				Penalva do Castelo	Real
C-86	SANGAS-SAIBRO	JOSÉ ALDEIA LAGOA & FILHOS, S.A.	Feld, Qz		Gouveia	Melo
C-134	SEIXALVO *	FELMICA - MINERAIS INDUSTRIAIS, S.A.	Qz, Feld, Li		Ponte de Lima	Cabração
C-22	SEIXOSO	UNIZEL - MINERAIS, LDA.	Qz, Feld	Feldspathic Sands	Felgueiras, Amarante	Borba de Godim and Telões
C-21	SENHORA DA ASSUNÇÃO	SOBAL - SOCIEDADE DE BRITAS E AREIAS, S.A.	Qz, Feld, Be	Feldspar	Sátão	Ferreira D'Aves
C-93	VALE GRANDE	JOSÉ ALDEIA LAGOA & FILHOS, S.A.	Qz, Feld	Feldspar	Tondela	Molelos and Dardavaz
C-94	VELA NORDESTE			Pegmatite	Guarda	Vela
C-71	VENTURINA	FELMICA - MINERAIS INDUSTRIAIS, S.A.	Qz, Feld	Feldspar	Sátão e Penalva do Castelo	Romãs
C-83	VILA SECA	FELMICA - MINERAIS INDUSTRIAIS, S.A.	Qz, Feld	Feldspathic sands	Mangualde	Chãs de Tavares, Travanca de Tavares

TABLE I.1

Inventory of active mining concessions in 2011 on pegmatitic deposits. *startup; ** in experimental exploitation. Source: DGEG (looked up in 15-05-2013). Qz-quartz, Feld - Feldspar, Be - Beryl, Sn - Tin, Li - Lithium, Ta - Tantalum, kaul - kaolin.

I. Introduction

Cadastre	Concession	Concessionaire	Deposit	Location	
				County	Civil Parish
C-102	ALAGOAS	JOSÉ ALDEIA LAGOA & FILHOS, S.A.	Qz, Feld	Almeida	Freineda
C-42	BENESPERA		Qz, Feld	Guarda	Benespera
C-43	CASTANHO SUL	FELMICA - MINERAIS INDUSTRIAIS, S.A.	Feld, Qz	Guarda	Gonçalo
C-101	CASTELO N.º1				
C-56	COMPANHEIRO	PEGMATÍTICA - SOCIEDADE MINEIRA DE PEGMATITES, LDA	Feld, Qz	Sátão	Vila longa
C-34	CUBOS	SOCIEDADE MINEIRA CAROLINOS, LDA.	Ber, Li, Sn, W, Ta, Qz, Feld	Mangualde	Mesquitela and Mangualde
C-31	FRONTEIRA	GRALMINAS - MINEIRA DA GRALHEIRA, S.A.	Qz, Feld	Fronteira	Fronteira
C-63	LAGARES	FELMICA - MINERAIS INDUSTRIAIS, S.A.	Sn, Feld, Qz	Vila Nova de Paiva	Queiriga
C-110	LOUSAS		Qz, Feld, Li	Boticas	Dornelas
C-44	PEDRA DA MOURA *	MINAS DA PEDRA MOURA, LDA..	Qz, Feld	Ponte da Barca	Touvedo (Salvador)
C-30	PEDRAS PINTAS	QUARTEX - SOCIEDADE MINEIRA DO ALENTEJO, LDA	Qz, Feld	Montemor-o-Novo	Lavre
C-124	PORTO VIEIRO	FELMICA - MINERAIS INDUSTRIAIS, S.A.	Feld, Qz, Li	Ponte Lima	Cabaço
C-40	QUINTA CIMEIRA		Qz, Feld	Sabugal and Belmonte	Maçaínhas and Bendada
C-28	S.MATIAS	GRALMINAS - MINEIRA DA GRALHEIRA, S.A JOSÉ ALDEIA LAGOA & FILHOS, S.A.	Qz, Feld	Beja	São Matias
C-96	SALGUEIRAL	FELMICA - MINERAIS INDUSTRIAIS, S.A.	Qz, Feld	Viseu	Torredeita and Couto de Baixo
C-7	SEIXINHOS	FELMICA - MINERAIS INDUSTRIAIS, S.A.	Feld, Qz	Gouveia	São Paio
C-67	SERRADO 1		Qz, Feld	Belmonte	Maçaínhas
C-68	SERRADO 2		Qz, Feld	Belmonte	Maçaínhas
C-24	TOJAL	PEGMATÍTICA - SOCIEDADE MINEIRA DE PEGMATITES, LDA	Kaolin	Mangualde	Chãs de Tavares
C-47	VELA	JOSÉ ALDEIA LAGOA & FILHOS, S.A.	Qz, Feld	Guarda	Vela
C-87	VIGIA *	FELMICA - MINERAIS INDUSTRIAIS, S.A.	Qz, Feld	Aguiar da Beira	Aguiar da Beira

TABLE I.2

Inventory of suspended mining concessions 2011 on pegmatite deposits. * On landscape recovery. Source: DGEG (looked up in 15-05-2013)

Cadastre	Holder	Area	Substance	Actual situation	District	County
MNPPP0301	FELMICA - MINERAIS INDUSTRIAIS, S.A.	Freixiosa	Qz and Feld	Requested	Viseu	Pernalva do Castelo and Mangualde
MNPPP0195	JOSÉ ALDEIA LAGOA & FILHOS, S.A.	Aldeia	Qz, Feld and Li	Requested	Viana do Castelo	Caminha and Viana do Castelo
MNPPP0164	JOSÉ ALDEIA LAGOA & FILHOS, S.A.	Cabanas	Qz, Feld and Li	Requested	Viana do Castelo	Ponte de Lima
MNPPP0194	JOSÉ ALDEIA LAGOA & FILHOS, S.A.	Vilarinho	Qz, Feld and Li	Requested	Viana do Castelo	Caminha, Vila Nova de Cerveira and Ponte de Lima
MNPPP0193	JOSÉ ALDEIA LAGOA & FILHOS, S.A.	Ledo	Qz, Feld and Li	Requested	Viana do Castelo	Vila Nova de Cerveira and Paredes
MNPP00111	FELMICA - MINERAIS INDUSTRIAIS, S.A.	Lameirões	Feld and Qz	Granted	Braga	Vieira do Minho and Fafe
MNPP00711	GRALMINAS - MINEIRA DA GRALHEIRA, S.A.	Vale de Mouro	Qz	Granted	Guarda	Trancoso
MNPPP0246	JOSÉ ALDEIA LAGOA & FILHOS, S.A.	Vilas Boas	Feld and Qz	In	Vila Real	Chaves
MNPPP0297	ALDEIA & IRMÃO, S.A.	Vilar de Cunhas	Qz and Feld	In announcement	Braga and Vila Real	Cabeceiras de Basto and Montalegre
MNPP00212	JOSÉ ALDEIA LAGOA & FILHOS, S.A.	Famalicão	Feld and Li	Granted	Guarda	Guarda
MNPP00312	IMERYS CERAMICS PORTUGAL, S.A.	Antigo	Qz, Feld and Li	Granted	Vila Real	Boticas
MNPP01812	ALDEIA & IRMÃO, S.A.	Porto	Qz and Feld	Granted	Braga	Cabeceiras de Basto
MNPP01712	ALDEIA & IRMÃO, S.A.	Matagão	Qz, Feld and Li	Granted	Guarda	Guarda
MNPP02212	FELMICA - MINERAIS INDUSTRIAIS, S.A.	Dornas	Feld and Qz	Granted	Braga	Amares
MNPP03812	SIFUCEL - SÍLICAS, S.A.	Laje de	Qz and Feld	Granted	Portalegre	Nisa
MNPP03812	SIFUCEL - SÍLICAS, S.A.	Laje de	Qz and Feld	Granted	Portalegre	Nisa and Crato
MNPP04112	FARIA LOPES & ALDEIA, S.A.	Bastelos	Qz and Feld	Granted	Braga	Fafe
MNPP03512	ALDEIA & IRMÃO, S.A.	Canedo - Covas	Qz, Feld and Li	Granted	Vila Real	Ribeira de Pena and Boticas

TABLE I.3

Inventory of contracts and requests for prospecting and exploration to date 15-05-2013. Source: DGEG

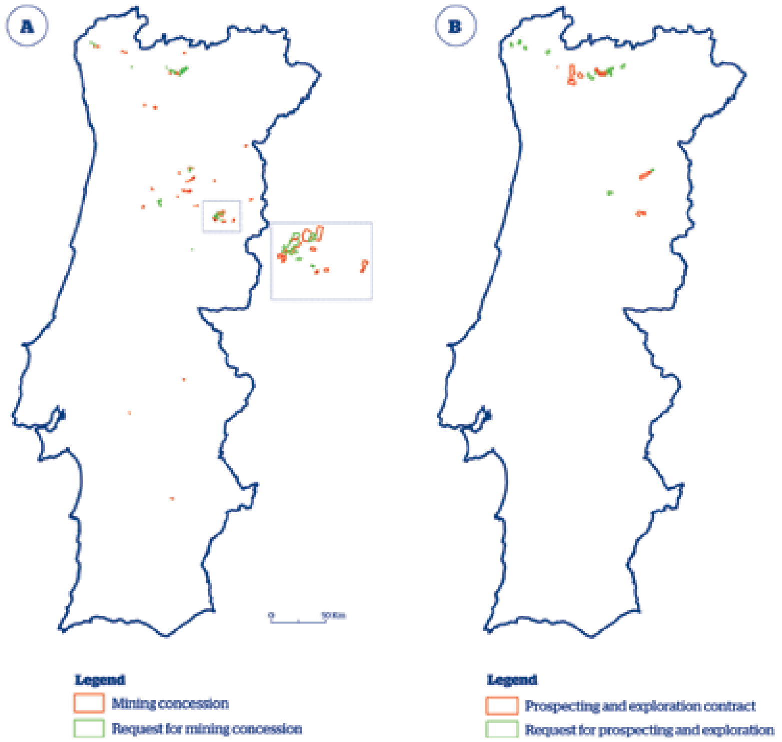


FIGURE I.4

Maps with distribution of concessions and areas subject to mining prospecting (referable to the listings of tabels I.1, I.2 and I.3); source: DGEG, 2013

I.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 (Ponte da Barca-Terras de Bouro), B1 (Chaves), B2 (Tâmega), B3 (Murça), C (Penedono-Armamar), D (Viseu--Satão), E (Guarda-Belmonte), F (Idanha-a-Nova), G (Torrão-Montemor).

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 bodies (whether masses or dykes). Are contemplated ceramic pegmatites enriched in rare metals of typologies LCT and NYF of Černý (1982), with a great intrinsic, structural, paragenetic and mineralogical diversity, which may reflect a greater diversity of situations and possibilities of distant detecting, assuming that their properties considered relevant for remote evidence can manifest any sign capable of being analyzed in this context.

I.3.1 Elements of geographical, geomorphological and vegetation framing

The areas selected for the study have their geographical coordinates identified in Table I.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 I.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 I.5.

	NW		NE		SW		SE	
	Long.	Lat.	Long	Lat	Long	Lat	Long	Lat
A	8°25'30"	41°49'45"	8°11'52"	41°49'47"	8°25'25"	41°42'29"	8°11'52"	41°42'29"
B1	7°33'47"	41°44'17"	7°21'51"	41°44'21"	7°33'58"	41°32'41"	7°21'57"	41°32'56"
B2	7°52'03"	41°38'57 "	7°39'26"	41°38'55"	7°52'03"	41°30'02"	7°39'31"	41°30'04"
B3	7°37'14"	41°25'22"	7°25'32"	41°25'24"	7°37'14"	41°19'27"	7°25'43"	41°19'23"
C	7°33'43"	41°06'23"	7°19'17"	41°06'17"	7°33'49"	40°55"59"	7°19'25"	40°55'53"
D	7°45'12"	40°53'23"	7°30'57"	40°53'19"	7°45'15"	40°44'56"	7°30'57"	40°44'55"
E	7°22'42"	40°28'35"	7°05'04"	40°28'25"	7°22'46"	40°20'35"	7°05'00"	40°20'29"
F	7°17'17"	40°05'56"	7°00'31"	40°05'54"	7°17'22"	39°57'01"	7°00'38"	39°56'50"
G	8°19'0 3"	38°49'01"	8°04'37"	38°49'02"	8°19'04"	38°40'39"	8°04'38"	38°40'41"

TABLE I.4

Coordinates of the vertices of the selected areas - geographical coordinates in datum WGS84

		Dimension (Km²)	District	Military maps	Geologic maps (50k)	
A	Ponte da Barca-Terras de Bouro	253	Viana do Castelo, Braga	29, 30, 42, 43	5B	Ponte da Barca
B1	Chaves	353	Vila Real	47, 61	6B, 6D	Chaves, Vila Pouca de Aguiar
B2	Tâmega	287	Braga, Vila Real	59, 60, 73, 74	6C, 6D	Cabeceiras de Basto, Vila Pouca de Aguiar
B3	Murça	179	Vila Real	88, 89, 102, 103	*Not published*	
C	Penedono - Armamar	389	Viseu, Guarda	139, 140, 149, 150	14B, 15A	Moimenta da Beira, Vila Nova de Foz Côa
D	Satão-Aguiar da Beira	313	Viseu, Guarda	158, 159, 168, 169	14D	Aguiar da Beira
E	Guarda-Belmonte	369	Guarda, Castelo Branco	214, 215, 225, 226	18C	Guarda
F	Idanha-a-Nova	397	Castelo Branco	257, 258, 269, 270	*Not published*	
G	Torrão-Montemor	322	Évora, Santarém	422, 423, 436, 437	35B, 36A, 35D, 36C	Mora, Pavia, Montemor-o-Novo, Arraiolos

TABLE I.5

Map coverage and administrative divisions of the selected areas

FIGURE I.5

Geographical position and administrative divisions of the areas selected for study

The most relevant physiographic components in each area are shown in Figure I.6.

The Digital Terrain Model for the Portuguese territory was obtained from the altimetry of satellite ASTER-SRTM/C-SAR (Shuttle Radar Topographic Mission/Sinthetic Aperture Radar) from NASA.

Generally, the selected areas correspond to the mountainous regions, marked by elevations up to 1300 m.

According to Figure I.6, the north and central north areas feature similarities with respect to altitude.

In the areas A and B2 the elevations develop large gaps and steep slopes. The corresponding altimetry amplitudes are shown in Table I.6.

The areas F and G correspond to regions of lower levels, up to 700m in F and up to 400m in G.

The main watercourses develop into structurally controlled valleys. This physiographic organization is imposed by the late-Variscan structuring, which formulates the major megascale shear zones, and by the neotectonics that reactivates them.

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.7. In these, the 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 ocher colors predominance.

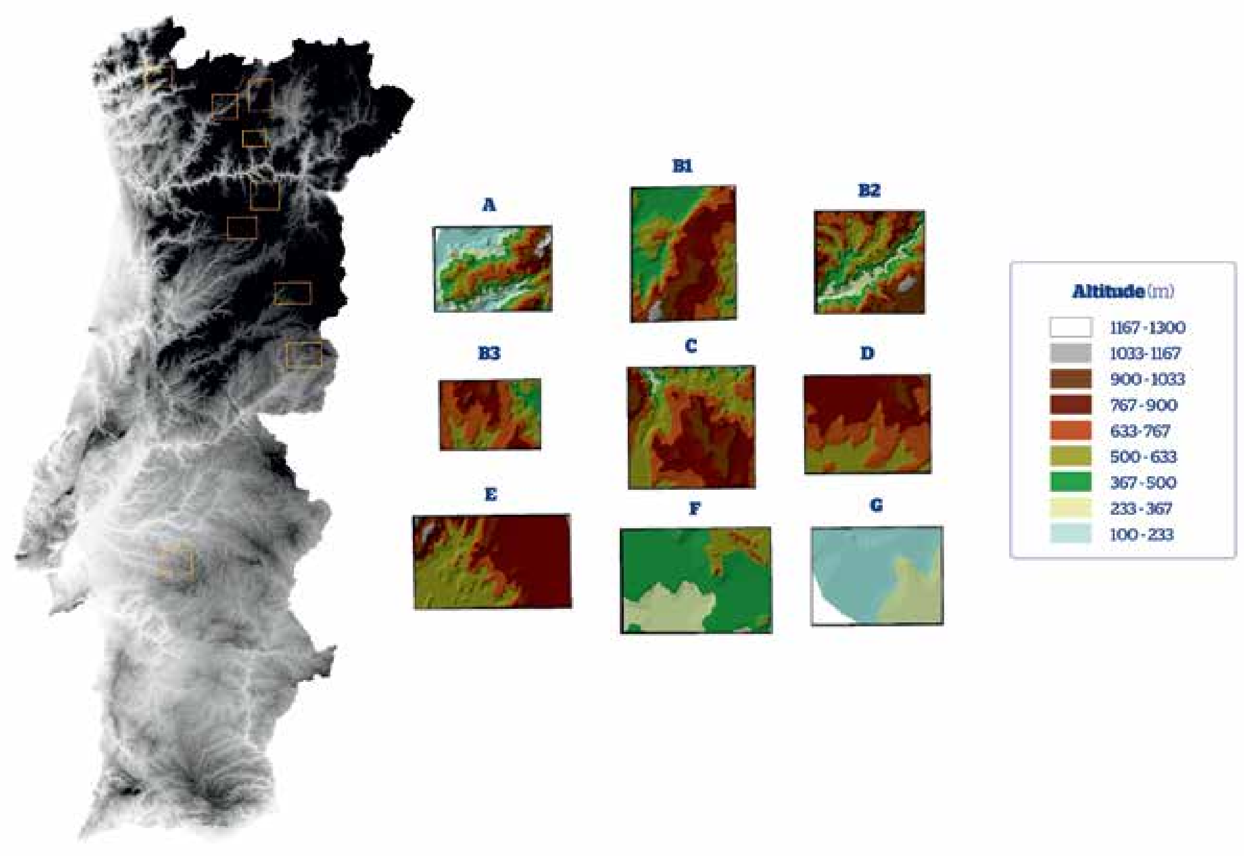


FIGURE I.6

Digital terrain model for the Portuguese territory with the implantation of the study areas (bounded by orange rectangles). Source - SRTM/C-SAR, NASA

	Altitude		A (%)	F (%)	U (%)	C	IES
	Min.	Max.					
A	1322	25	20	75	5	PN/BC	3
B1	1126	354	10	35	65	BC	1
B2	1194	186	15	77.5	7.5	-	3
B3	1022	445	20	50	30	-	2
C	950	264	10	65	25	-	2
D	942	553	25	67.5	7.5	BC	2
E	1140	469	20	70	10	PNT/BC	3
F	748	273	10	60	30	BC	2
G	214	131	15	40	45	-	1

TABLE I.6

Summary table on the trends of space planning in the selected areas; occupancy percentages approximated by visual estimation: A (% of agricultural area), F (% of forest area), U (% urban / complex), C (conservation status), IES (qualitative index of superficial exhumation) - 1 - low, 2 - medium, 3 - high

In Table I.6 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; Rabaça, 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.

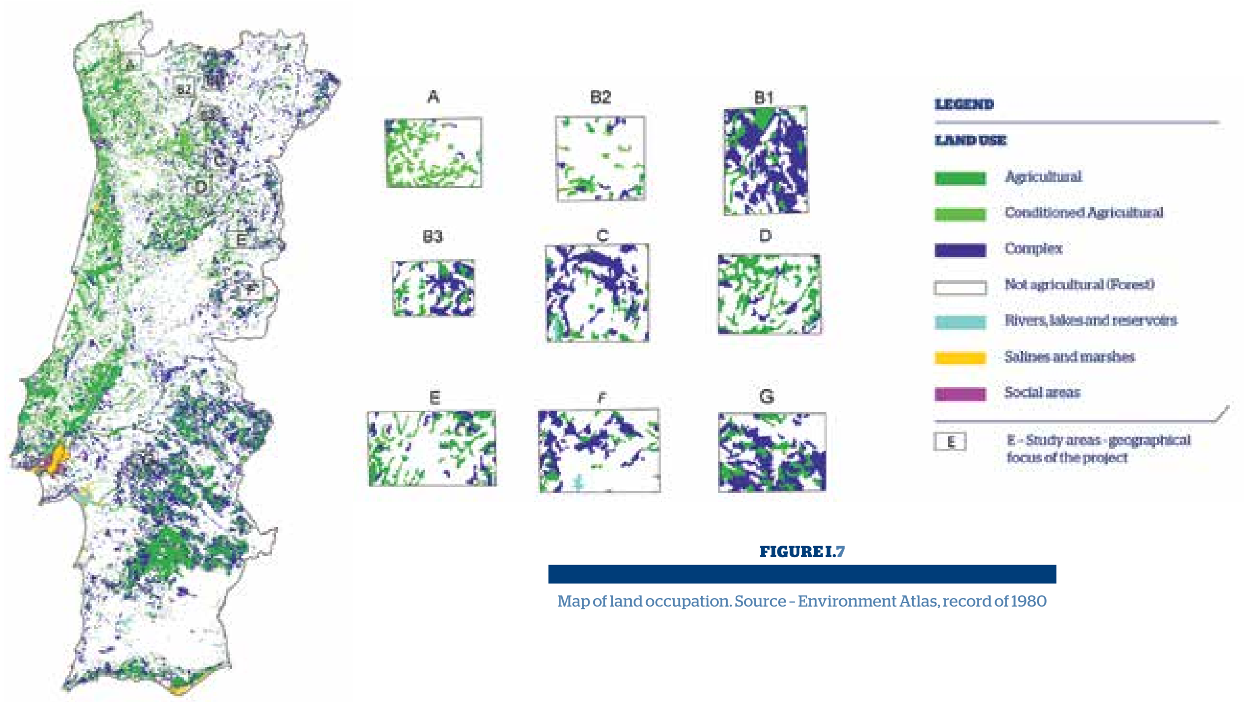


FIGURE I.7

Map of land occupation. Source - Environment Atlas, record of 1980

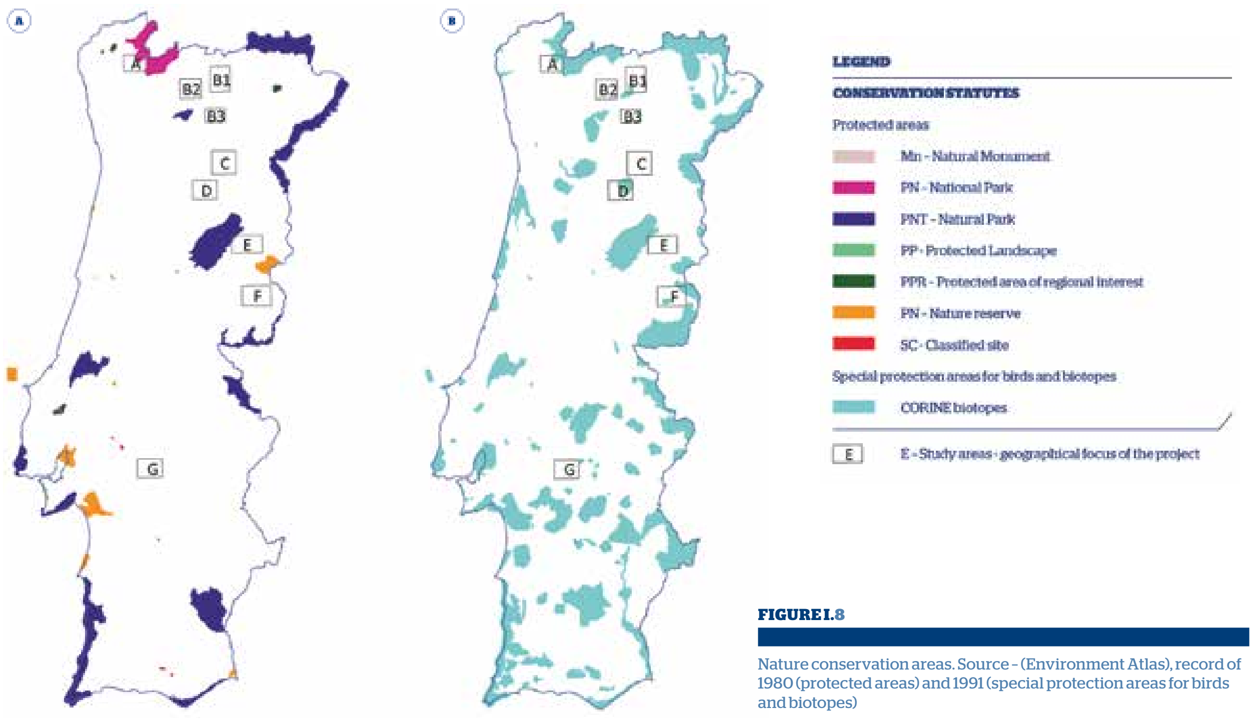


FIGURE I.8

Nature conservation areas. Source - (Environment Atlas), record of 1980 (protected areas) and 1991 (special protection areas for birds and biotopes)

I.3.2 Elements of geological framework

From the following assessment criteria is established and developed the general geological framework of the study areas:

- Tectonic and structural domains;
- Geological mapping on 1:50 000 scale;
- Regional divisions of pegmatites;
- Provinces and mining strips.

I.3.2.1 Tectonics and Structural Domains

The selected areas are part of the Iberian Massif, composed in the Portuguese territory by polygenic formations of 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 (ITCZ) (areas C, D, E and F) and Ossa Morena zone (OMZ) (area G), as shown in Figure I.9.

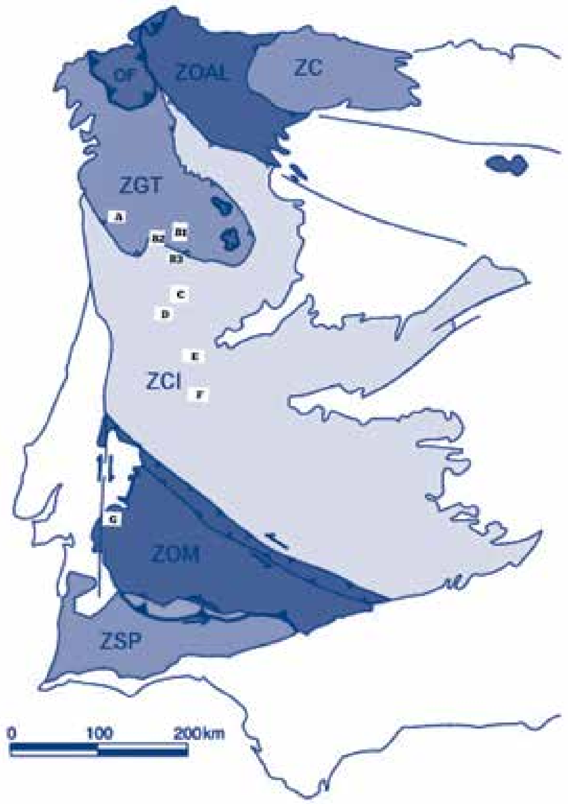


FIGURE I.9

Location of areas in the compartmentation of the Iberian Massif

The following fundamental characteristics of the compartmentalized terrain portions (e.g. Ribeiro, 2013) are recognized:

- **ZCI -** covers lithostratigraphic autochthonous sequences, without identifiable tectonic transport in the Variscan Orogeny; comprises turbidite facies, relatively homogeneous, assigned to the Greywacke -Schist Complex, Proterozoic and Cambrian, and the Ordovician and Silurian metassediments;

- **ZGTM -** includes parautochthonous and allochthonous complexes from the N of Portugal, thrusted on ZCI, formed by the overlapping and piling of contrasting paleogeographic units separated by thrusts. It is considered that the tangential Variscan tectonic features a restricted range in the parautochthonous, affecting lands with affinities to ZCI. The allochthonous grounds comprise the ophiolitic successions of Trás-os-Montes and integrate older continental grounds, transported by obduction during the Variscan Orogeny.
- **ZOM -** complex includes polygenic formations of the Upper Proterozoic to the Paleozoic and the south Portuguese ophiolite complexes. Its structural organization results from the definition 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 ZCI, and differentiated ver gence in parautochthonous grounds. 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 mantels-fold formation in the parautochtho nous grounds and the obduction of ophiolite complexes in central Trás-os-Montes. In ZOM it causes lying flat folds and thrusts with transportation from WSW 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. Régua-Verin fault). At this stage are still retaken, in a transcurrent 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.

Classification	Common facies	Ages U-Pb
Granitoids late to post-D3	- biotitic granites, biotite-muscovitic and two-mica sometimes porphyroid; - mainly biotitic granites often porphyroid; - gabbros, diorites, quartzic monzodiorites, granodiorites.	310-290 Ma
Granitoids syn-D3	- leucogranites and two-mica granites with variable deformation; - granodiorites and biotitic granites with variable deformation.	320-310 Ma
Granitoids prior-Variscan	- granitoids of the Upper Proterozoic to Lower Paleozoic (orthogneisses).	-

TABLE I.7

Geotectonic, petrographic and chronological classification of granites from northern and central Portugal (taken from Azevedo and Aguado, 2013)

Adapting recent review papers on the typology and petrogenesis of granites in northern and central Portugal (Azevedo and Aguado, 2013, 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 biotitic granites and granodiorites, volumetrically minors, 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 monzonitic granites, usually porphyroids, bearers of mafic microgranular enclaves, with low peraluminosity and without evident deformation. Represent type I or transitional I-S magmas produced by crystal 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 delamination of the asthenosphere. Also include later biotitic-muscovitic granites with more marked crustal affinity, hypothetically attributed to fractionation processes developed from those.

- **Post-D3 granites (or post-tectonics) –** generally correspond to biotitic facies, usually porphyroid, sub-alkaline, I-type, organizing concentrically zoned plutons, discordant relatively 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 megastructures and fundamental axes, viewing them as crustal anisotropy 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 plutonites and tardi-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-Verin fault –** megascalar late-D3 structure with polyphasic reactivation, NNE-SSW orientation, which controls the post-tectonic granites installation from the massif of Vila Pouca de Aguiar.

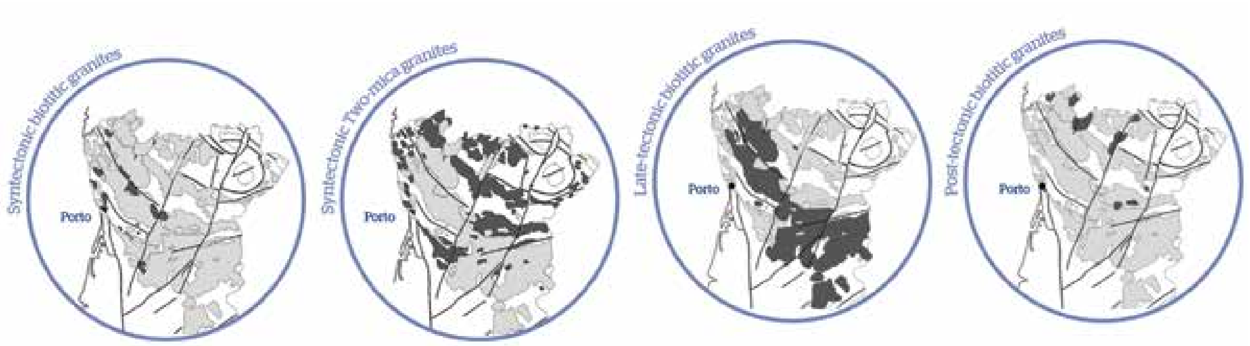


FIGURE I.10

Distribution of syn, late and post-tectonic granites in Northern and Central Portugal (according to Ribeiro et al. 1990 adapted by Dias and Coke, 2006)

I.3.2.2 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 areas of northern and central Portugal are recognized in 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 biotitic and generally porphyroid. They have greater representation in the geological mapping of area B1 (Chaves), emplaced according to the Régua-Verin fault (Figure I.12-A).

The late to post-tectonic granites, comprising biotitic facies with porphyritic tendency, and muscovitic-biotitic granites, predominate in the Beiras areas (C, D, E and F). In the areas D and F are also recognized spatially related quartz-diorite and coeval biotitic granodiorites (Figures I.13, 14).

In the Area G are represented diorites, gabbros, tonalites and syntectonic porphyroid biotitic 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 microsienites, lamprophyres with dioritic composition and amphibolic microdiorites. According to Teixeira (1981), in a study on the petrology and geochronology of this type of dykes in the Beiras 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±9MA and 226±2 Ma.

The parautochthonous lithostratigraphic units of the ZGTM are polygenic; they are represented in the areas B1, B2 and B3 by the Structural Domain of Carrazedo (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 Excomungada, Desejosa and Santa Justa, Neoproterozoic of Bateiras and undifferentiated formations of the Beiras 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 phyllites from the Volcano-sedimentary Complex of Moura - Santo Aleixo, old-Ordovician Silurian and sets of gneissic rocks and Proterozoic migmatites.

FIGURE I.11

Geological map from the Ponte da Barca - Terras de Bouro sector (Area A) - adapted from the Geological map of Portugal, northern sheet, 1:500 000 scale (Oliveira et al., 1992)

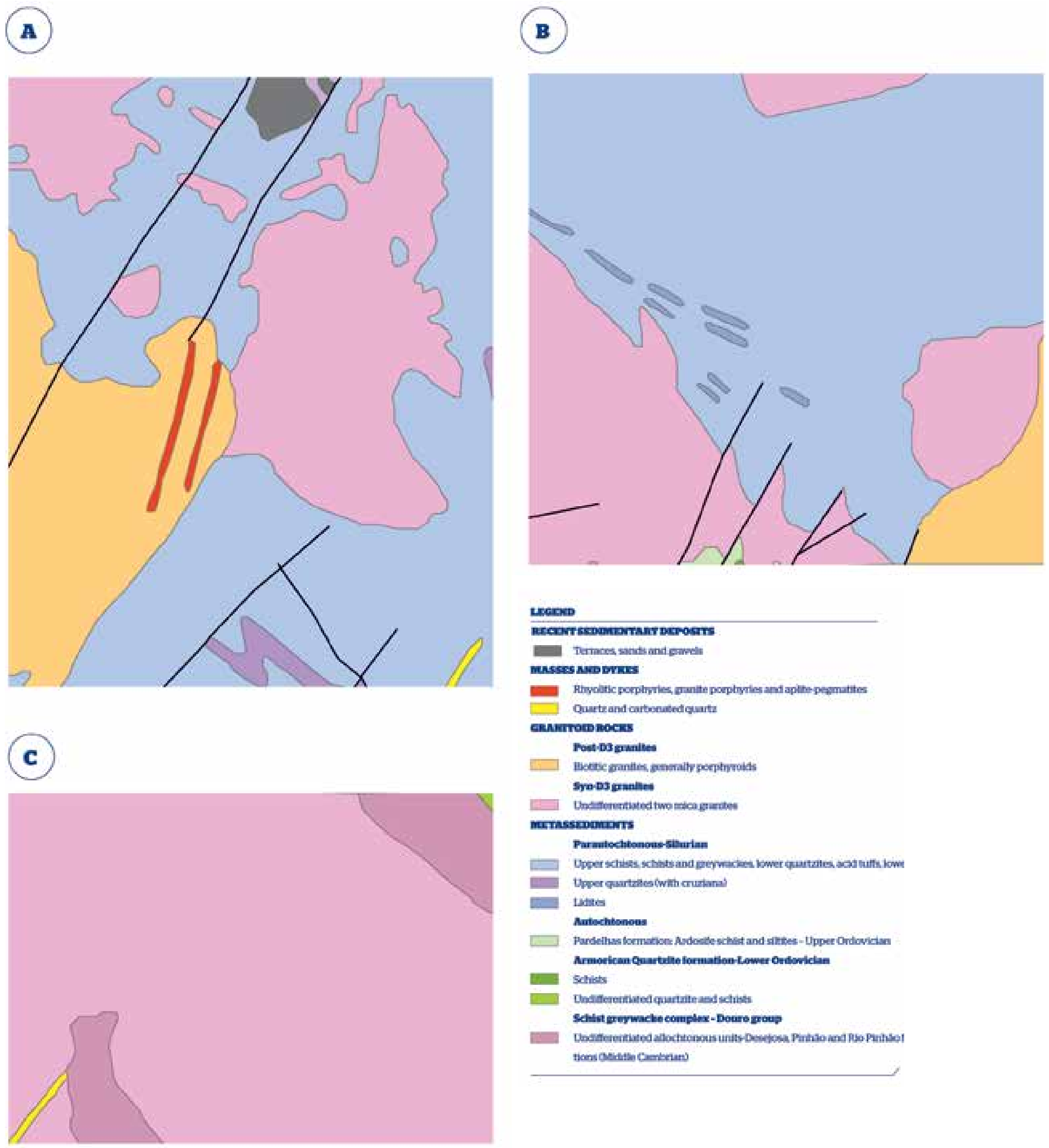


FIGURE I.12

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

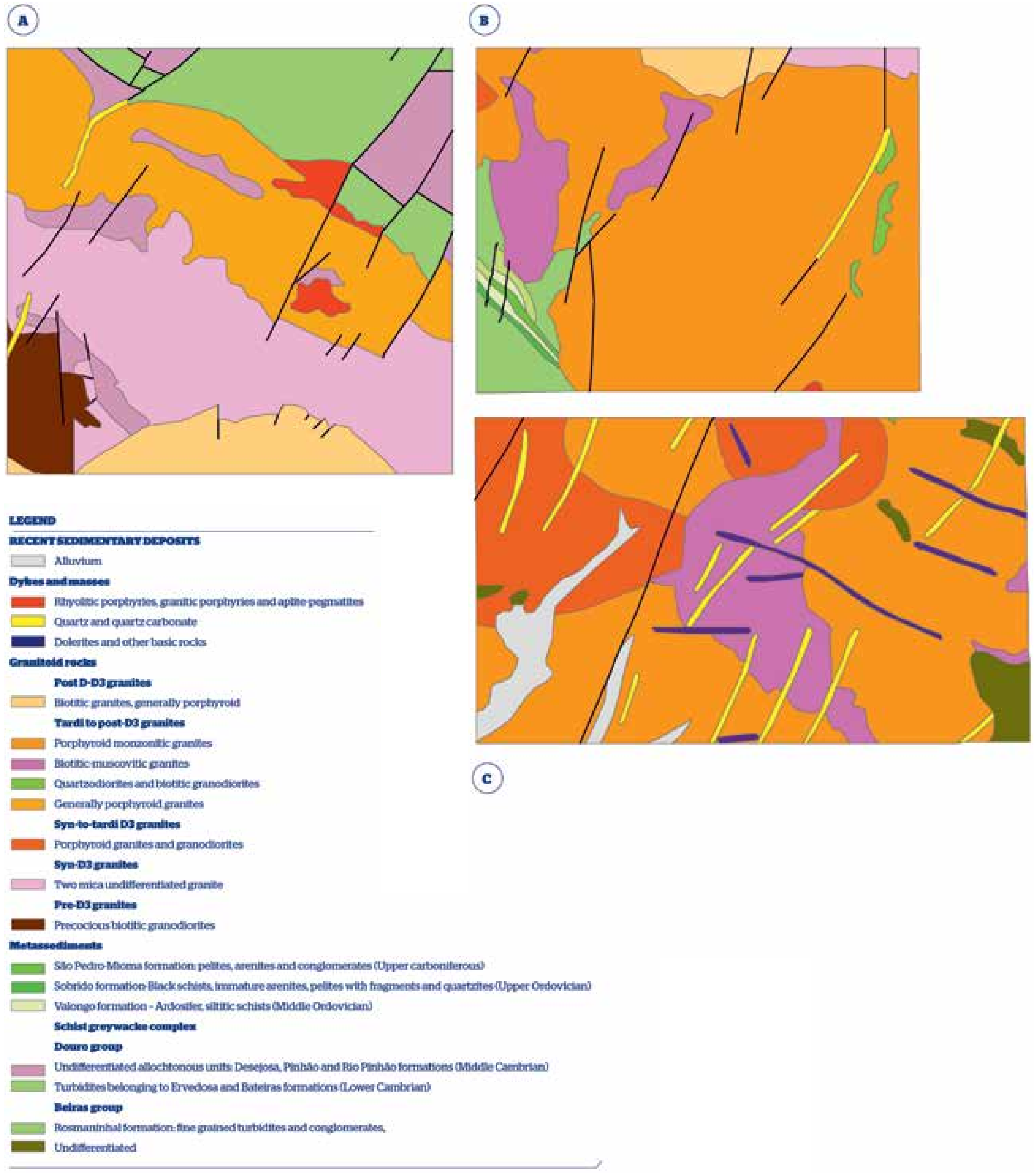


FIGURE I.13

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)

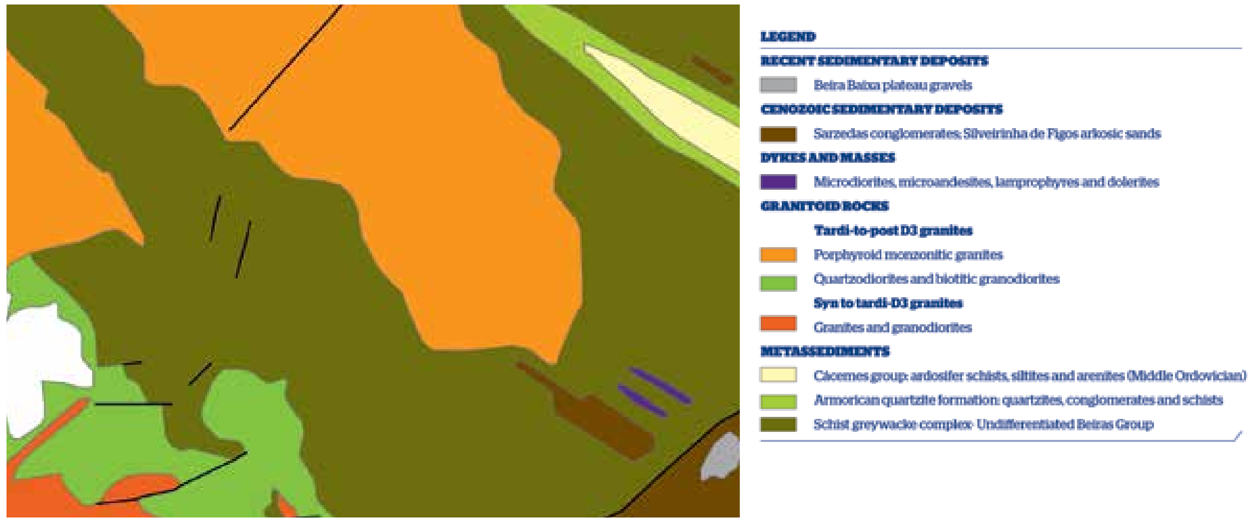


FIGURE I.14

Geological map from the area of Idanha-a-Nova (F) - adapted from the geological map of Portugal, northern sheet, 1:500 000 scale (Oliveira at al., 1992)

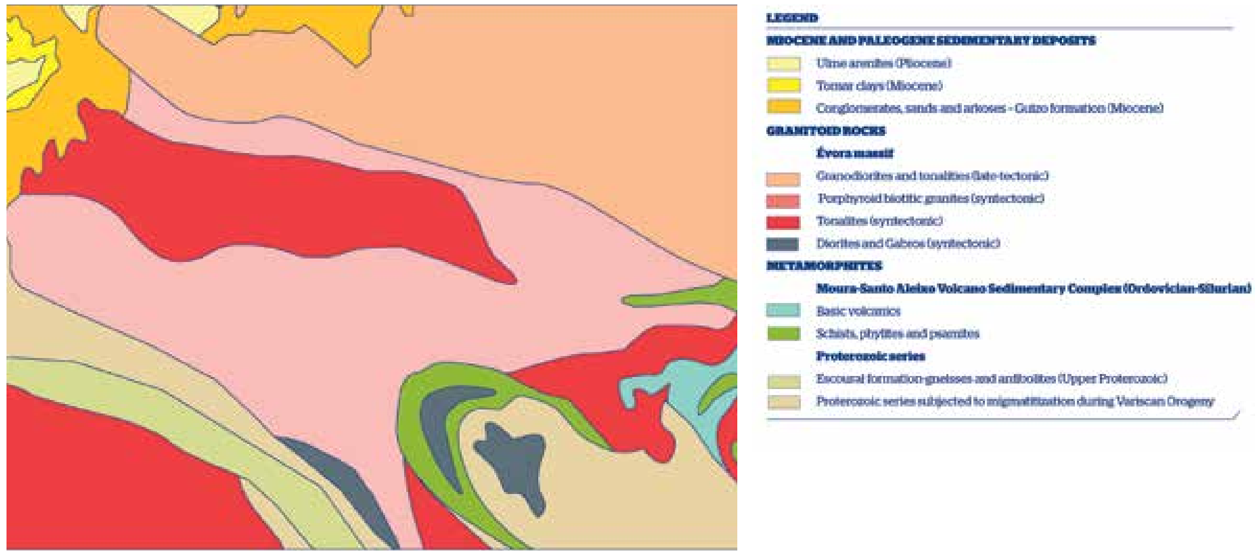


FIGURE I.15

Geological map from the Torrão-Montemor (G) sector - adapted from the geological map of Portugal, southern sheet, 1:500 000 scale (Oliveira et al., 1992)

I.3.2.3 Regional divisions of pegmatites

In northern and central Portugal most pegmatites arises 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), introduce 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 retaken, 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 on 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-Armorican Arc and also the stretching of the Syn and late-tectonic granitic massifs (Figure I.16).
- **Pegmatite or pegmatite field –** designates pegmatitic 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 deuteric alteration, microgranitic hypabyssal dykes and porphyries. The fields are predominantly inner or (perigranitic) outergranitic with installation within the granitic masses or enclosed in metassedimentary formations. Due to the complex evolution of the generator plutonite, they include one or more pegmatitic swarms.

Pegmatitic or aplite-pegmatitic swarm -describes 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 pegmatitic 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.

- **Pegmatitic or aplite-pegmatitic 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 paragenesis. They look more or less homogeneous in the case of bodies with coexistence of aplitic and pegmatitic facies. Other bodies are heterogeneous and hetero-granularand 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 (sill like bodies). Regarding specific mineralization they adjust to types LCT (with Li, Cs, Ta) or NYF (Nb, Y and F), as proposed by Černý (1982).

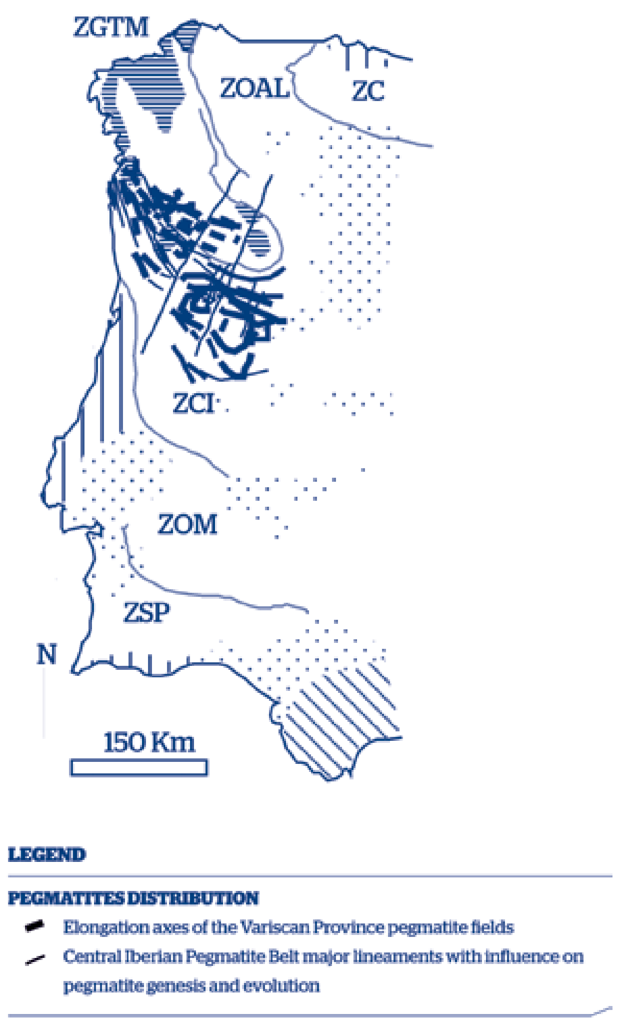


FIGURE I.16

Pegmatite fields position in the Central Iberian Pegmatite Belt (CCI) (adapted from Leal Gomes and Lopes Nunes, 2003)

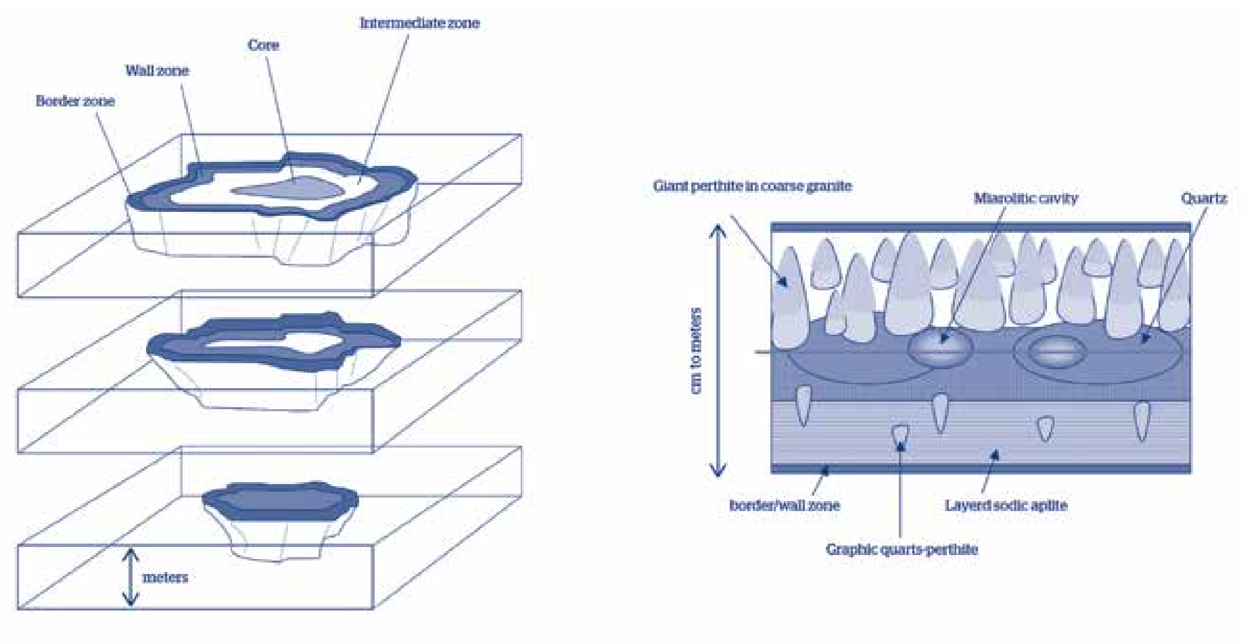


FIGURE I.17

Morphological attributes and internal zoning of pegmatitic bodies - conceptual examples adapted from London (2008)

The focus areas of this project can be seen as compartments of the Variscan Pegmatitic Province and Central Iberian Pegmatite Belt; represent sectors from pegmatite fields where each body is distinct from a structural and paragenetic point of view, within inner and outergranitic situations, organized according to swarms and groups and with 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 biotitic porphyroid granites, late to post-tectonic, regarding the 3rd phase of Variscan deformation, emplaced in dome portions. They correspond to bodies lightly to strongly zoned, locally miarolitics with bulky replacement units that comprise phosphates and sulfides. 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 terms, 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.

In the selected compartments, the regional division pegmatite field is the level of organization best suited for discriminating pegmatites. It is also the level of organization crucial in the application of remote mapping analysis and remote sensing.

Are referred the following works, with distinguished range and incidence inputs, for the definition of pegmatitic fields in the study areas:

- **Area A -** Pegmatitic field of Ponte da Barca-Terras de Bouro (Silva, 2002);
- **Area B2 –** Pegmatitic field of Barroso-Alvão (Lima, 2000; Martins and Lima, 2011);
- **Area D –** Pegmatitic field of Alto Vouga (Lobato, 1971; Trabulo et al., 1995 and Guimarães, 2012),
- **Area E -** Aplite-pegmatitic field of Guarda-Belmonte: swarms of Seixo Amarelo - Gonçalo (Ramos, 1998), Pega - Sabugal (Silva, 2006) and Bendada (Correia Neves, 1960).
- **Area G –** Pegmatitic field of Ciborro (Lima et al., 2013)

For the areas where were implemented prospecting and research routines, from the strategic to the tactical context, the structural discrimination and paragenetic diagnostic presented by these authors will be addressed (see Chapter II).

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 Thadeu (1965) overlap. Resuming the mineralization axes advanced in Neiva (1944), this author proposes the Metallogenic Septentrional Tin-tungsten Province division, which covers the pegmatitic and aplitic-pegmatitic dykes and outergranitic greisens mineralized with Sn-Nb-Ta. It is also included here W mineralized quartz veins resulting from the transcurrent reactivation of pegmatitic boxes during the late-Variscan period.

The extractive cycle dedicated to Sn and W 2nd half of the XX 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 Beiras) in: Viseu-Tondela-Gouveia strip (mining district of Urgeiriça), Moimenta- Trancoso-Celorico 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 torbernite.

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 undertook geological prospecting programs with field surveys. It was also considered to find in these areas larger pulverization of exploitations in pegmatites and bodies with higher reserve quantitative, 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 1:1000 scales, topographic surveys and drillings, overlooking the intersection of deposits.

The collection of reflectance data (spectroradiometry) 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 of the project, which had as its main objective the establishment of a spectral data base.

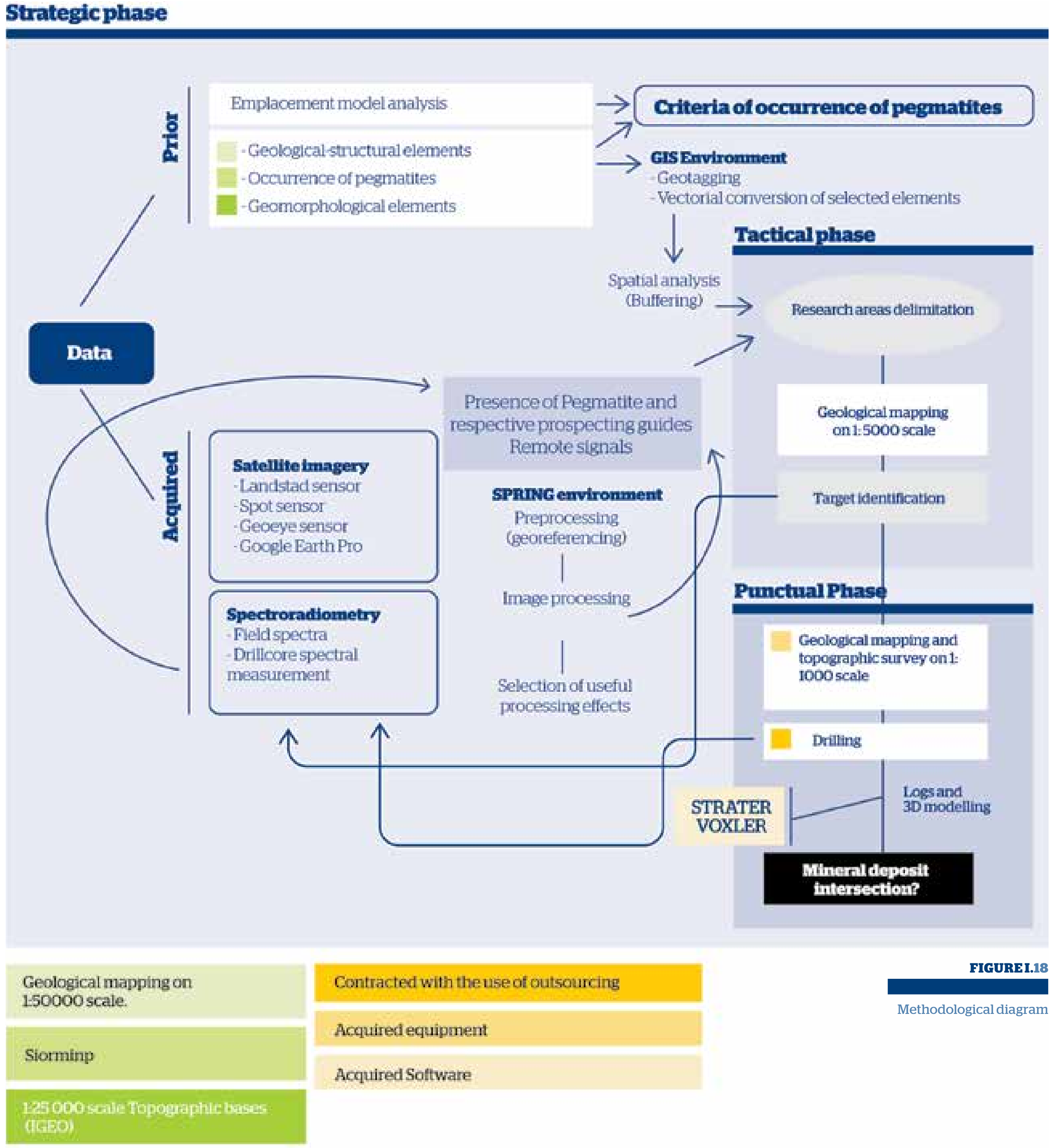


FIGURE I.18

Methodological diagram

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 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 organized in the correspondent database by substance or substances which constitute the useful mineralization of the deposit.

These elements were extracted, subjected to georeferencing and vectorization conversion with gvSIG 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);
- GeoEye 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 referrals (e.g. Gupta, 2003; 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 transmittance 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 distance.

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

	ETM+ (Landsat 7)	HRVIR (SPOT 5)	Geoeye
Launch	15/04/1999	4/03/2002	6/09/2008
Actal situation	Inactive (2003)	Active	Inactive
Type of platform	Spatial (satellite at 705 km altitude)	Spatial (satellite at 823 Km altitude)	Spatial (satellite at 648 Km altitude)
Type of orbit	Heliosynchronous, circular and nearly polar	Heliosynchronous, circular and nearly polar	Heliosynchronous
Spatial coverage (scan area) - size of the scene	185 x 170 Km	60 x 60 Km to 80 Km	15 x 15 Km to 50 x 300 Km
Inclination	98.2 º	98.7 º	98º
Length of Orbit	98.9 minutes	101.4 minutes	98 minutes
Passing time (Ecuador)	10:00 A.M.	10:30 A.M.	10:30 A.M.
Spectral resolution	8 bands	5 bands	5 bands
Spatial resolution	B1 - 30 m B2 - 30 m B3 - 30 m B4 - 30 m B5 - 30 m B6 - 60 m B7 - 30 m B8 (PAN) - 15 m	B1 - 10 m B2 - 10 m B3 - 10 m B4 - 10 m M (PAN) - 5 m	B1 - 1.65 m B2 - 1.65 m B3 - 1.65 m B4 - 1.65 m M (PAN) - 0.41 m
Radiometric resolution	8 bits	8 bits	
Temporal resolution	16 days	26 days on nadir; 2-3 days in order not to nadir	
Scanning date - images used	12-02-2004	11-06-2009	19-10-2009

TABLE I.8

Attributes for sensors and images of Landsat and Spot Geoeye typology used

Spectrum domain		Bands - wavelengths		
		ETM+ (Landsat 7)	HRVIR (SPOT 5)	Geoeye
Visible	Blue	B1 - 0.45-0.515 um		B1 - 0.45-0.51 (blue)
	Green	B2 - 0.525-0.605 um	B1 - 0.50-0.59 um	B2 - 0.51-0.58
	Red	B3 - 0.63-0.69 um	B2 - 0.61-0.68 um	B3 - 0.655-0.690
Infrared	Near-infrared	B4 - 0.75-0.90 um	B3 - 0.78-0.89 um	B4 - 0.78-0.92
	Mid-infrared	B5 - 1.55-1.75 um	B4 - 1.58-1.75 um	
	Thermal infrared	B6 - 10.4-12.5 um		
	Mid-infrared	B7 - 2.09-2.35 um		
Panchromatic	Panchromatic	B8 (PAN) - 0.52-0.90 um	M (PAN) - 0.61-0.68 um	M (PAN) - 0.45-0.80

TABLE I.9

Spectral resolution of satellites Lansat, Spot and Geoeye

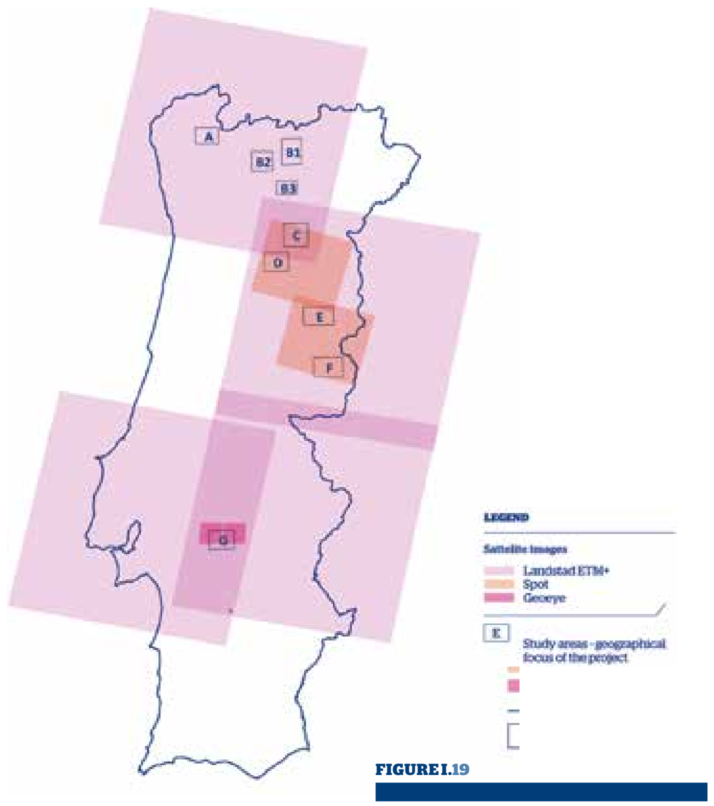


FIGURE I.19

Territorial coverage of satellite images used

Spectral domain	325 - 1075 nm
Spectral resolution	1 to 3 nm (3.5 nm to 700 nm)
Integration time	17 ms to several minutes
Collection rate	0.7 spectra/second (solar illumination)
Noise (radiance)	5.0x10^{-9} W/cm^2/nm/sr at 700 nm
Precision	± 5% at 400-900 nm
Observation angle	1, 10, 25 and 180º
Weight	1.2 Kg

TABLE I.10

Features of the portable spectroradiometer FieldSpec UV/VNIR

2 chapter

Orogenic pegmatite setting

Orogenic pegmatite setting

In this chapter the conceptual models on pegmatites emplacement are established. These gather occurrence criteria 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 framework, structure and paragenesis of pegmatitic fields in the selected study areas are also presented, including the distribution of indexes from the Siorminp database. It follows previous works done on pegmatite fields, which provides usable elements for a forecast on the distribution of bodies and swarms organization, regarding enclosing granites and deformation structures that constrain their host. This organizational forecast comes to support the demarcation of strips and productive massifs to be aware of in the satellite images processing.

II.1 II.1 Models of pegmatite emplacement

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 understanding is essential to the three-dimensional conjectures, which constitute the starting point on hidden pegmatite location forecast.

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 pegmatitic sets and the cartographic disposal of the fields obeys to a zonography conditioned by the distance to the parental granite source. The pegmatites located in the apical portions of the plutonic and perigranitic domes are little evolved. The possibilities of enrichment in rare metals and textural and paragenetic diversification (increase in the number of internal primary zones and diversity and extent of late metasomatic units) are incremented by the distance to the granite generator in the spread of magma 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 Brisbin (1986) kinematic model of pegmatitic intrusion-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 pressures with the prevalence of fragile conditions and relatively low directed constriction, anisotropies as fractures, cleavage, schistosity or stratification, produce preferential directions of minimum resistance to intrusion, hosting pegmatites with tabular morphology and preferential normal orientation regarding the compressive direction. At lower crust levels, the lithostatic pressure in ductile regime promotes the irregular intrusion of pegmatites (Figure II.1 B).

This model applies more strictly to outergranitic bodies and is best understood when the intrusion of pegmatitic 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 reactivations that contribute to modify the final morphologic patterns.

In the context of the Iberian Variscan Chain, with various phases of deformation and syntectonic polyphasic installation of granitic bodies, with local directed constrictions and interfering on the opening of dilatational hosting spaces, the acquisition of morphologies does not strictly follow the Brisbin model (Leal Gomes and Nunes, 2003). These authors, also considering different evolutionary stages of parental plutonites emplacement, adapt the conceptual organization matrix of Philips (1972, 1974) and Roberts (1970), to the placing of pegmatitic bodies around circumscribed granitic stocks, using the example of the Serra de Arga aplite-pegmatitic field, in Minho region (north of Portugal). Regarding those reference models, originally formulated to explain the strike and dip sequencing of injected dykes in subvolcanic anorogenic, permissive and isotropic environments, suggest the importance of the lateral expansion of the apical plutonite presented in the Philips (1972 and 1974) models, to understand the geometries of pegmatites that cross the granitoid contact with the enclosing metasedimentary formations. These assume the configuration of subparallel sills to the granite contact, being subhorizontal at distal locations (furthest from the plutonite) and inclined towards the granite when rooted therein (cone-sheet type peri-granite swarms). The most preponderant influence of the granitic magma displacement, near the massif, and the regional stress field in distal locations (creating dilatational hosting spaces) helps to understand this setting. In Figure II.1 C is presented the conceptual framework adapted from the work of Leal Gomes and Nunes (2003). In this scheme, the placement of the horizontal tabular pegmatitic bodies above the granitic domes is dependent on the internal relaxation of granitic stocks deployed in uplifting, according to the Brisbin (1986) model, for installations in fragile conditions.

In contrast to previous models of pegmatite emplacement, the bodies installation's organization is less known in an innergranitic context. Nevertheless, some recent work by Leal Gomes and Nunes (2003), Leal Gomes (2010) and Guimarães (2012) gather aspects that may indicate acquisition of form and internal structure trends in pegmatites. By using notions of morphoscopy 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 CIPB, they propose trends of placement and sequencing of shapes and dimensions stabilized in the granitic domes organization, supporting its usefulness for defining levels of pegmatite emplacement. In these studies, they invoke the Brun and Pons's (1981) kinematic model about the evolution of granitoid installations by ballooning in shearing zones, to explain the rise of pegmatite differentiates according to tendentiously diapiric shapes. They presuppose the possibility of a persistent and policyclic mobilization of magmas with more acidic composition (hotter), 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 detained by a rigid interface. From these, and by differentiation, they can evolve to pegmatitic bodies. The displacement in the granitic chambers occurs by density and viscosity contrast between the thin or pegmatitic acidic magma and the granitic magma with higher level of crystallization and, therefore, denser and more viscous. The geometries of the pegmatitic bodies that result from ascension mobilizations are classified as a type of pegmatitic bubble (embryonic geometries), hourglass, inverted droplet or turnip 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.1.D and E.

Regarding the pegmatitic magma generation potential in the interior of the granitic columns subject to differentiation, authors like Silva (2002) and Leal Gomes and Nunes (2003), invoke the role of mixing-mingling processes – hybridization of pegmatitic magmas by a mixture with more basic magmas – to explain the distribution of pegmatite bodies with conditioned alignment to certain proliferation corridors of mafic microgranular enclaves. The corresponding enclave swarms can assume a megascalar expression, defining patterns that are coherent with the injection trajectories of pegmatitic differentiates. Regarding the pegmatitic productivity is concerned the content transference of depressors elements of liquidus and mineralizers – higromagmaphile and volatile – to the felsic magmas, rising its potential as a generator of pegmatites (Leal Gomes and Nunes, 2003).

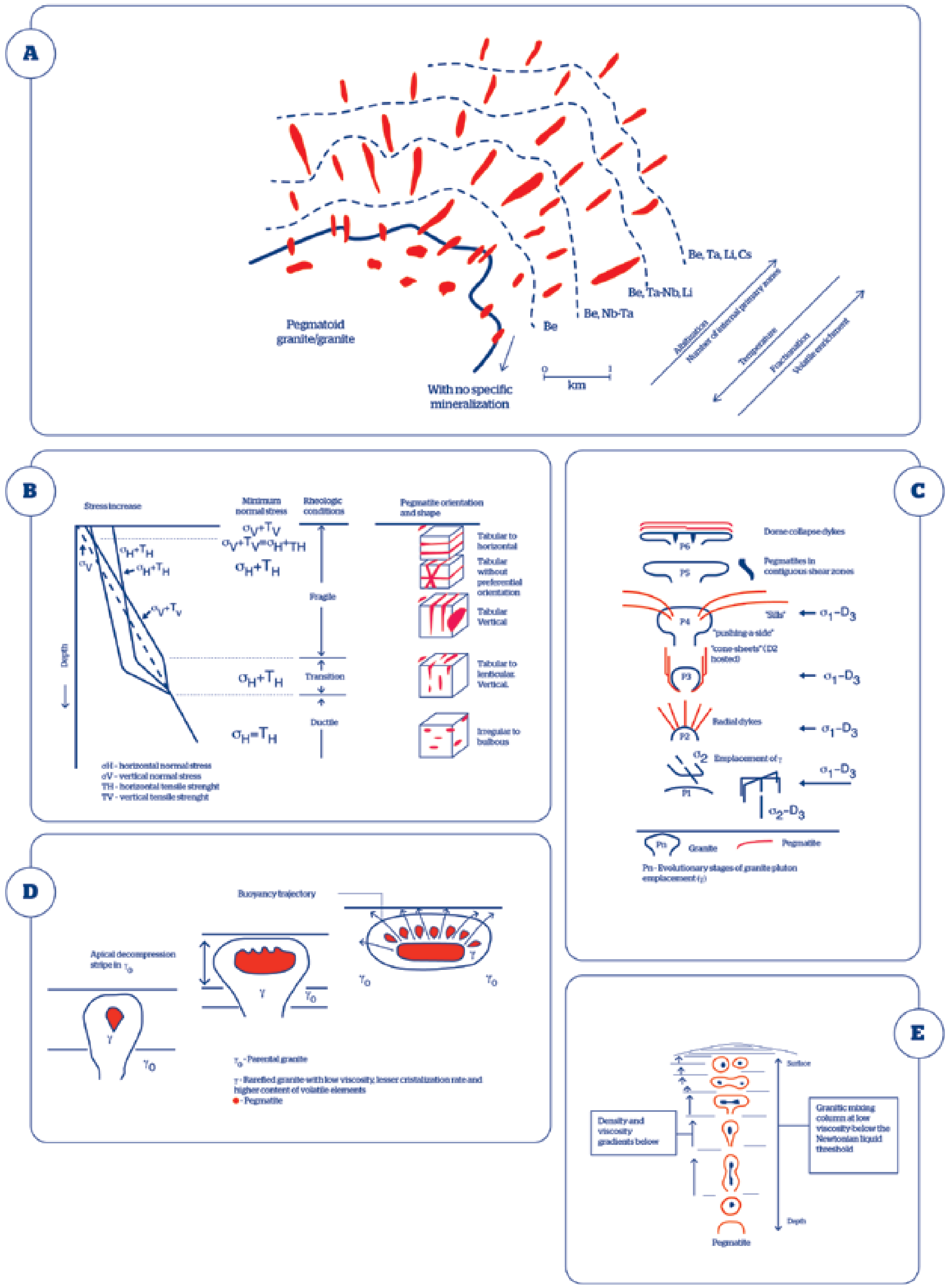


FIGURE II.1

Models of pegmatite emplacement adapted from Černý (1982) (A), Brisbin (1986) (B), Leal Gomes and Nunes (2003) and Guimarães (2012) (D and E)

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 for fluid supersaturation and leading to its release are explained by degassing mechanisms (e.g. Candela, 1997). These mechanisms establish that the release of volatile components, leading to the nucleation and fluid phase bubbles growth, which evolve towards the formation of open cavities as the magma crystalizes, occur in a magma that ascends to superior levels of the crust, by decrease in 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 ebullition. Other part of the fluid is released after crystallization during the secondary ebullition. 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.2, as proposed by Leal Gomes (1995).

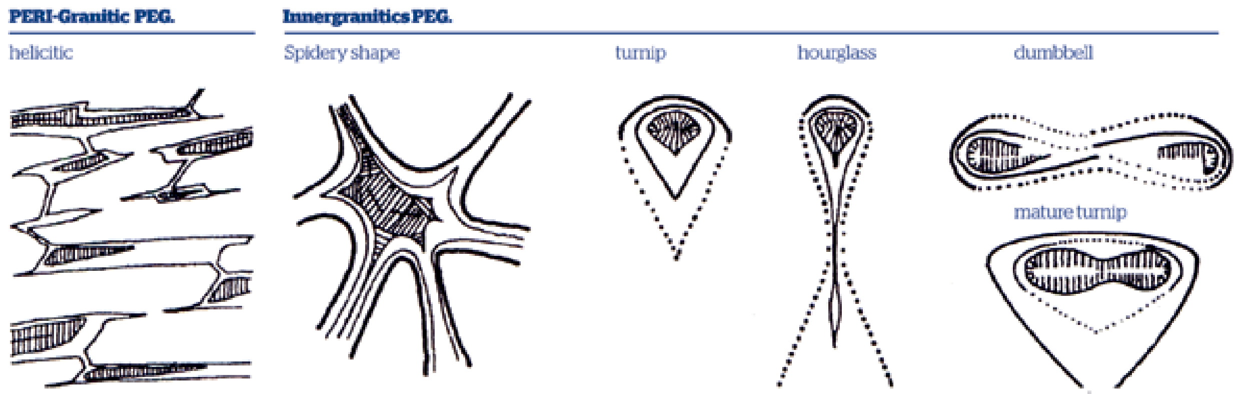


FIGURE II.2

Vertical sections representative of external morphologies and internal interface geometry observed, in pegmatites from CIPB (adapted from 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 stoped-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 proliferation.

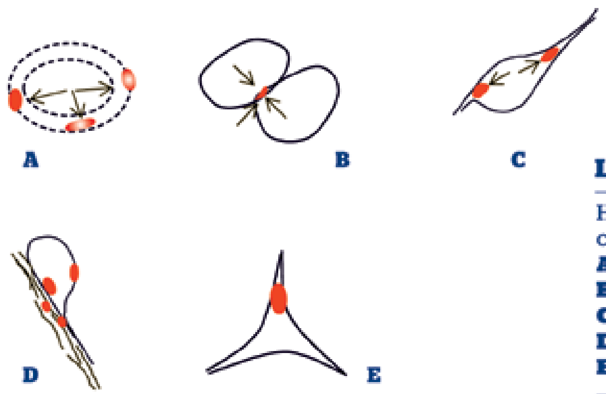
On the other hand, it is also expected that near structural levels of swarms placing, the granitic fractionation remains expressed in the acquisition of lithological heterogeneities within the plutons. Thus, the granitoids can be atypical near the differentiation spots. As supported by Cameron et al. (1949), quoted by Silva (2002), in an innergranitic context the granite-pegmatite transitions tend to be gradational, expressed, for instance, in the loss of the porphyroid character 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 conditions of magmatic flow, can, this 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 depends on the structural levels of placing in the exhumed and exposed massifs due to erosion. The possibility of displacements 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.



Legend

Hosting geometries – bi-dimensional sections susceptible of identification by distant analysis
A – Radiating pattern related to ballooning;
B – Coalescent pattern in the contact between two granitic facies;
C – Hosting pattern in transpressive structures;
D – Hosting conditioned to a mixing-mingling corridor;
E – Hosting in triple junction of granites.

FIGURE II.3

Bi-dimensional arrangements representative of situations of pegmatite setting in innergranitic context – geometric patterns susceptible of perception in remote mapping analysis

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 reconstitution 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.

II. Orogenic pegmatite setting

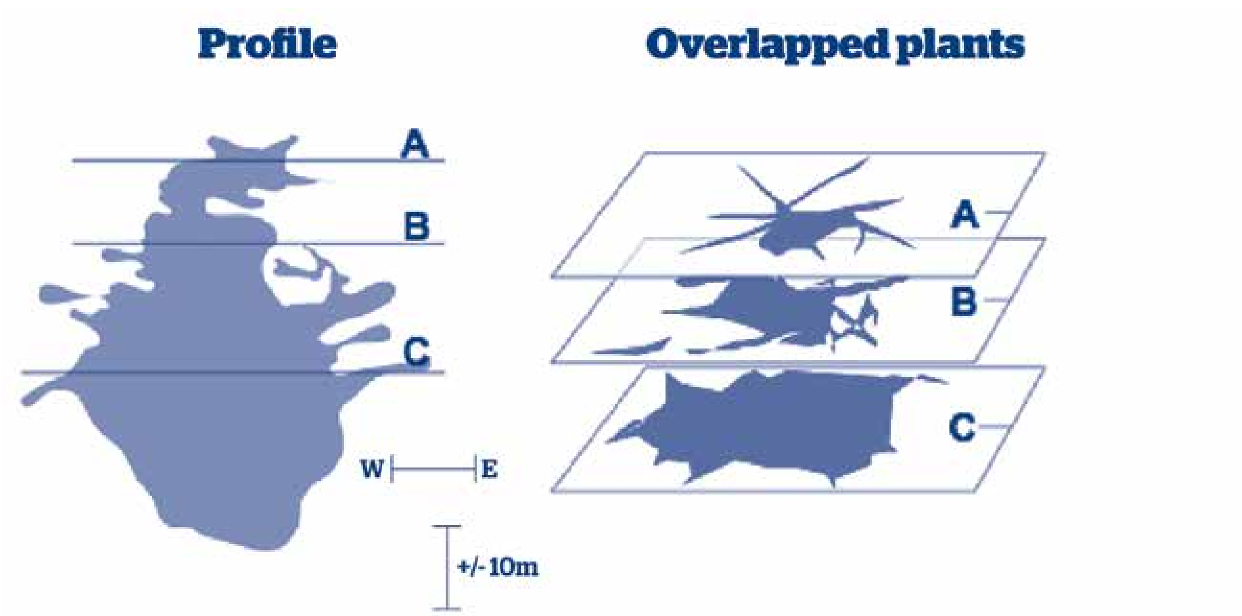


FIGURE II.4

Bi-dimensional sections representing pegmatitic shapes – plants deduced from 3D reconstitution of the Senhora da Paz pegmatite in Ponte da Barca (adapted from Guimarães, 2012).

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

• **Shades of gray –** reflectance measure expressed in gray scale;

• **Color –** natural or artificial, obtained through the conjugation of spectral bands, which provide better contrast resolution 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, diaclasites, 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 can manifest light tones in the images, expressing high values of reflectance. In the same way, overburdens with pegmatitic 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 tourmalinizations.

It is also considered the possibility of discriminating changes in granitic facies using as criteria the variations in coverage patterns – for example, variations in the rheological behavior pointed by the orientation and density of the diaclase net. On the other hand, low granulometry of gray shades can identify fine grained granites.

The magma mixture corridors can resemble strips, evidenced by a linear pattern with heterogeneous and heterogranular texture and tendentiously darker (with low reflectance) by the pulverization of granites with homogeneous meso and melanocratic enclaves.

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).

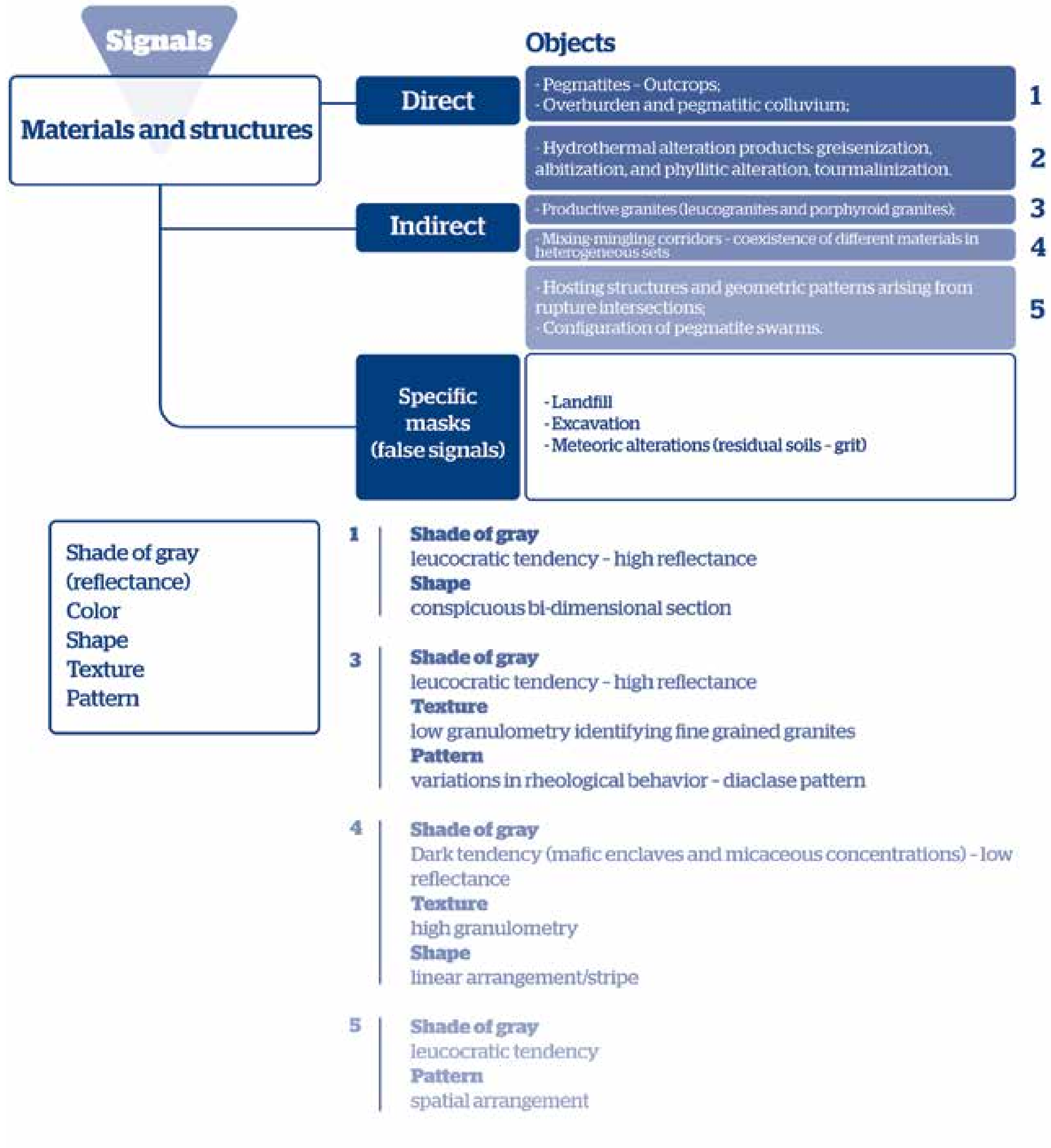


FIGURE II.5

Conceptual diagram on the remote attributes of pegmatites and their prospecting indicators, amenable to be recognized through the observation of satellite images

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

The framing developed on the areas selected in chapter I (areas A, B1, D and E) stems from the integration of the geological information obtained through geological mapping, published on 1:50 000 scale, of the coordinates of pegmatitic bodies looked up in Siorminp database and from the systemization of data collected in previous works.

The recognition of preferential trends for the distribution of bodies that support the demarcation of productive strips is intended.

II.3.1 Geological and mining framing of area A - Ponte da Barca -Terras de Bouro

The pegmatites that occur in Ponte da Barca region are essentially innergranitic bodies, more or less isodiametrical or irregular, with variable dimensions (Silva, 2002). These are zoned bodies with very abundant quartz (Qz>Fk) without major late units and with internal hyperaluminous units which, according to the classification of Ginsburg et al. (1979), correspond to ceramic pegmatites, dominantly potassic (Silva, 2002).

II.3.1.1 Geological framing on 1:50 000 scale

The geological mapping of the study area can be found on sheet 5-B - 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 facies patches, as observed in map 5B, is presented by decal and vector conversion in Figure II.6.

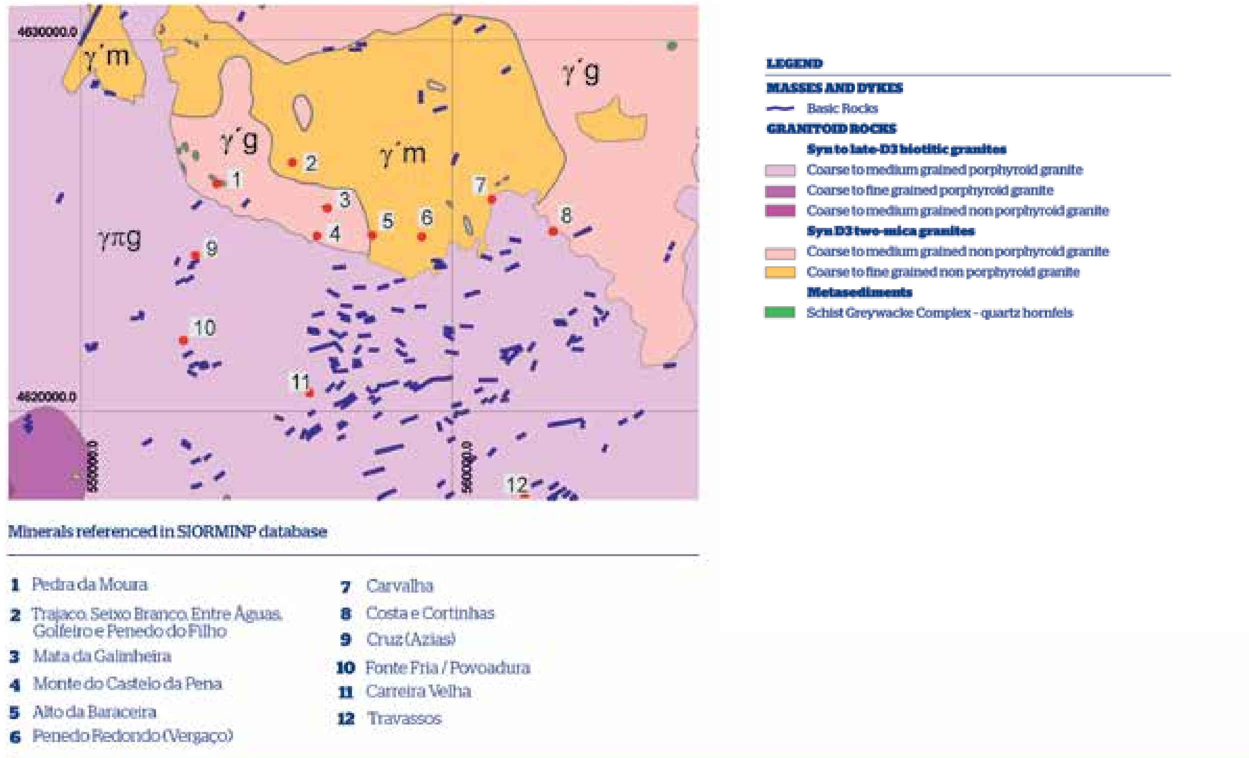


FIGURE II.6

Geological map on 1:50 000 scale of the Ponte da Barca-Terras de Bouro sector, with emplacement of pegmatitic outcropps looked up in the Siorminp database

The coarse or medium grained porphyroid granite (γπg) 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 argilization 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 facies. 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 azimuths ENE-SSW, NE-SW and NW-SE.

Still in Figure II.6, in the north, non porphyroid granites with significant petrographic variability outcrop. Important modifications in the granulometry lead to separate medium to coarse grained facies ($\gamma'g$) from the medium to fine grained facies ($\gamma'm$). There are also recognized strips of metasedimentary rock enclaves, represented near to the limit between porphyroid and non porphyroid granites.

II.3.1.2 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 hosting granites. Others are active deposits – Pedra da Moura and Mata da Galinheira. 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.2.

By establishing morphologic and mineralogical analogies for sets of bodies, this author separates the following pegmatitic groups: Seixas type, Pedra da Moura type and Penacova type.

Concession	Concession nº	Location	X	Y
Pedra da Moura	3530, 3531, 3533 / C44	Vila Chã (S. João Baptista), Azias and Touvedo	553687	4626319
Trajaco, Seixo Branco, Entre Águas, Golfeiro and Penedo do Filho (Seixas)	1147p, 3500	Vila Chã (S. João Baptista)	555730	4626890
Mata da Galinheira	3617 / C45	Vila Chã (S. João Baptista)	556693	4625650
Monte do Castelo da Pena	3534 / C45	Vila Chã (S. João Baptista)	556400	4624897
Alto da Baraceira	1157p	Vila Chã (S. João Baptista)	557900	4624912
Penedo Redondo	3504	Germil	559250	4624876
Cruz	3532	Azias	553107	4624364
Fonte Fria / Povoadura	1214p	Aboim da Nóbrega	552780	4622061
Carreira Velha	1017p	Mexães	556193	4620646
Carvalha	1053p	Germil	561139	4625895
Costa e cortinhas	1175p, 3596	Cibões and Brufe	562797	4625012
Travaços	3600	Vilar	562020	4617806

TABLE II.1

List of concessions for exploration of quartz and feldspar in the pegmatites of the Ponte da Barca - Terras de Bouro sector (Siorminp). Coordinates in dantum WGS84

Typology	Innergranitic swarms type I in the classification of Ginsburg *et al.* (1979), predominantly quartzose, affiliated in two-mica granites and syn and late-tectonic biotitics.
Morphology and morphoscopy	Isodiametric to elongated bodies with zoned internal structure and gradational contacts with the hosting granites. Bodies with dyke-like morphology, lenticular or tabular (rarer).
Internal structure/Zonality	The pegmatites evidence a well-marked internal zonality with the following major units: Marginal zone – usually undeveloped with similar minerals in its proportions to the peripheral granites minerals. Mural zone – distinguished by the greater granularity of crystals being frequent the existence of graphic textures and pluricentrimetric biotite perpendicular to the limit zone. Intermediate zone – the granularity of the crystals is always very coarse. It is separated an external zone were the potassic feldspar is predominant over the quartz and the plagioclase and a more internal zone were the quartz is more abundant than the feldspars, which can occur in the form of individualized gigacrystals. Units with phosphates and sulphides in the interface between the intermediate zone and the core are typical. Core – is constituted by an almost homogeneous mass of quartz that in some cases can include large crystals of potassic feldspar. In some bodies the core quartz has rosy coloration. In this unit or close surrounding area are frequently observed miarolitic cavities with variable volume were it can occur giant crystals of quartz in milky, hyaline and smoked varieties. Replacement units – result from the replacement or penetration of the previous areas by mineralogical associations of deuteric alterations or hydrothermal precipitation; have extremely diverse paragenesis.
Pegmatitic bodies with more significant productions	Seixas – explored for the production of quartz and feldspar with reserves ciphered in 500 000 tons of pegmatite. Mining suspended in the end of the 80s. Pedra da Moura – currently exploring granitic grit and pegmatitic quartz.
Pegmatitic groups	Seixas type pegmatites Pedra da Moura type pegmatites Penacova type pegmatites

TABLE II.2

Synthesis on the morphology, structure and paragenesis of pegmatites in the Ponte da Barca field (based on Silva, 2002)

FIGURE II.7

Parcial panoramics on the Pedra da Moura (A) and Mata da Galinheira (B) quarries. Photographs from 2013

Table II.3 describes in detail and on a paragenetic, morphological and structural perspective the grouped pegmatites. The structural location, type of hosting granitic facies and altitude are also included as attributes.

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 porphyroid granite (e.g. Pedra da Moura and Castelo da Pena). The morphology is variable from hourglass to inverted drop. It has a complex mineralogy being notable the volume occupied by the phosphated units. They are located at 540 to 650m high.

The pegmatites exploited in Pedra da Moura are organized as a rosary of irregular bodies with NW-SE direction. Here, as suggested by Leal Gomes et al. (2009), the presence of a metasedimentary roof-pendent and swarms of enclaves with flow orientations suggest the proximity of a dome, and are evidence of contamination processes consequence of mixing-mingling. According to the same authors, the general orientation of the corridor indicates the NW direction of injection of the different pegmatites.

The pegmatites exploited here are rich in quartz; the core frequently occupies 2/3 of the volume, being predominant the rose variety. Associations with the phosphates located in the transition between the intermediate zone and the quartz core, may correspond to 10% of the modal volume of the pegmatite. The immediately enclosing granite corresponds to a leucogranite with garnet and cordierite (Leal Gomes et al., 2009).

The access to the Mata da Galinheira quarry fronts, possibly due to the recent reactivation of the mine, revealed important nuclear masses of rose quartz (visible in Figure II.7B). Its interface with the intermediate zone is very rich in phosphates and sulphides. The micaceous units with muscovite, biotite and chlorite also retain remarkable contents of sulphides precipitated in cleavage planes of micas. The units filled with quartz follow a subhorizontal structure, suggesting the provable repetition of boxes and a greater possibility of lateral expansion of the masses in depth.

The Seixas type pegmatites have tendentiously arachnid shape morphologies and are characterized by the existence of miarolitic nuclear cavities with great volume, coated by druses of quartz gigacrystals; 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-mica granitic facies ($\gamma'g$ and $\gamma'm$).

The Penacova type pegmatites are fundamentally lenticular bodies essentially quartzose, with conditioned structure and affected by the regional late-Variscan tectonic. The existence of albitic and micaceous replacement units with sulphides is characteristic. These are installed according to NE-SW shear corridors in the interior of the porphyroid biotitic granite (e.g. Travaços) or in peri-cupular hosting ruptures of two-mica granites (e.g. Penedo Redondo).

	Occurrence	Morphology	Mineral comp. (accessory minerals)	Internal structure	Structural location	Hosting granitic facies	Altitude (m)
Pedra da Moura Ttype pegmatites	Pedra da Moura	Hourglass	Beryl, Nb-Ta-Ti oxids, primary phosphates (F-apatite or isokite, triplite-zwiezelite, trifilite-litiofilite) and secondary*; sulphides (pyrite, galena, blende, bismuthinite, matildite), sulfosalts and carbonates (oligonite)	Irregular rosary bodies; heterogeneous asymmetrically zoned pegmatites	Proximity to a corridor of mixing-mingling and roof-pendant metassedimentary; contact between granitic facies	Coarse grained two-mica facies granite; transition zones to the pegmatite include leucogranitic facies enriched in garnet and cordierite	550
	Mata da Galinheira	Inverted droplet (turnip) with apical extravasation headed south	Pyrite, ferrocolumbite, ilmenorútilo, apatite, xenotime, andalusite, zircon, scheelite Triplite-zwieselite, variscite, rockbridgeite and sulphides (pyrite> arsenopyrite> lolingite, chalcopyrite, blende)	Pegmatite with subhorizontal tabular internal quartzose	Interior of the granitic mass	Coarse grained two-mica facies granite	540
	Monte do Castelo da Pena	Inverted droplet with apical extravasation	Pyrite, arsenopyrite, triplite, andalusite	Zoned pegmatite	Dome or contact between different granitic lithologies zones	Coarse grained two-mica facies granite	650
	Alto da Baraceira	Arachnid shape with extravasation to N36ºW and N56ºW	Cassiterite, triplite	Zoned pegmatite	Dome or contact between different granitic lithologies zones	Interface between coarse grained and medium to fine grained two-mica granites	550
	Trajaco, Seixo Branco, Entre Águas, Golfeiro and Penedo do Filho	Arachnid shape	Fe and Mn phosphates, chlorite, apatite, sulphides (pyrite, galena, molybdenite)	Zoned pegmatite with large miarolitic cavities	Shear corridor	Fine to medium grained two-mica granite	250-350
Penacova	Penedo Redondo (Vergaço)	Arachnid shape, asymmetric	Arsenopyrite, pyrite, wolframite, apatite, scheelite	Pegmatite with approximately concentric zonality	peri-cupular ruptures	Fine to medium grained two-mica facies	800
	Travassos	-	Pyrite, apatite	Small heterogeneous bodies with approximately concentric zonality	Sheari corridor NE-SW	Biotitic porphyroid granite	790

TABLE II.3

Morphological-structural, compositional typology and structural location synthesis of the Ponte da Barca-Terras de Bouro pegmatites (according to Silva, 2002).*

* Inventory of secondary phosphates in the Pedra da Moura pegmatites (Leal Gomes et al. 2009): alteration in primary phosphates, wolfeite, eosforite, fairfieldite, vivanite, hureaulite, sicklerite, heterosite, purpurite, frondelite-rockbridgeite, OH-apatite; and in vacuolar fills childrenite, ritmanite, mitridaite, dufrenite, witmoreite, cacoxenite, strunzite, jahnsite, strengite, hureaulite II cyrilovite, paravauxite, tynsleite, bermanite, fairfieldite II, kryhanovskyite, laueite, stewartite, OH-ellestadite, hentschelite, kalunigite, Fe-sickelrite, messelite, Litiophosphat, Mn segelerite, lithiophorite, rockbridgeite-frondelite

II.3.2 Geological and mining framing of area B1 – Chaves

In the region of Chaves, the Seixigal pegmatite in Pereira de Selão that corresponds to a large body explored for production of quartz and feldspar, is paradigmatic. Mining began in 1968 and was maintained until 2000.

Reference works on the paragenesis, 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 1:50 000 scale

The area B1 is inscribed in 6B of Teixeira and Medeiros (1969) and 6D of Noronha et al. (1998) sheets from the geological map of Portugal on 1:50 000 scale.

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.

The north outcropping granites are medium to coarse grained two-mica syntetonic facies, tending porphyroid. The coarse grained Santa Barbara granite and the medium grained Minhéu-Lagoa granite, with facies 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 Aguiar massif biotitic granitic, facies correspondent to terms with medium to coarse grained porphyroids (Pedras Salgadas and Vila Pouca de Aguiar granites) and fine grained two-mica facies (Sabroso granite).

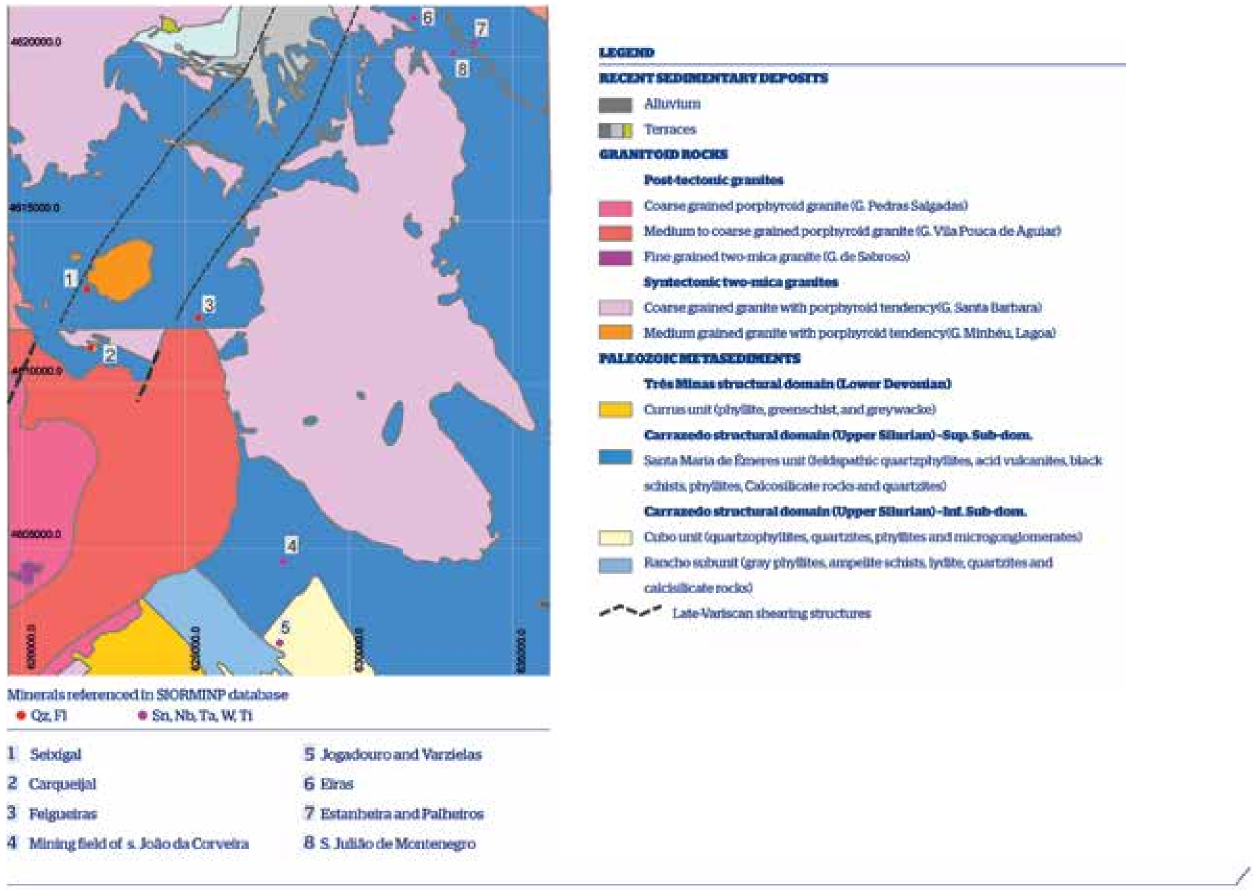


FIGURE II.8

Geological map on 1:50 000 scale of the Chaves sector according to Teixeira and Medeiros (1969) and Noronha et al. (1998)

The enclosing metasedimentary sequences described in Teixeira and Medeiros (1969) as schist-granitic complexes 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 Émeres, Cubo and subunit of Rancho, Upper Silurian). With a significant lithological diversity, they include phyllite, greywacke, quartz phyllites, acid metavulcanits, black shists, calcosilicatic rocks and microconglomerates.

In the geological map the structural NE-SW corridor is well delimited, correspondent to the late-Variscan Régua-Verin structure where the Santa Bárbara and São Pedro de Agostém granites and, in its extension to the south, the post-tectonic Vila Pouca de Aguiar massif are located (Figure II.8).

II.3.2.2 Typology and distribution of the pegmatites

According to Siorminp there are only 3 concessions attributed for quartz and feldspar exploration in the Chaves sector pegmatites – Seixigal, Carqueijal and Falgueiras (Table II.4 and Figure II.8).

The occurrences of Sn, Nb, Ta in pegmatitic dykes, aplite-pegmatitic and greisens with outergranitic installation are more numerous (Table II.5 and Figure II.8). There are small thickness bodies with variable directions, with past exploitation, in some cases focused on adjacent alluvial.

Concession	Concession nº	Location	X	Y
Seixigal	3465 / C85	Vilas Boas	622052	4613112
Carqueijal	1109p	Selhariz	622170	4611314
Falgueiras	3610	Moreiras	625460	4612247

TABLE II.4

Concessions attributed for quartz and feldspar exploration in pegmatites of the Chaves sector (Siorminp). Coordinates in dantum WGS84

Subst.	Concession	Concession nº	Location	X	Y	Deposit	Thickness of Dykes (m)	Atitude
Sn-Nb-Ta	Estanheira	2463, 2464	S. Julião de Montenegro	631709	4622108	!	0.60-3	E-W, vertical
Sn	Eiras	3243, 3244, 3245	Eiras e S. Julião de Montenegro	632066	4621412	! , a		
Sn-Nb-Ta	S. Julião de Montenegro	1847, 2462	S. Julião de Montenegro	633277	4620374	!	0.30-10	N 40 W, vertical
Sn-W	Estanheira and Palheiros	1445, 1736	S. Julião de Montenegro	633923	4620681	!	0.1-0.4	N 75 W
Sn-Ti	Jogadouro and Varzielos	2249, 2252, 2259	Carrazedo de Montenegro, Padrela, Tazem	627960	460227 4	! , q, a	<1.5	NW-SE; NE-SW, vertical
Sn	Minning pit of S. João da Corveira	1961, 2350, 2351, 3310, 3312, 3319	S. João da Corveira	628085	460477 5	"! , g, a	0.5-2.9	N 0-45 W; 30-45 W and 20-40 E

TABLE II.5

Attributed concessions for the exploration of Sn-Nb-Ta-W ores (cassiterite-columbite-tantalite-wolframite) in pegmatitic dykes and alluvium of the Chaves sector (Siorminp). Decoding of the type of deposit – ϖ (pegmatite), (aplite), a (alluvium), g (greisen), q (quartz). Coordinates in dantum WGS84

According to Pereira (2005), the Seixigal pegmatite corresponds to a tabular body with subhorizontal strike and stocksheider geometry type. It is located in a sector subject to dome collapse in intermediate position between Santa Bárbara granite (outergranite) and a post-tectonic biotitic granite, non-outcropping, that limits it inferiorly (innergranite, intersected by drilling). The contact of the pegmatite with the innergranite is gradational, with interfaces typical of fractionation, leading to the hypothesis of affiliation of the pegmatite on this granite. From it, successive accesses of pegmatitic felsic differentiates might have been produced, which was eventually filled and sealed by dilatational reactivations, in successive stages of dome collapse. The syntectonic Santa Bárbara granite worked as a unit buffer, necessary to accommodate the strain and contain the migration of residual granitic differentiated. The contact with the outergranite is gruff and discordant with the regional metasedimentary rocks.

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.

According to Pereira (2005) the main pegmatite mass has a complex internal structure, banded in parallel with the elongation, with a maximum extension of 200m, E-W direction, and 20m thick. The bands are disposed in sequences of horizontal structuring, very regular, with thicknesses variable from centimetric to metric, and that tends to decrease from E to W. The individual pegmatitic bands are homogeneous, with internal comb structure, and are composed by imbricated alkaline feldspar crystals and quartz. They present variable contents of biotite, ilmenite and apatite. In the pegmatite structuring a peripheral body with ellipsoid morphology is also recognizable, which should be proximal relatively to the main magmatic conduit, considering that the magmatic access to the previous structural units was done from this E-NE rooted body.

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).

FIGURE II.9

Panoramic images over the Seixigal mining pit, in 2011

Typology	Ceramic pegmatite with stocksheider geometry located on the syn to late-Variscan Santa Bárbara granitic plutonite SW edge, limited inferiorly by a parental post-tectonic biotitic granite. Has mixed trend NYF-(LCT) – very little specialized peraluminous phenacite subtype.
Organization and morphology	It is composed, essentially, by two units: - a main subhorizontal tabular body; - a peripheral pocket rooted E-EN with ellipsoidal morphology in proximal position relatively to the major magmatic conduit. The device is segmented due to late tectonic reactivation.
Dimensions	The largest body has 200m of maximum extension direction E-W and 20m thickness; the peripheral pocket has a larger axis with 100m being the smallest dimension 40m.
Internal structure and paragenesis	The main pegmatitic mass has a complex internal structure, banded parallel to the elongation. The bands are disposed in horizontal structuring sequences with thickness variable from centimetric to metric and that tends to decrease from E to W. The individual pegmatitic bands are homogeneous with internal comb structure; are composed by imbricated alkaline feldspar crystals and quartz and present variable contents of biotite (+ ilmenite), apatite and schlorite. The secondary units (venular and discordant substitution masses) are marked by albite, muscovite, apatite, chlorite and tourmaline; dykes with quartz-albite-cassiterite and gaps composed by apatite+quartz+pyrit or chlorite+albite+pyrite +/- blende +/- titaite +/-tantite are rarer; in the hydrothermal gap occurs the association quartz+apatite+phenakite +/- bertrandite +/- OH-herderite. The chloritic and sericitic are common in all pegmatitic units and enclosing granites. It can be observed a metasomatic edge with enrichment in biotite and porphyroblastic andalusite and quartz-muscovite-tourmaline veining.
Exploration	Mining began in 1968 and was maintained until 2000.

TABLE II.6

Characterization elements collected in Pereira (2005) on the Seixigal pegmatite, representative of the Chaves sector

II.3.3 Geological and mining framing of area D – Viseu-Satão

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

Lobato (1971) presents a reference work on the use conditions of quartz, feldspar and beryl, and correspondent beneficiation diagrams from Beiras pegmatitic deposits and especially its 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 12-D 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 NW-SE direction outcrops on the extreme SE of the Carboniferous Dúrico-Beirão groove shear zone (Iglésias e Ribeiro, 1981; Rodrigues, 1997). From the stratigraphic standpoint they comprise metapelites, metagraywacke and conglomerates of the Douro group (CXG, Câmbrico) Ordovician quartzites and schists and intracontinental old Carbonic sediments (carbonaceous schists, quartzites and metagraywacke) (Figure II.10).

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 porphyroid character. It includes mafic, micaceous and metasedimentary enclaves. It defines an arch that matches the oriental edge of this massif. Sheet 14-D recognizes "zones of dykes and aplite-pegmatitic masses" and small flaps formed by fine grained granite in their interior.

The north delimitation of the area covers the post-tectonic Pera Velha massif 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-S, NE-SW and NW-SE (Figure II.10).

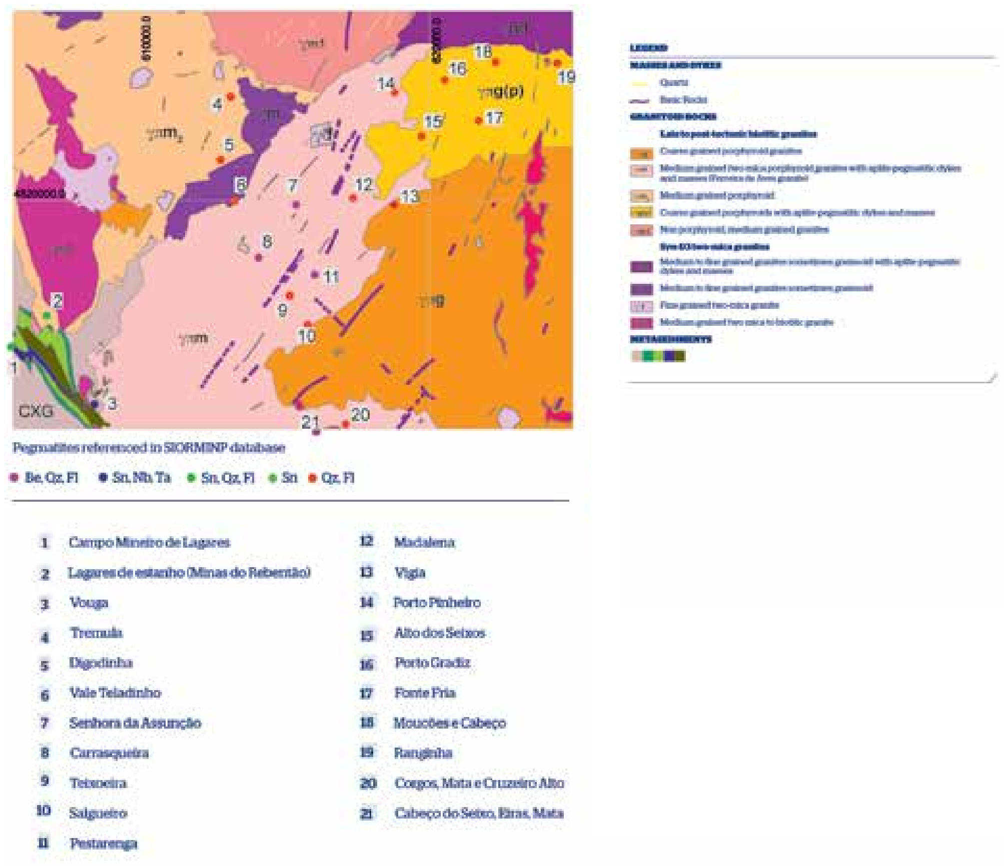


FIGURE II.10

Geological map on 1:50 000 scale of the Aguiar da Beira sector (according to Teixeira et al., 1972)

II.3.3.2 Typology and distribution of the pegmatites

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

The distribution of pegmatitic 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 are, 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 Černý (1982) they can be referred as miarolitic hybrids with beryl, phosphates 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 (Ferreira de Aves granite) present deeper location in the context of the massif structuring, scattered or in coupled sets. They contrast with in 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-ferriferous and lithinipherous-phosphatic 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.8.

They present Be, Nb, Ta (Nb>Ta), Li, Mo and Ti specialization which translates into a paragenesis represented by beryl (gigacrystals in the intermediate-core zone interface), bertrandite, fenacite, OH-herderite, columbite-tantalite, molybdenite and ilmenite. The Li is expressed in phosphate units. The south pegmatite is the one that presents greater mineralogical diversity, regarding phosphate phases, discriminating the primary phosphates triplite-zwiezelite, OH-herderite, trifilite-lithiophilite and F-apatite and the following descending associations by evolution in liquidus, subsolidus and in supergene state: rockbridgeite, vayryneite, roscherite, childrenite, ambligonite-montebrasite, brasilianite, augelite, lazuli-scorzalite, hureaulite, vivianite, sicklerite, heterosite, 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).

SUBST.	Occurence	Location	X	Y	Concessionaire	Altitude (m)
Qz_Fl_Be	Senhora da Assuncao - Varzea and Valdeireiras	Ferreira das Aves	615483	4520066	Sociedade Agrícola e Industrial Montanísco, Lda	780
Qz_Fl_Be	Preguica and Pestarenga	Ferreira das Aves	616107	4517673	José Pereira Barbosa Ramos	625
Be_Qz_Fl	Carrasqueira	Ferreira das Aves	614201	4518254	FELMICA - Sociedade Mineira da Carrasqueira, S.A	740
Qz_Fl	Madalena	Ferreira das Aves	617414	4520297	Felmica	750
Fl_Qz	Vigia	Aguia da Beira	618832	4520075	Felmica	820
Qz_Fl	Teixoeira	Ferreira das Aves	615264	4516965	Undefined	625
Qz_Fl	Salgueiro	Pinheiro and Ferreira das Aves	615874	4515971	Undefined	655
Qz_Fl	Corgos, Mata and Cruzeiro Alto	Romas	617157	4512585	Undefined	650
Qz_Fl_Be	Cabeço do Seixo, Eiras, Mata	Romas	616160	4512325	Undefined	630
Qz_Fl	Pestarenga	Ferreira das Aves	616272	4518575	QUARTEX - Sociedade Mineira do Alentejo, Lda.	858
Qz_Fl	Vale Teladinho	Outeiro de Baixo	613382	4520196	Undefined	
Qz_Fl	Alto dos Seixos	Aguiar da Beira	619759	4522408	SOCILICA - Soc. Mineira de Quartzo e Feldspato, Lda	870
Qz_Fl	Porto Gradiz	Gradiz	620540	4524316	Undefined	890
Qz_Fl	Fonte Fria	Gradiz	619759	4522408	Undefined	895
Qz_Fl	Moucoes and Cabeço	Gradiz	622283	4524933	Undefined	750
Qz_Fl	Ranginha	Gradiz	624383	4524904	Undefined	625
Qz_Fl	Paiva	Peva	611583	4525177	Albino Monteiro	770
Qz_Fl	Digodinha	Outeiro de Cima	612919	4521591	Undefined	830
Qz_Fl	Tremula	Forles	613247	4523743	Arnaldo Manuel Paiva Simões	785
Sn	Ribeiro da Queiriga	Queiriga	605169	4516665	Undefined	670
Sn_Nb_Ta	Fontainhas and Facho	Mioma	608602	4513250	Undefined	650
Sn_Qz_Fl	Lagares de Estanho (Minas do Rebentao)	Queiriga	606972	4516283	Undefined	759
Sn	Vouga	Mioma	607994	4514094	Undefined	650
Sn_Qz_Fl	Campo Mineiro de Lagares	Queiriga	605631	4515420	Areias da Queiriga, Lda	650

***Enclosing granitic facie type*:**

Innergranitic	Innergranitic	Innergranitic	Peri-granitic
Located in the interior of the late to post-tectonic medium grained porphyroid Ferreira de Aves granite	Located in the interior of the medium grained porphyroid granite/medium to fine grained granite sometimes gneissoid	Coarse grained porphyroid granite	Contact surface between: medium grained porphyroid granite, medium grained two-mica granite and metasediments

TABLE II.7

Inventory of pegmatitic occurrences in area D

600-700m	700-800m	800m

The peri-granitic pegmatites located on the SE side of the Carboniferous Dúrico-Beirão shear zone groove include sills rooted in the medium grained porphyroid granite and stanniferous dykes or estano-tungstic swarms of the Lagares mining district (Neiva, 1944).

The Queiriga pegmatitic group is representative (also called Lagares de Estanho or Mina do Rebentão in the documents of the mining acquis). The main body of this group has N20°W/45°E strike and dip, and 12m medium thickness (Puga et al., 2003). It is classified by the criteria of Černý and Ercit (2005), as LCT-petalitic type. Economically it manifests ceramic appetence and mineralizations ordered by abundance of Li>Be>Sn>Ta>Nb>W>Bi.

The Lagares mining field is characterized by pegmatitic and aplite-pegmatitic dykes striking E-W to N-S and NNW-SSE, variable dips and medium thickness between 0,1 and 1,5 m. In the Minas Velhas sector, the mining acquis refers the occurrence of quartz dykes, which in more recent works of Dias et al. (2006), and by the recognition of important contents of topaz in its paragenesis, are described as topazites, mineralized with cassiterite, columbite-tantalite, wolframite, rutile, arsenopyrite, gold, electrum and bismuth. According to the same authors they have enclosing tourmalinites with topaz porphyroblasts interstratified in the Antas Formation.

Typology	By combining the classifications of Cameron *et al.* (1949), Ginsburg *et al.* (1979) and Černý (1982) the Alto Vouga field pegmatites can be referred as innergranite, miarolitic, zoned, potassic, with beryl, phosphates, niobium-tantalates and Ti minerals.
Morphology and morphoscopy	The Senhora da Assunção pegmatitic group comprises 2 pegmatitic bodies coupled. The shape of each body is lenticular with a larger subhorizontal development from which emerge several protuberances with vertical development directed to the ceiling on the granitic chamber. The pegmatitic pair presents flat dumbbell disposition not being visible in the dismounts any kind of continuity or connection.
Dimensions	The subhorizontal development of the larger body in Senhora da Assunção group reaches 100m.
Internal structure / Zonality	The pegmatites have a well-marked internal zonality with the following main units: - mural zone – Feldspar quartz with graphic textures- Quartz + Potassic feldspar + +oxides. - intermediate quartz-feldspar zone – with quartz + potassic feldspar+ beryl, ixiolite, columbite-tantalite and muscovite. - intermediate feldspar zone – Potassic feldspar + beryl, ixiolite, ilmenite, triplite-zwiezelite, pyrite - quartz core – almost monomineralic - replacment masses– manganese-ferriferous and lithinipherous - chlorite, pecheblenda, thorbernite + /-autunite, malachite, eosphorite, phosphosiderite, alluaudite, or purpurite - lepidolite + /-Qz - or - kaolinite - or Mo. - late structure fillings – clay, quartz, microclinic, chlorític and sulphurets - Qz + chalcopyrite, iron oxides or montmorillonite.
Pegmatitic bodies with more significant productions	Senhora da Assunção, Pestarenga, Vigia
Swarms and pegmatitic groups	Sezures-Dornelas Trancozelos-Travanca de Tavares. Pegmatites isolated or coupled in sets (groups) –e.g. Senhora da Assunção group

TABLE II.8

Structural and paragenetic discrimination of innergranitic pegmatites in late to post-tectonic Aguiar da Beira massif (according to Trabulo et al., 1995

II.3.4 Geological and mining framing of area E – Guarda- Belmonte

The pegmatites belonging to the Guarda field are fundamentally dyke-like, LCT type, complex with rare metals (REL-LI) and are hosted in the interior of late to post-tectonic granitic facies.

II.3.4.1 Geological mapping on 1:50 000 scale

In 18-C sheet 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 – Fráguas-Pena Lobo massif.
- **Monzonitic porphyroid granites -** occupy the remaining space around that massif - Belmonte-Pega massif.

The metasediments represented as discontinuous patches in the interior of the Belmonte-Pega monzonitic granite, belong to the Schist-greywacke Complex of the Beiras group.

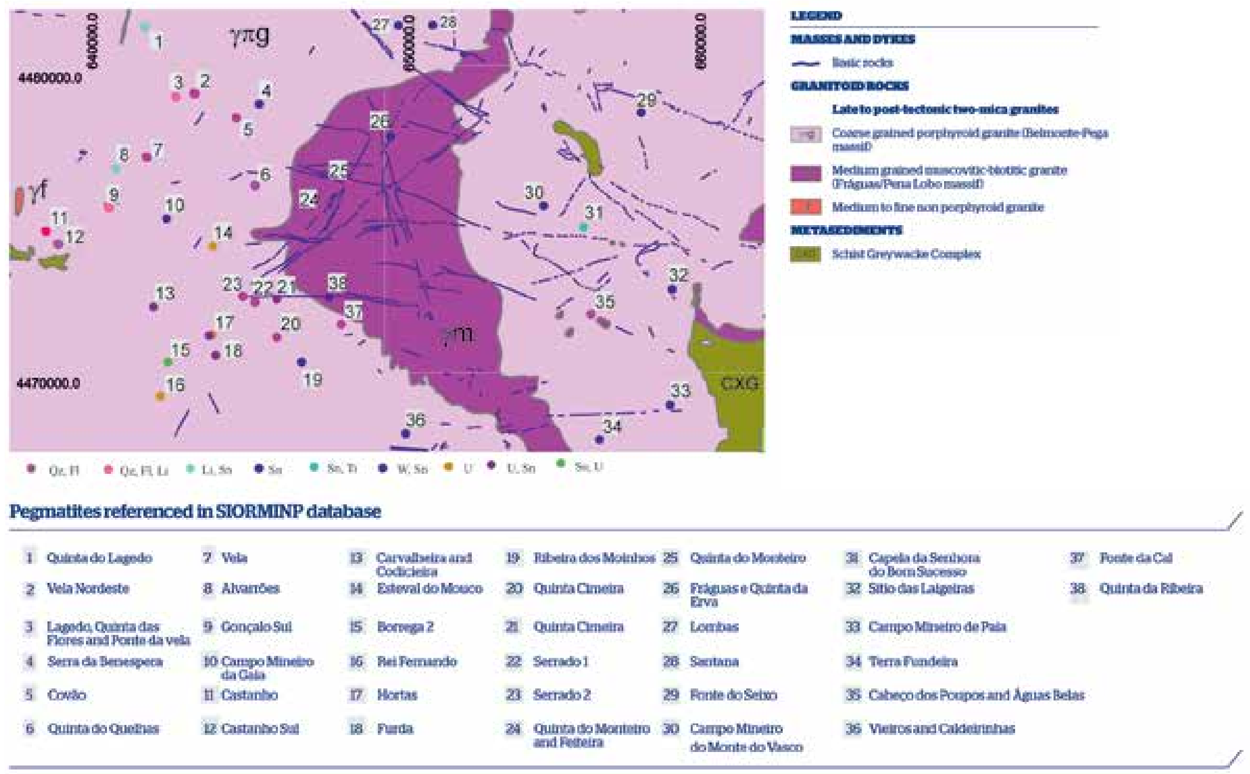


FIGURE II.11

Geological map on 1:50 000 scale of the Guarda-Belmonte sector (according to Martins et al. reviewed by Teixeira, 1963)

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 paragenesis. Includes subhorizontal and inclined dykes with associated aplitic and pegmatitic structures (Table II.10).

The most outstanding LCT specialization can be lithinipherous, with lepidolite or amblygonite, or berylipherous, expressing both 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.

Substance	Occurence	Location	X DT73	Y DT73	Concessionaire	Altitude (m)
Qz_Fl	Quinta Cimeira	Maçainhas and Bendada	646561	4471335	Felmica	630
Qz_Fl	Serrado 1	Maçainhas	645857	4472483	Felmica	580
Qz_Fl	Serrado 2	Maçainhas	645460	4472662	Felmica	540
Qz_Fl	Covão	Vela	645252	4478468	Aldeia & Irmão, S.A	640
Fl_Qz	Castanho Sul	Gonçalo	639434	4474357	E.N.U. - Empresa Nacional de Urânio, S.A	525
Fl_Qz	Quinta do Quelhas	Benespera	645855	4476269	E.N.U. - Empresa Nacional de Urânio, S.A	580
Qz-Fl	Cabeço dos Poupos and Águas Belas	Lomba and Águas Belas	656799	4472083	EXMIN - Companhia de Indústria e Serviços, S.A	840
Qz_Fl_Li	Gonçalo Sul	Gonçalo	641092	4475544	José Aldeia Lagoa & Filhos, Lda.	530
Qz_Fl	Vela	Vela	642321	4477196	José Aldeia Lagoa & Filhos, Lda.	580
Qz_Fl	Vela Nordeste	Vela	643881	4479255	José Aldeia & Filhos, Lda.	540
Fl Li	Castanho	Gonçalo	639040	4474776	PEGMATÍTICA - Sociedade Mineira de Pegmatites, Lda.	580
Qz_Fl	Fonte da Cal	Bendada	648665	4471762	Felmica	660
Qz_Fl	Quinta do Monteiro	Bendada	648909	4476304	Undefined	780
Qz_Fl	Quinta do Monteiro and Feiteira	Bendada and Benespera	647918	4475395	Undefined	770
Qz_Fl_Li	Lagedo, Quinta das Flores and Ponte da Vela	Vela	643282	4479149	Felmica	560
Li_Sn	Alvarrões	Gonçalo, Seixo Amarelo and Vela	642259	4481438	Sociedade Mineira Carolinos, Lda.	520
Li_Sn	Quinta do Lagedo	Vela	641315	4476828	José Aldeia Lagoa & Filhos, Lda.	780
Sn	Tapada da Deveza	Santana da Azinha	653163	4480846	Undefined	840
Sn	Fráguas and Quinta da Erva	Santana da Azinha	650294	4477818	Undefined	860
Sn	Sítio das Laigeiras and Lameira do Bezerrinho	Baraçal	659441	4472858	Undefined	850
Sn_Ti	Capela da Senhora do Bom Sucesso	Lomba	656572	4474880	Undefined	780
Sn	Vieiros and Caldeirinhas	Sortelha	650788	4468174	Undefined	490
Sn	Ribeira dos Moinhos	Bendada	647416	4470491	Undefined	490
Sn	Quinta da Ribeira	Bendada	648295	4472599	Undefined	540
Sn	Serra da Benespera	Benespera	646034	4478876	Undefined	600
W_Sn	Fonte do Seixo	Carvalhal Meão	658435	4478598	Undefined	803
Sn	Lombas	Joao Antão	650558	4481420	Undefined	900
Sn	Santana	Santana da Azinha	651658	4481431	Undefined	870
Sn	Campo Mineiro de Gaia (Maçainhas and Vale Mourão)	Gonçalo, Vela, Benespera, Belmonte, Maçainhas	643021	4475147	DRAMIN - Exploração de Minas e Dragagens, Lda.	530
Sn	Campo Mineiro de	Pousafoles do Bispo, Lomba,	655265	4475567	Undefined	776

<500 m	500-700 m	700-900 m

Topographic levels

TABLE II.9

Inventory of pegmatitic occurrences on area E

In the Gonçalo – Seixo Amarelo sector, Ramos (1998) and Ramos (2010) describe aplite-pegmatitic subhorizontal sills with about 3.5m thickness installed in fractures systems NNW-SSW consistent with the late-Variscan stress field. They describe 3 fundamental sill types – stanniferous, mixed and lithinipherous.

The first appear in inferior structural and topographic levels presenting simple structure, homogeneous, and minor paragenetic diversity. The lithinipherous bodies present lepidolite or amblygonite-montebrasite as specialization typomorphicminerals. A mineralogical inventory of the swarm contemplates the following accessory phases:

petalite, zinnwaldite, topaz, apatite, cassiterite, columbite-tantalite, microlite, 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 8cm, not exceeding 20cm; express albitization, tourmalinization, recrystallization of quartz, feldspars muscovitization and biotite replacing by zinnwaldite.

In the Pêga-Sabugal region the most outstanding specialization is berylipherous and dykes mineralized with lepidolite are less frequent. The swarms observed in Cabeço dos Poupos (Silva et al., 2006) are organized according to variable strikes; the dykes with subvertical inclination have average orientation E-W to WNW-ESSE and their subhorizontal bodies are distributed around the average strikes N10°E, 20°SE. The vertical bodies have variable thickness between 10cm and 15m and horizontal development that can reach 700m. The sills have thickness till 2.5m and outcrop extension that can reach 200m. The pegmatites have generally internal zonality and banded organization of aplitic and pegmatitic facies. They are predominant in the aplitic facies contact surfaces; typically pegmatitic structures develop mainly in nuclear positions at top. Rhythmic style aplitic 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 aplitic and pegmatitic facies imbrication with comb-structure potassic feldspar gigacrystals. The mineralogical reference association discriminated in Silva et al., (2006) includes quartz, orthoclase, perthitic microcline, albite, muscovite, lithinipherous muscovite, tourmaline, beryl, zircon, columbite-tantalite (ferrocolumbite, ferrotantalite), cassiterite, apatite and Fe-Mn phosphates (triplite, heterosite and eosforite). Centimetric halos with metasomatic zinnwaldite are also typical.

The geochemical modelings of Ramos (1998) suggest an affiliation relation between Gonçalo-Seixo Amarelo field, with the biotitic-muscovitic Pena Lobo granite. Silva et al., (2006) proposes a fractionation of the Pêga granite to generate the compositions observed in the Cabeço dos Poupos swarms.

In the Bendada pegmatites, the diversity of Fe-Mn and Li phosphates is remarkable, especially in late replacement units distributed in the intermediate-core zone 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 trifilite-litiofilite and triplite as primary phosphate phases and secondary associations with purpurite, manganosicklerite, stewartite, phosphosiderite, hureaulite, bermanite, rockbridgeite, vivianite, strunzite and wavelite. The sulphides identified include arsenopyrite, molybdenite, pyrite, and chalcopyrite. The uranium minerals – uraninite, sabugalite, torbernite, autunite, metatorbernite and phosphuranylite – occur mainly in later quartzose fillings.

Typology	Rare metals complex – LCT (REL-Li) – lepidolitic subtype and with beryl-columbite-phosphates (according to Černý and Ercit, 2005).
Morphology and morphoscopy	Sills and dykes inclined to subvertical.
Dimensions	Berylipherous, inclined and subvertical dykes with 10cm to 15cm thick and horizontal extension till 700m. Berylipherous and lepidolitic sills 2.5m thick and extension till 200m.
Internal structure / zonality	Aplite-pegmatitic homogeneous facies with comb-structure potassic feldspar, zoned or banded, sometimes with oscillatory organization of aplites and pegmatites. Metasomatic halos with zinnwaldite on the contact granite-pegmatite surface and banded disposition parallel to the dyke are typical. Reach 7 to 8cm in Gonçalo-Seixo Amarelo and 15cm in Cabeço dos Poupos.
Swarms and pegmatitic groups	Gonçalo-Seixo Amarelo Pêga-Sabugal Bendada

TABLE II.10

Structural and paragenetic discrimination of innergranitic pegmatite in area E (according to Ramos, 1998 and Silva et al., 2006)

II.4 II.4 Geological-structural and geomorphologic indicators of the approach to research areas

II.4.1 Productive granitic stripes and massifs

Through the analysis of geostructural frames of pegmatitic deposits occurrence and spatial distribution of their outcrops in relation to granitic paths and deformation structures, the following productive ranges and massifs were deduced for the selected areas:

a) Area A

- the cartographic concentration of pegmatitic indexes is more consistent along the interface established between two-mica granites and porphyroid biotitic granites, which seems to be equivalent to an emplacement corridor of two comagmatic 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 zone corridors.

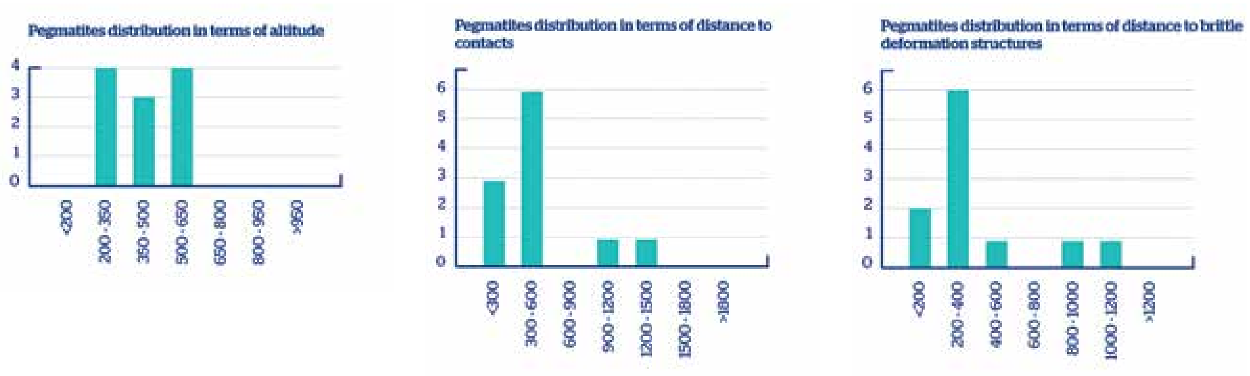


FIGURE II.12

Graphic representation of the distributions of Ponte da Barca pegmatites according to altitude, distance to contacts and distance to faults (from Silva, 2002). In the work of Silva (2002), the combined evaluation of geology and geomorphology by statistic study suggests the existence of a productive topographic level between 200 and 650m high. Concerning the distance of megascale tectonic accidents, this author defined two domains, one that comprises an occurrence range between 0 and 600m and the other one between 800 and 1200m. In relation to the distances to the nearest contacts, similar distance intervals are verified (lithological interface closer to the pegmatite body). (Figure II.12).

b) Area B1

Through the definition of the Seixigal pegmatite as a stocksheider type body with complex innergranite – outergranite, and due to the affiliation relation between the pegmatite and the post-tectonic innergranitic facies, it is suggested the main role of the Régua-Verin structure on the pegmatite installation, with the same tectonic conditioning.

c) Area D

- the main pegmatitic bodies are distributed in the interior of the Ferreira de Aves granite, which can manifest facies 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 berylipherous 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 pegmatitic bodies.

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 criteria of pegmatite occurrence, extracted from geological maps and topographic bases. The following criteria, identified in Table II.11 were selected:

- proximity to continuous lineaments – in 1:25 000 scale topographic maps were identified deformation structures. Linear structures superior to 5km were marked and converted into vectorial files.

- proximity to continuous domes to continuous lineaments and interrupted by oblique lineaments – in topographic maps on 1:25 000 scale, axis of elongated domes were identified. In marking them joining the points listed per line was considered.

- areas delimited by basic dyke-like bodies – the basic bodies were extracted from geological mapping on 1:50 000 scale and converted into vectorial lines; although considered late it is assumed that their emplacement was made on former reactivated structures.

- Proximity to indexes and known occurrences – revealed from Siorminp database, they were imported into GIS environment as file points.

After surveying the situations described, by decal and from topographic and geological published cartography and vectorial conversion, it was used the software GvSIG for its spatial intersection (buffering). With this purpose, the lines and points were converted into polygons, extrapolating the following distances of influence: domes and lineaments (400m), dykes of basic rocks (350m) and pegmatitic indexes (750m). From these intersections resulted the area in red on Figure II.13 that, by fulfilling all the defined criteria, matches locations with higher favorability for the detection of interest targets. Some of them came to corresponde to research areas.

The approach adopted is also schematized in Figure II.14, for instance, area D. The Salgueiro area was selected this way.

	Indicator criteria	Database and / or approximation method
Geological-structural	Proximity to indexes and known pegmatites	Siorminp
	Inclusion in productive massifs and ranges	Relation between the occurrence distributions and the granitic facies occurrences. (Geological mapping on 1:50 000 scale)
	Proximity to fragile deformation structures (continuous lineaments)	Topographic cartography on 1:25 000 scale
	Areas delimited by basic dyke-like bodies	Geological mapping on 1:50 000 scale
Geomorphologic-structural	Elongated domes contiguous to continuous lineaments (combination 1)	
	Combination 1 interrupted by oblique lineaments	Topographic cartography on 1:25 000 scale
Conjugation indicators	Intersections of criteria obtained with previous approaches	Buffering GvSIG

TABLE II.11

Geological-structural and geomorphological criteria favorable to the occurrence of pegmatites in innergranitic context

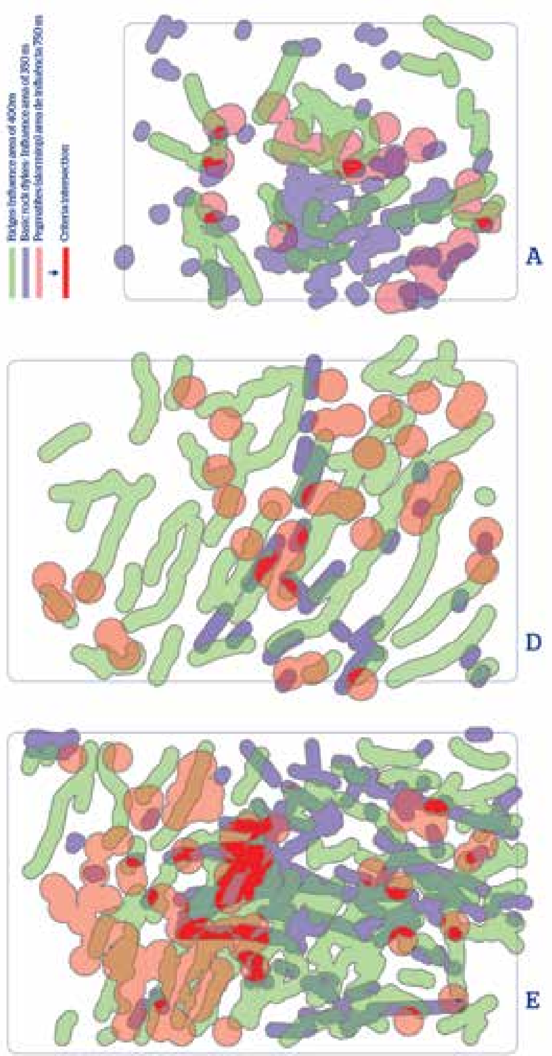


FIGURE II.13

Results of the intersections of geological-structural and geomorphological criteria in the study areas

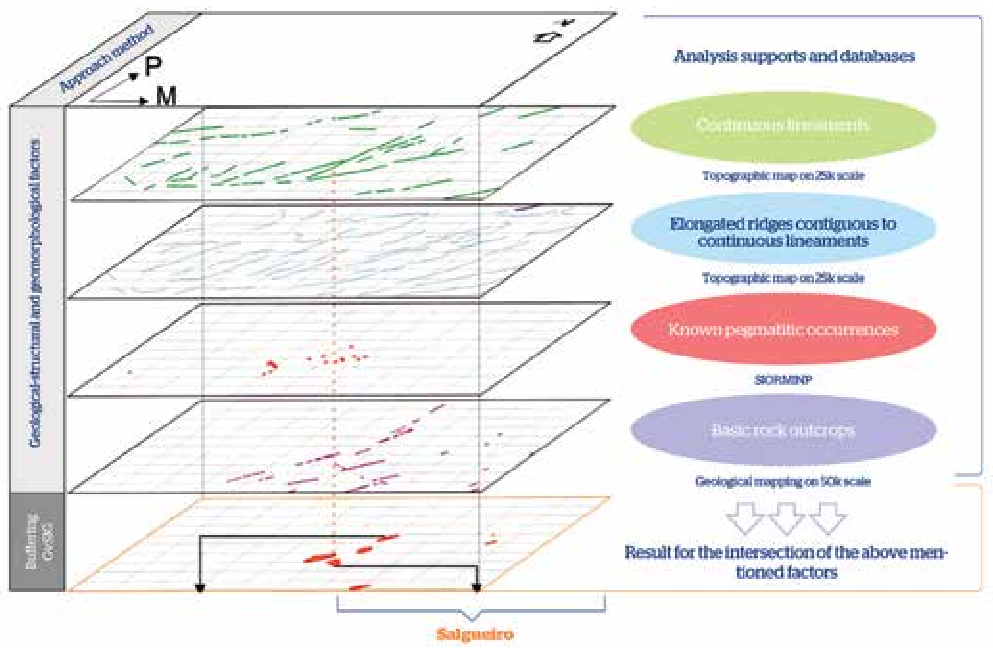
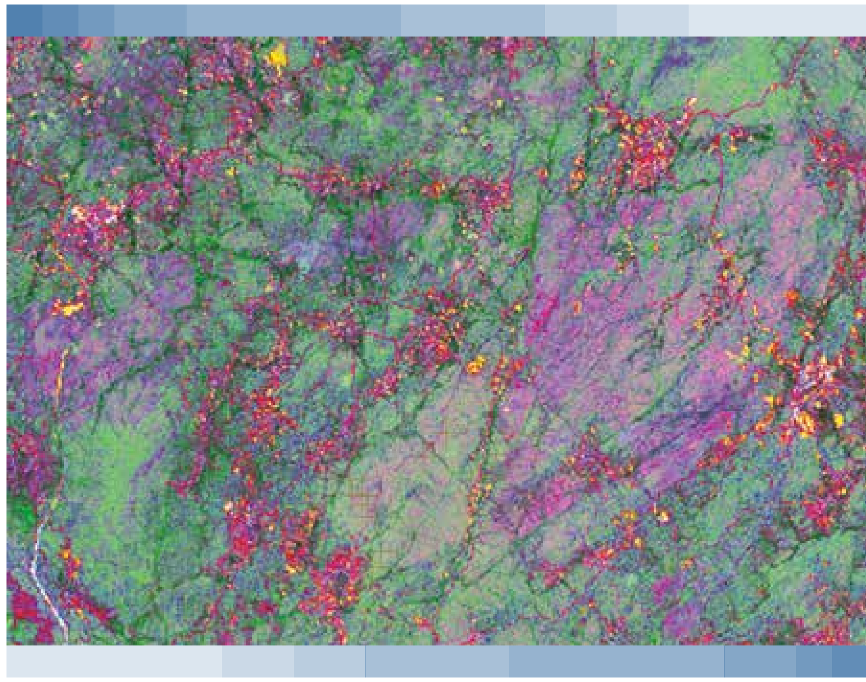


FIGURE II.14

Schematization of the methodological approach adopted in the delimitation of the Salgueiro research sector (area D)

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, equationed here as via to pegmatites prospecting.

III.1 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.

The histograms identify the number of pixels with certain gray value in the range 0-255 (8-bit grayscale).

- RGB combination of spectral bands – natural color and false-color images were obtained by the combination of 3 bands previously highlighted by contrast broadening.

Natural color images result from the attribution of 3 primary colors (blue, green and red) to bands 1, 2, and 3, respectively, which contain data from the electromagnetic spectra's visible domain. The notation will be RGB321. In false-color images at least one of the considered bands is out of the visible spectra domain having been attributed to it a RGB color.

- 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.

The main components images are based on a strong correlation that may exist between different bands in which the information is repeated. This way is resumed a group of variables in a new smaller set, without losing significant part of the information. The MCs ordain this information separating the most repeated information. The data on the initial bands is synthetized creating new bands in terms of their correlation. These new bands are independent and non-correlated. This way, the difference between materials can be easily detected (Chuvieco, 2000).

- 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 Maxver 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.II.6, 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 arachnid 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) are perceptible two compartments, or sectors, with differentiated aspect (a and b), with contrasts coming from minor vegetable coverage in the granitic patch at north. Pedra da Moura and Seixas 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 N30ºE (d).

The most relevant structural patterns are well seen in the image correspondent to band 8, panchromatic, from satellite Landsat (Figure III.2).

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 WNW-ESSE ruptures, which 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 Galinheira (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 hypothesis, 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 Galinheira, Castelo de Pena and Seixas 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 exhumed granitic facies.

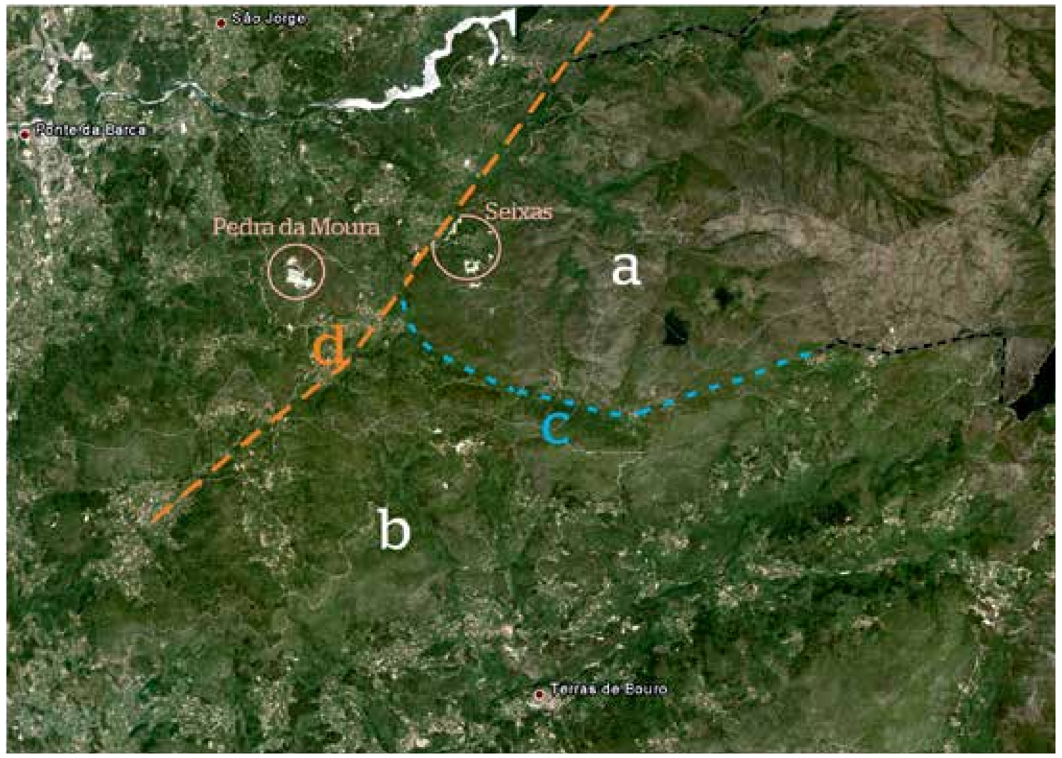


FIGURE III.1

Google Earth's image of area A - Ponte da Barca-Terras de Bouro

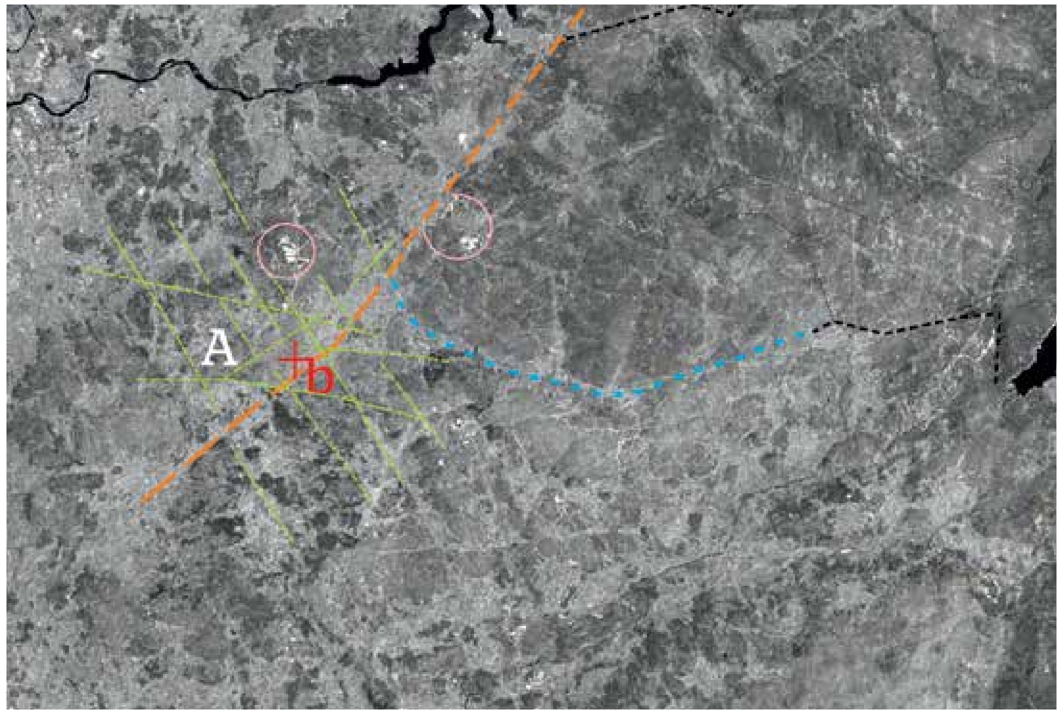


FIGURE III.2

Image correspondent to the panchromatic band (band 8) of satellite Landsat (area A)

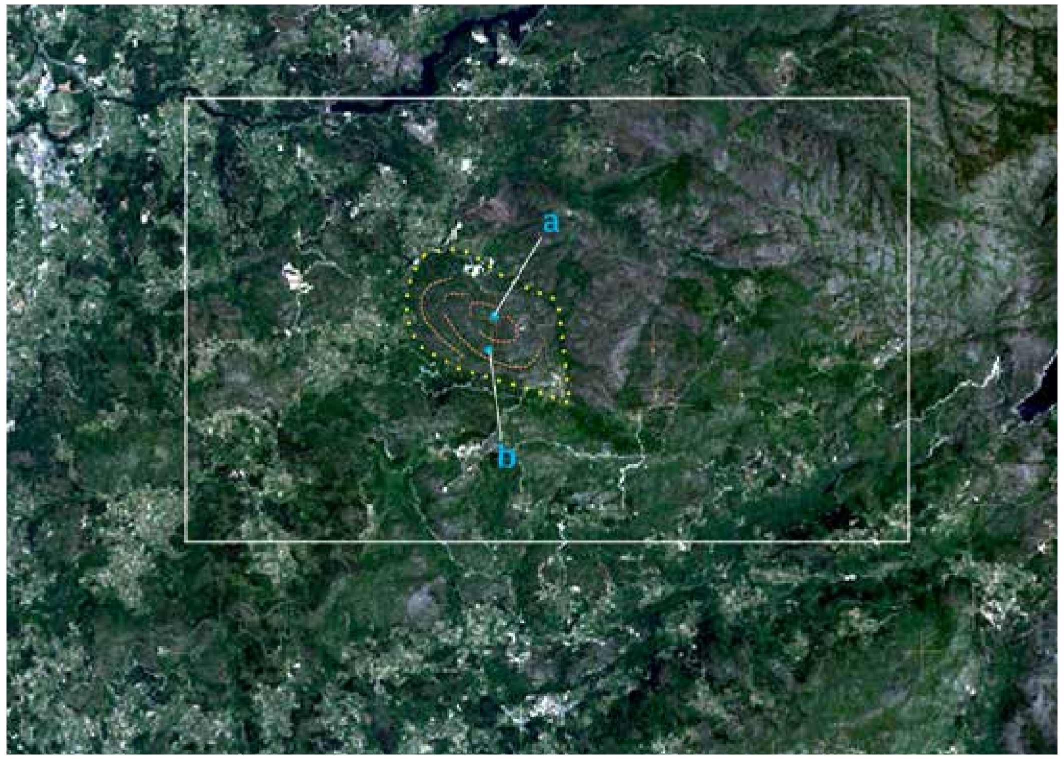


FIGURE III.3

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

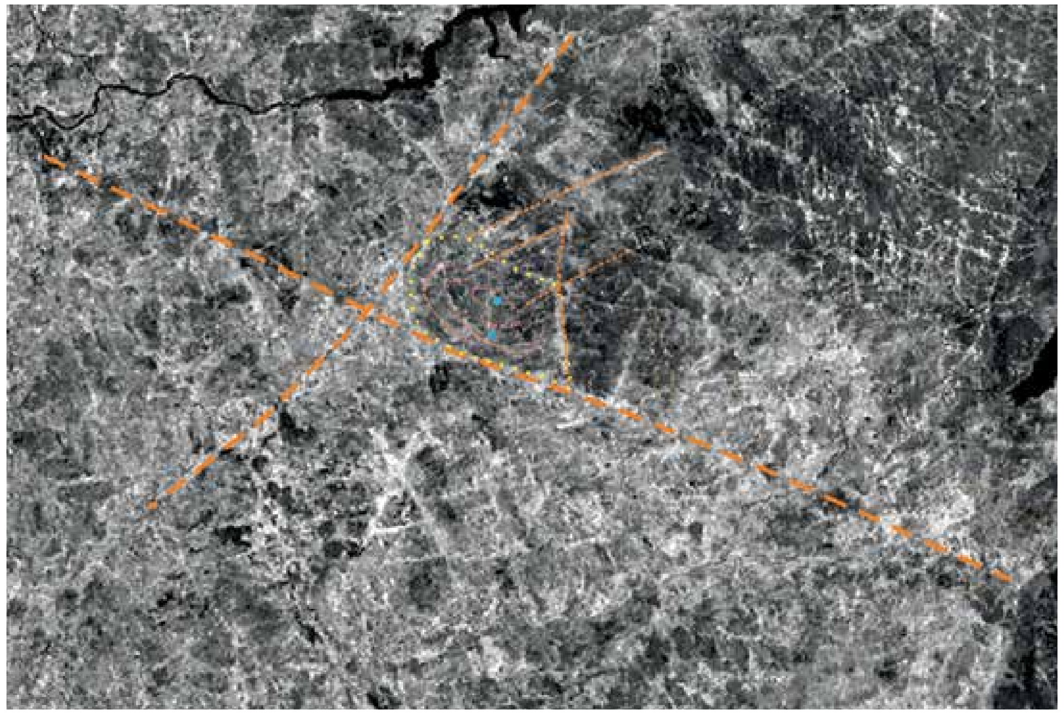


FIGURE III.4

"Image correspondent to the 2nd main component obtained through bands 1, 2, 3, 4, 5 and 7 of satellite Landstad (Area A)"

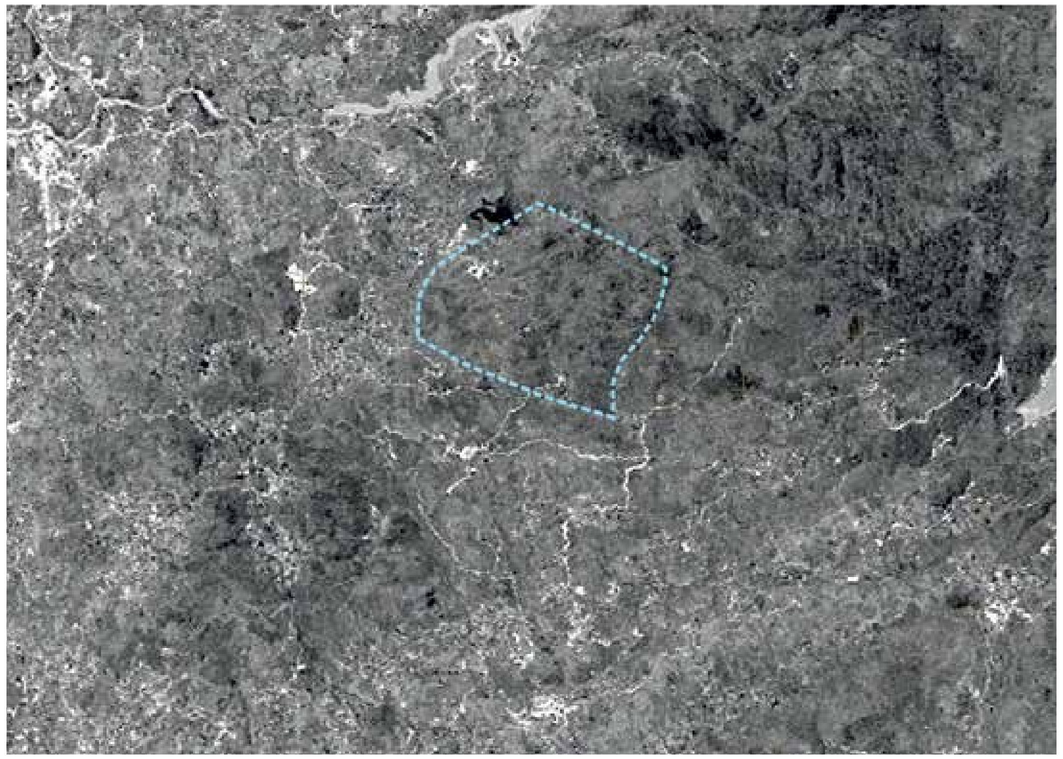


FIGURE III.5

Image correspondent to the 3rd main component obtained through bands of satellite Landstad relative to area A

III.2.2 Area B1 – Chaves

Through the revision of the tectonic conditioning of the Seixigal 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 megastructure, 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 megastructure is defined with good resolution and is segmented by structures with N-S azimuth. This fracturing pattern is repeated in the surroundings of the Seixigal 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 megastructure 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 subdomain (c).

The 3rd main component (Figure III.6D) improves the discrimination of metasedimentary formations represented at south and separates them from the Minhéu-Lagoa syntectonic two-mica granite. The cartographic design is correlated with the geological maps the following way:

- Minhéu-Lagoa syntectonic granite (a)
- Curros unit of the Três Minas Structural Domain and Rancho subunit of the Carrazedo inferior subdomain (b)
- Cubo unit of the Carrazedo inferior subdomain (c)
- Santa Maria de Émeres unit of the Carrazedo superior subdomain (d) – the corresponding patch, represented east of the Minhéu-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.

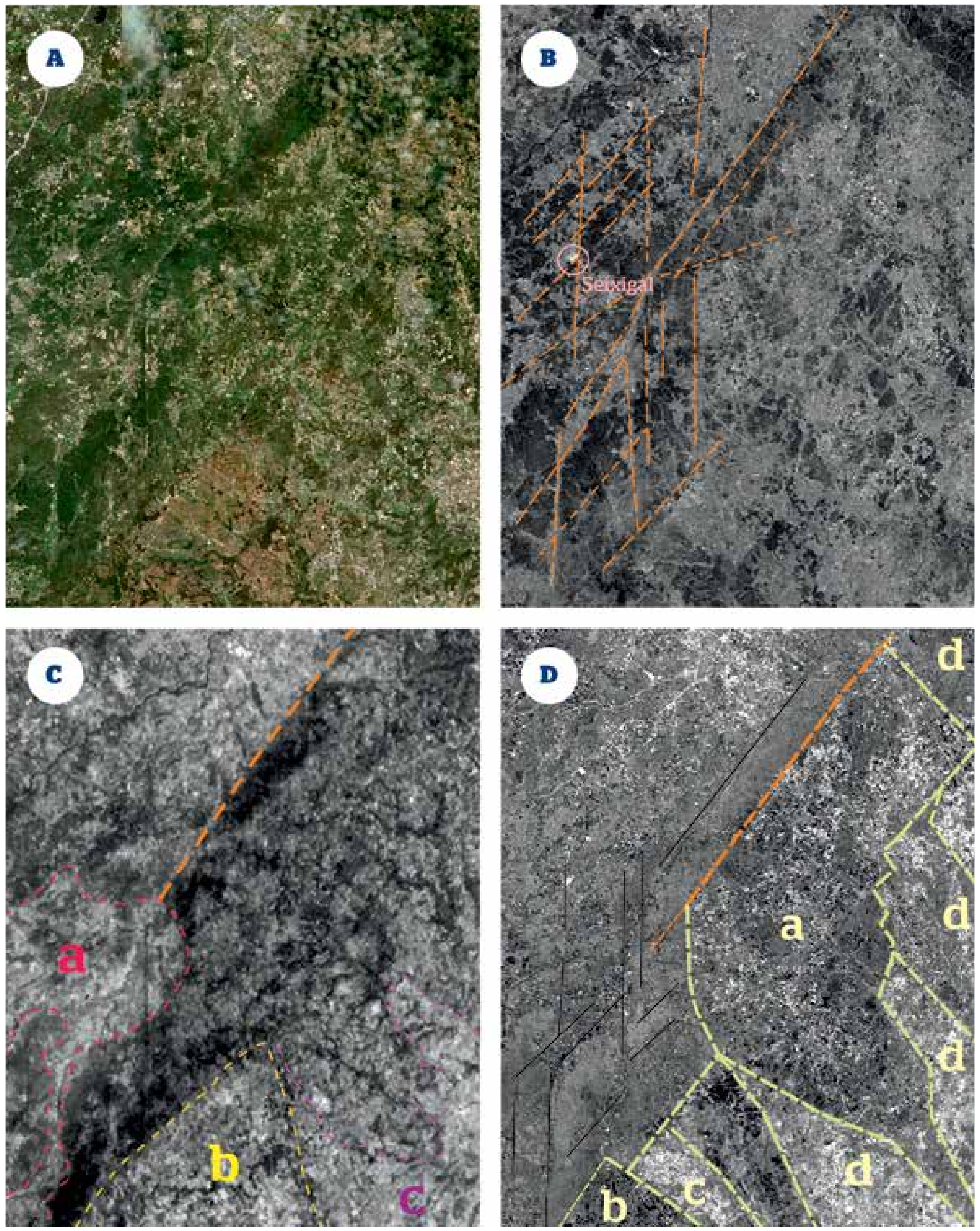


FIGURE III.6

Images of area B1: A - Google Earth Pro; B – band 8 of satellite Landsat; C – band 6 of satellite Landsat; "D – 3rd main component"

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 flaps 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's 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 N30ºE 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 geoh. Other compartment spreads to the south of the Senhora da Assunção pegmatite (b).

FIGURE III.7

Google Earth Pro's image relative to area D

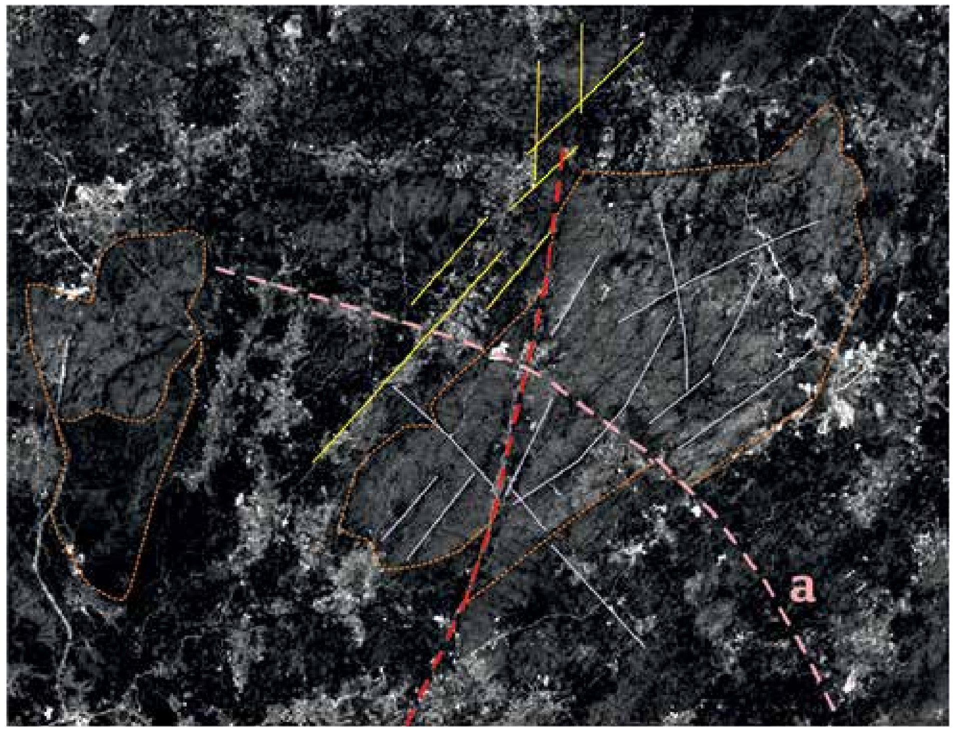


FIGURE III.8

Image corresponding to band 1 of satellite Landsat - area D

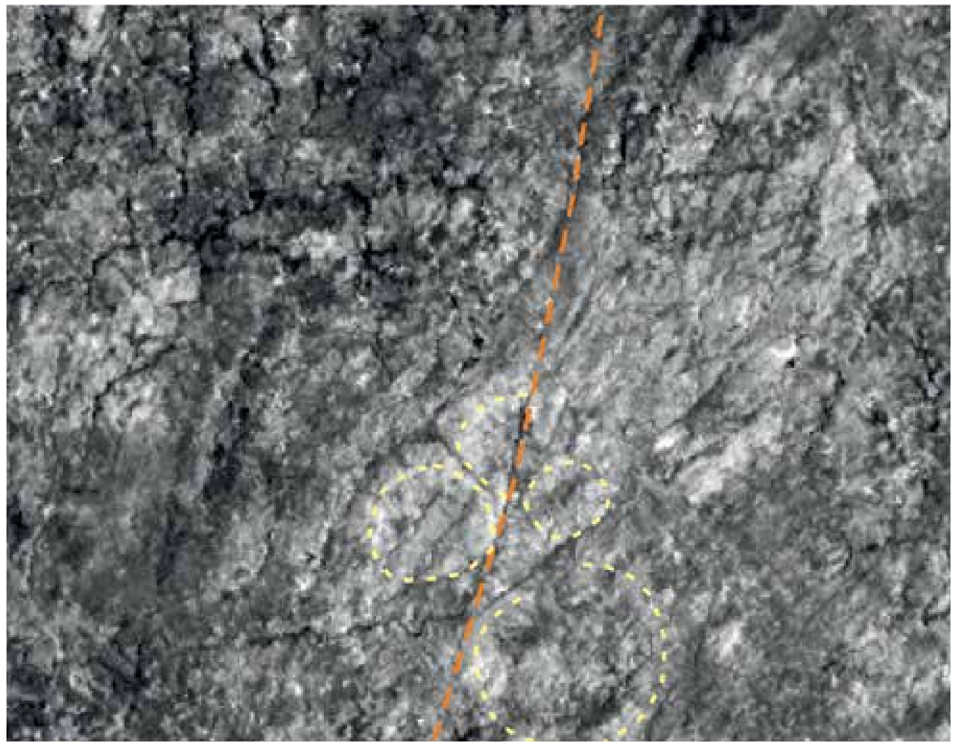


FIGURE III.9

Image corresponding to the band of satellite Landsat (area D)

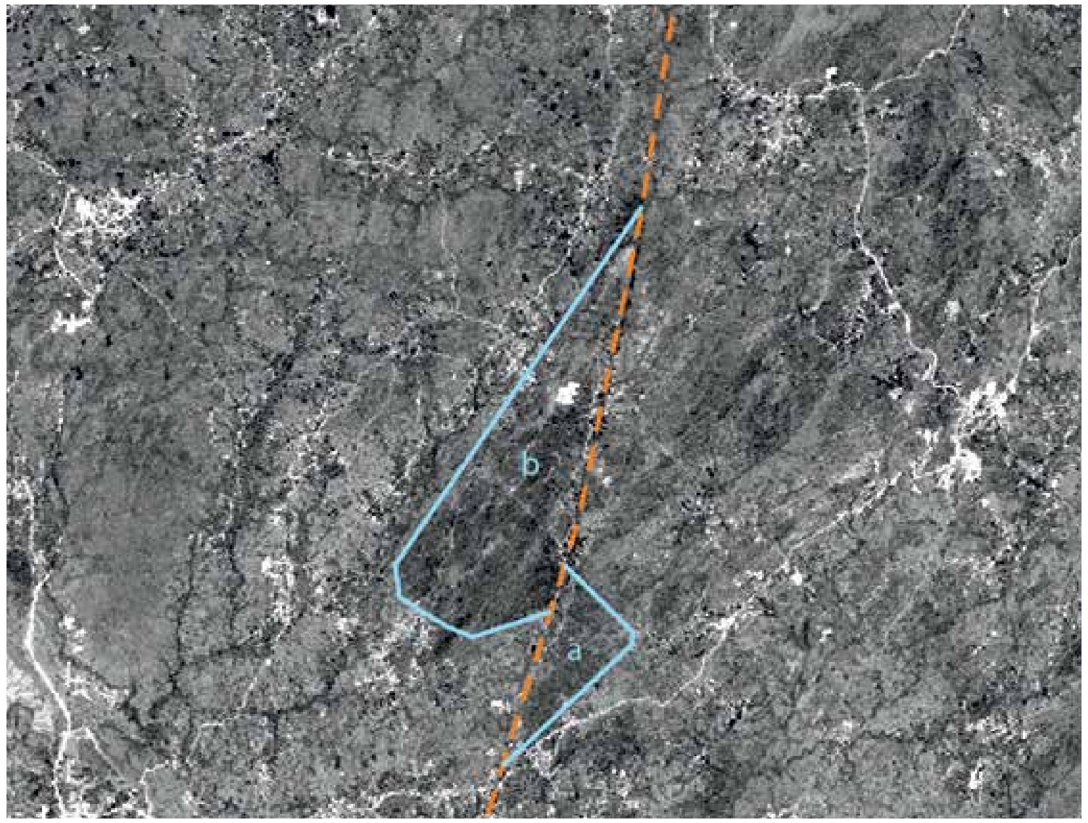


FIGURE III.10

3rd main component obtained through the bands of satellite Landsat (area D)

III.2.4 Area E – Guarda

From bibliographic research were established as potential targets in the Guarda sector beryliferous and lithiniferous 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 that 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

FIGURE III.11

Google Earth Pro's image relative to area E

FIGURE III.12

Color composition RGB751 of the sector E

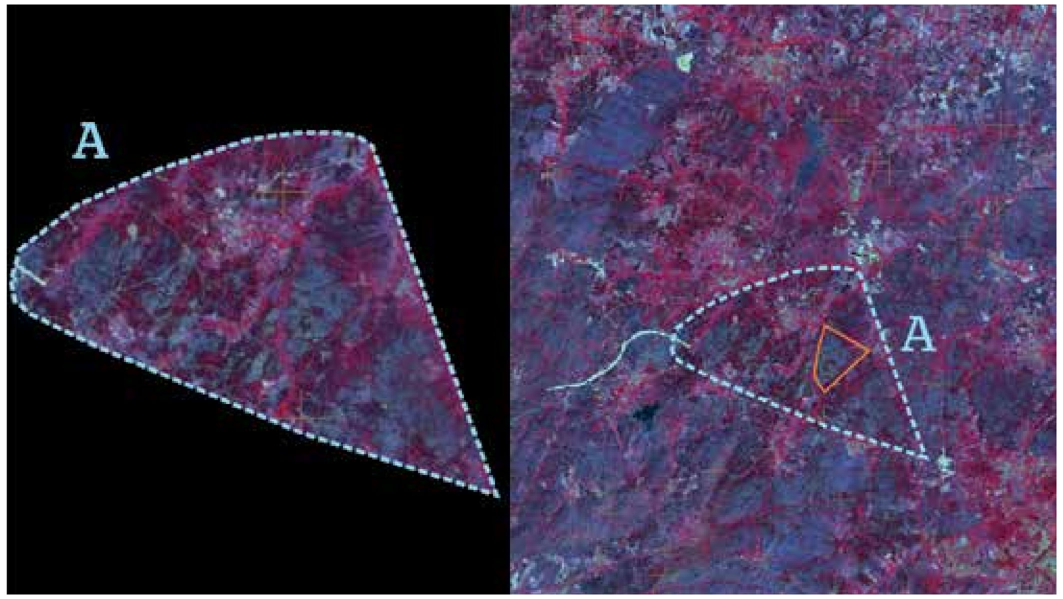


FIGURE III.13

RGB124 image obtained by the combination of satellite Spot bands

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.

According to this hypothesis, the observed alignments may correspond to images of convoluted fluids, expressing flow trajectories and, this way, representing differentiated phenocrysts clustering domains in the exhumed granitic facies.

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).

There are represented the 3 contrasting colors, patches that from a better spectral viewpoint correspond to porphyroid granites (1) and medium to fine grained granites (2) represented on geological map 5B and by inference to differentiated phenocrysts clustering domains (3).

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.

The reconstitution of scenario 1 to the Google Earth's morphology (Figure III.14, scenario 2) seems compatible with the proposed model, supporting the existence of concentric planar or plan-linear fluids, intersected by the topographic surface at high levels.

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 NE-SW ductile regime. This hypothesis suggested previously by Silva (2002) to explain the lateral extravasation to S of inverted droplet pegmatitic bodies in Mata da Galinheira 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 convulse, 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 .

This hypothesis is petrogenetically coherent as it presupposes a more effective fractionating possibility where, under tectonic conditioning, the dislocation of fluxes and their differentiates resulting by fractionating in the magmatic chambers is more intense.

The Galinheira (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.

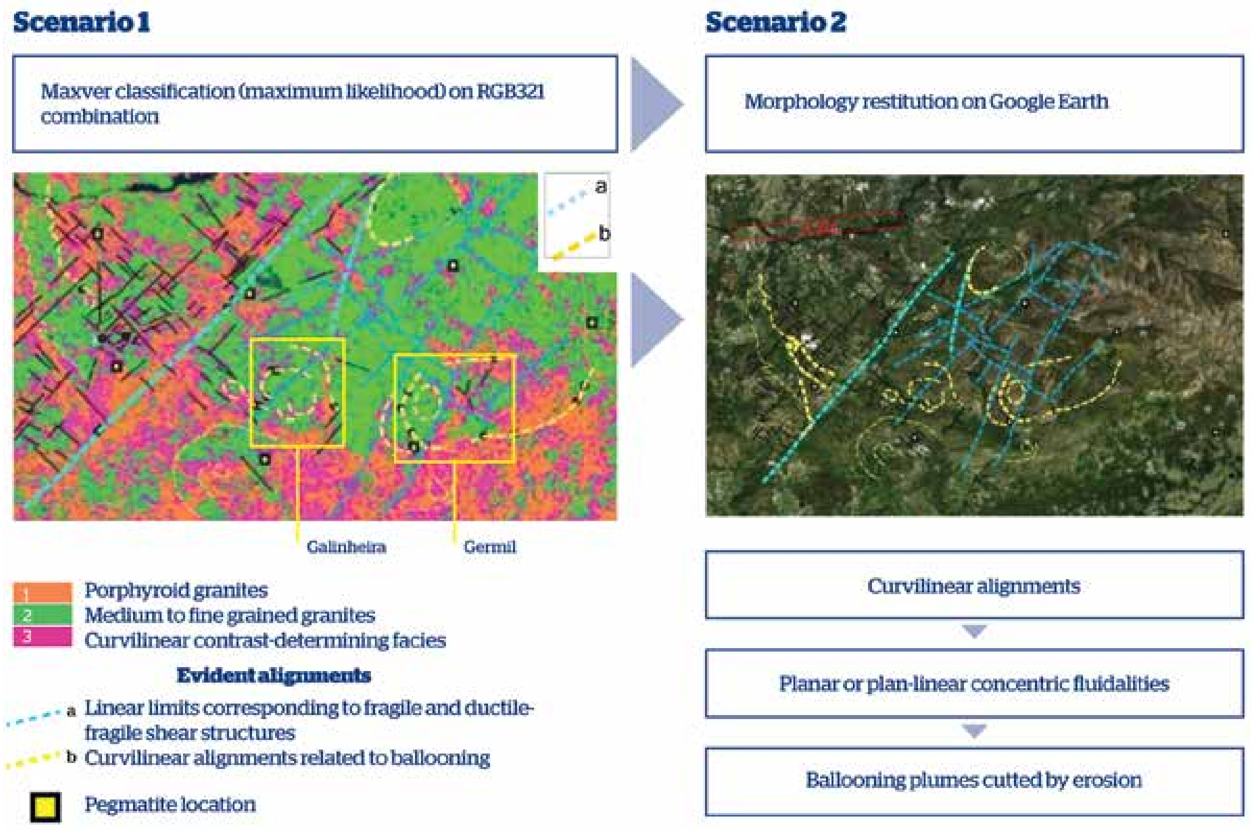


FIGURE III.14

Maxver classification of images and photointerpretation in productive interfaces - deducing of eventual productive ballooning plumes seem to control the emplacement and conformation of pegmatitic bodies in its periphery (scenario 2). Scenario 3 results from the restitution of scenario 2 to Google Earth's image- The classified area is delimited in figure III.3

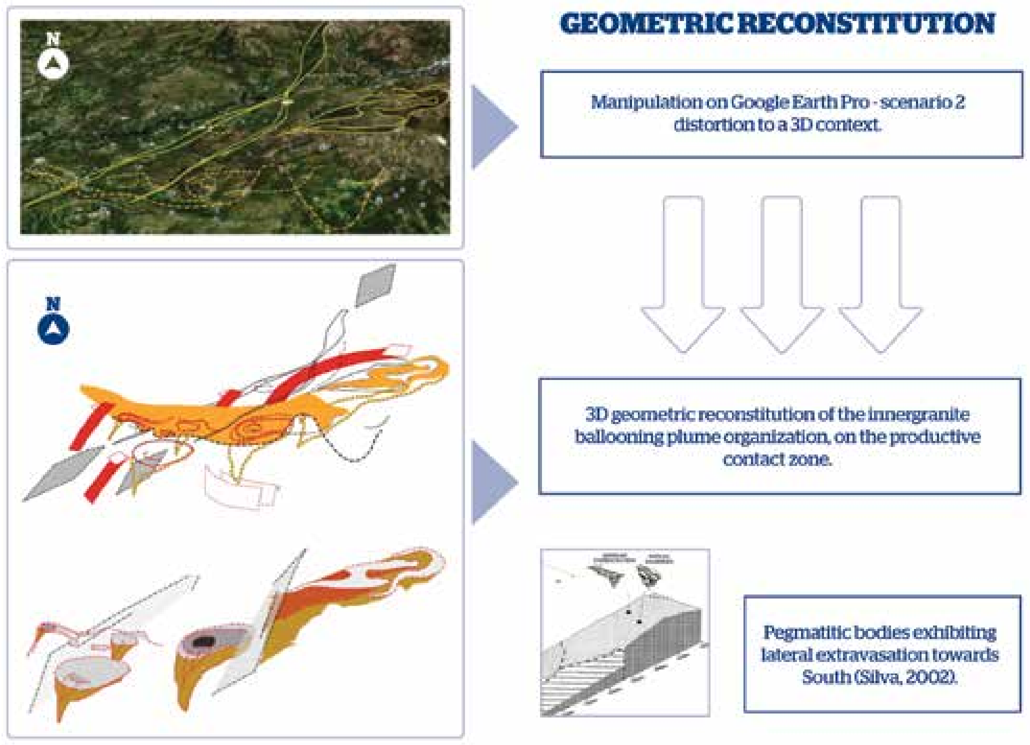


Figure III.15

Geometric 3D reconstruction of innergranitic ballooning plumes organization in the productive contact zone deduced from curvilinear alignments perceptible in distant analysis

FIGURE III.16

Mesoscale dispositive with evidence of differentiated phenocrysts clustering domains observed in Castelo de Aboim (Guimarães and Leal Gomes, 2010)

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 Poupos 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 Fráguas 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.

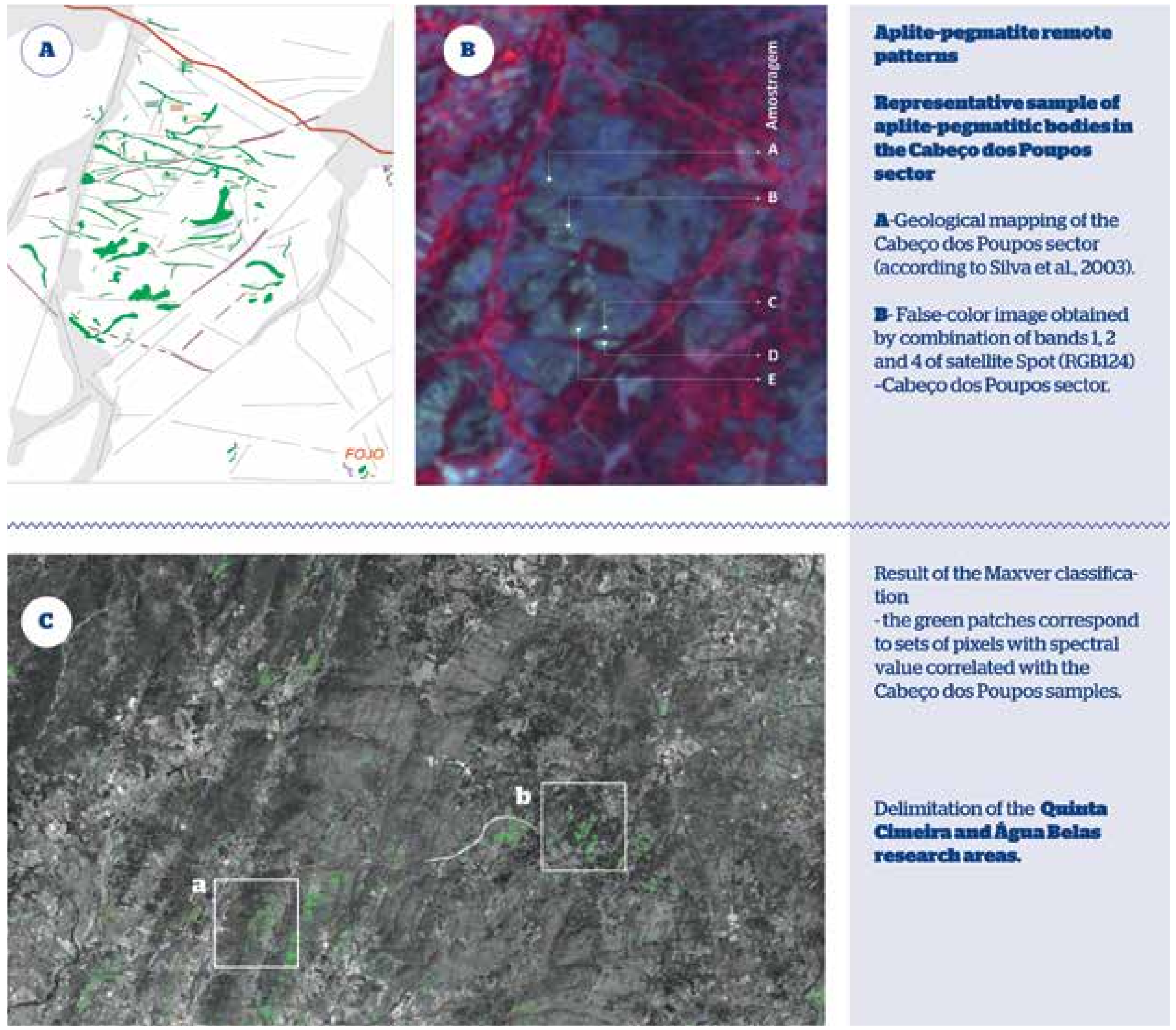


FIGURE III.17

Evidence of remote aplite-pegmatitic patterns in the Guarda area by Maxver classification

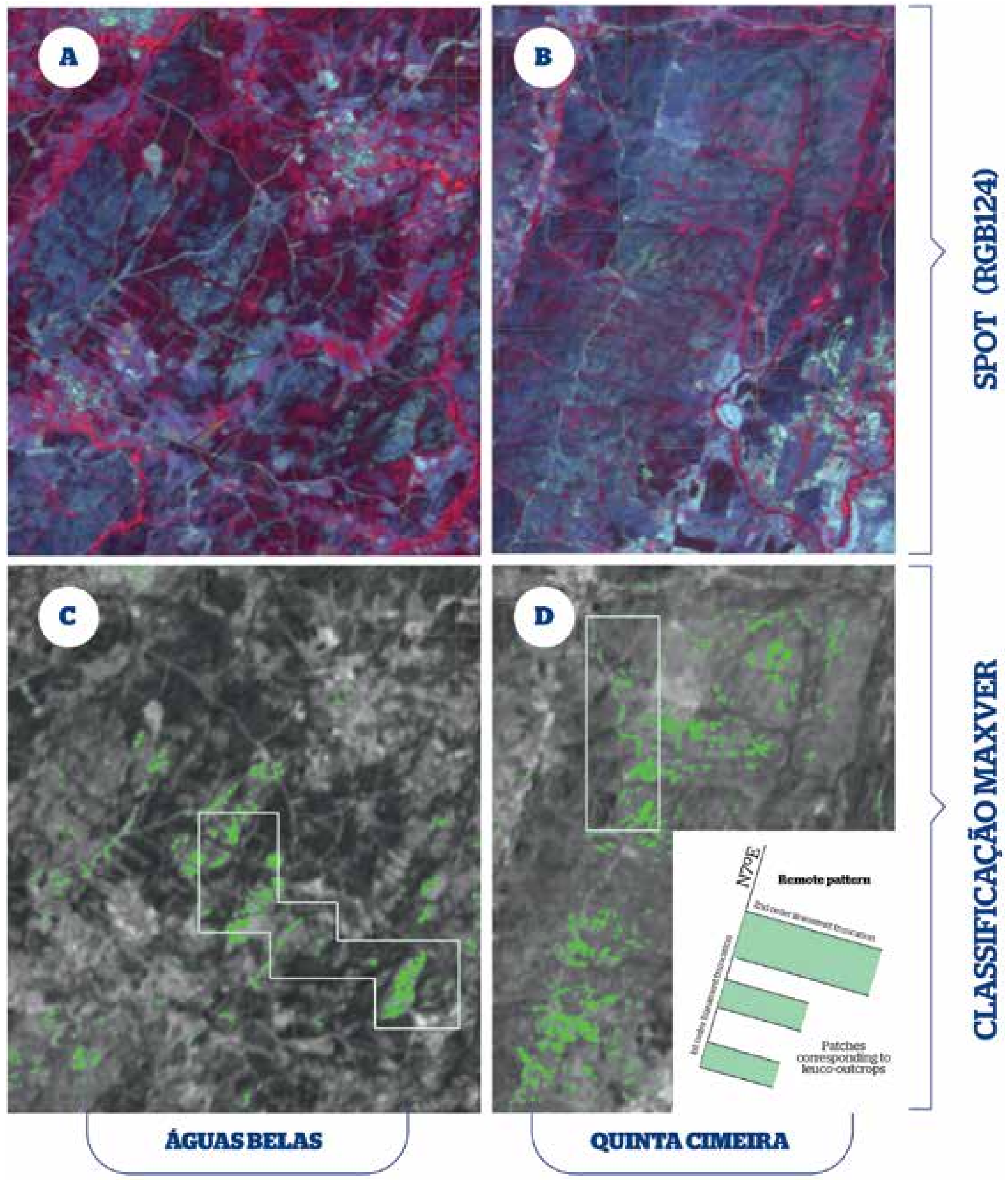


FIGURE III.18

Evidence of remote aplite-pegmatitic patterns and the distribution of patches resulting from Maxver classification (in green) in the Águas Belas and Quinta Cimeira sectors

RESEARCH AREA	TYPOLOGY OF THE SIGNAL OBTAINED THROUGH MAXVER CLASSIFICATION
QUINTA CIMEIRA	N7ºE linear pattern truncated by zones more or less heterogeneous elongated patches correspondent to leuco-outcrops, delimited by 2nd order truncations.
ÁGUAS BELAS	Diverse patterns: very dense, linear, elliptic heterogeneous and low density elliptic sigmoidal.

TABLE III.1

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

4 chapter

Geological investigation in research areas – substantiation of borehole location

Geological investigation in research areas – substantiation of borehole location

IV.1 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.13, 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.

Extensive areas of research		Criteria for the areas selection	Valency of the program
A	Azias	Shear corridors and their respective dilatational environments. Local in the intersection of NW-SE and NE-SW shear corridors with WNW-ESSE ruptures favorable to the occurrence of arachnid shaped bodies. Proximity to an explored pegmatitic body	Photointerpretation of Landsat images; Buffering GvSIG
	Germil	Productive contact between syntectonic two-mica granites and syn to late-tectonic porphyroid biotitic granites. Zone with curvilinear lineaments, concentric, correspondent to the outcrop of ascending magmatic plumes differentiated by ballooning.	Photointerpretation and Maxver classification
	Mata da Galinheira /Castelo da Pena	Productive contact between granites. Zone with curvilinear lineaments, concentric. Explored pegmatitic bodies from Mata da Galinheira and Monte do Castelo de Pena.	Photointerpretation MAXVER classification
B1	Pereira de Selão	Local in the interior of a Late Variscan NE-SW shear corridor with associated dilatational environments able to convey post-tectonic magmas. Proximity to Seixigal pegmatite (stocksheider type large bodie) Spot located in N30ºE/N-S structure intersection.	Tectonic conditioning of the Seixigal pegmatite emplacement and photointerpretation
D	Salgueiro	Geological/Geomorphological/structural criteria. Proximity to the Salgueiro pegmatitic index, included in the Ferreira de Aves productive massif, basic rock dykes delimitation, and proximity to elongated ridge adjoins to continuous lineament, interrupted by oblique lineament. Chromatic/textural contrast within the granite mass with general circular guidance, revealed by band 6 and main component 3 of Landsat image.	Buffering GvSIG Photointerpretation of Landsat images
	Assunção south	Chromatic/textural 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 Assunção pegmatite. Proximity to other minor pegmatitic indexes.	Photointerpretation of Landsat images
E	Quinta Cimeira	Spectral continuity. Area with high dispersion of aplite-pegmatitic patterns in MAXVER classification (90%) of sets of pixels corresponding to outcrops of aplite-pegmatites from the sector of Cabeço dos Poupos.	MAXVER classification of Spot images
	Águas Belas	Spectral continuity. Area with high dispersion of aplite-pegmatitic patterns in MAXVER classification (90%) of sets of pixels corresponding to outcrops of aplite-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 delimitation by basic rock dykes.	MAXVER classification of Spot images Buffering GvSIG

TABLE IV.1

Summary of the criteria used in the selection of extensive areas of research for the development of 1:5000 scale geological mapping

The planning and geological substantiation of the drilling program (for sub-outcropping pegmatitic 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: Azias, Germil and Mata da Galinheira/Castelo 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.

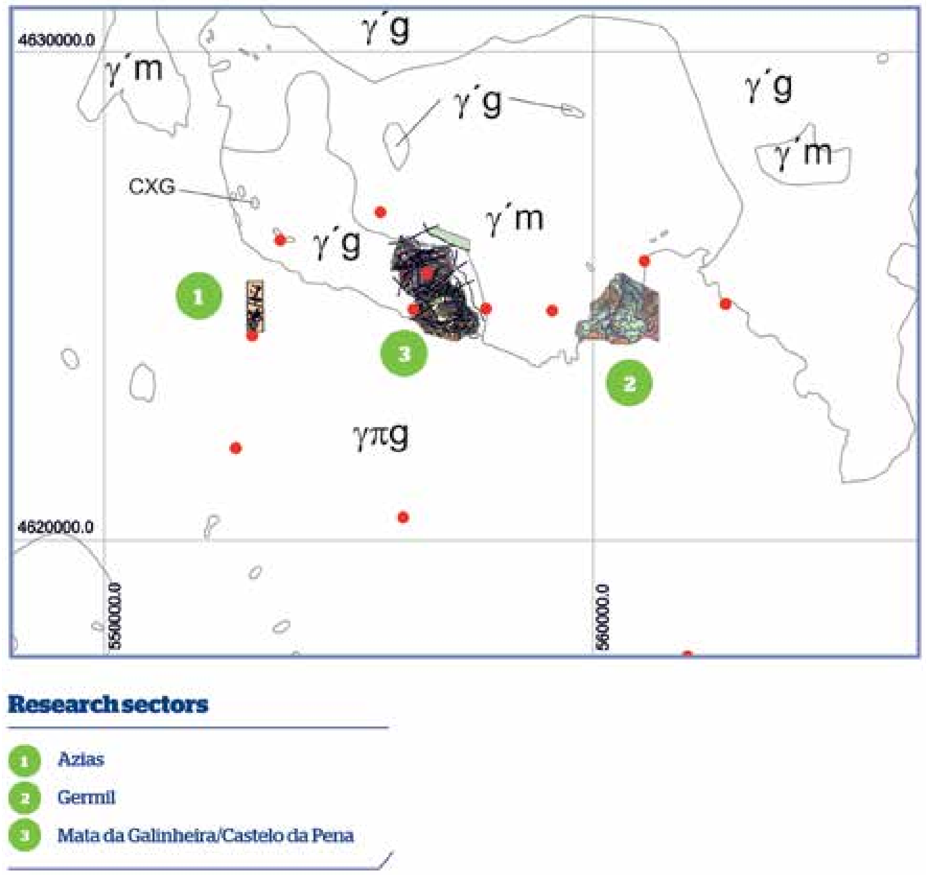


FIGURE IV.1

Research sectors location in the Ponte da Barca area – Azias, Galinheira/Monte do Castelo da Pena and Germil

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 N30°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 ultramicaceous 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 N22°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 N30°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.

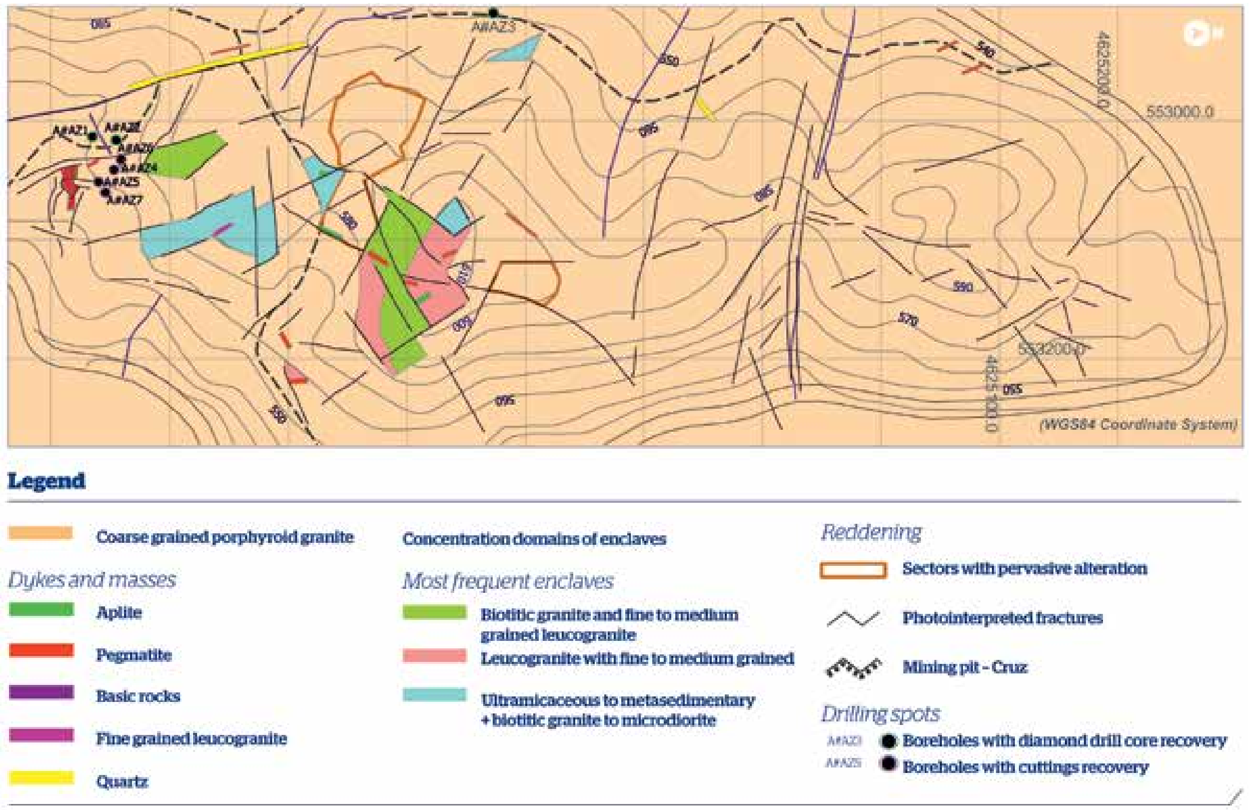


FIGURA IV.2

Geological map of the Azias sector obtained on 1:5000 scale. Observations arising from the geological survey on 1:1000 scale were incorporated into the design of the strips with the highest enclaves concentration

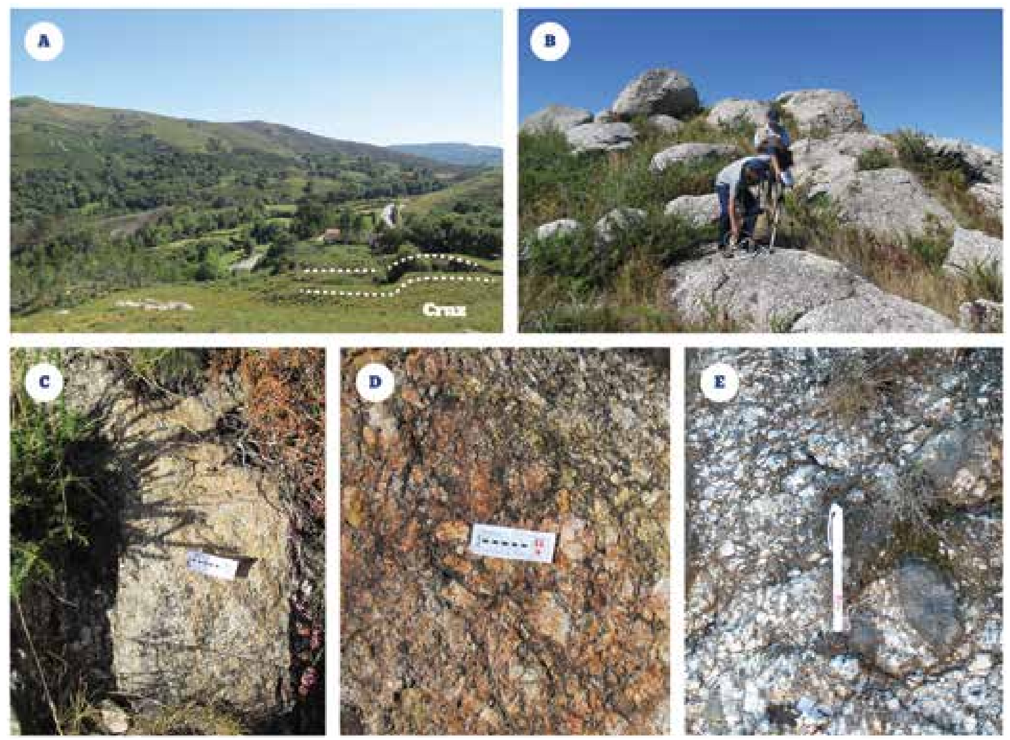


FIGURE IV.3

Partial views and relevant textural aspects observed in the Azias research area (view comments in the text).

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.

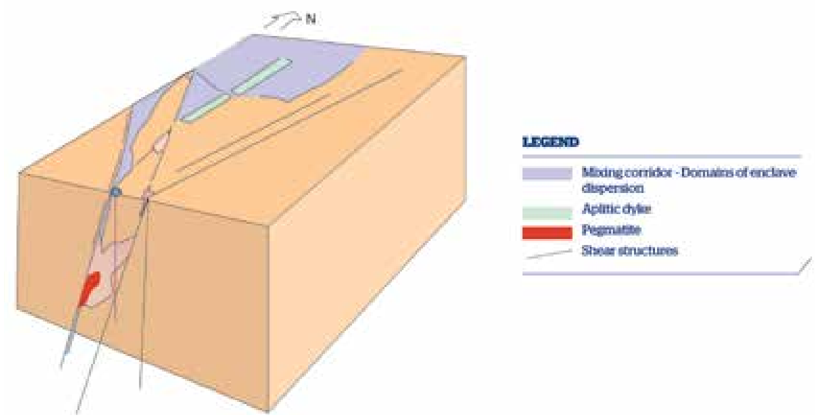


FIGURE IV.4

Pegmatitic bodies organization prediction in the Azias sector – three-dimensional simulation

Study area	Research sectors	Assignment	M	P	Depth (m)	Drilling type
A	Azias	A#AZ1	-19044.68	233321.52	30	R
		A#AZ2	-19041.48	233341.49	30	R
		A#AZ3	-19145.30	233660.68	36	R
		A#AZ4	-19016.49	233339.24	31	D
		A#AZ5	-19006.62	233326.13	31	D
		A#AZ6	-19025.43	233345.33	37	D
		A#AZ7	-18997.56	233332.05	21	D
	Germil	A#G1	-11261.04	233157.92	30	R
	Galinheira/ Castelo da Pena	A#CP1	-15480.89	233546.66	50	R

TABLE IV.2

Identification of the projected drillholes in area A, with location indication (coordinates in datum WGS84); R – drilling with drill core recovery; D – destructive drilling with cutting recovery.

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

A#AZ1, A#AZ2, A#AZ4, A#AZ5, A#AZ6, A#AZ7 - sector in the periphery of the Cruz pegmatite, in the following of an elongated strip of enclave proliferation with intermediate mafic composition parallel to N22°W alignments to where N30°E structures converge, with accommodation of aplitic dykes and structures N70°E filled by dykes of basic rocks.
A#AZ3 - Placed on the development of a N22°°W oriented megascale structure with quartzose fill; the alignment with the Cruz pegmatite, at south, predicts some continuity between pegmatitic 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.

TABLE IV.3

Major influences of the research program that led to the selection of drilling spots, in the Azias sector

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), charachterized by the contact of porphyroid 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 hyperaluminous 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).

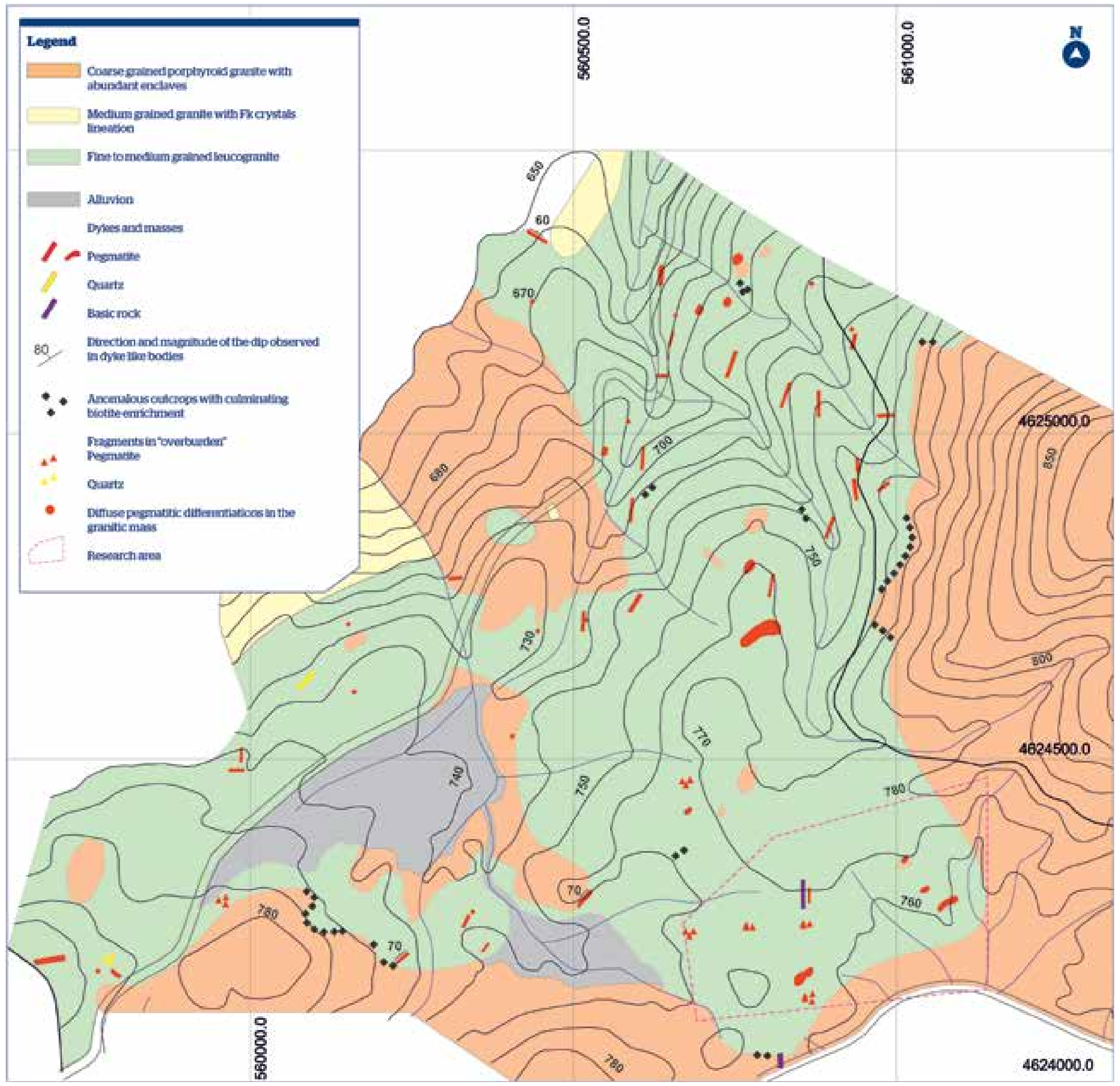


FIGURE IV.5

Geological map of the Germil area on 1:5000 scale, with the location of the key sector submitted to research

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%.

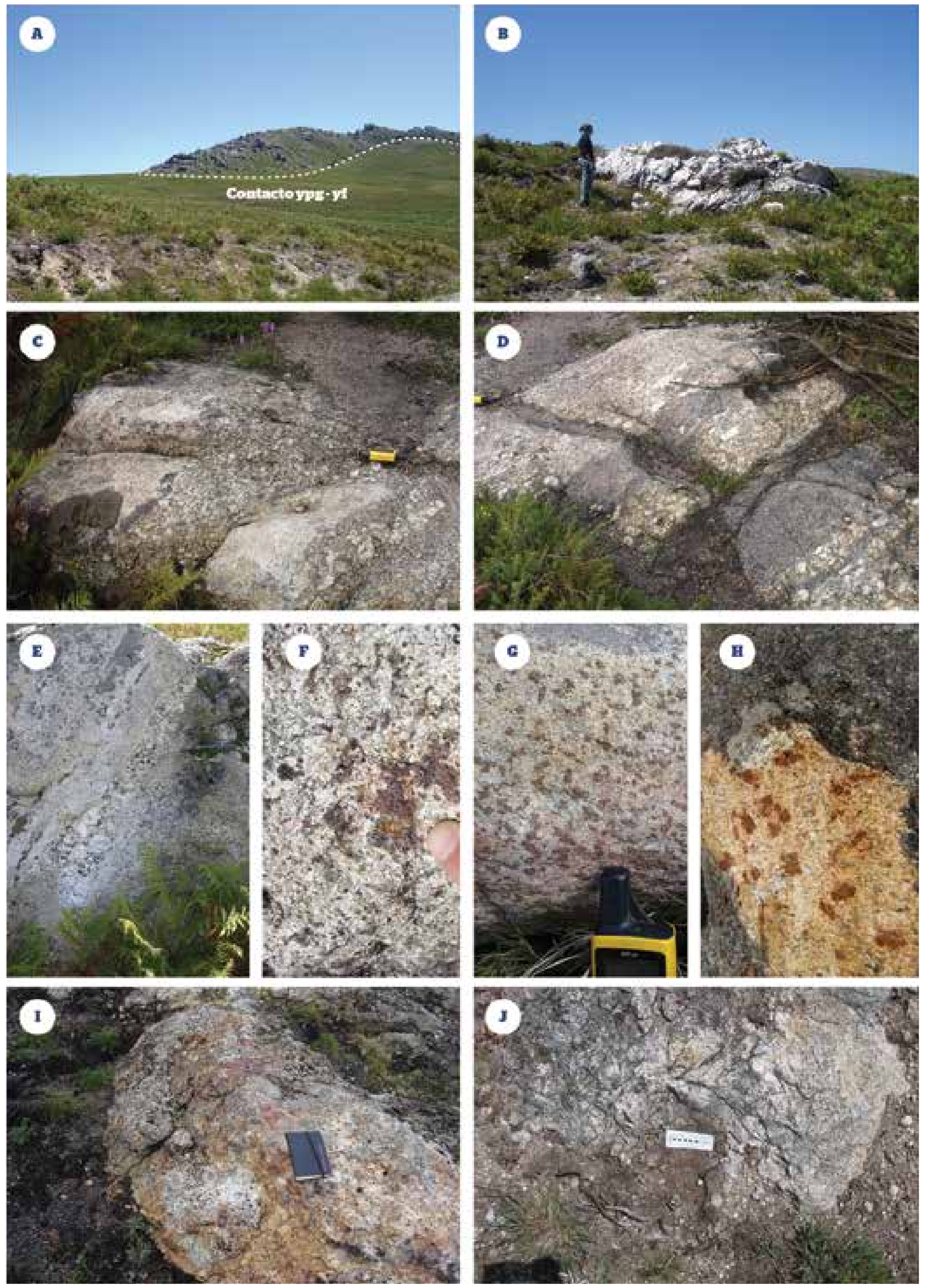


FIGURE IV.6

Documentation of individual outcrops, pegmatites and textures representing granitic facies neighboring pegmatites, detected in the Germil research area

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

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 innergranite belt established in the contact with the porphyroid granite, circumscribing those earthworks. This 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).

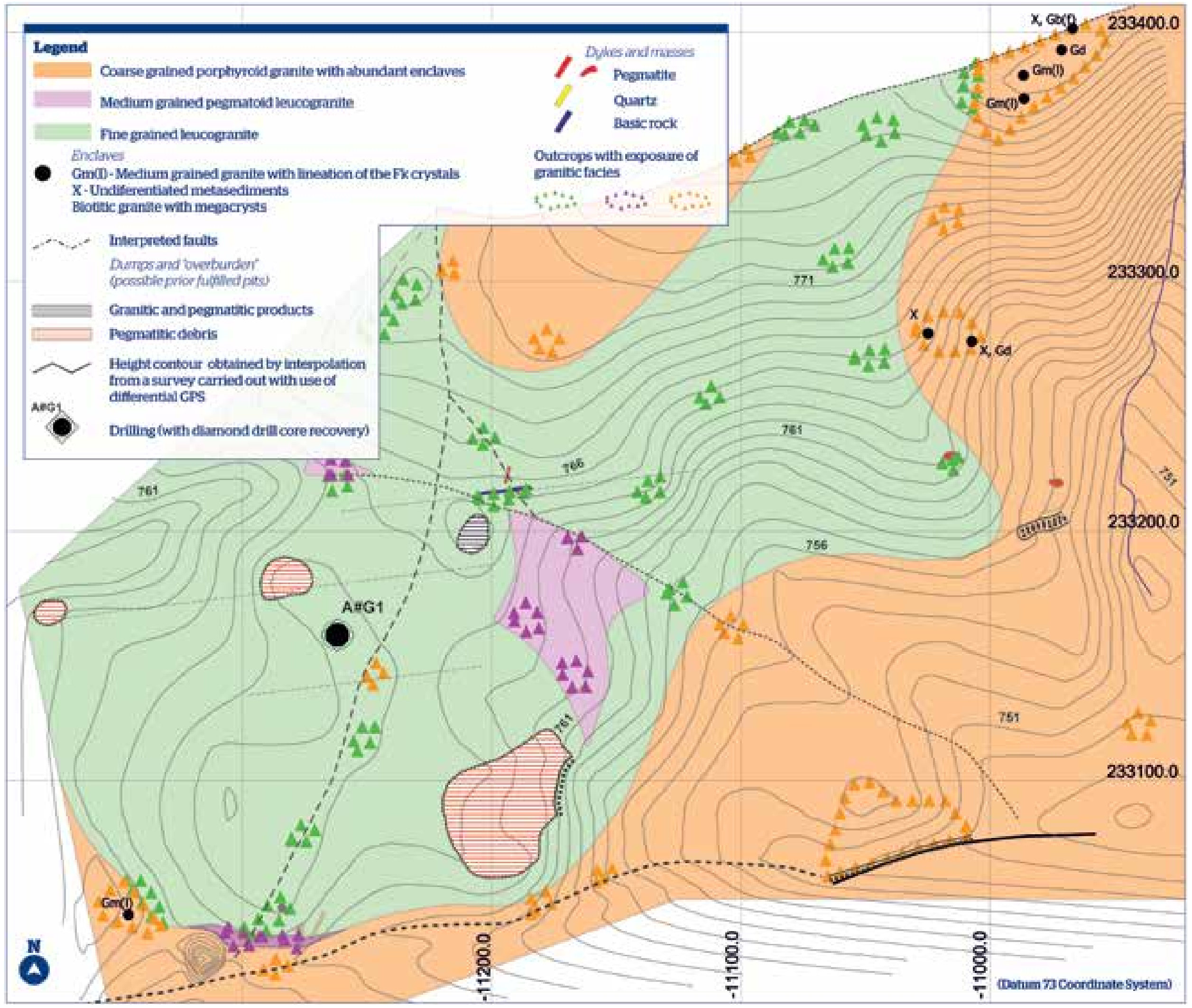


FIGURE IV.7

Map obtained by geological and topographic survey on 1:1000 scale in the key sector of Germil with marking of the drilling site

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

A#G1
- Space with possible previous quarries in pegmatite and strong evidence of granitoid differentiation. - Tectonic conditioning responsible for brittle faults with general ENE-WSW guidance marked by the strike of dykes of basic bodies and quartz, able to accommodate the distribution of pegmatitic bodies (including the pegmatite of Vergaço exploited at W); this direction may correspond to a flow orientation, hydraulic injection and deformation, conveyor of erosion.

TABLE IV.4

Main factors of the research program that led to the selection of drillhole sites in the Germil sector

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.

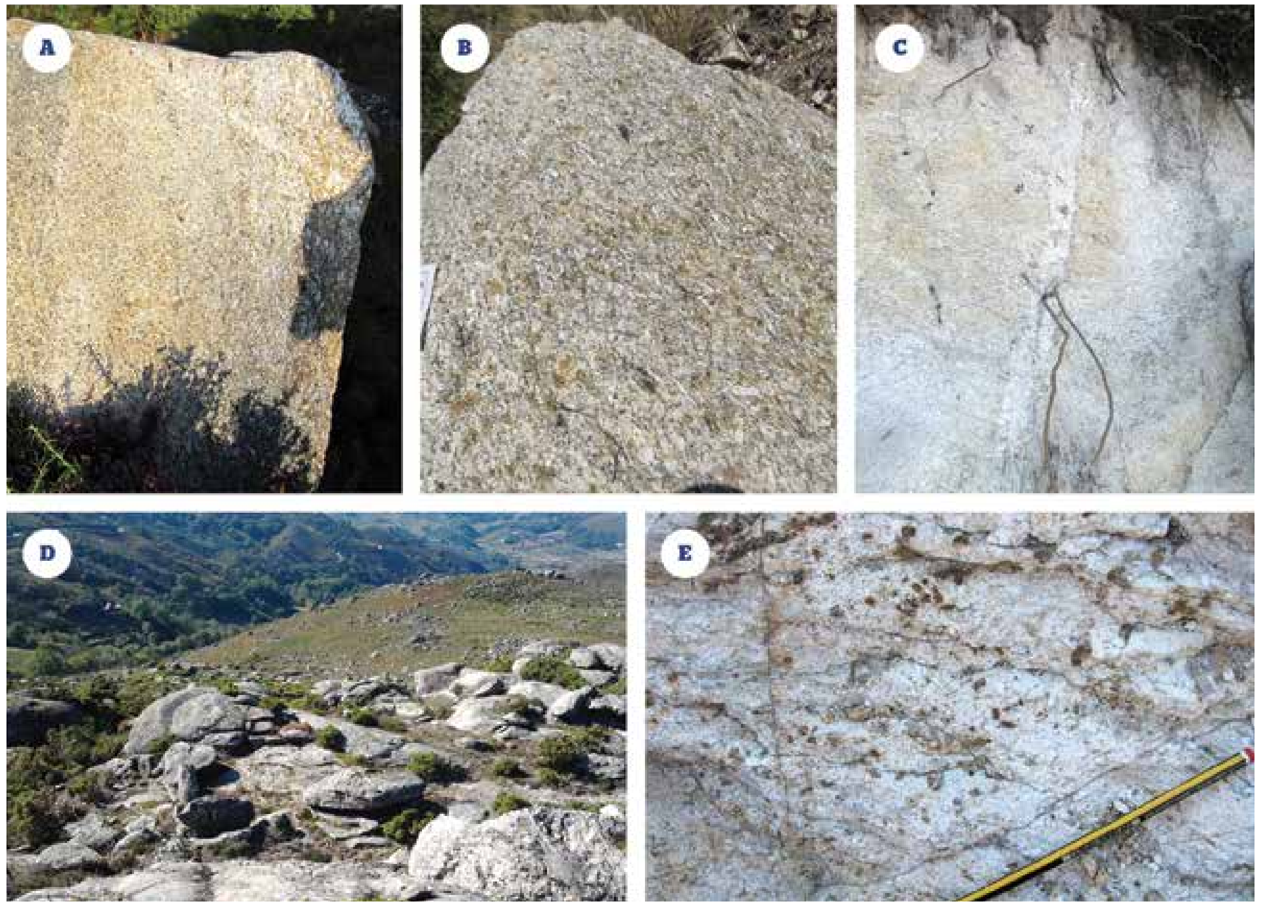


FIGURE IV.8

Petrographic aspects and relevant outcrops observed in the Mata da Galinheira / Monte do Castelo da Pena sector (view comments in the text)

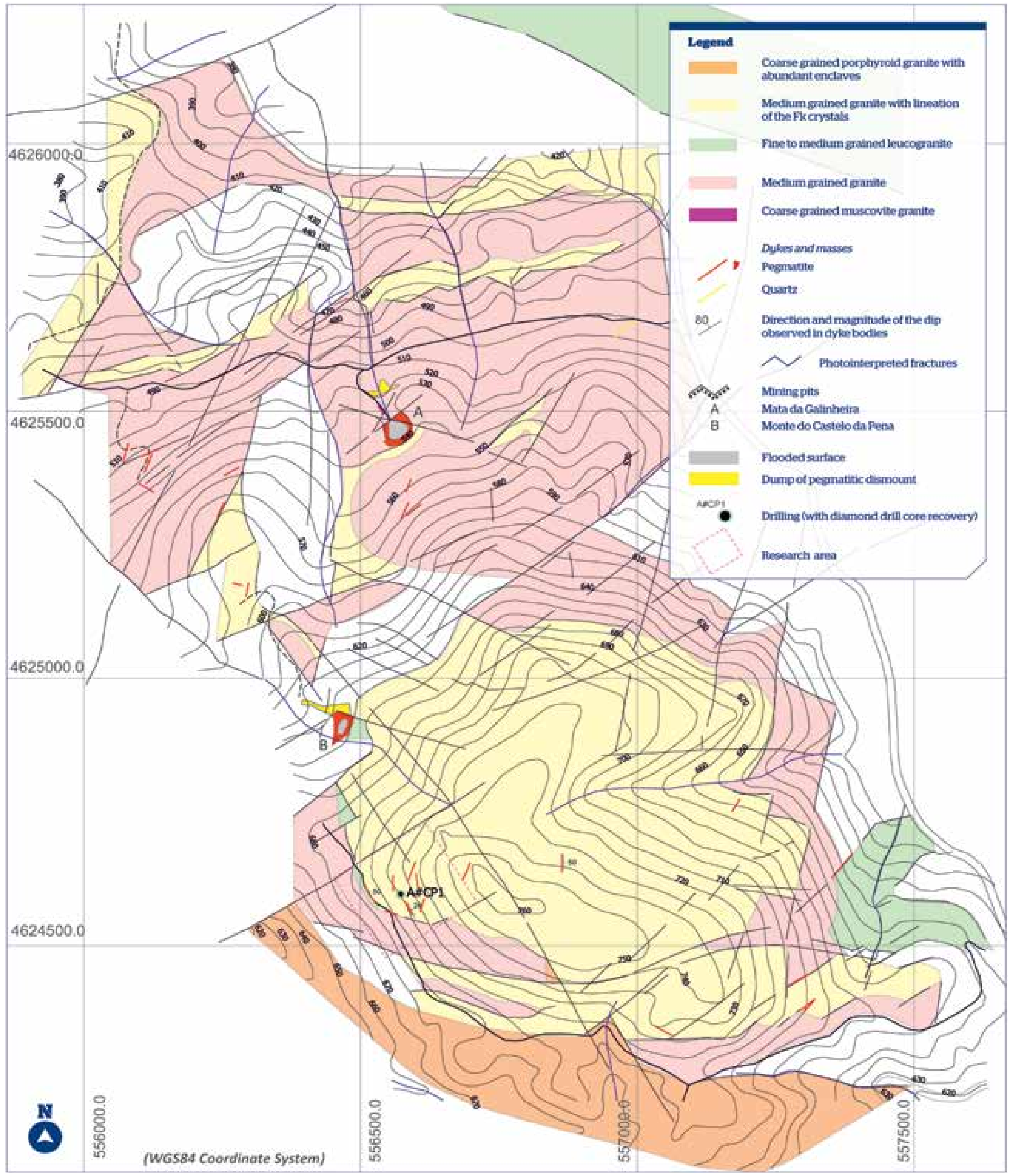


FIGURE IV.9

Geological map of Mata da Galinheira/Monte do Castelo da Pena area – survey on 1:5000 scale

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, manifests eminently pegmatite facies typical of an outer unit, with nodular biotite (Figure IV.7-E). The research drilling located here, designated A # CP1, is marked in Figure IV.8 and the coordinates are given in Table IV.2. It is estimated that it reaches a minimum depth of 50m so as to cross over the more fertile granitic contact.

A#CP1
- outcrop sector of pegmatitic dyke swarms, slightly inclined near a fluidal corridor, in an environment of granite contact, which strike and dip follows the topography.

TABLE IV.5

Major influences of the research program that led to the selection of drillhole locations in Mata da Galinheira / Castelo da Pena sector

IV.3 Geological investigation in the Area B1 – Chaves

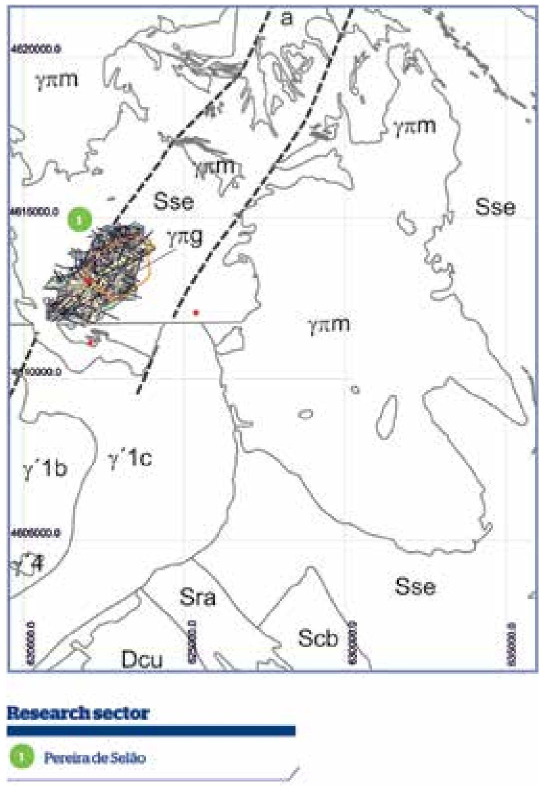


FIGURE IV.10

Location of Pereira de Selão research sector in the area of Chaves. Legend according to Figure II.8.

The possibility of detecting pegmatites with analogous setting to the Seixigal body appears as the main objective of the prospecting program.

The prospection 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 unities filled by the resurgent biotite granite. The possibility of being a stocksheider type pegmatite with post-tectonic innergranite/outergranite 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 innergranite (Figure IV.13-D);
- venular tourmalinization in the granite contact.

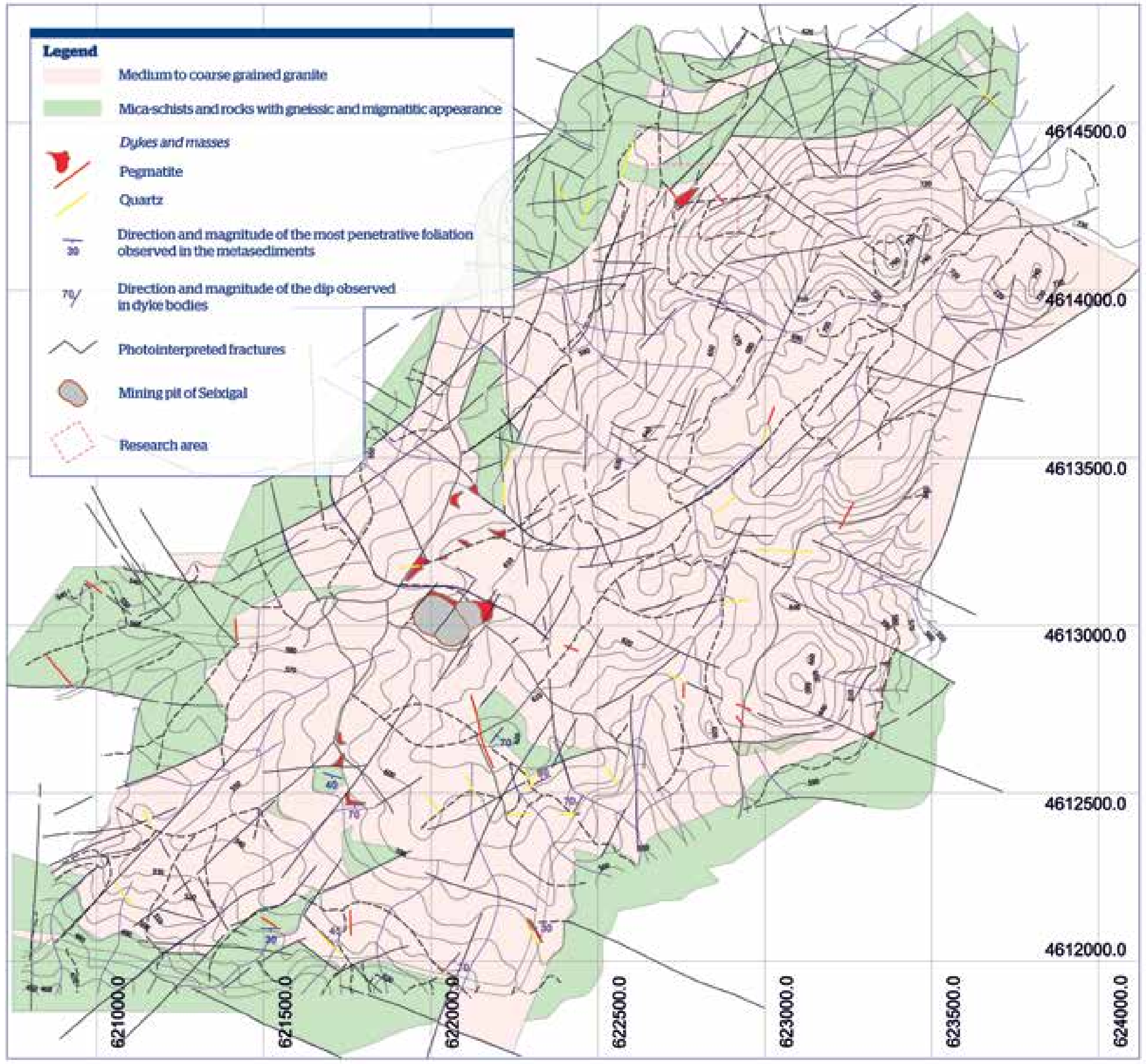


FIGURE IV.11

Geological map corresponding to Pereira de Selão area - survey on 1:5000 scale

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 outcropps 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.

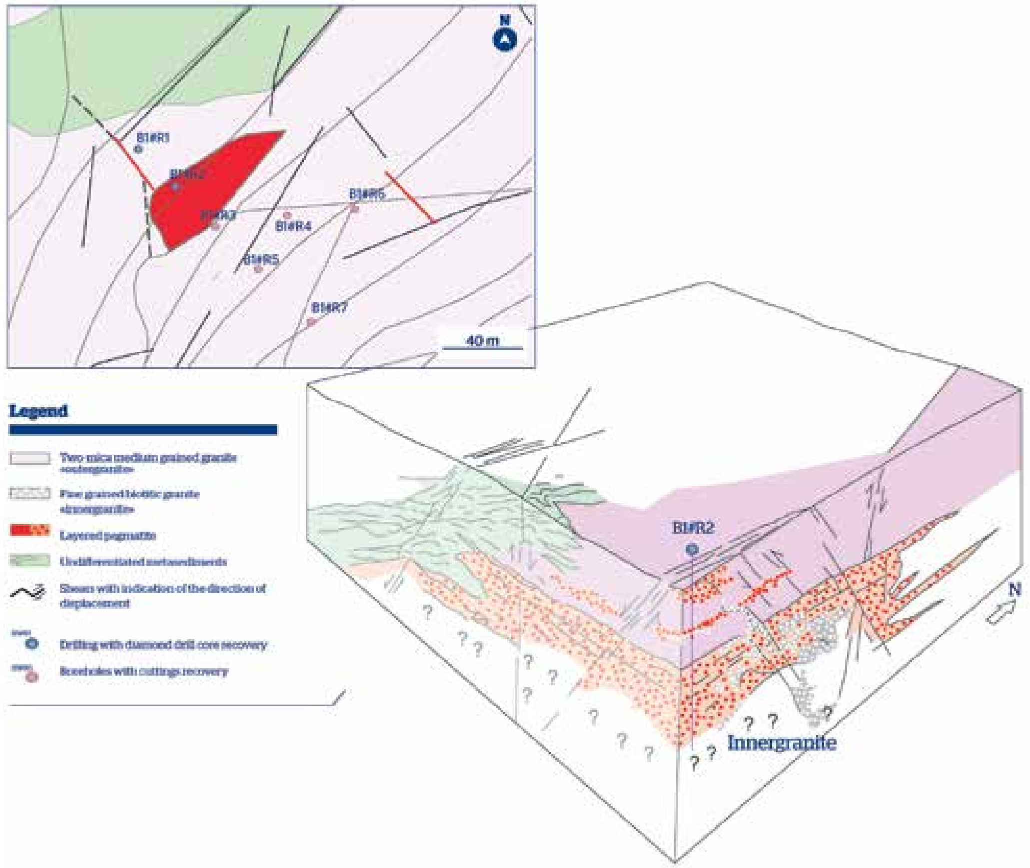


FIGURE IV.12

Drilling location and assessment on the three-dimensional arrangement of the Redial pegmatite

Study area	Research sector	Assignment	M	P	Depth (m)	Drilling type
B1	Redial	B1#R1	50586.61	222575.64	30	R
		B1#R2	50605.43	222556.44	37.5	R
		B1#R3	50626.22	222535.23	34	D
		B1#R4	50663.29	222540.86	37	D
		B1#R5	50648.00	222513.00	31	D
		B1#R6	50698.33	222543.50	31	D
		B1#R7	50674.73	222484.72	33	D

TABLE IV.6

Identification of projected drillholes in area B1, indicating the location (coordinates in datum 73) and depths reached in drilling;
R - drilling with drill core recovery; D - destructive drilling with cutting recovery

B1#R1 e B1#R2 Subhorizontal pegmatite outcrop with banded internal structure and interstitial innergranite.
B1#R3, B1#R4, B1#R5, B1#R6 e B1#R7 Locations in outcrop granite at higher elevations for investigation of lateral spread and depth of the previous tabular mass.

TABLE IV.7

Major influences of the research program that led to the selection of the drilling locations in the Redial sector

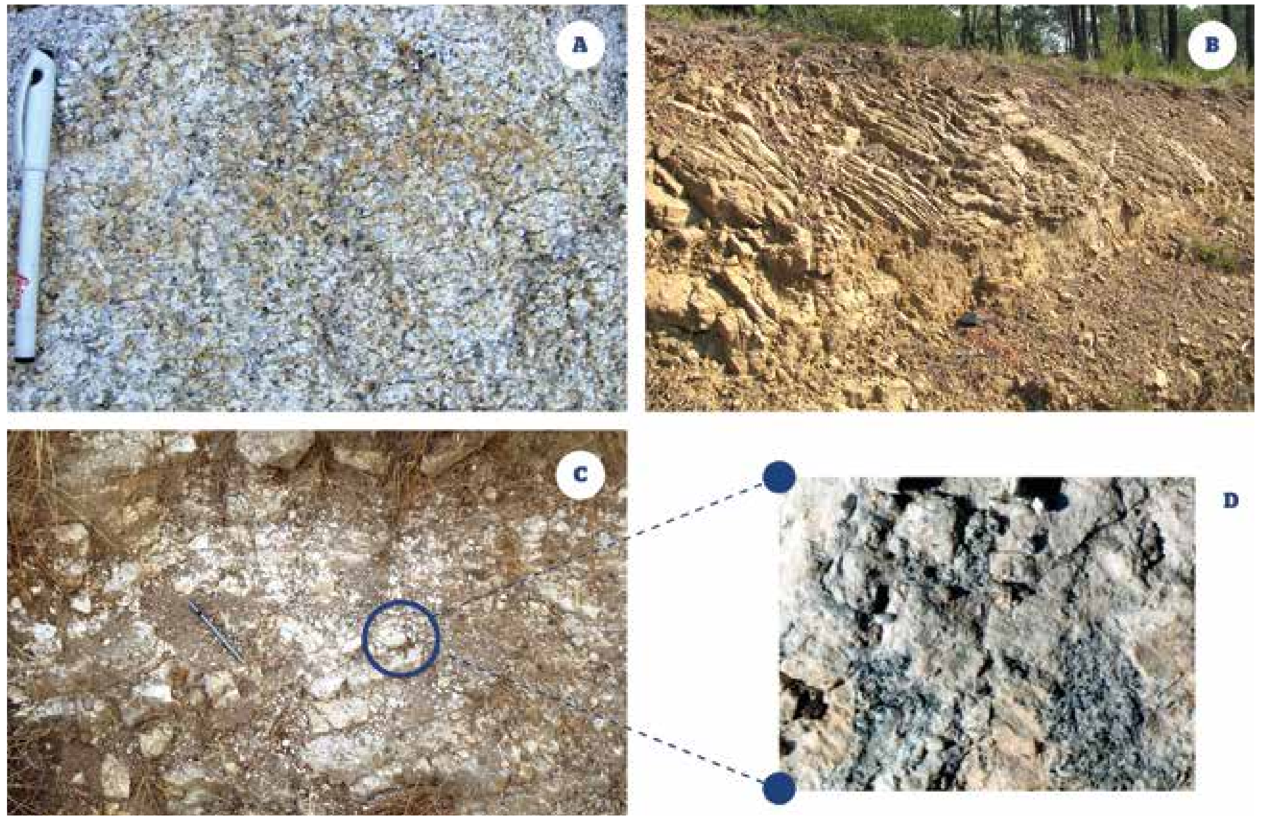


FIGURE IV.13

Illustration of representative outcrops of Santa Bárbara granite (A), surrounding metasediments (B) and pegmatite from Redial (C)

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.

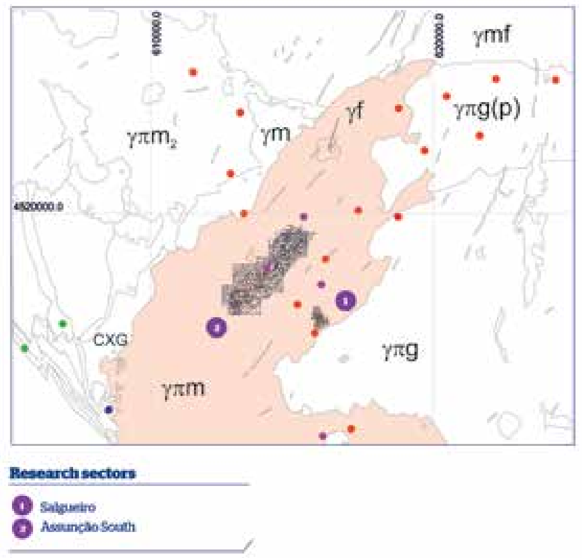


FIGURE IV.14

Location of the research sectors of south Assunção and Salgueiro in the area D. Legend according to Figure II.10

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

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 breccioid 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 20° 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 quartzose, that crystalize 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 coalesce, 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).

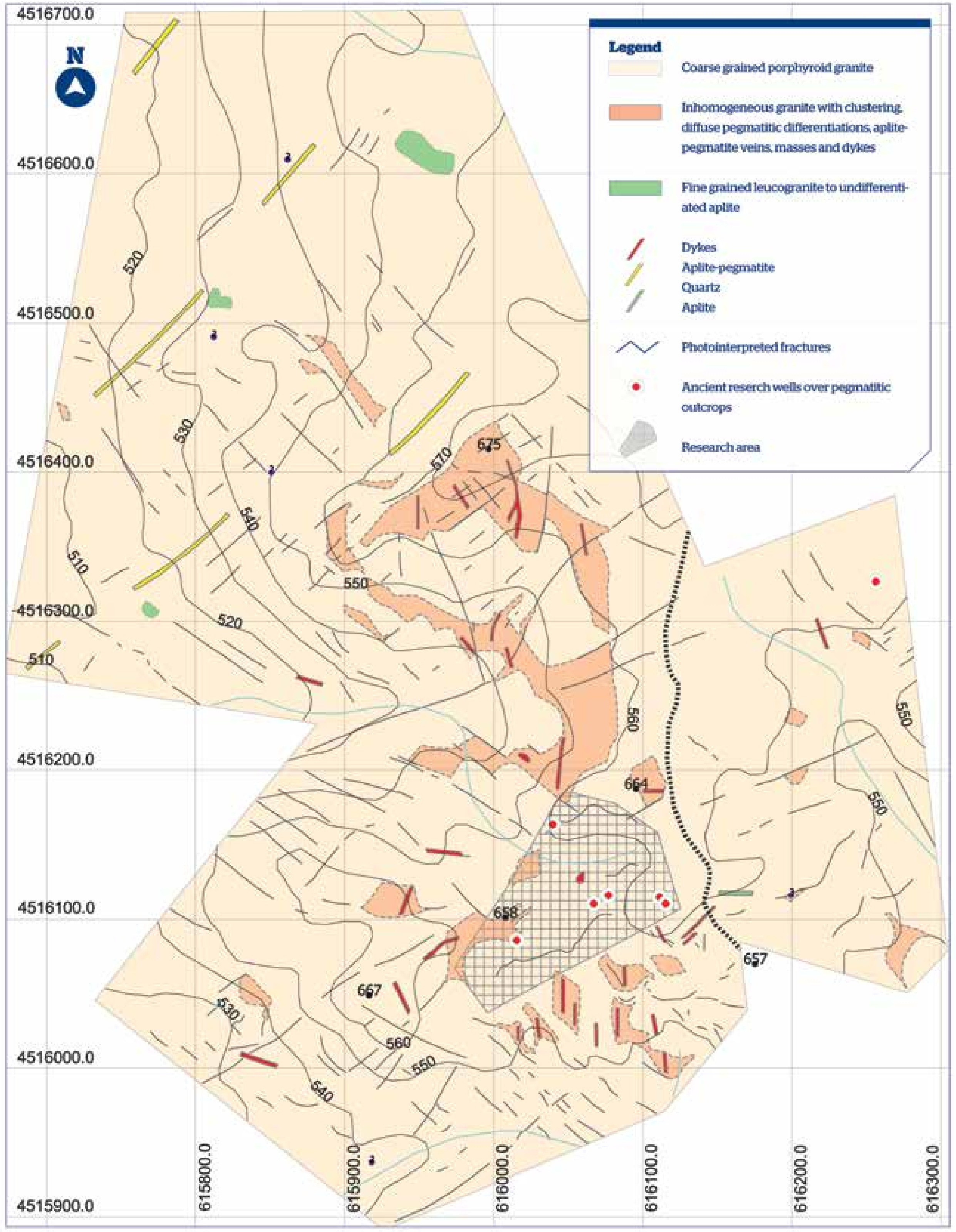


FIGURE IV.15

Geological map corresponding to the Salgueiro sector – survey on 1:5000 scale

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

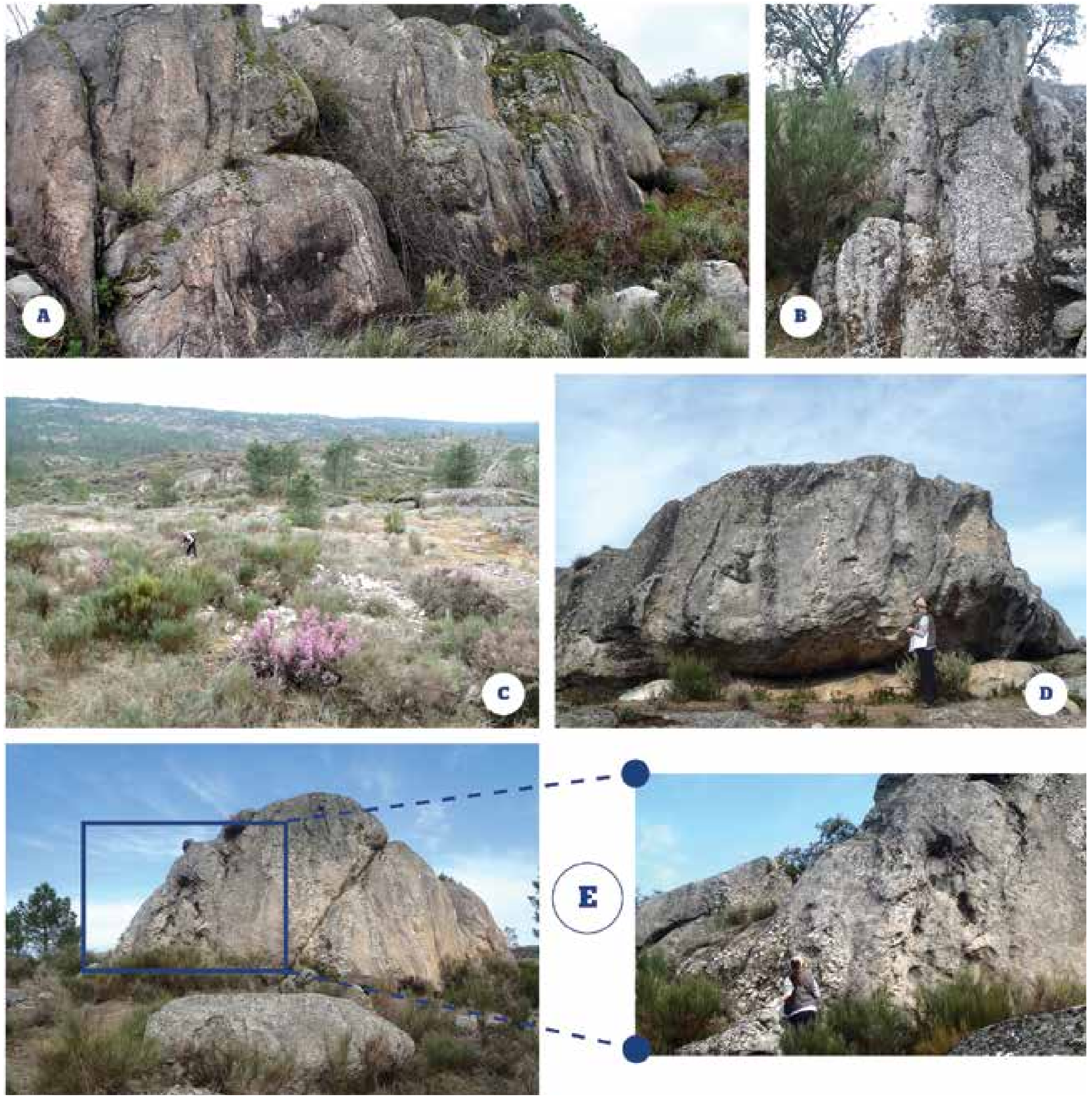


FIGURE IV.16

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

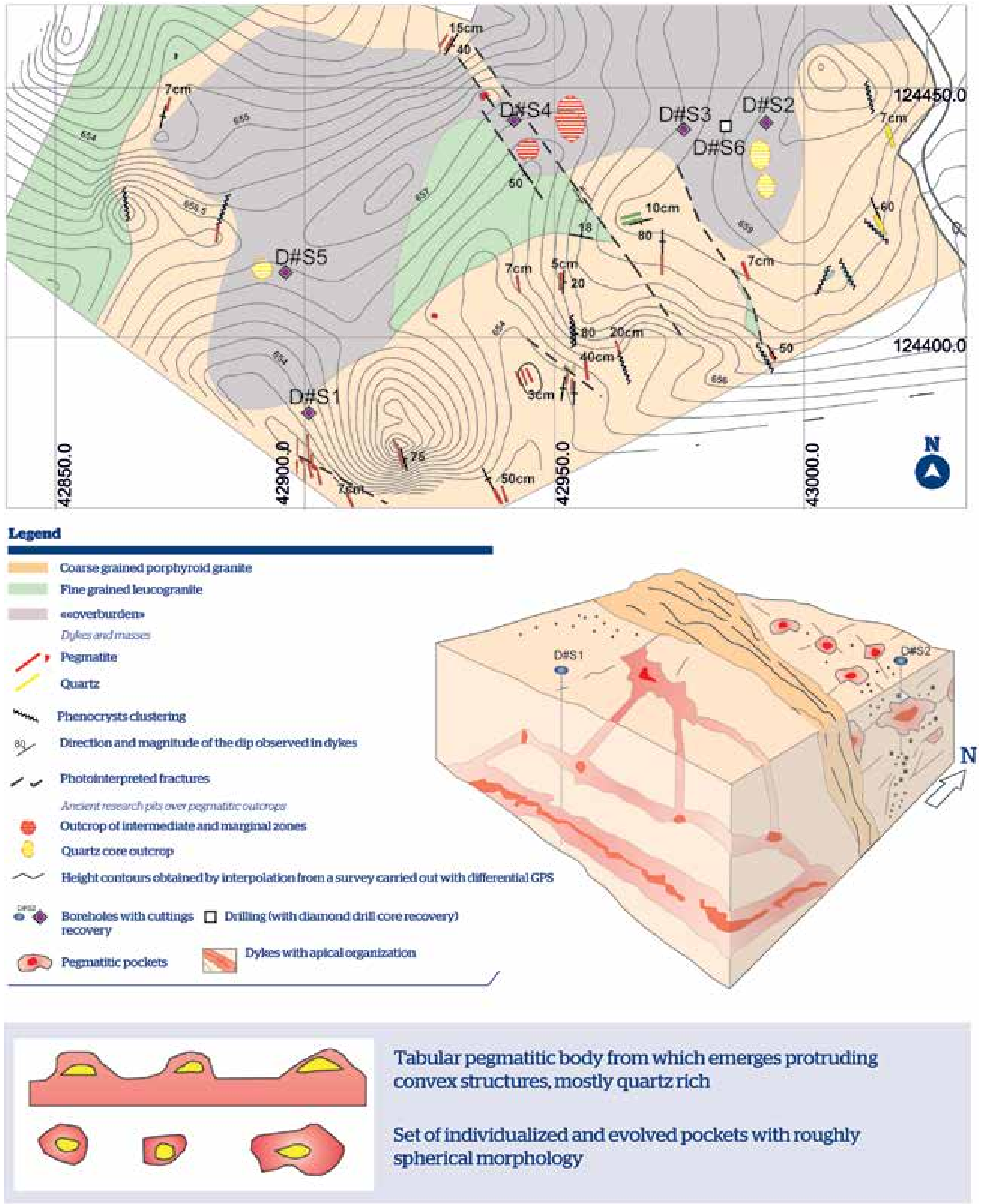


FIGURE IV.17

Geological map corresponding to the Salgueiro sector – survey on scale 1:1000

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 (NNE-SSW) 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 N30°E, E-W 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 II.1-E; 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.

Study area	Research sector	Assignment	M	P	Depth (m)	Drilling type
D	Salgueiro	D#S1	42900,82	124384,91	36	D
		D#S2	42992,43	124443,02	30	D
		D#S3	42975,40	124441,19	48	D
		D#S4	42941,41	124442,53	33	D
		D#S5	42896,10	124412,97	33	D
		D#S6	43003,00	124456,00	39	R
	Carrasqueira	D#C1	40952,86	126269,79	28.5	R
		D#C2	41003,50	126332,31	15	R
		D#C3	40996,84	126266,35	10.5	R
		D#C4	41379,40	126007,48	33	D
	Fraga	D#F1	41687,80	126845,70	30	R
	S. Matias	D#SM1	39808,23	125232,79	60	R

TABLE IV.8

Identification of the projected drilling campaign in area D indicating the location (coordinates in datum 73) and drilling depths reached; R – drilling with drill core recovery; D - Drilling on percussion (destructive)

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 plutonite 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 5cm^3 and 1dm^3. They are most often lenticular or elliptical (trimetric, prolates and oblates) assigning to the direction of greatest elongation the value of a lineation flow or magmatic stretching; the most common direction is N45°E.

Given the amount of different paragenesis of independent bubbles it was possible to form the subdivisions framework presented in Dias et al. (2013): 1- quartz intergrowths + chlorite +/- muscovite +/- alkali feldspar; 2 – bubbles with open cavities and centripetal growth of quartz + muscovite +/- microcline; 3- quartz + muscovite +/- potassic feldspar +/- F-apatite; quartz + schorl or chlorite + quartz as late-stage phases ; 4 – occluded phenocrystal of potassic feldspar; 5 – schorl + quartz on graphic intergrowth; 6 – cavity lining by quartz +/- muscovite lining the cavities and late chlorite +/- pyrrhotite.

As a consequence of the extraordinary boron enrichment, the tourmaline can be relatively abundant and it is possible to observe unusual associations in which the tourmaline and the quartz with graphic intergrowth are the only stages of miarolitic fill. In structural terms, the particularity of some bubbles presenting surfaces marked by crystals with centripetal growth from a gravity base and migration of open cavities to the periphery of the bubbles, suggest that the crystallization occurs under conditions of upcast mobility. Distensible radial fractures of hydraulic stress release, perpendicularly to the displacement, are also an evidence of that condition. (Figure IV.20-A).

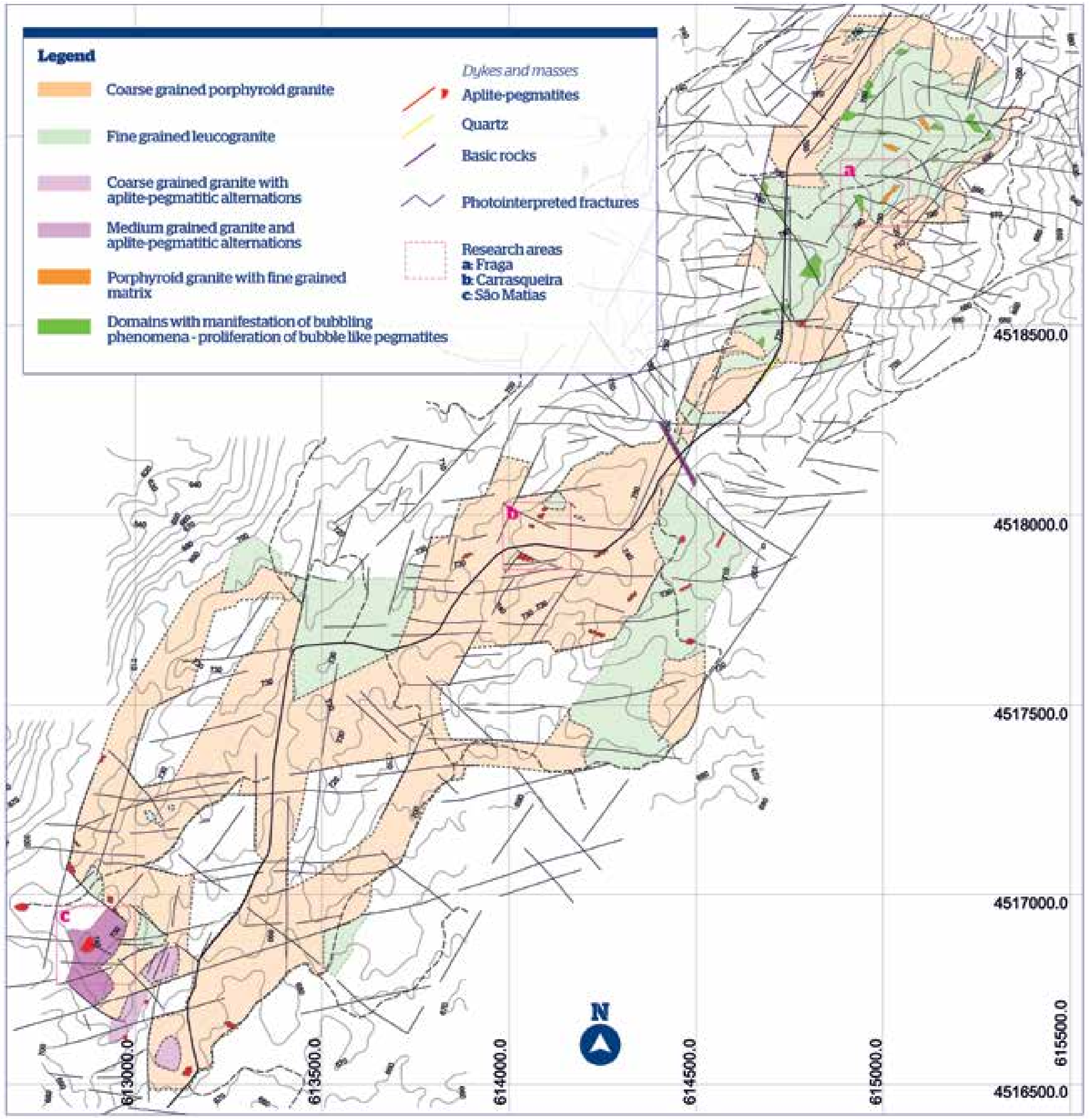


FIGURE IV.19

Geological map of the south Assunção sector obtained by field survey on 1:5000 scale

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 primarily 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.

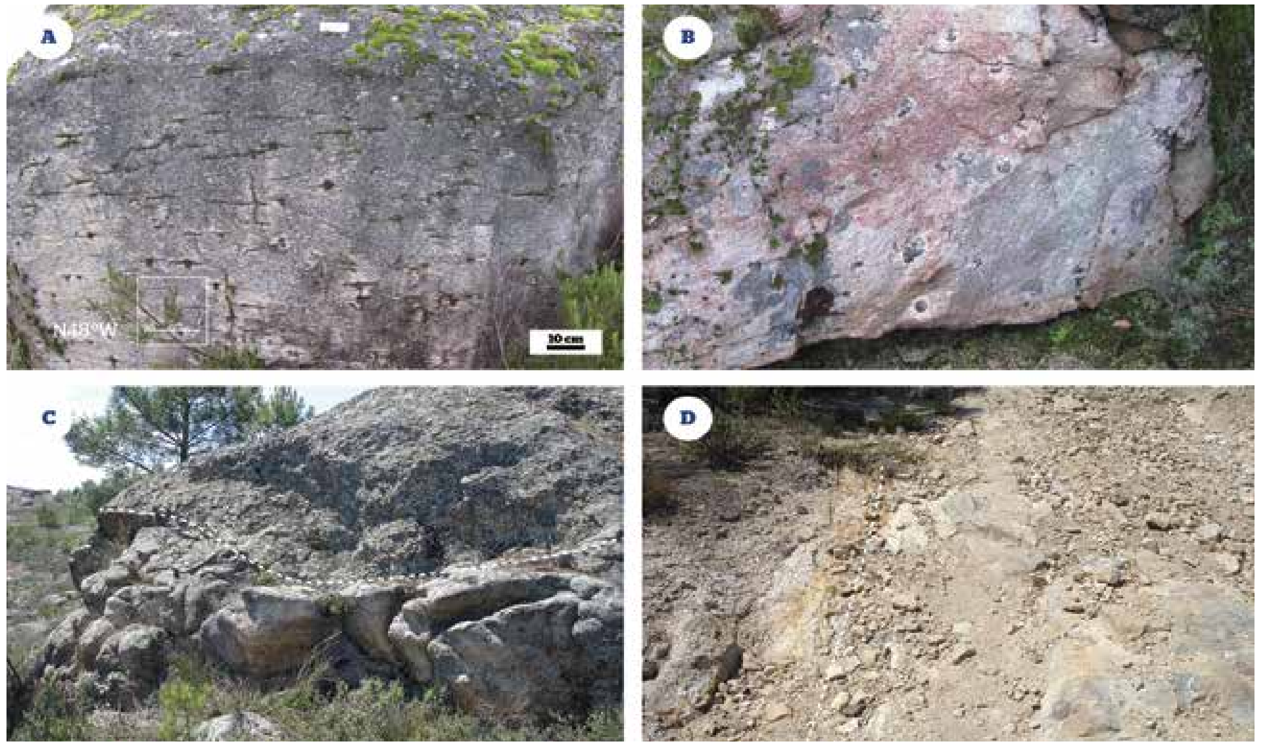


FIGURE IV.20

Outcrops of miarolitic granite with illustration of structural and textural aspects relevant to the interpretation of bubbling phenomena in the south Assunção sector (A and B). Examples of limits between fine grained granites and porphyroids (C and D).

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

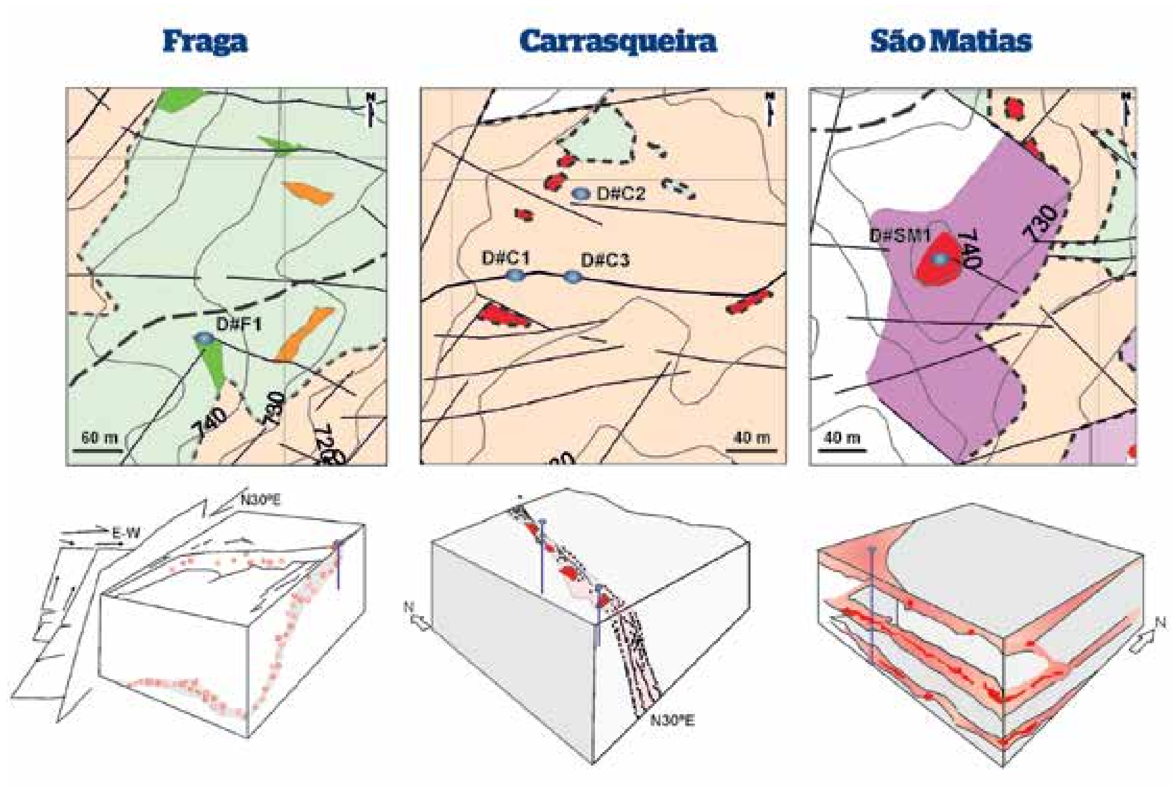


FIGURE IV.21

Drilling locations on the maps and 3D blocks interpretive of the distribution and progress of the pegmatitic masses in Fraga (A), Carrasqueira (B) and São Matias (C) sectors

In São Matias (Figure IV. 19) the outcropping pegmatites are subhorizontal dykes (sill bodies) with internal banded organizations and strips of aplitic "line-rock" coexisting with pegmatitic structures resulting from in situ crystallization. The most pronounced bodies were detected near São Matias Chapel and along the geodesic vertex of São Matias (Figures IV.22-C and D).

Next to these groups of dykes the enclosing granites exhibits graphic structures with radial plumose mica and diffuse pegmatitic differentiations (Figure IV.22-G). The transition to the pegmatites is gradual.

The pegmatitic settings observed suggest installation in higher structural levels near the uppermost section of the plutonite dome.

The observation of subhorizontal sills at altitudes of 740m (geodetic vertex of São Matias), 710m and 690m motivated the search to a depth of 60m, by drilling D#SM1 located near the geodesic vertex (Tab. IV.8 and Fig. 21-C).

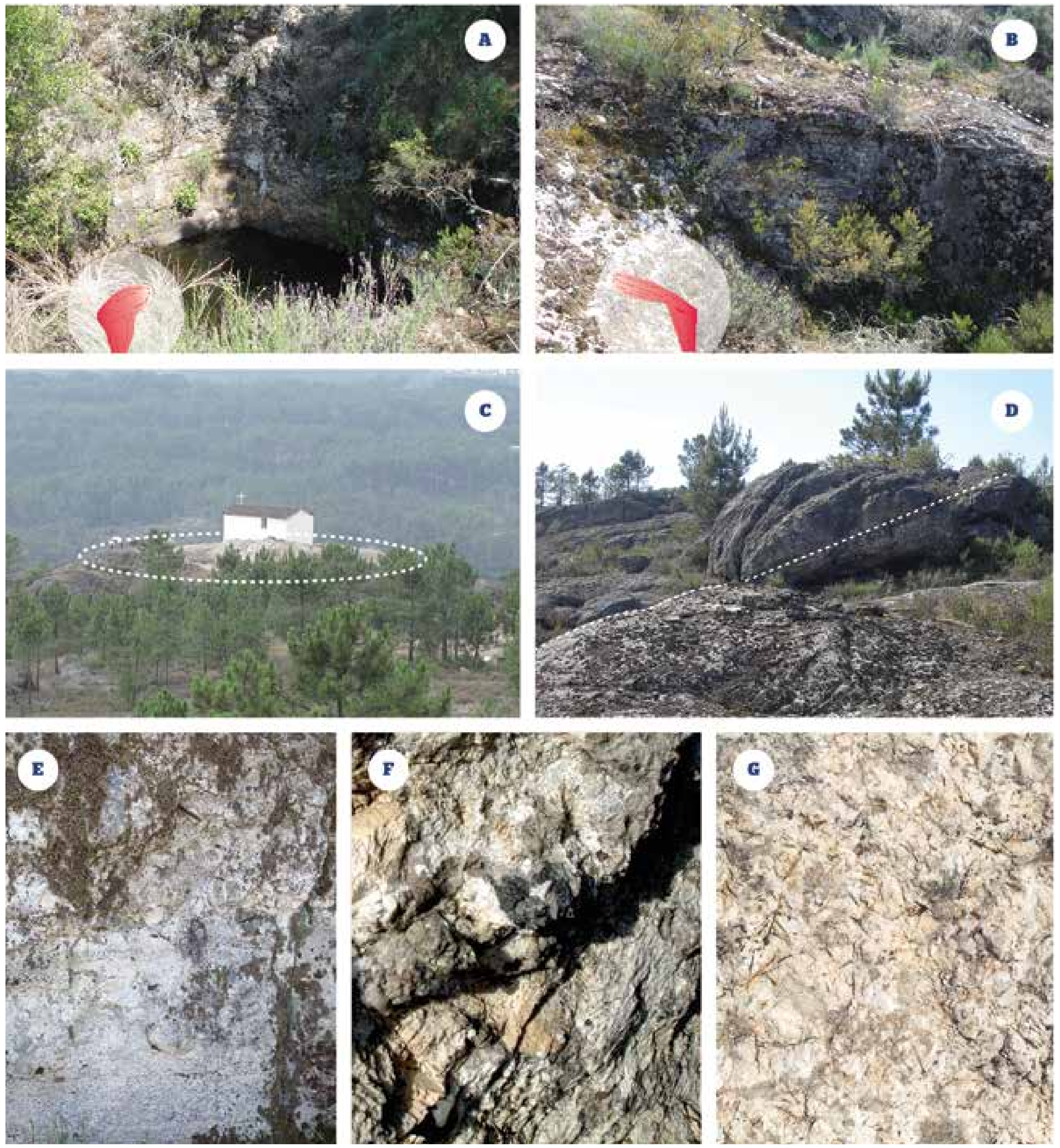


FIGURE IV.22

Photographs and geometric interpretation of the pegmatites explored in Carrasqueira (A and B); illustration of the pegmatite bodies and different facies in the São Matias sector (C – G).

IV.5 Geological investigation in the area E – Guarda

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 prospecting 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.

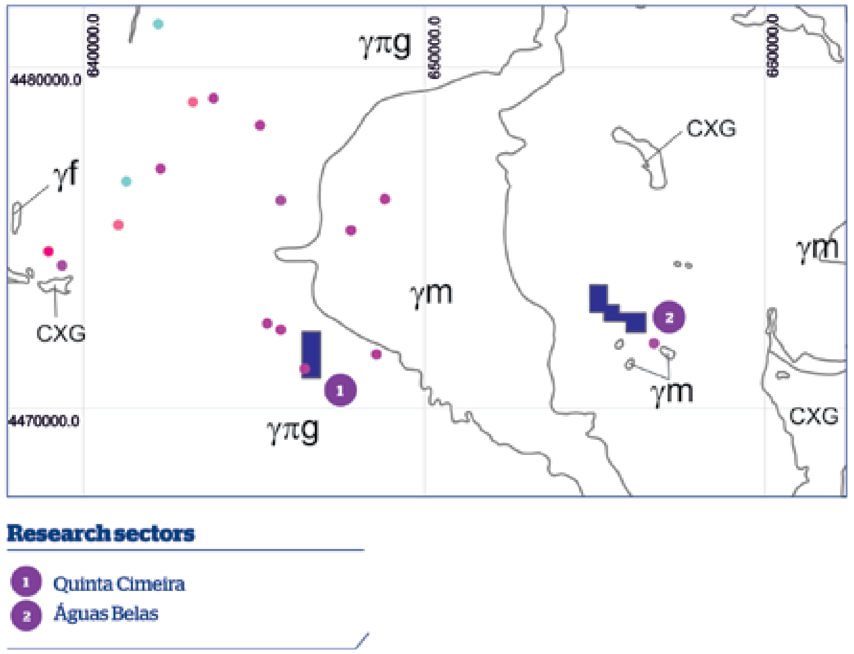


FIGURE IV.23

Location of the Quinta Cimeira and Águas Belas research sectors in area E. Legend according to Figure II.11

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 pegmatoid 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-SSE. Other dykes are distributed according to the NE-SW, ENE-WSW and NW-SE azimuths presenting variable thickness and dip.

In south Quinta Cimeira were exploited subhorizontal to slightly dipping veins, in two relatively small open pits separated by a dozen meters (Figure IV.25). In the open-cut pits are interspersed aplitic and pegmatitic facies rich in quartz, 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 in the 3D simulation of Figure IV.27. This hypotheses might be determined in the E#QC(S)1 drill hole . The drilling surveys E#QC(S)2 and E#QC(S)3 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 micaceous units (Figure IV.28-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-B). 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.

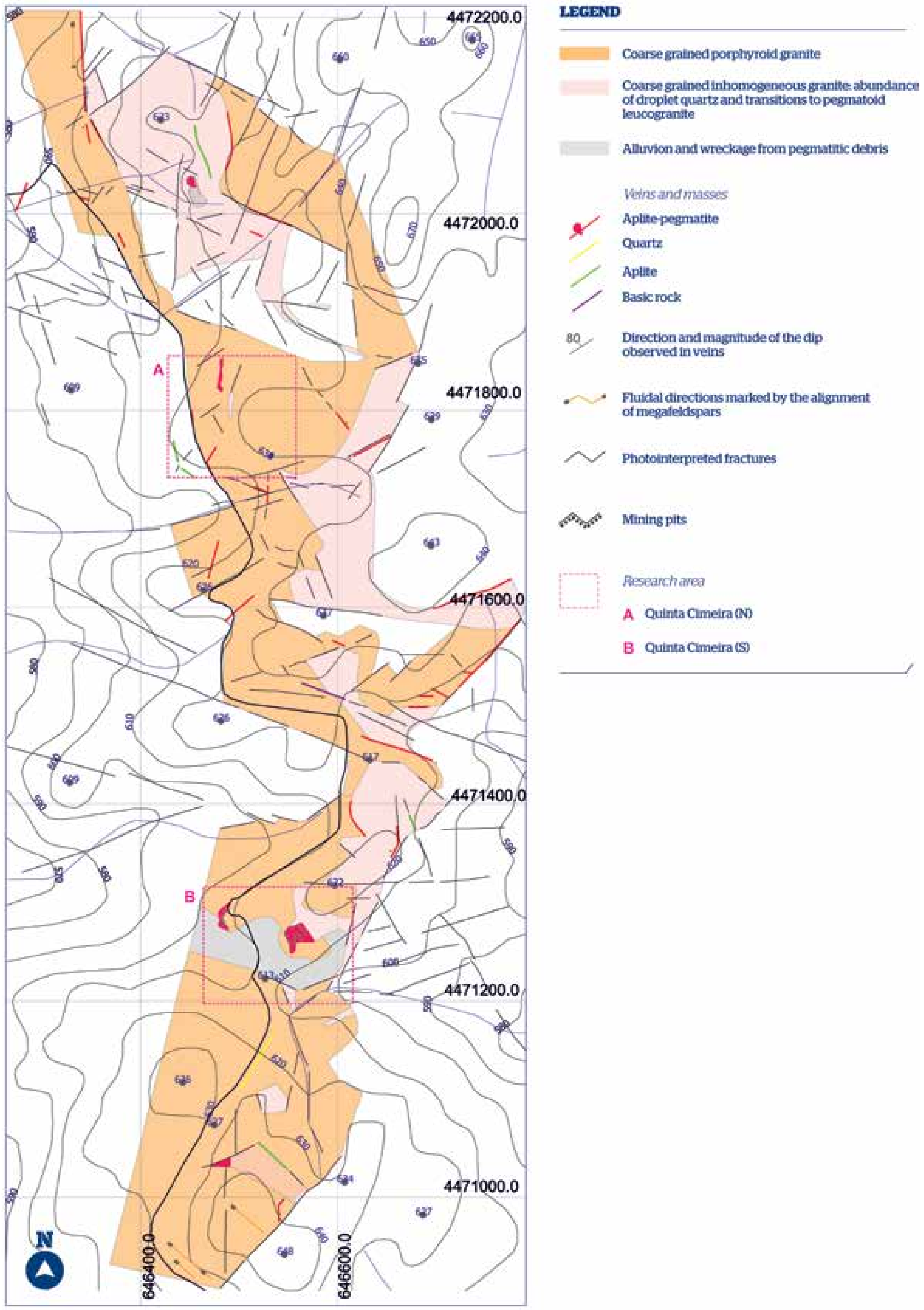


FIGURE IV.24

Geological map obtained by field survey in 1:5000 scale, from the Quinta Cimeira sector

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.

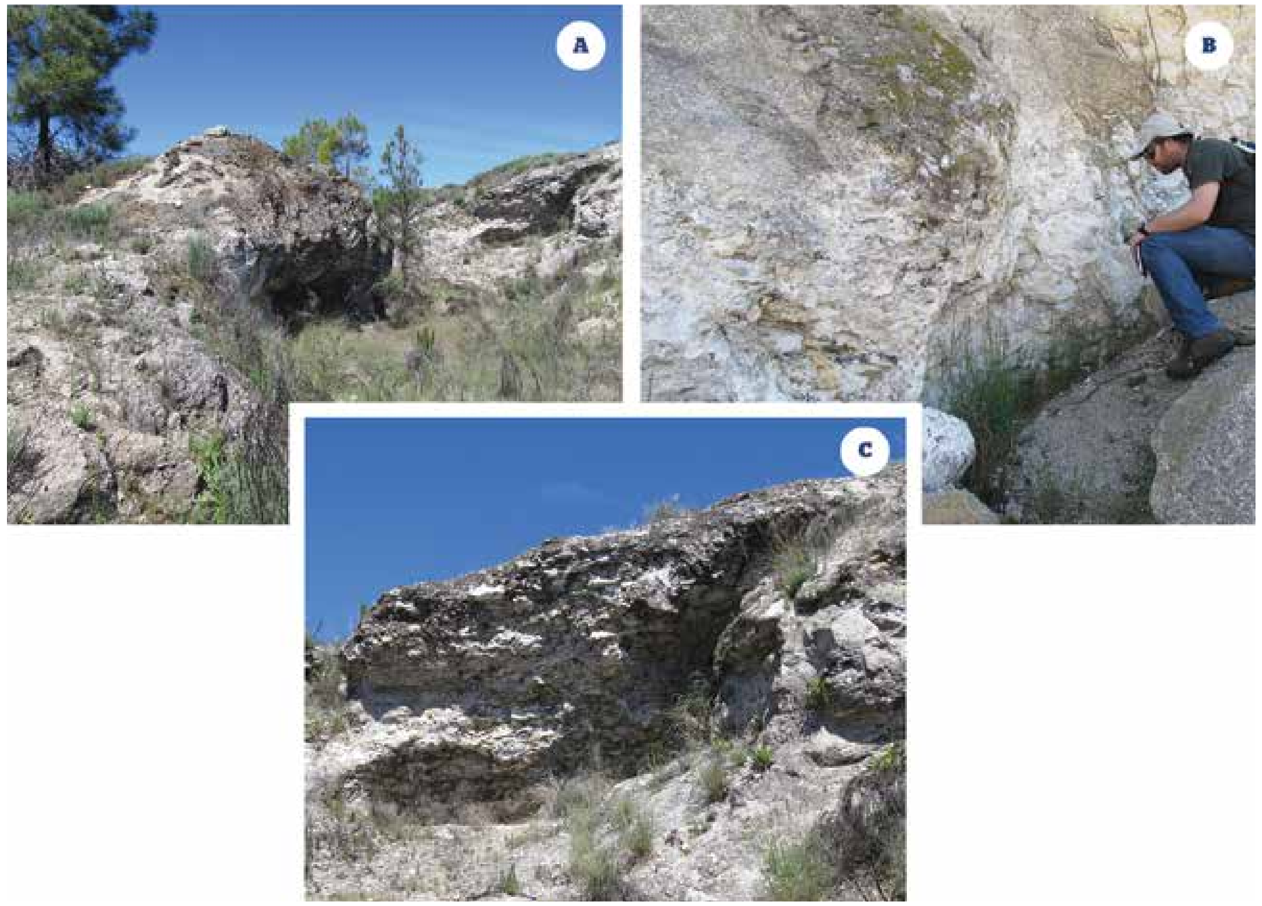


FIGURE IV.25

Photographs of trenches from the south part of the Quinta Cimeira open pit

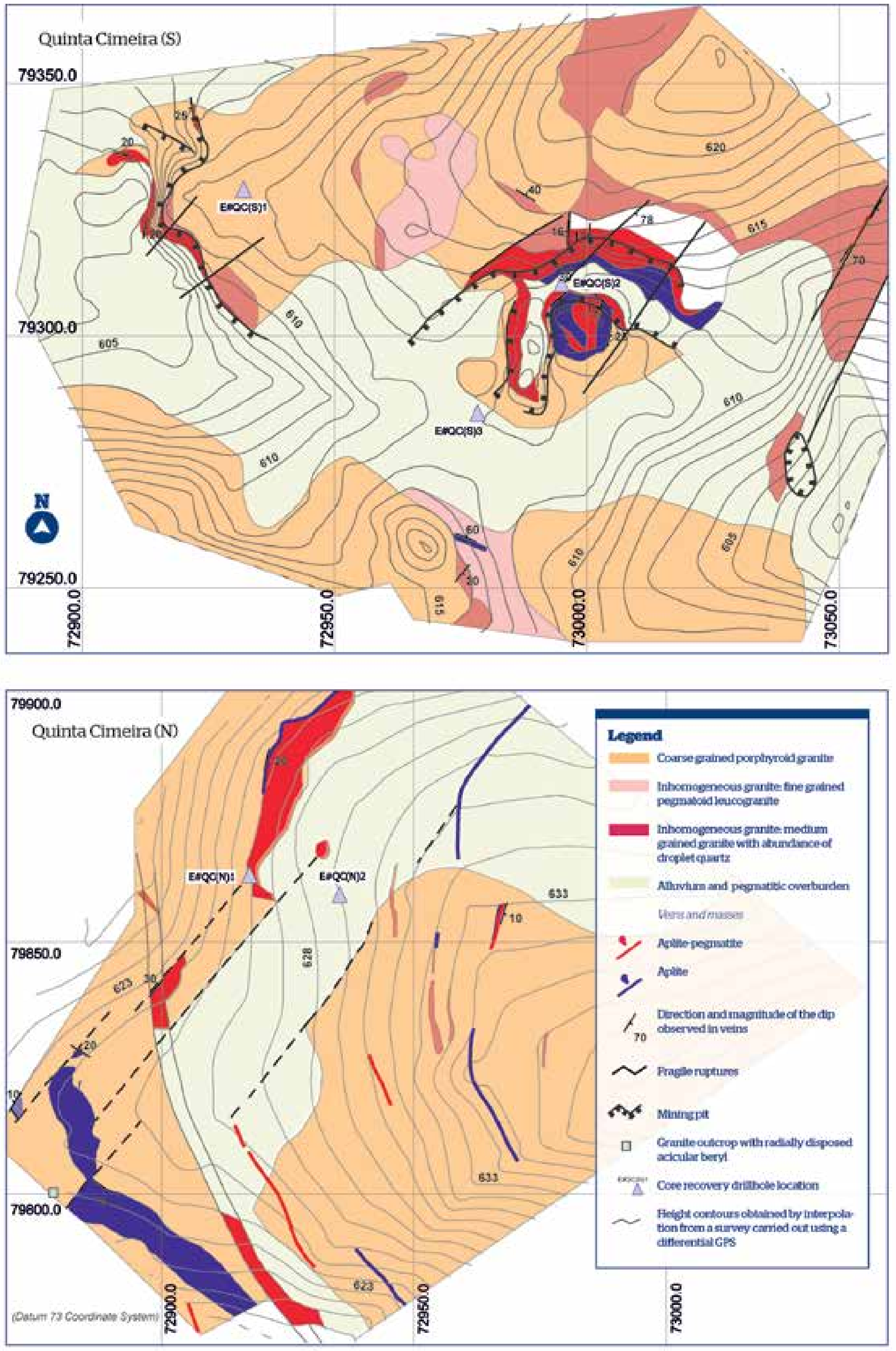


FIGURE IV.26

Geological maps on 1:1000 scale of the north and south Quinta Cimeira research areas

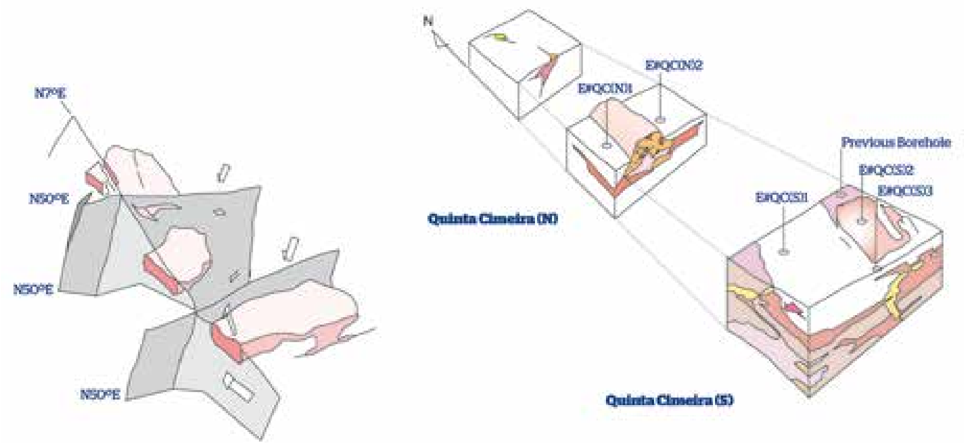


FIGURE IV.27

3D simulation of the pegmatitic bodies to be prospected in Quinta Cimeira

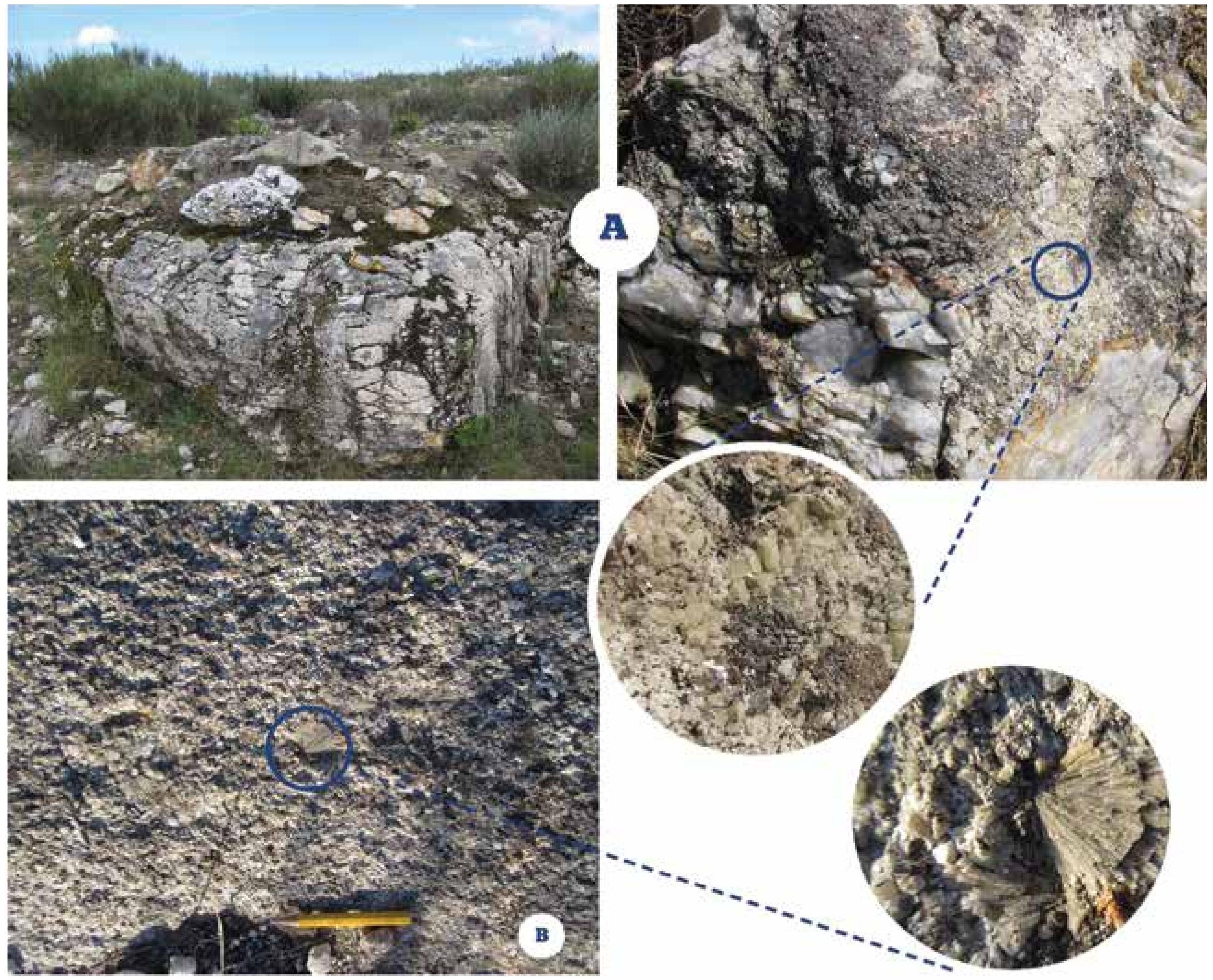


FIGURE IV.28

Thicker aplite-pegmatite in north Quinta Cimeira with illustration of the spread of beryl in their micaceous units and in the enclosing granite

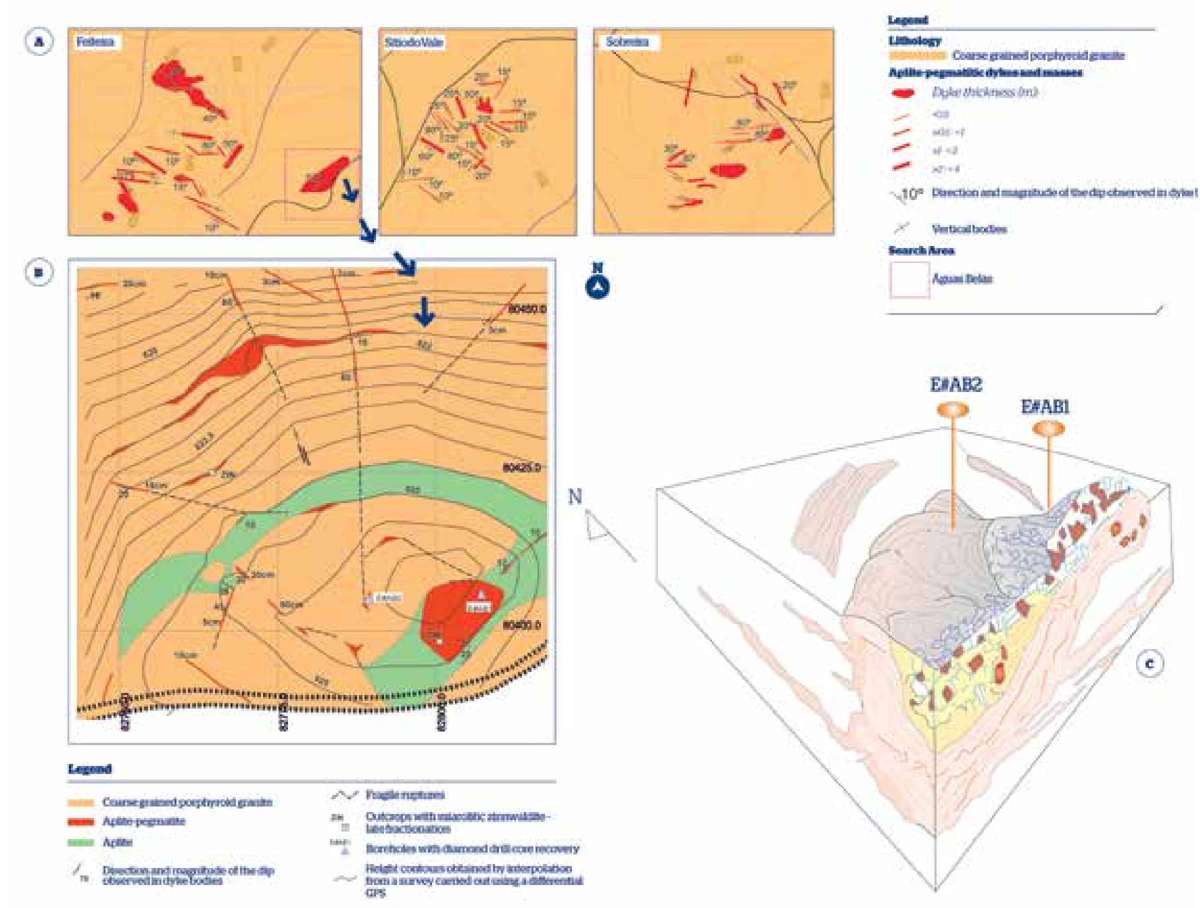


FIGURE IV.29

A-Representation of aplite-pegmatitic dykes mapped in the Águas Belas sector; B-Geological map of the Feiteira area (research area) on 1:1000 scale; C - Block-diagram representation of the pegmatitic body, speculation about the internal zone and drillings location

Study areas	Key sector	Assignment	M	P	Depth (m)	Drilling type
E	Águas Belas	E#AB1	82809.14	80383.29	15	R
		E#AB2	82797.20	80389.41	30	R
	Quinta Cimeira (S)	E#QC(S)1	72935.09	79304.96	30	R
		E#QC(S)2	72995.92	79285.36	16.5	R
		E#QC(S)3	72983.68	79261.47	22.5	R
	Quinta Cimeira (N)	E#QC(N)1	72923.34	79839.22	10.5	R
		E#QC(N)2	72937.32	79837.08	12	R

TABLE IV.9

Identification and location of the drillings projected in area E, (coordinates in datum 73) and the depth achieved in drilling; R - drilling with core recovery

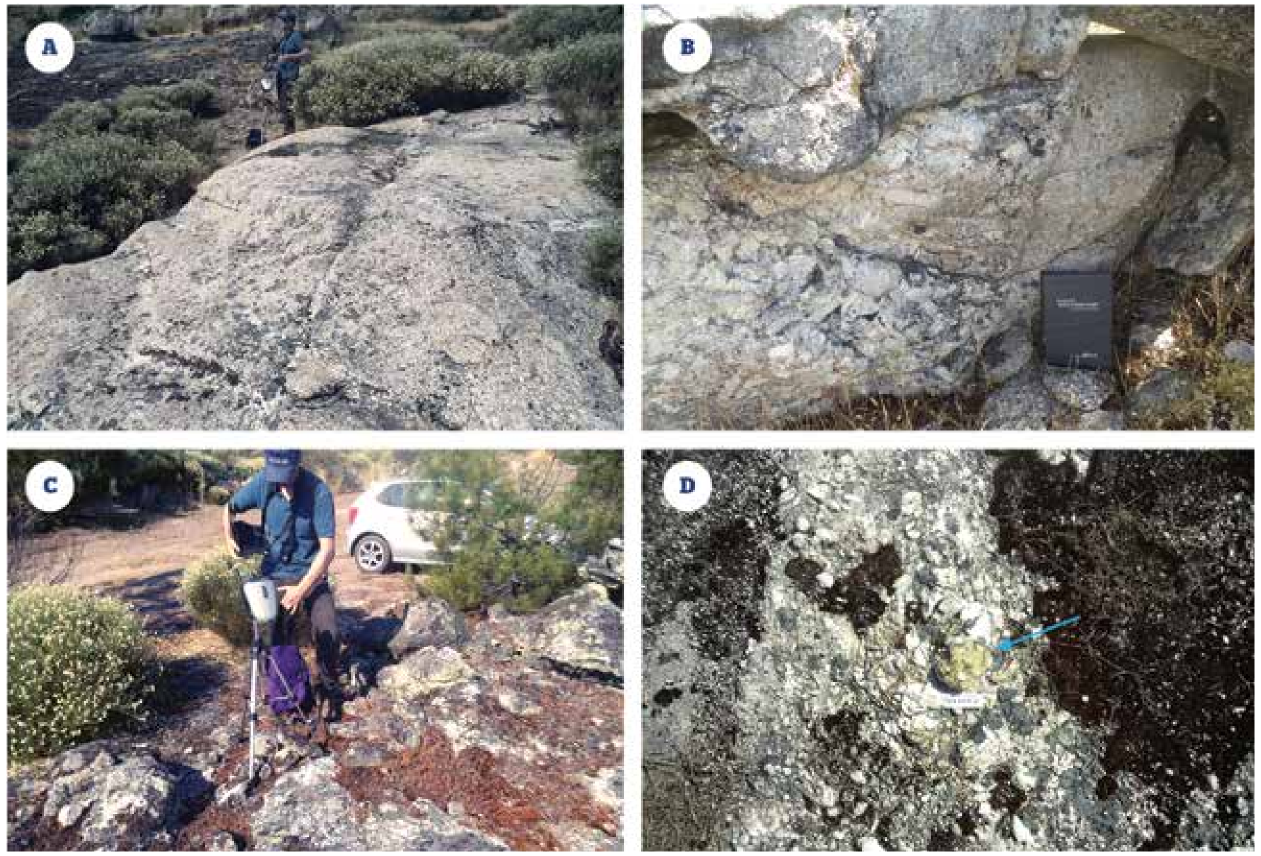


FIGURE IV.30

Photographs representing the organization of dykes in the Águas Belas sector (A and B) and representative of the aplite-pegmatitic body of Feiteira (C) pointing in figure D the occurrence of zinnwaldite.

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 1:50 000 mapping, were identified other granitic facies, tendentiously 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 phenocrystals caused by flow at low viscosity;
- Granites 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;
- Granites with drop-like quartz;
- Leucogranites carriers of cordierite and garnet (facies in transition to hyperaluminous pegmatites).
- Porphyroid granites differentially reddened by feldspar hematitization 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, Satão 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 Seixigal and Redial are distributed;
- the aplitic 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-Régua. 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.

5 chapter

Drillings and 3D modeling

V. Drillings and 3D modeling

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 pegmatites 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 modal biotite contents in enclosing granites.

The information gathered through drilling was used as an attempt for three-dimensional modeling of pegmatitic masses intercepted 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 Fraga 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 lineation of the potassic feldspar phenocrysts was made. It was also associated to the columns the indications of % of phenocrysts, the presence of biotitic schlieren and the existence of miarolitic cavities. 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 São Matias case were accounted granitic pegmatoid facies. The aplite-pegmatitic volumes that were here intersected, by representing differentiated collected in dome sectors subject to relaxation (see chapter IV), provided further information relevant to the volume expansion of the massif (work in progress).

Drilling	**Sum of the thicknesses of pegmatites or aplite-pegmatite intersected in each case (in meters)**
Area A	
AZ2	1.5
Area B1	
B1#R2	0.4
Area D	
D#C1	2.18
D#C2	3.3
D#C3	0.2
D#SM1	9.7
D#S1 (destructive)	8.0
Area E	
E#QC(S)1	1.5
E#QC(S)2	3.0
E#QC(S)3	1.74

TABLE V.1

Total thicknesses of pegmatites and/or aplite-pegmatite (undifferentiated) intersected by boreholes.
Note: In the São Matias drilling were accounted granitic pegmatoid facies

In the case of destructive drillings only the drilling D#S2, 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 3% of the corresponding concentrate (view Figure V.2).

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

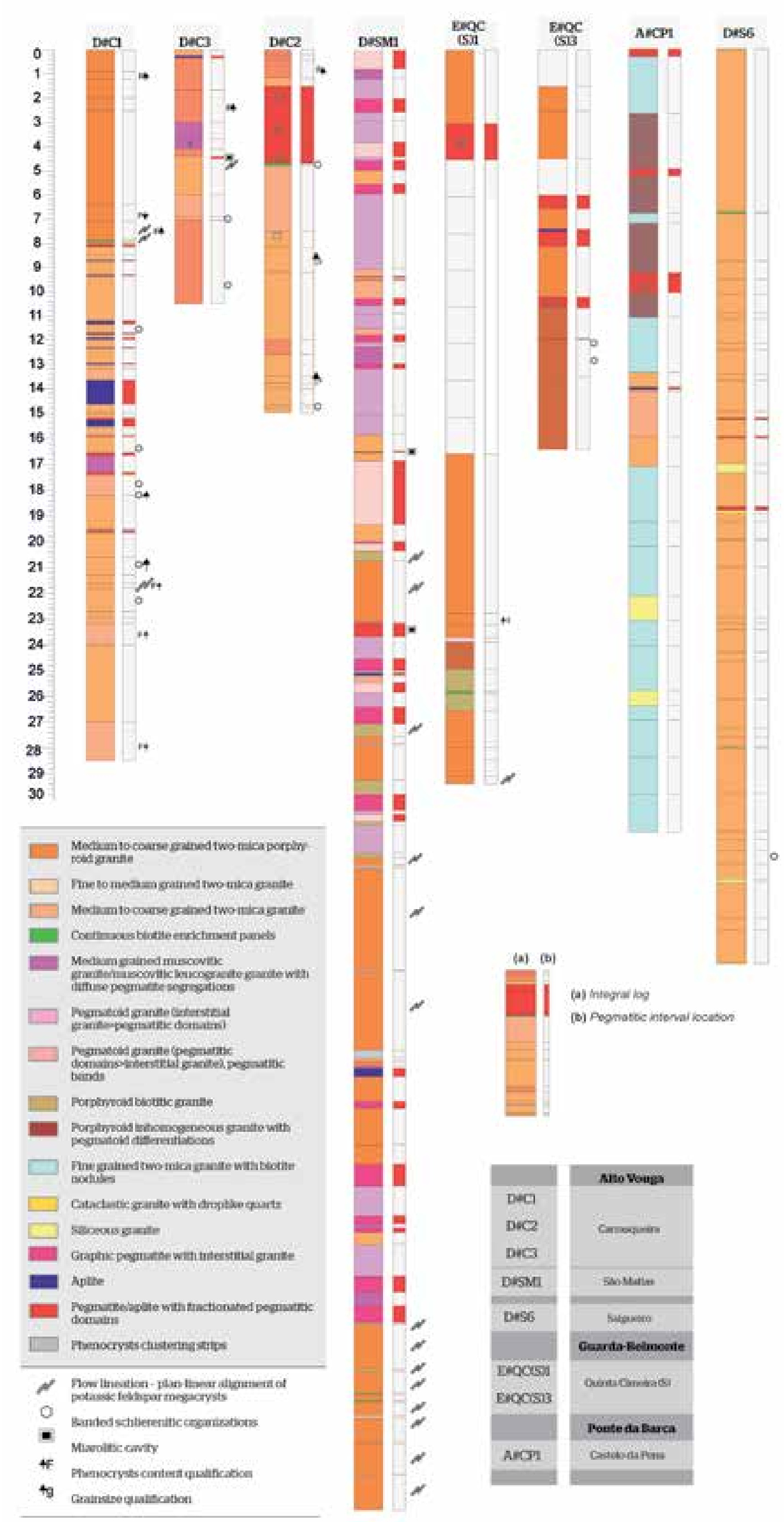


FIGURE V.1

Lithological columns obtained through diamond drilling with core recovery

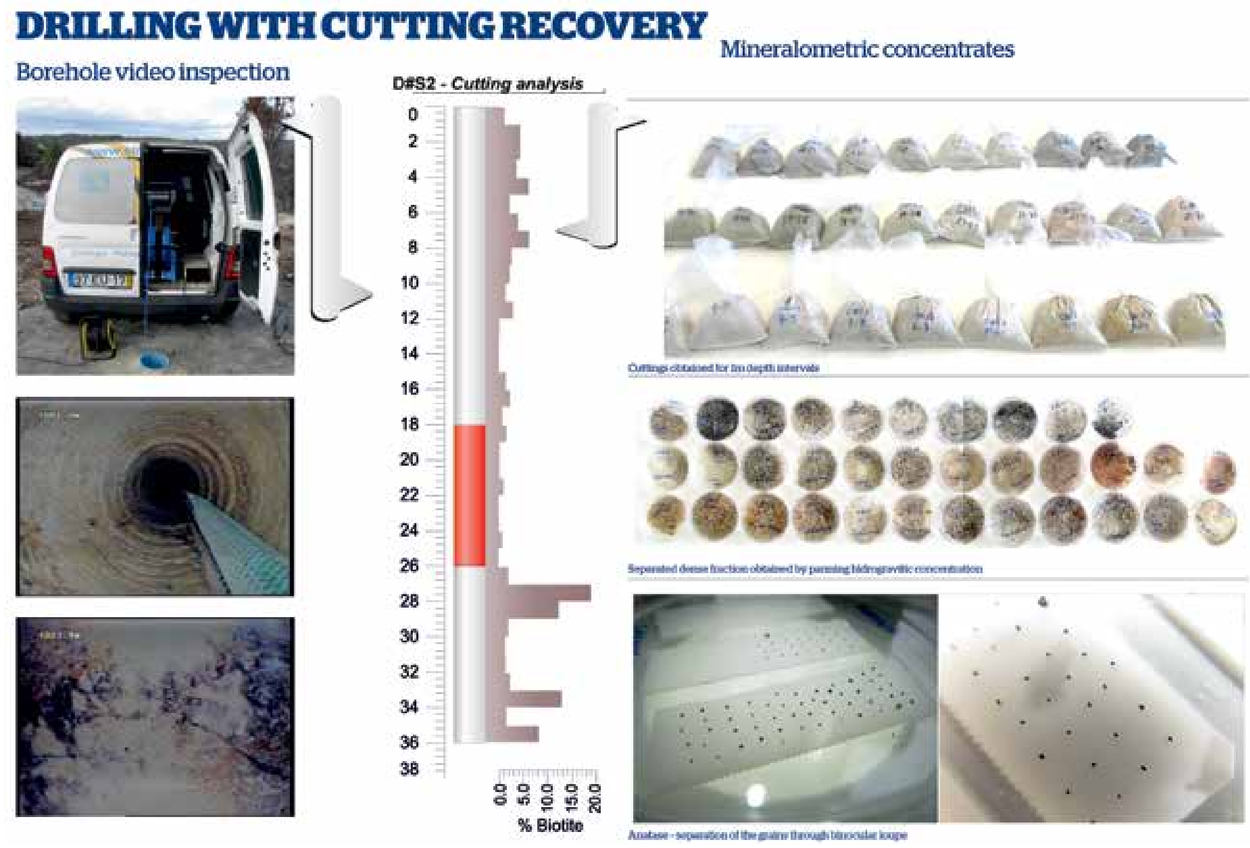


FIGURE V.2

Methodological scheme developed for the research and logs obtainment from destructive drilling.-Example of application to the D#S2 drilling (Salgueiro, area D)

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 Weinberg et 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 porphyroid two-mica facies and medium to fine grained granites with shortage of phenocrysts. These may transit to the following anomalous horizons:

A – ranges of fine grained leucogranites, sometimes muscovitic, with diffuse pegmatitic segregations;
B – ranges with felsic composites of granite and graphic pegmatite with coarse micaceous intergrowths, radial, and banded structures with feathery feldspars (pegmatoid granite);
C – enrichment ranges culminating in biotite, and more penetrative schlierenitic bands;
D – phenocrysts clustering domains;
E – penetrative lineations – convolutes and with horizontal and vertical tendency – marked by the fluidal alignment of potassic feldspar megacrysts;
F – ranges with pegmatitic bubbles carriers of miarolitic cavities, 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. Ranges with aplite-pegmatitic bands are developed in relation to these units. The sets have oscillatory rhythm, most frequently with 4 meters thickness, with spacing ranges of about 3 meters, as observed in log D#SM1 of Figure V.1.

Transitional granites and aplite-pegmatitic masses 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 ascendant evolution by fractionation of separated felsic magmas.

The schlierenitic organizations and some increments of the biotite contents along the drillholes also manifest oscillatory tendency. There are interfaces between these configurations and the presence of flow lineaments in the enclosing granitic 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 Klomínsky (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 potassic 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 Paterson 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 pegmatitic volumes situated in the triple junctions and dilatational knots in shear nets, the internal dome fractionation is expressed in the acquisition of lithological heterogeneities, in the plutons 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 segregation processes seem to favor fractionation and have the ability to increase the appearing of transitional and pegmatitic 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 mechanic drillings 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 drillings program done previously. The software VOXLER® was used for the software modeling.

The comprehension of the pegmatitic bodies shape in 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 (XYZ – 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 mechanic drillings campaigns (Ferreira and, 2011).

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

In PROSPEG, 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 PROSPEG, is presented in a simple way in Figure V.3.

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

The insertion of data in the modeling software implies the creation of three-dimensional matrixes (lattices) (X, Y, Z, C) 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 weighing. In order to overcome this situation, to the C values was given the binominal "pegmatite/null", in which the presence of aplite/pegmatite corresponds the numerical value 100 and all the other lithologies correspond to the null value 0. This way the value of C respects a binary logic (0= absence of pegmatite; 100=presence of aplite/pegmatite).

The data treatment is therefore less complex, not compromising the 3DGM obtaining of pegmatitic bodies.

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..

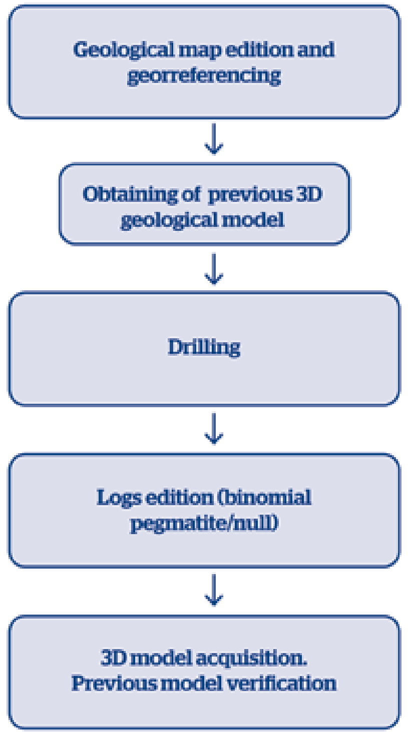


FIGURE V.3

Methodological sequence used in creating 3DGM

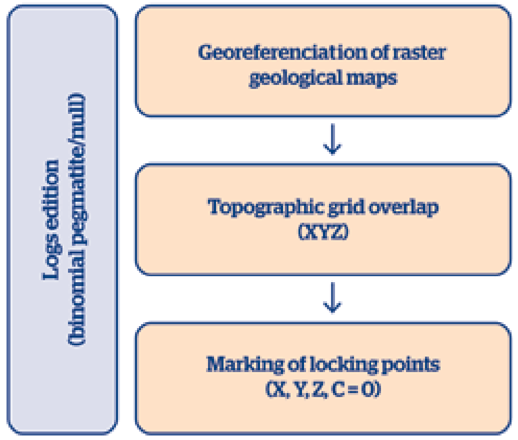


FIGURE V.4

Edition of the drilling logs

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 matrixes previously generated (crossing of drillings data, geological mapping and topographic survey), in which all surface points have the same numeric values.

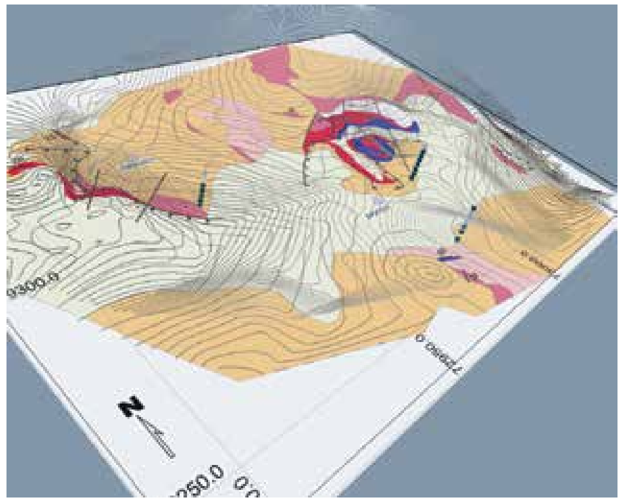


FIGURE V.5

Overlapping of drillings over geological mapping and generated DTM

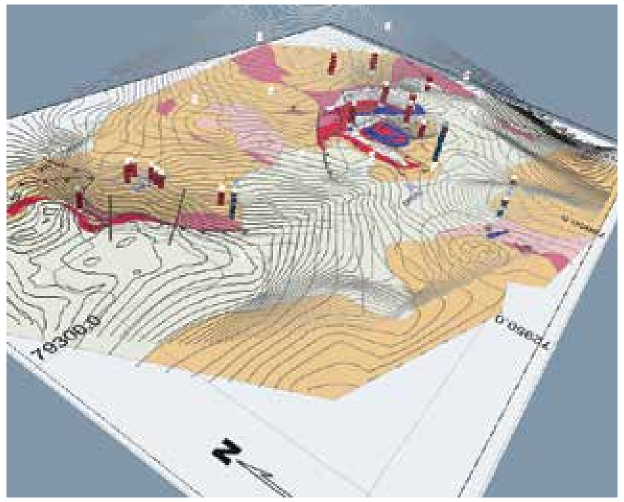


FIGURE V.6

Overlapping of drillings and locking points over geological mapping and generated DTM

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).

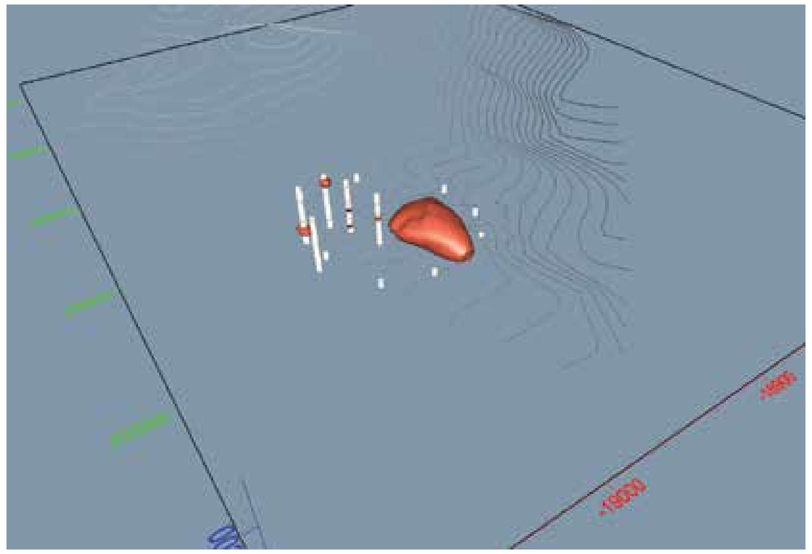


FIGURE V.7

3DGM obtained for the Azias area on a generated topographic base (SW view)

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

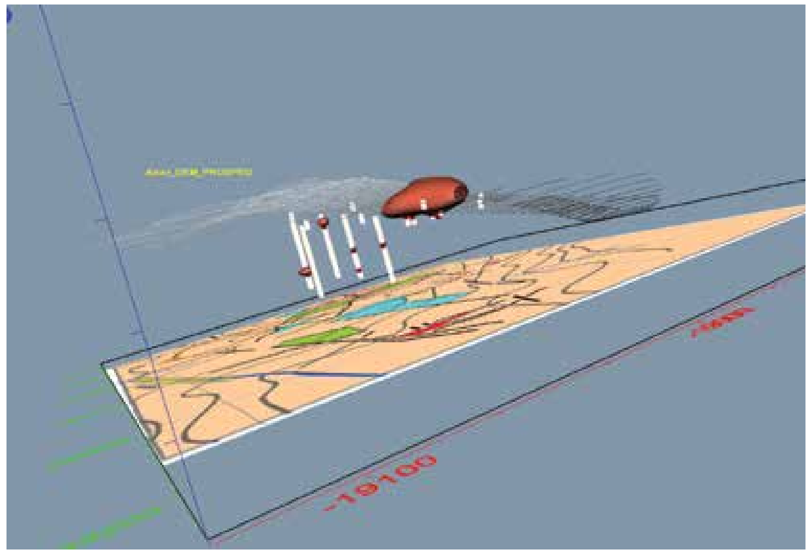


FIGURE V.8

Perspective of the 3DGM generated for the Azias area on 1:1000 geological background

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.

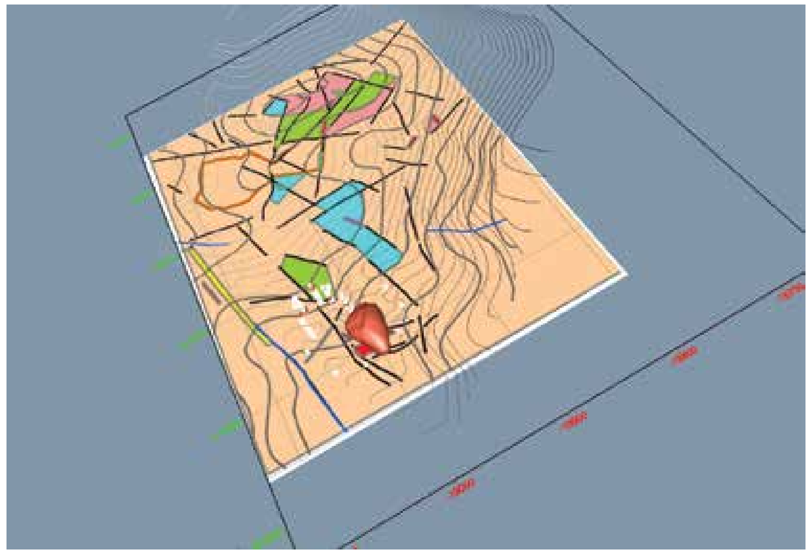


FIGURE V.9

Perspective of the 3DGM created for the Azias area evidencing the setting with mapped structures

Area B1 - Chaves

In B1 area a drilling campaign was done, based on the previous geological model presented in Figure IV.7 in the Redial 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 pegmatitic 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 four spots selected should be perceived in an integrated way within the study area (view map 1:5000).

The previous three-dimensional simulation supporting the mechanic drillings in the work areas of Fraga, Carrasqueira and S. Matias, can be seen in Figure IV.21.

Figure V.10 represents the 3DGM obtained for the Salgueiro sector, on the respective topographic base (SSE view), understood as the most promising regarding the geological variability in terms of shape/volume of the aplite/pegmatite bodies. The previous three-dimensional simulation detail can be seen in Figure IV.17.

Figure V.11 represents the 3DGM obtained on geological mapping on 1:1000 scale and its respective topographic base.

Figure V.12 represents the 3DGM obtained for Carrasqueira research area through distinct perspectives. The previous three-dimensional simulation that supported the 3DGM can be seen on Figure IV. 21.

Figure V.13 represents the 3DGM created for Carrasqueira on geological background 1:1000 (SW view).

The 3DGM obtained for area D can be considered as approximations to the previous three-dimensional modeling. In all cases it was possible to obtain 3DGMs with similitude in terms of shape and dimension to the previous modeling represented in Figure IV.21, enhancing its application potential to the study done against the incorporation of new data.

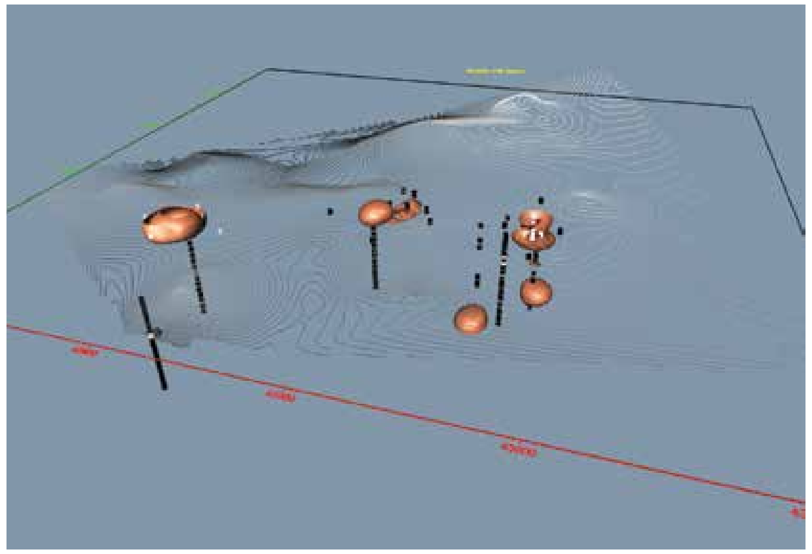


FIGURE V.10

3DGM created for the Salgueiro area

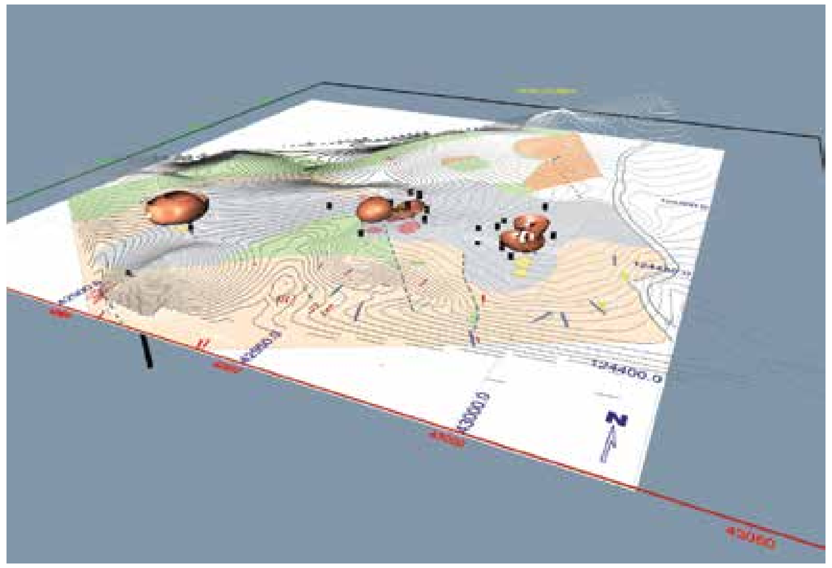


FIGURE V.11

Perspective on the 3DGM created for the Salgueiro area with geological base 1:1000 (SSW view)

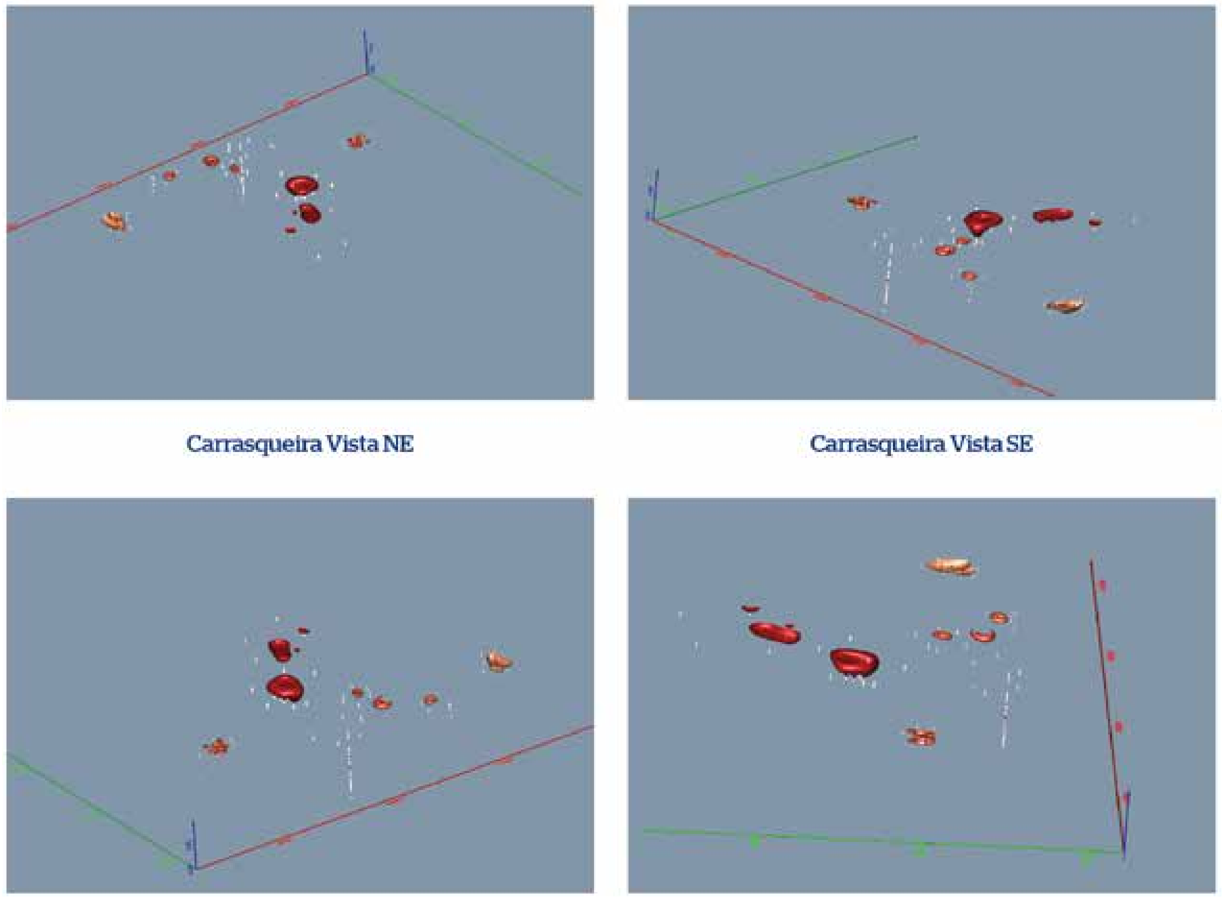


FIGURE V.12

3DGM obtained for Carrasqueira

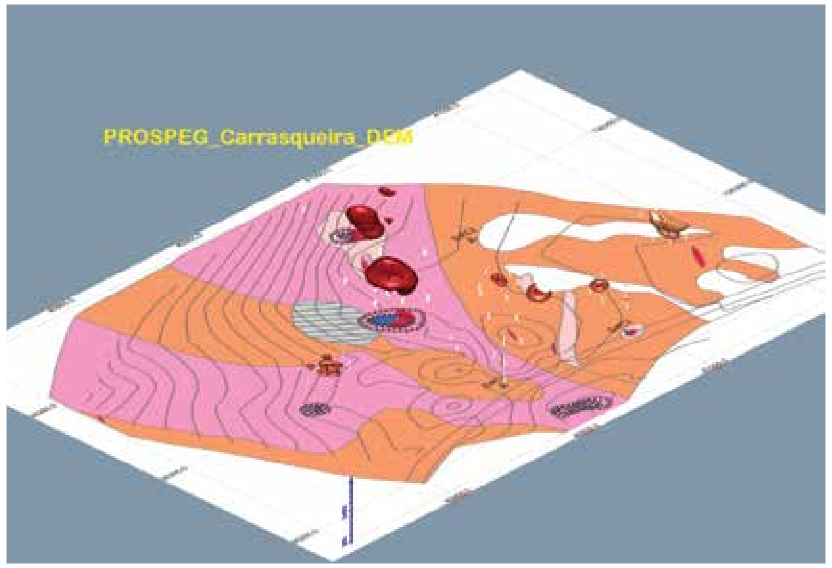


FIGURE V.13

3DGM created for Carrasqueira on 1:1000 geological background

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.14 illustrates the 3DGM obtained for the Quinta Cimeira south area, on the respective topographic base.

Figure V.15 represents the 3DGM obtained for Quinta 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.

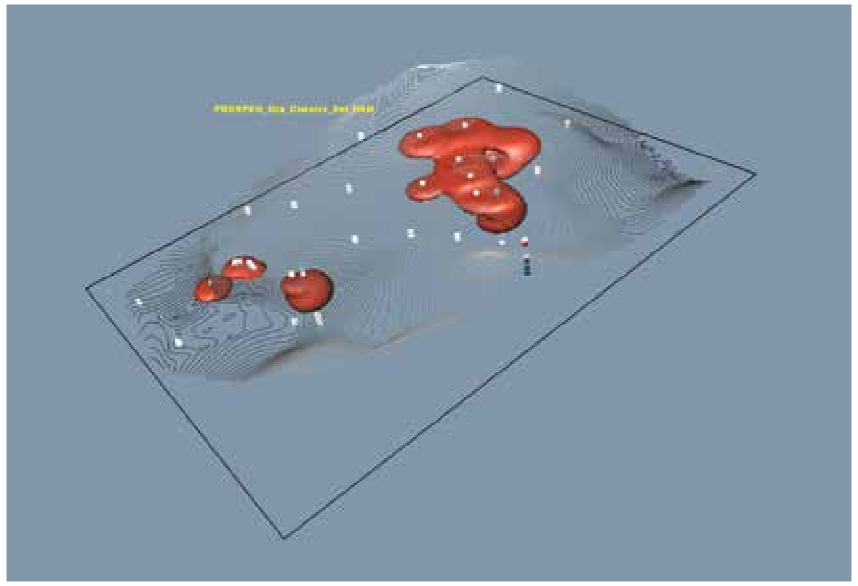


FIGURE V.14

3DGM obtained for the Quinta Cimeira area

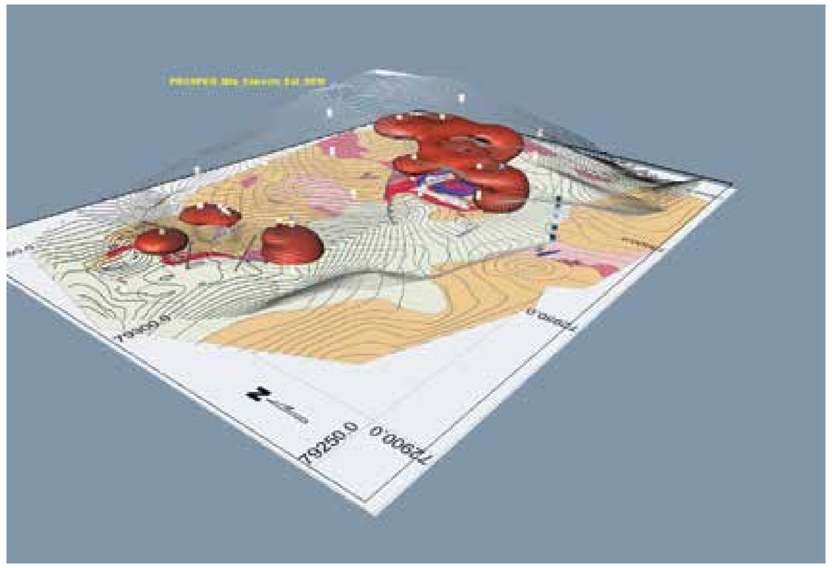


FIGURE V.15

3DGM obtained for Quinta Cimeira on 1:1000 geological background

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.

6 chapter

Spectral characterization of pegmatitic masses and enclosing lithologies spatially related

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, spatial 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, perceived by the variation in the color 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 the total reflection of the received radiation, respectively.

The electromagnetic spectrum of an object corresponds to the division of electromagnetic radiation, according to its wavelength, as shown in Figure 1.

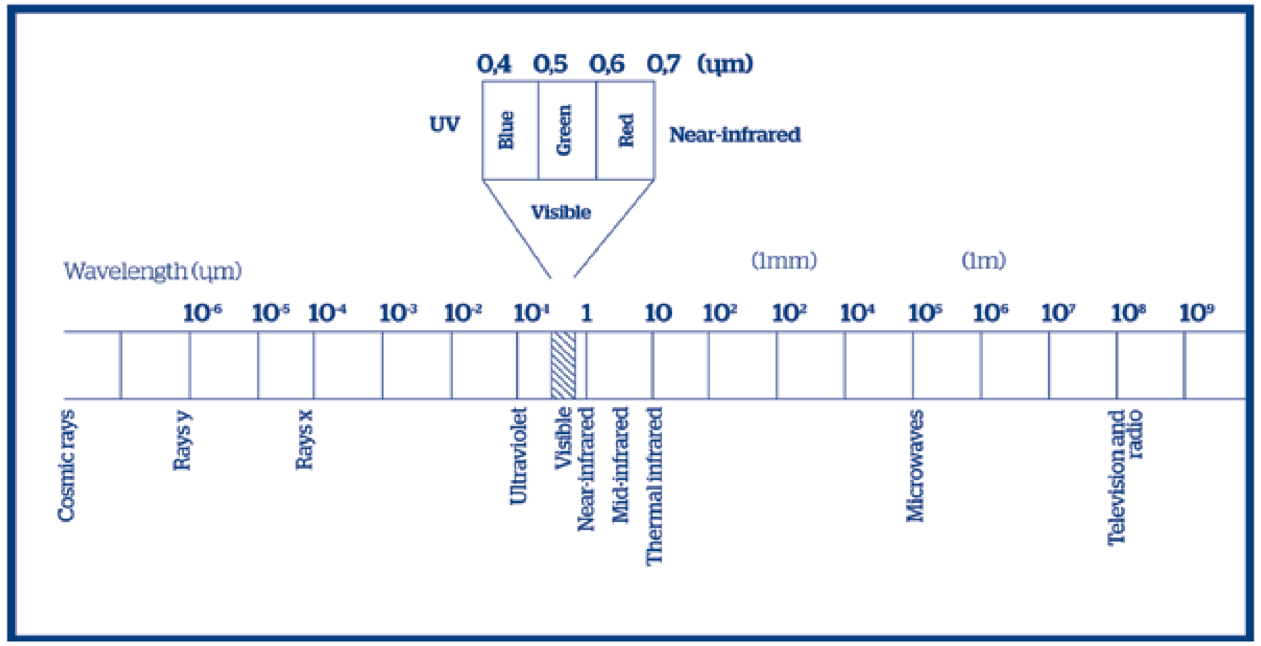


FIGURE VI.1.1

Spectrum of electromagnetic radiation (Alonso et al., 2005)

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), contemplates the following division of bands:

a) band of the visible spectrum (0,4 to 0,7μm) - 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). The three bands are the primary colors perceptible to the human eye;

b) near-infrared (0,7 to 1,3μm) - also often called reflection 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 vegetable masses and moisture concentrations;

c) mid-infrared (1,3 to 8 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) Microwaves (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 are 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 spectral 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 spatialy 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 basis, 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 analysis of satellite images based on reflectance is a valid tool in lithological discrimination, according to Rowan, et al. (1977), Goetz&Rowan (1981) and Abrams (1984) (in Wester, 1992).

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 Wester (1992), there must be a prior determination of spectrum regions on which it is possible to distinguish the different lithologies.

The spectral measurements obtained under PROSPEG 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.

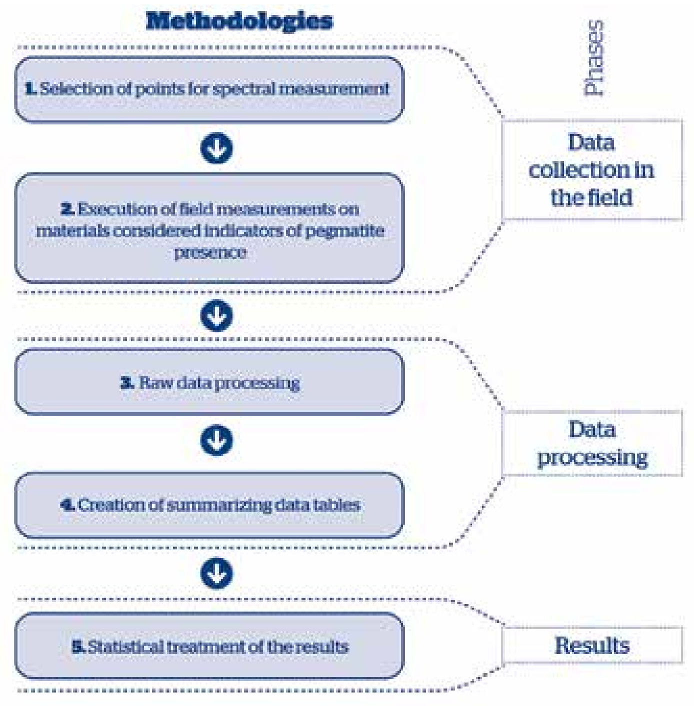


FIGURE VI.2

Work methodology adopted for spectral characterization

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.

Descriptor	Considered properties
Target	Identification of the target of measurement and distinction between outcrop and artifact (occasionally, distinction between heap and quarry).
Lithology	Description according to detailed mapping carried out previously and after petrography.
Petrographic description	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.
Intensity of the reddening	Indication of the reddening intensity variation by microcyclization and hematization of feldspars, when observed, capable of affecting the measurement results.
Particular aspects	Indication of the presence of penetrative structures and venations, other textural aspects, capable of altering the spectral measurement results.
Coating by lichens	Indication of the percentage of coverage by lichens for later comparison with the spectral curves obtained on not covered rock.
Munsell color	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.

TABLE VI.1

Descriptors used in the preparation of individual sampling and measurement records

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.

FIGURE VI.3

Photograph of the sample Assunção 2 - Area D, which integrates the photographic record

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 m and an adjustable integration time, manually, of 17 milisseconds 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.

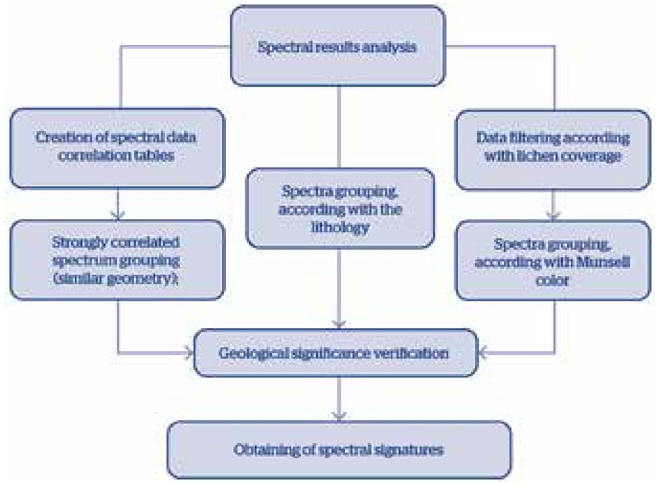


FIGURE VI.4

Methodological sequence adopted in the results treatment phase

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.

Area	Sector	Spectra obtained
A	Azias	23
	Galinheira	32
	Germil	15
	Pedra da Moura	17
B1	Redial/Seixigal	23
D	Assunção	13
	Carrasqueira	17
	Fraga	10
	Salgueiro	10
	São Matias	12
E	Qta Cimeira N	31
	Águas Belas	14
G	Lobeira/Ciborro	13
	Pedras Alvas	5

TABLE VI.2

Identification of the number of spectra obtained for the different geographic areas and sampling sectors

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.

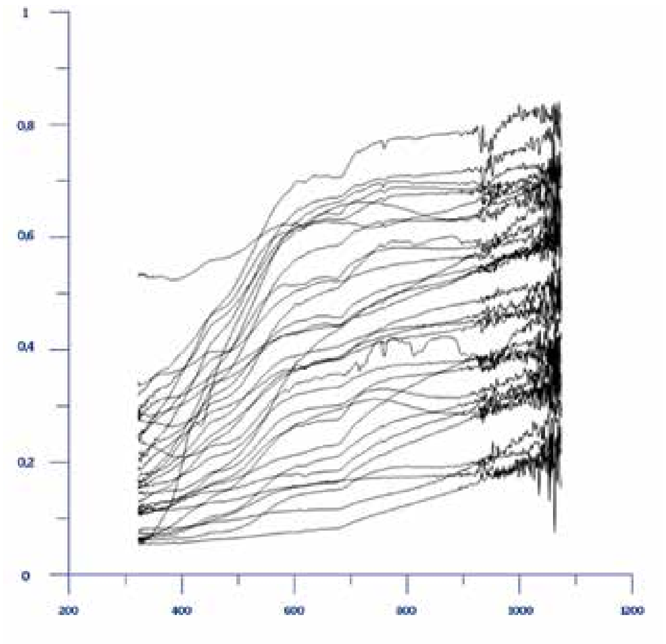


FIGURE VI.5

Presentation of the spectra obtained in the sector of Mata da Galinheira (Area A)

The spectra shown are the result of the average reflectance measured in the targets for a wavelength interval, 325-1075 m. From 980 m, 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 litological 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.

It was intended, this way, to determine statistical relationships between the different reflectance curves obtained in order to establish eventual signatures characteristic of similar lithologies.

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 percursors (genetic) in potentially productive granitic systems.

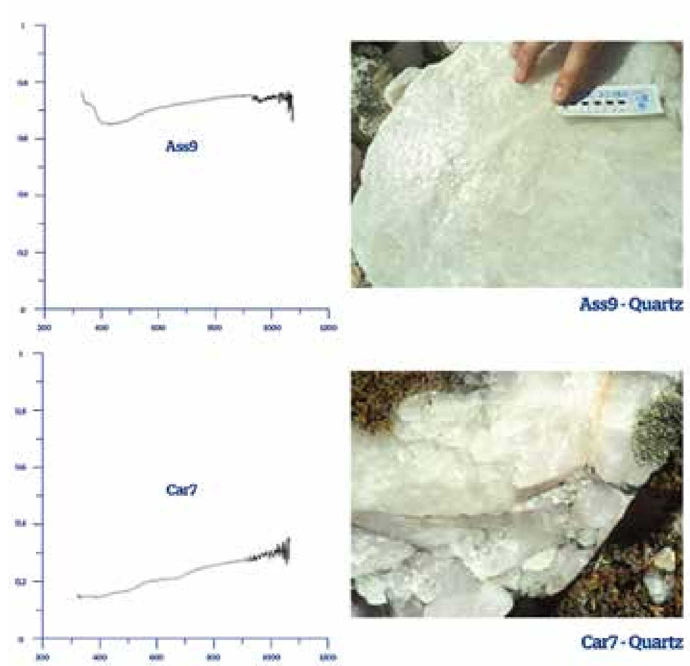


FIGURA VI.6

Image that shows strong discrepancies between spectral curves corresponding to the same lithology

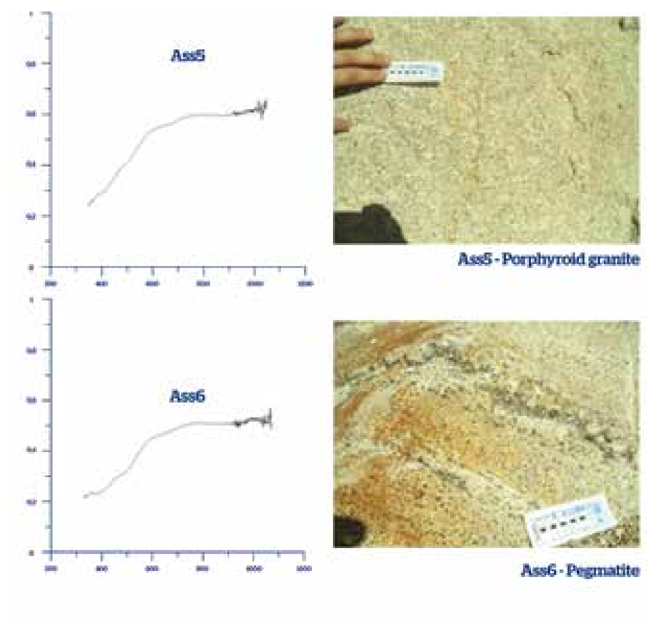


FIGURE VI.7

Image that shows strong geometrical and numerical correlation between spectral curves from lithologies evidenced in the photos

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.

	Areas				
	A	B1	D	E	G
Lichenes (>35%)	10	-	5	6	1
Colors N	11	-	3	1	-
Quartz	-	-	4	1	2
Pegmatite	12	4	7	9	-
Undifferentiated pegmatite material	6	-	2	4	-
Pegmatitic bubble	-	-	1	-	-
Aplite	-	2	-	2	-
Porphyroid granite	14	-	3	3	-
Coarse granite	-	4	-	-	-
Medium granite	1	2	2	1	-
Fine granite	8	-	8	1	-
Fine grained porphyroid granite	6	-	-	-	-
Basic rock	1	-	-	-	-

TABLE VI.3

Number of spectra obtained, by classes, for different areas

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 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 in a remote mapping analysis context.

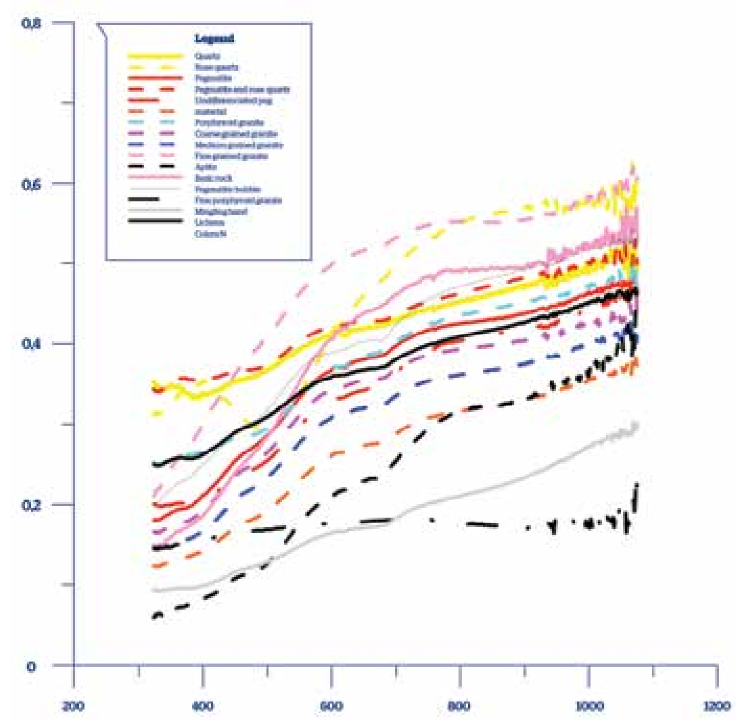


FIGURE VI.8

Average spectral signatures for the considered classes, based on the reflectance values of all the studied areas (yy - reflectance; xx - wavelength in μm for all graphs)

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 kaolinization observed in this facies.

The spectral signature of milky quartz appears distinct from the other 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.

The mingling corridors, the basic rock and the targets with lichens coating with >35% present the lower reflectance values from all lithologies considered, but are not distinguishable.

Given the overall purpose of PROSPEG, it is of particular importance the analysis of the spectral curves of the pegmatitic masses and undifferentiated pegmatitic material and also of lithotypes that, genetically or spatially, are related to the pegmatites. In general their spectral signatures appear almost indistinguishable from the spectral signatures of the enclosing granites. In order to explain this behavior, a particular analysis to these spectra was done.

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.

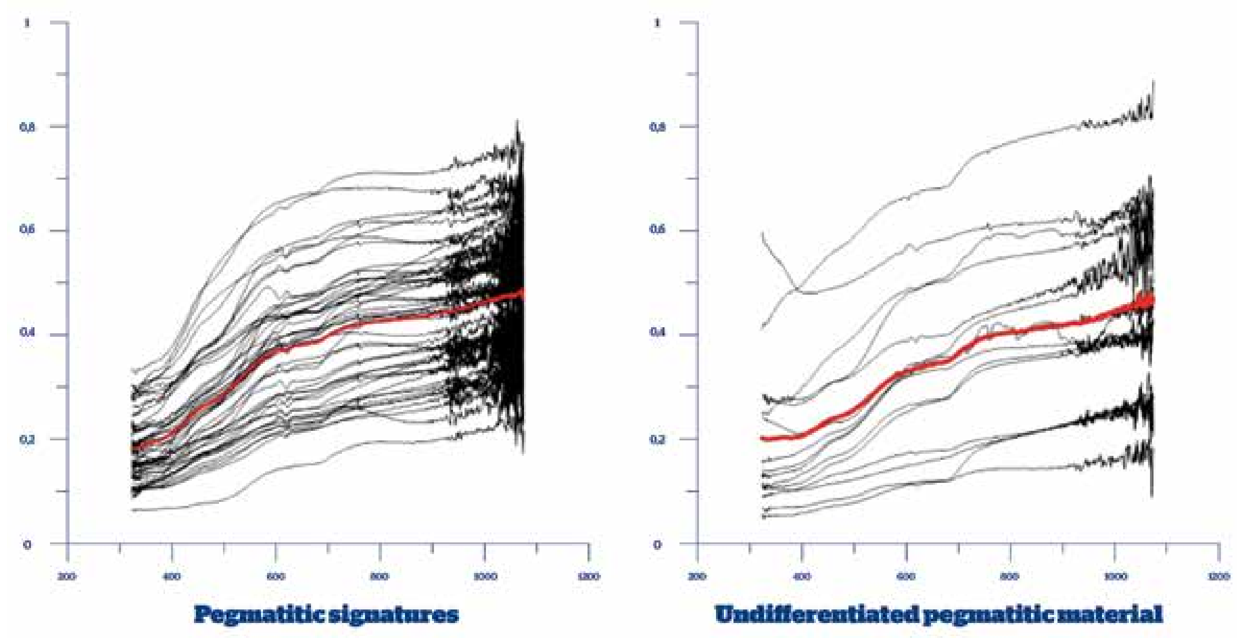


FIGURE VI.9

Spectral signatures of different pegmatitic samples, representing up red the average spectral signature of the lithology

However, the average spectral signature tends to homogenize and hide particular aspects of reflectance of different areas, which advises an independent approach for each area. Moreover, individual pegmatitic signatures present, almost invariably, inflections at 500, 620, 700 and 780μm, and similarly, the signatures for undifferentiated pegmatitic materials present more conspicuous inflections at 500, 620 and 700μm.

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.

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

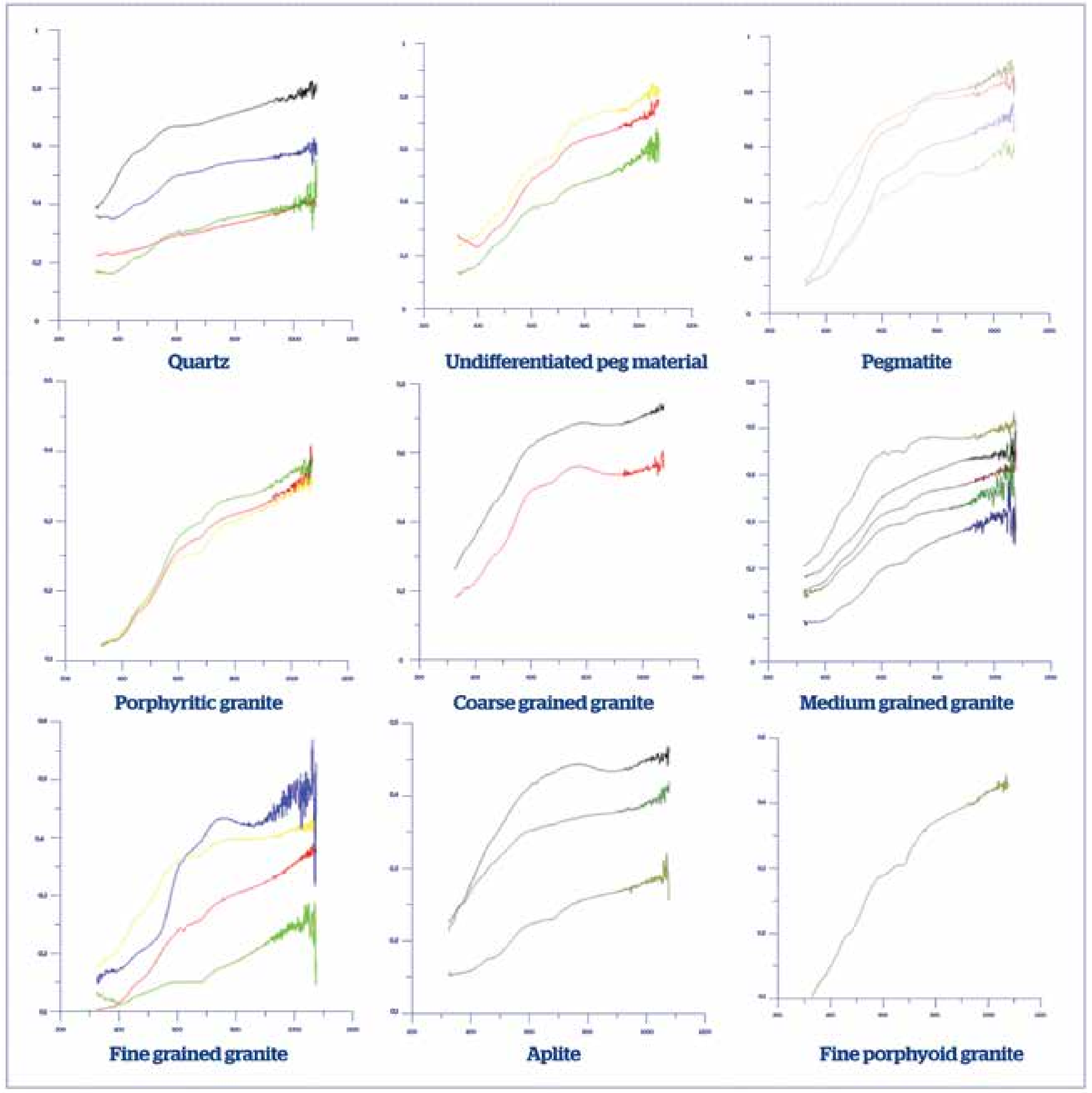


FIGURE VI.10

Average spectral curves by area for different lithologies (Area A - yellow line, Area B1 - black line, Area D - Red Line, Area E - Green Line, Area G - blue line)

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.

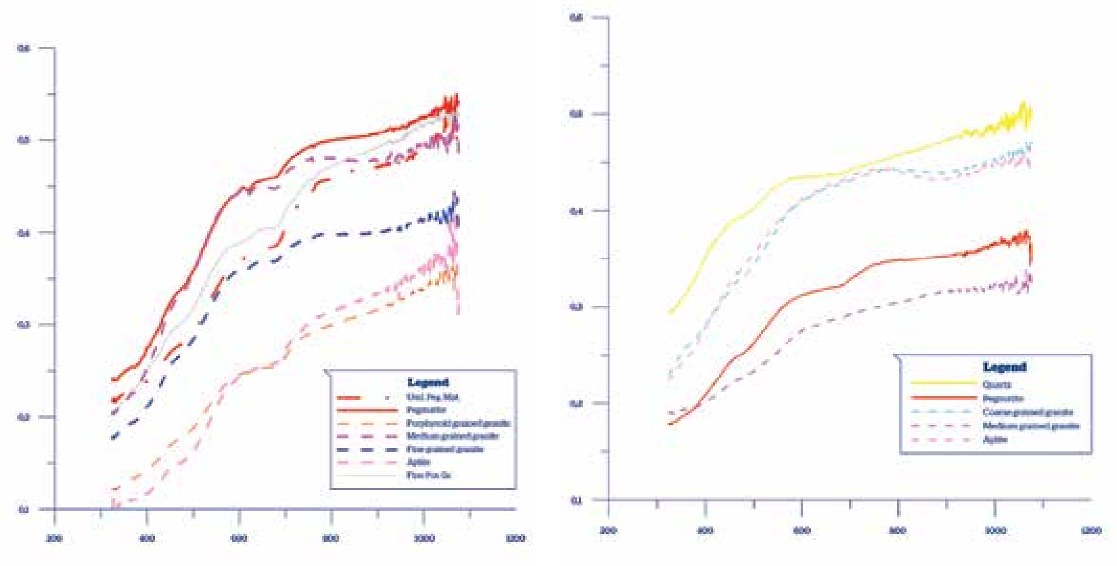


FIGURE VI.11

Spectral relationships obtained for the main lithologies observed in the study areas (Areas A and B1)

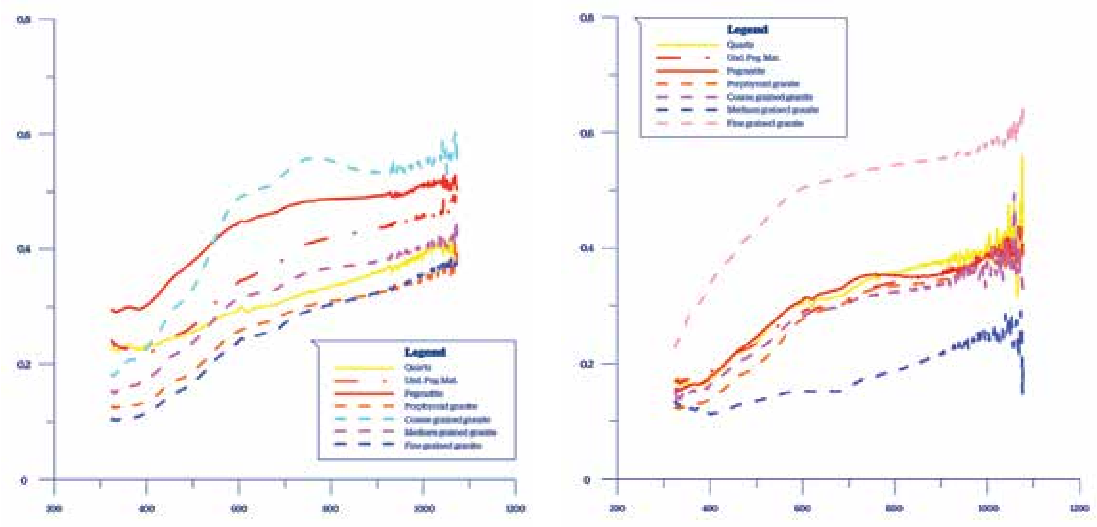


FIGURE VI.12

Spectral relationships obtained for the main lithologies observed in the studied areas (Areas D and E)

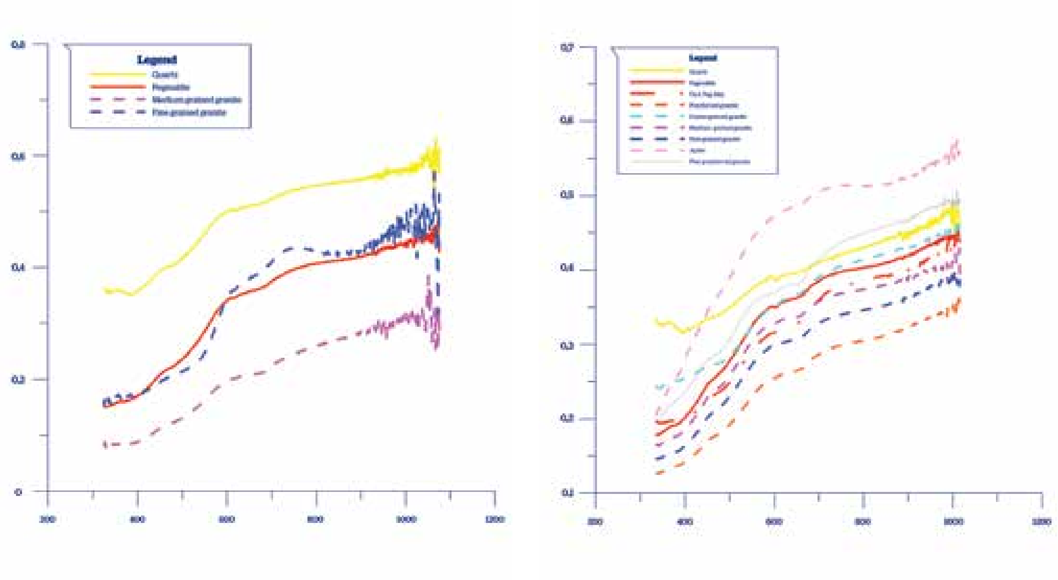


FIGURE VI.13

Spectral relationships obtained for the main lithologies observed in the study areas (Area G and overall average)

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 600μm 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 550μm, 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 - 760μm 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 425-580μm. 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. kaolinization);
- Very localized hydrothermal alteration phenomenas and with less spatial expression (e.g. reddening, epidotization, zinwalditization).

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 lithologies, helping the remote mapping analysis.

The lichen coating, from 35% in outcrop area, acquires a mask effect that obliterates spectral relations, creating spectrally a self-signature, with typical low reflectances.

Likewise, rocks that exhibit neutral Munsell 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.

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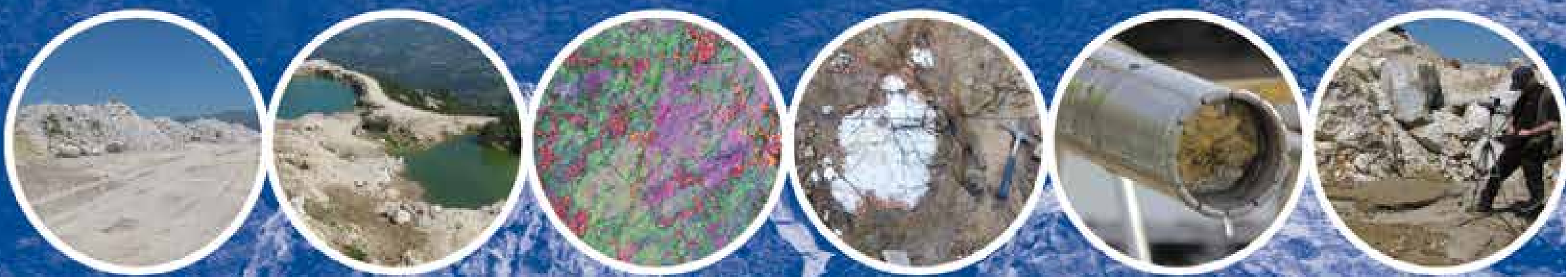

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