THE BORBOREMA PEGMATITE PROVINCE, NE-BRAZIL REVISITED*

H. Beurlen[1]
S. Barreto[1]
R. Martin[2]
J. Melgarejo[3]
M. R. R. da Silva[1]
J.A. Souza Neto[1]

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[1]Federal University of Pernambuco (UFPE) Dept. of Geology; beurlen@ufpe.br
[2] McGill University, Montreal-Canada, [4] University of Barcelona, Spain.

INTRODUCTION

The Borborema Pegmatite Province (BPP) in Northeastern Brazil was known since World War I, when it was exploited for mica. At the end of World War II it became famous as one of the world's most important producers of Ta-ore and of beautiful specimens of exotic minerals. Recently it became an important supplier of raw materials for the Brazilian ceramics industry. Its most famous product nowadays is the turquoise blue copper bearing "Paraíba Tourmaline". In spite of this importance, very few systematic geological studies were performed about the BPP in the last fifty years and several important questions remain unsolved or were never addressed, like the classification of the pegmatites based on geochemical techniques and paragenetical properties, comparison with other pegmatite fields, their regional zoned distribution and the identification of the granitic (or other) source. The present review will focus these points based on previous literature and geochemical and geochronological data and field observations, obtained in the last two decades, mainly as introduction on the knowledge on the BPP for the post-symposium field trip participants.

GEOLOGICAL SETTING

The pegmatites of the province are concentrated in an area of approximately 75 x 150 km, in the southeastern part of the Seridó Foldbelt – Rio Grande do Norte Tectonic Domain of the Borborema Tectonic Province, between 5°45' and 7° 15' of southern latitude and 35° 45' and 37° western longitude, in the States of Paraíba and Rio Grande do Norte, NE - Brazil. The Seridó Foldbelt in this area consists of the Jucurutú, Equador and Seridó formations of the Neoproterozoic Seridó Group (Van Schmus 2003). Most (80%) of the over 750 known rare-element-mineralized granitic pegmatite bodies are intruded in garnet-cordierite and/or sillimanite-biotite schists of the upper Seridó Formation. Less than 10% are emplaced in the underlying quartzites, metarkoses and meta-conglomerates of the Equador Formation (Da Silva et al. 1995). The remaining bodies are hosted by gneisses and skarns of the Jucurutú Formation, by late to post-tectonic granites or by gneisses and migmatites of the Paleoproterozoic basement sequence. The regional metamorphism of the Seridó Group is of the Abukuma type and attained the amphibolite facies. More details about the geology of the area will be discussed by Elton et al. (2009) in this issue.

REGIONAL ZONED DISTRIBUTION

The only model of a regional zoned distribution of the Be-Li-Ta-Sn bearing pegmatites so far proposed for the BPP distinguishes a very discontinuous distal zone, dominated by REE-enriched pegmatites, supposedly followed inward by a zone of Sn-bearing pegmatites, an intermediate zone dominated by beryl-bearing pegmatites and an inner, beryl-tantalite-bearing zone. The proposed model, however, does not fare well in a statistical evaluation because the so-called Sn-zone bears also many pegmatite bodies exploited only for Be- or Ta-ore. Also, cassiterite is a common accessory coexisting with columbite group minerals in the inner, so-called, Ta-Be zone (Da Silva et al. 1995). The spatial distribution proposed by this model is also in disagreement with the general principle that more fractionated (Ta-, Li- rich) pegmatites should be concentrated in greater distances in comparison with less fractionated (Be- and REE-rich) pegmatites. A central source pluton, which would be expected, was not identified either. Instead, four subtypes of late tectonic Neoproterozoic ("Brasiliano Cycle") granites, occur in the area as several independent intrusions of seemingly random distribution. There is no apparent correlation between the distribution of the mineralized pegmatites and a large intrusion of a particular granite type. This lack of connection with a central granite intrusion led some authors to postulate an anatectic origin of the mineralized pegmatites of the BPP. Another possible alternative explanation for this apparent absence of zonation is that several smaller pegmatite fields surrounding several smaller source intrusions overlap each other.

INTERNAL ZONATION

Johnston (1945) first classified the pegmatites of the BPP as *homogeneous* (usually sterile, generally concordant, without internal structure) or *heterogeneous* (usually enriched in Be-Li-Ta-Sn-minerals and with very variable fabric and mineralogical composition). He proposed a model of internal zoning of the heterogeneous pegmatites distinguishing the following zones, from the margins to the center: Zone I, typically composed of comb-textured muscovite (tourmaline or biotite are also observed in some cases) intergrown with medium-grained quartz, Na- and K-feldspar; Zone II, formed by a homogeneous medium-grained K-feldspar + quartz ± albite pegmatite with common graphic intergrowths of quartz and perthite, showing an inward increasing grain size; Zone III is composed almost exclusively by large perthite crystals (blocky feldspar zone), and Zone IV, a monomineralic nucleus of massive (milky or rose) quartz. These four zones may well be compared respectively to the border, wall, intermediate zones and quartz core, names later adopted worldwide to describe the most usual pegmatite zonation. He also recognized the importance of replacement pockets enriched rich in albite and/or muscovite, tourmaline as sites of enrichment in ore minerals and fosfates.

GEOCHEMISTRY AND MINERAL PARAGENESIS

A first study of the trace element geochemistry in feldspars and micas and its relation to variations in mineral paragenesis of ten mineralized pegmatites led Da Silva et al. (1995) to the attribution of the

BPP pegmatites to the beryl-columbite-phosphate subtype of the rare-element pegmatite class and LCT family according to Černý's classification. More recently, compositional data on tourmalines, garnet and spinel, and trace-element geochemical data on micas and feldspar, and the zoning of the mineral paragenesis, indicate a higher degree of fractionation for several other mineralized pegmatites. This is the case of Quintos and Capoeira 2, which were classified as examples of the spodumene subtype (Soares 2004) and of Carrascão as being of the lepidolite subtype. Less fractionated, but still heterogeneous pegmatites were also recognized as being of the beryl subtype, free of phosphates, with magnetite, Ta-rich rutile and ixiolite as main ore minerals. Mineral chemistry data of Nb-Ta oxides from 29 pegmatites allowed Beurlen et al. (2008) to identify pegmatites of both, the Beryl-Columbite-Phosphate and Complex Spodumene subtypes of rare element class of granitic pegmatites according to Černý & Ercit (2005). A difficult problem using mineral paragenesis, zonal structure, and mineral geochemistry (mainly feldspar and mica) for the pegmatite classification is that in many of those pegmatites for which there is an available historical record, a strong vertical or longitudinal zoning is observed and would allow to classify different portions of a single body as belonging to different types or subtypes. This is the case of. Boqueirão, Capoeira 2, Carrascão, Quintos and Batalha pegmatites.

GRANITIC SOURCE

Most contributions to the literature on pegmatites of the BPP implicitly assume an origin from a granitic source, however without a clear indication of the source granite type or particular intrusion. In contrast, Ebert (1970) argued in favor of a palingenteic origin of the BPP pegmatitesbecause of the lack of a clear field relation with a particular granite type or intrusion. Pegmatite ages using U/Pb isotopes in columbite group minerals, $^{40/39}$Ar in biotites, and in a Sm/Nd in whole rock/garnet/K-feldspar isochron range respectively between 509± to 515± Ma, 523±2.5Ma and 494±15Ma respectively (Baumgartner et al. 2006, Araújo et al. 2005 and this contribution).

Amongst several different Neoproterozoic to Cambro-Ordovician, syn- to post-tectonic granite types that occur in the BPP, the youngest one is a late- to post-tectonic peraluminous pegmatitic granite type, which occurs in several small randomly distributed intrusions, with ages of U/Pb isotopes in monazite of 528±12Ma (Baumgartner et al. 2006) and ages obtained by chemical U/Th/Pb EMPA dating in uraninite, xenotime and monazite of 520±10Ma (Beurlen et al. 2009). Most authors since the 1980ies agree that these small stocks of S-type, leucocratic, pegmatitic granites (attributed to the G4 phase of granitic magmatism of Jardim de Sá et al. 1981 or type GR3 by Da Silva et al. 1995), are the most probable parental granites of the mineralized pegmatites. Due to the small size, usually less than 0.5km^2 across, granite intrusions of this type were systematically omitted in the geological maps of the area and never described in detail. More recently it was also possible to identify four larger intrusions of this type of pegmatitic granites with extents between 4 and 40km^2. The recently opened quarries for exploitation of this pegmatitic granite type as dimension stone allow to distinguish four textural facies: 1) medium homogeneous grained leucogranite; 2) layered sodic (garnetiferous) aplite; 3) porphyritic leucogranite with graphic feldspar-quartz megacrysts; 4) pegmatitic facies. These facies are identical to those described as source-granites in rare-element granitic LCT pegmatite fields elsewhere. REE patterns characterized by low bulk REE contents and a disturbed "kinked appearance" and other geochemical parameters are also very similar to those referred by Černý et al. (2005). In addition, gahnite, cassiterite, ferro- and manganocolumbite were found as accessory minerals in the pegmatitic granites. Baumgartner et al. (2006) consider the age difference of 11Ma found between these pegmatitic granites and the pegmatites to large to accept them to be co-genetic. All the other findings and, last not least, the still very large differences between geochronological results of different authors, suggest that these pegamtitic granites must still be seriously considered as probable source granites of the mineralized pegmatites of the BPP. A new geological mapping, more precise geochronological data and the analysis of their spatial relation with the different pegmatite subtypes is necessary to confirm or discard this hypothesis and may be the main tool for the exploration of most promising areas for Ta- and may be, Cs-mineralized pegmatites in the province.

FLUID INCLUSIONS

Fluid inclusion studies in some of the mineralized pegmatites allowed to establish the crystallization conditions between 580°C (liquidus) and 420°C (solidus) at ± 3.5kb (Beurlen et al. 2001) from a melt saturated in both, low salinity H_2O and CO_2 in a first stage and in H_2O with increasing salinity. Preliminary studies of melt inclusions suggest that two immiscible melts coexisted during early stages of crystallization. These are respectively a peraluminous and a peralcaline melt fractions, (Thomas et al. 2006). All these conditions are considered typical of granite derived Rare-Element class granitic pegmatites.

CONCLUSIONS

Considering the internal structure, mineralogical distribution and geochemical data on K-feldspar, white micas, Nb-Ta-oxides, tourmalines, garnet and spinel, it becomes clear that the pegmatites classified as "heterogeneous" (Johnston 1945) include examples of several types and subtypes of LCT family, Rare Element Class pegmatites if the modern pegmatite classification models of Černý & Ercit 2005 are applied: at least examples of the beryl-columbite, beryl-columbite-phosphate and complex-spodumene, complex-lepidolite (± gemmologic elbaite) and albite (± cassiterite) pegmatite types and subtypes were tentatively identified. The impossibility to determine a granite-linked zoned regional distribution of these types may be the result of the fact that there is no single central source pluton but several smaller granitic intrusions in the province and the zoning around them may overlap each other.

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