GEOLOGY OF GEMSTONE DEPOSITS IN SOUTH BRAZIL[1]

Pedro Luiz Juchem [2], Tania Mara Martini de Brum [2], Adriane Comin Fischer [3], Antonio Liccardo[4], Nelson Luiz Chodur [4]

1 – Financial support by CNPq, CAPES, FAPERGS and PROPESQ-UFRGS. 2 – Gem Laboratory – Universidade Federal do Rio Grande do Sul (UFRGS) – labogem@ufrgs.br; 3 – Departamento Nacional de Produção Mineral (DNPM) – adriane.fischer@ufrgs.br; 4 – Geology Department – Universidade Federal do Paraná (UFPR) – liccardo@ufpr.br; chodur@ufpr.br;

ABSTRACT

In south region of Brazil, there are several gem material deposits in different geological units. The largest and more important are agate and amethyst geode deposits in Serra Geral Magmatic Province, a Cretaceous volcanic sequence of Paraná Basin. These deposits are more expressive in Rio Grande do Sul State (RS), but similar deposits occur sparsely in west of Santa Catarina State (SC) and southwest of Paraná State (PR). Diamond alluvial deposits in Tibagi River valley (PR) are known by the special gem quality of the stones. In north of SC, ruby and sapphire occur in colluvial deposits associated to granulitic rocks. A large deposit of petrified wood is known in central region of RS, hosted in Gondwanic rocks, which commercial use is prohibited. Serpentinites originated from Precambrian mafic rocks are exploited in southwest RS and used as fine carving objects.

INTRODUCTION

Brazil is one of the largest and more important Gemstone Province in the world, due to the amount, variety and quality of the exploited gem materials. In south Brazil region – RS, SC and PR – important gem materials deposits occur, related to different geological units (Figure 1). The largest and more important deposits are of agate and amethyst in RS, which are included in the most important deposits of the world. Other important gem material deposits are of opal, ruby, sapphire, diamond, serpentinites and petrified wood. These gemstones are exported to several countries as cut gems, collection samples and ornamental gemstones.

GEOLOGICAL SETTING

In south Brazil region, there are five main important geological units. Crystalline rocks occur in the Precambrian shield, in two main groups: 1) the metamorphic rocks - granulitic gneisses, migmatites, amphibolites, deformed granitoids and mafic and ultramafic rocks - with 2.0 to 2.5 Ga; and 2) younger granitic and metamorphic rocks - tonalites, granodiorites, alkali granites, syenites and schists, phyllites, quartzites and marbles - with 550 to 650 Ma (Almeida *et al*., 1986). In RS, these rocks are known as the Sul Riograndense Shield, in SC they are mainly in the Granulitic Complex of Santa Catarina, and in PR they correspond to Açungui Group.

The Gondwanic sedimentary rocks were deposited in the huge intracratonic Paraná Basin, which covers an area of about 1,600,000 km^2 in central-eastern South America. This sedimentary basin had a complex geological evolution, ranging from late Ordovician to late Cretaceous age (Milani *et al*., 1998). A number of depositional settings, including glacial beds, shallow marine to continental facies were successively established, controlled by climatic and tectonic factors. Desert sandstones (Botucatu Formation) were deposited during Triassic and Jurassic age, in the last sedimentary event of Paraná Basin, being nowadays one important underground water reservoir.

Serra Geral Magmatism, one of the major Continental Flood Basalt (CFB) events in the history of Earth, covered 75% of Paraná Basin with several lava flows. This volcanism originated through deep fractures in the Earth`s crust, related to western Gondwana rupture and South Atlantic Ocean opening (Piccirillo *et al.,* 1988). These rocks – named as Serra Geral Formation – are mainly tholeiitic basalts and basaltic andesites (>90%). Acid rocks (rhyodacites and rhyolites) may occur at the top of the volcanic sequence (± 4% of lava volume) and are more common in RS and SC (Piccirillo *et al.,* 1988; Roisenberg, 1989). Radiometric Ar-Ar age data reported by Turner *et al.* (1994) and Mantovani *et al.* (1995) yielded 127-137 Ma for the volcanic activity. Wildner *et al.* (2007)

proposed to name these rocks as Serra Geral Group, with twelve units related to basic rocks and four units related to acid rocks.

Cretaceous sediments are continental sandstones with reddish violet colour, covered by recent sediments in some areas. The Coastal sediments are mainly Quaternary to recent continental, marine and transitional units, originated during sea level oscillations that occurred since Pliocene.

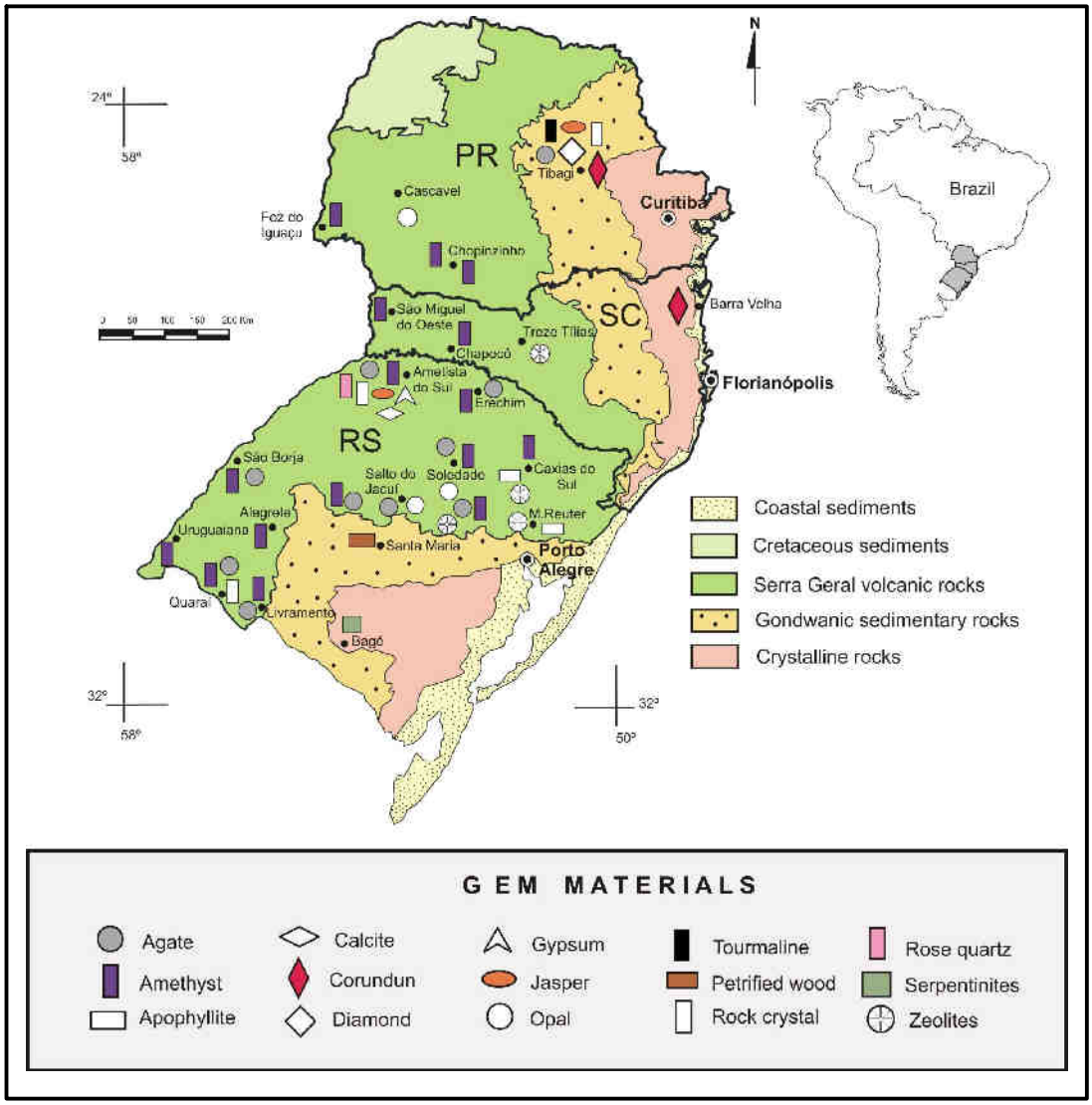

Figure 1 – Gem Materials Map of south Brazil region, with the most important gem deposit localities and their geological settings. Modified from Juchem *et al.* (2004).

AGATE AND AMETHYST DEPOSITS

Agate and amethyst occur in geode deposits in Serra Geral volcanic rocks, mainly in RS. The amount and quality of these gems have turned this State into the second brazilian gem exporter and one of the main worldwide suppliers of agate and amethyst to the international market. Rock–crystal, milky and rose quartz, onyx, jasper, calcite, apophyllite, zeolites, opal, gypsum, and barite can also occur inside geodes, or associated in these deposits (Juchem *et al.*, 2004).

In central RS is the main agate mining region, known as Salto do Jacuí Mining District (Santos *et al.*,1998), within an area of about 100 km^2 which encloses more than 150 mine fronts. Mining activities are done mainly by open-pit in an altered basaltic/andesitic rock and also in small underground adits (Figure 2). The mineralized rock is aphanitic, and has a groundmass of glass and

microlites of plagioclase, clinopyroxene and opaque minerals, with some microphenocrysts of the same composition (Strieder & Heemann, 2006). Agate usually occurs completely filling roundish to egg-shaped cavities with about 20-40 cm (up to 1 m), but some cavities can be incompletely filled and/or followed by a colourless to milky quartz layer and rarely by amethyst. Well formed calcite and spherical or needle-like Fe and Mn oxides can occur as late minerals; these opaque minerals can also occur as agate inclusions, sometimes in moss-like patterns. Agate is usually dyed in order to improve or modify the natural colours. Onyx deposits occur near Salto do Jacuí, but most of this mineral in the trade is actually dyed agate.

Gem quality opal occurs in Salto do Jacuí and also in several small deposits between this region and Soledade. The opal can occur associated with agate – as a late layer inside geodes, or intercalated with the agate bands – but also cementing breccias, filling centimetric vesicles or along lava flow structures (Augustin *et al.,* 2004). Black colour opal filling small cavities and thin fractures was recently described in SW of PR, in the same volcanic formation (Juchem *et al.*, 2004).

The most important amethyst mining region is in north of RS, named as Ametista do Sul Mining District (Santos *et al*., 1998). The deposits occur in an area of about 300 km^2 within 10 municipalities, which encloses more than 350 mine fronts. In this region, large amethyst-bearing geodes are extracted from fresh massive basalt in horizontal underground adits (100 to 200 m) and also in some open-pits (Figure 2). In this Mineral District, four amethyst-bearing lava flows were identified and seem to share a common structural and lithological pattern all over the region (Juchem *et al.,* 2007). The mineralized basalt is aphanitic, with microphenocrysts of altered labradorite, augite and sometimes relicts of mafic minerals. The groundmass has the same mineral composition, plus opaque minerals (ilmenite, Ti-magnetite). These minerals can be enclosed by an altered (clay minerals) glassy matrix and also by a recrystallized material that reminds quartz and feldspar. The mineralized geodes in this region are mainly rounded tubular cavities, commonly with more than 1 m of length. These cavities are usually incompletely filled with a thin outer layer of microcrystalline quartz, sometimes banded (agate), followed by a centimetre-scale layer of colourless to milky quartz with progressive colour increase to amethyst. Four successive crystallization sequences can be observed, due to different hydrothermal flows. The outermost layer of the geodes is usually lined with celadonite, related to hydrothermal alteration of the basaltic wall-rock. Mineralogical and geochemical results, including solid and fluid inclusion studies and oxygen isotope data, show that these minerals have been deposited in epithermal conditions, with temperatures close to that of the Earth's surface, from fluids having at least a component of meteoric water (Juchem, 1999). These low temperatures were confirmed further by Gilg *et al*., (2003) and also by Fischer (2004).

Euhedral rose quartz may occur with amethyst crystals. Late minerals in the geodes are mainly calcite and also gypsum (selenite variety) and barite (Juchem *et al*., 2004). Selenite, a hyaline variety of gypsum, occurs only in two mines. The crystals are always euhedral with prismatic to tabular habit in parallel aggregates, ranging from few centimeters up to 1m of length. The crystallization in geodes as well as the big size, characterizes it as a unique and exceptional selenite deposit in the world. The gem material classified in the trade as jasper, actually are breccias composed by irregular fragments of agate, basalt and sandstone. Glass and glassy rocks that occur at the limit between lava flows have been used as carvings and improperly named as jasper.

Similar deposits of amethyst occur in west of SC and southwest of PR. Recent mining in Chopinzinho region (PR) are producing good gem-quality amethyst crystals from geodes with 50 to 60 cm up to 1 m of length (Juchem *et al*., 2008). Agate and amethyst deposits in the region between Quaraí and Livramento (RS) are sporadically exploited during the last years. Despite the low mineral production, amethyst crystals are of good gem quality. Mineralized geodes (30 to 40 cm of length) from this region are exploited mainly in colluvial and alluvial deposits, but also in an altered basalt to andesitic-basalt unit, in surface mines (Augustin *et al.,* 2007). In Caxias do Sul (RS) there are two regions where amethyst is produced during the last years. One amethyst-bearing altered lava flow has been identified, which is aphanitic with microphenocrysts of labradorite, augite and opaques, with a groundmass of altered (clay minerals) volcanic glass and crystallites. Geodes are usually roundish to elliptical cavities (10 to 40 cm of length) and are exploited in surface mines. Petrographic and chemical classification show that these rocks are rhyolites and dacites (Sirtoli *et al*., 2005). This is the only amethyst deposit known until now in south Brazil that occurs in acid lava flows.

Amethyst may be heat-treated in order to produce yellow quartz (citrine), which is improperly known in the trade as "Rio Grande topaz". Natural citrine has not been found in these deposits.

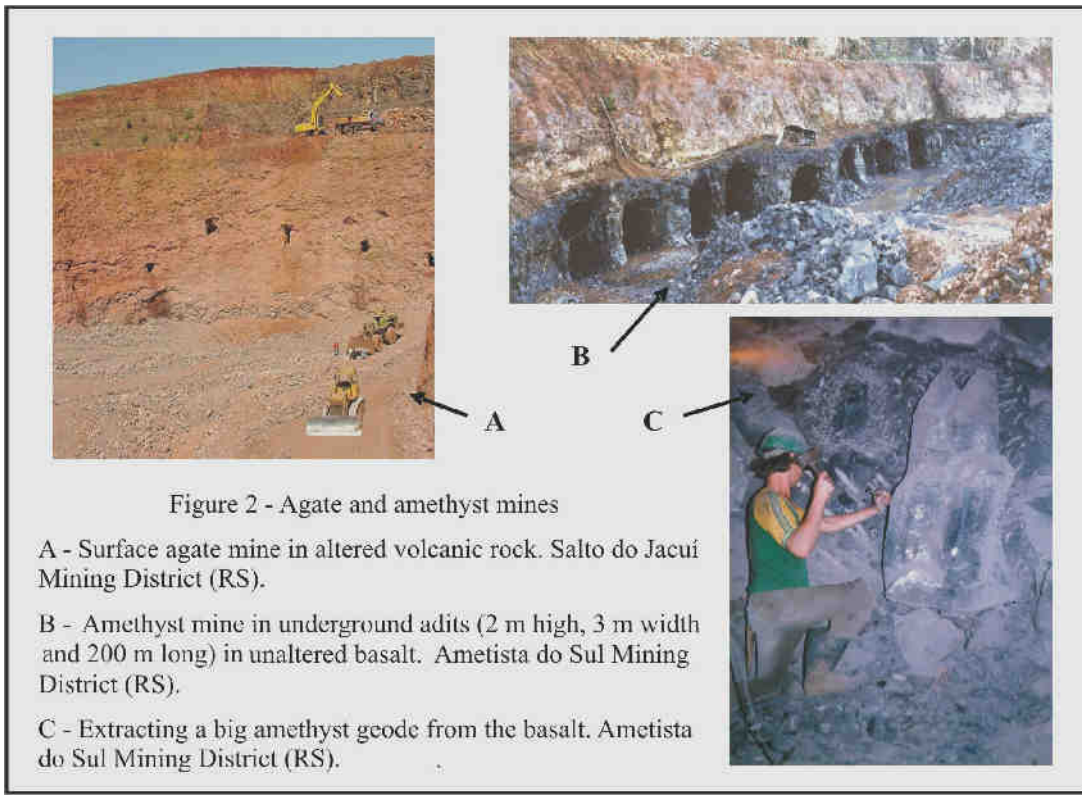

Figure 2 - Agate and amethyst mines

A - Surface agate mine in altered volcanic rock. Salto do Jacuí Mining District (RS).

B - Amethyst mine in underground adits (2 m high, 3 m width and 200 m long) in unaltered basalt. Ametista do Sul Mining District (RS).

C - Extracting a big amethyst geode from the basalt. Ametista do Sul Mining District (RS).

Zeolites and apophyllite may occur in several regions, filling geodes or associated with other geode minerals in Serra Geral volcanic rocks. Apophyllite occurs as centimeters-long colourless to greenish well-formed crystals. Zeolites occur as some millimeters to a few centimeters sized crystals, being identified stilbite, mordenite, heulandite, scolecite, laumontite, epistilbite, chabazite, analcime, stellerite and levyne (Simas *et al.,* 1999).

Several models for the genesis of mineralized geodes in volcanic rocks have been proposed, but there are still many questions to be discussed. As suggested by many workers (e.g. Leinz, 1949; Gilg *et al*., 2003) an immiscible fluid, probably volatiles from the magma, may have formed the cavities in the basaltic rocks. The cavity forming fluids, or late magmatic fluids, or hydrothermal fluids may have deposited the minerals inside geodes. Bossi & Caggiano (1974) suggested that the geode formation was related to the incorporation of sand (Botucatu Formation) while the lava was still fluid, and this detritic quartz was transformed further into the silica minerals. Recently, Strieder&Heemann (2006) suggested that the mineralized rock in Salto do Jacuí Mining Disctrict were intruded in regional volcanic units, incorporating Botucatu sandstone. This sand may have reacted with the hosted rocks, originating the agate geodes. Duarte *et al.* (2005) suggested an epigenetic origin for both, the cavities and the mineralization: water from Botucatu sandstones flows into the volcanic rocks and opened the cavities by deformation of the altered basalt. The same silica enriched fluid may have deposited the silica minerals inside these cavities.

DIAMOND DEPOSITS

Diamond occurrences in alluvial gravel deposits, usually associated with gold, are known in Tibagi River (PR) and affluents that drain Gondwanic marine and glacial sedimentary rocks (Chieregati, 1989). Usually the stones are of small size and may exhibit several fractures. These features suggest a long sedimentary transport and prevent the determination of the diamond source. Despite the small size of the stones, the Tibagi diamond is famous for its special gem quality. However, there are some reports of special clear rough stones with up to 5 carats. During the last

century, this gemstone was only occasionally exploited. Nowadays, there is an increase in diamond exploitation with about eighty points of extraction along the Tibagi River (Figure 3).

Recent studies identified other gem materials in the gravel. These minerals are blue and green sapphire in translucent to opaque crystals; gray, red, brown and black agate; orange and yellow jasper; hyaline quartz; and black tourmaline.

RUBY AND SAPPHIRE DEPOSITS

Large recent colluvial deposits with ruby and sapphire, associated to granulitic rocks occur in Barra Velha (SC). The sediments are poorly sorted, composed by blocks, gravels and pebbles of milky quartz and fragments of quartzites and granitic rocks, with a sandy to clay-size matrix (Chodur, 1997). Prismatic corundum crystals, with about 1 to 5 cm of lenght are common in these sediments (Figure 3). Ruby is the most common variety but sapphire with rose, white, brown, gray and black colours also occur. The crystals are opaque to translucent and may exhibit colour zoning, silk, chatoyance and asterism, which produce nice cut and collection stones. Black sapphire with silk, shows a velvet-like appearance which produces special cut stones.

A fuchsite-quartzite occurs associated with the granulitic rocks in this region. There are reports that this material can be cut, producing stones similar to emerald.

Figure 3 – Exploitation of corundum and diamond. A – Extracting ruby and sapphire, in Barra Velha (SC). The bar is 5 cm long. B – Extracting diamond from the gravel in Tibagi River (PR).

SERPENTINITES

Serpentinites are exploited in southwest RS, and are used as carving objects for ornamental purposes. These rocks were originated from gabbros and peridotites in shearing zones, included in Cambaí and Vacacaí units, from neoproterozoic time (Rivaldo, 2006). Antigorite, chrysotile, lizardite, talc, magnetite and relicts of amphiboles, pyroxenes and olivine in foliated, mylonitic, mesh, ribbon and deformed textures are the main petrographic features. The colour varies from light yellowish green to dark green, in irregular distribution, with patches, veins and bands of black, white, yellowhish white, brown and purple colours (Rivaldo, 2006; Juchem *et al.,* 2007). Polychromated serpentinites, a rare and valuable ornamental gemstone in the international trade, also occur in this region.

PETRIFIED WOOD

One of the most important Earth silicified fossil wood records occurs in Santa Maria region (RS). These large deposits are included in three Gondwanic sedimentary units: Mata, Santa Maria and Caturrita Formations and represents a mesophytic flora originated due to climate changes that took place in Meso-Neotriassic transition (Guerra-Sommer & Scherer, 2000). Fragments of trunks that can reach up to 30 m of length are widespread in an area of about 305 km^2. The fossils can exhibit gray, white, pinkish, reddish, yellowish and brown pigmented colours with different degrees of silica

replacement and preserved vegetable structures. This paleobotanic record constitutes an important scientific inheritance that is not properly studied, and its commercial use is now prohibited by law.

REFERENCES

Almeida, F.F.M. 1986. Distribuição Regional e Relações Tectônicas do Magmatismo Pós-paleozóico do Brasil. Revista Brasileira de Geociências. SBG. vol.16, nº 4, p. 325-349.

Augustin, A.H., Pulz, G.M., Juchem, P.L., Brum, T.M.M. & Hartmann, L.A. 2007. Geologia do depósito de agata e ametista Mina Novo São João, Livramento, RS. Pesquisas em Geociências, UFRGS. No prelo.

Augustin, A. H., Juchem, P. L., Brum, T. M. M., Fischer, A. C. 2004 Opala no Rio Grande do Sul In: XLII Anais do XLII Cong. Bras. Geologia. B. Horizonte, MG. SBG. v.único. p.T 861

Bossi, J. & Caggiano, W. 1974. Contribuicion a la Geologia de los Yacimientos de Amatista del Departamento de Artigas. Anais do XXVIII Cong. Bras. Geologia. P. Alegre, RS. SBG. p.301-317.

Chieregati, L. A. 1989. Aspectos mineralógicos, genéticos e econômicos das ocorrências diamantíferas da região nordeste do Paraná e sul de São Paulo. Dissertação de Mestrado. Instituto de Geociências/USP. p. 180.

Chodur, N. L. 1997. Mineralogia e geologia dos depósitos de rubi e safira da região de Barra Velha, SC. São Paulo. Tese de Doutorado-Instituto de Geociências/USP. p. 110.

Duarte, L.C., Hartmann, L.A; Vasconcellos, M.A.Z. 2005. Epigenet geode formation in the world class amethyst deposit of the southern Paraná Basaltic Province. Simp. Bras. de Metalogenia. Gramado (RS). CD-Rom, p. 6.

Fischer, A. C. 2004 Petrografia e geoquímica das fases silicosas dos geodos mineralizados à ametista (região do Alto Uruguai, RS, Brasil). Porto Alegre, p. 159. (Tese - Doutorado) IG-UFRGS.

Gilg, H.A.; Morteani, G.; Kostitsyn, Y.; Preinfalk, C.; Gatter, I.; Strieder, A.J. 2003. Genesis of amethyst geodes in basaltic rocks of the Serra Geral Formation (Ametista do Sul, RS, Brazil): a fluid inclusion, REE, oxygen, carbon and Sr isotope study on basalt, quartz, and calcite. Mineralium Deposita, vol. 38, p. 1009-1025.

Guerra-Sommer, M., Scherer, C. M. S. 2000. Middle Late Triassic Petrified Forests from Mata sandstone at Rio Grande do Sul State, BR: a preliminary geological, taphonomic and biostratigraphic setting. Revista Universidade Guarulhos, Guarulhos, v. 5, p. 117-120.

Juchem, P. L. 1999 Mineralogia, geologia e gênese dos depósitos de ametista da região do Ulto Uruguai, Rio Grande do Sul. São Paulo, p. 225. (Tese - Doutorado) IG - Universidade de São Paulo.

Juchem, P. L., Brum, T. M. M., Fischer, A. C., Chodur, N. L., Liccardo, A. 2004 Gem materials map of South Brazil Region Developments in Science and Technology - Applied Mineralogy. São Paulo: International Council of Applied Mineralogy do Brasil, 2004. v.2. p.513 - 516

Juchem, P. L., Strieder, A. J., Hartmann, L. A., Brum, T. M. M., Pulz, G. M., Duarte, L. C. 2007 Geologia e mineralogia das gemas do Rio Grande do Sul. Ed. Comunicação e Identidade, v.único, p. 177-197.

Juchem, P. L., Chodur, N. L., Liccardo, A., Hartmann, L. A. 2008. Geologia das jazidas de ametista de Chopinzinho (PR) em basaltos da Bacia do Paraná. Anais do IV Simpósio de vulcanismo e ambientes associados. Cascavel, PR.: Editora Coluna do Saber, 2008. v.CDRoom. p. 1 – 6.

Leinz, V. 1949. Contribuição à geologia dos derrames basáltico do Sul do Brasil. Geologia, São Paulo. p. 66.

Mantovani, M. S. M.; Stewart, K.; Turner, S.; Hawkesworth, C.J. 1995 Duration of Paraná magmatism and implications for the evolution and sources regions of continental flood basalts. Proceedings Symp. physics and chemistry of the upper mantle. Anais da Academia Brasileira de Ciências, vol. 67, supl. 2, p. 163-170.

Milani, E.J., Faccini, U.F., Scherer, C.M., Araújo, L.M.; Cupertino, J.A. 1998 Sequences and Stratigraphic Hierarchy of the Paraná Basin (Ordovician to Cretaceous), Southern Brazil. Bol.IG USP, Série científica 29.

Piccirillo, E.M.; Comin-Chiaramonti, P.; Bellieni, G.; Civetta, L.; Marques, L.S.; Melfi, A.J.; Petrini, M.I.B.; Raposo, M.I.B; Stolfa, D. 1988 Petrogenetic aspects of continental flood basalt-rhyolite suites from the Paraná Basin (Brazil). In: The Mesozoic Flood Volcanism Paraná Basin. IAG-USP p. 179-205.

Rivaldo, N. P. 2006. Caracterização geológica e tecnológica de serpentinitos, Vila Palmas e Cerro da Mantiqueira, RS, Brasil. 34p. Trabalho de conclusão do curso de Geologia, IG-UFRGS.

Roisenberg, A. 1989 Petrologia e Geoquímica do Vulcanismo Ácido Mesozóico da Província Meridional da Bacia do Paraná. Tese de Doutorado - Curso de Pós-Graduação em Geociências, UFRGS. P. Alegre. 285 p.

Santos, E.L.; Maciel L.C. & Filho, J.A.Z. 1998. Distritos Mineiros do Rio G. do Sul. 35 p. (DNPM-1° Distrito).

Sirtoli, M.; Juchem, P. L.; Augustin, A.H. 2005. Depósitos de ametista em Caxias do Sul (RS) nas rochas vulcânicas da Formação Serra Geral. In: Anais do III Simpósio de Vulcanismo e Ambientes Associados. Cabo Frio, RJ. Sociedade Brasileira de Geologia - Núcleo Rio de Janeiro/Espírito Santo. vol. 01, p. 53-58.

Simas, M. W.; Schenato, F.; Formoso, M. L. L. 1999 Mineralogical Studies of Zeolites of a Flood Basalt, Morro Reuter Region, Paraná Basin, RS. Anais Academia Bras. Ciências, R. Janeiro, v. 71, n. 4, p. 827-827.

Strieder, A.J. & Heemann, R. 2006. Structural constraints on Paraná basalt volcanism and their implications on agate geode mineralization (Salto do Jacuí, RS, Brazil). Pesquisas, vol.33, nº 1, p.37-50.

Turner, S; Regelous, M.; Kelley, S.; Hawksworth, C.; Mantovani, M.S.M. 1994 Magmatism and continental break-up in South Atlantic: high precision ^{40}Ar -^{39}Ar geochronology. Earth and Planetary Sciences Letters nº.121, p. 333-348.

Wildner, W.; Hartmann, L.A.; Lopes, R.C. 2007. Serra Geral Magmatism in the Paraná Basin - A new Stratigraphic proposal, chemical stratigraphy and geological structures. I Workshop - PROBLEMS IN WESTERN GONDWANA GEOLOGY. RGEOTEC. p. 8.