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ARTICLE

The Mata Azul pegmatitic field, Tocantins/Goiás, central Brazil: geology, genesis and mineralization

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ABSTRACT: *In Goiás and Tocantins States, Central Brazil, several granitic pegmatites were characterized and grouped for the first time. These pegmatites had been intensely explored by hand in the past, producing mainly gemstone varieties of tourmaline and beryl. Barren, beryl- and tourmaline-bearing pegmatites occur across an area of 2,000 km^2 where they intrude regional metasedimentary rocks and peraluminous granites. K-feldspar (mostly altered to kaolin), quartz and mica (mainly muscovite) are the major minerals. The main accessory minerals are beryl, tourmaline, garnet, albite, Fe-Mn phosphate aggregates, and trilithionite. The paragneiss surrounding the barren pegmatites was affected by thermal metamorphism and later hydrothermal alteration, producing Ca-silicates, Ti-Nb-Y oxides and sulfides. Leucogranites of the Mata Azul Suite are peraluminous and syn- to post-orogenic with geochemical characteristics of the LCT granite-pegmatite group. LA-ICP-MS U-Pb geochronology in monazite yields an age of 519 ± 2.8 Ma. Additionally, U-Th-Pb chemical dating of uraninite reveals a maximum age between 500 and 560 Ma. These ages, the field relationships, the mineralogy and the geochemical data suggest that the granites of the Mata Azul Suite are the probable sources of the studied pegmatites. The mineral associations and the mineral chemistry are used to define the degree of fractionation of the pegmatites. We propose that the group of studied pegmatites represents a pegmatitic field, called the Mata Azul Suite Pegmatitic Field.*

KEYWORDS: *Pegmatites; Mata Azul Suite; Tocantins; LCT granite-pegmatite family.*

INTRODUCTION

Pegmatite is a singular group of igneous rocks that usually exhibit exotic mineralogy and geochemistry. Its genesis can be either from an evolved magma or from the anatexis of a protolith. The pegmatites with granitic composition (Li-Cs-Ta (LCT) and Nb-Y-F (NYF) families) are the most studied, either because of their more common genesis or because of their economic potential. Although pegmatite occurrences are frequently found as small bodies, pegmatites are considered economically important because of their industrial minerals, rare metals and especially their gems. In the north of Goiás and in the south of Tocantins, pegmatites were found and mined by hand for decades, but have never been properly studied. Although there are pegmatites with LCT and NYF composition in this area, the minor occurrence of NYF bodies, their limited exposed area and the very different chemical-mineralogical signature from LCT dikes were taken into account to study only the groups of LCT granitic pegmatites at this time; these groups were characterized and assembled into a pegmatitic field for the first time, allowing a proposition for the source of the pegmatites. Some NYF pegmatite descriptions can be found in Kitajima (2002). The delimitation of a pegmatitic field with a probable parental rock can help to identify new occurrences of mineral resources from granitic pegmatites. The study of this pegmatitic field along with known occurrences of pegmatites associated with older suites in Tocantins and Goiás States could result in the proposition of new districts and a new pegmatitic province in central Brazil.

GEOLOGICAL SETTING

The studied area lies in the Tocantins Structural Province (Fig. 1), which is considered a Neoproterozoic orogenic system

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composed of extensive fold belts (Araguaia, Paraguai and Brasília) that connect three continental blocks: the Amazon craton, the São Francisco craton and the Paranapanema block (Almeida *et al.* 1981). The Mata Azul granites and pegmatites crop out in the Brasília Fold Belt, a large Brasiliano/Pan-African orogenic belt in central Brazil. The geological framework of the Brasília Belt basement (Goiás Massif in Fig. 1) is represented by:

- Archean granite-greenstone terranes;
- Paleoproterozoic metasedimentary, metavolcanic and metaplutonic rocks related to the Campinorte Magmatic Arc;
- Mesoproterozoic rift to post-rift sequences constituted by A-type tin-bearing granites of the Goiás Tin Province and metasedimentary rocks of the Serra da Mesa Group;
- Meso- to Neoproterozoic metavolcano-sedimentary sequences and layered mafic-ultramafic complexes.

In a recent mapping program, Araújo Filho *et al.* (2017) added granitic rocks of the Aurumina Suite and metasedimentary rocks of the Ticunzal Formation to the geological context of the studied region (Fig. 2). Until now, these Paleoproterozoic units have been described only in the external zone of the Brasília Fold Belt (Botelho *et al.* 2006). An important component of the Brasília Belt is the Goiás Magmatic Arc, a Neoproterozoic juvenile volcanic/plutonic association extending N-S for approximately 800 km (Pimentel and Fuck 1992, Pimentel *et al.* 2011, Cordeiro

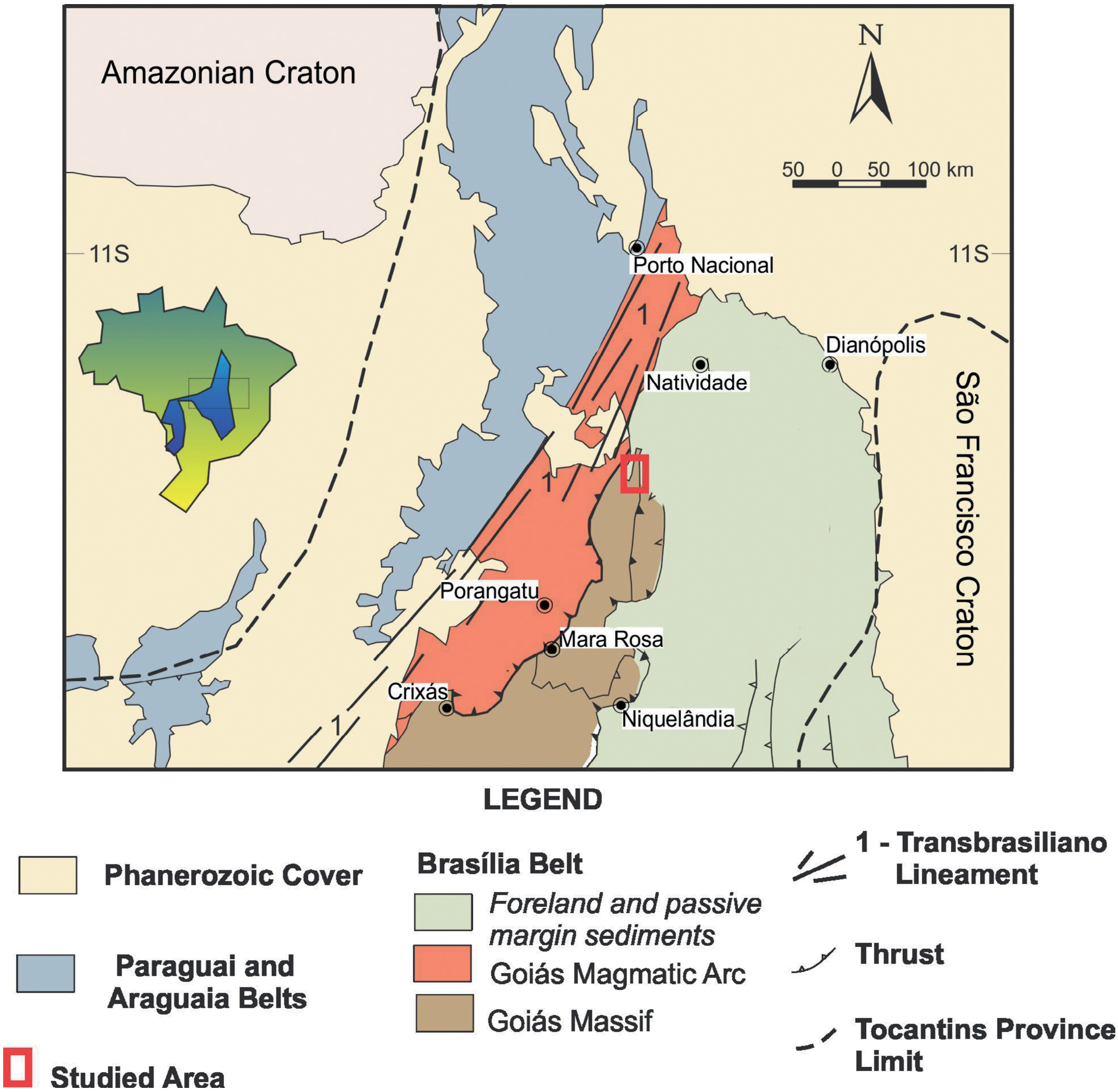


Figure 1. Simplified map of the Tocantins Structural Province with the studied area in red. Based on Fuck *et al.* 2014.

et al. 2014). The Goiás Magmatic Arc is divided into the Arenópolis Arc to the south and the Mara Rosa Arc to the north. The latter is composed of metavolcano-sedimentary sequences, tonalitic–granodioritic orthogneisses, and post-orogenic intrusions represented by gabbro-diorite and granite plutons. The Mata Azul granites and pegmatites are related to the evolution of the Mara Rosa Arc and are represented by a small number of 560 Ma post-collisional intrusions (Polo and Diener 2013).

MATERIALS AND METHODS

Field and sampling

Approximately 80% of the samples used in this study were collected from mining tailings and the rest from ancient artisanal mining. Since many of the mining sites were abandoned, vegetation, water and tailings had been taking over the area. The samples were properly cataloged and registered by photos.

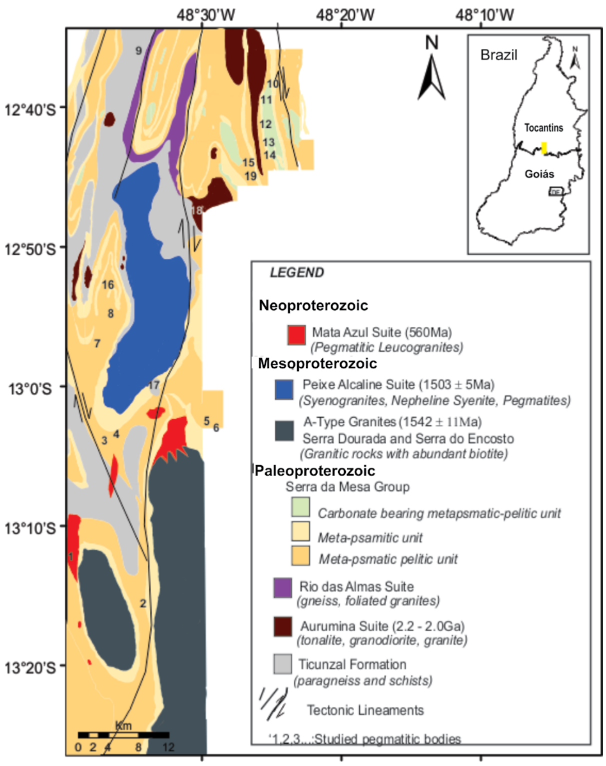


Figure 2. Geological map of the area containing the studied pegmatites. (1) Levantina quarry; (2) Córrego das Pedras; (3) Jóia da Mata; (4): "4"; (5) "5"; (6) "6"; (7) São Júlio; (8) Pichorra; (9) Fazenda Mesquita; (10) Berilão; (11) Marta Rocha; (12) Zé do Fole; (13) Índio; (14) Boanerges; (15) Marimbondo; (16) "16"; (17) "17"; (18) Onça; (19) Marimbondinho. Map based in Polo and Diener (2013) and Araújo Filho *et al.* (2017).

Analytical methods

The identification and chemical analysis of minerals from the pegmatites were performed by different techniques. X-ray diffraction by the powder method was performed in a Rigaku ULTIMA IV unit adapted with a copper tube using a 35 kV accelerating voltage and a beam current of 15 mA. Mineral compositions were determined in an electron probe microanalyzer (EPMA) JEOL JXA-8230 superprobe with five spectrometers using a voltage of 15 kV and a beam current of 10 mA. The analytical standards used were albite (Na), microcline (K), wollastonite (Si and Ca), topaz (F), vanadinite (V and Cl), $TiMnO_3$ (Ti and Mn), Fe_2O_3 (Fe), forsterite (Mg), barite (Ba), celestite (Sr), pollucite (Cs), tantalite, columbite (Ta and Nb), artificial glass with 3.5% of various oxides (ETR), uraninite (U) and galena (Pb). The identification of certain oxides included in muscovite lamellae was made by means of Raman spectroscopy with a Renishaw RL633 machine using a laser with a wavelength of 632.8 nm, silicon reference and objective lenses of 5 and 50 times magnification. Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Spectroscopy (EDS) analyses were also performed to identify mineral inclusions. Whole-rock geochemical analyses were obtained in the Acme Analytical Laboratories, using inductively coupled plasma atomic emission spectroscopy (ICP-AES) for major elements and inductively coupled plasma mass spectrometry (ICP-MS) for trace elements. Major, rare earth and refractory elements were determined following the lithium tetraborate fusion and nitric acid digestion of a 0.2 g sample. A separate 0,5 g split was digested in aqua regia for analysis of base and precious metals.

Two different methods were used for dating the pegmatites. In the first method, monazite crystals were dated by laser ablation multi-collector inductively coupled plasma source mass spectrometer (LA-MC-ICP-MS) in a monazite standard (44069) with a spot of 25 µm and a frequency of 10 Hz. The second geochronological method used was chemical dating of uraninite in the electron microprobe, with the results of U and Pb in weight percentage applied to equation (3) of Bowles (1990).

THE GRANITIC PEGMATITES

Knowledge of the pegmatite intrusions in Goiás and Tocantins States dates back many years. Macambira (1983), Marini and Botelho (1986), Botelho and Moura (1998), Sparrenberger and Tassinari (1999), Pereira (2002), and Araújo Filho *et al.* (2017) mention pegmatite intrusions associated with the Goiás Tin Province and granitic rocks of the Aurumina Suite. In southern Tocantins State, the municipalities of Palmeirópolis, São Salvador and Jaú do Tocantins hold the majority of pegmatite and granite pegmatite intrusions. Some of these intrusions have never been described in the specialized literature; among them, at least ten are mineralized and had been mined.

Marimbondo, also known as Marimbondão, was the first pegmatite body found in the region in the 1970s, leading to the discovery of numerous other pegmatite intrusions, as reported by local artisanal miners. The 1970s and 1980s were the peak time of beryl (gem and industrial) and tourmaline mining in the area. During the 1990s, mineral extraction declined, leading to mine abandonment and consequently to the obstruction of access. Because of the abandonment, the mining sites became covered by water, vegetation and tailings, leading to great difficulty in describing the details of the pegmatite bodies.

During the development of this study, 25 occurrences of pegmatites and granites were visited (Fig. 2). Most of them are located in the Tocantins State (near the cities of Palmeirópolis, São Salvador and Jaú do Tocantins). Some of the occurrences are located in Goiás State, more specifically in the region of Montividiu do Norte. This study is focused on pegmatite intrusions with beryl and tourmaline mineralization, and on smaller nonmineralized pegmatite bodies.

The mineralized pegmatites can be divided into two main groups: pegmatites explored for beryl and pegmatites explored for tourmaline. Based on current descriptions, the pegmatite bodies are named in this study as follows: Onça, Pichorra, São Júlio, Fazenda Mesquita, Jóia da Mata, outcrops “4”, “5” and “6”, Córrego das Pedras, Marimbondo, Marimbondinho, Zé do Fole, Boanerges, Índio, Marta Rocha and Berilão. Despite the abundance of barren pegmatite dikes in the studied area, most of them are strongly altered; only three fresh barren granite-pegmatite and pegmatite outcrops are well described: Levantina quarry and outcrops “16” and “17” (Fig. 2).

Pegmatites explored for beryl

There are four beryl-bearing pegmatites: Onça, Pichorra, São Júlio and Fazenda Mesquita (Figs. 2 and 3). All of

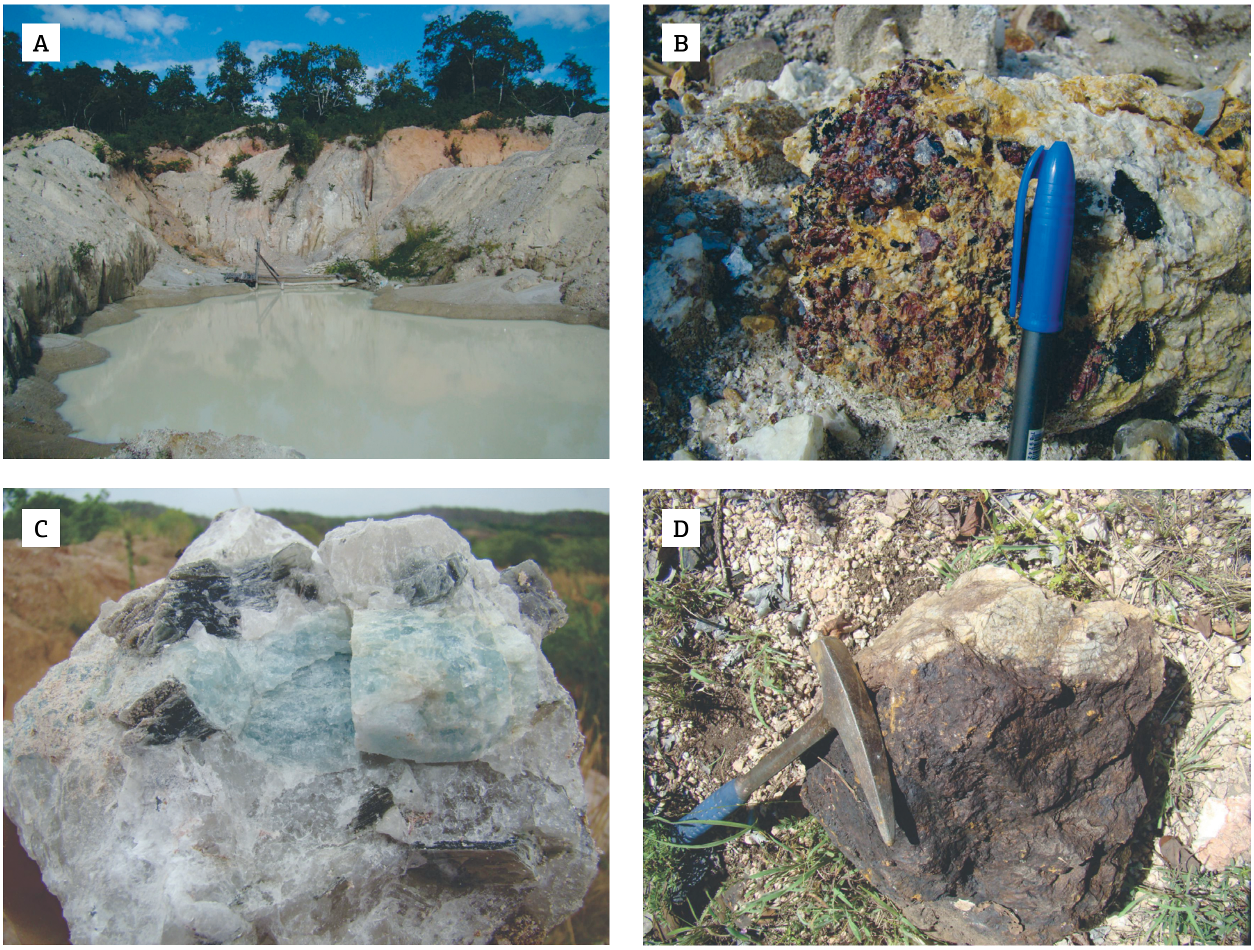


Figure 3. Pegmatites explored for beryl. (A) Submerged area in the Onça pegmatite. (B) Red almandine crystals from the Onça pegmatite. (C) Sample with blue beryl crystal found in the São Júlio pegmatite. (D) Aggregate of Fe-Mn phosphates from the Fazenda Mesquita pegmatite.

them have limited accessible areas, due to either submergence (Fig. 3A) or blocking of the access tunnels. The bulk mineral composition found in tailing samples consists of quartz, K-feldspar, kaolin and muscovite. The main accessory minerals are schorl, almandine (Fig. 3B), beryl (Fig. 3C), albite, green polycrystalline muscovite and Fe-Mn phosphates (Fig. 3D). There are also traces of Fe and Mn oxides and hydroxides, phosphate alteration products, spessartine garnet, Fe-columbite, gahnite and uraninite. The Fe-Mn phosphates are described by Queiroz and Botelho (2017).

Pegmatites explored for tourmaline

The pegmatites explored for tourmaline in Goiás and Tocantins occur in different landscapes, such as in flat to considerably hilly terrain, on the tops and slopes of hills, and on the slopes of the Serra Dourada mountain range. The pegmatite bodies have round to NE-SW elongated shapes, with dimensions ranging from tens to hundreds of meters, as for the 200 m-long Marimbondo pegmatite. The tourmaline-bearing pegmatites can be separated into two different groups: the southern group, which is composed of the Jóia da Mata, Córrego das Pedras, "4", "5" and "6" pegmatite bodies, and the northern group, which contains the Marimbondo (Fig. 4A), Marimbondinho, Zé do Fole, Índio, Boanerges, Marta Rocha and the Berilão (Fig. 2) pegmatite bodies. Only an altered wall zone is observed in situ in all these pegmatites.

In both groups, similar mineralogy is found (Fig. 4). Kaolin, quartz, microcline and muscovite represent the predominant bulk composition, and the accessory minerals are albite, trilithionite, spessartine, beryl, pink montmorillonite, Fe-Mn oxides, spodumene and colorful tourmaline crystals.

According to the classification of Henry *et al.* (2011), the chemistry of the tourmaline crystals (Tab. 1) can be divided into three primary groups: alkali, calcic and x-vacant. The black tourmaline is classified mainly as schorl, and a small number of crystals, which are in contact with the country rock, are classified as dravite. The colorful tourmaline crystals are divided into three types: elbaite (the most common colorful tourmaline in the study area), rossmanite and liddicoatite (rare occurrence in the northern group). Frequently, a great number of tourmalines crystals contains the prefix "fluor", due to their high fluorine content in the W crystallographic site, F > 0,5 apfu.

Barren pegmatites

Dikes of barren pegmatites with an exposed area of tens of meters and a NE-SW orientation are scattered throughout a wide area in the studied region. Although a large portion of these bodies is totally kaolinized, some of them are well exposed and present a well-preserved mineralogy. A special outcrop is located just over 20 km northeast of the Levantina Quarry (Fig. 2) in a roadcut of highway TO-498 (Fig. 5A), where several dikes of granitic composition cut a paragneissic rock over an extent of tens of meters. These intrusions, whose thickness varies from few centimeters to more than 4 m, comprise three facies: mica-poor and mica-rich leucogranites and pegmatite (Figs. 5B and 5D). The thicker pegmatite dikes are not concordant and have a pink color with some white shades. The essential minerals are quartz, microcline (Fig. 5C) and albite (An3-7) in approximately the same proportion. Mica is rare, in some cases forming clusters of muscovite and rare biotite. The most common accessory minerals are almandine, which can be represented by well-preserved face crystals, and more rarely green-colored fluorapatite as isolated euhedral crystals. Iron oxides are widespread in the surface of microcline and sometimes in biotite, which can account for the rock color. By means of EDS analysis using an electron microprobe, crystals of zircon and Fe-columbite were identified. In some places, centimetric miarolitic cavities host a large number of euhedral crystals of muscovite and quartz.

The smaller dikes, up to 1 m thick, may be discordant or concordant, with predominately white color and localized pink shades when in contact with the larger granitic mass (Fig. 5F). The basic mineralogy of the smaller dikes is more than 90% quartz and plagioclase (albite/oligoclase), with K-feldspar and micas in minor proportions. In some dikes, typical pegmatite zoning is represented by K-feldspar with graphic intergrowth in the mural zone, larger feldspars, quartz and muscovite in the intermediate zone, and massive quartz in the core. Some quartz veinlets cut the larger dikes, as well as the smaller ones.

The intrusions described above form a complex network of concordant to discordant dikes of granite/pegmatite containing many paragneiss enclaves. The contact between the intrusions and the country rock is always sharp, with the edges of the intrusions exposing a rectilinear, sometimes meandering, contact line. Some aspects of digestion of the country rock were observed in the enclaves and near the contact line (Fig. 5E).

Country rock of the pegmatites and alterations

Mineralized pegmatites

Due to the lack of good outcrops and the limited exposure of rocks, the contact relationships between the mineralized pegmatites and the country rocks cannot be clearly observed. In the Marimbondinho pit, part of a pegmatite dike is in discordant contact with an altered and red-colored quartz-biotite-muscovite schist showing a strong crenulation cleavage. The country rock of this pegmatite body contains a large number of fine dravite grains near the contact, indicating metasomatic reactions between these rocks (Fig. 6), whereas only a few centimeters away from the pegmatite no dravite crystals are formed. In the Onça mine pit, the wall zone of the pegmatite is in contact with an extreme altered granitic rock, consistent with regional granitic rocks described in the area by Araújo Filho *et al.* (2017). Although it is not possible to observe the contact relation between the pegmatite and the country rock, blocks and scattered outcrops of

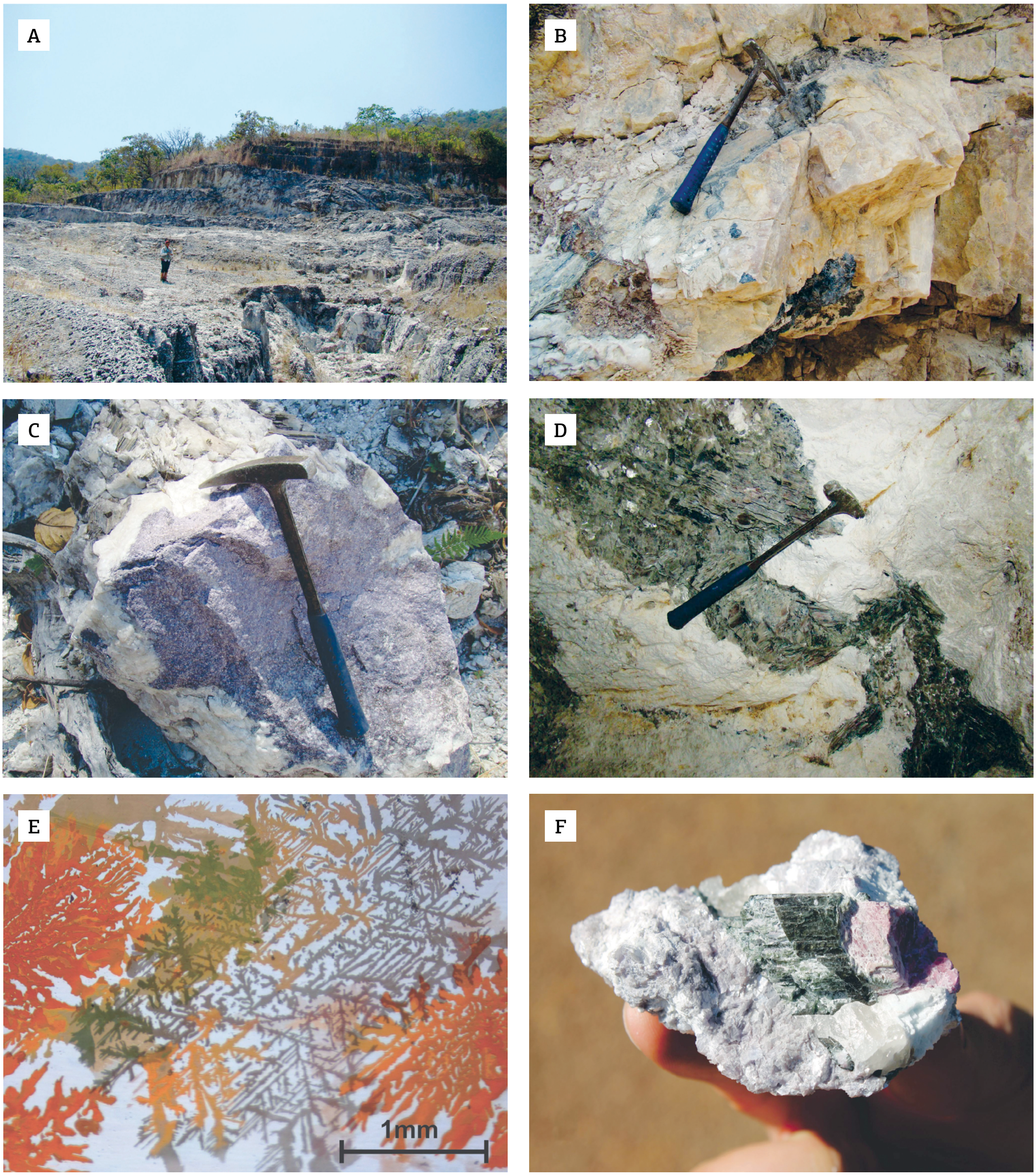


Figure 4. Pegmatites explored for tourmaline. (A) Exposed area of the Marimbondo pegmatite. (B) Quartz block with centimetric crystals of schorl in the Berilão pegmatite. (C) Aggregate of lepidolites in block of quartz. (D) "Books" of muscovite surrounded by kaolin in the Zé do Fole pegmatite. (E) Iron oxides as inclusions in muscovite. (F) Elbaite known as "watermelon tourmaline" associated with purple lepidolite and white albite.

Table 1. Representative composition of tourmaline crystals.

	Dravite	Schorl	F-elbaite (blue)	Pink elbaite	F-elbaite (green)	F-liddicoatite (Pink)	Pink rossmanite
SiO_2	38.64	34.57	36.74	37.94	37.63	37.24	37.94
TiO_2	0.38	0.38	0	0.02	0.06	0	0.00
Al_2O_3	31.19	33.49	40.18	41.64	40.82	41.5	40.83
FeO	4.42	12.46	2.19	0.01	1.39	0	0.09
MnO	0.00	0.36	1.39	0.10	0.47	0.18	0.98
MgO	8.51	2.52	0.02	0.01	0.01	0.02	0.06
CaO	0.54	0.37	0.22	0.28	0.70	3.11	0.44
Na_2O	2.45	2.26	2.18	2.00	2.10	1.02	1.19
K2O	0.08	0.05	0.03	0.02	0.02	0.02	0.06
F	0.48	0.28	1.12	0.98	1.00	1.1	0.84
H_2O*	3.54	3.45	3.22	3.36	3.34	3.33	3.39
B_2O_3*	10.92	10.39	10.87	11.08	11.07	11.17	10.99
Li_2O*	0.78	0.22	1.67	2.10	2.02	2.5	2.05
Total	101.93	100.8	99.83	99.05	100.7	101.19	98.87
O=F	-0.20	-0.12	-0.47	-0.41	-0.50	-0.55	-0.42
Crystallographic site distribution							
X site							
Ca	0.09	0.07	0.04	0.05	0.12	0.52	0.08
Na	0.76	0.73	0.68	0.61	0.64	0.31	0.37
K	0.02	0.01	0.01	0.00	0.00	0.00	0.01
☐	0.14	0.19	0.28	0.34	0.24	0.16	0.55
∑X	1.00	1.00	1.00	1.00	1.00	0.99	1.00
Y site							
Al	0.00	0.38	1.44	1.66	1.47	1.41	1.63
Ti	0.05	0.05	0.00	0.00	0.00	0.00	0.00
Mg	1.87	0.63	0.01	0.00	0.00	0.00	0.01
Mn	0.00	0.05	0.19	0.01	0.06	0.02	0.13
Fe	0.59	1.74	0.29	0.00	0.18	0.00	0.01
Li	0.50	0.15	1.07	1.32	1.28	1.56	1.21
∑Y	3.00	3.00	3.00	2.99	2.99	2.99	3.00
Z site							
Al	5.85	6	6	6	6	6	6
Mg	0.15	-	-	-	-	-	-
T site							
Si	6.15	5.78	5.87	5.95	5.91	5.80	6.01
Al	-	0.22	0.13	0.05	0.09	0.21	-
B site							
B	3	3	3	3	3	3	3
W site + V site							
F	0.24	0.15	0.57	0.49	0.50	0.54	0.42
OH	3.76	3.85	3.43	3.51	3.50	3.46	3.58

*Calculated values. Cations based on 31 O; ☐: vacancy.

different lithotypes are observed near several pegmatite bodies. Fragments of strongly weathered mica schists are found in the tailing area of Córregos das Pedras and Jóia da Mata pegmatites. In the northern group region, tourmaline-bearing pegmatites, mica schists, quartzite and calc-silicate rocks are the components of the valleys and hills where the pegmatites bodies are located. Schist and quartzite are found on slopes close to the Marimbondo, Marimbondinho and Berilão pegmatites.

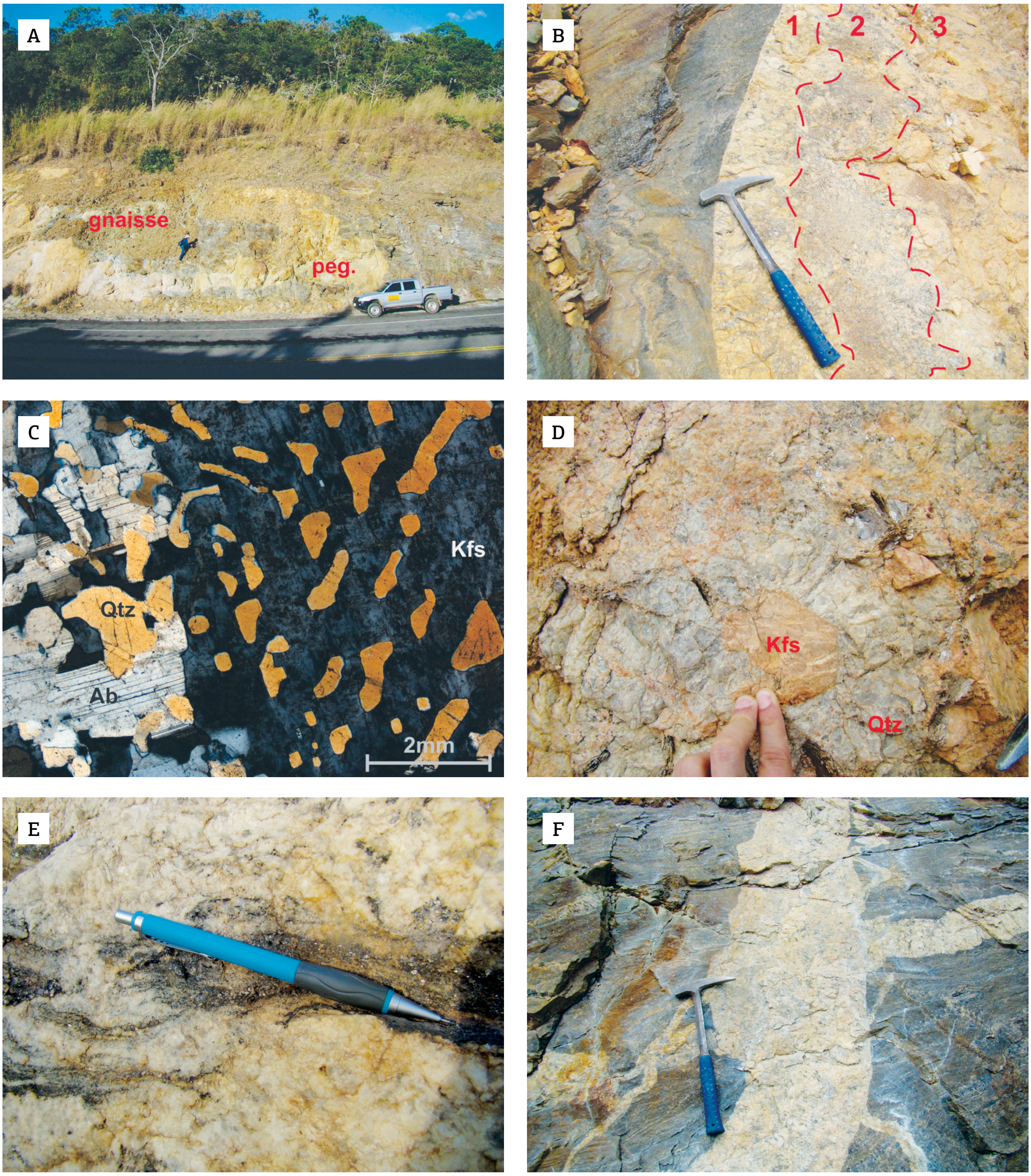


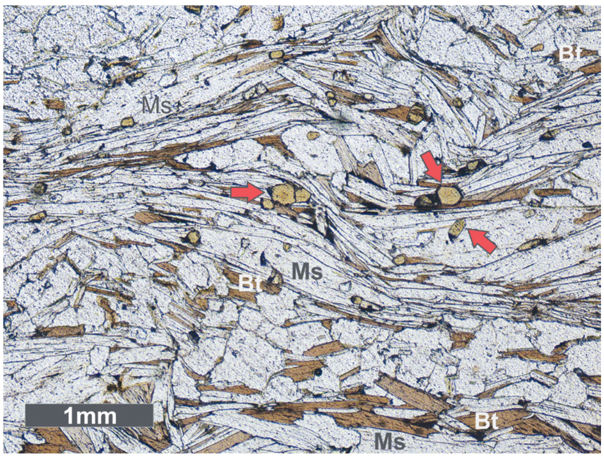
Figure 5. Barren pegmatites. (A) Outcrop showing light pegmatite intrusion in dark paragneiss country rock. (B) Detail of the contact paragneiss-pegmatite and the three facies of the simple pegmatite, 1: coarse-grain leucogranite, 2: coarse-grain leucogranite with abundant mica, 3: pegmatitic facies. (C) Photomicrograph of graphic texture. (D) Pegmatitic texture with K-feldspar and quartz. (E) Evidences of digestion in paragneiss. (F) Concordant and discordant minor dykes.

Calc-siliciclastic rocks are the main country rocks and are found close to the other pegmatite bodies. According to Araújo Filho *et al.* (2017), these calc-siliciclastic rocks are related to the Serra da Mesa Group, while other metasedimentary rocks can be associated with the Ticunzal Formation. The Onça pegmatite is most likely intrusive in peraluminous granites of the Aurumina Suite. In the literature, the metasedimentary units (Ticunzal and Serra da Mesa formations) are metamorphosed to amphibolite grade.

Barren dikes

The country rocks of the barren dikes are the metasedimentary units Ticunzal and Serra da Mesa. Only in the "17" pegmatite is the contact between country rock and pegmatite clear. In the "17" pegmatite, the paragneiss country rock probably belongs to the Ticunzal Formation (Araújo Filho *et al.* 2017), containing quartz, biotite, strongly sericitized plagioclase (An20-22) and potassium feldspar. The accessory minerals include muscovite, apatite, zircon, monazite, and ilmenite. The emplacement of these pegmatite dikes induced contact metamorphism, forming alteration halos just over a few tens of centimeters from the contact. The exception is the completely altered enclaves occurring as meter-scale blocks immersed in the intrusions. Later, hydrothermal alteration affected the intrusion and the country rock; all these processes resulted in a particular mineralogical assembly (Tab. 2).

There are four zones — 1, 1A, 2 and 3 — that can be described as the result of thermal metamorphism (Fig. 7). Zones 1 and 1A are the closest to the intrusion and consequently were affected by a higher thermal gradient in relation to the unmodified rock. These two zones are composed mainly of Fe- and K-rich hornblende and clinopyroxene (Fig. 8), followed by minor titanite (Fig. 8) and allanite. Fluorite and carbonates are secondary minerals, products of allanite and amphibole alteration.



Bt: biotite, Ms: muscovite.

Figure 6. Photomicrograph of dravite-bearing schist. The metasomatic tourmaline crystals that grow in the contact with a pegmatite are indicated by red arrows.

Zones 2 and 3 are farther from the pegmatite than zones 1 and 1A; thus, they experienced less heating, and a different metamorphic mineralogy formed, composed of amphibole (in smaller proportion), biotite, titanite, and Mn-rich almandine.

Zone 5 occurs at the contact between the country rock and previously described albite-rich small dikes. This zone is approximately 2 cm wide and shows concentrations of polycrase-(Y) and rutile enriched in Nb and Ta (ilmenorutile), formed by a metasomatic process characteristic of this type of dike (Tab. 3). The enrichment of Nb and Ta in the rutile increases towards the intrusion (Fig. 8).

A hydrothermal phase affected the pegmatite and the country rock and caused silicification in both rocks, and fractures were filled with the major mineral phases of this event, quartz and sulfides along with intense oxidation. The main sulfide is a late-formed pyrrhotite, present as anhedral crystals that occur in fractures and become dispersed in zone 1. Small amounts (no more than 1%) of chalcopyrite crystals are identified. Garnet crystals, in concentrations between 5 and 30 vol.%, are also common in samples from the hydrothermalized area, showing higher Ca contents in relation to the garnet crystals from zone 3 (Fig. 9). In the hydrothermal garnet, the concentrations of the almandine and grossular molecules are almost the same (28 to 40 wt.%), with a significant content of spessartine (20 to 24 wt.%).

The last stage of alteration present in the minor intrusions and country rock is the formation of sulfates. Meteoric water percolating in fractures of the paragneiss and intrusive bodies caused hydration of the pre-existing sulfides, producing minerals such as pickeringite — $MgAl_2(SO_4)_4{\bullet}22H_2O$ — and alunogen — $Al_2(SO_4)_3{\bullet}17H_2O$.

A possible origin for the calc paragenesis is related to calc-silicate rocks from the Serra da Mesa Group, cropping out near (30–50 m) this location. The thermal metamorphism generated a mass transfer by fluid circulation on a small scale; rocks belonging to the Ticunzal Formation and Serra da Mesa Group are commonly in contact, so, after the intrusion, the Ca component removed from the Serra da Mesa rocks was remobilized to the contact with the Ticunzal Formation.

Geochronological data

Geochronological information on the pegmatites of this study is scarce, and all attempts to date them using the zircon U-Pb method have failed because of the scarcity of this mineral and the presence of metamict crystals. However, the determination of the age of the pegmatites is very important for comparison with the age of the probable parental granite. An option for U-Pb dating is the use of the monazite that is identified in the Boanerges pegmatite. Brown greenish crystals of monazite of the kaolinized wall zone of the body are dated to 519.9 ± 2.8 Ma (Tab. 4, Fig. 10).

An alternative method for dating rocks is the analysis of Th- and U-bearing minerals such as monazite, xenotime and

Table 2. Representative composition of some metasomatic minerals.

	Mg-Hornblende (zone 2)	K Fe-Hornblende (zone 1)	Fe-Actinolite (zone H)	Diopside (zone 1A)	Hedenbergite (zone H)	Titanite (zone 2)	Titanite (zone 1)	Titanite (zone H)	Garnet (zone 3)	Garnet (zone H)
SiO_2	49.38	43.35	50.01	52.15	49.44	30.91	31.63	31.21	35.11	37.29
TiO_2	0.23	0.27	0.08	0.04	0.06	34.70	26.35	29.81	0.12	0.15
Al_2O_3	6.79	10.21	1.93	0.27	0.72	4.00	9.25	6.68	22.53	19.69
FeO	8.31	15.26	21.06	12.18	22.81				24.47	19.57
Fe_2O_3	4.84	5.28	4.30			0.71	0.58	1.00		
MnO	0.82	1.23	0.81	1.33	1.40	0.20	0.17	0.15	13.06	8.86
MgO	14.40	8.33	7.88	10.79	3.79	0.17	0.10	0.05	1.33	0.28
CaO	11.83	11.70	11.85	23.66	21.59	27.47	28.40	28.03	0.72	13.46
Na_2O	1.11	1.09	0.27	0.17	0.21	0.07	0.05	0.02		
K_2O	0.54	1.31	0.13							
F	0.91	0.97	0.22			1.46	3.02	2.34		
H_2O*	1.65	1.52	1.87							
O = F	0.38	0.41	0.09			0.61	1.27	0.98		
Total	99.96	99.58	99.89	100.59	100.03	99.07	98.26	98.29	100.34	99.29
Formula contents										
Si	7.108	6.570	7.592	1.984	1.984	1.003	1.017	1.012	2.856	3.005
Ti	0.025	0.031	0.009	0.001	0.002	0.847	0.637	0.727	0.007	0.009
Al	1.151	1.824	0.346	0.012	0.034	0.153	0.351	0.255	2.168	1.877
Fe^2	1.001	1.934	2.674	0.387	0.765				1.909	1.319
Fe^3	0.524	0.602	0.491			0.026	0.021	0.036		
Mn	0.100	0.158	0.105	0.043	0.048	0.005	0.005	0.004	0.900	0.605
Mg	3.090	1.882	1.783	0.612	0.227	0.008	0.005	0.002	0.162	0.034
Ca	1.825	1.901	1.927	0.964	0.928	0.955	0.979	0.974	0.063	1.162
Na	0.310	0.321	0.078	0.012	0.017	0.004	0.003	0.001		
K	0.100	0.254	0.025							
F	0.416	0.467	0.106			0.149	0.307	0.240		
OH	1.584	1.533	1.894							
							% almandine		60.64	38.95
							% grossular		2.20	34.50
							% spessartine		31.50	20.51

Fe in titanite as Fe_2O_3. Numbers of cations on the basis of 23 O for amphiboles, 6 O for pyroxene, 5 O for titanite e 12 O for garnet.

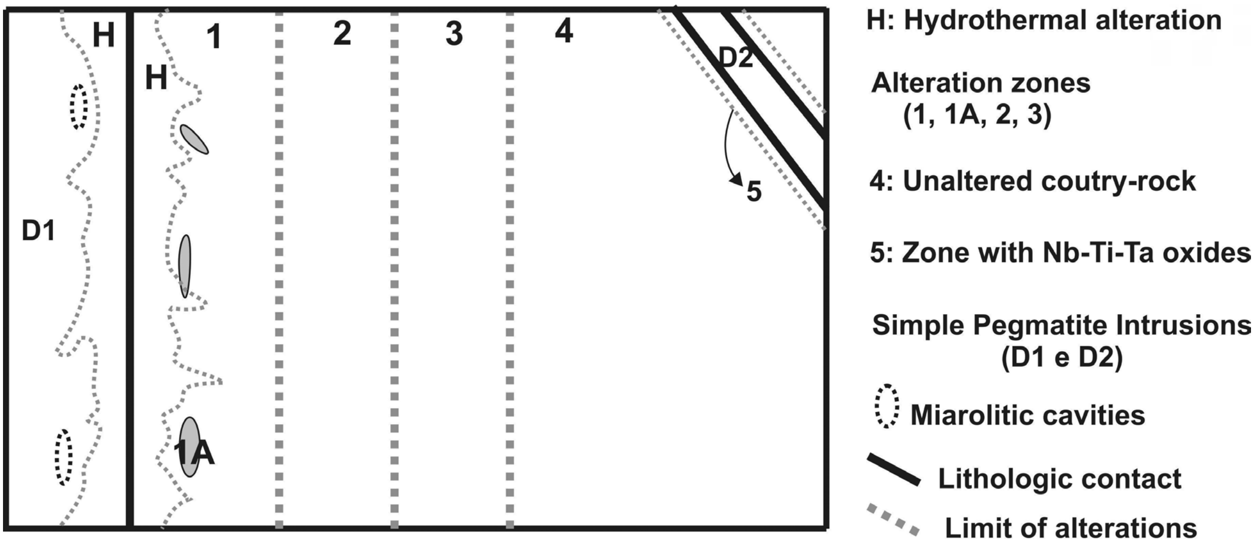


Figure 7. Scheme showing the relationship between the pegmatitic intrusion and the associated alteration halo. The alteration halo varies from 20 cm to 2 m long.

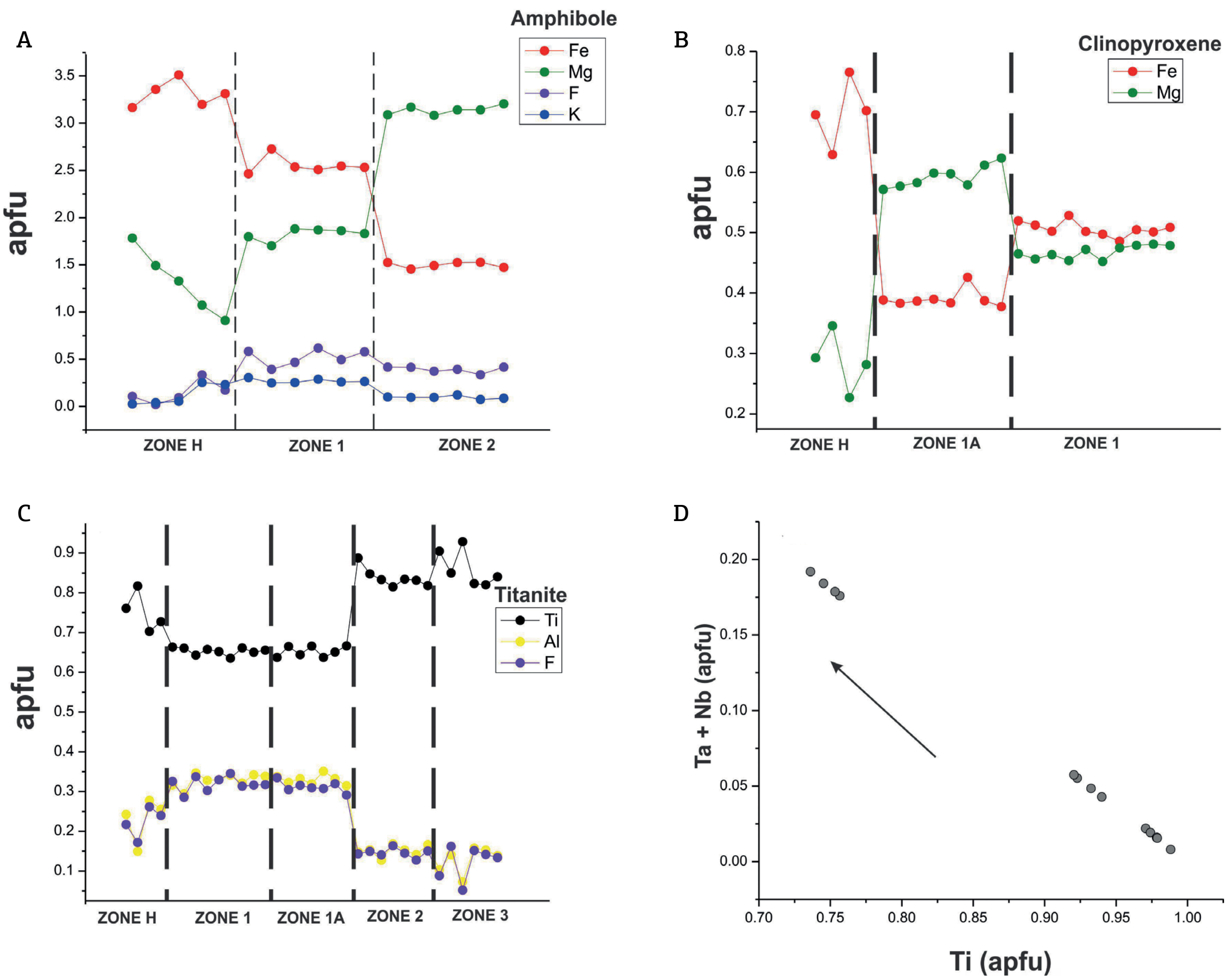


Figure 8. Element distribution (in apfu) in metasomatic phases. (A, B, C) Amphibole, clinopyroxene and titanite. (D) Negative correlation between Ta + Nb vs Ti in rutile and ilmenorutile; arrow indicates the direction of paragneiss-pegmatite contact.

Table 3. Representative composition of metasomatic oxides found in the paragneiss-pegmatite contact.

	Rutile I	Ilmenorutile	Ilmenorutile II	Y-Polycrase
Ta2O5	0.23	6.03	14.21	9.99
Nb2O5	1.25	5.35	16.44	21.21
TiO2	97.56	85.57	61.34	21.14
U3O8				9.67
ThO2				3.27
Y2O3				11.35
Gd2O3				1.30
Dy2O3				2.98
Er2O3				1.88
MnO				0.20
Fe_2O_3	0.86	3.5	8.89	2.88
CaO				2.49
Total	99.81	100.1	99.98	86.89
Formula contents				
Ta	0	0.022	0.060	0.167
Nb	0.007	0.033	0.116	0.589
Ti	0.988	0.923	0.757	0.977
U				0.126
Th				0.046
Y				0.612
Gd				0.107
Dy				0.104
Er				0.065
Mn				0.011
Fe^3	0.004	0.018	0.052	0.140
Ca				0.163

Fe_2O_3 as total Fe. Number of cations on the basis of 2 O for rutile and ilmenorutile and 6 O for Y-polycrase.

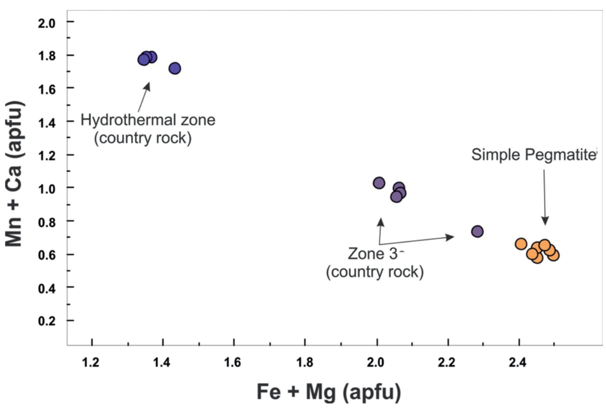


Figure 9. Chemical composition of garnet crystals showing the difference between the country rock metasomatic garnet and the pegmatite garnet.

uraninite using an electron microprobe, a nondestructive, in situ, and high-resolution method. This method was applied in 0.05–1 mm euhedral to subhedral crystals of uraninite from the São Júlio pegmatite. In this method, it is assumed that all Pb of the sample has a radiogenic origin from the decay of U and Th. Thus, as suggested by Kempe (2003), well-preserved crystals with little or no alteration visible in backscattered images were analyzed.

U and Pb results were used in equation (3) of Bowles (1990) to produce calculated chemical ages between 411 and 560 Ma, which corresponds to the minimum age interval of uraninite crystallization (Tab. 5 and Fig. 11). The uraninite from the São Júlio pegmatite can be chronologically linked to the 519 Ma Boanerges pegmatite. Considering that the uraninite crystals are included in a phosphate mass that was exposed in some areas to hydrothermal activity, as confirmed by the Fe-Mn phosphate association (Queiroz and Botelho 2017), it is reasonable to think that a certain amount of Pb in the uraninite has been lost; Alexandre and Kyser (2005) described Pb loss and cation substitution in uraninite as a result of the late circulation of fluids and their influence on chemical dating. In study samples, despite the good condition of the uraninite crystals analyzed, the hydrothermal activity could have affected the uraninite to some extent.

THE MATA AZUL SUITE AT LEVANTINA QUARRY

The Mata Azul Suite is poorly described in the literature. Lacerda Filho *et al.* (1999) and Polo and Diener (2013) refer to this suite as post-tectonic granitic intrusions of Neoproterozoic age, crosscutting metasedimentary rocks of the Serra da Mesa Group and containing several pegmatite dikes. Polo and Diener (2013) mention in their geological map a zircon U-Pb age of 560 Ma, but no references to sampling area and type of rock are noted.

In this work, the type area of this suite, as well as the sampling area, is located in a quarry for ornamental rocks belonging to the Levantina enterprise, next to the Mata Azul district, in the municipality of Montividiu do Norte. The granite is a white leucocratic rock forming a 7 km-long elongated pluton in slightly hilly terrain (Fig. 2). There are a number of complex textures in the mining area of the quarry, including aplite facies (gray color) of centimetric to metric scale and coarse leucogranite and pegmatite facies with potassic feldspar megacrystals. The mineralogical composition of all facies is basically the same and only differs slightly in the mineral percentage. These rocks contain quartz, bluish-gray potassic feldspar, white plagioclase, perthitic texture zones and, to a lesser extent, biotite and muscovite (mica up to 10%). The plagioclase is usually oligoclase (An11-15), and it is the most abundant feldspar in the coarse leucogranites, also occurring locally in the aplites.

The most common accessory mineral is dark red almandine, which occurs in the aplitic facies and coarse leucogranite. This mineral sometimes forms nodules with a large number of millimetric crystals. The second most common accessory mineral is fluorapatite, which can also form crystal agglomerates. Zircon, monazite and cassiterite are also identified either in thin sections as a small number of crystals or by EDS analysis.

Table 4. Analytical data for U-Pb in monazite of the Boanerges Pegmatite.

	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{235}U$	1 σ %	$^{206}Pb/^{238}U$	1σ%	Rho	Age (Ma) $^{207}Pb/^{235}U$
MZ20	411	1.662	2.58	0.0785	1.26	0.49	994
MZ18	437	1.106	1.35	0.0948	0.86	0.64	756
MZ17	308	3.810	3.29	0.1675	2.57	0.78	1595
MZ3	2965	0.783	0.90	0.0937	0.71	0.79	587
MZ32	365225	0.638	1.07	0.0821	0.57	0.54	501
MZ29	36150	0.617	1.43	0.0827	0.94	0.66	488
MZ28	78488	0.623	0.83	0.0808	0.56	0.67	492
MZ27	4760	0.651	0.92	0.0782	0.63	0.68	509
MZ26	4869	0.642	1.16	0.0790	0.80	0.68	504
MZ25	4059	0.625	1.16	0.0764	0.82	0.71	493
MZ24	25051	0.569	1.47	0.0724	1.01	0.68	457
MZ23	2008	0.645	1.61	0.0783	0.94	0.59	505
MZ22	2732	0.561	2.09	0.0749	0.79	0.38	452
MZ21	24094	0.600	1.25	0.0835	0.87	0.69	477
MZ19	168798	0.632	0.90	0.0811	0.64	0.71	498
MZ16	10229	0.613	1.27	0.0777	0.89	0.70	486
MZ8	28341	0.694	1.41	0.0880	0.92	0.65	535
MZ6	23456	0.696	1.42	0.0882	0.92	0.65	537
MZ5	23831	0.685	1.29	0.0867	0.94	0.73	530
MZ4	35301	0.704	1.22	0.0894	0.83	0.68	541
MZ2	148937	0.706	0.95	0.0899	0.77	0.81	542
MZ1	115607	0.716	1.18	0.0918	0.95	0.81	548
MZ30	152456	0.650	0.91	0.0831	0.56	0.61	508
MZ14	34481	0.656	1.10	0.0842	0.68	0.62	512
MZ12	8306	0.660	2.17	0.0847	2.06	0.95	515
MZ31	10983	0.675	0.97	0.0839	0.58	0.60	524
MZ15	4670	0.665	1.44	0.0838	1.07	0.74	518
MZ13	13640	0.659	1.15	0.0834	0.77	0.67	514
MZ11	7526	0.668	0.87	0.0842	0.53	0.61	519
MZ10	10574	0.663	1.02	0.0843	0.75	0.73	517
MZ9	21056	0.673	2.06	0.0848	1.37	0.67	523
MZ7	5412	0.678	1.31	0.0841	0.87	0.67	525

The leucogranite facies from the Levantina quarry is strongly peraluminous with an A/CNK value between 1.05 and 1.35. It contains low contents of Fe, Mg, Ca, Ti, Ba and rare earth elements (REE) and high contents of Rb, Ga, B and F, indicating extremely fractionated evolved granite bodies (Tab. 6).

DISCUSSION AND THE MATA AZUL PEGMATITIC FIELD

The frequent presence of Li-minerals (lepidolite, trilithionite, elbaite, spodumene) and the scarcity of Y and REE minerals in the pegmatites described in the previous sections indicate that they belong to the LCT family (Černý 1990, 1991, Martin and De Vito 2005). According to the classification of Černý and Ercit (2005), the pegmatites explored for beryl belong to the beryl type, and the pegmatites explored for tourmaline belong to the complex type. Most of the pegmatites studied here can be classified in the following subtypes: the Pichorra, São Júlio and Fazenda Mesquita pegmatites are considered to belong to the beryl-columbite-phosphate subtype, and all of the pegmatites explored for tourmaline, excepting the Berilão pegmatite, belong to the elbaite subtype.

Much evidence corroborates the proposition that the Mata Azul Suite is the source of the studied pegmatites; its complex textural variation presented at Levantina quarry (coarse leucogranite, aplite and crosscutting pegmatites) and the geochemical signature previously described are very similar to many descriptions of granite sources of pegmatites around the world (Černý 1982, 1991, Martin and De Vitto 2005, Beurlen *et al.* 2009, Wise and Brown 2010).

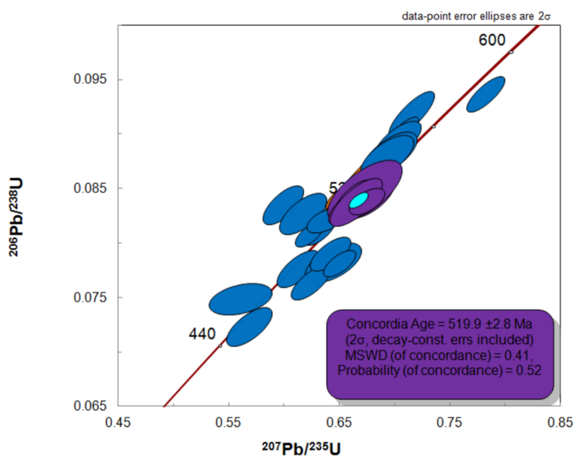


Figure 10. U-Pb Concordia diagram of monazite from the Boanerges pegmatite. The purple ellipses were used to calculate the concordia age.

Table 5. U-Pb values and the calculated age by the chemical dating.

Sample	U (%)	Pb (%)	Age (Ma)
Urn 1	76.70	5.00	448.0
Urn 2	77.22	5.84	516.9
Urn 3	77.45	5.90	520.9
Urn 4	75.78	5.76	519.1
Urn 5	76.74	5.75	512.1
Urn 6	72.66	5.82	546.3
Urn 7	73.87	5.08	471.5
Urn 8	74.14	5.42	500.4
Urn 9	71.36	4.77	459.1
Urn 10	74.55	5.47	501.9
Urn 11	77.20	5.12	455.9
Urn 12	72.77	4.73	447.2
Urn 13	76.23	4.74	428.3
Urn 14	75.86	5.51	496.8
Urn 15	75.72	5.12	464.5
Urn 16	76.10	5.67	509.7
Urn 17	81.93	6.51	542.1
Urn 18	81.90	5.71	477.7
Urn 19	84.21	6.53	529.6
Urn 20	80.31	5.66	482.9
Urn 21	79.65	5.04	435.1
Urn 22	80.84	6.21	524.7
Urn 23	78.84	5.76	500.4
Urn 24	81.07	6.41	539.4
Urn 25	80.22	4.92	422.1
Urn 26	80.48	5.95	506.1
Urn 27	78.42	4.68	411.5
Urn 28	81.89	5.32	446.9
Urn 29	80.96	5.87	496.4
Urn 30	81.44	5.46	460.3
Urn 31	81.13	6.12	515.6
Urn 32	80.88	6.37	537.4
Urn 33	81.59	6.05	507.0
Urn 34	81.51	6.13	513.8
Urn 35	81.08	6.20	522.5
Urn 36	81.27	6.26	526.0
Urn 37	81.42	6.19	519.6

U: Uranium; Pb: Lead; Urn: Uraninite crystal.

The occurrence of evolved granites, simple pegmatites and mineralized pegmatites suggests the existence of a granite-pegmatite system in the study area. In the models proposed by Trueman and Černý (1982), Černý (1991) and London (2008), the regional evolution of granitic-pegmatitic bodies can be observed at different scales, ideally starting from the roof of a parental pluton, from which many pegmatitic bodies are ejected, and mainly following a vertical trend. Chemical fractionation produces zoning in relation to the granite source, and this differentiation becomes stronger in the more distant bodies. The chemical fractionation is invariably reflected in the mineralogy of each pegmatite, and those closest to the parental granite bodies have simple mineralogy, sometimes containing only quartz, feldspar and micas. In contrast, the farthest bodies have higher volumes of minerals containing volatile elements and/or rare metals. In Figure 12, a simplified model shows the relation between the different facies of parental granite and pegmatites.

The coarse-grained leucogranite from the Mata Azul Suite, sampled at the Levantina quarry, contains three of the four facies related to the ideal parental rock: two-mica leucogranite, coarse muscovite leucogranite and pegmatitic leucogranite (Fig. 12). The top of the granite source has pegmatitic apophyses that can be correlated to the minor intrusions previously described. If it is assumed that fractionation occurred in the parental granite, intrusions such as "MA17" are pegmatitic ejections connected to the source that can be extremely fractionated, producing sodic dikes such as the one represented by the sample MA22 (Fig. 13).

Barren pegmatites ejected from the granite source form the first halo of dispersion (Fig. 12), as exemplified in the Novo Horizonte district, where pegmatite "16" (Fig. 2), which is mostly homogeneous, displays a typical texture of a pegmatite body with ordinary mineralogy: quartz, microcline, biotite, muscovite and almandine.

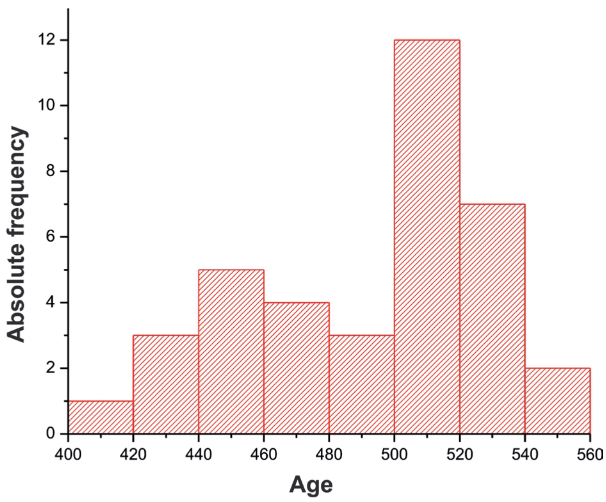


Figure 11. Frequency histogram of the calculated uraninite ages.

The chemical composition of the garnet crystals is one of the main tools for distinguishing the degrees of evolution among barren and mineralized pegmatites. Černý and Hawthorne (1982), Baldwin and Knorring (1983), Whitworth and Feely (1994), and Lima *et al.* (2009) proved that the Mn/Fe ratio in garnet increases with the fractionation of a granitic body towards the pegmatites. Therefore, it is expected that the garnet from more evolved bodies would be richer in spessartine than the garnet from less evolved bodies and from the granite source.

The chemical compositions of the garnet from the Mata Azul leucogranite, the barren pegmatites "17" and "16" and the mineralized pegmatites Onça and Boanerges are shown in Table 7. The garnet crystals of the pegmatites were collected in the preserved or altered wall zone of these bodies. The values of the Mn/(Mn + Fe) ratio and the proportion of spessartine clearly increase towards the most differentiated bodies and exhibit a negative correlation with Fe and Mn in Figure 14.

The degree of differentiation between the least and the most evolved mineralized pegmatite is clearly indicated by their mineralogy. This comparison can be done using minerals present in both groups, such as beryl. Figure 12 shows an ideal scheme where beryllium is the first rare metal element to become saturated and therefore to be incorporated in a mineral phase (beryl). The beryllium affinity to plagioclase (London and Evensen 2002) and the lack of this mineral in the early pegmatites suggest that beryl is formed in the highly evolved pegmatites. In this pegmatite group, beryl has blue-green and sometimes yellow colors that correspond to the aquamarine and heliodor varieties. The chemical composition of beryl and consequently its color change during the fractionation of pegmatite bodies. Cornejo and Bartorelli (2010) stated that in pegmatite fields from Minas Gerais aquamarine and heliodor gems are not found together with goshenite (colorless beryl) and morganite (pink beryl). Černý (1975, 2002) stated that this beryl evolution is related to a decrease in Fe and an increase in alkalis due to the evolution of pegmatitic bodies.

Beryl crystals from pegmatites explored for beryl and tourmaline were analyzed, and representative data are shown in Table 8. In the first group of pegmatites, beryl has mainly green and blue colors, and less commonly some shades of yellow. According to the artisanal miners, aquamarine and heliodor were collected from this type of pegmatite. In the pegmatites explored for tourmaline, beryl crystals are mostly white, translucent and sometimes transparent with shades of very light green or pink. Bicolor fragments (pink and green) were rarely collected and always presented faded colors with rare pink beryl crystals (morganite) of a stronger color. The total FeO content in beryl from the first group reaches 0.73 wt.%, while in the second group the highest

Table 6. Chemical composition of coarse grain leucogranites associated to the Mata Azul Suite and paragneiss.

Major elements								
	Levantina quarry intrusion					Minor intrusions		Paragneiss
	MA1	MA2	MA3	MA4	MA5	MA17	MA22	RE17
SiO_2	73.87	70.1	71.6	71.4	74.4	75	74.8	68.45
TiO_2	0.01	0.02	0.01	0.01	0.01	< 0.01	0.01	0.64
Al_2O_3	15.23	14.3	13.95	14.15	13.75	14.3	15.33	16.01
FeO_t	0.69	0.79	1.18	1.12	0.92	0.47	0.19	1.99
MnO	0.08	0.06	0.2	0.15	0.11	0.04	< 0.01	0.07
MgO	0.06	0.09	0.08	0.07	0.07	0.03	0.08	2.06
CaO	0.56	0.35	0.56	0.68	0.68	0.49	1.92	2.55
Na_2O	4.05	3.05	3.91	4.33	4.47	5.2	6.48	5.94
K2O	4.81	6.03	3.6	3.2	3.14	3.62	0.48	1.44
P_2O_5	0.12	0.12	0.09	0.1	0.15	0.09	0.08	0.2
LOI	0.5	0.49	0.49	0.44	0.41	0.7	0.6	0.5
Trace elements (ppm)								
Be	3	---	---	---	---	6	72	6
Rb	211.2	---	---	---	---	207.8	38.9	61
Cs	1.9	1.95	1.46	1.31	1.09	2.5	0.4	1.8
Ba	15	31.3	15.9	11.2	10	32	35	212
Sr	19.3	22.6	22	21.4	23.1	22.1	106.2	130.2
Ga	21.2	19.4	18.9	20.7	18.1	24.6	26.2	14.7
Sn	3	---	---	---	---	3	3	3
Ta	0.6	---	---	---	---	1.3	3.5	0.9
Nb	8	8.8	7.6	8.4	5.9	21.9	7.8	17.3
Th	1.3	1.78	0.81	3.01	1.13	2.8	0.6	11.3
U	4.7	---	---	---	---	5.7	3.2	3.3
Zr	35.8	17	7	63	15	20	8	195.1
Hf	1.8	---	---	---	---	1.5	1	4.9
Y	10.4	7.2	12.2	20.5	7.8	10.8	8	23.7
Zn	3	---	---	---	---	8	22	72
B	7	---	---	---	---	6	3	
F	263	---	---	---	---	216	263	
Li	31					40	35	
REE (ppm)								
La	2	2.6	1.4	4.4	2.1	2.9	3.2	35.1
Ce	4.8	5.2	2.5	9.1	4	6.5	7.3	84.1
Pr	0.59	0.62	0.31	1.17	0.47	0.72	0.89	8.58
Nd	2.5	2.2	1	4.1	1.6	2.3	3.3	34.1
Sm	0.8	0.86	0.48	1.52	0.61	0.85	1.35	7.05
Eu	0.06	0.08	0.09	0.08	0.08	0.09	0.48	1.41
Gd	0.83	0.79	0.67	1.92	0.61	1.03	1.43	5.65
Tb	0.26	0.18	0.24	0.49	0.17	0.29	0.3	0.87
Dy	1.4	1.21	1.91	3.37	1.3	1.65	1.68	5.37
Ho	0.31	0.25	0.36	0.67	0.28	0.26	0.28	0.99
Er	1.06	0.81	1.21	2.06	0.87	0.98	0.66	2.85
Tm	0.2	0.15	0.26	0.39	0.18	0.14	0.13	0.41
Yb	1.74	1.1	2.18	2.9	1.38	1.13	0.79	2.8
Lu	0.22	0.16	0.29	0.43	0.19	0.14	0.1	0.4

REE: Rare Earth Element; LOI: Loss on ignition.

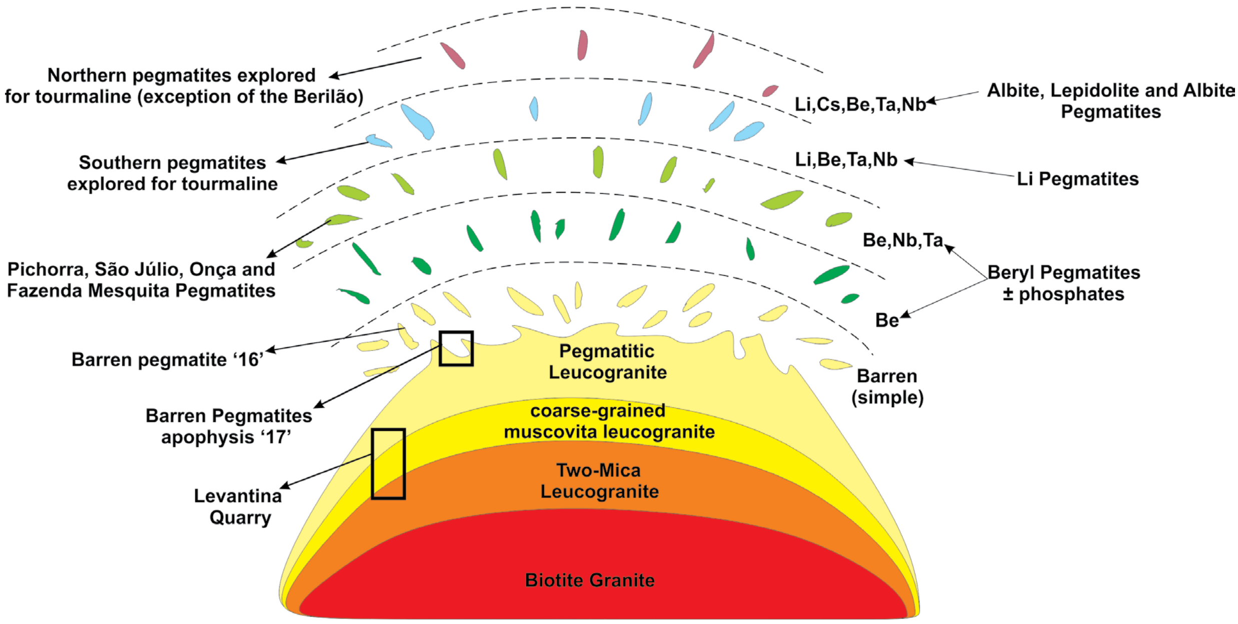


Figure 12. Schematic representation of regional zoning and evolution from a simple biotite granite to a complex pegmatite, applied to the studied pegmatites. Modified from Trueman & Černý 1982) and London (2008).

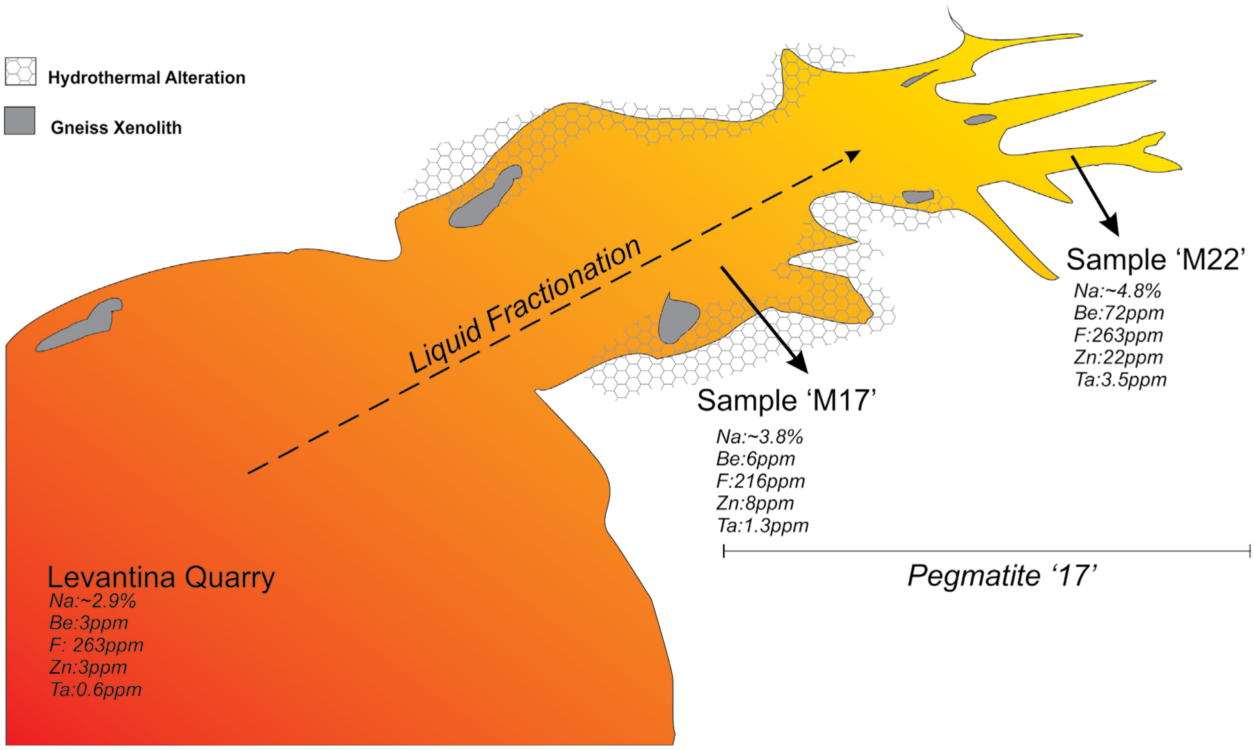


Figure 13. Schematic representation showing the roof of a leucogranitic intrusion of the Mata Azul Suite represented by the Levantina quarry and pegmatitic apophysis of the "17" barren pegmatite (samples "M17" and "M22") with the content variation of some elements. The dashed arrow indicates the evolution of the magma.

Table 7. Representative composition of garnet crystals.

	Mata Azul Suite	"17" simple pegmatite	"16" simple pegmatite	Onça pegmatite (beryl)	Boanerges pegmatite (tourmaline)
	Almandine	**Almandine**	**Almandine**	**Almandine**	**Spessartine**
SiO_2	35.00	34.99	34.99	35.00	37.62
TiO_2	0.00	0.15	0.08	0.06	0.02
Al_2O_3	21.00	20.61	20.68	23.00	19.95
FeO_{total}	35.17	34.41	32.42	28.45	15.01
MnO	6.26	8.27	11.17	13.18	27.57
MgO	1.23	0.43	0.15	0.80	0.04
CaO	0.39	0.53	0.22	0.25	0.52
Total	99.05	99.38	99.71	100.74	100.73
Formula content					
Si	2.912	2.919	2.918	2.838	3.068
Ti	0.000	0.010	0.005	0.003	0.001
Al	2.061	2.029	2.035	2.211	1.919
Fe	2.448	2.401	2.261	1.997	1.023
Mn	0.441	0.584	0.789	0.905	1.905
Mg	0.152	0.054	0.019	0.097	0.005
Ca	0.034	0.047	0.019	0.021	0.045
Mn/(Mn + Fe)	0.15	0.20	0.26	0.31	0.65
Final member composition					
% almandine	78.44	76.52	71.66	63.95	32.41
% spessartine	15.14	20.02	27.04	31.90	65.85
% pyrope	5.23	1.84	0.64	3.40	0.17
% grossular	0.00	0.00	0.00	0.75	1.03

Number of cations on the base of 12 O.

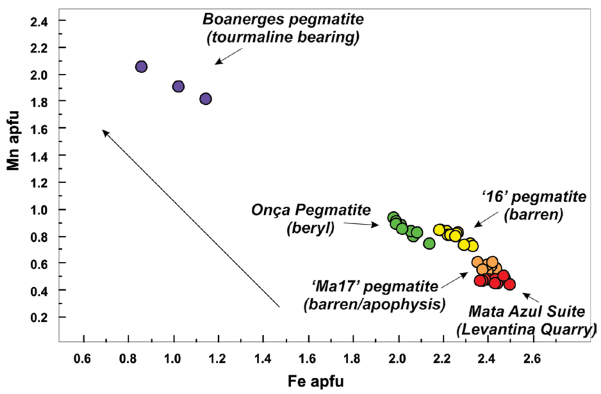


Figure 14. Chemical composition of garnet crystals from the parental Mata Azul leucogranite and the associated pegmatites, showing a negative correlation between Fe and Mn. Arrow indicates the direction of fractionation.

FeO content is 0.36 wt.%. The maximum alkali content in beryl from the first group is 0.56 wt.%, while in the second group the alkali content reaches 1.64 wt.% in a pink crystal. Thus, the beryl type can be used as a trace of the degree of chemical evolution of the two main types of mineralized pegmatites.

The abundant presence of albite and Li-rich minerals, such as elbaite and trilithionite, is also evidence of the higher degree of chemical fractionation of the pegmatites explored for tourmaline. Moreover, these pegmatites are subdivided into northern and southern groups, and their evolution degree can also be associated with this geographical location. The pegmatites of the northern group, with the exception of the Berilão pegmatite, are more evolved than those of the southern group based on the following minerals:

- the presence of trilithionite mica and the rare occurrence of spodumene ($LiAlSi_2O_6$);
- the uncommon elbaites, especially the pink type with low values of Fe and high values of Li and Al;
- the presence of albite masses with a singular mineral association.

According to Černý (1991), a pegmatitic field is a terrane occupied by pegmatite groups within a common geological and structural environment, usually smaller than 10,000 km^2. The pegmatites are generated during a single tectonomagmatic stage of the regional evolution; they have the same granitic source and approximately the same age. The pegmatite bodies studied here were not generated from a unique intrusion, but they evolved from different bodies of a single suite. In this study, based on petrographic, geochemical and geochronological data, the Mata Azul Suite is considered the probable source for the granitic pegmatites, which are likely related to the evolution of the leucogranites.

The approximately 2,000 km^2 study area is located at the border region of Goiás and Tocantins States (Fig. 15). However, once there are pegmatites and granite bodies from the Mata Azul Suite that are not included in this study, the pegmatite-bearing area can be extended farther. Thus, the region regarded as the Mata Azul Pegmatitic Field could be larger, particularly to the northeast of the Berilão pegmatite, where artisanal miners have reported a number of pegmatite occurrences towards the Retiro district in the region of São Salvador do Tocantins.

CONCLUSIONS

In central Brazil, Goiás and Tocantins States, several granitic pegmatites are first characterized and grouped in a pegmatitic field called the Mata Azul Suite Pegmatitic

Table 8. Representative composition of beryl crystals from pegmatites explored for beryl and tourmaline.

	São Júlio Beryl-bearing Pegmatite		Boanerges and Marimbondo Tourmaline-bearing Pegmatites				
	Blue	Green	White 1	White 2	White 3	White 4	Pinkish
SiO_2	65.45	65.44	64.42	64.01	64.19	65.09	64.93
Al_2O_3	18.5	18.38	18.83	19.87	20.01	18.61	18.74
FeO_{total}	0.73	0.68	0.26	0.17	0.36	0.27	0.03
MnO	0.03	0	0.03	0.02	0.01	0.04	0
Na_2O	0.3	0.38	0.89	0.93	0.72	0.82	1.21
K_2O	0.03	0.03	0.04	0.02	0.04	0.03	0.04
Rb_2O	0.05	0.04	0.07	0.00	0.04	0	0
Cs_2O	0.05	0.11	0.13	0.17	0.2	0.11	0.39
Total	85.14	85.06	84.67	85.19	85.57	84.97	85.34
Formula contents							
Si	5.965	5.972	5.917	5.845	5.841	5.947	5.928
Al	1.987	1.977	2.038	2.138	2.146	2.004	2.016
Fe	0.056	0.052	0.020	0.013	0.027	0.021	0.002
Mn	0.002	0.000	0.002	0.002	0.001	0.003	0.000
Na	0.053	0.067	0.158	0.165	0.127	0.145	0.214
K	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Rb	0.001	0.001	0.001	0.000	0.001	0.000	0.000
Cs	0.000	0.001	0.001	0.002	0.002	0.001	0.004
Be*	3	3	3	3	3	3	3

*Be fixed in the ideal 3 apfu. Number of cations on the base of 15 O.

Field. These granitic pegmatites have LCT origins and are divided into groups that are barren, explored for beryl and for tourmaline, based on the main mineral resource extracted by miners.

Most of the bulk compositions consist of quartz, K-feldspar, kaolin and muscovite, and the main accessory minerals are garnet, beryl, tourmaline, albite, trilithionite and Fe-Mn phosphates. Surrounding the barren pegmatites, there is an

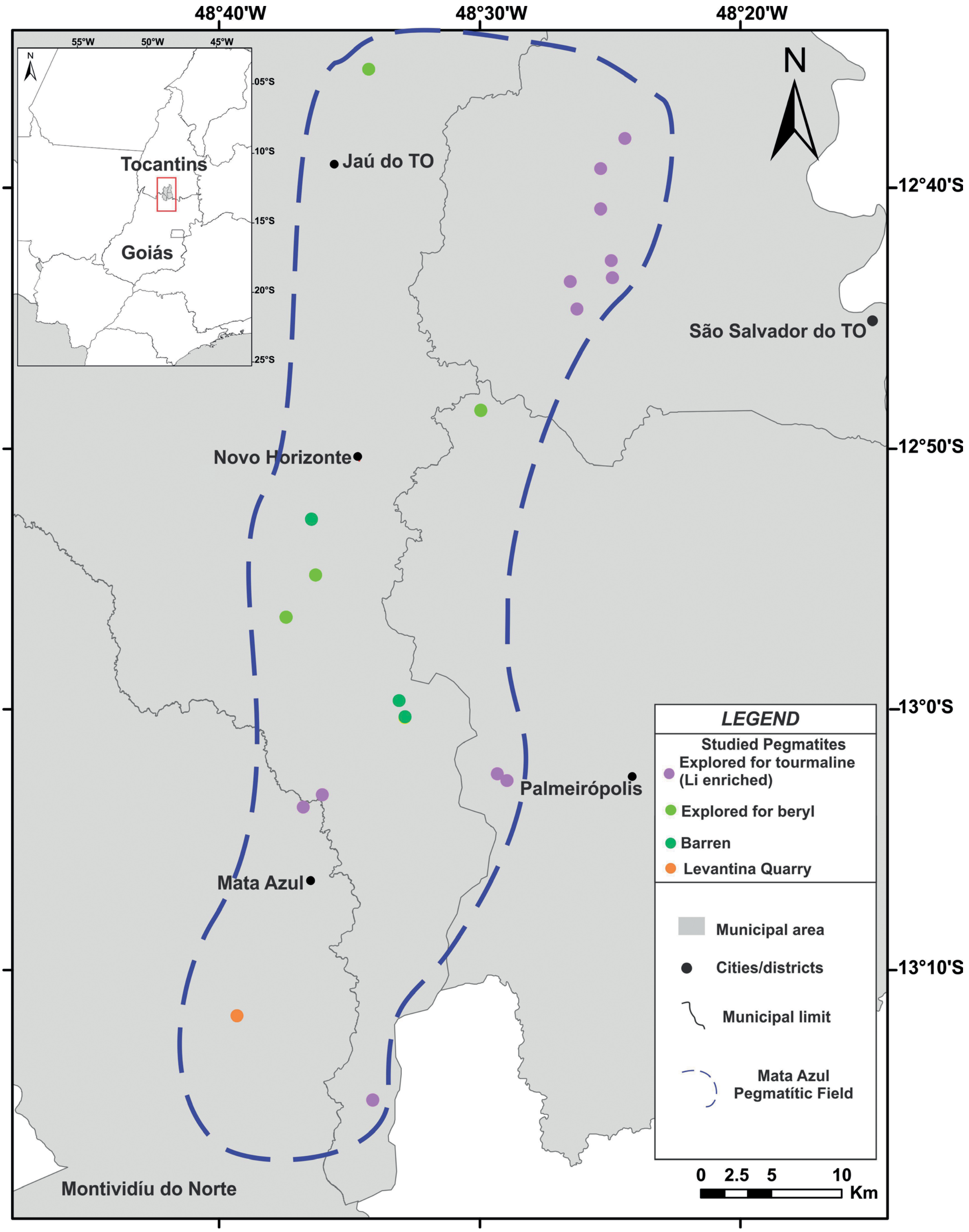


Figure 15. Current area of the Mata Azul Pegmatitic Field in blue.

association composed of Ca minerals and sulfides formed due to thermal metamorphism and hydrothermal activity.

Monazite crystals from the Boanerges pegmatite are dated to 519.9 ± 2.8 Ma. by the U-Pb method, as an alternative isotopic age; U-Th-Pb chemical dating in uraninite from the São Júlio pegmatite yields ages varying from 411 to 560 Ma.

Petrographic and chemical characteristics from the Mata Azul Suite are used to link their leucogranites to the granitic pegmatites studied. The barren pegmatites and those explored for beryl and tourmaline show fractionation from the least to the more chemical evolved, evidenced by mineralogical data such as the mineral associations and beryl and garnet chemistry. The location of the Mata Azul granitic intrusions may be useful as a prospecting guide for pegmatites that have proven profitable for gemstone exploration, especially aquamarine and tourmaline.

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