GEM MATERIALS IN RIO GRANDE DO SUL STATE, BRAZIL – A FIELD TRIP GUIDE

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This field trip took place in Rio Grande do Sul, the southernmost State of Brazil, in November/2014, during the activities of the "Cycle of lectures on gemology and geology of gemstone deposits", organized by Gem Laboratory (LABOGEM) – Universidade Federal do Rio Grande do Sul (UFRGS).
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2. ABSTRACT

Agate and amethyst are the most important gemstones produced in southern Brazil, hosted in volcanic rocks, being Rio Grande do Sul State the main world producer of these minerals. In central region of this State (Salto do Jacui area) are the most importante agate mines, developed in open pits in the altered volcanic rocks. In the north of this State (Ametista do Sul area) there are the largest amethyst deposits of the world, exploited in horizontal adits opened in the fresh rock, which can reach up to 200 meters in lenght. In this region, besides mineral processing companies, there are several mineral stores, a museum inside a deactivated mine that shows how amethyst is extracted, a winery developed within deactivated mining galleries and the unique church in the world covered internally with amethyst. In Soledade region there are few exploitation areas of agate and amethyst, but the main improvement industry and bussines firms are located in this town.

2. 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 – States of Rio Grande do Sul (RS), Santa Catarina (SC) and Paraná (PR) – there are important gem materials deposits, related to different geological units (Figure 1). The most important are agate and amethyst geode deposits in Serra Geral Magmatic Province, a Cretaceous volcanic sequence of Paraná Basin. 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, whose commercial use is currently prohibited. Serpentinite originated from Precambrian mafic and ultramafic rocks are exploited in southwest RS and used as fine carving objects.

The largest agate and amethyst mines are in RS, which are reported as the most important deposits of these gemstones in the world. The host rocks were originated by an intense volcanic activity in Cretaceous, related to the separation of South America and Africa continents. Agate deposits occur mainly in central region of Rio Grande do Sul (Salto do Jacuí county), whereas amethyst huge deposits are in N of this State, in Alto Uruguai region (mainly in Ametista do Sul county).

3. GEOLOGICAL SETTING

In south Brazil region, there are five main important geological units (Fig. 1).

1) 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, 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 are in the Açungui Group.

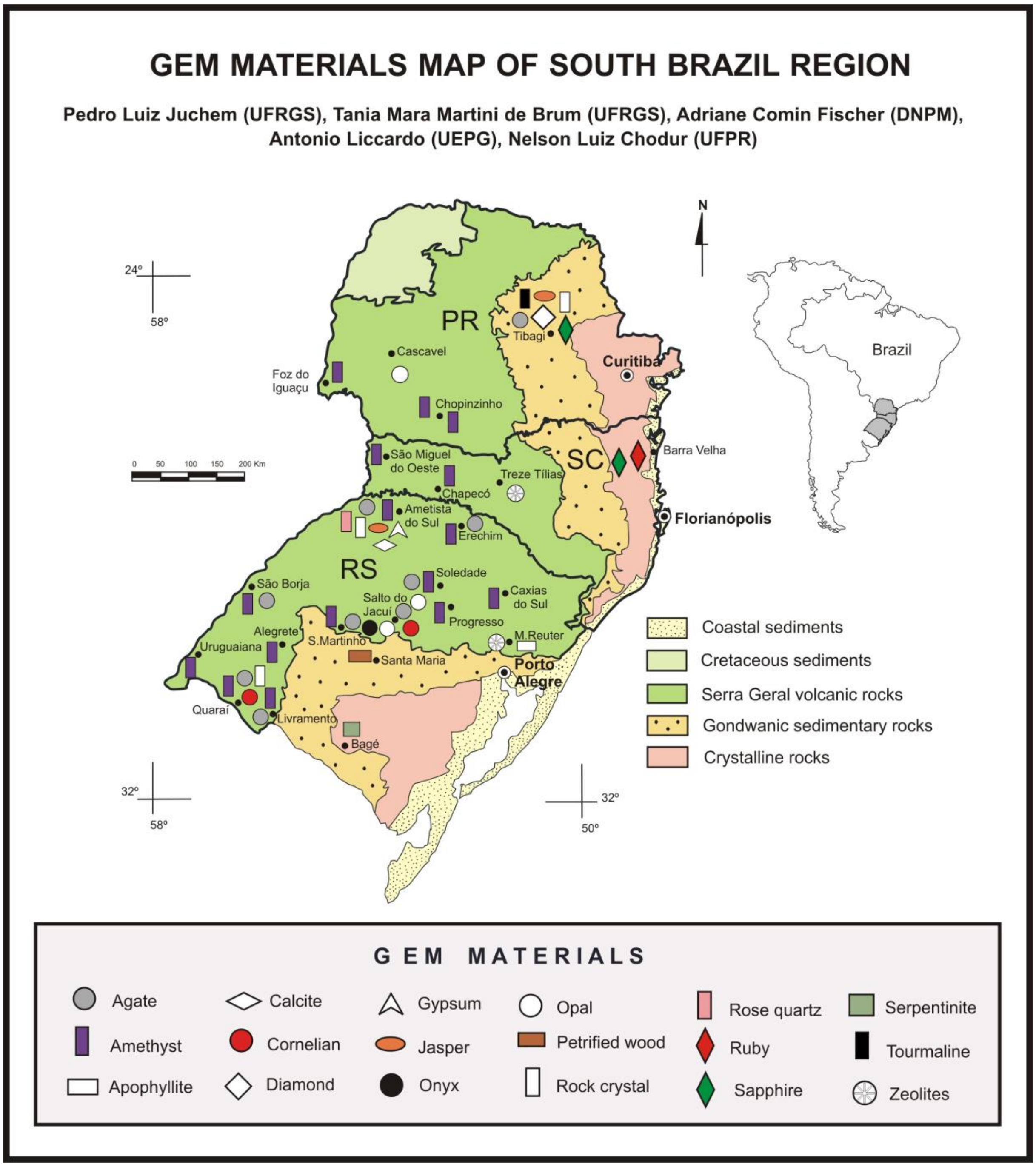

Figure 1 - Gem Materials Map of South Brazil region (PR – Paraná State, SC – Santa Catarina State, and RS – Rio Grande do Sul State), with the most important gemstone deposit localities and their geological settings. Modified from Juchem *et al.* (2011).

2) 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.

3) SERRA GERAL VOLCANIC ROCKS are related to 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 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, Nardy *et. al*., 2008 and 2011). A minor remnant of these rocks is found in Etendeka (Huab basin in NW Namibia), which once formed a single magmatic province with Paraná Basin (Bellieni *et al*., 1984). The product of this volcanic activity, named as Serra Geral Formation (White, 1908; Leinz, 1949), overspreads through an area of about 1,200,000 km^2, covering approximately 75% of Paraná Basin area. Subhorizontal and discontinuous flows reach individual thickness of 1 to 50 meters, originating a lava pile of nearly 2,000 meters thick at the basin center (Milani, *et al.*1998). During the earlier volcanic eruptions the Botucatu desert environment persisted, which is confirmed by intercalations of aeolian sandstones with the lava flows.

Radiometric age data obtained from different geochronological methods (e.g. K/Ar, Rb/Sr) were extensively proposed by several authors for Serra Geral magmatism (e.g. Creer *et al*., 1965; Amaral *et al*., 1966; Cordani & Vandoros, 1967; Sartori *et al*., 1975; Fodor *et al*., 1985; Melfi, 1967; Cordani *et al*., 1980; Mantovani *et al*., 1985; Piccirillo *et al*., 1987 and Rocha Campos *et al*., 1988). More accurate Ar-Ar data reported by Turner *et al.* (1994) and Mantovani *et al.* (1995), yelded ages between 137-127 Ma for the volcanic activity, and data reported by Mincato (2000), yelded ages between 133.9 and 130.36 Ma, whereas data of Thiede and Vasconcellos (2010) obtained with the same method, indicated a peak of volcanic activity at 134 ±0,6 Ma and a short duration of the volcanism (1,2 Ma). Recently results reported by Brückmann *et al.* (2014) using U-PB (SHRIMP) data of Serra Geral magmatic zircon crystals, yelded ages between 134,5 ±2,1 Ma and 119,3 ±0,95 Ma, indicating a duration of the volcanism much greater than previously considered.

Using petrological and geochemical data integrated with the geocronological evolution of the volcanism and the understanding of three-dimensional structures, Wildner *et al.* (2007) proposed to name these rocks as Serra Geral Group. This Group would have twelve Formations related to basic rocks - Esmeralda, Campos Novos, Alegrete and Gramado (low Ti/Y), Paranapanema, Campo Erê, Cordilheira Alta and Capanema (intermediate Ti/Y), Novas Laranjeiras, Pitanga, Urubici and Ribeira (high Ti/Y) – and four Formations related to acid rocks - Várzea do Cedro and Palmas (low Ti), Ourinhos and Chapecó (high Ti-Zr)

4) CRETACEOUS SEDIMENTS are continental sandstones with reddish violet colour, covered by recent sediments in some areas.

5) The COASTAL SEDIMENTS are mainly Quaternary to recent continental, marine and transitional units, originated during sea level oscillations that occurred since Pliocene.

4. 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). The agate deposits are located near the margins of Jacuí and Ivaí rivers within an area of 100 km^2 and encloses about 150 mine fronts.

Figure 2 shows a schematic rock section observed on the agate mines, where two lava flows can be observed. According Heemann (1997), the lower unit, where agate mineralization occurs, is a weathered lava flow, with three different zones. The lower zone is more mineralized with agate than the middle zone, and is a basaltic/andesitic rock (48 to 56 % of SiO_2) of gray to brownish gray colors with 2,0 to 4,0 meters of thickness and with remnants of a less or not weathered black glassy rock. The middle zone is an altered aphanitic dacitic rock (~ 64 to 67 % of SiO_2) with 2,0 to 3,0 meters of thickness and reddish-brown to yellow-brown colors. The upper zone has 0,5 to 2,0 m thickness with yellowish to grayish yellow color of a strongly weathered rock, which originally may have been a volcanic glass. The upper unit (2 to 4 meters thick) is an aphanitic gray to brownish-gray weakly altered dacitic lava flow, with a regular horizontal fracture pattern (Strieder & Heemann, 2006; Juchem *et al.,* 2007).

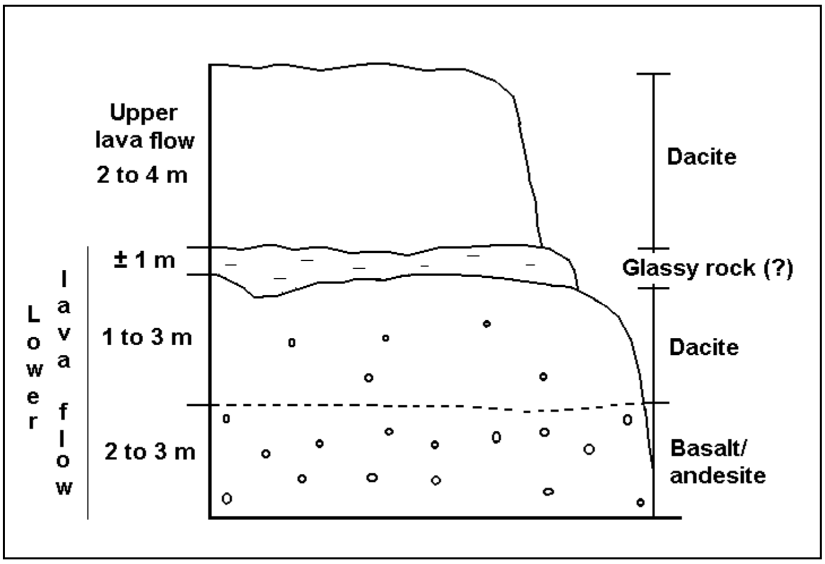

Figure 2 - Schematic rock section in Salto do Jacuí agate mines, showing the two mineralized zones in a lava flow, followed by a strongly weathered layer, covered by a dacitic lava flow.

The lava flow is marked by oriented elliptical geodes or by differential altered volcanic lines. Sandstone and glassy dykes with 2 to 30 centimeters of thickness and 0,1 to 3 meters of length are observed in the mineralized zones. Sandstone and glassy enclaves with equant or elliptical shape can also be observed. Some geodes show a banded structure at the base, alternating layers of sandstone and/or glassy rock and agate. These features suggest a link between the sandstone and the origin of silica mineralization.

The geode extraction is made by local miners (garimpeiros) in open pits as well as in small underground adits (10 to 50 m) open into the altered volcanic rock (Fig. 3 and 4). Large volumes of rock, soil and regolith are removed using tractors, drilling machines and sometimes explosives, in order to reach the mineralized level of the rock. The removal of the geodes along the ground or the pit slopes are made by manual collecting, using tools such as mattock, spade, chisel and hammer (Juchem *et al*., 1987).

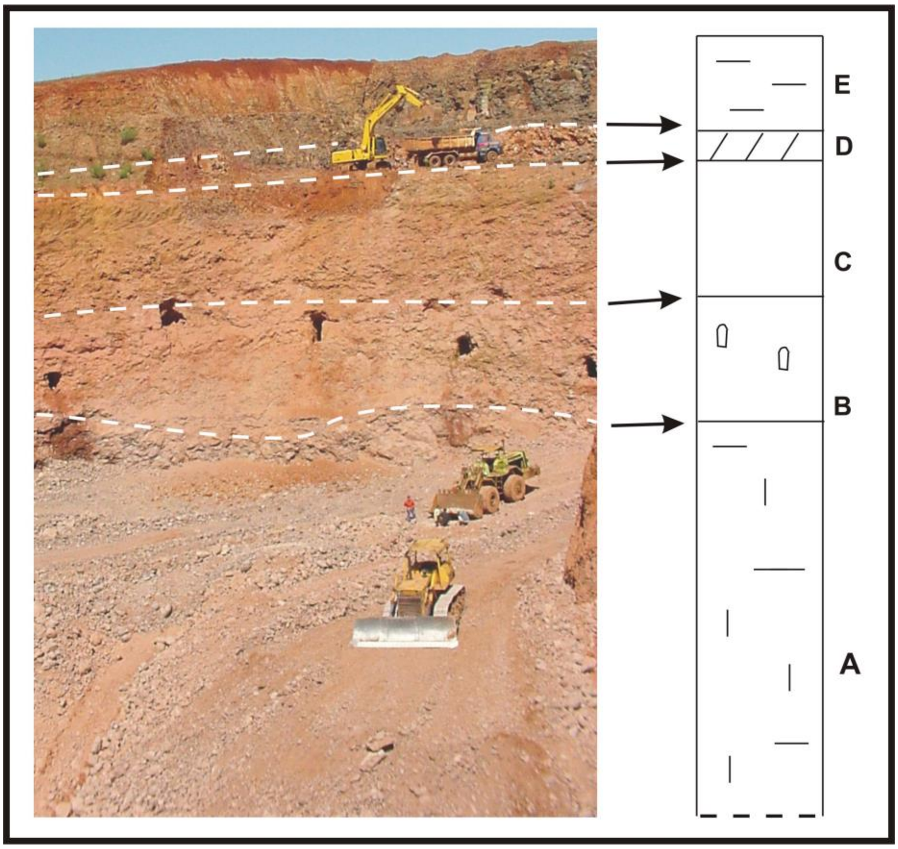

Figure 3 – Surface agate mine in Salto do Jacui Mining District, showing a typical lithological profile. **A** – Ground rock below the mineralized lava flow. **B** and **C** – mineralized flow of basaltic/andesitic composition (A) with a zone of dacitic composition. **D** – Upper glassy (?) zone of the lava flow, strongly weathered, with yellowish to grayish yellow color. **E** – The upper unit - a weakly altered dacitic flow.

Figure 4 – Surface agate mining in Salto do Jacuí Mining District. **A** and **B** – open pits and underground adits opened in the weathered volcanic rock. **C** – miners collecting agate geodes in the removal regolith. **D** – agate geodes to be commercially classified; in the back, the surface mine.

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. Euhedral 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 or fern-like patterns. Agate can occur as horizontal or wall-layered bands, being common geodes with both types. Complex band patterns, with exotic drawings may also occur (Fig. 5). The colors observed are gray, bluish-gray, pale-blue, brown, red, and black&white. Agate is usually dyed in order to improve or modify its natural colors. The common colors obtained are red, blue, pink, green and black, in different hues. Onyx deposits occur near Salto do Jacuí, but most of this mineral in the trade is actually dyed agate. The geodes are commonly cut into halves, or in plates for further polishing (Fig. 5). Some manufactured products are made, like rings, necklaces, bracelets, earrings, watches, vases, pyramids, boxes and bowls. It is also used as cut gems, mainly in cabochon but also in faceted stones for the jewelry trade.

Gem quality opal in white, blue, yellow, brown, brownish-yellow, orange, pink and red colors occurs in Salto do Jacuí and also in several small deposits between this town 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, filling fractures or along lava flow structures (Augustin *et al.,* 2004; Brum & Juchem, 2014). Black colour opal filling small cavities and thin fractures is described in SW of PR, in the same volcanic formation (Juchem *et al.*, 2004).

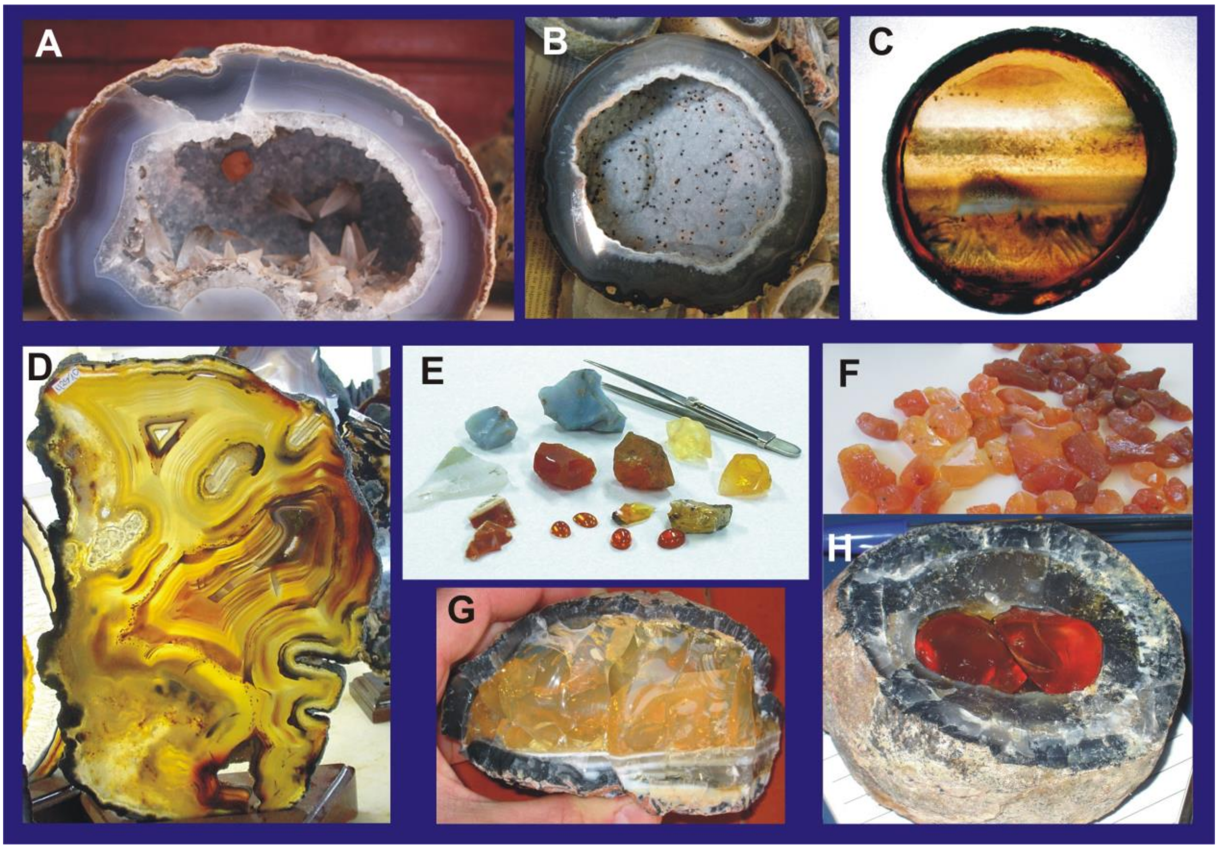

Figure 5 – Agate and opal in Salto do Jacuí region. **A** – the halve of a geode filled with agate, quartz and well formed calcite crystals. **B** – the halve of a geode filled with agate and spherical Fe and Mn oxides. **C** – a polished scenic agate plate; **D** – a polished agate plate showing a complex pattern of banding. **E** – opal samples of different colors. **F** – fire opal samples. **G** – a geode piece filled with agate and yellow to orange opal; **H** – a geode piece filled with agate and two “balls” of fire opal.

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 Mineral District, four amethyst-bearing lava flows were identified and seem to share a common structural and lithological pattern all over the region (Gomes, 1996; Scopel, 1997; Juchem, 1999). This characteristic allows to establish a vertical schematic section for the mineralized basalt (Fig. 6). Figure 6 show two lava flows, being the lower the mineralized basalt, where four structural zones are identified. A thin lower vesicular zone (~0,50 m), that is a brownish-gray basalt usually with a transitional contact with the central zone; this central zone has about 10 m of thickness and is a massive gray to greenish-gray basalt, with few vertical and horizontal jointings and are called by the miners as “laje” (slab). At the top of this zone the big mineralized geodes occur. Above this zone, there is a dark gray to black basalt level (0,5 to 1,0 m) with many irregular jointing, called by the miners as “cascalho” (gravel), which are usually the roof of the horizontal adits. This layer may be followed by an altered basalt level (0,5 to 1,0 m) with an horizontal jointing pattern. The upper zone (1 to 5 m) is an altered light-gray to dark-gray vesicular basalt. It was observed that between the mineralized basalt and the upper lava flow, layers of sandstone and/or breccia with few centimeters to 2 meters of thickness can occur. The breccia is composed by irregular clasts of sandstone or basalt, cemented by lava, usually mixed with sand and microcrystalline quartz.

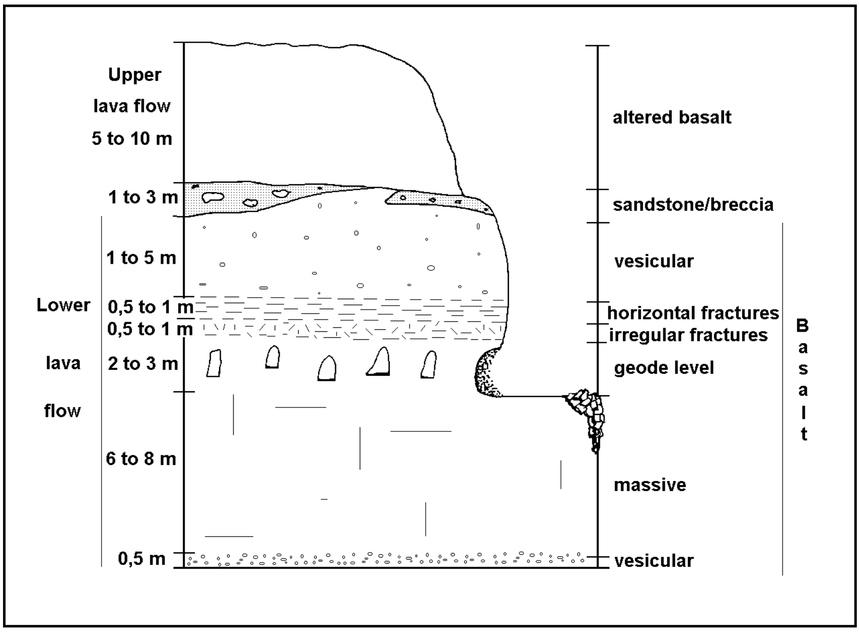

Figure 6 – Schematic rock section from Ametista do Sul Mining District, showing the different zones in the mineralized lava flow.

In this region, large amethyst-bearing geodes are extracted from the fresh massive basalt in horizontal underground adits (100 to 200m, and even more) whose roof is supported by columns of the prospected rock (Figure 7). In most of the mine fronts is possible to see the characteristic profile of this mineralized lava flow, as described above.

The horizontal adits are open in the basalt, using drilling machines, explosives and manual tools such as mattock, spade, chisel and hammer. After a detonation, the miners do an avaliation of the geodes that out crop the mine walls. With a hammer and chisel, the miners open a small hole in the geode and look inside with a small lamp in order to see its interior. An evaluation is made of the mineral species, the size and color of the crystals and the size of the geode itself. If the miner decides to take out the geode, he begins to peel it out of the rock using hammer and chisel or a pneumatic hammer (Fig. 8). If the miner decides do not take out the geode, or after the removal of the mineralized geodes, a new detonation causes the advancing of the gallery.

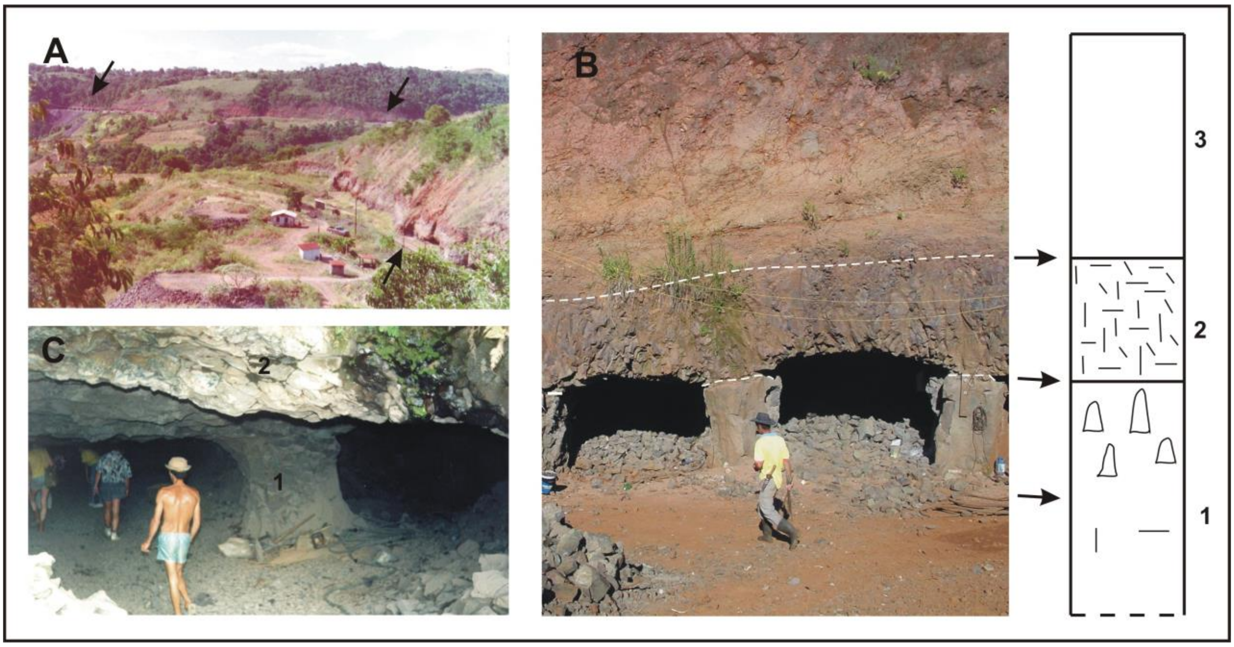

Figure 7 – Amethyst mines in Ametista do Sul Mining District. **A** – a number of mine fronts in the same topographic level; **B** – A mine front showing a typical lithological profile: 1 – upper mineralized level of the massive basalt where the horizontal adits are open (laje). 2 – non mineralized fractured basalt (cascalho). 3 – upper weathered basalt level. **C** – The entrance of an horizontal adit, where is possible to see a column of the the "laje" (1) and the "cascalho" (2) in the roof of the galleries.

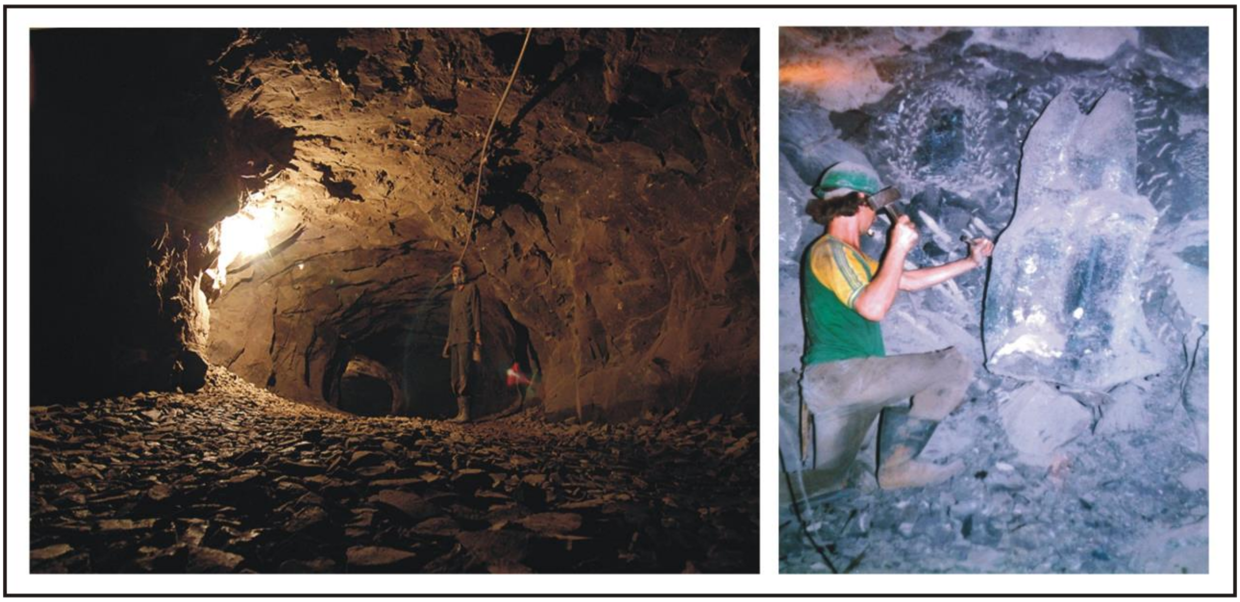

Figure 8 – Adits in amethyst mines in Ametista do Sul Mining District. At left, a view inside an adit with a prospector using respirator mask (Photo by Antonio Liccardo). It is possible to see some small geodes in the walls. At right, manual extracting of a bifurcated geode, observing the viewing hole covered with paper and the mold of an extracted smaller geode.

The mineralized geodes in this region are mainly rounded tubular cavities, vertically oriented within the rock. Geodes with 1 meter of length are common, and sometimes can reach two or three meters in length and up to one meter in diameter (Fig. 9). Irregular or roundish geodes and centimetric cavities can also occur. These cavities are usually incompletely filled with two crystalline silica phases: a thin outer layer of massive microcrystalline quartz, sometimes banded (agate), followed by a centimetric layer of coarse fractured colorless to milky quartz. Quartz crystals from this layer may show a progressive color increase to violet hues, originating amethyst. Several successive crystallization sequences can also be observed.

Amethyst is used as ornamental gemstone and as cut gems for jewelry. Most of the geodes are cut into two halves and exposed for sale (Fig. 9). Amethyst crystals can also be submitted to heat treatment, which causes changes in its color centers, in order to produce citrine, the yellow variety of quartz (Fig. 9). The colors obtained vary from pale to deep yellow, commonly showing brownish and reddish hues. A small portion of the production is destined for the jewelery market. The outermost layer of the geodes is usually lined with green to bluish-green celadonite, according to Scopel (1997) related to hydrothermal alteration of the basaltic wall-rock.

Figure 9 – Amethyst geodes cut in two halves exposed to sell in a gemstone store. Faceted amethyst and citrine (heat treated amethyst) and earrings of silver and amethyst.

Mineralogical and geochemical results, including solid and fluid inclusion studies and oxygen isotope data, show that silica minerals inside geodes 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).

Centimetric euhedral rose quartz may rarely occur associated with amethyst crystals, as well as jasper associated with the geodes. Late minerals inside geodes are mainly calcite and less commonly gypsum (selenite variety) and barite, which occur over the silica minerals as euhedral crystals (Fig. 10). 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 (Juchem *et al.*, 2011). The gem material classified in the trade as jasper, actually are breccias composed by irregular fragments of agate, basalt and sandstone. Glassy rocks that occur at the limit between lava flows have been used as carvings and improperly named as jasper.

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 (Juchem, 1999) 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. 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.

Figure 10 – Minerals associated with amethyst that occur in Ametista do Sul Mining District. **A** and **B** – well formed late calcite crystals. **C** – parallel aggregate of well formed tabular gypsum crystals, selenite variety, inside a quartz geode. **D** – a superb hialine selenite crystal over quartz crystals. **E** – carved and polished jasper. **F** – euhedral to subhedral crystals of rose quartz; **G** – well formed tabular barite crystals, over quartz and calcite inside a geode.

FIELD TRIP DESCRIPTIONS

DAY 1

- Travel from Porto Alegre to Salto do Jacuí – 315 km – about 5 hours
- At morning, visit an agate mine, as described above and shown in figures 2, 3 and 4..
- Lunch in Salto do Jacuí.
- Travel to Soledade – 127 km – about 2 hours
- Visit two Gemstone processing firms and gemstone shops (Figs. 9 and 11)
- Overnight in Soledade at Agata Hotel

DAY 2

- Travel to Ametista do Sul – 235 km – about 3h 30 min
- Visit an amethyst mine as described above and shown in figures 6, 7 and 8
- Visit the Amethyst Museum, the Amethyst Church and a Winery
- Overnight in Ametista do Sul at Ferrari Hotel

Figure 11 - Gem processing and gemstones workshop in Soledade **A** – Polishing agate geodes and agate plates. **B** – Dying agate geodes and plates. **C** – Exposition of polished agate plates. **D** – Geode pieces filled with amethyst, citrine (heat treated amethyst) and calcite crystals.

The Amethyst Museum

In the Amethyst Museum, special mineral samples and big geodes collected in Alto Uruguai region in the last 30 years are exposed (Fig. 12). The museum has continuity to an inactive underground mine gallery, which has many outcrops of mineralized geodes. From an outside belvedere it is possible to see several mines in activity in a hill slope right in front.

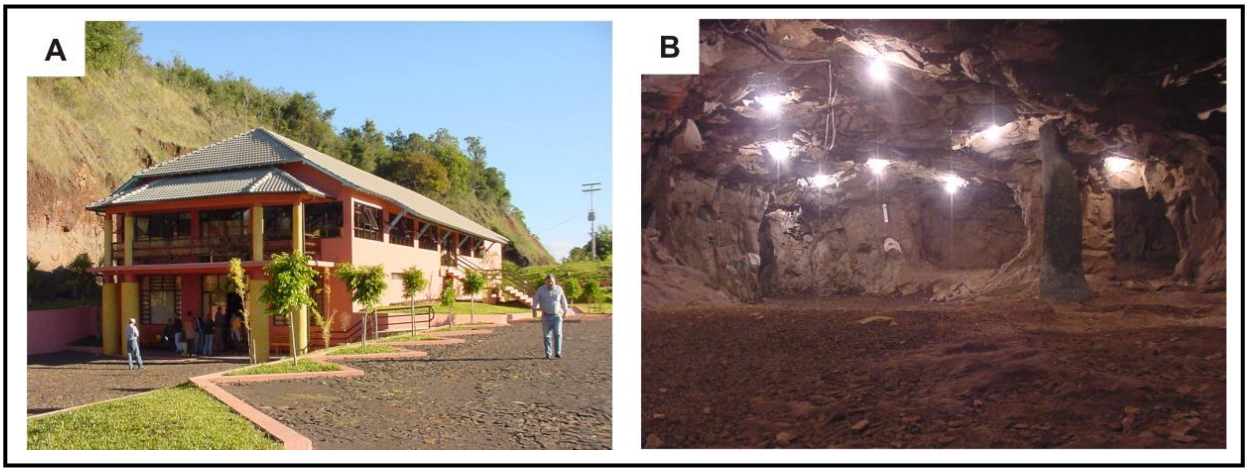

Figure 12 – The Amethyst Museum. **A -** the entrance of the Museum where a big mineral collection are exposed. **B -** a view of the inactive underground gallery with mineralized geodes in the walls of the ancient mine.

The Amethyst Church

The church was recently rebuilt and is a tribute to St. Gabriel, patron of the town of Ametista do Sul. During construction, several amethyst producers in the region contributed with samples of pieces of amethyst geodes that were used to cover part of their inner walls, which makes it unique in the world (Fig. 13). Several adornments of the altar and baptismal font are also made of amethyst geodes.

Figure 13 – View from outside of the Church of St. Gabriel in Ametista do Sul and its main altar, with the sidewall covered with amethyst geode pieces.

The Winery

A winery located near the main entrance of the town, was built over a rejection material deposit of an amethyst mine. The maturation of these wines is done within a deactivated amethyst mine in several underground galleries, where is possible to see many mineralized geodes encrusted in the volcanic rock. In these galleries are deposited thousands of bottles of different kinds of wine (Fig. 14). These galleries are ideal for maturing wines, because they are dark and have constant temperature and humidity during all the year seasons.

Figure 14 – View of the entrance of the winery and one of the underground galleries with wine bottles maturing. It is possible to see some mineralized geodes in the walls.

DAY 3

- Visit to a gemstone shop in Ametista do Sul
- Travel back to Porto Alegre – 440 km – about 6h 30 min

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