Research article

PEGMATITE FIELDS OF SÃO PEDRO DE FERROS, ANTÔNIO DIAS AND MARILAC, MINAS GERAIS STATE, BRAZIL: PETROGRAPHIC CHARACTERIZATION

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Abstract

Pegmatites are rocks of granitic or metasomatic origin with grains from 30 mm to gigantic crystals that are formed in fluid phase of the magmatic liquid, enriched with incompatible elements, thats why they can be considered as gemstones and industrial minerals deposits. Both geological studied mineralizations in the present article were formed by an anatexis process, with fractional crystallization, or partial fusion. The Jatobá Mine in the Pegmatitic Field of Ferros-Antônio Dias, in Santa Maria de Itabira, explores the aquamarine gem, a beryl variety, in a pegmatite that is located closer to the granitic system of the quartz core of the pegmatite body and is embedded in a gneiss granitic rock from the Guanhães Complex. The collected sample was a Quartz alkali feldspar sienite in the QAP diagram. The blue colour of beryl is mainly due to the presence of trace amounts of iron (Fe) as impurities within the crystal structure. On the other hand,

the Duas Cores Mining represents the Pegmatitic Field of Marilac, near Governador Valadares, where the primary interest lies in the exploration of bicolored tourmaline. This mineral is in a very weathered pegmatite, positioned more at the end of the granitic system and embedded in the mica-schist rock of the São Tomé Formation. The sample was named as a Tonalite in the QAP Diagram. The colour variation of the explored gem is related to the enrichment of the Li element in the cationic sites of its mineral structure.

Keywords: Pegmatites; Oriental Pegmatitic Province; Beryl; Quartz; Igneous process; Petrography.

Introduction

Pegmatites are rocks of igneous or metasomatic origin, with equi to unequigranular texture, generated in discontinuities of contacts borders, in dikes or pocket shapes, in a crystallization process with a fluid phase [11]. They are composed of alkali feldspars and quartz, and are usually present as accessory minerals like mica, tourmaline, beryl, and fluorite [13].

A common characteristic is that they have giant crystals and may represent potential deposits of industrial minerals (e.g., feldspar, muscovite), rare metals (e.g., lithium, tin, beryllium) and/or gems (e.g., aquamarine, topaz, tourmaline) [9].

Pegmatites are distal deposits of granitic rocks, i.e., they form mostly in the peripheral regions of the plutonic body, as well as skarns, veins, massive sulfides, and epithermal deposits [9]. The main economic interest related to the rock in this study is the exploration of beryl as gems, and as beryllium (Be) ore [7], as well as feldspars, widely used in the glass and ceramic industries [4].

In Brazil, there is a vast occurrence of pegmatites distributed in the Eastern, Northeastern and Southern Provinces [4], represented in Figure 1.

The Oriental Pegmatite Province (OPP) of Brazil is distributed along the states of Minas Gerais (MG), Espírito Santo and Bahia (Figure 1). The study area is within the OPP, in the Pegmatite Districts of Governador Valadares (DGV) and Santa Maria de Itabira (DSMI), in MG.

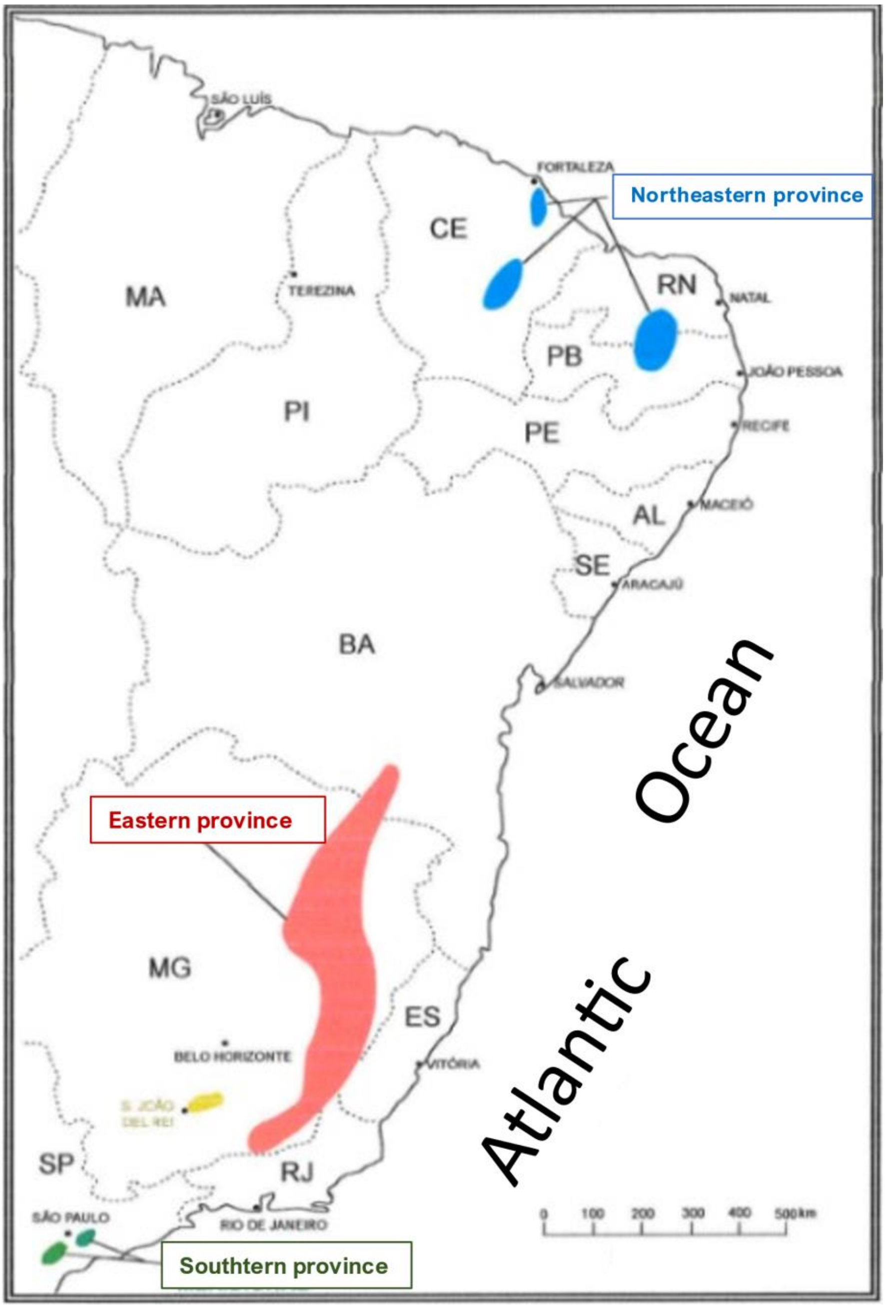

Figure 1. Pegmatite Provinces of Brazil grouped by Paiva, 1946. OPP is in the center of MG (Minas Gerais), BA (Bahia) and ES (Espírito Santo) states [4].

The present work will focus on the Ferros - Antônio Dias (DSMI) and Marilac (DGV) Pegmatite Fields, where aquamarine and niobium tantalates occur.

A distinction will be made of the mineralogical composition of the samples collected in the field, emphasizing the presence of gems. Thus, it will be possible to indicate the relationship between the genesis of the rocks and the minerals formed, and to compare the results of the Pegmatite Fields studied.

REGIONAL GEOLOGY

EASTERN BRAZIL PEGMATITIC PROVINCE (PPO)

The divisions and subdivisions of the pegmatite areas were proposed by Ginsburg's et al. (1979), cited by Marciano [7]. According to these authors, a Pegmatite Province is the grouping of pegmatite fields or belts of a single metallogenic unit. The Pegmatite Districts are inserted within the province and are differentiated through geological and geographical features. Pegmatite Fields unite rocks of a single formation type with the same age, igneous source, and geological-structural environment. The last subdivision is the Pegmatite Groups, where the morphological, structural, and textural patterns are well defined, as well as the structural control.

The Oriental Pegmatite Province (Figure 1) occurs in the São Francisco and Mantiqueira Provinces with the stratigraphy represented in Annex I. It is located along the Araçuaí Belt and the Atlantic Belt, from Zona da Mata (far south) to the Itambé region in Bahia (far north), extending 800 km in length and approximately 125 km in width [3]. The pegmatites of the region are both from granitic residual intrusive magmas, and anatectic origin, from partial fusion [8].

Bilal et al. [1] classified these two major groups of the pegmatite bodies of the OPP. The first one was generated in the first phase of the Brasiliano event (± 582 Ma) composed of zoned (quartz core) granitic pegmatites of fractional crystallization (550-700 ºC, 4-5 kbar), lithium enriched and associated to syntectonic magmatism. This group is found in the regions of Governador Valadares, Teófilo Otoni, São José da Safira, Galiléia, Araçuaí and Itinga.

The second is characterized by anatectic bodies.

Anatexis can be both a dry and a wet partial melting process, depending on the presence of fluids like water during the melting. In anatexis processes the focus is on the liquid that is generated and not on recrystallisation. Crustal granites are anatexis granites, in which the crust has undergone partial melting (anatexis process) [11]. The pegmatites formed are beryl-rich, originated by partial crustal melting during the second phase of the Brazilian event (520 to 500 Ma), along with porphyritic leucogranites. They are located in the regions of Caparaó, Espera Feliz, Santa Maria de Itabira and Marilac [1].

Gandini [4] places the Marilac Pegmatite Field within the Governador Valadares Pegmatite District, although the two units are part of distinct groups in the Bilal et al. [1] classification. However, it is consistent with the data of Dardenne and Schobbenhaus [3], which indicate that the Marilac Field is within the DGV, and is composed of anatectic pegmatites. Therefore, the two areas of the present work are composed of anatectic bodies.

PEGMATITE DISTRICTS OF THE STUDY AREA

The study area encompasses two pegmatite fields within the OPP, the Ferros-Antônio Dias Pegmatite Field (CFAD) and Marilac (CM), both in the state of Minas Gerais.

CFAD is in the Santa Maria de Itabira Pegmatite District (DSMI), and it includes other fields, such as the Guanhães-Sabinópolis field, in addition to CFAD [7] (Figure 2). The DSMI is limited by Serra do Espinhaço, to the west, and by Quadrilátero Ferrífero, to the south [7]. The CFAD is composed of zoned and simple pegmatites which are hosted in a volcanosedimentary sequence of Paleoproterozoic age, embedded in gneisses and granitoids. These pegmatites are embedded in the Guanhães Complex, which consists of gneisses and quartz-feldspar rich granitoids, with the presence of beryl and columbo-tantalite [2] [3].

The dimensions of the bodies can vary from 50 to 100 m in length, and from 5 to 10 m in average thickness, with tabular to lenticular shapes, and discordant with the host rocks [8].

As described earlier, the Santa Maria de Itabira Pegmatite District (SMIPD), in addition to encompassing the Ferros-Antônio Dias field, also includes the Guanhães-Sabinópolis field [7]. For understanding, it is observed that the mineralogy of the two fields is similar, being characterized by the presence of mica, quartz, microcline, ferrocolumbite-tantalite, euxenite, samarskite, monazite, fluorite, beryl, topaz, and garnet [8]. The economic importance of this area is primarily because it is a generator of emerald, alexandrite, and aquamarine [2].

Further northeast is the Governador Valadares District (DGV) (Figure 2), which includes the Marilac, Galiléia-Conselheiro Pena and São José da Safira Fields, a division proposed by Newman [8]. Biotite-schist is the most common source rock, but granitoids and quartzites also occur [8]. The pegmatites have tubular and lenticular shapes, concordant with the host rocks [3].

In the mineralogy of the Pegmatite Fields, it is observed the presence of beryls and tourmalines in Marilac; lithium minerals and phosphates in Galiléia-Conselheiro Pena; and colored tourmalines in São José da Safira stand out [8]. In addition, micas, feldspars (K and Na), spodumene, beryl, ambligonite, tourmaline and columbo-tantalite have been exploited since World War II from the pegmatites of the DGV. They are known for the quality of their gems and collectors' items, as there is a large quantity of agglomerated crystals [3].

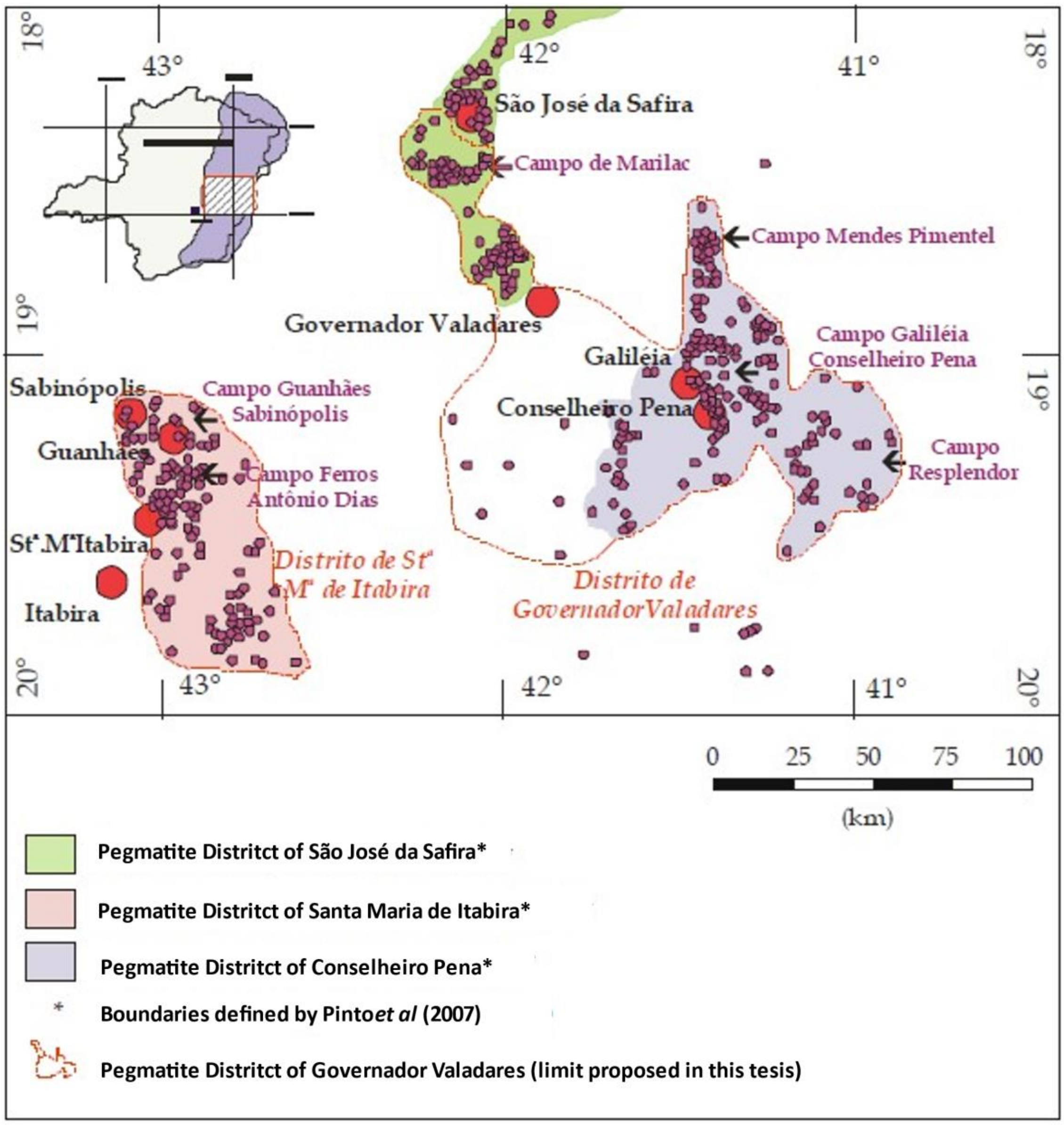

Figure 2. Pegmatite Districts of Santa Maria de Itabira and Governador Valadares with the limits proposed by Newman [8] in dotted line. The colored boundaries proposed by Pinto et al. [8], will not be used in the present work [8]

LOCAL GEOLOGY

PEGMATITE FIELD OF FERROS-ANTÔNIO DIAS

It is in the southeast border of the Araçuaí Belt within the DSMI (Figure 2), present in the geological sheets of Conceição do Mato Dentro, Itabira, Ipatinga and Coronel Fabriciano in the CPRM registry. In the northern part, the geology, presented in Annexes II and III, characterized by a volcanosedimentary sequence, and related to the Borrachudos Suite (Paleoproterozoic granitic event). The mineralized region is close to the contact of the Guanhães Complex (granites with ultramafic schists/gnaisses) [2].

In the southern part (Annexes IV), the country rocks can be a fine to medium leucocratic gneiss composed mainly of quartz, feldspar and biotite, also a medium-grained mesocratic foliated granite [2].

The pegmatite bodies are often simple and zoned (core of milky quartz, intermediate zone of K-feldspar and quartz and an undifferentiated zone with quartz, muscovite, kaolin, albite, and feldspar) [2]. These bodies have dimensions of 10 to 50 m long and 5 to 10 m thick with a predominantly tabular shape and sometimes lenticular. Some are concordant with the host rocks, but others are discordant [8].

The essential mineralogy consists of alkali feldspar, muscovite and quartz, and the accessory minerals are beryl, fluorite, titanite, pyrite and garnet [8].

According to Silva [2], in the Second World War mica was intensively exploited, in rocks with occurrence of amethyst and topaz as well. Currently, the main mineral exploited is aquamarine, with a small production of emerald, alexandrite, and garnet. The minerals kaolin, muscovite, feldspar, and quartz are stockpiled as by-products. Columbite/tantalite is rarely found.

The Jatobá mine, visited during the CFAD study, is represented by point number 10 on the CPRM pegmatite registration map [2] inserted in this work as Annex II. It is in the Guanhães Complex, a basement divided into three formations: metavolcanic rocks; chemical and clastic metasediments with the presence of Itabirito (banded iron formation); graywacke and pelitic rocks transformed into gneisses with bands of quartzite, ferruginous quartzite, ironstone formations and amphibolite [8].

PEGMATITE FIELD OF MARILAC

Marilac is located northwest of Governador Valadares, within the DGV. It is inserted in the Santa Maria do Suaçuí and Marilac sheets, in the CPRM registry, and represented by Annex V with its geological information.

The pegmatites are predominantly zoned, tabular or lenticular, medium sized, concordant with the host rocks, but can be homogeneous, large, and small sized, and discordant. They are mainly inserted in mica schists of the São Tomé Formation (Rio Doce Group), in the Santa Rosa Granite and in the Basal Complex (biotite gneiss), rarely occurring in quartzite and calc-silicate rocks [2] [8].

The main mineralogy is composed of K-feldspar, quartz, muscovite, with accessory biotite, kaolinite, albite, apatite, autunite, beryl, niobium-tantalates, tourmaline, and garnet [8]

During World War II, the war industry of the Allied Countries was supplied by the production of mica and beryl from CM [2]. Until this day the region is of great economic importance for the exploitation of gems, collection minerals, and industrial minerals, such as quartz of various varieties, feldspar, kaolinite, mica, garnet, niobium-tantalates, tourmaline (black, blue, and pink), and beryl (industrial, aquamarine, morganite, and goshenite) [8].

Duas Cores Mine, visited for the CM study, is represented in Annex V by the point number 10. This mining is inserted in the São Tomé Formation, characterized by metasediments composed of schists of mineralogy essentially composed of quartz, mica, feldspar, and sillimanite, with minor amounts of garnet, tourmaline, quartz veins and dozens of pegmatites associated [8].

Materials and Methods

The first stage of the work consisted of bibliographic research to obtain information about the origin and economic importance of the pegmatites. After data collection, the study has been chosen, being the Pegmatite Field of Ferros-Antônio Dias and the Pegmatite Field of Marilac. The maps used for orientation were the Geological Map of Santa Maria do Suaçuí and Marilac, for the Governador Valadares field [2], and the maps of Conceição do Mato Dentro, Ipatinga, Itabira and Coronel Fabriciano for the Santa Maria do Itabira field [2].

Based on the CPRM pegmatite bodies registry [2] (maps represented in

Annexes II, III, IV and V), the areas Jatobá Mine (DSMI) and Duas Cores Mine (DGV) were defined as targets for the work.

After visiting the fields and collecting samples from each area, these samples were analyzed and described macroscopically for classification on the QAP Diagram (Streckeisen [12]). A thin section was also made for the Ferros-Antônio Dias Field (Jatobá Mine) and described microscopically.

Results

JATOBÁ MINE

The visit to the Jatobá Mine, coordinates 706000L and 7856700N, located in the Guanhães Complex, took place on October 2017. Strong weathering was observed in the kaolin and in the host rock, the granite gneiss (orthogneiss). The mine comprises two bodies/veins, one mineralized and the other barren. The mine explores aquamarine, the blue variety of beryl; however, the minerals quartz (smoky and hyaline); K-feldspar; muscovite and biotite, and, more rarely, amethyst, fluorite and albite are also found. The Jatobá Mine is 30 meters long and 7 meters deep, has produced many gems of high economic value and is still active.

After visiting the Jatobá Mine, two sample of pegmatite were collected of which one was described macroscopically (Figure 3). The sample is phaneritic, leucocratic, supersaturated in silica, with a massive structure, composed of K-feldspar, biotite, and quartz.

K-feldspar (65%) has hypidiomorphic prismatic habit to xenomorphic crystals, with fine- to medium-grained (<1 mm to 3 mm). The biotite (20%) has lamellar habit, fine to medium grain size (<1 mm to 3 mm). Quartz (15%) presents granular texture with fine to medium grain size (<1 mm to 2 mm).

According to the QAP Diagram (Annex VI), the pegmatite rock sample is classified as a quartz alkali feldspar syenite.

Figure 3. Pegmatite sample, classified as Quartz alkali feldspar in the QAP Diagram, with K-feldspar grain size between < 1mm and 3 mm, biotite grains size between <1 mm to 3 mm, and quartz grain size between <1 mm and 2 mm, collected at the Jatobá Mine.

DUAS CORES MINE

The visit to Duas Cores Mine (805666L and 7956656N), occurred also in October 2017. It was observed that the mica schist bedrock of the São Tomé Formation was highly weathering and transformed into very fine kaolin with several veins of quartz and muscovite, besides the presence of schorlite (black tourmaline) with very weathered and agglomerated crystals. The gem explored in this mine is bicolor tourmaline. Despite not having much economic value, schorlite is easily found, and is of great relevance, since it is an indicator of other minerals of interest. Rarely, there is the presence of tourmaline in blue and green colors, as well as in varieties known as aquamarine, green apatite, blue, and pink, along with a small presence of citrine and hyaline quartz crystals. The mine is 300 meters long and 20 meters deep and was in maintenance stage, so the gems were not yet being extracted.

After visiting Duas Cores Mine, the sample collected in the field was described (Figure 4). The pegmatite sample is phaneritic, holocrystalline, supersaturated in silica, with a massive structure, and composed of plagioclase, quartz, and black tourmaline, which grain sizes varies between <1 mm to 1.5 cm.

The plagioclase (70%) shows hypidiomorphic tabular habit to xenomorphic crystals, with fine to coarse granulation (<1 mm to 1.5 cm). Quartz (25%) shows hypidiomorphic prismatic habit, with fine to coarse granulation (<1 mm to 1.3 cm). Black tourmaline (5%) has a hypidiomorphic hexagonal prismatic habit, with fine to coarse grain size (<1 mm to 1.5 cm).

According to the QAP Diagram [12] (Annex VI), the pegmatite rock sample was identified as a Tonalite.

Figure 4. Pegmatite rock sample, classified as a Tonalite in the QAP Diagram [12], with plagioclase grain size between <1 mm and 1.5 cm, quartz grains size between <1 mm to 1.3 cm, and black tourmaline grain size between <1 mm and 1.5 cm, collected at Duas Cores Mine.

The study of the thin section (Figures 5 and 6) indicates the presence of microcline (40%), orthoclase (18%), plagioclase (15%), quartz (10%), biotite (7%), amphibole (5%), opaque minerals (3%) and accessory minerals (2%). The microcline found presents granular texture, with fine to medium grain size (1 mm to 3.75 mm) and irregular contact. On the other hand, the orthoclase is granular, with fine to medium grain size (0.3 mm to 3 mm), and irregular contact. The plagioclase shows granular texture, with fine granulation (0.4 mm to 0.9 mm), and irregular contact. In the sequence, the quartz shows granular texture and fine to medium grain size (0.2 mm to 3 mm), with inclusion of sericite, amphibole, and biotite, and irregular contact. Biotite showed hypidiomorphic lamellar habit of fine to medium grain size (0.17 mm to 1.42 mm) and irregular contact. Amphibole showed granular texture and fine-grained (0.12 mm to 0.43 mm) and irregular contact. Finally, the opaque minerals showed granular texture, fine to medium-grained (0.12 mm to 4 mm) and irregular contact.

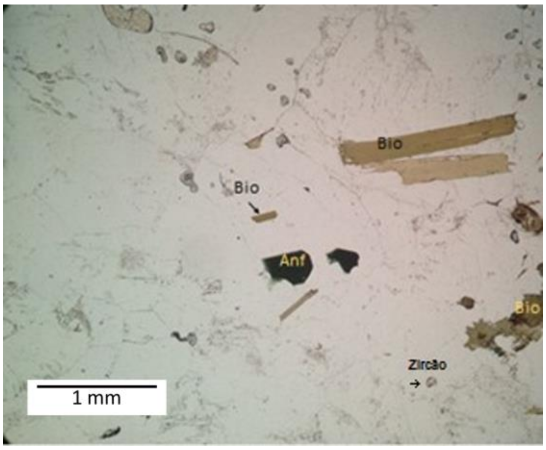

Figure 5. Parallel Nicol thin section with presence of biotite (Bio), amphibole (Anf) and Zircon.

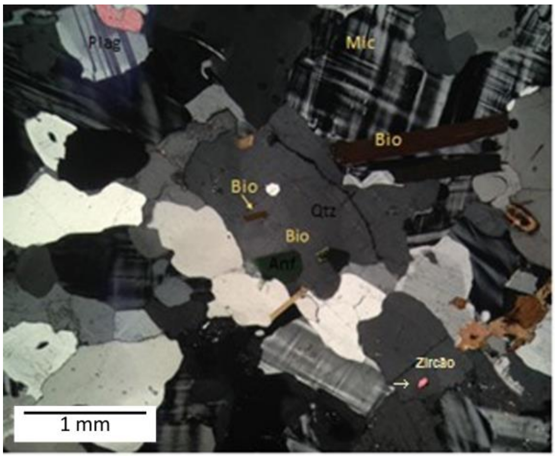

Figure 6. Crossed nicols thin section showing a quartz crystal (Qtz) with inclusion of biotite (Bio), amphibole (Anf) and Zircon. In addition to showing microcline (Mic) crystals with cross-hatched twinning and polysynthetic twinning plagioclase (Plag).

Both pegmatites studied in the present work were formed by an anatexis process, in which liquids resulting from partial melting were involved [11]. The composition of anatectic pegmatites, in general, corresponds to the lower temperature liquids in the Ab-An-Or-Q-H2O (albite-anortite-ortoclase-quartz-water) occurs within granitic systems [10]. The existing of incompatible elements present in the fluid phase, together with the enrichment of water vapor rejected by the quartz and feldspar structures, causes the residual magmatic fluid to be enriched in elements such as Li, Be, B, C, P, F, Nb, Ta, Sn, W and others.

Both chosen pegmatite areas are complex, thus presenting a marked mineralogical zoning with a quartz core, surrounded by a zone with large feldspar crystals, where rare minerals and gems (such as Beryl) are concentrated, followed by a band of quartz and feldspar of smaller granulation, and, closer to the bedrock, muscovite, or tourmaline [10], as exemplified in Figure 7.

Despite the similarity of the formation environments, the mineralogy of the pegmatite in this work shows some differences in their mineralogy and, so in their gems also. The Jatobá Mine, in the Ferros-Antônio Dias Camp, presents a pegmatite body hosted in orthogneiss of the Guanhães Complex. The gem found is Aquamarine, a variation of Beryl, but there is also exploration of feldspar, quartz, and mica. In Duas Cores Mine, in the Marilac pegmatite field, the bedrock is mica schist from the São Tomé Formation, and the most important gem is tourmaline and its variations (bicolor, black, green, and red), where beryl, goshenite, garnet, morganite and quartz are also explored [2].

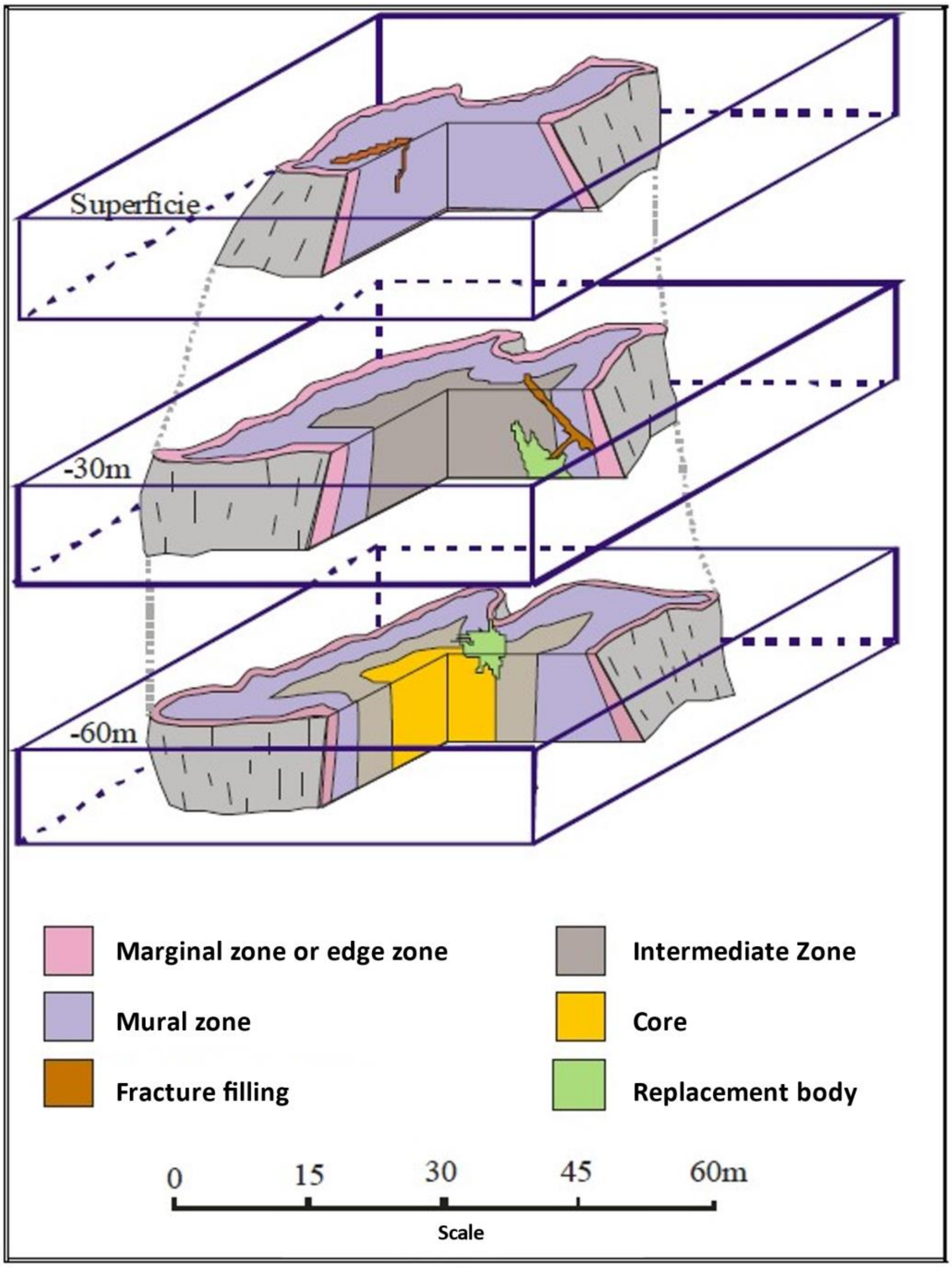

Figure 7. Block diagram representing the basic internal structure of zoned pegmatitic bodies and the relationship between zones [8].

Conclusion

The pegmatites of the Marilac and Santa Maria de Itabira area (CFAD) are simple, predominantly zoned bodies, with a quartz core, rich in gem and industrial minerals. It was concluded in this work that aquamarine (Be_3 Al_2 [Si $O_6]_{18}$) from the Ferros-Antônio Dias Field forms in bodies closer to the core and its blue color is related to the intrusion of Fe in the mineral's structure [2]. In addition, the pegmatites producing tourmaline (Na,Ca)(Mg,Al)$_6$ [B_3 Al_3 Si_6 (O,OH)$_3$ 0]) as in the Marilac Field, are positioned more externally in the intrusive igneous body, and the bicolor variation of the tourmaline extracted in Duas Cores Mine refers to the Li [10].

The study of pegmatites is not something simple and can cover a range of opportunities. These are bodies that vary their composition mainly among accessory minerals according to their position in the granitic system. The studied bodies may comprise large crystalline bodies with high economic value, but more in-depth and detailed work is needed in the future to determine the cost and profit of gem exploitation.

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Annexes

Annex I

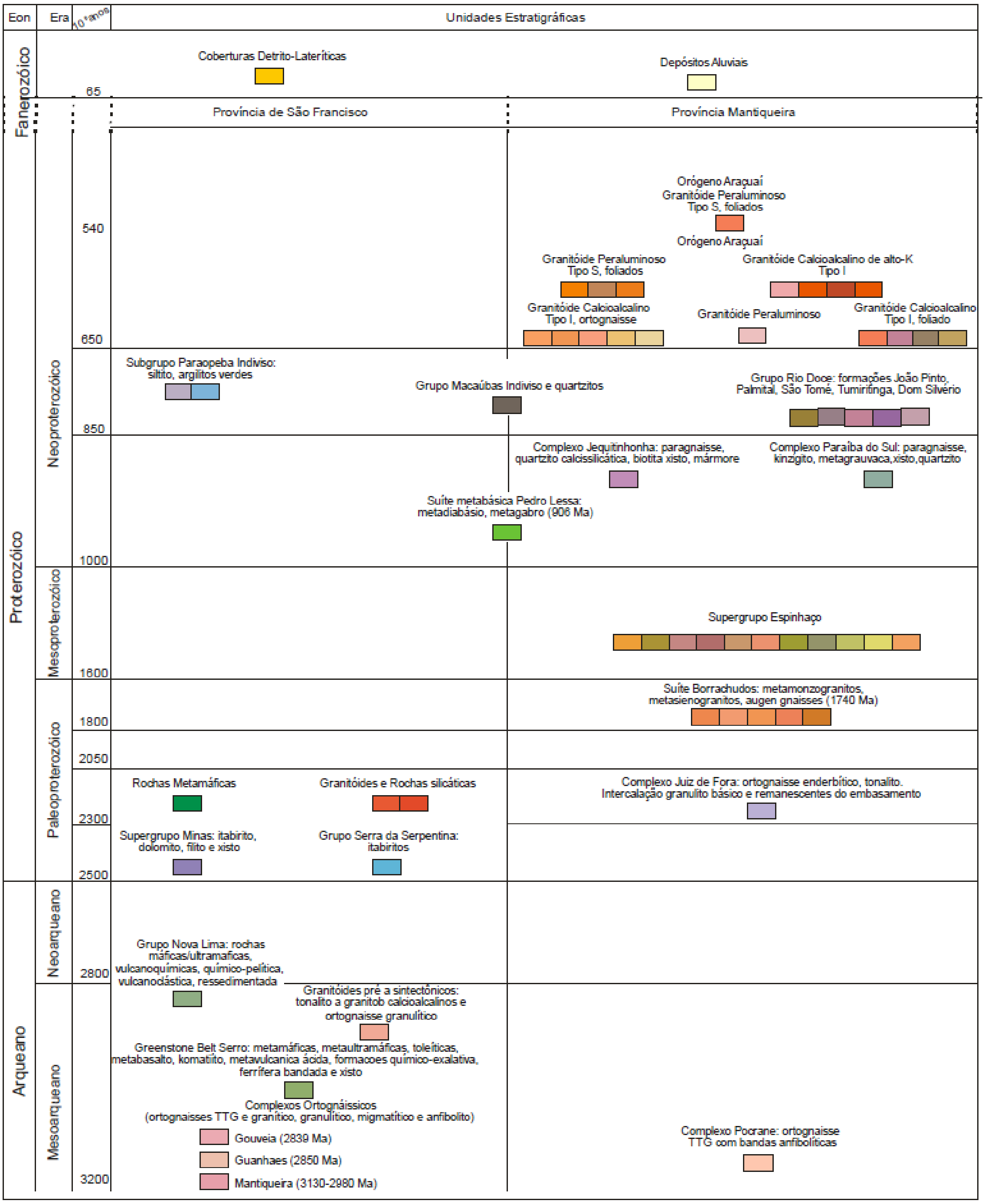


Figure 8. Stratigraphy of the São Francisco and Mantiqueira Provinces. The CFAD is located within the Guanhães Complex, and the CM in the São Tomé Formation (Rio Doce Group) [8].

Annex II

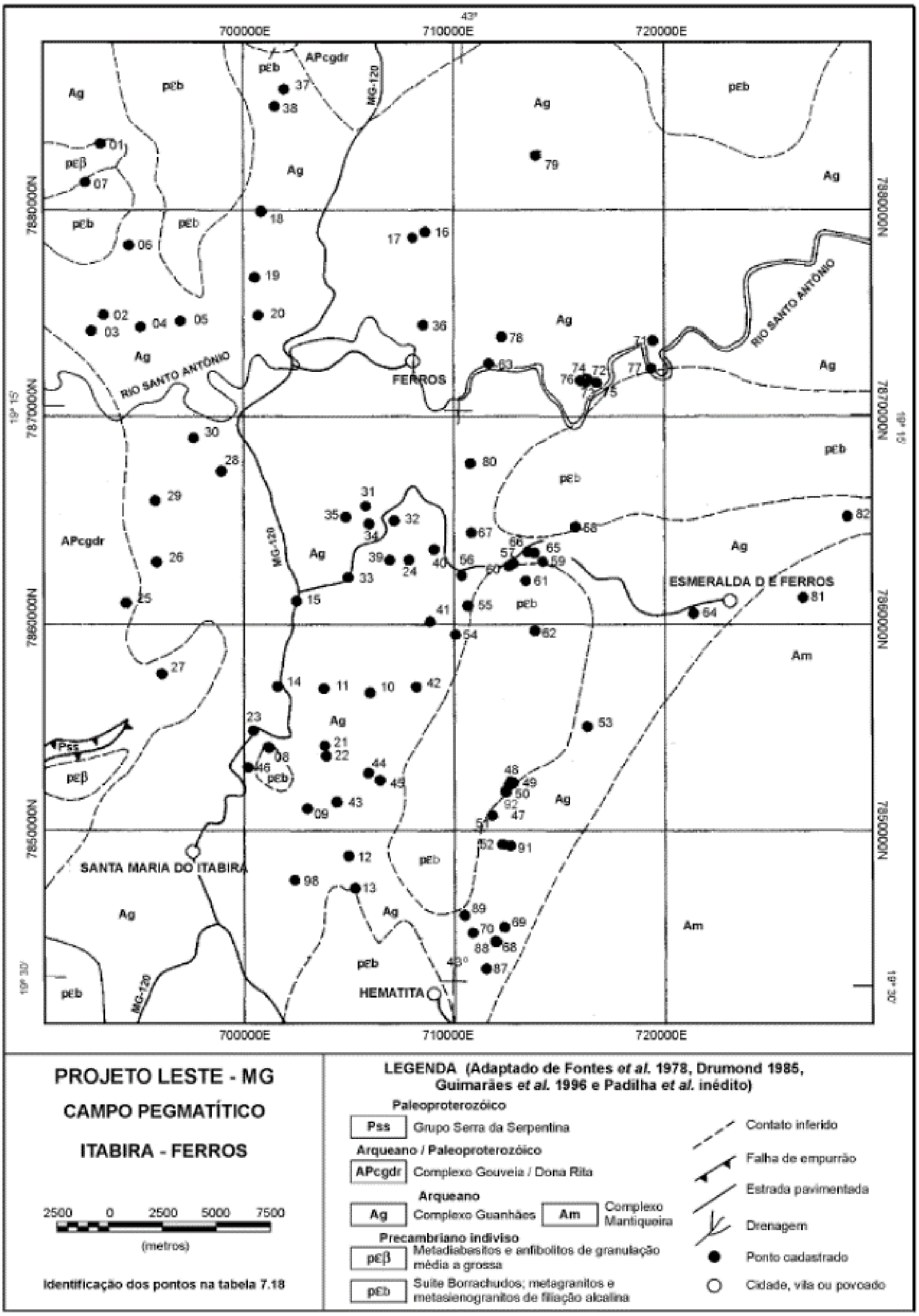


Figure 9. Simplified local geology of the Ferros-Antônio Dias Pegmatitic Field (northern area). The Jatobá Mine is located at number 10 [2].

Annex III

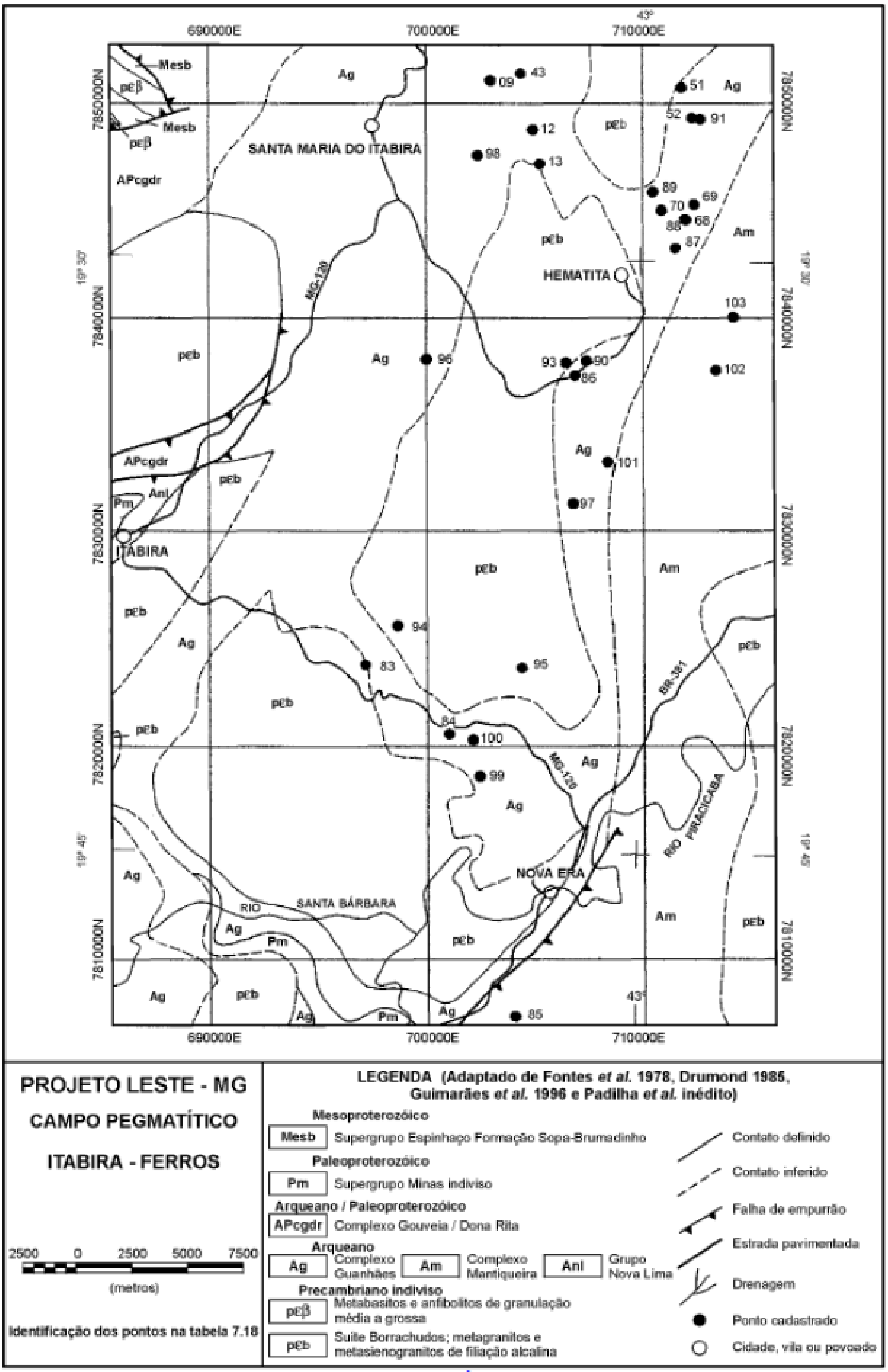


Figure 10. Simplified local geology of the Ferros-Antônio Dias Pegmatitic Field (intermediate sheet) [2].

Annex IV

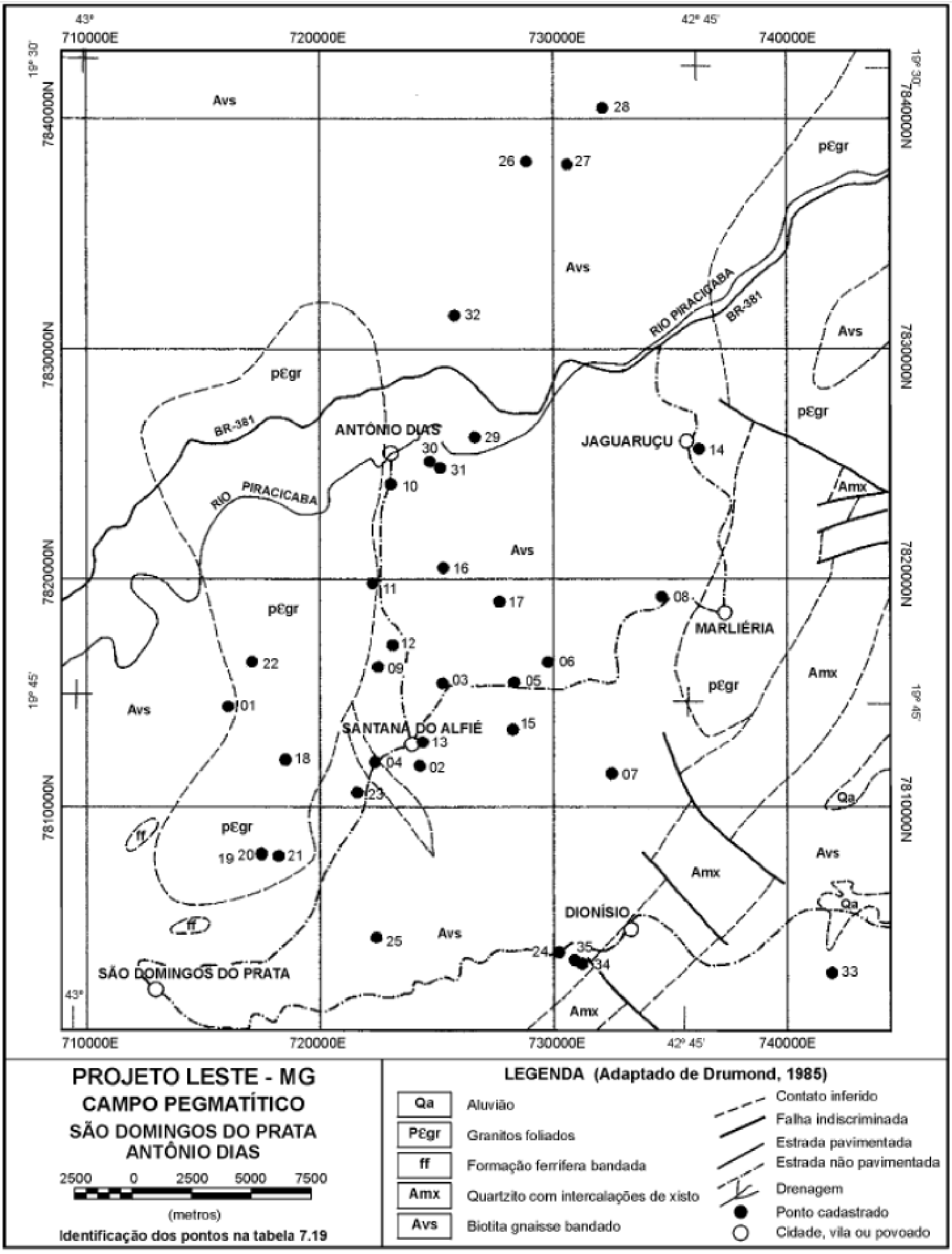


Figure 11. Simplified local geology of the Ferros-Antônio Dias Pegmatitic Field (southern area) [2].

Annex V

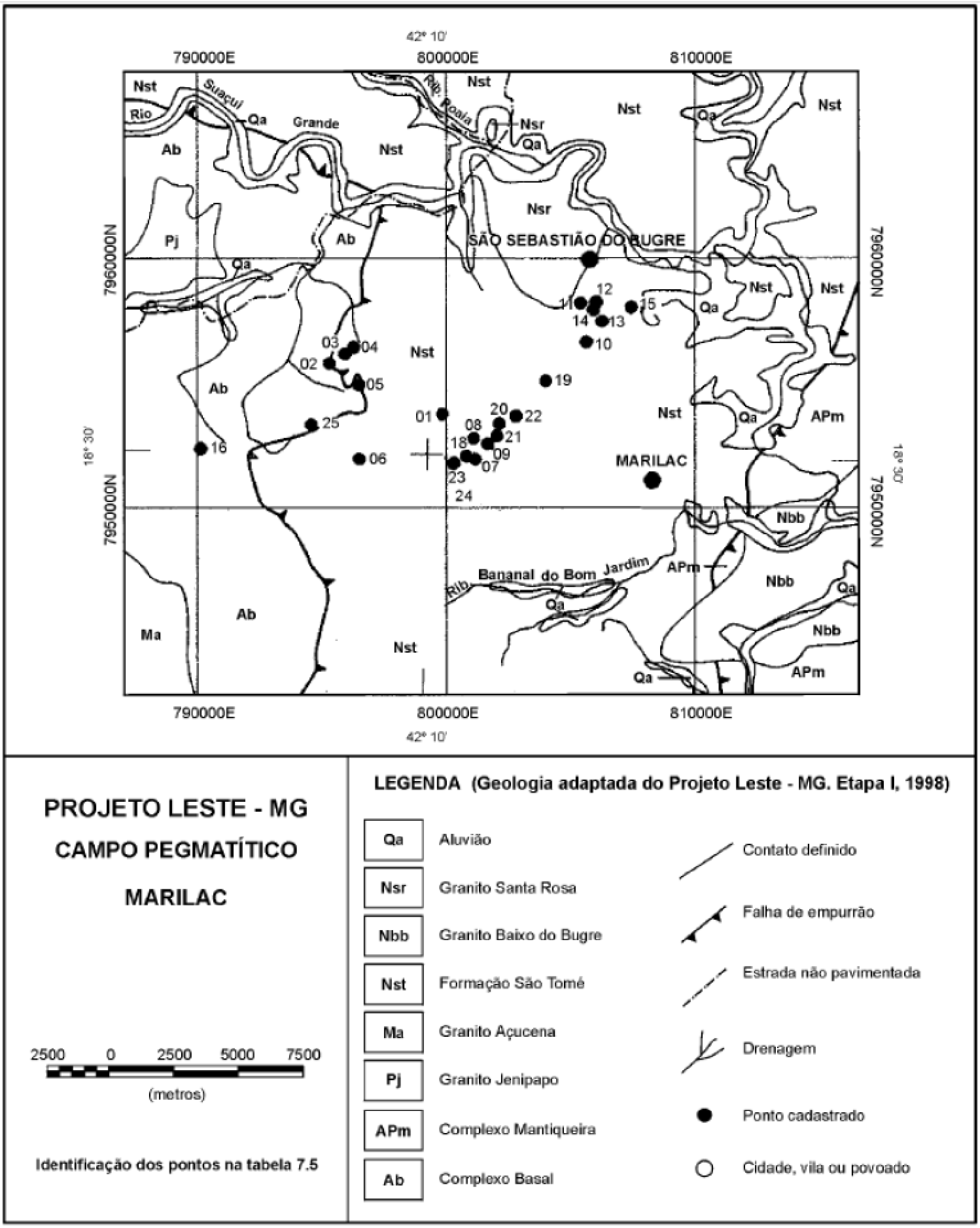
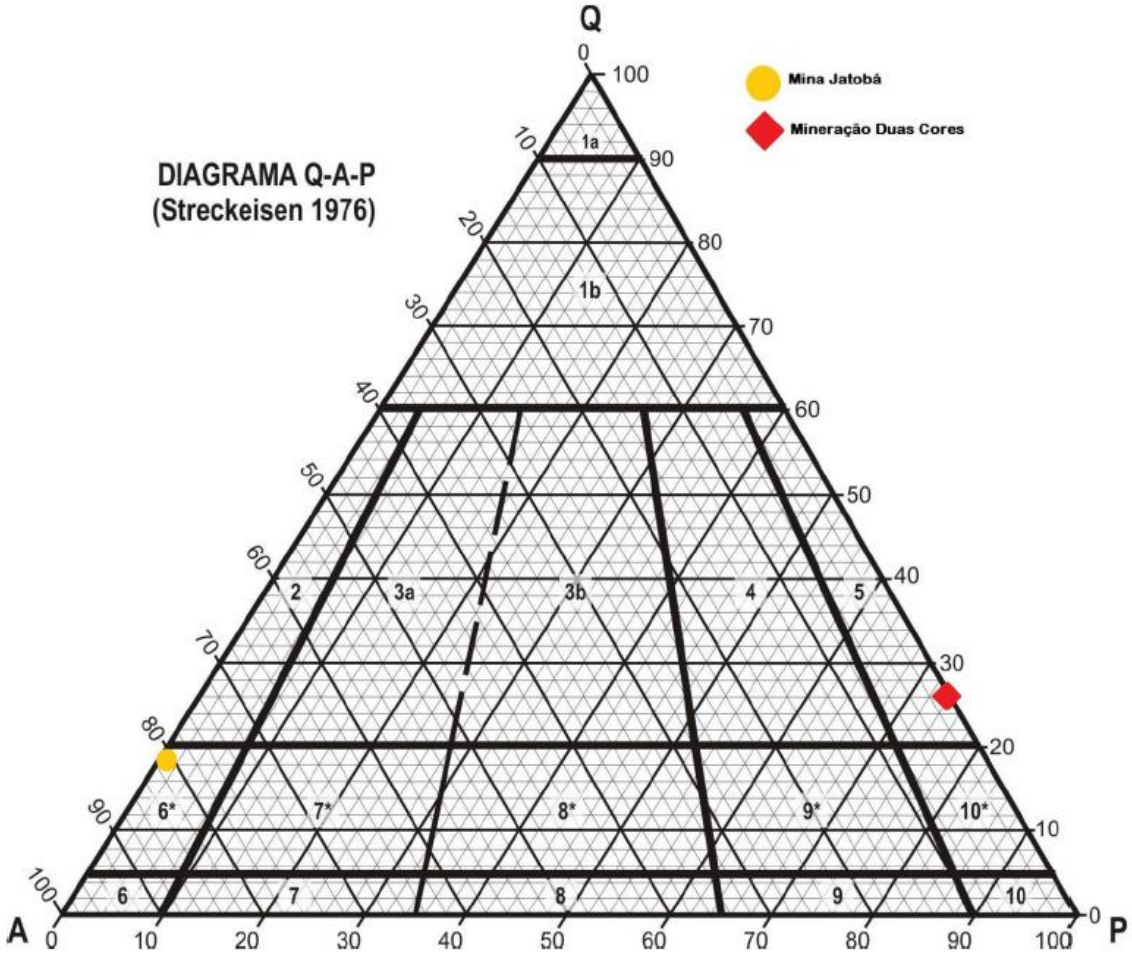


Figure 12. Simplified local geology of the Marilac Pegmatitic Field. The Duas Cores Mining is located at number 10 [2].

Annex VI



Rocha Plutônica	Rocha Vulcânica
1a = Quartzolito **1b** = Quartzo Granitóides	**2** = Álcali feldspato riolitos
2 = Álcali feldspato granitos	**3a/3b** = Riolitos
3a = Sienogranitos **3b** = Monzogranitos	**4/5** = Dacitos
4 = Granodioritos	**6** = Álcali feldspato traquitos
5 = Tonalitos	**6*** = Quartzo álcali feldspato traquitos
6 = Álcali feldspato sienitos	**7** = Traquitos
6* = Quartzo álcali feldspato sienitos	**7*** = Quartzo traquitos
7 = Sienitos **7*** = Quartzo sienitos	**8** = Latitos
8 = Monzonitos **8*** = Quartzo monzonitos	**8*** = Quartzo latitos
9 = Monzodioritos/Monzogabros	**9/9*/10/10*** = Basaltos/Andesitos
9* = Quartzo monzodioritos/quartzo monzogabros	
10 = Dioritos/Gabros/Anortositos	> 40% M = Basaltos < 40% M = Andesitos
10* = Quartzo dioritos/quartzo gabros/quartzo anortositos	

Figure 13. Streckeisen diagram with the plot of the obtained concentrations for the collected samples [12].