The emeralds of Fazenda Boa Esperança, Tauá, Ceará, Brazil: occurrence and properties

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Abstract

The emerald-producing Fazenda Boa Esperança (Tauá, Ceará) in Brazil, the regional and local geology, and the properties of the emeralds are discussed.

The emerald occurrence is situated in biotite schists and tremolite-bearing schists containing phlogopite and chlorite. Its formation is closely related to anatectic pegmatites which have intruded into the rock series. The emeralds are associated with very large apatite crystals and locally, with corundum.

Chemical analyses show low contents of Cr_2O_3 and V_2O_3 (<0.25 wt.%) and rather high contents of FeO (0.91-1.17 wt.%), MgO (2.42-2.69 wt.%) and Na_2O (1.69-1.96 wt.%).

The following substitutions explain the low Al-contents:-

$$Al^{3+,VI} = (Mg,Fe)^{2+} + Na^+$$
$$Al^{3+,VI} = (Fe,Cr,V)^{3+,VI}$$
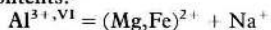
The Tauá emeralds contain many mineral inclusions. So far, phlogopite, tremolite, molybdenite, allanite and apatite have been identified. In addition, accumulations of very small fluid droplets and/or mineral dust and plane cavities occur, mostly exhibiting a one-phase filling. The concentrations of these inclusions lower the gemmological quality of the emeralds.

1. Introduction

The Fazenda (farm) Boa Esperança lies 40 km NNE of Tauá, a small town in the south-east of the federal state of Ceará (Figure 1). The region is one of the driest in Brazil, and the caatinga vegetation typical of this arid area known as the Sertao, consists essentially of low thorny bushes, stunted trees and numerous species of cacti.

The emerald deposit of Fazenda Boa Esperança, which lies less than 1 km east of National Highway BR 020 (linking Fortaleza with the capital Brasilia), has been known for a long time. Since the early 1950s, emeralds (and/or green beryls) have been extracted by garimpeiros (Brazilian freelance miners). At the beginning of the 1970s, the mining company Mineração Sao Pedro Limitada began serious mining operations on a larger scale, but soon gave up due to the high development costs involved. In 1983, the company Mineração Brasileira Ltda. undertook detailed geological mapping of the area (Andrade, 1983; Korpershoek, 1983).

2. Geology

Figure 2 presents the regional geology in which the emerald deposit at Fazenda Boa Esperança is situated.

The following presentation of the regional and local geological conditions of the emerald deposit is based on the work of Gomes *et al.* (1981), Mello *et al.* (1978) and Korpershoek (1984).

2.1 Regional Geology

Over 80% of the surface of Ceará State is mainly composed of Precambrian crystalline rocks. Apart from this, granitic and dioritic-gabbroidal intrusive rocks and pegmatites also occur.

At the end of the Brazilian orogenesis (ca. 650-600 million years), the main geological structures including the characteristic faults, had been formed. Tectonic movements along some of the faults during the Palaeozoic-Mesozoic eras led to a partitioning of the crystalline basement into numerous fault blocks. Thus, Fazenda Boa Esperança lies on the southern border of the Bloco Santa Quiteria, which is described in Figures 2 and 3 as Unit II. In the north, the Bloco Santa Quiteria overlies leptites and, to a lesser degree, biotite gneisses of Unit III. On the other hand, in the more southern area the Bloco Santa Quiteria underlies a polymetamorphic volcano-sedimentary unit, the Complexo de Pedra Branca (Unit I in Figures 2 and 3).

The latter is lithologically very varied and is composed of quartzites, leptites, mica schists, para- and ortho-gneisses, migmatites, amphibolites, serpentinites etc. The Complexo de Pedra Branca is
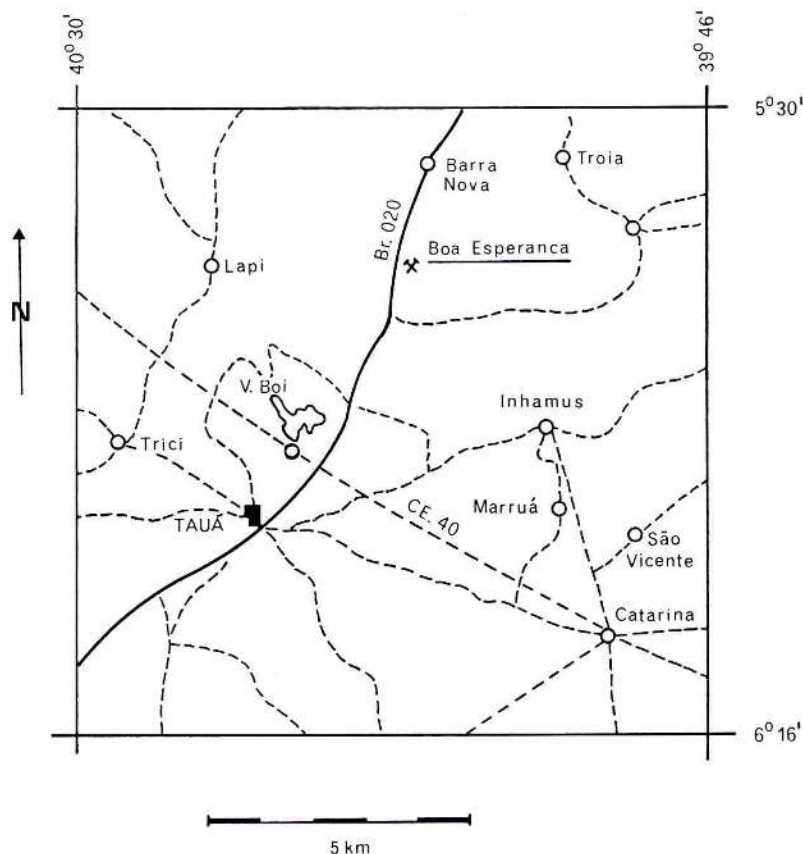
Fig. 1.   Geographical situation of the emerald deposit at Boa Esperança, Tauá, Ceará.

regarded as a 'Nucleo Antigo'* at least 2000 million years old, and overprinted by the Brazilian orogenesis.

In the Bloco Santa Quiteria, several diorite massifs occur whose age and stratigraphical correlation are still unknown. Furthermore, several gabbro bodies occur with a minimum age of 1900 million years, and two granite intrusions occur within the largest diorite massif (Diorito de Tauá). The intrusions are considered to be syntectonic with the Brazilian orogenesis.

A system of rhyolitic to dacitic dykes appear in the south-western portion of the Bloco Santa Quiteria, which cut both the Complexo de Pedra Branca and the Tauá diorite. These dykes can be up to 300 metres wide and several kilometres long. Other dykes belonging to the same lithological type, fill concentric fractures in the syntectonic granites

*Blocks which split a folded region into different zones. They may have been formed during an earlier period, or originated from the same deformation phase which folded the region but, however, had already consolidated (Khain & Sheynaann, in Gomes *et al.*, 1981).
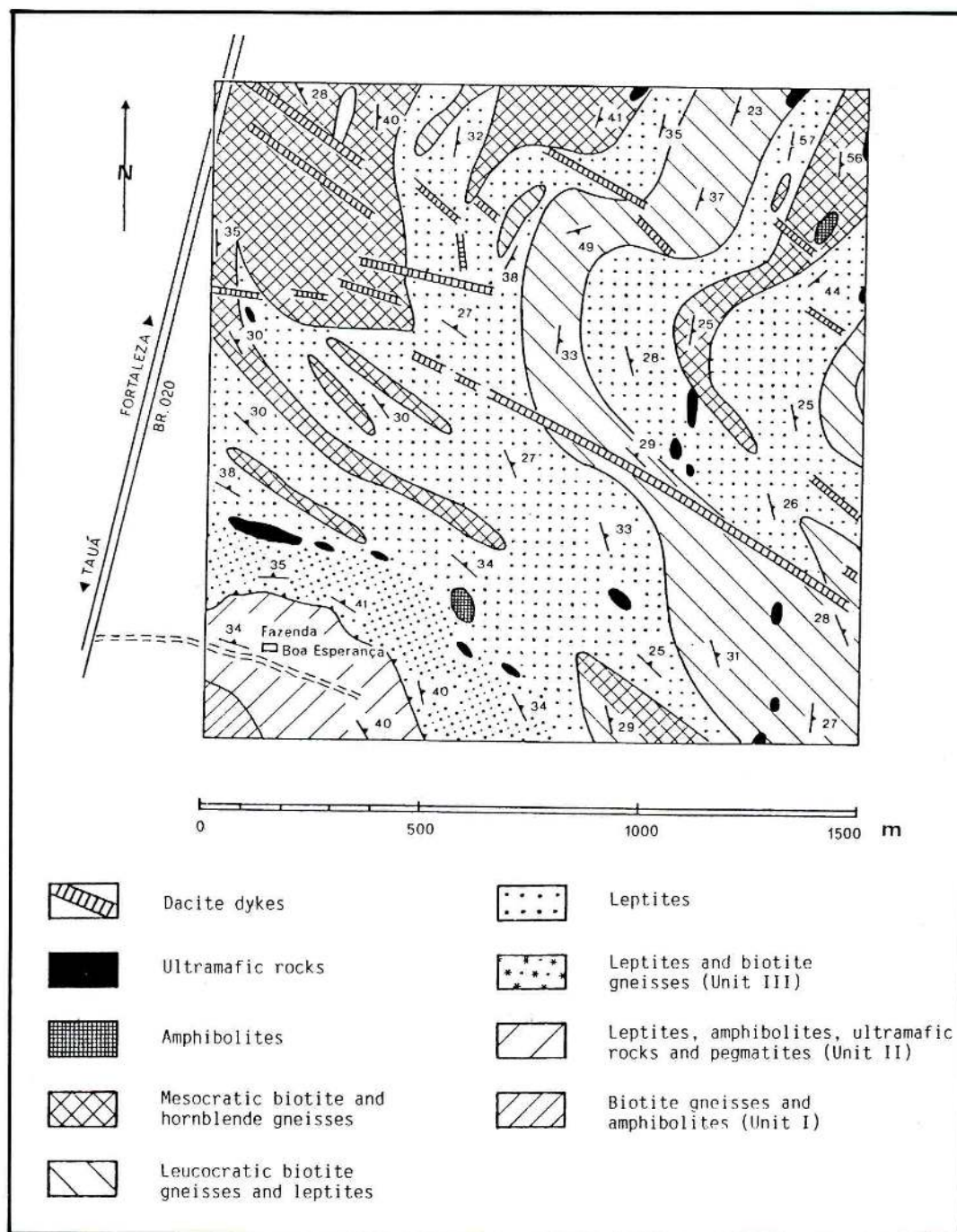
near Tauá. The age of these late-tectonic dykes is given as about 600 million years.

2.2 *Local geology and genetic aspects*

Tectonically speaking, the Fazenda Boa Esperança lies on the southern border of the Bloco Santa Quiteria (Unit II in Figures 2 and 3). This area is mainly composed of biotite gneisses and -schists and leptites, as well as ultramafic rocks, amphibolites and a large number of pegmatites (Figure 3).

Emerald is found in the biotite schists near the pegmatite veins. This unit lithologically presents a very varied development and comprises ultramafic rocks (metamorphosed to talc-schists, tremolites etc.), metabasites, amphibolites (often undergoing transformation to hornblende-gneiss), leptites, as well as biotite gneisses and emerald-bearing biotite schists. The latter are, at least partially, described as 'tremolite schists with phlogopite and chlorite' (Cassedanne and Mello, 1979). Additionally, numerous dykes and pegmatite veins occur.

Fig. 2.   Regional geology of the emerald deposit.
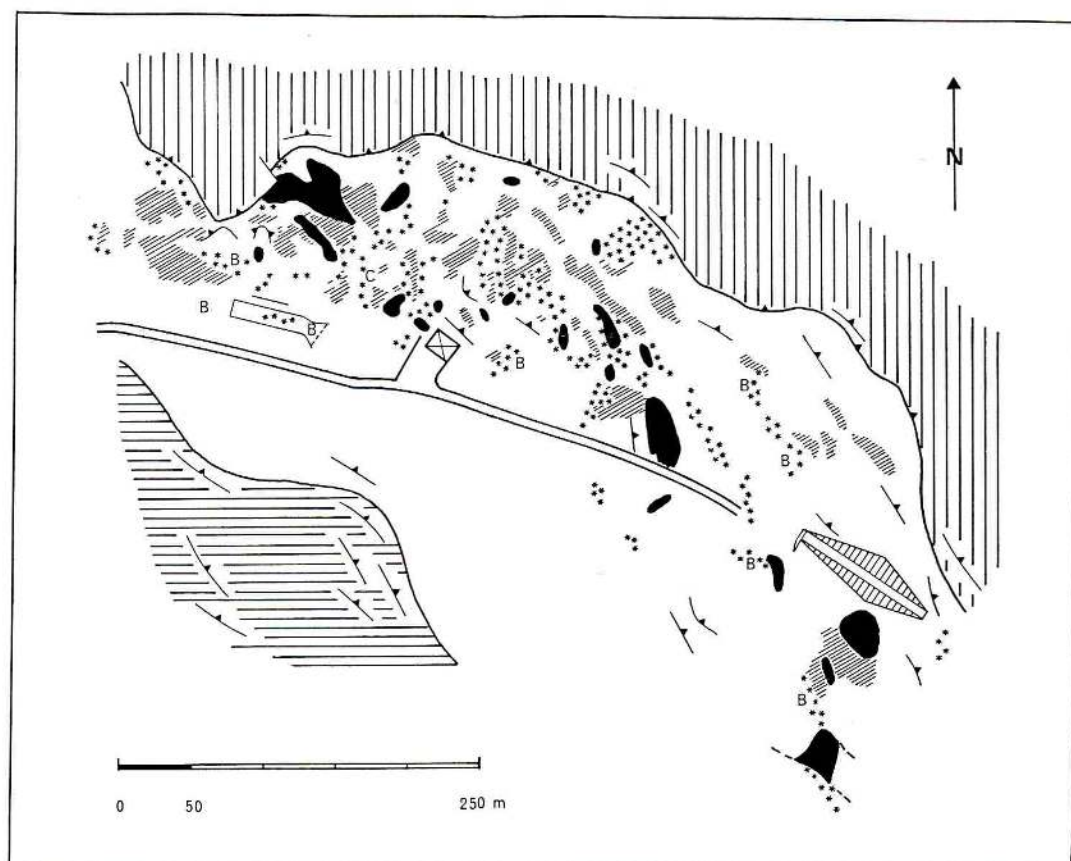
Leptites and (to a lesser degree) biotite gneisses — Unit III

Pegmatites

Ultramafic rocks

Amphibolites

Biotite gneisses and -schists

Unit II

Biotite gneisses and (to a lesser degree) amphibolites — Unit I

B = beryl, emerald
C = corundum, sapphire

Fig. 3. Local geology of the emerald deposit.

The complete volcano-sedimentary sequence as well as the layers directly overlying it were intensively folded; the volcano-sedimentary unit underwent at least three deformation phases.

The ultramafic rocks occur as oval, lenticular or irregular bodies. These, as did the other rocks of the unit, experienced a regional metamorphism and were transformed to talc-schists, talc-tremolite schists, and tremolitites. Some of the ultramafic rocks contain grains of magnetite and are considerably magnetic.

The numerous pegmatites form long and irregular bodies, and also concordant intrusions. They usually have a simple composition mainly of quartz and albite. They are coarse- to fine-grained, with the latter appearing to be the predominant type.

Cassedanne and Mello (1979) suggest that this fine-grained facies originates from the cataclasis during the tectonic deformation. The pegmatites as well as the leptites contain minute red grains of garnet.

The pegmatites are mainly quite homogeneous. Where differentiated, muscovite-rich portions occur, or, in some, finely-layered biotite can be present. Sometimes, concentrations of quartz are developed. Apart from these, the following minerals are present: beryl, columbite-tantalite, tourmaline, apatite, molybdenite and native bismuth or bismutite (Cassedanne and Mello, 1979).

The pegmatites do not seem to be directly derived from late magmatic processes, which usually are accompanied by significant hydrothermal activity. Such an origin would seem to be improbable, because their unusual composition can only with difficulty be linked to a simple granitic origin. They were probably locally mobilised during the regional metamorphism, when pressure and temperature rose notably. This led to a partial anatexis and to the formation of Na-rich pegmatites, determined by the nature of the host-rock. Their composition differs from the K-rich pegmatites in the hanging wall, reflecting the composition of the neighbouring leptites (Korpershoek, 1983).

The emerald-bearing biotite schists (or tremolitic schists with phlogopite and chlorite) neighbouring the 'anatectic' pegmatites are products of chemical reactions (metasomatism) between the pegmatites and the basic or ultrabasic rocks. By exometamorphic processes, i.e. through the change of the original rock by the addition of components of another surrounding chemical medium, the necessary elements for the formation of beryl can reach the biotite schist and crystallize in the form of exometamorphic beryl (or emerald). Most of the beryls so-formed correspond to those which are found in the pegmatites themselves, i.e. they are mostly pale green; the beryl variety emerald is only formed where an adequate supply of colour-providing elements from the basic or ultrabasic rocks is available. Chromium is possibly supplied by some of the chromian magnetite in the ultramafic rocks.

The emeralds are generally small and seldom longer than 2 cm. Occasionally, fragments of larger crystals have been found. The prismatic crystals (combination of six-sided prisms and basal pinacoid) exhibit different shades of green, whereby an apple-green seems to be the most abundant colour. According to Cassedanne and Mello (1979), this green colour in the Tauá emeralds stems from the addition of vanadium. The authors' chemical analyses could not confirm this, and their work suggests rather that Cr and Fe are responsible for the colour (see section 3).

In a preliminary classification of emerald deposits (Schwarz, 1987), the Tauá occurrence was assigned to the 'classical' type of genesis, characterized by the association of mafic-ultramafic rocks and pegmatites (Be-supplier). As the Tauá pegmatites cannot be considered to be 'true' pegmatites containing light elements, but rather as mobilisations, i.e. anatectic pegmatites, the question as to the origin of the Be has still to be answered. The question of whether this deposit and other similarly-formed emerald mineralizations should be considered to be a sub-type of the classical emerald genesis, or rather as a specifically separate class of genesis, will only be resolved after further detailed studies are carried out.

The emerald is occasionally associated with unusually large (up to 15 cm), beautifully formed apatite prisms. These are dark green to bluish in colour and often so clear and free of inclusions as to make them of great interest to the gem cutter.

Apart from emerald, corundum has been observed in Unit III in three habits (Figure 3) (Korpershoek, 1984). Firstly, the mineral occurs as minute (<0.1 mm) xenomorphic grains of the blue variety of corundum – sapphire, which occurs as an accessory mineral in the tremolite-talc schist. Also, colourless to blue corundum crystals have been found in a contact metamorphic rock mainly composed of oligoclase (20-22% An). These corundums are characterized by a nearly right-angled parting of the rhombohedron $(10\overline{1}1)$. The third habit of the corundum is as colourless, prismatic crystals, originally up to 3 mm long, which have largely been replaced by sericite, and which occur together with black tourmaline in muscovite schists.

3. Optical and chemical data of the Tauá Emeralds

Optical data stemming from a number of authors

Table 1. Refractive indices and birefringences of the Tauá emeralds

n_e	n_o	$\triangle n$	Reference
1.580 ± 0.001	1.586 ± 0.001	0.006	Cassedanne & Mello (1979)
1.579	1.587	0.008	Branco *et al.* (1984)
1.579 − 1.582	1.585 − 1.589	0.006 − 0.008	Schwarz (1987)★
1.570 − 1.574	1.577 − 1.581	0.007 − 0.008	Schwarz (1987)★★

★Range of optical data in dark emeralds
★★Range of optical data in light emeralds

concerning the emeralds from Fazenda Boa Esperança are presented in Table 1.

The electron microprobe analyses (Table 2) were carried out with an ARL-SEMQ instrument, in which the WDS spectrometer was used in combination with an energy dispersive system (EDS, TN 2000) (Schwander and Gloor, 1980). The instrumental working conditions were 15kV accelerating voltage, 30mA beam current with a beam diameter of about 2 micrometres. The standards used for the analyses comprised synthetic oxides and simple silicate minerals.

The analyses were cationically normalized to Si = 6 atoms. Low Cr_2O_3 and V_2O_3-values (<0.25 wt.%) contrast with high values for FeO (0.91 − 1.17 wt.%), MgO (2.42 − 2.69 wt.%) and Na_2O (1.69 − 1.96 wt.%). The low Al contents are compensated by Mg and Fe^{2+} through the reactions:

(a) $Al^{3+,VI} = (Mg,Fe)^{2+} + Na^+$
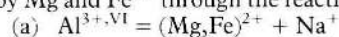
Cr, V and Fe (Figure 4) likewise compensate:

(b) $2Al^{3+,VI} = Fe^{3+,VI} + (Cr,V)^{3+,VI}$
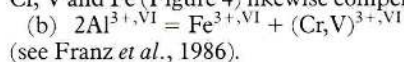
(see Franz *et al.*, 1986).

The calculations at the bottom of Table 2 show that principally substitution-type (a) occurs in the case of these emeralds, and differences in charge between Mg^{2+} and Fe^{2+} versus Al^{3+} are compensated by Na^+. Figure 4, exhibiting a gradient <1 shows a slight excess of (Mg+Fe) over Na. This can be explained by a small amount of Fe^{3+} which need not be compensated chargewise by Na^+. Probe analyses cannot indicate oxidation state nor position of the ions within the lattice and as the Fe can occur either as Fe^{2+} or Fe^{3+} in the octahedral or tetrahedral positions, a certain degree of uncertainty in the crystal chemical treatment of this element can occur. Figure 4 compares chemical plots between the Tauá and Itabira emeralds (Hänni, *et al.*, 1987). The Tauá samples are characterized by a larger

Table 2. Microprobe analyses of Tauá emeralds

SiO_2	66.92	67.13	65.99	63.16	63.76	63.75
Al_2O_3	15.83	15.57	14.84	14.66	14.93	14.84
Cr_2O_3	.10	.19	.06	.23	.10	.23
V_2O_3	.00	.00	.06	.00	.00	.00
FeO	.91	1.17	1.05	1.03	1.00	1.11
MgO	2.46	2.69	2.42	2.46	2.47	2.55
Na_2O	1.69	1.73	1.91	1.85	1.96	1.87
Total	87.91	88.48	86.33	83.39	84.22	84.35

Formula On the basis of 6 Si atoms

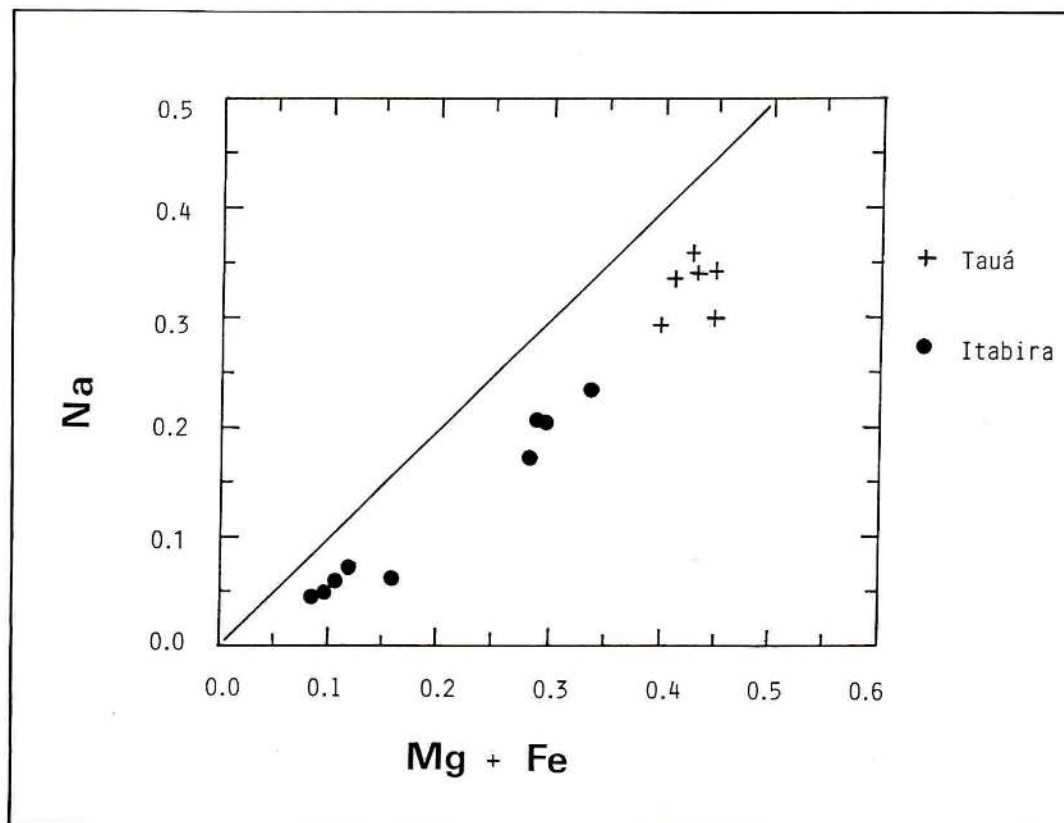|						
Si	6.000	6.000	6.000	6.000	6.000	6.000
Al	1.673	1.640	1.591	1.654	1.656	1.646
Cr	0.007	0.013	0.004	0.017	0.007	0.017
Fe^{2+}	0.068	0.087	0.080	0.081	0.079	0.088
Mg	0.329	0.358	0.328	0.348	0.346	0.358
Na	0.293	0.300	0.336	0.341	0.358	0.342
Σ	8.370	8.398	8.339	8.441	8.446	8.451

Total Fe calculated as FeO

Fig. 4.   Comparison between the relationship Na vs. (Mg+Fe)
in emeralds from Tauá and Itabira.

amount of Na, Mg and Fe, substituting for Al, than in the Itabira material.

4. Inclusions

The most conspicuous property exhibited by the Tauá emeralds is the presence of numerous mineral inclusions, which strikingly reflect the mineralogy and geology of the area at the time of the formation of the emerald. So far, the following mineral inclusions have been identified:

Biotite/phlogopite

The probe analyses in Table 3 show that the mica inclusions in the Tauá emeralds are phlogopite (Mg/Fe>2). Their distribution pattern in the host crystal as well as variations in habit and colour indicate the occurrence of two distinctively different genetic types; firstly, of protogenetic inclusions mainly of a dark brown colour with irregular or rounded shapes and which are irregularly distributed within the emerald (Figures 10, 11). In contrast to these, mica crystals of syngenetic origin are crystallographically oriented. These are in the

form of thin pseudohexagonal platelets lying either parallel to the basal plane of the emerald or parallel to the prism planes of the emerald, intersecting each other at angles of 60 and 120° (Figure 11). Their colour is usually a light brown.

Tremolite

The habit of the tremolite crystals varies from prismatic needles to thick stalks or 'bamboo-like' forms (Figures 5, 6). The crystals are colourless through weakly green to dark green, are randomly oriented throughout the emerald crystal, and sometimes form dense aggregates. These are typical protogenetic inclusions, and are often broken at one or both ends, or 'sharpened' to a pencil-like form (Figure 7). Table 3 gives two typical analyses. The chemical analyses of the amphiboles correspond to tremolite or tremolitic hornblende respectively.

Molybdenite

Although molybdenite (Figure 8) occurs in part as perfect although often warped (pseudo-) hexagonal platelets with a metallic lustre, partially

Table 3. Microprobe analyses of mineral inclusions in Tauá emeralds

	Phlogopite		Tremolite*	Allanite**
SiO_2	42.58	41.68	52.41 − 56.04	31.28
TiO_2	.32	.31	.00 − .12	.00
Al_2O_3	12.44	12.35	2.42 − 4.48	14.43
Cr_2O_3	.11	.17	.22 − .47	.00
V_2O_3	.00	.00	.00 − .03	.00
FeO	6.70	7.68	6.45 − 7.00	10.60
MnO	.04	.00	.12 − .40	.00
MgO	22.90	21.90	19.06 − 20.33	1.27
CaO	.04	.06	11.40 − 12.17	9.71
Na_2O	.63	.56	.63 − 1.17	.21
K_2O	8.74	8.68	.00 − .05	.13
F	~2.4	~2.7	.90 − 1.20	n.d.
Total	96.90	96.10		67.63

* Range encountered in 8 inclusions of tremolite; fluorine not quantitatively determined in all crystals.

** Partial analysis. Cerium was qualitatively determined; usually about 30 wt.% in allanites.

corroded crystals are more common and these then take on irregular 'ink stain' or skeletal forms (Figure 5).

Allanite (orthite)

Allanite appears both as zoned prismatic and thick 'stems' (stalks), and as fibrous columnar crystals with a dark brown colour, mainly arranged in sheaf-like aggregates (Figure 8). Table 3 presents a partial chemical analysis of an allanite crystal.

Apatite

Apatite forms colourless and transparent crystals, occurring mainly as short prisms.

Other mineral inclusions

One of the mineral inclusions could not be identified. This is a strongly orangeish-red coloured irregular crystal (Figures 5, 14).

The Tauá emeralds can contain numerous tremolite crystals (with very little or no mica), but can also be totally free of tremolite. This depends on the composition of the respective host rock of the emerald, i.e. whether the latter is mainly a biotite/phlogopite schist or a tremolite-bearing schist with phlogopite and chlorite.

In general, the Tauá emeralds produced nowadays are not of a high quality, mainly due to the large number of inclusions in them. Apart from the mineral inclusions described above, many minute particles exist which, in part, form dense clouds resulting in reduced transparency. These collections of minute liquid droplets and/or mineral dust are more or less evenly distributed throughout the emerald (Figure 12).

Shallow cavities (mainly containing a single phase) and numerous cracks add to the general opacity (Figure 13).

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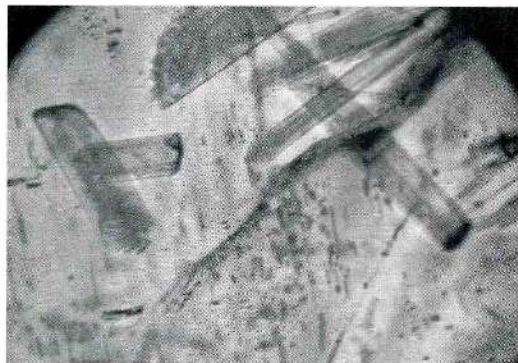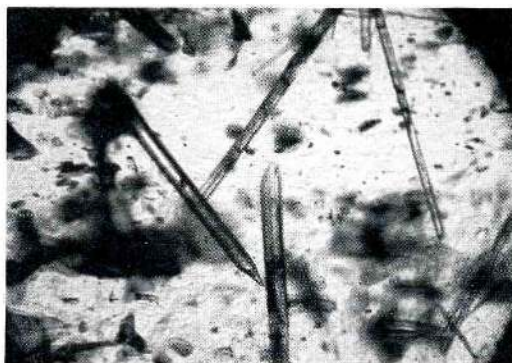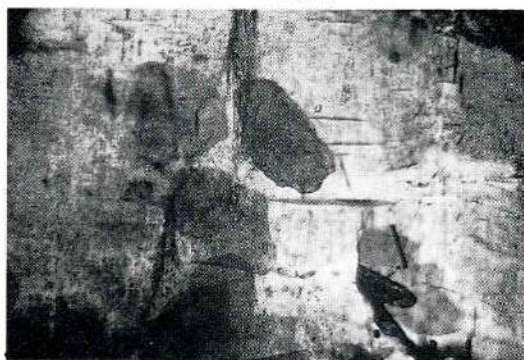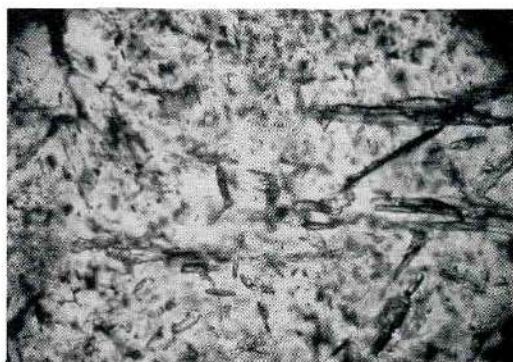
Fig. 7a

Fig. 7b

Fig. 10

Fig. 12

Fig. 13

Fig. 5.   Tauá emeralds with numerous protogenetic mineral inclusions. Apart from columnar-prismatic or bamboo-like tremolite crystals with a light- to dark-green colour, brownish, mainly rounded, micas and opaque molybdenite can be seen. The latter mineral is usually strongly corroded when it then forms ink-spot or skeletal textures. On the left of the figure, a strongly orange-red unidentified crystal can be seen. 35x.

Fig. 6.   Prismatic crystal of tremolite with a dark green colour, at one end intergrown with molybdenite. 50x.

Fig. 7a. Protogenetic crystal of tremolite. These are broken at one or both ends, indicating the effects of mechanical influences (transport, tectonic movements) prior to inclusion in the emerald. A further indication of the

protogenetic origin of these crystals is supplied by the totally random orientation to that of the host crystal. 50x.

Fig. 7b. Pencil-shaped protogenetic tremolite crystals, randomly oriented within the emerald. 50x.

Fig. 8.   Perfectly formed, (pseudo-) hexagonal platelet of molybdenite (black, opaque) with dark brown columnar crystals of allanite, which usually occurs in sheaf-like aggregates. 70x.

Fig. 9.   Association of mineral inclusions in a Tauá emerald shown in polarized light (crossed nicols): columnar-prismatic tremolite crystals next to mica platelets and opaque molybdenite. 35x.
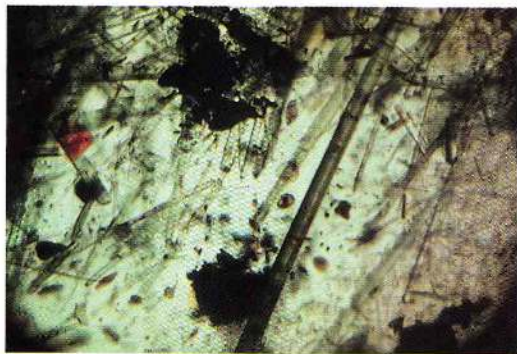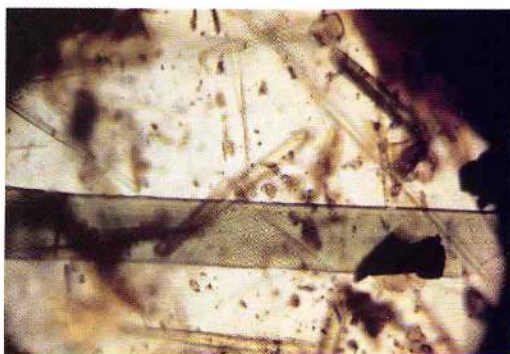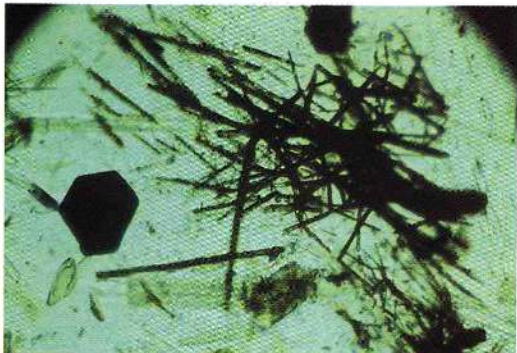
Fig. 5

Fig. 6

Fig. 8

Fig. 9

Fig. 11

Fig. 14

Fig. 10. Protogenetic dark brown mica inclusion (phlogopite). The crystals are irregularly bordered and randomly oriented in the emerald. 50x.

Fig. 11. This Tauá emerald contains numerous mica crystals which can be classified into two genetic types:
a) mica crystals with a protogenetic origin, and which are characterized by their usually dark colour and irregular forms. They are randomly oriented in the emerald host crystal;
b) syngenetic mica crystals are transparent, light brown platelets usually with a definite pseudo-hexagonal outline. They lie either parallel to the basal plane of the emerald, or parallel to the prism face of the emerald (the crystals appear as dark streaks in the Figure, which intersect at angles of 60 and 120°).

Fig. 12. Numerous minute particles (liquid droplets and/or mineral dust), the large number of which lead to a distinct reduction in the transparency and therefore the gemmological quality of the Tauá emeralds. 50x.

Fig. 13. The reduction of transparency in the emeralds can be caused by the numerous shallow cavities, which often contain a single-phase filling (liquid or gas). 70x.

Fig. 14. Strongly orange-red unidentified crystals on the left/right border of the photograph. 70x.

Note: All photographs were taken using immersion liquids.

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