Mineral. Deposita 25, 57–64 (1990)

MINERALIUM
DEPOSITA

Origin of emerald deposits of Brazil

G. Giuliani[1,2], **L. J. H. D. Silva**[3] **and P. Couto**[4]

[1] ORSTOM, Universidade de Brasilia, Brazil
[2] C.R.P.G., 15 Rue N.D. des Pauvres, BP 20, 54501 Vandoeuvre-les Nancy, France
[3] Mineração Caraiba Metais Ltda, Bahia, Brazil
[4] Secretaria das Minas e Energia, C.P.R.M./SGM, Bahia, Brazil

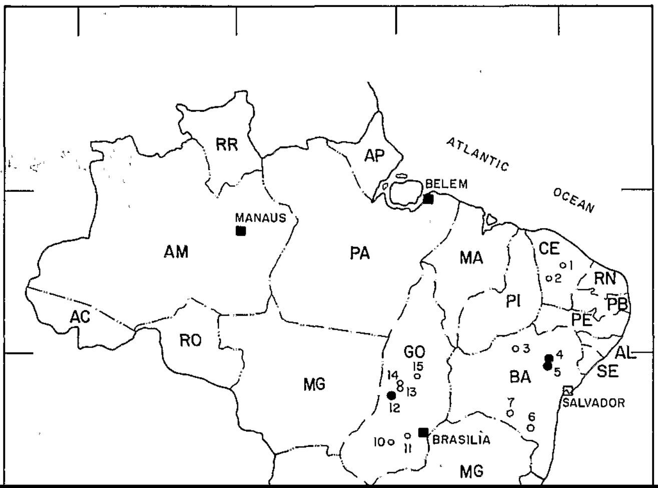
Abstract. Precambrian emerald deposits of Brazil are found in a typical geologic setting with Archean basement and supracrustal, ultramafic, granitoid and rocks. Volcano-sedimentary series occur as imbricated structures or as bodies affected by complex folding and deformation. Emerald mineralization belongs to the classic biotite-schist deposit, which formed by the reaction of pegmatitic veins within ultrabasic rocks. At the same time, pegmatite-free emerald deposits linked to ductile shear zones are also known. Emerald formation is attributed to infiltrational metasomatic processes provoking a K-metasomatism of the ultrabasic rocks and also a desilication of the pegmatites. A new classification based on the geological setting, structural features, and ore paragenesis is proposed.

Gemstone deposits are of great importance in Brazil. Agate, amethyst, tourmaline, and topaz represent the important gemstones in terms of weight while emerald is characterized by its high commercial value and represents the main export as uncut and cut gems.

In 1961, the first economic occurrence of emerald was discovered at Salininha (Bahia State), renewing interest

Itaberai prospects (Fig. 1), where pegmatite veins are absent. The pegmatites are directly linked to intrusive granitic bodies with limited local extension, or are related to important and extended pegmatite provinces as in Minas Gerais and Ceará (Giuliani and Couto 1988a).

The aim of this paper is to present an overview of the geological setting, structural features, and ore paragene-



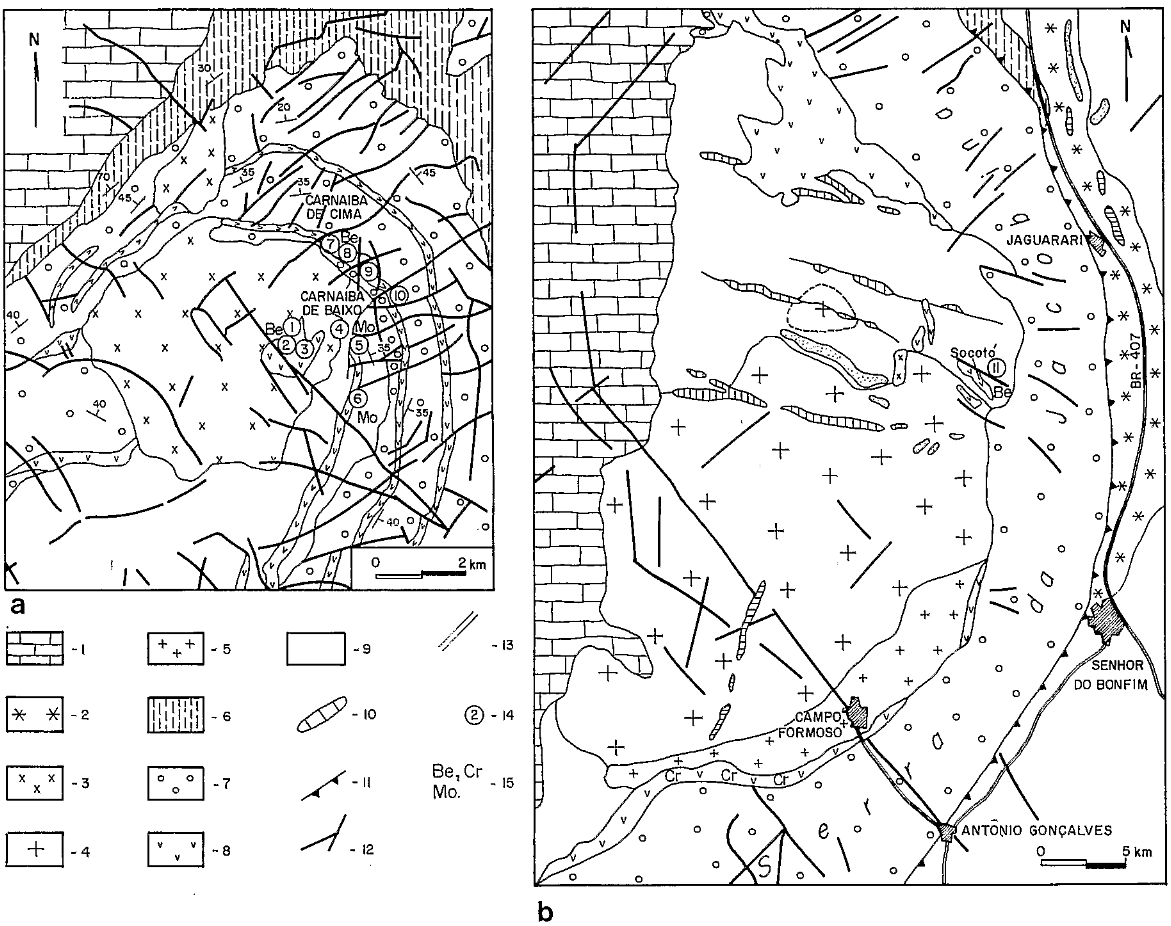


Fig. 2. a Geology of Carnaíba and **b** Campo Formoso mining districts. 1, carbonate Proterozoic cover; 2, Jaguarari granitoid; 3, Carnaíba leucogranite; 4, two-mica, porphyroid to fine-grained Campo Formoso leucogranite; 5, two-mica, coarse-grained Campo Formoso leucogranite; 6, chlorite schist, phyllites; 7, volcano-sedimentary formations of the Serra da Jacobina; 8, serpentinites; 9, Archean gneisses; 10, silicified zones; 11, thrust fault; 12, faults; 13, roads; 14, prospecting pits (1, Bode; 2, Lagarta; 3, Gavião; 4, Formiga; 5, Braúlia; 6, Marota; 7, Trecho Velho; 8, Trecho Novo; 9, Bica; 10, Cabra; 11, Socotó); 15, Be, green beryl-emerald; Cr, chromite; Mo, molybdenite

sis of the main emerald deposits of Brazil. Therefore, this should contribute to the discussion of the mechanism of ore formation and the main process involved in forming the associated metasomatic rocks. A new classification for these deposits is proposed.

Emerald deposits of Brazil

The emerald deposits are located in rock sequences consisting of Archean basement, Proterozoic volcano-sedimentary series, and granites with their magmatic to late-magmatic equivalents. The basement includes generally tonalitic gneisses, migmatites, diatexites, or granite gneiss. The volcano-sedimentary series are composed of intercalated iron formations, acid and basic-ultrabasic horizons, cherts, and quartzites, which sometimes belong to a greenstone belt sequence (as in Santa Terezinha de Goiás) and occur as imbricated structures (Socotó) or are affected by complex folding and deformation (Carnaíba).

The Carnaíba and Socotó emerald prospecting pits (Bahia State)

These deposits are associated with two Proterozoic leucogranite massifs intruding the Serra da Jacobina volcano-sedimentary series and older gneissic-migmatitic Archean basement (Santana 1981; Rudowski et al. 1987; Rudowski and Fonteilles 1988; Rudowski 1989).

The Carnaíba prospecting pits (Fig. 2a) are found around the Carnaíba granite and are divided into two main districts (Couto and Almeida 1982; Moreira and Santana 1982), i.e., Carnaíba de Cima, including the Trecho Velho, Trecho Novo, Bica, and Cabra pits, located 1000 m above sea level, and Carnaíba de Baixo, displaying pits developed in serpentinite roof pendants in granite (Bode, Gravião, Lagarta, and Formiga) or mined in country rock terranes (Marota, Braúlia).

The emerald mineralization is related to intrusive albitic (albite-oligoclase) or quartz-albitic pegmatoids (Brazilian name corresponding to desilicified pegmatites), or quartz veins crosscutting the serpentinites. Two kinds of veins are distinguished: (1) fracture veins

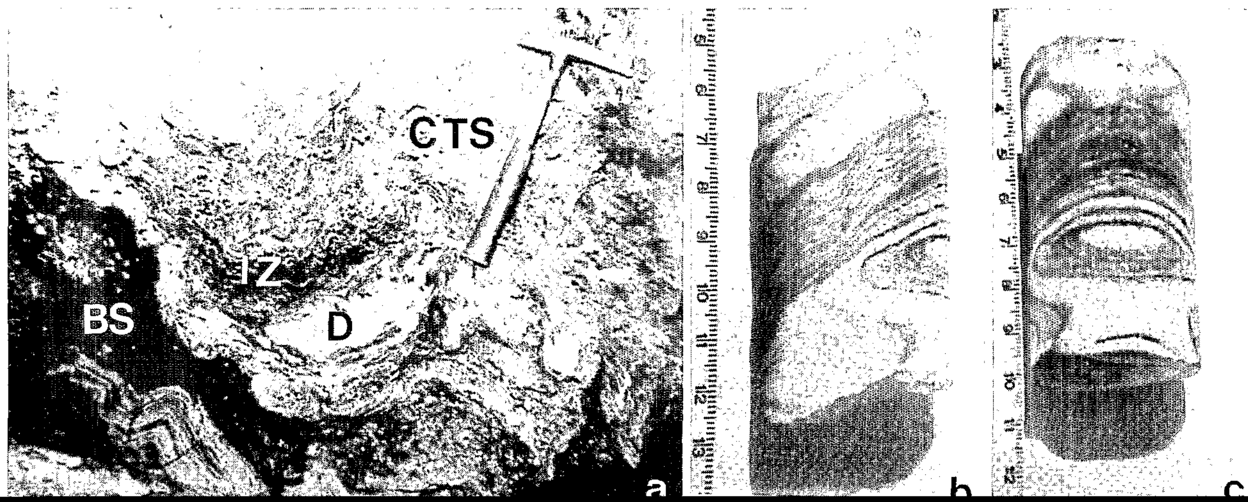


Fig. 3a–c. Santa Terezinha de Goiás deposit. Trecho Novo prospecting pits (167 galleries). **a** Aspect of the biotite schist (BS) which illustrates the circulation of fluids along lithologic contact between carbonate-talcschist (CTS) and pockets of dolomite (D). A successon of small infiltrated zones (IZ) corresponding to a bed-by-bed fluid injection and circulation may be observed. The major "biotitite" layer is pyrite-rich; emerald is well developed in (D) and (CTS). **b, c** Typical sheath fold from Santa Terezinha de Goiás affecting chlorite-quartz schists. Drilling hole of Trecho Damiaõ prospecting pit

called "frinchas" and (2) contact veins called "esteiras", which are developed along the contact of quartzites and intercalated serpentinites (Trecho Novo, Cabra, and Bica

The Santa Terezinha de Goiás emerald deposit (Goiás State)

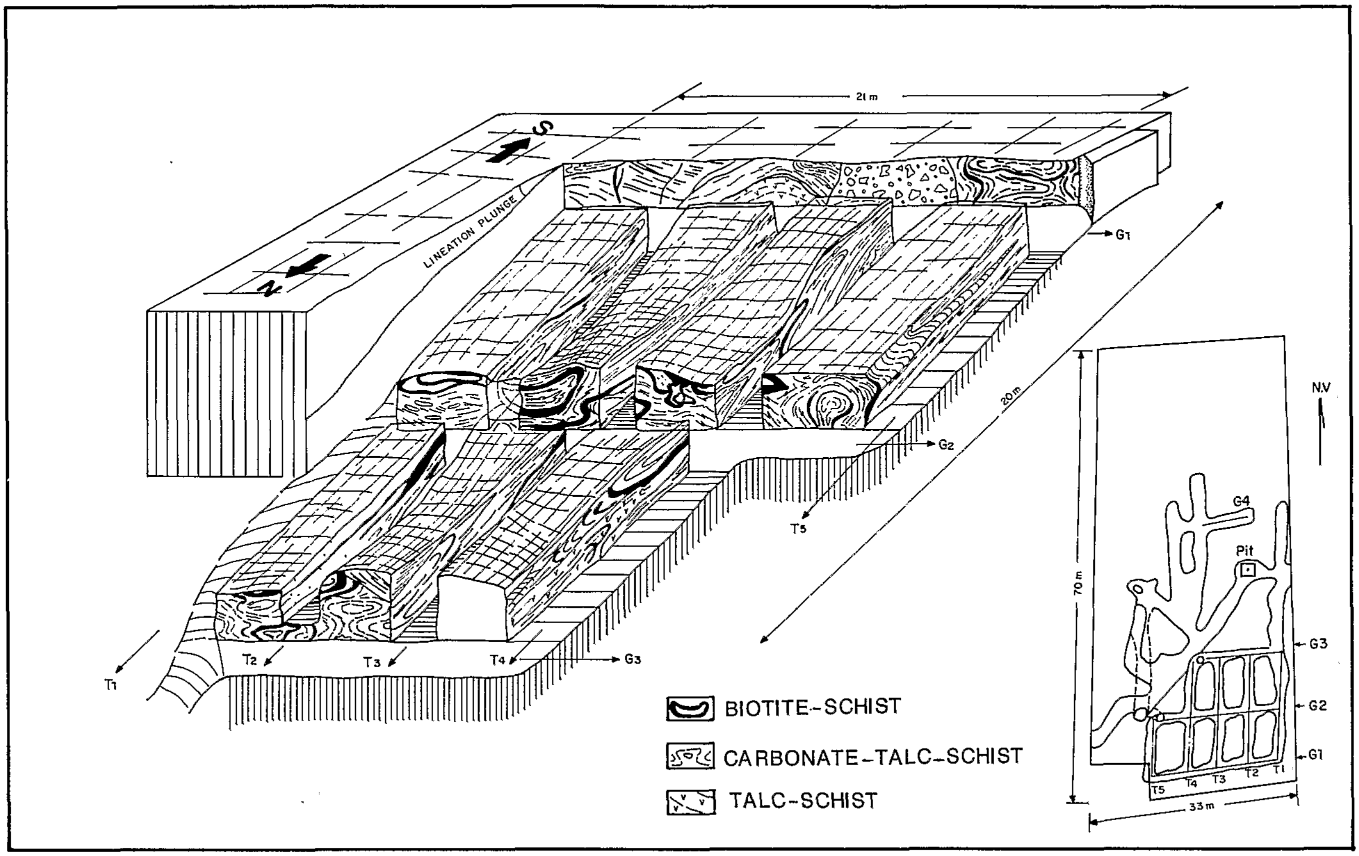


Fig 4. Structural block diagram of the Trecho Novo 167 underground mine (EMSA mining compagny). **a** Layout of the mine (level 86). The G1 to G4 galleries are horizontal, and the T1 to T5 crosscuts have axes striking 350°/15°. **b** Combination of the two sets of maps of the G and T galleries

vided the main sites for thrusting and, moreover, facilitated the migration of the tectonic movement, yielding well-developed sheath folds in a very homogeneous sequence. The axes of the sheath folds show a statistical parallelism with the tectonic lineation: their plunge ranges 10°–20° toward 345° azimuth.

The deformation in Santa Terezinha de Goiás took place mainly in the plastic field. Fault planes can be observed in the galleries, but they are part of the process of thrusting and folding. Brittle deformation is not important in the area, especially with regard to the structural control of the emerald mineralization.

The structures described above are frequently observed also in the diamond drill cores from the surrounding prospects. The sheath fold shown in Fig. 3 b, c is from the Damião prospect, which is located 2 km southwest of the Trecho Novo underground mines in the central part

lineation. The sequence of drawings in Fig. 5 illustrates the structural history of the area and the controls of the mineralization process.

The Belmont emerald mine (Minas Gerais State)

This mine is located at the contact between Archean paragneiss and a highly deformed granitic unit, which belongs to the Borrachudo granite type (Schorscher et al. 1982). The metamorphic sequence is composed of meta-arenites and metagraywackes with intercalated mafic formations. The Lower Proterozoic mafic Belmont mine formations, transformed into biotite, talc-chlorite schists, are 750–1000 m wide and strike NE. They are intruded by a number of pegmatite bodies which are concentrated between the deformed granite and the schists; the peg-


S_1
"SYNFORM"
"ANTIFORM"
"ANTIFORM"

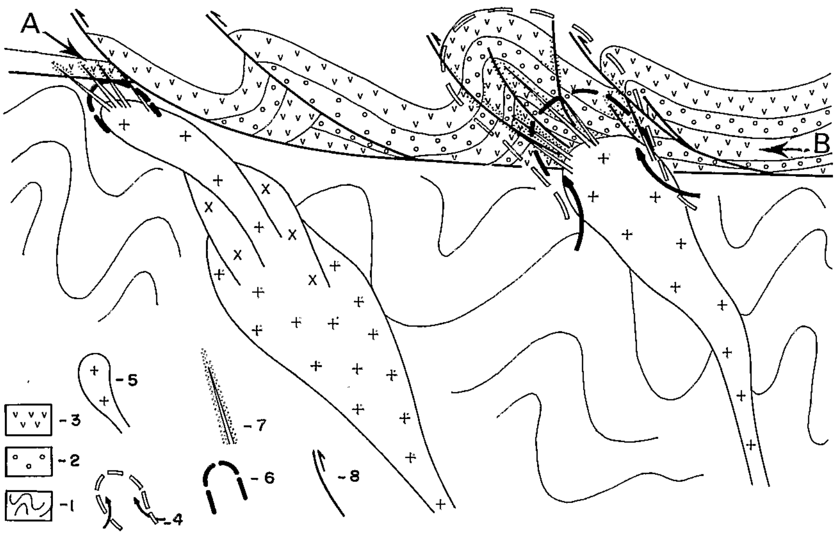


Fig. 6. Model for the type-I emerald deposit clearly associated with pegmatitic veins derived from younger granitic intrusions and crosscutting a volcano-sedimentary sequence. A, *Socotó* prospecting pits (Bahia State) where the mineralization is linked to pegmatoids; the granitic intrusion is absent at the level of observation. B, *Carnaíba* mining district (Bahia State), the typical "granitic emerald-type deposit" showing the relationships between leucogranite, pegmatitic veins, and its consequent hydrothermal metasomatism. 1, Archean basement; 2, quartzite; 3, serpentinite; 4, convective hydrothermal system; 5, granitic intrusions; 6, "molybdenite cup" developed around the granite; 7, pegmatitic (pegmatoid) vein; 8, thrust fault

content of the Q.S.S.? At the moment no data are available; if they are Be-rich, the K-, Al-, Si-, and F-rich infiltrating fluids reacting with the Cr-free Q.S.S. would result in the formation of beryl; no beryl mineralization has yet been encountered in the Q.S.S.

Following the epigenetic model, the Santa Terezinha de Goiás emerald mineralization will appear to be the result of a two-stage process: (1) a metamorphic reaction

the important and famous aquamarine-beryl pegmatite province of Minas Gerais.

The emerald occurrences of Tauá (Schwarz et al. 1988) and Coqui (Mariano et al. 1988) are also characterized by the absence of undeformed intrusive granitoids. The mineralization is related to the intrusion of a dikes swarm consisting of beryl, garnet, tourmaline, colombo-tantalite, and aquamarine, pegmatites within Archean

Table 1. Geology, mineralogy, and chronology of the three main types of emerald deposits of Brazil. Ba, Bahia State; GO, Goiás State; CE, Ceará State

Deposits Occurrences		Type I		Type II	Type III	
		Carnaíba (1) Socotó (2) BA	Pirenópolis GO	Santa Terezinha de Goiás GO	Itabira MG	Tauá (1) Coqui (2) CE
Volcano-sedimentary series (V.S.S.)	Nature	Serpentinites	Talc-chlorite schist	+ carbonate-talc schist + chlorite schist + quartz-sericite schist	– biotite schist – talc-chlorite schist	– amphibolite – biotite schist – tremolite schist – augen gneiss
	Metamorphism	greenschist facies	greenschist facies	greenschist facies	greenschist facies	amphibolite facies
	Age	Lower Proterozoic	Middle Proterozoic	Lower Proterozoic (?)	Lower Proterozoic	Upper Proterozoic
	Name	V.S.S. of Serra da Jacobina	Araxá Series	V.S.S. of Santa Terezinha	metasediments of Minas Supergroup	(1) Independencia complex (2) Caico and Nordestino complexes
Intrusive rocks	Nature	pegmatite veins	pegmatitic veins	–	pegmatitic veins	pegmatitic veins
	Typical mineral association	beryl (molybdenite)	garnet	–	beryl aquamarine	columbite tantalite beryl aquamarine (2) cassiterite (2)
	Related γ	(1) Carnaíba (2) Campo formoso	Quebra Rabicho			
	Age	Transamazonic 1.9 Ga	pre-Uruçuano (?)	–	probably Brazilian 0.5–0.7 Ga	Brazilian? (1) Brazilian (2) 0.5–0.7 Ga
Emerald and metasomatic rocks	Nature	phlogopitite	phlogopitite	+phlogopitite +phlogopitite-talc carbonate schist +phlogopitite-carbonate schist	phlogopitite	phlogopitite
	Typical mineral association	molybdenite alexandrite (1) scheelite apatite tourmaline phenakite (2)	tourmaline apatite (cassiterite)	pyrite chromite (Mg, Al) carbonate (Mg)	alexandrite chrysoberyl	apatite bismutite (1)
	Emerald composition	(2) (2)				(1) (2)
	Cr_2O_3	0.28 0.29	0.08	0.57	0.31	0.19 0.04
	FeO	0.62 0.75	0.61	1.15	0.73	1.05 0.04
	MgO	1.51 2.05	2.73	2.84	1.48	2.48 0.66
	Na_2O	1.29 1.09	1.77	1.77	0.92	1.84 0.59

Summary and conclusions

Brazilian emerald deposits are found in a typical geological setting with Archean basement and supracrustal, ultramafic, and granitoid rocks. The tectonic relationships with their surroundings are not yet entirely understood, but three main types of emerald deposits may be characterized:

Type I: Typical deposits associated with mafic-ultramafic rocks, granitic proximal intrusives, and related pegmatites; for example, the Carnaíba and Socotó prospecting pits (Bahia State).

Type II: Important emerald-biotite schist deposits characterized by the absence of pegmatitic veins and developed in ductile shear zones; for example, the Santa Terezinha de Goiás prospecting pits (Goiás State).

Type III: Deposits related to the presence of aquamarine, beryl and/or Nb-Ta-cassiterite-bearing pegmatites of uncertain origin, such as the Belmont mine (Minas Gerais State).

The different features of these three types of deposits are presented in Table 1. Some conclusions may be drawn as follows. In all the deposits, emerald mineralization is found in biotite schists, and each type is characterized by a typical ore paragenesis. In the granitic type, Mo and to a lesser degree, W are important metals associated with emerald; for instance, the Carnaíba mining district is at the moment responsible for the total Brazilian molybdenite production. In type II, pegmatites are absent and emerald mineralization is contemporaneous with the structural evolution of sheath folds in a ductile shear zone. In this case, the "biotitization" is associated with intense pyritization yielding frequent pyrite-emerald intergrowths. It appears that the Santa Terezinha geological and structural setting is favorable for the investigation of metals such as gold which is already exploited in the surrounding Archean basement. In the third type of deposit, aquamarine (Belmont mine) or Sn, Nb-Ta aquamarine (Coqui, Tauá) are the main characteristic minerals of the pegmatites.

The differences in ore paragenesis and emerald chemistry are probably related to differences in fluid composition; the first investigations in fluid inclusions in emerald (Cheilletz 1988; Giuliani and Weisbrod 1988; Hänni et al. in press) confirm a notable variation in bulk composition and salinity of the fluids related to each type of emerald deposits.

Acknowledgements. During the field and laboratory investigations we have benefited from discussions with many researchers. We would especially like to thank J. C. Barros, A. Beus, A. Cheilletz, A. Experidão, R. A. Fuck, H. Jost, R. G. C. B. Marino, M. Pichavant, L. Rudowski, D. Schwarz, and E. A. Silva. We acknowledge the CPRM/SGM of Salvador da Bahia for field support. We thank the engineers A. Crosara and O. Generoso president of the EMSA Group and technical director of the Penery Mining Compagny (Goiânia, Go) respectively, who permited the development of field work and mapping of the galleries in Santa Terezinha de Goiás. We thank also the project "Granitoides da Bahia" grants, convention FINEP/4F n° 4.2.86.0344.00, for the research support, N. Ariplinio and E. C. Ashano for english corrections, and Neiva E. for drawings.

References

Beus, A.A.: Geochemistry of beryllium. W.H. Freeman Editor, 401 p. (1966)

Cheilletz, A.: Etude préliminaire des inclusions fluides du gisement de béryl de Coqui, Ceará, Brésil. Unpubl. Report. 15 p. (1988)

Costa, S.A. de G.: Correlação da sequeñcia encaixante das esmeraldas de Santa Terezinha de Goiás com os terrenos do tipo greenstone belt de Crixas e tipologia dos depositos. Anais XXXIV Congresso Brasileiro de Geologia, 2:597–614 (1986)

Couto, P.A., Almeida, J.T.: Geologia e mineralizações na aera do garimpo de Carnaíba; Bahia. Anais XXXII Congresso Brasileiro de Geologia, 3:850–861 (1982)

De Wit, M.J., Hart, R.A., Hart, R.J.: The Jamestown ophiolite

Giuliani, G., Couto, P.: O metassomatismo de infiltração e sua importancia nos depositos de esmeralda do Brasil. Anais VII Congresso Latino-Americano de Geologia, Belém, 1:459–475 (1988 b)

Giuliani, G., Fernandés, P.C.A.: The Archean and Proterozoic molybdenum mineralizations of the Bahia State, Brazil: Metallogenetic implications. Anais VII Congresso Latino-Americano de Geologia, Belém, 1:230–242 (1988)

Giuliani, G., Weisbrod, A.: Scanning electron microscopy (SEM) and its applications: determination of solid and daughter minerals in fluid inclusions from some Brazilian emerald deposits. Anais VII Congresso Latino-Americano de Geologia, Belém, 1:445–458 (1988)

Hänni, H.A., Schwarz, D., Fischer, M.: The emeralds of the Belmont Mine, Itabira – Minas Gerais – (in press)

Korzhinskii, D.S.: Theory of metasomatic zoning. Clarendon press Oxford, 162 p. (1970)

Mariano, R.G.C.B., Giuliani, G., Cheilletz, A., Clementelle, L.: Os berilos verdes da região de Coqui, Municipio de Quixeramobin: novas ocorrências des esmeraldas no estado do Ceará. Anais XXXV Congresso Brasileiro de Geologia, Belém, 1:383–405 (1988)

Moreira, M.D., Santana, A.J.: O garimpo de Carnaíba, geologia e perspectivas. Anais XXXII Congresso Brasileiro de Geologia, Salvador, 3:862–874 (1982)

Rudowski, L., Giuliani, G., Sabaté, P.: Les phlogopitites à émeraude au voisinage des granites de Campo Formoso et Carnaíba (Bahia, Brésil): un exemple de minéralisation protérozoique à Be, Mo et W dans des ultrabasites métasomatisées. C.R. Acad. Sci. Paris, T. 301, Série II, 18:1129–1134 (1987)

Rudowski, L., Fonteilles, M.: Existence de deux séries évolutives distinctes dans les granites peralumineux de Campo Formoso, et leur relations avec le granite de Carnaíba et les minéralisations à émeraudes (Serra de Jacobina, Bahia, Brésil). C.R. Acad. Sci. Paris, T. 307, Série II, 8:935–940 (1988)

Rudowski, L.: Pétrologie et géochimie des granites transamazoniens de Campo Formoso et Carnaíba (Bahia, Brésil), et des phlogopitites à émeraudes associées. Unpubl. Doctorate Thesis Paris VI, 300 p. (1989)

Rupasinghe, M.S., Dissanayake, C.B.: Charnockites and the genesis of gem minerals. Chem. Geol. 53:1–16 (1985)

Santana, A. de J.: Projeto Carnaíba. Relatorio final. CBPM, Vol. 1 (1981)

Silva, L.J.H.D., Giuliani, G.: Controle estrutural da jazida de esmeraldas de Santa Terezinha de Goiás: implicações na gênese, tectônica regional e no planejamento da lavra. Anais XXXV Congresso Brasileiro de Geologia, Belém, 1:413–427 (1988)

Silva, K.K.M.W., Siriwardena, C.H.E.R.: Geology and the origin of the corundum-bearing skarn at Bakamuna, Sri Lanka. Mineral. Deposita 23:186–190 (1988)

Sinkankas, J., Read, P.: Beryl. Butterworths Gem Books, 225 p. (1986)

Smirnov, V.L.: Ore deposits of the U.S.S.R., V. 3, Deposit of beryllium, Pitman Publications, England (1977)

Schorscher, H.D., Santana, F.C., Polonia, J.C., Moreira, J.M.P.: Quadrilatero ferrifero – Minas Gerais State: Rio das velhas greenstone belt and Proterozoic rocks. Intern. Symposium on Archean and Early Proterozoic Geologic Evolution and Metallogenesis. Excursion guides, 1–43, Salvador, Brazil (1982)

Schwarz, D.: Classificação genetica des ocorrências de esmeralda. Anais XXXIV Congresso Brasileiro de Geologia, Goiânia, 4:1854–1862 (1986)

Schwarz, D.: Esmeraldas – inclusoẽs em gemas. Imprensa Universitaria UFOP Ouro Preto, 450 p. (1987)

Schwarz, D., Hänni, H.A., Martin, F.L., Fischer, M.: The emeralds