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GEOLOGY

Gemology of Emeralds from Tauá, Brazil

Gemologia das Esmeraldas de Tauá, Brasil

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Abstract

In Brazilian territory many occurrences do not have their gemological and optical properties documented or made public. This research aimed to analyze the mineralogical and gemological aspects of emeralds from the city of Tauá (Brazil), utilizing gemological instruments such as a refractometer, dichroscope, spectroscope, polariscope, hydrostatic balance, ultraviolet lamp, and gemological microscope. The examined emeralds exhibit typical features found in emeralds worldwide, except for an above-average birefringence, similar to certain beryls from the state of Ceará. This highlights the significance of gemological characterization not only at the regional levels but also on a localized scale. Additionally, studying occurrences in varied geological settings is essential, as the formation environment influences mineral properties.

Keywords: Gemological beryl; Geochemical characteristics; Ceará gems

Resumo

No território brasileiro muitas ocorrências não têm suas propriedades gemológicas e óticas documentadas ou tornadas públicas. Esta pesquisa teve como objetivo analisar os aspectos mineralógicos e gemológicos de esmeraldas da cidade de Tauá (Brasil), utilizando os seguintes instrumentos gemológicos como refratômetro, dicroscópio, espectroscópio, polariscópio, balança hidrostática, lâmpada ultravioleta e microscópio gemológico. As esmeraldas examinadas exibem características típicas encontradas em esmeraldas em todo o mundo, exceto por uma birrefringência acima da média, semelhante a outros berilos do estado do Ceará. Isso destaca a importância da caracterização gemológica não apenas a nível regional, mas também em uma escala local. Além disso, estudar ocorrências em cenários geológicos variados é essencial, pois o ambiente de formação influencia as propriedades minerais.

Palavras-chave: Berilo gemológico; Características geoquímicas; Gemas do Ceará

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1 Introduction

On a global level, research on gems is ongoing, with gemological studies constantly being updated. Moreover, the properties of minerals utilized as gemstones can provide insights or even uncover new aspects of the geological history of the regions where they are found. In Brazil, there is a considerable gap in this area; numerous mineral occurrences lack detailed studies or tabulated gemological and optical properties, even in locations with historically significant production. Although Brazil is a major gem-producing region, much remains unknown about the gemological characteristics of its minerals, even in areas that have previously been important sources of gems (Terra 2020).

Emerald, a variety of beryl, is a green mineral commonly used as a gemstone and is the most prized member of the beryl group, ranking as the fifth most valuable gem in the market. Beryl is an aluminum and beryllium silicate that crystallizes in the hexagonal system, with the general formula $Be_3Al_2Si_6O_{18}$. Emerald's green coloration results from trace amounts of Cr_2O_3 (typically around 0.3%), which weakens the mineral's structure. Since 1963, V_2O_5 has also been recognized as a chromophore element following the discovery of new deposits (Arem & Clark 2023). Although beryl is generally defined as $Be_3Al_2Si_6O_{18}$, it can incorporate small amounts of alkalis (Deer et al. 2010). The most significant emerald deposits are found in Colombia, while Brazil—one of the world's leading suppliers—hosts numerous occurrences, primarily in the states of Bahia, Goiás, and Minas Gerais (Schumann 2020).

Given the abundance of emeralds in Brazil, various studies have examined their distinct properties and host rocks, as analyzed by Araújo Neto et al. (2019), Araújo Neto et al. (2021), Bergmann et al. (2017), Biondi (1990), Brod & Blaskowski (2021), Duarte et al. (2003), Jordt-Evangelista et al. (2016), Giuliani et al. (2019), Lynch et al. (2014), Ollier et al. (2015), Pulz et al. (1998, 2000), Saeseaw et al. (2019), Santiago (2018), Santiago et al. (2018, 2019), Scholz et al. (2010), Schwarz (1987, 2001), Souza et al. (2012), and Zwaan et al. (2012).

This study focused on the mineralogical and gemological attributes of five emerald crystals from the municipality of Tauá, in the state of Ceará, Brazil, which geologically belongs to the Pedra Branca Unit. The properties of these specimens were compared with general global data as part of the identification process, a standard procedure for gemological materials. Additionally, their gemological, optical, and geochemical characteristics were analyzed in relation to other Brazilian emeralds (Schwarz 1987). It is important to highlight that gemological characterization plays a crucial role in forensic and investigative contexts, assisting in the detection of fraud and imitations (IBGM 2009). Moreover, it serves to determine potential sources of the mineral for commercial assessment, directly impacting its market value. In Brazil, beyond these applications, this type of study holds significant relevance, as Article 655 of the Brazilian Civil Code (Law n° 10.406, 2002) stipulates that banks and government institutions can accept gemstones as collateral in cases where a debt is legally enforced (Brazil 2002). In the country, the most used gemstones to settle debts in judiciary are diamond, ruby, sapphire and emerald.

2 Geological Context

The Tauá region is inserted in the southern portion of the Ceará Central Domain, at the Borborema Province. The occurrence of emeralds at Tauá (former Fazenda Boa Esperança) was discovered in 1954 and has been exploited sporadically since then, with mining activities paralyzed since 1973. According to Schwarz (1987) and references therein, the Tauá emerald is geologically inserted in the Pedra Branca Unit (current Cruzeta Complex, Pinéo et al. 2020), an Archean unit reworked during the Brasiliano Orogeny.

The deposit area is localized in a series of high-grade metamorphic rocks, predominantly gneisses and migmatites (Cassedanne et al. 1979; Castelo Branco et al. 1984). Locally, ultramafic rocks (altered to talc schists, phlogopite-tremolite schists, talc-tremolite schists and tremolithites), metabasites (amphibolites and hornblende gneisses), biotite gneisses and biotite-emerald schists may occur (Cassedanne 1984), in addition to pegmatitic and aplitic lenses (Cassedanne et al. 1979).

Pegmatitic lenses occur as homogeneous elongated and irregular pegmatitic bodies or as concordant intrusions, with coarse- to fine-grained (aplytes, in the sectors affected by tectonic deformation), composed essentially of quartz, albite and apatite (Cassedanne et al. 1979). These pegmatites were likely locally mobilized during the regional metamorphism, through partial melting, when pressure and temperature rise notably. This led to a partial anatexis and to the formation of Na-rich pegmatites (Korpershoek 1983).

Locally, pegmatite bodies may contain beryl, columbite-tantalite, tourmaline, apatite, molybdenite and bismuthite crystals (Cassedanne 1979, 1984). Emeralds are usually found in the contact between the pegmatitic bodies and the schist, and more rarely, inside the pegmatite intrusions Schwarz (1987). The emerald-bearing biotite schists (or tremolitic schists with phlogopite and chlorite) neighboring the anatectic pegmatites are products of a metasomatic process between the pegmatites and the basic or ultrabasic rocks (Schwarz et al., 1988).

According to the classification of Brazilian emerald deposits by Giuliani et al. (2019), the emerald occurrence at Tauá is assigned to the classical type of genesis (Type I), due to the association with pegmatites.

3 Material and Methods

In this research, five emeralds (Figure 1) from the municipality of Tauá (Ceará) were randomly selected from several commercial specimens, thus representing a representative sample from the region. The samples were obtained in a raw state and, later, were cut into different formats. Additionally, a color table used by the trade that has 384 colors (Color Code: Infographic of color codes in HTML, 2013) was used to classify the color of the gems.

The research method applied for the gemological characterization performed in the gems of Tauá (Ceará), which included the use of classic instruments of gemological analysis, being applied the use of refractometer, polariscope, hydrostatic balance, dichroscope, ultraviolet lamp, spectroscope and gemological microscope. For the mineralogy of the samples, visual observations, and the hardness of the remaining fragments of the cut of the five gems were used, in addition to the geochemistry of the emeralds studied.

3.1 Refractometer

It was used a Rayner Dialdex refractometer with attached light source (monochromatic filter included) to determine the birefringence, character and optical signal of the investigated gems. Furthermore, a quartz (rock crystal) with known refractive indices and birefringence was used to test the calibration of the refractometer. We made six readings to guarantee maximum precision according the procedure described by Anderson (Anderson 1984).

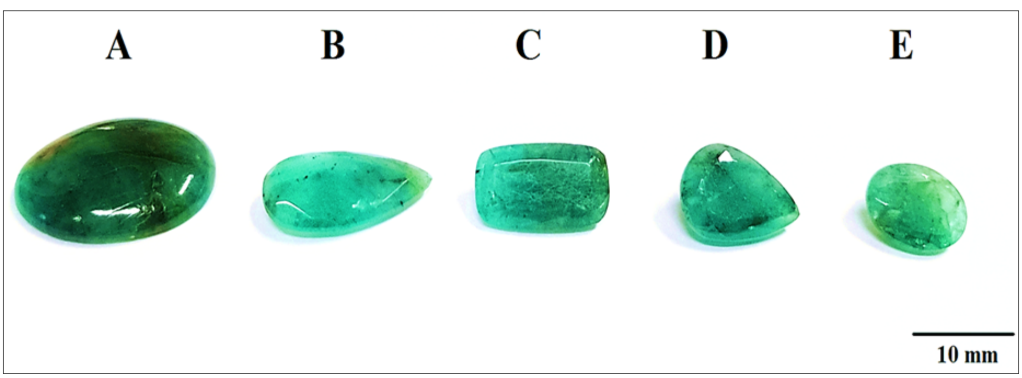

Figure 1 Emeralds studied from Tauá region, Brazil: A. Gemstone (Dark Green), dimensions: 18.00 x 13.28 x 3.70 mm; B. Gemstone (Medium Sea Green), dimensions: 15.47 x 7.87 x 3.03 mm; C. Gemstone (Spring Green 4), dimensions: 12.21 x 7.13 x 4.36 mm; D. Gemstone (Sea Green), dimensions: 11.32 x 7.79 x 4.66 mm; E. Gemstone (Forest Green), dimensions: 9.31 x 7.20 x 3.85 mm.

3.2 Polariscope

It was used a GIA polariscope with a coupled light source. This instrument allows to identify whether the analyzed material is anisotropic or isotropic. The instrument consists of two polarizing plates, called polarizer sets (Hurlbut & Switzer 1979). The method consists of leaving the polarization plates perpendicular to each other and rotating the mineral, placed between the plates.

3.3 Hydrostatic Balance

Two scales were used, one hydrostatic (Marte AD5002) and the other analytical (AND HR200) to ensure maximum precision in the density of the garnets. Relative density is a property independent of the location and size of the analyzed samples. It is defined as weight per volume, represented in g/cm3 or kg/m3 (Schumann 2020).

3.4 Dichroscope

It was determined the pleochroism of the gems using a dichroscope. To measure it, we employed a portable dichroscope from GIA (Gemological Institute of America). Pleochroism is caused by the distinct absorption of light in birefringent crystals, which can be strong, moderate, or weak. This phenomenon does not occur in isotropic, amorphous, and opaque gems, not in most translucent ones (Schumann 2020).

3.5 Spectroscope

A portable spectroscope from GIA (Gemological Institute of America) without a coupled light source to determine the absorption bands of the samples, it was used an artificial luminosity. In a very similar way to the dichroscope, the material is analyzed through the spectroscope, requiring moderate luminosity (artificial or natural) (Schumann 2020).

3.6 Ultraviolet Light Lamp

It was used an ultraviolet light lamp from GIA (Gemological Institute of America) to test the fluorescence of the garnets. Fluorescence is a very important method for the identification of gems since it is caused by the presence of unusual activating chemical elements in the mineral's crystalline structure (Schumann 2020).

3.7 Gemological Microscope

It was used a Meiji EMZ 75339 gemological binocular microscope with a coupled light source was used with defined magnification objectives (0.7X, 1X, 1.5X, 2X, 2.5X, 3X, 3 .5X, 4X 4.5X), 16X magnification eyepieces; samples were analyzed using a light background. This equipment allows immediate reading of the various types of color zoning, solid inclusions, fractures in the crystal structure (healed fractures), spots and crystal changes (fingerprints) and acicular inclusions (silk inclusions) (Anderson 1984; Hughes 2017; Oliveira 1967).

4 Results and Discussions

Through comparison with the commercial color table, it was determined that the emeralds crystals from the municipality of Tauá (Ceará, Brazil) have the color Green 1 (Sea Green - result of the combination of the hue, saturation and shade) that it's considered good; the other four samples (Dark Green, Medium Sea Green, Spring Green 4 and Forest Green) have colors judged medium by the trade (Arem & Clark 2023). There are no details about the color quality of the Tauá emeralds in the research of Schwarz (1987).

Gemologically/Optical and mineralogical data acquired was compared with the base of worldwide data from the International Gem Society (IGS) (Arem & Clark 2022) and in several works of great recognition and worldwide credibility, works from 1971 to 2020 (Anderson 1984; Bonewitz 2013;; Hurlbut & Switzer 1979; IBGM/DNPM 2009; Nassau 1980, 2020, Webster 1981).

For the optical characterization of these minerals, the refractometer was the first and principal step, proving that the studied emeralds are negative uniaxial. The values of No in the analyzed gems are always greater than the values of Ne, which is why their optical signal is negative in minerals of type negative uniaxial value of No greater than Ne. The refractive indices of the analyzed emeralds varied subtly between 1.579 (Spring Green 4) and 1.583 (Medium Sea Green and Forest Green) for No, and between 1.566 (Spring Green 4 sample) and 1.571 (Forest Green sample) for Ne.

The values of Tauá emeralds from this study are relatively different to the indices of emeralds by Schwarz (1987) from minerals of the same region, the values have a large variable, between 1.577 and 1.589 for No, and between 1.570 and 1.582 for Ne. Some Ne values (1.566 and 1.569) in this study are not within the variability of the Schwarz data. Geographically, emeralds from Bahia are closer to emeralds from Tauá than other Brazilian occurrences. The five sites of Socotó, Carnaíba, Salininha, Açude Sossego and Bom Jesus dos Meiras show a high variability in the refractive indices of their emeralds, ranging from between 1.573 to 1.590 for No and from 1.566 and 1.586 for Ne (Schwarz 1987); none of the regions have values similar to those of Tauá, except for the region of Bom Jesus dos Meiras, which has values close to those of this study. The refractive index of this studied emerald is 1.566-1.602, the character and optical sign is uniaxial negative (Anderson 1984; Arem & Clark 2023; Bonewitz 2013; IBGM/DNPM 2009; Schumann 2020).

Emeralds have a double refraction (birefringence) between 0.004 and 0.006 (Arem & Clark 2023; Hurlbut & Switzer 1979; Nassau 1980; Schumann 2020; Webster 1981); the values of the analyzed gems of the Tauá are always above to 0.005, with values ranging from 0.006 and 0.010; amethysts from the municipality of Santa Quitéria (Ceará) (Oliveira et al. 2020) and aquamarines (Oliveira et al. 2024) from Quixeramobim (Ceará) also have above average birefringence.

Anomalous birefringence in gems may occur due to a possible deformation in the crystalline lattice, which can interfere with the speed of ray routing, of ordinary (No) and extraordinary (Ne) of crystals, modifying and increasing in this way the double refraction (birefringence) without necessarily compromising the gemological quality. While the gems in this study have an above average double refraction; the emeralds from Schwarz (1987) have a birefringence within the average of 0.006 to 0.008 (Shcwarz 1987).

Using a polariscope, it was also possible to conclude infer that emeralds analyzed are anisotropic, which was expected, since they are birefringent and crystallize in the hexagonal system (Arem & Clark 2023; Deer et al. 2010; IBGM 2009; Schumann 2020).

The pleochroism or dichroism, which is analyzed with the dichroscope showed the presence of a low intensity dichroism in all samples, which is a common feature in emerald. The smaller the compensation (difference) between the rays (in this case, Ne and No) that are vibrating perpendicularly inside the mineral, the smaller the observed absorption (pleochroism). Emerald pleochroism is generally weak or moderate (Arem & Clark 2023; IBGM 2009; Schumann 2020). There are no data available for this property from Schwarz (1987) on emeralds from Tauá.

The absorption spectrum recorded by the spectroscope is very close to the standard characteristic of emeralds; the values obtained in common for this mineral species are 680, 620, 580 and 470 nm (Arem & Clark 2023; Schumann 2020). The values commonly obtained for the samples studied were of the order of 680, 585 and 470 nm for all gems. There are no data available for this characteristic from Schwarz (1987) on emeralds from Tauá.

All the five gems analyzed using the incidence of ultraviolet light did not show fluorescence. This data indicates that the specimens do not contain fluorescence or phosphorescence activating elements, such as Cr2O3 and rare earth elements (REE), such as lanthanum, cerium, samarium, europium, thulium, terbium and dysprosium. The REE, when in the presence of a UV lamp, is energized and jumps to the next layer of its valence, returning after a period of time and repeating this cycle as long as the exposure to the UV light lasts; when energized and returning to its normal and stable valence layer, the element releases the accumulated energy in the form of light. The luminescence of emeralds is distinctive and can help positively identify an emerald; natural untreated emeralds are usually inert and rarely weak (color red or orange red), emeralds with oil have a medium fluorescence (yellow green) (Anderson 1984; Arem & Clark 2023; Bonewitz 2013; IBGM/DNPM 2009; Schumann 2020). There is no data available for this characteristic by Schwarz (1987) from emeralds of Tauá.

The emeralds studied have a wide variability in density and no a single value for all samples, with the lowest values ranging from 2.73 g cm³ (Dark Green) to 2.88g cm³(Medium Sea Green). Using the use of the hydrostatic balance, the results were obtained within the expected range and show a pattern. The gems tending to blue, Medium Sea Green and Spring Green 4, have the highest densities, 2.88 and 2.85 g cm3 respectively. While the emeralds that do not tend to blue, Dark Green (2.73 g cm³), Sea Green (2.79 g cm³) and Forest Green (2.77 g cm³) have the lowest relative densities. This can be explained by the composition of these gems having denser amounts of elements in their chemical composition. The emeralds density varies from 2.68 to 2.78 g cm³ (Arem & Clark 2022; Schumann 2020). The Tauá emeralds studied by Schwarz (1987) have a relative density between 2.65 and 2.69 g cm³; having constancy in this characteristic. Moreover, the values are quite different from those obtained in this study (2.73-2.88 g cm³).

The diaphaneity analysis of the specimens took place through the visualization of an object, pen tip, through the emeralds. The image has a well-defined outline and sharpness in transparent samples. Therefore, this data was compiled in one table (Table 1), as part of the characterization of the minerals. The results of gemological data from the Tauá emeralds (CE, Brazil) obtained in this research are all available in Table 1.

All five samples studied have a vitreous luster. Using the remaining cut fragments, the hardness of the samples was obtained on the Mohs scale, the emeralds analyzed have hardness 8. Emeralds on a global scale have vitreous luster, this green beryl has hardness ranging from 7.5 to 8 (Anderson 1984; Arem & Clark 2023; Bonewitz 2013; IBGM/DNPM 2009; Schumann 2020).

Table 1 Gemological/optical and mineralogical characteristics of emeralds from Tauá, Brazil.

Sample	Properties						
	Diaphaneity and Hardness (Mohs)	**Refractive index; Character and Optical Signal; birefringence**	**Pleochroism**	**Absorption Spectrum / nm**	**Fluorescence**	**Relative Density / g cm⁻³**	**Inclusions and internal aspects**
Dark Green	Semi-translucent 8	1.580 – 1,572; Uni (-) 0.006	Present: Weak	680; 585; 470	Absent	2.73	Fractures; solid inclusions, isolated and grouped; color center.
Medium Sea Green	Semi-transparent 8	1.583 – 1.571; Uni (-) 0.010	Present: Weak	680; 585; 470	Absent	2.88	Fractures; solid inclusions, isolated and grouped; color centers; liquid-filled fractures.
Spring Green 4	Semi-transparent 8	1.579 – 1.568; Uni (-) 0.009	Present: Weak	680; 585; 470	Absent	2.85	Fractures; solid inclusions, isolated and grouped; color centers; liquid-filled fractures; color bands
Sea Green	Translucent 8	1.581 – 1.571; Uni (-) 0.008	Present: Weak	680; 585; 470	Absent	2.79	Fractures; solid inclusions, isolated and grouped; color centers; filled fractures; oriented (sometimes) fluid inclusions.
Forest Green	Semi-transparent 8	1.583 – 1.573; Uni (-) 0.008	Present: Weak	680; 585; 470	Absent	2.77	Fractures; solid inclusions; filled fractures; filled and hollow growth tubes; fluid inclusions perpendicular to the fracture.

In the gemological microscope, the five studied emeralds are characterized by fractures, fluid and solid inclusions, so that these features help, when necessary, in cases of mineral origin. In the Dark Green sample, several solid inclusions were found, these are presented individually and are sometimes grouped (without orientation); fractures and a color center (Figure 2A) was also found. The gem that comes closest to the blue-to-blue color, Medium Sea Green, has the same features as the Dark Green specimen: fractures, solid inclusions (isolated and grouped without orientation) and color centers; however, liquid-filled fractures were visualized. The Spring Green 4 emerald presents all the internal aspects mentioned in the Medium Sea Green sample, however, a small and only one occurrence of color bands (Figure 2B) were identified. The Sea Green specimen presents several types of internal aspects, such as: fractures, solid inclusions (isolated and grouped without orientation), filled fractures and fluid inclusions. These fluids are mostly grouped (Figure 2C) and have a slight orientation at times, almost no ungrouped fluid was found. The Forest Green emerald has fractures, solid inclusions (without orientation) amid some fluid inclusions (Figure 2D), filled fractures, filled and hollow growth tubes and rare fluid inclusions perpendicular to the fracture.

The fluid inclusions present show that during geological events with decreased intensity in activities (cooling and crystallization), some remaining fluids containing volatiles were retained in the structure of emeralds, a common phenomenon in beryls. Depending on their concentration, organization and distribution along the crystal, it allows them to be classified into syngenetic (during the mineral's growth) and epigenetic (after the specimen's formation) (Hughes 2017).

5 Conclusions

The five gems studied are uniaxial negative and have oscillating refractive indices ranging from 1.568 (N_e) to 1.583 (N_o). The birefringence of all minerals is above 0.005, with values reaching 0.010. The pleochroism is present and classified as weak in all samples. The captured absorption spectra are in the order of 680, 585 and 470 nm. All the five gems do not have fluorescence. The emeralds from Tauá have an oscillating relative density, ranging from 2.73 to 2.88 g cm³. Microscopically, the minerals in the region have solid and fluid inclusions were visualized; color bands; color centers; filled fractures; oriented fluid inclusions hollow tubes; and fractures. All these characteristics above are standard for the emeralds in different parts of the world, except for the birefringence well above the average.

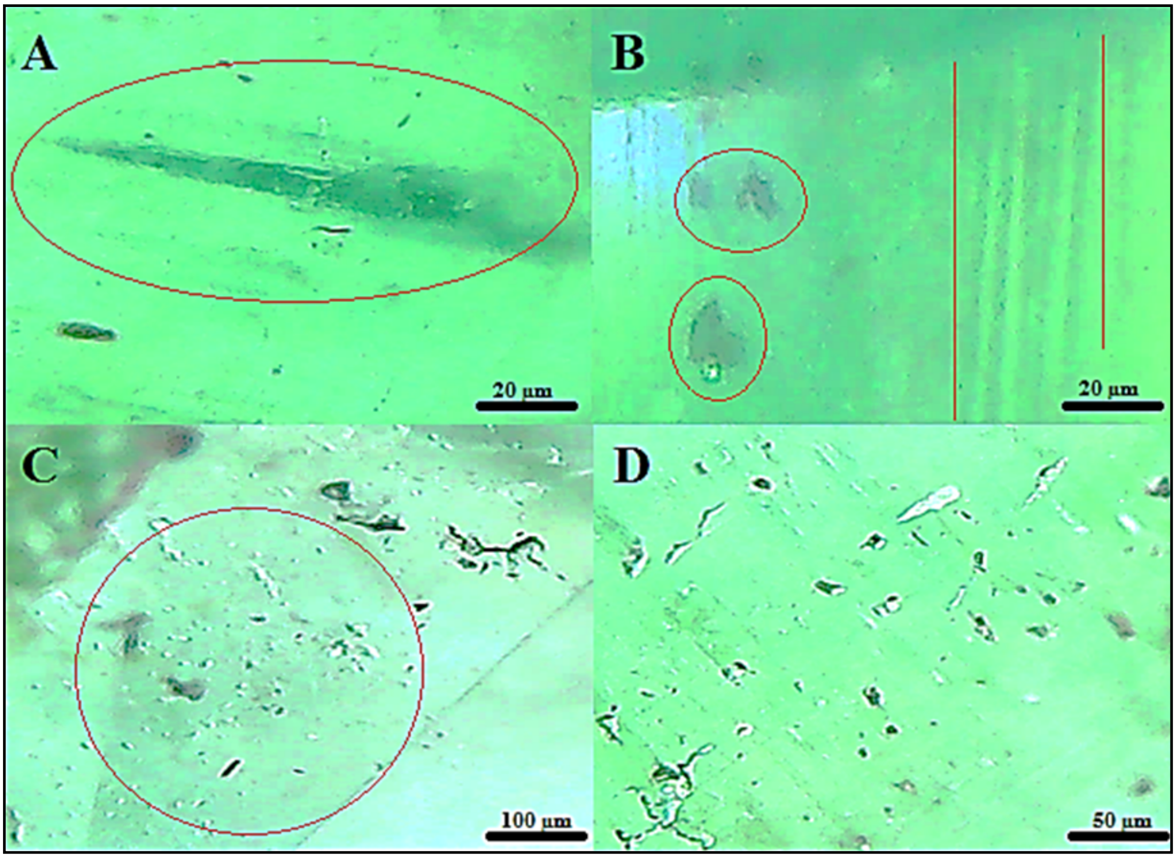

Figure 2 Transmitted light micrograph of inclusions in emeralds from the Tauá-CE, Brazil. Due to the low visibility of the emeralds, which was caused by the low diaphaneity. It was difficult to obtain good photographs of the internal aspects. Aspects indicated in red: A. Color center present in the Dark Green gem; B. Color banding and some solid inclusions in the Medium Sea Green sample; C. Grouped and unoriented fluid inclusions in the Sea Green emerald; D. Solid inclusions amidst some fluid inclusions in the Forest Green gem.

Therefore, it is important to characterize the occurrences in different geological contexts, as the formation environment directly interferes in the characteristics of the minerals. Due to the importance of emeralds, future studies will explore their crystallography, mineral chemistry, spectroscopy, and even magnetic properties.

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Author contributions

Issac Gomes de Oliveira: writing - original draft; funding acquisition; investigation; methodology; project administration; visualization; validation. **Laryssa de Sousa Carneiro:** contextualization. **Alina de Oliveira Ribeiro:** review; editing. **Conceição Regina Fernandes Alves:** review; editing. **Gabriel Czar dos Santos:** review; editing. **Lee Andrew Groat:** supervision; validation. **Lucilene dos Santos:** supervision; validation. **Carlos William de Araújo Paschoal:** supervision; validation. **Tereza Falcão de Oliveira Neri:** supervision; validation.

Conflict of interest

The authors declare no conflict of interest.

Data availability statement

All data included in this study are publicly available in the literature.

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