Anais da Academia Brasileira de Ciências
ISSN: 0001-3765
aabc@abc.org.br
Academia Brasileira de Ciências
Brasil

Rao, A. Bhaskara

Silica enrichment, graphic granite and aquamarine growth: a new exploration guide

Anais da Academia Brasileira de Ciências, vol. 74, núm. 3, september, 2002, pp. 533-538
Academia Brasileira de Ciências
Rio de Janeiro, Brasil

Anais da Academia Brasileira de Ciências (2002) 74(3): 533-538
(Annals of the Brazilian Academy of Sciences)
ISSN 0001-3765
www.scielo.br/aabc

Silica enrichment, graphic granite and aquamarine growth: a new exploration guide

A. BHASKARA RAO*

Institute of Geosciences, University of Brasilia 70910-900 Brasilia. Brazil.

Manuscript received on February 8, 2001; accepted for publication on April 22, 2002.

ABSTRACT

Granitic pegmatites are traditionally known to contain graphic, perthitic and myrmekitic intergrowths related to quartz and K- and Na- feldspars. They are further considered to characterise the pegmatite types distinguishing them from the granites and other related plutonic rock types. Graphic granite is accepted also as a synonym to granitic pegmatite.

Systematic studies, by the author and colleagues, on the granitic pegmatite gem deposits have permitted the definition of two aquamarine gem provinces in ENE Brazil, one in the NeoProterozoic and the other in the Archaean sequences. Potash feldspars in the pegmatites in the former show perthitic intergrowths, whereas in the latter graphic intergrowth dominates with anomalously coarse centimetric quartz along the cleavages of K-feldspar. Several granitic pegmatites hosted in Archaean complex, in Lages Pintadas Aquamarine Province, Santa Cruz, RN State, present this texture-structure.

Graphic intergrowth is attributed to the eutectic crystallization, succeeded by hydrothermal fluids with silica enrichment permitting the growth through diffusion and nucleation of quartz and along cleavages of potash feldspar. In the Archaean terrain, the abundance of recycled chert forming metapsammitic migmatites traversed by numerous quartz veins and coarse graphic granites, has contributed to the growth of beryl and also the aquamarines.

Key words: Archaean terrain, quartz veins, pegmatite deposits, graphic intergrowth, and Aquamarines.

INTRODUCTION

Systematic studies on the gem (aquamarine and tourmaline) pegmatite deposits in Rio Grande do Norte (RN) and Paraiba (PB) States permitted the definition of three gem provinces, till today, conditioned to geological-structural-lithological parameters (Bhaskara Rao and Adusumilli 1998, Bhaskara Rao et al. 2000). They are aquamarine and tourmaline gem provinces. The importance of their demarcation is that all the granitic pegmatites within each one of them contain a definite paragenetic association that characterises the presence of the gem variety. Such a definition is of significance in formulating both exploration and exploitation strategies in the studied regions.

E-mail: bra@yawl.com.br
*Foreign Member of Academia Brasileira de Ciências

AQUAMARINE GEM PROVINCES

Among the gem provinces defined, two are of Aquamarine. One of them is limited to the synform of NeoProterozoic biotite schists of Seridó Formation, extending from Acari (RN) in the North to São José de Sabuji (PB) in the South. The second is enclosed in the Archaean migmatitic-gneisses of the *Caicó Complex*, located around Lajes Pintadas town (RN).

Principal Characteristics

These provinces contain several old and new workings and deposits of granitic pegmatites and veins of quartz mineralised in gem aquamarines. In the first nine deposits were studied in detail, whereas in the second six deposits were visited, with field observations, among nineteen catalogued. The distinct characteristics and contrasts are tabulated below (Table I).

Significant Aspects

The following significant aspects are noted and need mention.

1) In both the provinces the aquamarine gems show a tendency to develop well in association with abundant quartz.

2) The gems have a deeper colour and hue in such an association with quartz, and often attain good sizes.

3) Graphic inter-growth (graphic granite) is virtually absent (!) in the pegmatites of the NeoProterozoic environment, and is constant, intense and in varied forms with abundant quartz in the K-feldspars within the Archaean host.

4) There is a total domination of mineralised quartz veins over true granitic pegmatites in the Archaean, distinct from the NeoProterozoic where zoned pegmatites dominate with the participation of bands, pods and veins of quartz.

These aspects seem to be excellent field guides for the exploration of these gems in the Archaean and NeoProterozoic terrains.

GRAPHIC INTER-GROWTH

Mineral inter-growth studies in petrological sciences have been extensive and the relations between K-feldspars, Na- feldspars with K-feldspars, and these with quartz have been true attractions. Wahlstrom (1939), Cerny (1971), Martin (1982), Fenn (1986), Lentz and Fowler (1992), and Baker and Freda (1999) are only a few among many known works.

Graphic Granite

Graphic granite also was used as a synonym for granitic pegmatite for a long time, since the graphic inter-growth was considered as an indispensable element to identify a pegmatitic rock. Graphic is the typical inter-growth of K-feldspar, frequently microcline but formerly always considered as orthoclase, and quartz. But this denomination was also extended to several other inter-growths with Na- and Ca- feldspars, though some are considered *sensu stricto* myrmekitic by tradition.

The problem of their evolution also attracted several petrologists and even today the choice depends on the personal preference towards physical-chemical parameters or laboratory evidences or field characters. From the magmatic-eutectic to metamorphic-metassomatic evolution, and substitutions or diffusion or ex-solution or fillings, the genetic aspects considered are numerous. The facts have to be appreciated critically along with other data. Within this context the following citations are appropriate.

Fenn (1986) attributes the origin of graphic granite to variable temperature, pressure and composition and the texture to simultaneous growth of quartz and feldspar in a kinetically driven, non-equilibrium situation. "The growing interface of the host phase, a sodic alkali feldspar, is degraded from planar to cellular by the development of a SiO_{2-} (and probably H_2O_-) enriched boundary layer. Between the cell boundaries, the SiO_2 content of the residual liquid achieves a level of super-saturation that allows quartz to nucleate and grow along with the feldspar." Swanson and Fenn (1986) report that subhedral to euhedral quartz grains are normally restricted to volcanic or hypabyssal plutonic rocks where the quartz phenocrysts develop without any interference from adjacent grains.

Jahns and Burnham (1969), and Jahns (1982) consider the vapour phase dominated by water as responsible for the distinction of pegmatites from typical granites as a consequence of aqueous vapour saturation in the melt (with crystals). The eutectic crystallization near equilibrium and the simultaneous crystallization of quartz, plagioclase and potash

TABLE I

Comparison of the aquamarine provinces.

Character	NeoProterozoic Province	Archaean Province
Host system	Biotite schists.	Migmatic-gneisses, both meta-psammitic and metapelitic.
Mineralised unit	Partly and poorly zoned K-Si rich pegmatites.	Quartz veins. Banded Si-K rich pegmatites.
Mineralogy	Constant: opaque beryl, biotite and rose quartz. Sporadic: schorl and muscovite.	Abundant opaque beryl and smoky quartz; rose quartz very rare; and mega quartz as aggregates. Sporadic: muscovite, biotite, schorl and zeolites.
Perthitic inter-growth.	Fine and frequent.	Fine and very rare.
Graphic inter-growth.	Not frequent, very fine when present.	Abundant and constant; variable in sizes and in intensity attaining even cm length and breadth, mainly as colourless quartz with greasy luster, transparent to translucent.
Beryl	Opaque brown and green types.	Opaque green, bluish green and semi-precious aquamarine types
Aquamarine gem	Along the nucleus of opaque types; occasionally in vein quartz as small perfect gems.	Quality gems abundant in quartz veins as long prismatic crystals; good crystals traverse from feldspar to quartz zone, but only partially as gems.

feldspar in eutectic proportion is evidenced in the transition to pegmatite, normally characterised by graphic intergrowth.

Simulations and Experimental Appraisals

Baker and Freda (1999) conclude that the Ising model simulations of quartz and albite show excellent inter-growths when growth is equal to diffusion, on the structures produced by a eutectic crystallization of an albite-quartz composition. Each adatom in the simulation is about 1 nm and the textures created (with dimensions of about 10^{-7}) are similar to those found in the granitic pegmatites (5-7 orders of magnitude larger, *viz.* centimetres to meters in size). Quantitative comparison (Fowler 1995. *cit*. Baker and Freda 1999 p. 731) of the simulated structures with natural textures from microscopic (atomic) to macroscopic (centimetric) scale has been achieved through the determination of fractal dimensions of both types of textures. These are perfectly applicable to granitic pegmatites.

A technique is developed by X-ray computerised tomography (CT) and image analysis, using a medical X-ray CT scanner by Ikeda et al. (2000), to study the three dimensional interconnections and the shape of crystals in a graphic granite. Using the binary images, the connection analysis of quartz was performed based on the percolation theory (cluster labelling). The technique proved that 89.9% of the quartz rods are interconnected, and are consistent to the observations recorded by Simpson (1962). The specimens used show the development of quartz in typical graphic growth, with deviations, indicating clear growth in more than one direction and certainly in more than one generation.

The Archaean Environment

Bhaskara Rao et al. (2000, unpublished) report on the graphic growths in the Lages Pintadas region located in the Archaean environment. Cherts are known to be abundant in this period and hydrothermal silicification has occurred in many horizons in this domain (Knauth 1994). The migmatitic gneisses host large number of quartz veins or granitic pegmatites with veins and pods of quartz, possibly related to the psammitic or pelitic nature of the host sediment. The presence of conspicuously coarse graphic intergrowths in such granitic pegmatites hosted in the Archaean sequences, uncommon in the NeoProterozoic (Bhaskara Rao and Adusumilli 1998), corresponds and attests to silica enrichment. Thus, the genesis proposed to this intergrowth is a eutectic crystallization of K-feldspar and quartz, followed by nucleation and growth by late stage low temperature under cooled Si- rich solutions in more than one generation.

GRAPHIC INTER-GROWTH AS AN EXPLORATION GUIDE

In earlier studies, Bhaskara Rao and Adusumilli (1998) have proposed that silica enrichment in the late stage evolution of the pegmatites, and the formation of quartz veins, favours the growth of gem aquamarines.

In Archaean environment two types of association could be identified:

1) Dark migmatitic gneisses, metapelitic in nature, traversed by thin veins or dykes of granitic to aplitic pegmatites. The pegmatites in this domain show the presence and domination of graphic inter-growths.

2) Silica-rich migmatitic gneisses, metapsammitic (Väisänen and Höltta 2000), traversed by remobilised silica as quartz veins.

The constant presence of the well grown and conserved gem aquamarine crystals both in such pegmatitic veins with graphic inter-growths, and also silica veins testifies to the following facts.

1) The Archaean chert-silica has predominantly taken part in the tectonic evolution of the systems that resulted in the migmatitic- gneissic complexes.

2) The syn- and post tectonic stabilisation that released the hydrothermal silica with Be- and the late stage crystallisation of the pegmatitic veins have suffered an intense substitution or had a simultaneous crystallisation with the result that the graphic inter-growths have developed consistently as a prelude to beryl growth.

3) The beryl-quartz affinity is known through the "stability relations in quartz saturated portions of the system $Be0\text{-}Al_20_3\text{-}Si0_2$" (Barton 1986) indicating that silica catalyses and stabilises the formation and growth of beryl.

4) Evensen et al. (1999, p 733) mention that the mineral assemblage beryl + chrysoberyl + quartz may be relevant to the magmatic portion of their crystallisation, but in natural systems beryl is the predominant mineral through the back reaction of chrysoberyl.

   $3\ BeAl_2O_4 + 2\ KAlSi_3O_8 + 6\ SiO_2 =$
   $Be_3Al_2Si_6O_{18} + 2\ KAl_3Si_3O_{10}(OH)_2$
   Chrysoberyl + Potash Feldspar +
   + Quartz = Beryl + Muscovite

   $2H_2O$ to be added to complete the equation.

5) Sporadic influx of Si-rich hydrothermal solutions must have favoured the growth of aquamarine directly in the quartz veins. Also through substitution, along the channel structure and selective leaching of elements of the already crystallised opaque beryl, in the pegmatites aquamarines normally have evolved (Bhaskara Rao et al. 1997).

CONCLUSION

Thus, in the gem pegmatite deposits in the Archaean of ENE Brazil, the presence of conspicuous *coarse* graphic intergrowth in the K-rich granitic pegmatites with pods and veinlets of quartz indicating silica enrichment in the system, could be considered a favourable exploration guide for the location of aquamarines. This is observed in the Lages Pintadas aquamarine province, with numerous pegmatite and quartz vein deposits, till now exploited. The applicability of this conclusion to similar regions elsewhere is promising.

ACKNOWLEDGEMENT

This contribution is Gems 22 of Rao's Ideas Bank, who arranged a sponsor for our field works.

RESUMO

Pegmatitos graníticos são tradicionalmente conhecidos por terem intercrescimentos gráficos, pertíticos e mirmequíticos, relacionados a quartzo e feldspatos potássicos e sódicos. Também são considerados para caracterizar os tipos de pegmatitos, distinguindo-os dos granitos e outros tipos de rochas plutônicas relacionadas. Granito gráfico é aceito como sinônimo do pegmatito granítico.

Estudos sistemáticos, do autor e seus colegas, sobre depósitos de pegmatitos graníticos de gemas permitiram a definição de duas províncias de gemas águas marinhas no ENE do Brasil: uma no NeoProterozóico e outra em seqüência Arqueana. Feldspatos potássicos na primeira apresentam intercrescimentos pertíticos e, na outra, o intercrescimento gráfico domina com quartzo grosseiro centimétrico anômalo ao longo das clivagens de K-feldspato. Diversos pegmatitos graníticos encontrados no complexo Arqueano, na Província de Águas Marinhas de Lages Pintadas, Santa Cruz, Estado do RN, apresentam esta textura-estrutura.

Intercrescimento gráfico é atribuído a cristalização eutética, sucedida por fluidos hidrotermais com enriquecimento de sílica permitindo o crescimento através da difusão e nucleação de quartzo e ao longo das clivagens de feldspato potássico. No terreno Arqueano, a abundancia de chert reciclado formando migmatitos metapsamíticos atravessados por numerosos veios de quartzo e granito gráfico grosseiro, contribuiu para o crescimento de berilo e da água marinha.

Palavras-chave: Terreno Arqueano, veios de quartzo, depósitos de pegmatito, intercrescimento gráfico, águas marinhas.

REFERENCES

Baker D and Freda C. 1999. Ising models of under cooled binary system crystallization: Comparison with experimental and pegmatite textures. Amer Mineral 84: 725-732.

Barton MD. 1986. Phase equilibria and thermodynamic properties of minerals in the BeO-Al_2O_3-SiO_2-H_2O (BASH) system with petrologic applications. Amer Mineral 71: 277-300.

Bhaskara Rao A and Adusumilli MS. 1998. Geological and exploration characteristics of an Aquamarine Gem Pegmatite Sub-Province in ENE Brazil. IMA '98 Meeting, Toronto. Abstracts: A.17, Poster 17 pp.

Bhaskara Rao A, Adusumilli MS and Castro C. 1997. Evolution and exploration parameters of gem beryls from Varzea do Serrote Pegmatite, Rio Grande do Norte State, Brazil. XVII Simp Geol do Nordeste, Fortaleza. Resumos expandidos 15: 414-418.

Bhaskara Rao A, Adusumilli MS and Castro C. 2000. Gem tourmaline deposits of Serra das Queimadas Sub-Province, ENE Brazil. Geology and Ore Deposits 2000, Reno, USA. Abstracts.

Cerny P. 1971. Graphic intergrowths of feldspar and quartz in some Czechoslovak pegmatites. Contrib Mineral Petrol 30: 343-355.

Evensen JM, London D and Wendland RF. 1999. Solubility and stability of beryl in granitic melts. Amer Mineral 84: 733-745.

Fenn PM. 1986. On the origin of graphic granite. Amer Mineral 71: 325-330.

Fowler AJ. 1995. Mineral crystallinity in igneous rocks: Fractal method. In: CC Barton and PR LaPointe. Ed. Fractals in the Earth Sciences. Plenum Press. p.237-249.

Ikeda S, Nakano T and Sack RO. 2000. Three-dimensional study on the interconnection and shape of crystals in graphic granite by X-ray CT and image analysis. Mineralog Mag 64: 945-959.

JAHNS RH. 1982. Internal evolution of pegmatite bodies. Min Assn Canada. Short Course 8: 293-327.

JAHNS RH AND BURNHAM CW. 1969. Experimental studies of pegmatite genesis. I. A model for the derivation and crystallisation of granitic pegmatite. Econ Geol 64: 843-864.

KNAUTH LP. 1994. Petrogenesis of Chert. In: Silica. Reviews in Mineralogy, Min Soc Amer 29: 233-258.

LENTZ DR AND FOWLER AD. 1992. A dynamic model for graphic quartz -feldspar intergrowths in granitic pegmatites in the Southwestern Greenville Province. Canadian Min 30: 571-585.

MARTIN RF. 1982. Quartz and feldspars. In: Granitic Pegmatites in Science and Industry. Min Assoc Canada. Short Course Handbook 8: 41-62.

SIMPSON DR. 1962. Graphic granite from the Ramona pegmatite district, California. Amer Mineral 47: 1123-1138.

SWANSON SE AND FENN ME. 1986. Quartz crystallization in igneous rocks. Amer Mineral 71: 331-342.

VÄISÄNEN M AND HÖLTTA P. 1999. Structural and metamorphic evolution of the Turku migmatite complex, southwestern Finland. Bull Geol Soc Finland. No.71, Pt.1: 177-218.

WAHLSTROM EE. 1939. Graphic granite. Amer Mineral. 24: 681-698.