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PEG2009 PRE-SYMPOSIUM FIELD TRIP GUIDE: EASTERN BRAZILIAN PEGMATITE PROVINCE (MINAS GERAIS)

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Abstract

Pegmatite gemstones became officially known in the Brazil history since the last decades of the 17th century, when green tourmalines were found in the central-northeastern Minas Gerais region by Fernão Dias Paes Leme, one of the most famous leaders of Brazilian colonizers. Later, pioneer naturalists and geologists of the 19th century first decades, such as von Eschwege, von Spix & von Martius and Saint-Hilaire, referred to pegmatite gem deposits and/or trading of coloured gems in regions of the Araçuaí, Jequitinhonha, Doce and Mucuri river valleys. However, only in the 20th century, particularly during and after the Second World War, pegmatites became important mineral deposits in Brazil owing to efforts to increase the production of mica, beryl and quartz for the USA military industry. This mining development was accompanied by pioneer geologic studies and several new mineral specimens were discovered. Accordingly, the Brazilian pegmatite populations were grouped into the Eastern, Northern and Southern Brazilian pegmatite provinces. These provinces were defined mainly based on the geographical distribution of pegmatites, because at that time Brazil lacked geological maps even for a regional approach. This guide was elaborated for a pre-symposium field trip held before 2009 PEG - 4th International Symposium on Granitic Pegmatites, and focused on different aspects of pegmatites located in three important districts of the Eastern Brazilian Pegmatite Province (EBPP), namely São José da Safira, Conselheiro Pena and Araçuaí pegmatite districts. The field trip included from primitive garimpos for mineral exploitation to a very organized mine, showing pegmatites with different mineral (beryl, phosphate, spodumene or tourmaline) specializations that are related to distinct geologic settings and genetic conditions. A visit to a quarry for dimension stone on a pegmatite body was also scheduled. This guide also presents a synthesis on the geologic setting of the main EBPP pegmatite districts and their main features, followed by brief descriptions of the field trip

stops. Those were the Ipê Pegmatite in Governador Valadares town, Sapucaia Pegmatite in the town of Galileia, Boa Vista and Cigana Pegmatites in the town of Conselheiro Pena, K2 Ornamental Pegmatite Quarry in Itinga town, CBL Spodumene Mine in Araçuaí town, Água Santa Mine and a pegmatite swarm which occurs along a road cut of the BR-342, both located in the town of Coronel Murta.

Keywords: Pegmatites, Eastern Brazilian Pegmatite Province, Gemstones, Minas Gerais.

1. Introduction

The Eastern Brazilian Pegmatite Province (EBPP) encompasses a very large region of about 150,000 km^2, from Bahia to Rio de Janeiro states, but more than 90% of its area is located in eastern Minas Gerais State, specifically in the geotectonic unit called Araçuaí orogen (Fig. 1A). Since its definition by Paiva (1946) the limits and subdivisions of the province have been redefined and refined (Fig. 1B), according to more detailed maps and analytical data (*e.g.*, Correia-Neves *et al*. 1986; Pedrosa-Soares *et al*. 2001a, 2011; Morteani *et al*. 2000; Netto *et al*. 2001; Pinto & Pedrosa-Soares 2001).

During the 20th century, the pegmatites of the EBPP were mainly characterized by their gem production (aquamarine, tourmalines, topaz, quartz varieties and others), Sn, Li and Be ores, industrial minerals (mainly feldspars and muscovite), and rare minerals (phosphate and lithium minerals, oxides of Ta, Nb, U, and other minerals). Since the 1990's, however, the EBPP became a scenario of economic declining, because its long history of predatory mining together with increasing legal and environmental surveillance. In the 2000's, a new mining activity on pegmatites began; the quarrying for dimension stone, and, in many cases, has been much more economically attractive than the traditional *garimpos*.

2. Geological setting

More than 90% of the EBPP is located in the Araçuaí orogen that extends from the eastern edge of the São Francisco craton to the Atlantic margin (Pedrosa-Soares et al. 2001b, 2008, and references therein). Based on field relations, geochemical-petrological attributes and zircon U-Pb geochronological data, the granitic rocks of the Araçuaí orogen have been grouped into five different supersuites, named G1, G2, G3, G4 and G5 (Pedrosa-Soares et al. 2001b, 2008, 2011).

In relation to the development stages of the orogen, G1 is pre-collisional (630-585 Ma), G2 syn-collisional (585-560 Ma), G3 is late to post-collisional (545-520 Ma), and G4 and G5 are post-collisional (535-490 Ma). Both G1 and G2 supersuites underwent orogenic compressive deformation. G3 granites generally lack the regional foliation, whereas G4 and G5 consist of intrusive plutons that cut and disturb the regional structure.

Countless EBPP pegmatites crystallized from ca. 630 Ma to ca. 490 Ma, i.e., they are directly related to the development of the Brasiliano event. They are of two types: anatectic or residual pegmatites. The distribution of both pegmatite types, their relations to host rocks and parent granites, as well as their ages and main mineral resources allow to distinguish eleven pegmatite districts in the EBPP, Araçuaí orogen (Table 1

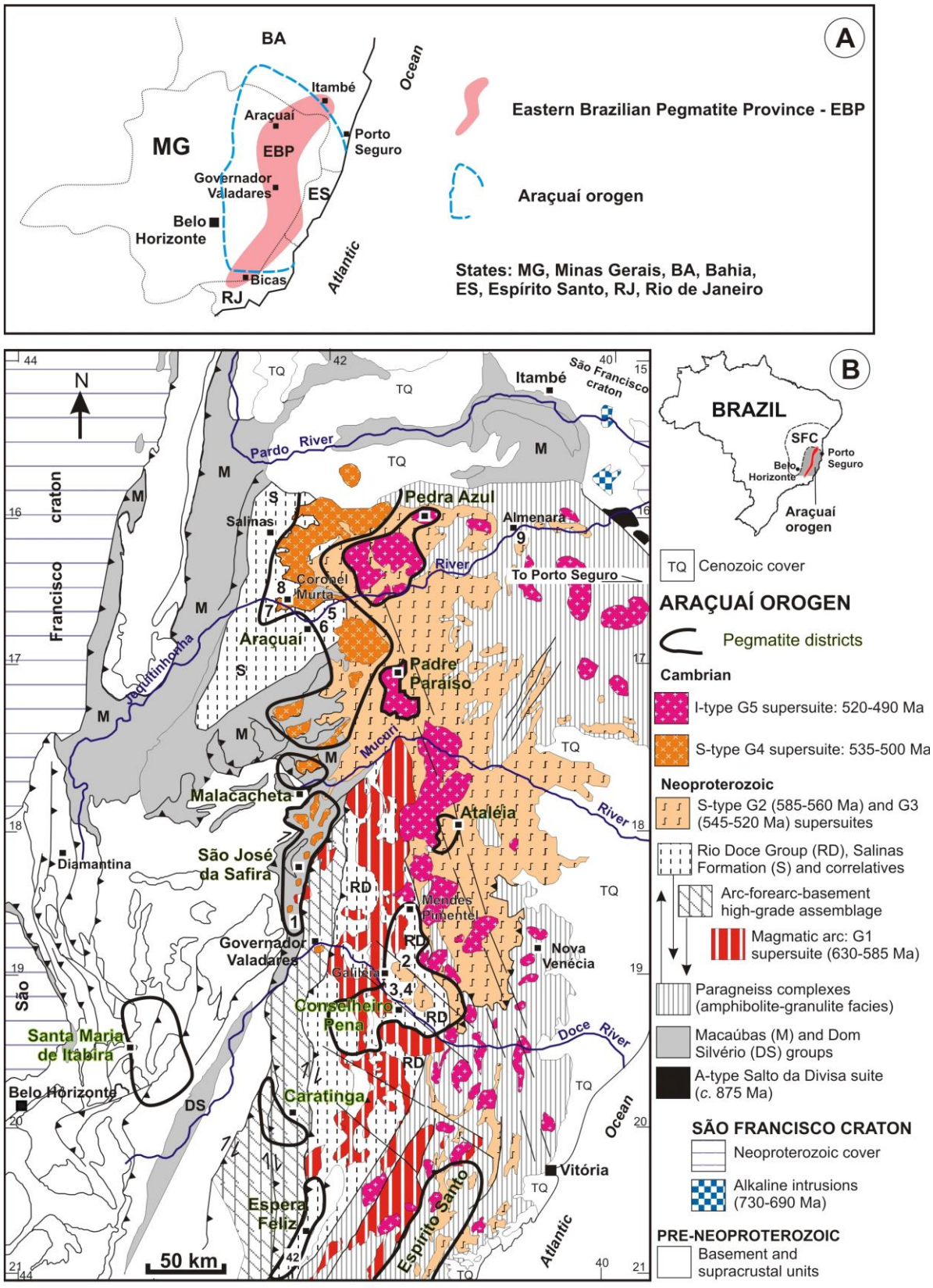

Figure 1: A) Location of the Eastern Brazilian Pegmatite Province (EBP). B), geological setting of the EBP districts in the Araçuaí orogen (modified from Pedrosa-Soares et al., 2001, 2009). Field trip stops: 1, Ipê; 2, Sapucaia; 3, Boa Vista; 4, Cigana; 5, K2; 6, CBL; 7, Água Santa; 8, Coronel Murta; 9, Cordierite Granite.

Table 1: EBPP pegmatite districts in the Araçuaí orogen (Pedrosa-Soares et al. 2011). Age references: a, Pedrosa-Soares et al. (unpubl. data); b, Noce et al. (2000); c, Whittington et al. (2001); d, Silva et al. (2008); e Petitgirard et al. (2009); f, Nalini et al. (2000a); g, Basílio et al. (2000); h, Ribeiro-Althoff et al. (1997); i, Fernandes et al. (2000); j, Queiroga et al. (unpubl. data); k, Horn (2007); l, De Campos et al. (2004). (*)Pegmatite size in relation to thickness: very small, < 0.5 m; small, 0.5 to 5 m; medium, 5 to 15 m; large, 15 to 50 m; and very large, > 50 m thick. (**) Based on Cerný (1991).

District name and age	Main mineral resources and collection minerals	Pegmatite size(*), type and class(**)	Parent and host rocks
Pedra Azul, *c*. 497 Ma[a]	aquamarine, topaz, quartz	very small to small, residual, rare element	G5 granites
Padre Paraíso, *c*. 519 Ma[b]	aquamarine, topaz, quartz, goshenite	very small to small, residual, rare element	G5 granite and charnockite
Araçuaí, 525-500 Ma[c.d]	spodumene, ornamental granite, ge varieties of tourmaline, beryl and quart industrial feldspar, schorl, amblygoni (montebrasite), albite, petalit cleavelandite, apatite, rare phosphate cassiterite, columbite-tantalite	very large to very small, residual, rare element	G4 granites; mica schist, metawacke, quartzite, meta-ultramafic rock
Ataléia, *c*. 519 Ma[b]	aquamarine	very small to small, residual, rare element	G5 granite
São José da Safira, *c*. 535 Ma[e]	industrial feldspar, tourmaline, beryl ore, muscovite, aquamarine, garnet, albite, cleavelandite, apatite, heliodor, Mn-tantalite, bertrandite, microlite, zircon	very large to medium, residual, rare element to muscovite	G4 granites; mica schist, metawacke, quartzite, meta-ultramafic rock
Conselheiro Pena, *c*. 582 Ma[f]	industrial feldspar, gem varieties of tourmaline, beryl and quartz, beryl ore, triphylite and rare phosphates, kunzite	very large to medium, residual, rare element	G2 granites; mica schist, quartzite, meta-ultramafic rock
Malacacheta, *c*. 535 Ma[g]	alexandrite, chrysoberyl, muscovite, beryl	residual pegmatites and hydrothermal systems	G4 granite; mica schist, meta-ultramafic rock
Santa Maria de Itabira, *c.* 650-500 Ma[h,i]	emerald, alexandrite, aquamarine, amazonite	hydrothermal systems and anatectic pegmtites	ultramafic schist, iron formation, migmatite
Caratinga, *c*. 575 Ma[j]	kaolin, corundum, beryl	anatectic, abyssal	migmatitic paragneiss
Espera Feliz, *c*. 500 Ma[k]	aquamarine, topaz, quartz	very small to small, residual, rare element	G5 granite
Espírito Santo, 575-490 Ma[l]	kaolin, quartz; aquamarine, topaz	mainly anatectic; very small to small residual bodies	migmatitic paragneiss and G5 granites

3. Field trip logistics

The area encompassing the province is shown in Figure 2. It is served mainly by Confins International Airport, Tancredo Neves and Teófilo Otoni Airport. The first field trip stop (Ipê Pegmatite) can be accessed from Belo Horizonte to Governador Valadares by BR-381 road for 360 km, and then for 38 km more to the NW of Governador Valadares through BR-451, BR-259 and unpaved roads. The region of Galileia is accessed from Governador Valadares 67 km to the east through BR-381 and BR-259. Second field trip stop (Sapucaia Pegmatite) is 16 km ENE of Galileia and is accessed by unpaved road. The third and fourth field trip stops (Boa Vista and Cigana Pegmatites) are reached from Galileia by BR-259 and unpaved road for 11 and 14 km to the south, respectively.

The other field trip stops, in the region of Araçuaí, are accessed from Governador Valadares passing through Teófilo Otoni and Itaobim towns by BR-116 for 300 km to the north. Then, Taquaral village is reached by BR-367 for 47 km WSW of Itaobim. From Taquaral, CBL Mine is 16 km SW through BR-367 and unpaved road. Araçuaí town is located 20 km SW of Taquaral village, also by BR-367 road access. From Araçuaí, Água Santa Mine is 43 km NNW through BR-342. Finally, the last field trip stop is a pegmatite swarm that occurs along a road cut of the BR-342, located around 2 km to the north of Coronel Murta town. Regional geologic maps of the focused areas, Galileia, Taquaral – Itinga, and Coronel Murta are shown in Figures 3, 4 and 5.

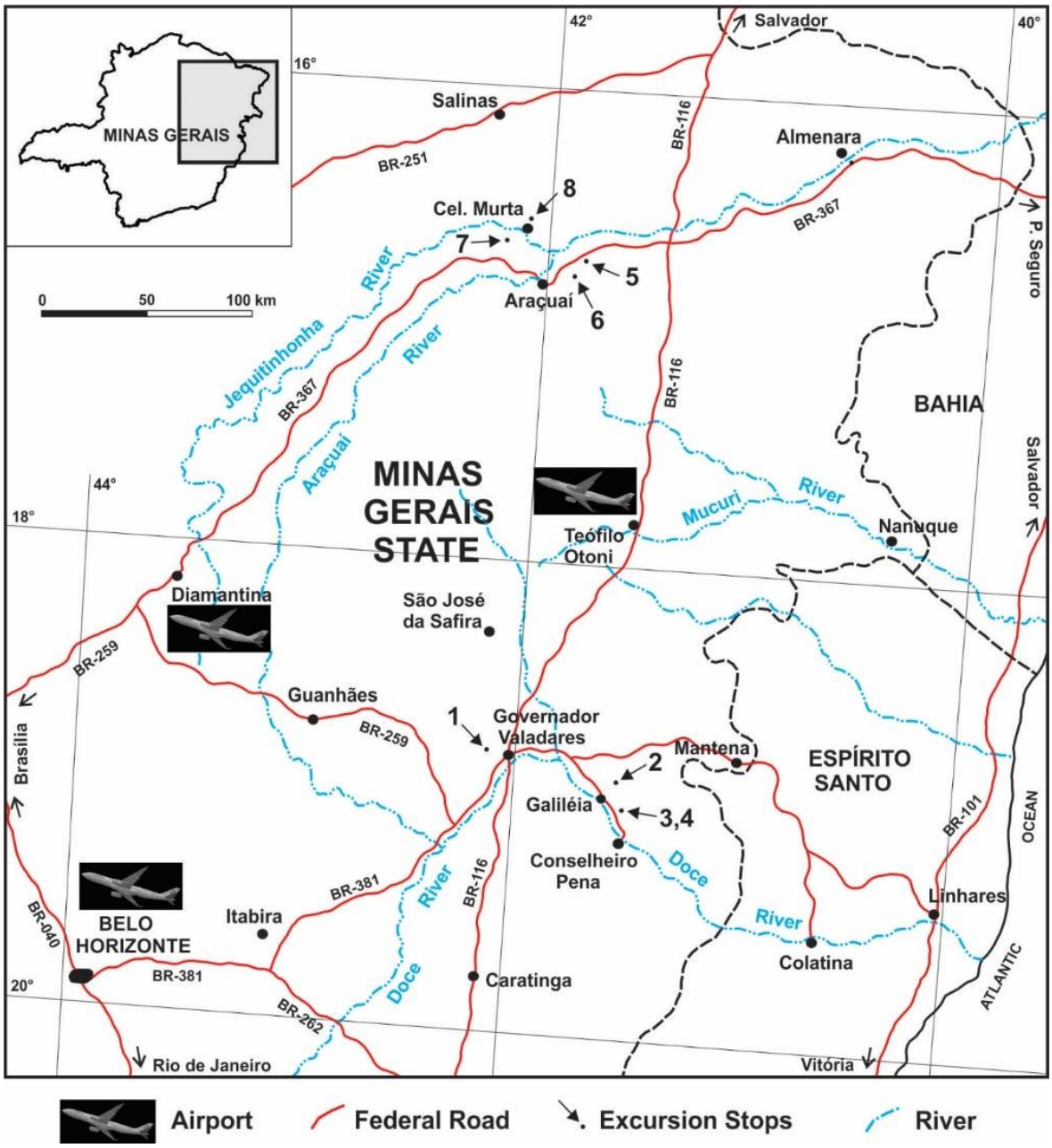

Figure 2. Location of field stops, roads and airports: (1) Ipê Pegmatite, (2) Sapucaia Pegmatite, (3) Boa Vista Pegmatite, (4) Cigana Pegmatite, (5) K2 Quarry, (6) CBL Mine, (7) Água Santa Mine, (8) Coronel Murta pegmatite swarm.

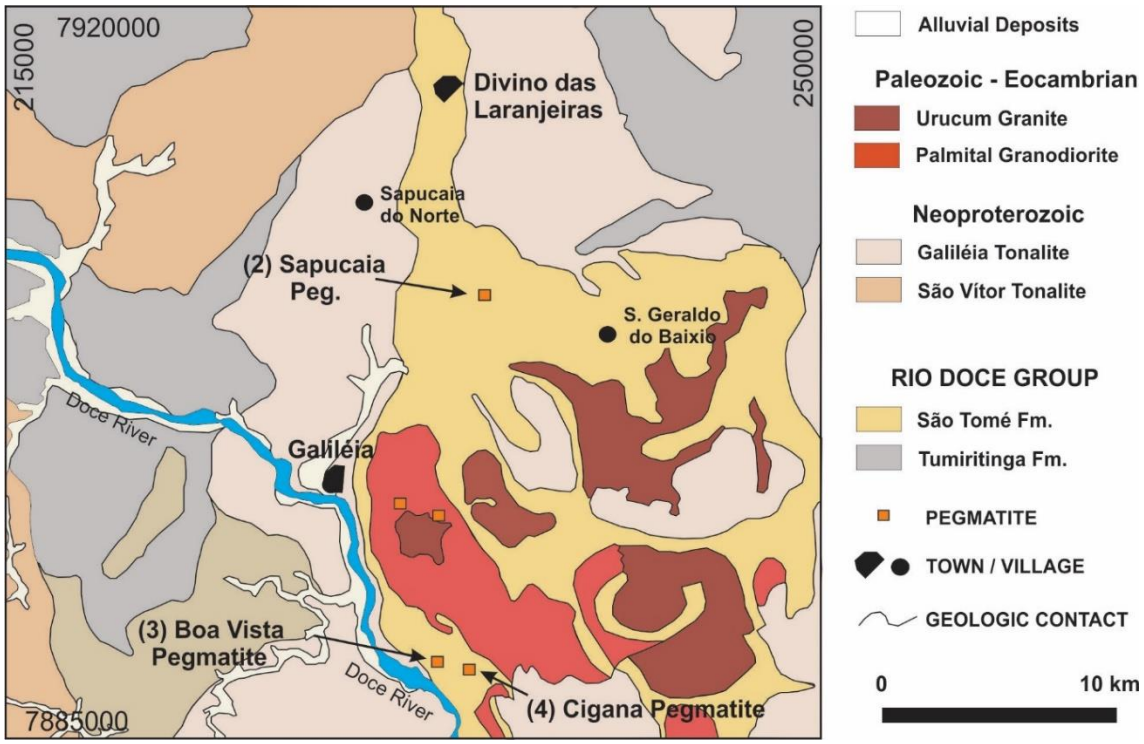

Figure 3: Geologic map of part of the Conselheiro Pena pegmatite district (according to Nalini et al. 2000b, and Vieira 2002). Field trip stops: (2) Sapucaia (Proberil) Pegmatite, (3) Boa Vista (Eduardo) Pegmatite, (4) Cigana (Jocão) Pegmatite.

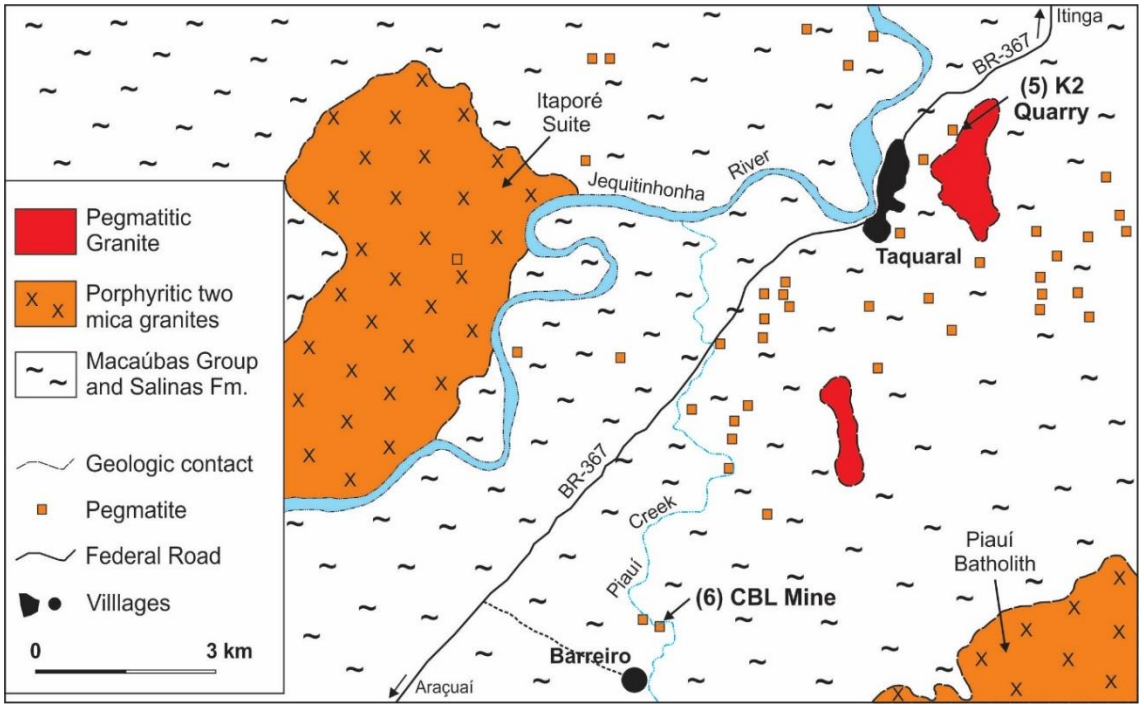

Figure 4: Geologic map of the Itinga pegmatite field, Araçuaí district (modified from Costa 1989, and Paes et al. 2008). Field trip stops: (5) K2 quarry; (6) CBL spodumene mine.

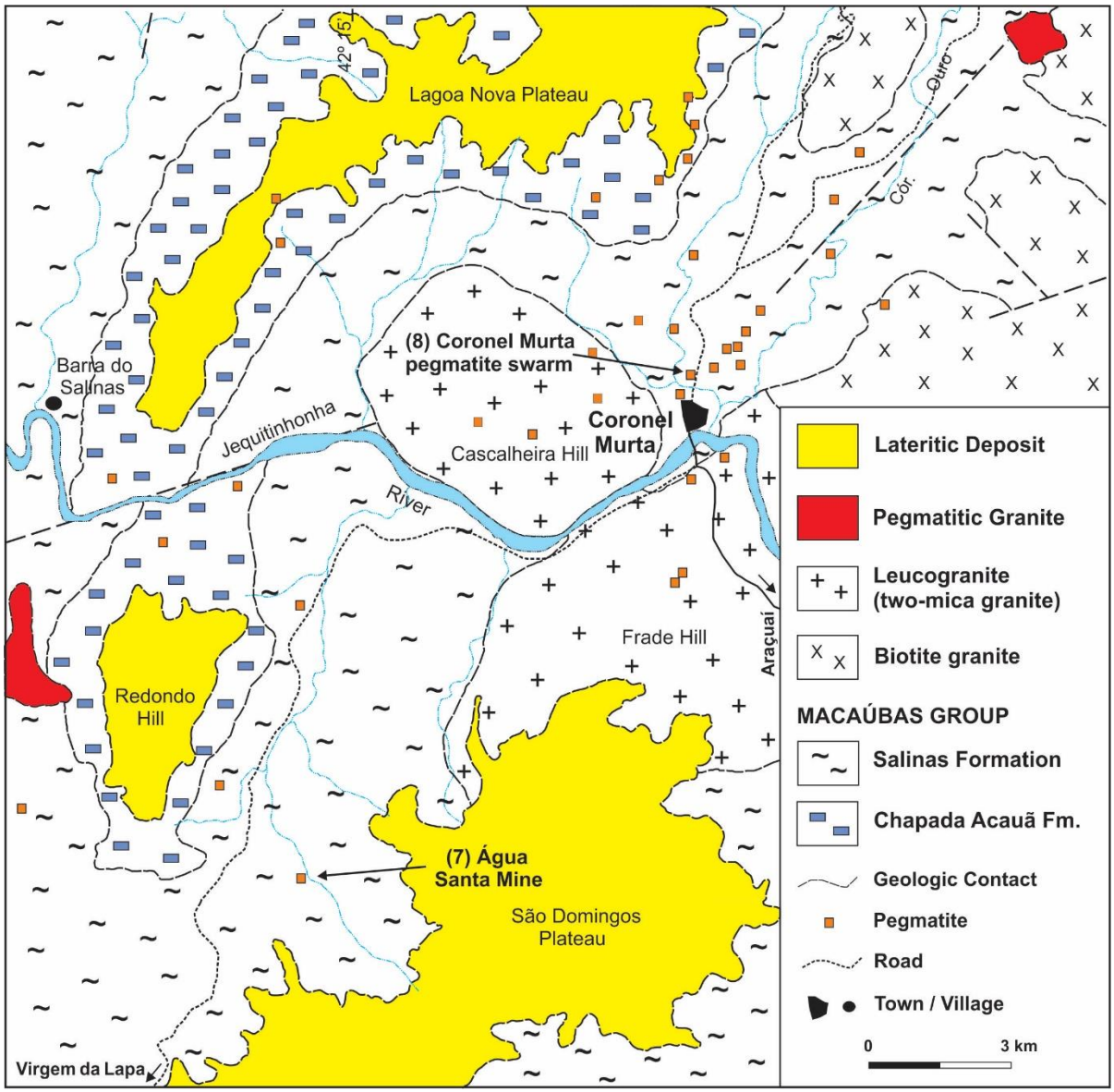

Figure 5: Geologic map and cross-section of the Coronel Murta pegmatite field (according to Pedrosa-Soares 1984, 1996, Pedrosa-Soares et al. 1990, 2001a). Field trip stops: (7) Água Santa Mine; (8) Coronel Murta pegmatite swarm.

4. Outcrops

The list of field trip stops described in the present guide is given in Table 2, with their UTM coordinates. Geological details and key points of each location are presented in the next sections.

Stop 1. Ipê Pegmatite

The Ipê Pegmatite (Fig. 6A and 6B) is located in the Golconda pegmatite field of the São José da Safira district (Fig. 1B and 2). Since the Second World War this pegmatite has been mined for beryl ore, muscovite, K-feldspar and collection minerals. Data from this pegmatite and its minerals are found, e.g., in Achtschin et al. 1996 and Netto et al. 2001.

Table 2: Field trip stops with UTM coordinates.

Field Trip Stop	Latitude coordinate	Longitude coordinate
Ipê Pegmatite	7925056N	805118E
Sapucaia Pegmatite	7908300N	238300E
Boa Vista Pegmatite	7888200N	235900E
Cigana Pegmatite	7888894N	237388E
K2 Ornamental Pegmatite Quarry	8153779N	197287E
CBL Mine	8142540N	189721E
Água Santa Mine	8151251N	792457E
Coronel Murta Pegmatite Swarm	8162400N	800440E

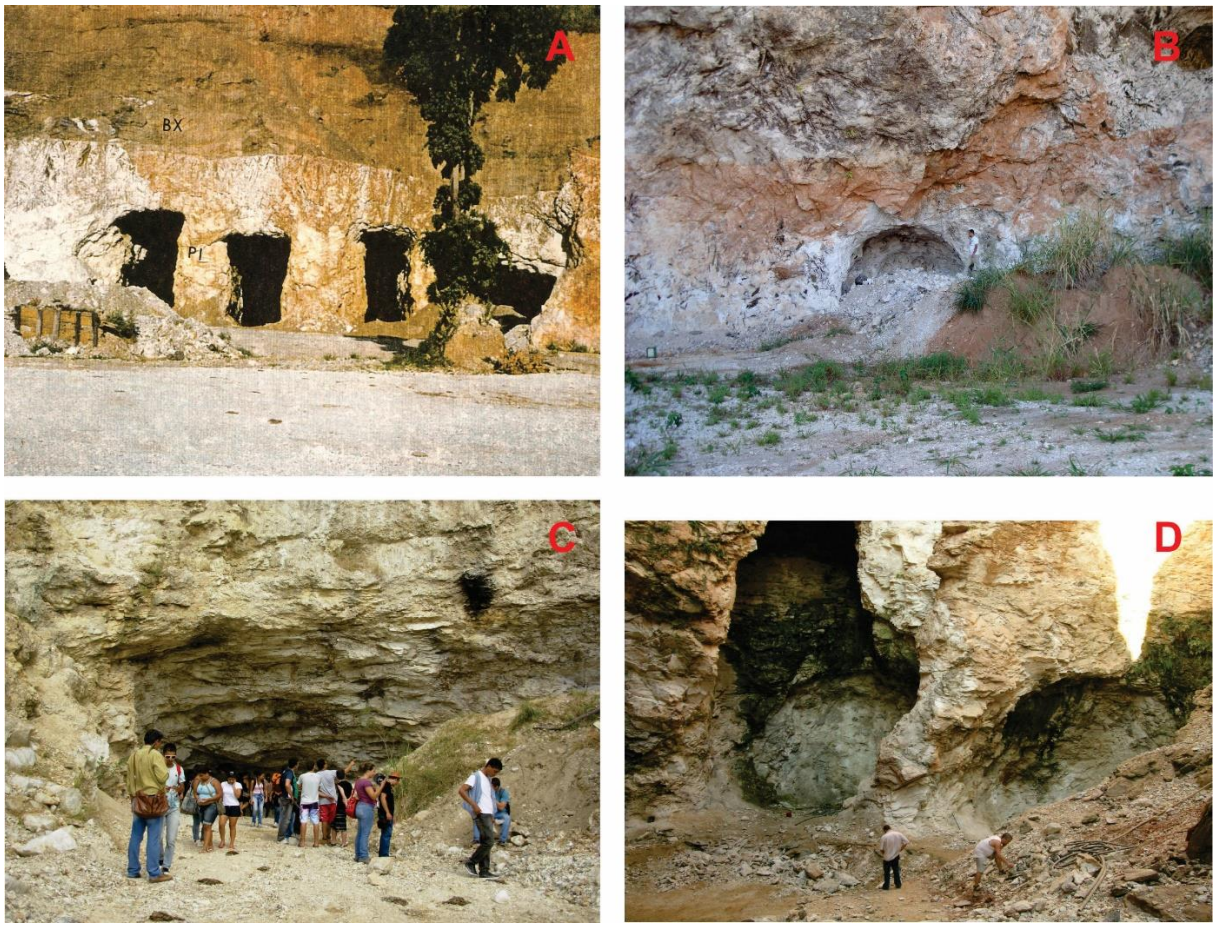

Figure 6: A. General view of the Ipê Pegmatite in the 1990s, showing its horizontal morphology. B. Same pegmatite, registered during pre-symposium field trip, when it was mined for rare minerals found within small replacement bodies. C. Sapucaia Pegmatite view during visitation occurred previously to the symposium with Minas Gerais Federal University students. D. General view of the Boa Vista Pegmatite (photos from the authors).

The host rock is a garnet-quartz-mica schist of the distal Macaúbas Group (Ribeirão da Folha Formation, cf. Pedrosa-Soares et al. 2001b, 2008; previously considered to belong to the Rio Doce Group by some authors). This rock shows a striking NNE-trending low-angle dip schistosity (dip azimuth / dip angle = 100/15º) that envelops the pegmatite body. The pegmatite shows many schist xenoliths and roof-pendants. Tourmalinization, with schorl crystals up to 3 cm, occurs in the schist along the contact with the pegmatite and around schist xenoliths. The Ipê pegmatite is a flat tabular- to lens-shaped body with a minimum thickness around 20 m and more than 100 m along the strike. Its dip is 15º ESE to horizontal. This pegmatite shows a clear primary zoned structure, fracture fillings and replacement bodies.

The upper marginal zone is 20 to 30 cm thick and consists of quartz, biotite, muscovite, perthite and albite. The wall zone, ranging in thickness from many decimetres to a few meters, consists of medium- to coarse-grained graphic intergrowth of perthitic K-feldspar and quartz, with minor muscovite, biotite, beryl, garnet and columbite-tantalite. Outstanding mica books are roughly orthogonal to the pegmatite upper margin. The intermediate zone consists of very coarse-grained (blocky) perthitic K-feldspar and minor colourless and rose quartz crystals, muscovite and beryl (including aquamarine). Giant crystals of perthitic K-feldspar commonly show cores of graphical intergrowth wrapped by pure perthite. The innermost primary zone is represented by massive quartz cores, composed of rose, milky and colourless quartz.

Fracture fillings cut primary zones and show a symmetrical banding given by alternating albite and muscovite-garnet bands. Corrosion texture can be seen in primary minerals close to fracture fillings. The replacement bodies (pockets) consist of cleavelandite, zoned greenish to yellowish gray muscovite, aquamarine, biotite, microlite and zircon. Superb samples of bertrandite, a very rare beryllium silicate hydroxide, have been found in the Ipê Pegmatite.

Stop 2. Sapucaia (or Proberil) Pegmatite

The Sapucaia Pegmatite (Fig. 6C) is located 16 km from Galiléia town (Fig. 3). It is hosted by biotite schist of the Rio Doce Group (São Tomé Formation; Netto et al. 2001). Sapucaia Pegmatite is a well-zoned lens- to balloon-shaped body, with the longer axis trending to NW-SE. The body dip is about 70º to NE.

It is a lithium-rich pegmatite with spodumene and triphylite. Internal hydrothermal (metasomatic) fluids and weathering processes generated many secondary phosphates after the primary phosphate (triphylite). The Sapucaia Pegmatite is the type-locality for eight minerals: arrojadite-(PbFe), barbosalite, faheyite, frondelite, lipscombite, moraesite, ruifrancoite and tavorite. Many other phosphates are known such as variscite, saleeite, phosphuranylite, vivianite, xenotime-(Y), sabugalite, meurigite-(K), laueite, cyrilovite, eosphorite, augelite, and bermanite (Scholz 2006; Scholz et al. 2008).

The mining activities started in the beginning of the 20th century, but the main activity was during the Second World War, for the production of industrial beryl and muscovite. Currently, the Sapucaia Pegmatite is mined for industrial feldspar and collection minerals.

Stop 3. Boa Vista (or Eduardo) Pegmatite

This pegmatite mine is located at the Boa Vista creek valley (Fig. 3), an important locality for the production of gem quality spodumene, tourmaline, morganite and quartz (Cassedanne & Cassedanne 1981). The pegmatite is mined as an open pit mine since the 1960's decade for the production of feldspar (Fig. 6D). The pegmatite body is hosted by a quartz-biotite schist of the Rio Doce Group. It is a NW-SE trending sub-vertical and well-zoned pegmatitic body. This pegmatite is a Li- and P-rich body, with minerals such as spodumene and triphylite.

Recently, well crystallized red variscite has been found.

Stop 4. Cigana Pegmatite

The Cigana Pegmatite (also called Jocão Pegmatite) is located 17 km from Galiléia (Fig. 3). Since the 1960's, it has been mined for production of industrial feldspar (perthite), spodumene, beryl and samples for collection. It is also hosted by a quartz-biotite schist of the Rio Doce Group. Its longer axis trends in the NW-SE direction with a sub-vertical dip. It is also a pegmatite rich in Li and P, with significant contents of spodumene and triphylite. Hydrothermal/metasomathic fluids generated within the pegmatite and the weathering process produced many secondary phosphates after the primary phosphate triphylite, including reddingite, hureaulite, lithiophilite, vivianite and fairfieldite (Scholz 2006; Scholz et al. 2008).

Stop 5. K2 Ornamental Pegmatite Quarry (Taquaral Village)

From this quarry, K2 Company extracts blocks of pegmatite material for ornamental (dimension stone) use (Fig. 4). The main pegmatite is a lens-shaped body with a minimum thickness of 5 m. The host rock is a cordierite-biotite schist of the Salinas Formation. The pegmatite is concordant with the country rock schistosity and shows a low-angle dip to SE.

Stop 6. CBL Spodumene Mine

The important CBL spodumene mine (Fig. 7A and 7B), also called Cachoeira Mine, is located at the Itinga pegmatite field, along the Piauí River low valley, around 18 km (by road) to the east of Araçuaí town (Fig. 4). The following descriptions are based on Romeiro (1998), Romeiro & Pedrosa-Soares (2005) and updated information given by Geologist Carlos Ribeiro Luiz (CBL).

Figure 7: A. Cachoeira Mine (CBL) underground gallery for spodumene extraction. B. Detailed view of the same mine, showing giant spodumene crystal in quartz-feldspar matrix. C. General view of the Água Santa feldspar Mine. D. Detail of meter sized schorl crystals aggregate which is a distinctive feature of Água Santa Mine (photos from the authors).

A swarm of spodumene-rich pegmatites make up the Cachoeira pegmatitic group, the Itinga field subdivision where is located the CBL Mine. These pegmatites are roughly tabular bodies with lens-shaped terminations, show thickness ranging from decimetres up to 30 m and length varying from a few meters to more than 300 m along the strike. The pegmatite bodies and their segments form an array of en echelon pattern. The CBL pegmatites consist of perthitic microcline, spodumene (on average 23%), albite, quartz and muscovite, totalizing more than 95% of the body volume. Montebrasite, beryl, cassiterite, columbo-tantalite and cookeite are accessory mineral.

The host rocks are cordierite-biotite-quartz schists with minor intercalations of calcsilicate rocks of the Salinas Formation. Xenoliths in the pegmatites seem to be randomlly distributed. Pegmatites intruded along two different striking surfaces of medium- to high-angle dip: the NW-dipping schistosity and the SE-dipping fracture cleavage. The pegmatites emplaced along the NW-dipping schistosity are called concordant bodies, whereas those hosted by the SE-dipping fracture cleavage are discordant.

The pegmatites always show sharp contacts with the host rock and a discontinuous, thin, fine-grained chilled margin (that could be interpreted as a marginal zone of granitic texture). Spodumene crystals perpendicular to the contacts are very common. No internal zoning can be seen, although variations of crystal size occur in specific sites, like in the tops and low-angle dip segments of the pegmatites. Despite of the thickness of the pegmatites, they are homogeneous bodies with spodumene, as well as the other essential minerals, disseminated along them. This is one important factor that favours the mining process.

Stop 7. Água Santa Mine

The Água Santa Mine (Fig. 7C) is located at the southwestern area of the Coronel Murta pegmatite field, around 18 km from this town and 52 km from Araçuaí (Fig. 5). It was studied in detail, together with other 19 feldspar mines of the Coronel Murta pegmatitic field, by Pinho-Tavares et al. (2006). Since 1996, the LUFI Mining Company (LUFI Mineração Ltda) has exploited perthitic K-feldspar, as well as beryl, schorl and collection minerals (mainly quartz crystals) as by-products, from the Água Santa Mine, the largest feldspar mine of the whole Araçuaí district.

The Água Santa Pegmatite is a very large (>50 m thick) body poorly exposed in the surface. The few outcrops of the hanging wall and footwall contacts show concordant relations between the pegmatite and the host rock, a garnet-quartz-mica schist of the Salinas Formation, suggesting a NE-trending pegmatitic body, with variable dips from 35º to 80º to SE. Data from surface and subsurface suggest a concordant lens-shaped body with a length greater than 200 m along the strike.

This pegmatite is a simple zoned body, showing primary zones and replacement bodies, with rather ordinary mineralogical assemblages. The marginal zone is fine- to medium-grained ("granitic") and consists of perthitic microcline, quartz, albite, Fe-muscovite and schorl. The wall zone is characterized by a medium- to coarse-grained graphic intergrowth of perthitic microcline and quartz, with albite, schorl and gray muscovite. Two intermediate zones are recognized. The first ("external") intermediate zone consists of a mass of microcline, quartz and muscovite, and small to giant radial aggregates of schorl (the outstanding "tourmaline curtains") that crystallized from the wall zone inwards and close to quartz cores (Fig. 7D). The second ("internal") intermediate zone consists

mostly of giant crystals of perthitic microcline associated with quartz, muscovite and beryl.

There are several small to large quartz cores which can show some beryl and/or triphylite (and rare secondary phosphates). The replacement bodies and pockets essentially show albite, muscovite and quartz crystals (jacaré, or crocodile quartz). Albite-rich fracture fillings cut the intermediate zones and quartz cores. The radial aggregates of schorl underwent late hydrothermal alteration, evidenced by coats and fracture fillings of fine-grained albite and Li-muscovite, resulting in brittle schorl crystals.

Stop 8. Coronel Murta Pegmatite Swarm

This pegmatite swarm occurs along a road cut of the BR-342, approximately 2 km to the north of Coronel Murta (Fig. 5). The pegmatites are vertical and trend N60°E, concordantly with the schistosity and compositional banding of the host rocks which are quartz-mica schist and metawacke with intercalations of calcsilicate rocks of the Salinas Formation.

It is a good example of an array of well-exposed, small (< 5 m thick) non-zoned pegmatites, showing interesting features such as: contact relations between pegmatites and country rocks, local deformation and engulfment of host rocks by pegmatites, abrupt pegmatite terminations along strike and dip, distinct geometrical relations between pegmatite external surfaces, pegmatitic apophyses, xenoliths of country rocks, crystallization of pegmatite minerals close to and far from the contacts, tourmalinization and muscovitization of host rocks and xenoliths.

5. Final comments

Three pegmatite districts were visited during this field trip: São José da Safira (Stop 1), Conselheiro Pena (Stops 2, 3 and 4) and Araçuaí (Stops 5, 6, 7 and 8). In these districts, pegmatites are of LCT (lithium-cesium-tantalum) type, derived from tardi- to post-tectonic granites of G2 and G4 supersuites. In variable volumes, those pegmatites are mined for ore minerals (spodumene), industrial minerals (feldspar, quartz and mica), gem minerals (mainly tourmalines, aquamarine, morganite, topaz, kunzite, garnet, etc.), but are also rich in rare minerals. In this context, Sapucaia Pegmatite stands out for being the type locality of eight phosphate minerals firstly described in Brazil: arrojadite-(PbFe), barbosalite, faheyite, frondelite, lipscombite, moraesite, ruifrancoite and tavorite.

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