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SCANNING ELECTRON MICROSCOPY (SEM) AND ITS APPLICATIONS: DETERMINATION OF SOLID AND DAUGTHER MINERALS IN FLUID INCLUSIONS FROM SOME BRAZILIAN EMERALD DEPOSITS

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RESUMO

Informações químicas e morfológicas, obtidas ao microscópio eletrônico de varredura (MEV), com prévias observações ópticas, permitiram não só obter novos dados gemológicos a respeito das esmeraldas brasileiras, mas sobretudo identificar os minerais de saturação - MS - de suas inclusões fluidas - IF -. Dois tipos de jazida foram estudadas: aquelas cuja relação genética com granitóides é evidente, exemplos de Carnaíba e Socotó (Bahia), outras cujos relações com veios pegmatíticos são duvidosas, como em Santa Terezinha e Itaberaí (Goiás). Nestas jazidas, a esmeralda é associada a zonas de flogopititos cujo zoneamento metassomático resulta da percolação de uma solução em rochas por um sistema de poros finos. Reações químicas na rocha permitiram alterações na composição da solução e assim uma mudança nas inclusões sólidas e minerais de saturação aprisionados pela esmeralda. Estas reações metassomáticas entre fluidos ricos em Be e formações básicas ricas em Cr, Mg, Fe, produzem em todas as jazidas estudadas a formação de flogopita, anfibólio (tremolita e/ou actinolita), esmeralda e sulfetos (pirita, calcopirita e pentlandita). As diferenças entre as várias jazidas estudadas são: 1º/ nos tipos de inclusões fluidas associadas: esmeraldas de Carnaíba e Socotó mostram geralmente, inclusões tubulares com várias formas (agulhas, tubos, canais hexagonais ou sob a forma de "concha de belemnite", enquanto que em Santa Terezinha e Itaberaí, as cavidades de IF são raras e desenvolvidas a partir de inclusões sólidas; 2º/ nos sólidos e MS: a/os xistos carbonatados ricos em Cr de Santa Terezinha, permitiram a formação e o aprisionamento de dolomita, ankerita, anfibólio magnesiano e magnésiocromita. b) Socotó e Carnaíba mostram que as esmeraldas relacionadas aos veios pegmatiticos são ricas em MS sob a forma de sais complexos. O exemplo de Socotó é bem claro, podendo-se observar a evolução do fluido desde o veio pegmatítico (I) até a sua zona de flogopitito (II) adjacente: — Em I, o quartzo da matriz mostrou minerais de saturação tipo K, Cl identificados como silvita e também sais tipo Ca, Cl, Fe, todos associados com inclusões fluidas do tipo S (i.é. IF polifásicas com sólido). — A esmeralda desenvolvida no I, apresenta também misturas de sais complexos com várias composições: Fe, Cl; Ca,Cl,Mn,Fe; Fe, Cl,Mn; Ca,Cl,Fe,Ba,K. — Na esmeralda situada no flogopitito (II), os MS são: Ca, Cl,Fe,Mn,K; Cl,Mg,Fe; Cl,Na,Mg; eles mostram também a presença quase constante de Mg, elemento móvel, fornecido pelos serpentinitos durante a percolação do fluido. No caso de Santa Terezinha de Goiás e Itaberaí, os MS são quase ausentes mostrando que as soluções eram diluidas.

INTRODUCTION

— The identification of solid inclusions as trapped or as daughter minerals is always of academic interest (Kalyuzhnyi, 1958; Roedder, 1972, 1984). Roedder (1972) explicited the methodology to identify solid minerals (s.1) but optical means are always limited by the size, imbricated occurrence and sometimes xenomorphic shape of the multisolid inclusions. Successful determinations are possible in the case of microchemical, cristallographic and optical means (Rankin and Le Bas, 1974; Coveney and Kelly, 1971). Metzger et al. (1977) demonstrate that scanning electron microscopy (SEM) provided a powerful tool for the study of daughter minerals in fluid inclusions and their successful approach was applied to complex multisolid inclusions from various environments as carbonatites (Nesbitt and Kelly, 1977), tin-tungsten mineralizations (Kwak and Tan, 1980; Cheilletz, 1984) or porphyry copper deposits (Le Bel, 1979; Wilson et al., 1980).

Nature of solid inclusions in gemstones is obviously of peculiar interest for gemologists, relatively to the quality of the gem enhancing the value or desvaluing it, specifiying it origin, characterizing it geochemical growing environment and discrimining it with synthesized gems. Optical, X-ray and electron microprobe are the usual gemmological methods allowing to specification of mineral inclusions in gems (Sinkankas and Read, 1986). Complete determination of these solid inclusions requires evidently more sophisticated method, and at the moment, no work was done using SEM method.

Between all the gems, emerald is of first importance in Brazil and gemmological studies on solid inclusions are still realized (Schwarz, 1984; Schwarz and Mendes, 1985; Schwarz, 1986), evidencing reports of unidentified daughter or trapped minerals. Preliminary study on fluid inclusions for some emerald deposits from Brazil (Giuliani, in preparation), demonstrate that daughter minerals display a remarkable and constancy amounts within inclusions but with differences following the type of deposit.

It this paper, we demonstrate in spite of some limitations and ambiguities in the determination of the daughter minerals, that SEM* technique has useful applications not so in fluid inclusion interpretations as determining morphology size, spatial repartition of fluid inclusion cavities and displaying a compositional limit for the original fluid, but also in gemmology permiting some unambiguous identification of solid inclusions.

EMERALD MINERALIZATIONS OF BRAZIL

Brazil represents the most representative world producer in volume and in emerald quality. Nowadays, four economic emerald deposits are in production (Fig. 1): the prospecting pits of Carnaíba and Socotó (Bahia State), Santa Terezinha de Goiás (Goiás State) and the Itabira mine (Minas Gerais State). In addition, other occurrences are of minor economic significance.

Typical emerald mineralization is associated with biotite-schist rocks resulting from the chemical interaction between granitoidic rocks within basic and ultrabasic formations: the so called schist - type beryl deposit (Sinkankas and Read, 1986) or glimmerite

* the study was realized on a Cambridge Stereoscan 250 SEM, V = 25 KV, multichannel analyses PGT System III.

(Smirnov, 1977). Brazilian emerald deposits belong to two types (Schwarz, 1986): I type: association mafic-ultramafic rocks (or their metamorphic derivates) with pegmatitic veins; II type: absence of pegmatitic formations.

Four deposits were chosen to illustrate the application of the SEM techniques. The firsts are the prospecting pits of Socotó and Carnaíba, typical and classic emerald type mineralizations (type I), already described by Cassedanne (1985) and Rudowski et al. (1987 a,b); secondly, the deposit of Santa Terezinha de goiás (Cassedanne and Sauër, 1984; Costa, 1986) and the occurrence of Itaberaí (type II) (Leinz and Leonardo, 1936) in which the lack of pegmatitic veins assumes a non "magmatic" origin for beryllium (Schwarz, 1986).

INCLUSION-BEARING MINERALS FROM EMERALDS OF CARNAÍBA, SOCOTÓ, SANTA TEREZINHA DE GOIÁS AND ITABERAÍ PROSPECTING PITS.

Deposits from Bahia State

Emeralds* from Carnaíba can be easily discriminated from those of Socotó. Generally, they exhibit and hexagonal prism with a size up to 10 cm long and with a diameter varying from 0.5 to 10 cm. The crystals which grown from a biotitic or feldspathic matrix show sometimes the pinacoid (0001) termination.

Under the microscope, the sections show the presence of a regular coloured zoning developed along the c-axis, and also pyramids and striaes of growing, already described by Schwarz (1984). Microscopic and SEM observations evidenced a great fracturation affecting emerald during and after it formation, causing a diminution of the crystal transparency. Besides, rehealing of these fractures, which are generally oriented perpendicular to the c-axis, is materialized by alignment of biphased inclusions (gas + liquid). These secondary inclusions are dominant but it is always possible to observe primary fluid inclusions kept during the emerald growth; they consist in thin tubes (50 to 100 µm long) disposed along the c-axis and infilled with a liquid and a gas phase (which volume (V_g) represents 40 to 80% of the total volume of the inclusion). Some of these primary inclusions are multiphased, and present daughter minerals i.e minerals or solid phases which crystallized from the fluid upon cooling. Unfortunately, SEM observations do not reached these desirable daughter mineral inclusions and further investigations are necessary for the knowledge of these components present as dissolved constituents in the fluid inclusion during the entrapment. Sole, phlogopite which forms a constant protogenetic or syngenetic inclusion was observed (Plate 1 Fig. 5).

Protogenetic inclusions or crystalline solid inclusions are relatively rare, except phlogopite. Schwarz (1984) evidenced tourmaline, albite, molybdenite, lepidocrocite, goethite, emerald and tremolite (?). The straight association wih molybdenite is an important feature of Carnaíba emerald. At the moment, Carnaíba district assumes the main brazilian production of molybdenum; the Mo-mineralization is well expressed near the contact of the granite, and the Marota prospecting pit became a Mo-mining area: here, rosettes of molybdenite (cm to 5 cm wide) associated with green beryl are frequent. We can note also emerald inclusions into emerald crystals (Plate 1, fig. 6).

Emeralds from Socotó differ by the size of their hexagonal prisms which are smaller (up to 5 cm long, 0.2 to 1 cm large), their

* emerald in the s.1, including also green beryl

transparency related to a minor fracturation and its more intense green coloration. For this study, emerald from phlogopitites (E_1) and from associated albitic-pegmatoid veins (E_2) were studied, including also the hyaline quartz of the pegmatoid veins (Qz).

EMERALD - Growth structures are characterized by the following features:

- growing zones are underlined by a typical zoning marked by a variety of colour evoluing from pale to intense green tones. The variation in colour from every zone is not progressive, and generally dark zones exhibit a great concentration of protogenetic phlogopites.
- growing zones of E_1 and E_2 are underlined by primary fluid inclusions which can be divided in two kinds:
  - tubular inclusions are the commonest and they range in form from huge and hexagonal tubes to long hairs or needles. These last form alignments parallel to the c-axis and the size of the needles varies up to 100 µm. They are biphased and with sometimes solid and daughter minerals (Plate 2, Fig.2, Plate 1, Fig. 1). The morphology of the cavities are not always regular and swellings are common. These fine tubes are often associated to zones enclosing a large number of greater tubes, giving rise to a diminution of the crystal transparency and occasioning the so called "rain effect". These tubes present a conical form like a "belemnit rostre" with an extension up to 200 µm (Plate 2, Fig. 3). They can occur also as channels with sub-hexagonal sections (Plate 2, Fig. 1), with a size of 100 to 150 µm and an extension up to 1 mm. Under the microscope, they appear brown-dark coloured; SEM analyses from the walls of these channels display only Fe, probably iron oxides or hydroxides; frequently, syngenetic phlogopites, as encountered in the fine tubular inclusions are seen.

    All the tubular inclusions are generally infilled by a two phased fluid (liquid + gas) with solid inclusions and daughter minerals. X-ray spectra evidenced abundant phlogopite (Si, Al, K, Fe, Mg components); persistent Fe, Cl peaks suggesting the existence of Fe hydroxy-chlorides, or Fe chlorocarbonates or oxy-chlorides, corresponding in thin section to prismatic high relief minerals with a moderate refringence; iron peak allowing the presence of Fe oxides or hydroxydes; Cl, Na (Mg) with an amorphous form; Ca, Cl, Mn, Fe elements (Plate 1, Fig. 1) analysed in a rounded pseudo-rhombic crystal expecting a more complex phase than $CaCl_2.6H_2O$; epidote with Si, Ca, Al, Fe components; emerald presenting it hexagonal prismatic habit with an X-ray analysis showing Si, Al, Cr,Fe (Plate 2, Fig. 6).
  - indented or swelled fluid inclusions are also frequent and present a size ranging from 5 to 30 µm. They are dispersed regularly in the host crystal with sometimes an aligment parallel to the c-axis. They correspond to multisolid inclusions with a liquid, gas phase (Vg occupying 40 to 50% of the total volume of the inclusion) and daughter minerals. X-ray spectra obtained with the SEM revealed the persistence of complex salts covering the walls of the cavities or minute crystals. Plate 2, Figure 4 shows the presence of Cl, Fe, Mn salts associated with phlogopite and rhomboedric carbonates (Ca, Mn, Fe or Ca, Mn) suggesting the presence of ankerite. In other cases, (Plate 1, Fig. 2), the following elements were analysed: Ca, Cl, Fe, Mn, K and also Ca, Cl, Fe, Ba, K; Ca and Cl are the main elements of these prismatic, rounded, pseudocubic or lamellar solid salts. Another type of salt was encountered presenting an amorphous habit and formed with Cl, Mg and iron. Other more common daughter

minerals are actinolite (Plate 2, Fig. 5), phlogopite associated with iron carbonates (Ca, Fe) and probably magnetite showing an octaedral from (Fe only).

Protogenetic inclusions which correspond to solid particles present in suspension in the fluid are common and identified as phlogopite, tremolite and actinolite. These inclusions are formed on the crystal surfaces or can have been settled out of the fluid. Generally, they act as nucleii for the development of tubular primary fluid inclusions which extend upward along the c-axis before becoming bridged by the growth of the crystal. This bridging over will depend naturally on the velocity of the growing. A consequence of this phenomena is that these protogenetic inclusions can be entrapped as solid inclusions and be confused with daughter minerals.

QUARTZ - quartz from emerald-bearing albitic pegmatoid veins was also investigated. Under the microscope, three major types of fluid inclusions were observed:

- a multisolid type (type S) presenting a liquid phase > to the vapor phase (Vg = 20-30% of the total volume of the inclusion), with one or two daughter minerals. The main abundant and persistent is sylvite (K,Cl peaks on SEM) with a pseudocubic habit and a bright yellow colour; another unknown mineral which was already encountered in the emerald type E_2, is a white coloured prismatic solid which X-ray spectra evidences so the Cl peak (Plate 1, Fig. 3). Finally, mixtures of complex salts were evidenced such Ca, Cl, Fe (with Ca = Cl in composition): it forms generally, agregates widespread in the cavity (Plate 1, Fig.4).
- a fluid inclusion type with a liquid phase < to the vapor phase (Vg = 80-90%; type V). Types V and S are closely associated and distributed regularly in the matrix or sometimes localized on the same fractures.
- a third type characterized by a liquid phase representing 50 to 60% of the total volume of the inclusion (type L) which is scattered within the quartz.

DEPOSITS FROM GOIÁS STATE

Emeralds from Santa Terezinha de Goiás are little sized hexagonal prisms (3-5 cm long, 0.2 to 1 cm large), with generally a pale green colour. Under the microscope, its show an irregular distribution of colours and also insignificant zoning. Striaes of growing can be easily observed but primary tubular inclusions, as observed in Carnaíba and Socotó are rare. SEM method permits to confirm the scarcety of these fluid inclusions and the constancy of solid inclusions.

Precoce fluid inclusions are widespread in the crystal; they are small (size $\lesssim$ 10 µm) and very often contain solid inclusions and daughter minerals. The most abundant solid inclusions are carbonate, spinel and phlogopite, as described by Schwarz and Mendes (1985):

- carbonates are generally evidenced by their rhomboedric cleavages (Plate 3, Fig. 1); X-ray spectra indicate the presence of dolomite (Ca, Mg, Fe; Ca, Fe,Mg, Mn) with Fe and Mn substitutions, with sometimes Ca, Fe, Mn compositions allowing to consider the mineral as ankerite.
- another constant solid inclusion encountered also as daughter mineral is a member of the spinel group: the magnesiochromite (Plate 3, Fig. 3 and 4). It is present in all the studied emeralds with major local concentration. It generally exhibits a subautomorphic shape but sometimes an octaedral form. X-ray analysis indicate Cr, Fe, Mg. No

alumina was detected and these data are in agreement with those of Miyata et al. (1987) but do not preclude the presence of picotite, as described by Schwarz and Mendes (1985).

- Phlogopite is always present but more often as solid inclusion permiting, during crystal growth, the formation of a fluid inclusion cavity.
- Pyrite and also amphibole (Plate 3, Fig. 2) were also observed in the emeralds.

Itaberaí emerald is little sized (crystals up to 1 cm in diameter, 3 to 4 cm long) but possesses an intense dark green colour. The fracturation is not intense and the solid inclusions are rare. All these features permit to consider this gem of good quality. SEM observations permit to confirm also the rarety of fluid inclusions which are small ($\lesssim 10$ µm) and generally biphased. Daughter minerals are absent and protogenetic inclusions are limited mainly to phlogopite (Plate 3, Fig. 5). SEM evidenced also the presence of a Ni-Fe arsenosulphide (Plate 3, Fig. 6). X-ray spectra revealed Fe, Ni, As, S as major components suggesting either pentlandite (or arsenopyrite with Ni substitution). The absence of X-ray spectra standard of pentlandite do not permit us to eliminate this uncertainty; However, the ratio 2 Ni/Fe allows to preclude arsenopyrite .

CONCLUSIONS

Scanning electron microscopy permited to complete the gemmological data already obtained on emerald from Brazil (Cassedanne and Sauër, 1984; Schwarz, 1984; Schwarz and Mendes, 1985; Schwarz, 1986), but chiefly the identification of fluid inclusion daughter minerals. SEM views allowed also to visualize the morphology and the distribution of the cavities of fluid inclusions kept during the emerald growth (primary or secondary fluid inclusions). Thus, the semi-quantitative analysis combined with the observed cristallographic forms of the crystals was adequate to specify or at least to limit the possible mineral identity. The knowledge of these daughter minerals is of first importance because it can display a compositional limit for the original fluid, associating the volumes of the daughter crystals at room temperature to the microthermometric features.

Emerald deposits of Brazil are linked to infiltrational metasomatic processes (Giuliani and Couto, 1988). The formation of emerald requires the circulation of acid Be-bearing fluids enriched also in F, Cl, B and CO_2 into channels developed in Fe, Mg, Cr rich ultrabasic rocks. The importance of emerald mineralization will depend of several factors: fluid-rock interaction, width and composition of the ultrabasic formations, time of circulation of the hydrothermal system and the thermodynamic evolution of the associated fluid phases.

In all the cases, emerald is associated to phlogopitite rich zones; these metasomatic zoning results from the flowing of a solution into tho rocks and the percolating by a system of fine pores. Chemical reactions allow change in the composition of the solution and so, a change in the solid inclusions and daughter minerals kept by emerald. These metasomatic reactions produced in all the studied deposits, the formation of a Mg, Cr, rich phlogopite, Mg amphibole (tremolite and/or actinolite), emerald and sulphides (pyrite, chalcopyrite, pentlandite) (Table 1). This constant and important feature illustrates perfectly the migration of mobile elements such Mg, Fe, K which combined with inert ones as Ti, Cr, Al and Ca. Meanwhile, this study reveals that emerald associated to pegmatoids is quite different from emerald having no evident genetic connexion with pegmatitic veins; this difference can be explicited by the nature of the infiltrating fluids but mainly by the composition of the infiltrated formations. The carbonated talc-schists with intercalated Mg carbonates from Santa Terezinha de Goiás will allow to have the formation of Ca-rich solid inclusions and daughter minerals in the infiltrating fluid such as dolomite, ankerite but also Mg-amphibole. The presence of magnesiochromite implies that the solution was at a moment Cr-Mg saturated. Chromium is known as an inert element and Mg a mobile one; so, it signifies that emerald-bearing formations were rich in Cr, implications confirming the data of Costa (1986).

Another typical difference between the two kind of deposits is the type of fluid inclusions associated to emerald. Carnaíba and Socotó prospecting pits exhibit regular tubular inclusions with various forms as needles, hexagonal channels or "belemnit rostrum". Santa Terezinha de Goiás and Itaberaí present few cavities of fluid inclusions. It is also interesting to note the importance and the variety of daughter minerals found in Socotó relatively to the other deposits. Infortunately, the daughter minerals observed in multisolid inclusions from Carnaíba were not found in this SEM study. But for instance, it appears that emerald from pegmatoid veins are daughter minerals-rich with sometimes complex salts. The example of Socotó is particularly illustrative. The evolution of the fluid can be followed since the pegmatoid to the emerald bearing phlogopitite. In the pegmatoid vein, the quartz matrix exhibits K, Cl daughter minerals identified as sylvite and also Ca, Cl, Fe mixtures associated to a S type fluid inclusion.

Emerald type E_2, developed in the pegmatoid vein presents also complex salt mixtures with various compositions: Fe, Cl; Ca, Cl,Mn, Fe; Fe,Cl,Mn; Ca,Cl,Fe,Ba,K; the fluid appears Fe, Cl, Ca rich.

Relatively to emerald type E_1, the salts are always complex with also Ca, Cl, Fe, Mn, K mixtures, but also with Cl, Mg, Fe or Cl, Na, Mg compositions.

In E_2, the presence of Mg is more predominant than E_1 and, we can notice also that iron oxides are abundant and persistent daughter mineral in E_1 and E_2.

It is interesting to note that daughter minerals from E_2 type show the presence of Mg. This element is a highly mobile and probably the Ca, Fe, Mn, Ba, K - chloride solution on entering the Mg-rich serpentinite environment, precipitates Mg - Fe - Mn - K silicates and produces $MgCl_2$ solutions in exchange of the Fe- chlorides used. Consequently, as the fluid circulation is limited in the case of an infiltrating vein, normally the $MgCl_2$ content increases away from the source.

Without doubt, microthermometric studies will allow us to verify these hypothesis. On the basis of the first melting temperature data measured for frozen inclusions, and the present daughter minerals product determinations, we could choose the correct phase diagram to represent the system of the fluids (i.e $CaCl_2$-KCl-$MgCl_2$-H_2O). This selection is primordial because the determination of the composition of the liquid phase is always one of the source of error in the calculation of bulk composition for fluid inclusions.

Emerald from pegmatoid veins, as in the case of Socotó and Carnaíba, appears rich in daughter minerals revealing that the associated fluids are rich in salts. For Santa Terezinha de Goiás and Itaberaí the daughter minerals are quasi absent, and this lack of precipitated phases from fluid inclusions upon cooling, reflects that the solutions were more dilute and not supersaturated with soluble complex salts.

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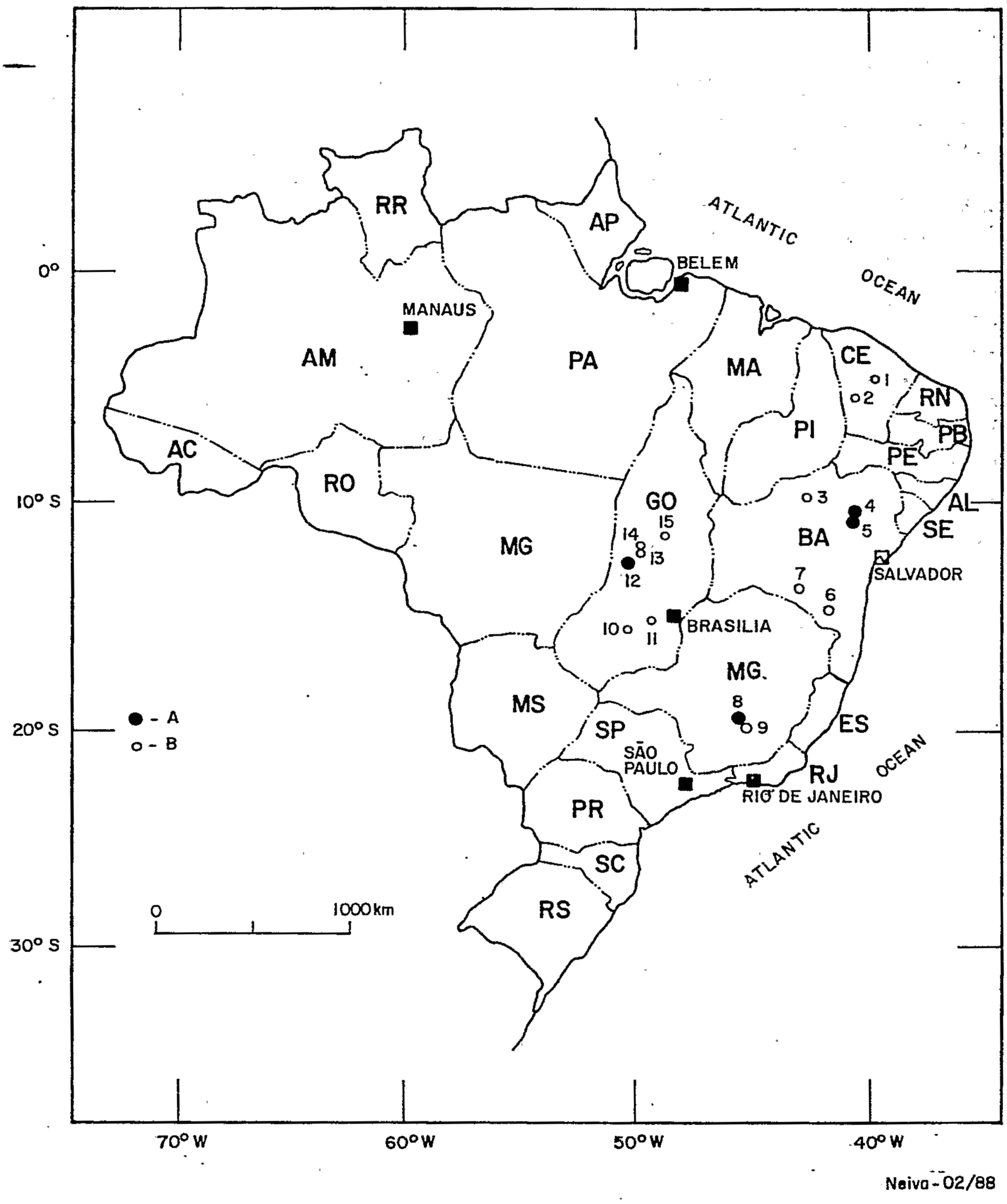

FIGURE 1: Main emerald brazilian deposits and occurrences. A: deposits; B: occurrences. Ceará State: 1 - Coqui; 2 - Tauá. Bahia State: 3: Salininha; 4: Socotó; 5: Carnaíba; 6: Anagé; 7: Brumado. Minas Gerais State: 8 - Itabira; 9 - Santana dos Ferros. Goiás state: 10 - Itaberaí; 11 - Pirenópolis; 12 - Santa Terezinha de Goiás; 13 - Mara Rosa; 14 - Porangatu; 15 - Pela Ema.

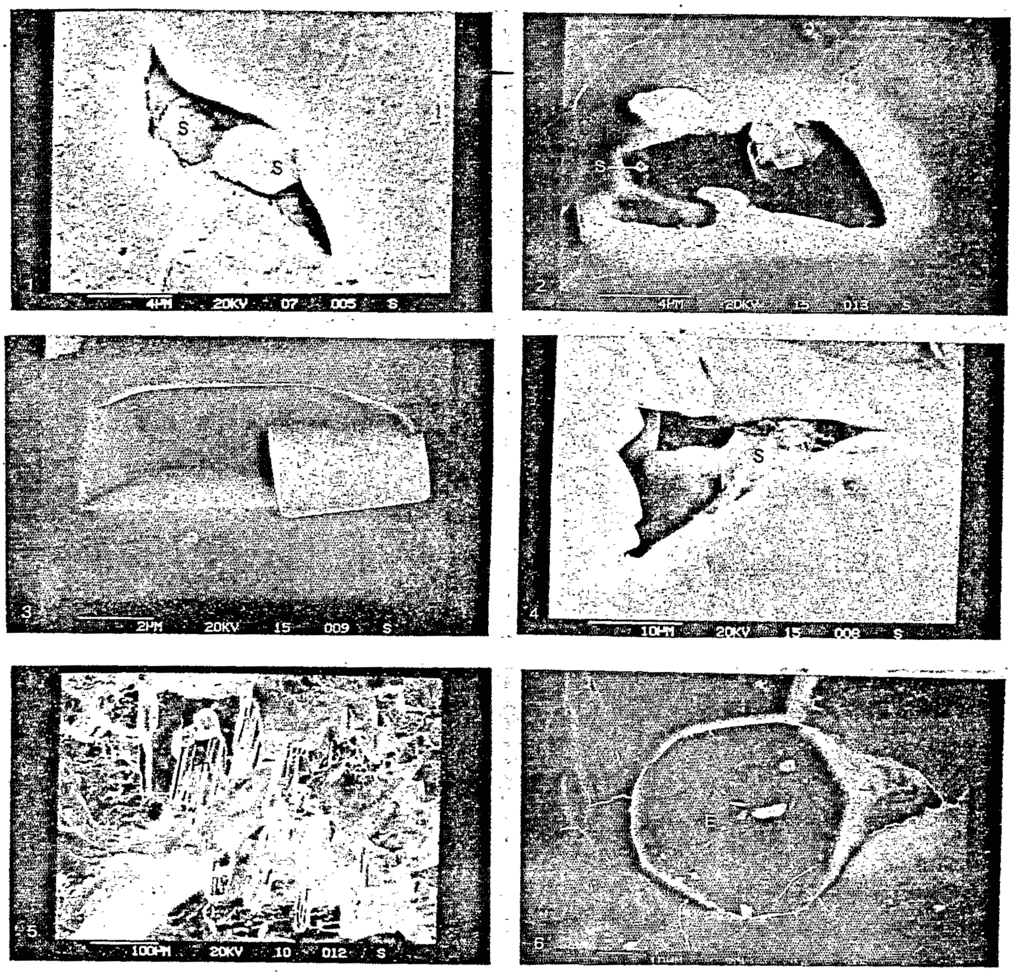

Plate 1 - Solid and daughter minerals in fluid inclusions of emerald from Socotó (Photos 1 to 4) and Carnaíba (Photos 5 and 6), Bahia State, revealed by Scanning Electron Microscopy (SEM). Photo 1: Ca, Cl, Mn, Fe salts (S) from tubular fluid inclusions. Photo 2: daughter minerals encountered in swelled fluid inclusions. S=salt with Ca, Cl, Fe, Mn, K composition. Photo 3: quartz matrix from the emerald-bearing pegmatoid veins; prismatic salt which X-ray spectra evidences so chloride (Cl). Photo 4: Ca, Cl, Fe complex salt deposition (S) in a cavity of fluid inclusion from quartz matrix. Photo 5: Protogenetic crystals of phlogopite (Ph) in cavity of fluid inclusions from Carnaíba emerald. Photo 6: Emerald inclusions (E), in emerald.

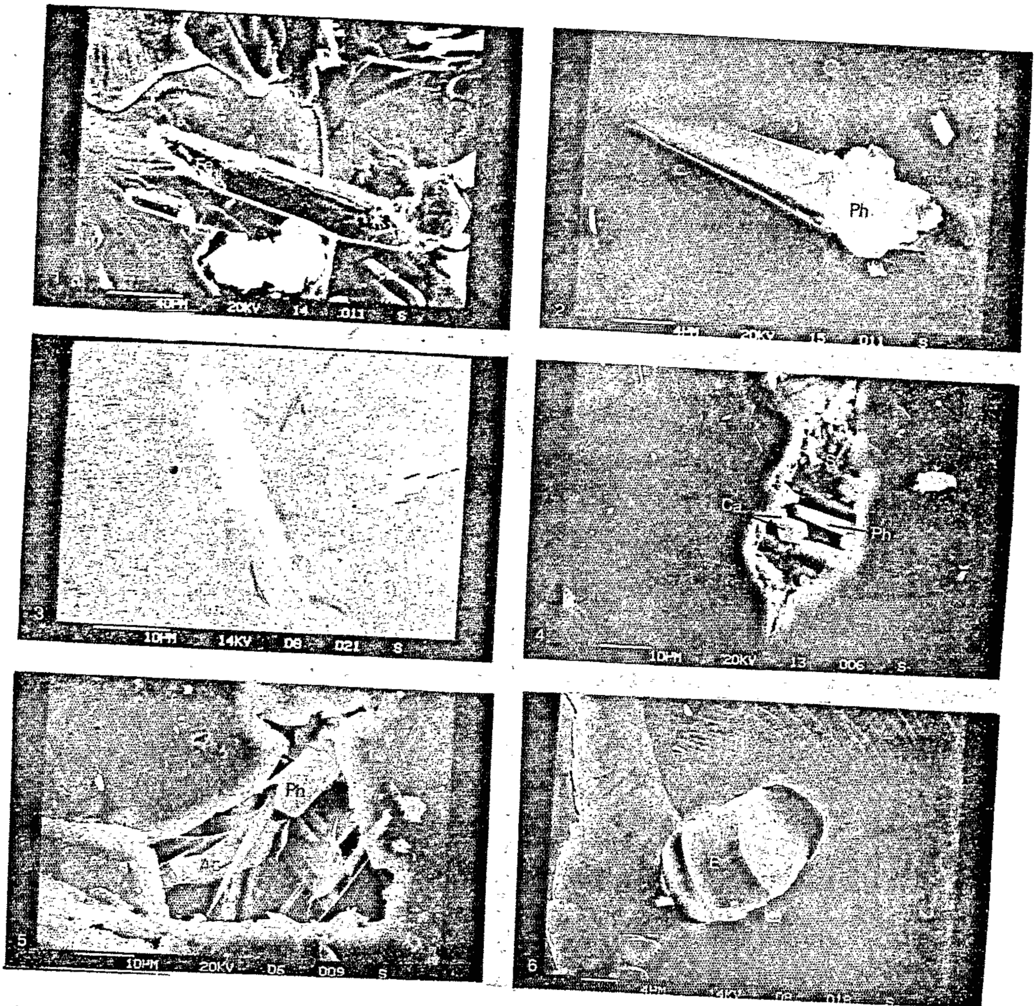

Plate 2 - Solid and daughter minerals in fluid inclusions of emerald from Socotó (Bahia State). Photo 1: aspect of channels with sub-hexagonal sections in emerald. Deposition of iron oxides or hydroxides (Fe) on the wall of the channel. Photo 2: aspect of a tubular inclusion with crystals of phlogopite (Ph). Photo 3: tubular inclusion presenting a conical form like a "belemnit rostre". Photo 4: daughter minerals associated to an indented fluid inclusion showing Cl, Fe, Mn salts (S) with phlogopite (Ph) and rhomboedric carbonates (Ca), with Ca, Fe, Mn composition. Photo 5: Daughter minerals observed in an indented fluid inclusion with phlogopite(Ph) and actinolite (Ac). Photo 6: emerald inclusion (E) in a tubular inclusion with a Si, Al, Cr, Fe composition.

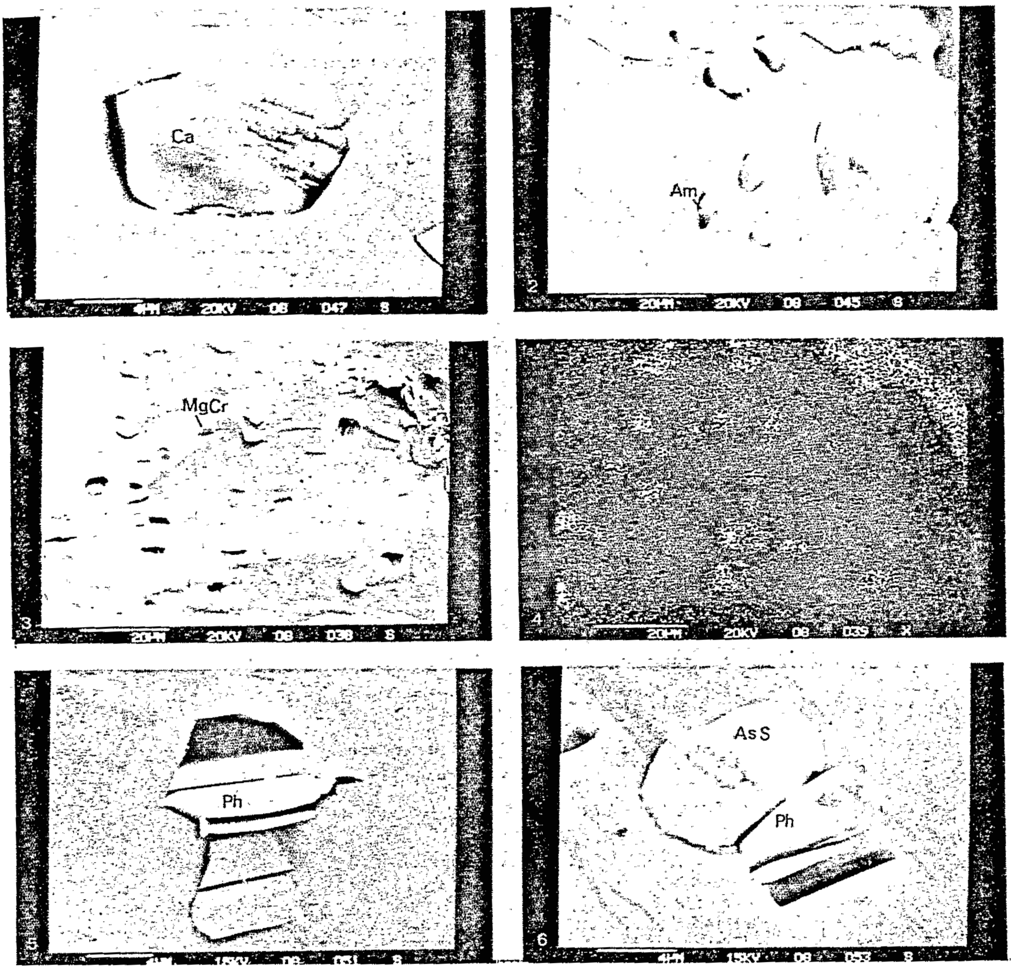

Plate 3 - Solid and daughter minerals in fluid inclusions of emerald from Santa Terezinha de Goiás (Photos 1 to 4) and Itaberaí (Photos 5 and 6) - Goiás State. Photo 1: solid inclusion with Ca, Mg, Fe composition revealing the presence of dolomite (Ca). Photo 2: Amphibole (Am), observed in fluid inclusion cavity. Photo 3: magnesiochromite with a Cr, Fe, Mg composition as solid and daughter minerals in emerald. Photo 4: characteristic X-ray image showing the distribution of chromium in the solids from the field of photo 3. Photo 5: Phlogopite (Ph) forming a protogenetic inclusion in emerald. Photo 6: Association of pentlandite (AsS) and phlogopite (Ph) as solid inclusions.

		SOLID MINERALS	DAUGHTER MINERALS[o]
CARNAÍBA I	EMERALD	Molybdenite*[o] Tourmaline* Albite* Lepidocrocite* Goethite* Emerald*[o] Phlogopite* Tremolite*[o]	phlogopite
SOCOTÓ I	EMERALD	Phlogopite*[o] Tremolite*[o] Actinolite* Hematite* Limonite* Emerald*[o]	TABULAR FLUID INCLUSIONS: Fe:oxides or hydroxydes Al,K,Fe,Mg,Cr:phlogopite Fe,Cl; Cl,Na,Mg; Ca,Cl,Mn,Fe: chloride salts Si,Ca,Al,Fe:epidote Si,Al,Cr,Fe:emerald Si: quartz Cl,Fe,Mn; Ca,Cl,Fe,Mn,K; Ca,Cl,Fe,Ba,K; Cl,Mg,Fe; Cl: Chloride salts INDENTED FLUID INCLUSIONS: Fe: oxides or hydroxydes Al,K,Fe,Mg,Cr: phlogopite Ca,Mn,Fe; Ca,Mn; Ca,Fe: carbonates Ca,Mg,Fe,Si actinote
	PEGMATOID QUARTZ	Sylvite[o] Emerald[o] Phlogopite[o]	K,Cl; Cl; Ca,Cl,Fe: Chloride salts
SANTA TEREZINHA DE GOIÁS II	EMERALD	Dolomite* Ca,Mg,Fe; Ca,Fe,Mg,Mn: Dolomite[o] Ca,Fe,Mn: Ankerite[o] Cr,Fe,Mg, Magnesiochromite[o] Phlogopite[o] Pyrite*[o] Amphibole[o] Magnesite* Picotite* Chalcopyrite* Pentlandite* Talc* Emerald*[o]	Ca,Mg,Fe; Ca,Fe,Mg,Mn; Ca,Fe,Mn: carbonates Cr,Fe,Mg: magnesiochromite phlogopite
ITABERAÍ II	EMERALD	Phlogopite[o] Pentlandite[o]	phlogopite

Table 1: Recapitulation of solid and daughter minerals encountered in emerald from some brazilian emerald deposits. *: data from Schwarz (1984) and Schwarz and Mendes (1985); o: this work; I= deposits straightly linked to pegmatitic veins; II= deposits not associated with pegmatitic veins. For socotó, the underlined daughter minerals as "phlogopite" represent crystals belonging to emerald-bearing phlogopitite zone (Emerald E_1); the other ones are related to emerald-bearing pegmatoid vein (Emerald E_2).