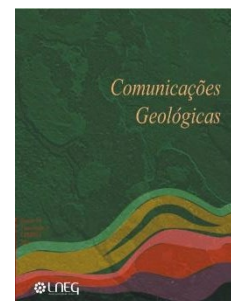


# Gemological analysis of ruby origins: a case study

## Análise gemológica das origens do rubi: um estudo de caso



I. Gomes de Oliveira<sup>1</sup>, J. Sousa Cardoso<sup>1</sup>, J. Coutinho Franco<sup>1</sup>, B. Ravielly dos Santos<sup>1\*</sup>,  
S. Andrade da Silva<sup>1</sup>, L. dos Santos<sup>1</sup>, I. Clezar Mattos<sup>1</sup>, T. Falcão de Oliveira Neri<sup>1</sup>

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**Abstract:** Gemstones are substances of natural, artificial or synthetic origin, which due to their hardness, rarity, uniqueness, diaphaneity and beauty are used as adornments. In the market, ruby is the second most expensive type of gemstone. Depending on its size, it can exceed the value of the diamond, besides being the most valuable colored gem in the market. It is a variety of the mineral corundum, just like sapphire, and it is a form of crystallized alumina ( $Al_2O_3$ ) and the responsible for its red color is chromium. There are deposits in many different places around the world, being common the practice of speculating the origin of the ruby based on the shade of red. Provenance strongly impacts the commercial value of the gem. Several faceted rubies were donated to the Federal University of Ceará. This project aims to discover from what regions (countries) the donated rubies are coming, using gemological characteristics. To establish the origin of the specimen collection, the following methods and equipment were used: bibliographic research about rubies characteristics, refractometer to measure refractive indexes, dichroscope for pleochroism analysis, ultraviolet lamp (UV) for determination of fluorescence, and especially the gemological (stereoscopic) microscope to study the types of inclusions in transparent to translucent rubies. Using the methods cited, it was possible to produce, successfully, the gemological characterization of the specimens and deduce, based on strong evidence, what was the geographic origin of the studied specimens. Through microscopy it was deduced that all the faceted stones are natural and the whole collection include stones from the following countries: Burma, Thailand, Pakistan, Sri Lanka and Tanzania. Results are gathered systematizing bibliographic data and analytical results in order to identify the country of origin of the rubies.

**Keywords:** Ruby, gemology, countries, optical properties, federal police.

**Resumo:** Gemas são substâncias de origem natural, sintética ou artificial que devido a sua dureza, raridade, singularidade, diáfaneidade e beleza são utilizadas como adorno. No mercado, o rubi é a segunda espécie de gema mais cara. Em idêntico tamanho pode superar o valor do diamante, além de ser a gema corada mais valiosa para o mercado. Trata-se de uma variedade do mineral corindo. Tal como a safira, é simplesmente alumina ( $Al_2O_3$ ) cristalizada no sistema trigonal e o elemento cromóforo invocado

para a aquisição da sua cor vermelha é o crómio. Existem jazidas em diferentes lugares do mundo, sendo comum a prática de especular sobre a procedência dos rubis com base na tonalidade de vermelho que ostentam. A proveniência influencia o valor comercial da gema. Este estudo visa estabelecer a origem geográfica dos rubis lapidados doados à Universidade Federal do Ceará, utilizando informação bibliográfica e características gemológicas dos diferentes espécimes. Para estabelecer a procedência dos exemplares foram utilizados: bibliografia referente às características dos rubis e equipamentos de análise tais como, refratômetro para leitura do índice de refração, dicróscópio para análise do pleocroísmo, luz ultravioleta (UV) para estudo da fluorescência e principalmente o microscópio gemológico para estudo dos tipos de inclusões nos rubis. Utilizando os métodos citados, sistematizou-se a caracterização gemológica dos exemplares, procurando deduzir a sua procedência geográfica. Com base na análise microscópica concluiu-se que todos os exemplares são naturais e que a coleção inclui exemplares oriundos dos seguintes países: Birmânia, Paquistão, Sri Lanka, Tailândia e Tanzânia. Em síntese final, numa tabela reúnem-se dados bibliográficos e resultados analíticos relativos às amostras estudadas. Essa tabela também identifica os países de onde provêm os rubis.

**Palavras-chave:** Rubi, gemologia, países, propriedades óticas, polícia federal.

<sup>1</sup> Universidade Federal do Ceará, Av. da Universidade, 2853 - Benfica, Fortaleza, Brasil.

\* Corresponding author / Autor correspondente: [breno.ravielly@hotmail.com](mailto:breno.ravielly@hotmail.com)

### 1. Introduction

Gems have been used as adornments from the height of great ancient empires to the present day. In addition to generating tens of billions of dollars in trade annually, the ruby is present in society in other ways. Whether in popular culture or in the jewelry of monarchies or famous jewel brands. With such commercial and social impact, various fraud attempts and scams related to rubies

are recurrent and very common due to the high commercial value involved. In Brazil, the precious stones most used to settle debts in the judiciary are Diamond, Ruby, Sapphire and Emerald. Although Asia has historically been the largest producer of ruby gemstones, there are many other sources, including the United States, Australia and, more recently, Africa. The origin definitely affects the value of rubies (Smigel *et al.*, 2021). Gemological characterization is used to identify the origin of the mineral (directly interfering in its commercial value), as gems from specific countries are rarer and more valued in trade, such as ruby from Burma, sapphire from India or Burma, and emerald from Colombia (Groat *et al.*, 2019; Palke *et al.*, 2019; DNPM/IBGM, 2009; IBGM/DNPM, 2009) and also for forensic and criminal investigation cases.

The ruby, the second most valued gem on the market, has characteristics that vary according to the source – region or country. The color generally varies according to the deposit; however, the place of origin cannot be deduced from this fact, as different shades may occur within the same deposit. Therefore, the “Burma ruby” denomination is much more about the quality than the color of the gem. The most popular color is pure red with a small shade of blue called “pigeon’s blood”. Non-gemological corundum is abundant throughout the world, but the material used as a gem has a restricted occurrence. It is known to occur in at least 15 countries. Only 1% of ruby production is suitable for jewelry; among this, specimens from Burma are more commercially valued than those from the other 14 countries (Hurlbut, 1979; Smigel *et al.*, 2021; Schumann, 2020). A ruby weighing 5 carats (1 gram) of excellent quality that isn’t Burmese, costs an average of 57 thousand dollars. While a ruby in the same conditions, mentioned to come from Burma, can achieve a value of 126 thousand dollars. The characteristics of rubies from other producing countries are often neglected, with only the gems from Burma receiving higher attention. As so, there is a critical need to identify the provenance through some properties which are diagnostic of the source. For example, it is known that Burmese rubies are richer in vanadium (Sutherland *et al.*, 2015).

Ruby is a variety of the mineral corundum; just like sapphire, it is simply alumina ( $\text{Al}_2\text{O}_3$ ) crystallized in the trigonal system, and the element responsible for its red hue is chromium. Corundum crystals of other colors are classified as sapphires; and  $\text{Fe}^{2+}$ ,  $\text{Fe}^{3+}$ , and  $\text{Ti}^{4+}$  ionic interactions are the chromophoric agents of sapphires (Zaw *et al.*, 2015). These gemstones can also show zoning and color centers due to fluctuations in chromium content (Sutherland *et al.*, 2017). The optical/gemological properties are well known, which allows the ruby to be identified easily. Inclusions are very frequent, but this does not necessarily mean a decrease in quality and may prove the legitimacy of natural rubies, as opposed to synthetic gems. The type of inclusion often indicates the original deposit of the stone. The inclusion of rutile needles may produce a silky appearance or a cat’s-eye effect in some stones cut as cabochons. There is also the highly valued asterism, resulting from a set of inclusions, organized like a star with a variable number of points. This star appears to move over the surface of the gem as it grows (Nassau, 1990; Smigel *et al.*, 2021). Many gemological corundum deposits result from metasomatic processes. Small-scale metasomatism mainly involves desilication reactions between silico-aluminous melts and rocks (pegmatites, gneisses, etc.) and silica-poor rocks (ultramafics and meta-carbonate rocks), and leads to the formation of deposits of limited size (Simonet *et al.*, 2008).

In Brazil, corundum occurs in Quaternary colluvial deposits, concentrated on the flanks of local hills (colluvial ramps), also

distributed in the regional plains. The gravels are mainly composed of pebbles of milky quartz, quartzite and quartz-feldspathic lithic fragments, distributed in a gray sandy clayey matrix (Chodur, 1997). There are 29 occurrences of corundum, including rubies, recorded in Brazil, the majority of which are found in alluvial deposits associated with metamorphic terrains or associated with igneous alkaline complexes. Geochemical, optical, genetic and inclusion studies were carried out on the occurrences of Brazilian rubies (Liccardo *et al.*, 2000; Liccardo, 2003; Liccardo *et al.*, 2005, 2006).

Deposits of high-quality stones are located in Myanmar (Burma), with small reserves found and distributed in other places such as Thailand, Sri Lanka and Madagascar (Bonewitz, 2013; Phyo, 2019; Rakotondrazafy *et al.*, 2008). Thai rubies can be saturated in color, presenting a dark tone, but they can also have a weak color (Level, 1980). Rubies from deposits in Sri Lanka vary between raspberry red and light red (Hughes, 2017).

This research deals with the identification of the countries of origin of rubies through optical/gemological characteristics, using bibliographic research and data collected in samples donated to the Federal University of Ceará (UFC) by the Federal Police, which resulted in the production of a table that shows the identification of the stones and of their sources. In Brazil, this study is even more important, as art. 655 of the Brazilian Civil Code establishes that banks and government agencies accept cut stones in pledge when a debt is subject to collection in court; in the country, the most used gemstones to settle debts in judiciary are diamond, ruby, sapphire and emerald (Lei n° 10.406, 2002).

## 2. Methodology

209 samples of cut rubies weighing 0.2 ct (carat) were duly analyzed. The data on these gems, together with bibliographic studies, made it possible to create a table that allows determining the origin through some gemological characteristics, such as, refractive index, pleochroism, fluorescence and the content of inclusions. To analyze these characteristics, we used the following equipment:

### 2.1 Refractometer

With this instrument it is possible to measure the refractive index of the mineral. Its index is located between 1.40 and 1.81 in transparent or translucent crystals. It is also possible to determine the birefringence, character and optical signal of the analyzed gemstones, the latter are obtained through mathematical calculations. For a complete reading and with a minimum margin of error, it is necessary to carry out four to six readings, rotating the material around 45 degrees with each new reading (Anderson, 1984).

### 2.2 Dichroscope

The Dichroscope allows visualizing the pleochroism of the gems. Pleochroism is caused by the distinct absorption of light in birefringent crystals. This characteristic is graded into three levels. If the change in tone in the mineral is very visible, pleochroism is classified as strong, when the variation is not so visible it is considered medium and when the change is barely noticeable, it is classified as weak. This phenomenon does not occur in isotropic, amorphous and opaque gemstones, nor in the most translucent ones (Schumann, 2020). The change in the colors of the analyzed gems, when the microscope stage is rotated, is due to the lack of compensation for the refractive indices of anisotropic gems. It is

considered a consequence of variable refractive indexes revealed as a color or tone variation when light propagates through a stone in different directions.

### 2.3 Ultraviolet illumination

A method of great importance for the identification of gemstones, uses ultraviolet light lamps illuminating the mineral specimens. In this case, fluorescence might be produced, caused by impurities in the crystalline lattice (Schumann, 2020). Fluorescence is the visible light emerging from a material exposed to short wavelength electromagnetic radiation (Pehrson, 2017). Gemstones that contain notable amounts of iron in their composition do not exhibit fluorescence.

### 2.4 Gemological Microscope

This instrument is a stereoscopic microscope that allows immediate observation of different types of color zoning, solid inclusions, “healed fractures” and “fingerprints” (particular combinations of healed fractures and fingerprints), and acicular inclusions that resemble silk (silk inclusions) (Hughes, 2017). In transparent and translucent minerals, stereoscopic microscopy makes it possible to visualize the inside of the gems. Through the different types of inclusions, growth lines and air bubbles it is possible to identify products that imitate natural gemstones but may be synthetic. These are manufactured in the laboratory in order to reproduce the optical effect, color and appearance of natural minerals, but they do not have their physical and chemical properties, nor exactly the same crystalline structure (IBGM/DNPM, 2009).

## 3. Results and discussion

Through bibliographic research (Bonewitz, 2013, P.224; Hughes, 2017; IBGM/DNPM, 2009; Level, 1980; Gubelin, 1982; Nassau, 1990; Pehrson, 2017; Phyo, 2019; Promwongnan and Sutthirat, 2019; Smigel *et al.*, 2021; Sutherland *et al.*, 2015, 2017; Schumann, 2020; Rakotondrazafy *et al.*, 2008) a table (Tab. 1) was prepared with information on the 5 main ruby supplier countries (Fig. 1). This table aims to indicate the origin of this mineral. 209 ruby samples that supported the preparation of the table and its usefulness. Since rubies from Brazil have some similarities with these rubies, their properties were compared to those of these 5 countries.

The use of the dichroscope to analyze pleochroism was the first step implemented to deduce the country of origin of rubies. Gems with strong pleochroism (Burma and Sri Lanka) (Hughes, 2017; Bonewitz, 2013; Pehrson, 2017; Phyo, 2019; Schumann, 2020) were easily differentiated from other specimens, as this characteristic is moderate (Thailand and Tanzania) to weak or absent (Pakistan) in other rubies (Gubelin, 1982; Pehrson, 2017; Smigel *et al.*, 2021). Some rare Brazilian rubies present moderate pleochroism (Liccardo, 2003), having some similarity with rubies from two of the five main ruby producers (Thailand and Tanzania). In general, pleochroism classified as weak (and uncommon) is the result of a low absorption due to the induced compensation in the expression of ordinary (no) and extraordinary (ne) refractive indexes.

Using a short-wave ultraviolet lamp, it was possible to analyze the intensity of fluorescence in the rubies. The specimens from Burma (Bonewitz, 2013; Schumann, 2020; Smigel *et al.*, 2021) are the only ones to have fluorescence classified as strong. Sri Lankan gemstones show a moderate fluorescence. Rubies from Thailand and Tanzania have weak fluorescence and minerals from Pakistan do not show fluorescence (Hughes, 2017; Pehrson, 2017; Phyo, 2019; Gubelin, 1982; Pehrson, 2017; Smigel *et al.*, 2021). In rubies from the latter

Table 1. Origin of rubies and their respective optical characteristics.

Tabela 1. Origem dos rubis e suas características óticas.

Gem	Refraction	Pleochroism	Fluorescence	Inclusions
Rubies Burma (Myanmar)	1.765-1.773	Present: Strong	Present: Strong	Silk mesh (Rutile Needles); growth lines; Zircon, Garnet, Mica, other minerals and fluid inclusions
Rubies Sri Lanka	1.76-1.78	Present: Strong	Present: moderate	Rutile needles; Zircon crystals with halos; Biotite and mica flakes; color zoning; Spinel, Graphite, Ilmenite, Apatite crystals
Rubies Pakistan	1.762-1.770	Present: Week or Absent	Absent	Monazite inclusions; Spinel, Rutile, Magnetite, Pyrite and Calcite (Dolomite); Fluid and biphasic inclusions
Rubies Thailand	1.76-1.78	Present: moderate	Present: Week	Fluid, round and opaque inclusions; feathers; mineral inclusions (Garnet, Silimanite and Spinel) and absence of rutile
Rubies Tanzania	1.76-1.78	Present: moderate	Present: Week	Fluid inclusions; inclusions of Apatite, Spinel, Graphite and Zoisite

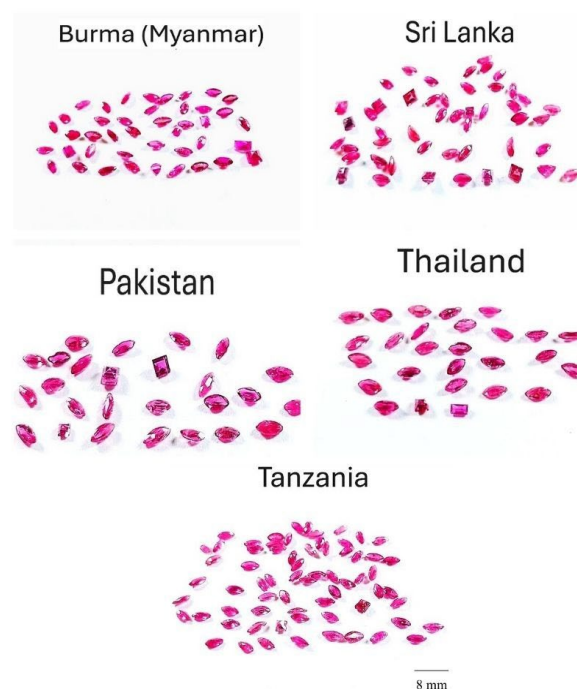


Figure 1. Samples of rubies (0.2 ct) from Burma (Myanmar), Sri Lanka, Pakistan, Thailand and Tanzania.

Figura 1. Amostras de rubis (0,2 ct) de Burma (Myanmar), Sri Lanka, Paquistão, Tailândia e Tanzânia.

country, these specimens do not contain elements that activate fluorescence or phosphorescence, such as rare earth elements (such as lanthanum, cerium, samarium, europium, etc.). Brazilian rubies have low intensity (weak) fluorescence (Liccardo, 2003), just like minerals from Thailand and Tanzania.

The rubies analyzed using a gemological microscope did not show air bubbles, molten crystals, curved growth lines and thick waists with flaws, which would indicate a synthetic material and/or “doublet” and “triplet”. This confirmed that all the samples are natural (IBGM/DNPM, 2009). Among the inclusions found in Burmese rubies, there are zircon crystals (Fig. 2A) and according to Phyo *et al.* (2020) these are approximately 200 million years old. Rutile needles are also present (Fig. 2B), as are garnet and fluid inclusions (Anderson, 1984; Schumann, 2020; Sutherland *et al.*, 2015; Smigel *et al.*, 2021). Sri Lankan specimens are characterized mainly by the inclusion of rutile needles and graphite, ilmenite or apatite as well as some zircon crystals with surrounding radioactive damage halos (Fig. 2D). The presence of distinctive color bands (Fig. 2C) and color zoning (Pehrson, 2017) is also characteristic. Samples from Pakistan are commonly characterized by the inclusion of calcite (or dolomite), biphasic inclusions (Fig. 2E) (including a fluid phase), monazite, spinel, rutile, magnetite (Fig. 2F) and pyrite (Gubelin, 1982). Opaque inclusions were recognized in Thai rubies (Fig. 2G) as well as fluid inclusions (Fig. 2H) and three aluminous minerals (garnet, sillimanite and spinel). The presence of at least a dozen mineral species inside rubies from Thailand is known (Promwongnan and Sutthirath, 2019). In rubies from Tanzania, fluid inclusions, apatite (Fig. 2I), spinel, and graphite (Fig. 2J) were visualized. The gemological microscope is the only way allowing to distinguish Thai and Tanzanian rubies, as they share the same refractive index, pleochroism and fluorescence (Hughes, 2017; Smigel *et al.*, 2021). Brazilian rubies have inclusions of zircon, rutile, apatite, ilmenite, hematite, monazite and mica (Liccardo, 2003), having some similarities with the inclusions of the 5 main ruby supplier countries. The inclusion of hematite is the distinguishing feature for the Brazilian origin.

The refractometer showed that all samples are rubies, as they have a refractive index situated between 1.76-1.78 and a birefringence of 0.007-0.010, in addition to being uniaxial negative (Schumann, 2020; Smigel *et al.*, 2021). The index of Brazilian gems (1.761-1.771) (Liccardo, 2003) is close to the refractive index interval of Pakistani rubies (1.763-1.770) (Gubelin, 1982).

Of the 209 gemstones analyzed (Fig. 1) to assist in creating the origin identification table (Tab. 1), 43 were identified as being from Burma, 47 from Sri Lanka, 25 from Pakistan, 27 from Thailand and 67 from Tanzania. It is evident in figure 1 that the rubies from the mentioned countries are visually very similar. The most peculiar ones are those from Thailand and Tanzania, as they have a more evident pink hue compared to the others. Samples from Brazil reveal optical properties that do not match the set of characteristics of any of the 209 specimens. Therefore, there are no doubts regarding the naturalness and geographical origin of the samples. The most relevant characteristics to establish the origin of rubies are pleochroism, fluorescence and the set of inclusions. The refractive index works as supporting evidence.

#### 4. Conclusions

Table 1 constitutes a technical and scientific framework encompassing the identification of rubies, and distinction of their sources. It is useful at technical education levels of undergraduate or postgraduate students, and even for amateur enthusiasts interested in gemological issues.

The analyses that were carried out proved to be suitable and accurate means to identify and distinguish rubies coming from the five main supplier countries: Burma, Sri Lanka, Thailand, Tanzania and Pakistan.

This study was sought not only to highlight the attributes of Burmese rubies but also to identify and characterize non-Burmese minerals. The use of the refractometer allows the detection of several imitations because of the disparities regarding the index of refraction and birefringence. The use of such an instrument provides a faster selection, as substitutes and imitations generally have a lower refractive index than that of ruby. Using a dichroscope, the pleochroism of materials is analyzed. This instrument is essential to correctly classify the degree of pleochroism of the samples. Analysis with an ultraviolet lamp is of great relevance with rubies, as there are three possible fluorescence intensities for rubies, and these are decisive to establish their origin. When accurately measuring and classifying pleochroism and fluorescence, the possibility of a misleading procedure of

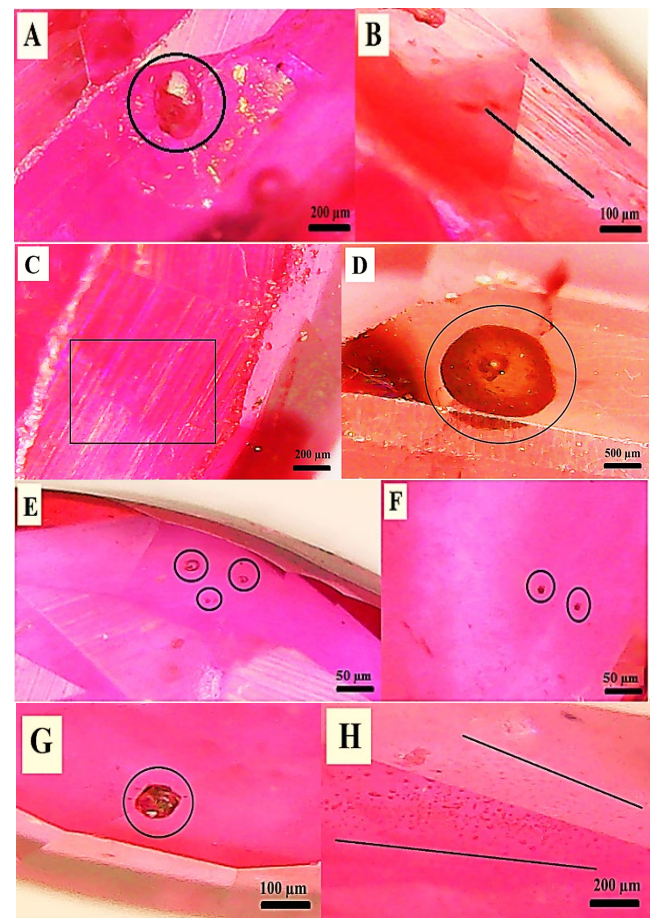


Figure 2. Types of inclusions observed in the analysed rubies: A) inclusion of zircon in a ruby from Myanmar; B) rutile needles in a ruby from Myanmar; C) color bands in a Sri Lanka ruby; D) zircon with halo in a ruby from Sri Lanka; E) biphasic inclusions in a ruby from Pakistan; F) magnetite inclusions in a ruby from Pakistan; G) opaque inclusion in a ruby from Tanzania; H) fluid inclusions in a ruby from Myanmar; I) inclusion of apatite in a ruby from Tanzania; J) graphite inclusions in a ruby from Thailand.

Figura 2. Tipos de inclusões observadas nos rubis analisados: A) inclusão de zircão num rubi de Myanmar; B) agulhas de rutilo num rubi de Myanmar; C) bandas de cor num rubi do Sri Lanka; D) zircão com halo num rubi do Sri Lanka; E) inclusões bifásicas num rubi do Paquistão; F) inclusões de magnetite num rubi do Paquistão; G) inclusão opaca num rubi da Tanzânia; H) inclusões fluidas num rubi de Myanmar; I) inclusão de apatite num rubi da Tanzânia; J) inclusões de grafite num rubi da Tailândia.

identification becomes small. The proposed framework (Tab. 1) created to identify the provenance of rubies, combines bibliographic studies and gemological data acquired for 209 samples of rubies. It can assist in the exclusion of erroneous determinations in the evaluation of other sets of rubies. Studies and identification regarding origin are necessary, as the market value attributed to rubies from Burma is much higher than that of rubies from other origins.

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