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A Comparative Study of the Gemological Characteristics and Inclusions in Spinels from Myanmar and Tajikistan

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Abstract: Currently, most of the popular spinels in the jewellery market come from Myanmar and Tajikistan. It is well known that provenance is one of the main factors affecting the value of a gemstone, and the geographic origin of a gemstone can be determined by examining its gemological and inclusion characteristics. This study systematically characterized the conventional gemology of spinels from Myanmar and Tajikistan and compared the inclusions in the spinels from these two countries by means of gemological microscopy and Raman spectroscopy. The results showed that most red and pink Myanmarese spinels were octahedral or contact twins, while Tajikistani spinels are slabbed or octahedral distorted crystals. Columnar zircon is frequently found in Tajikistani spinels but rare in Myanmarese spinels, appearing as tiny accessory inclusions. There are three types of carbonate inclusions (magnesite, dolomite, and calcite) in Myanmarese spinels, but Tajikistani spinels have only one (magnesite). In addition, spinels of different origins include special inclusions. Myanmarese spinels contain pyrite inclusions; Tajikistani spinels contain rutile and talc inclusions.

Keywords: spinel; inclusions; gemological characteristics; Raman spectrum; Myanmar; Tajikistan

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1. Introduction

Spinel is an oxide of Mg and Al whose ideal formula is $MgAl_2O_4$. The use of spinel as a gem has a long history. Due to its resemblance to ruby, it is sometimes mistaken for it [1–3]. With the discovery of large sizes of red spinels in the Mahenge mine in Tanzania in 2007, the appeal of spinel increased considerably [4,5]. However, most of the spinels on the jewellery market come from Myanmar and Tajikistan. Myanmar is the most famous source for medium/small-sized red spinels, while Tajikistan is the world's leading source for coarse, large-sized spinels [5]. However, the spinels of these two geographical origins both look remarkably similar, and it is difficult to distinguish them with the naked eye, just by color.

At present, in the literature, there are far more studies on spinels from Myanmar than those from Tajikistan. More importantly, there is a lack of comparative studies on the gemological and inclusion characteristics of the spinels of the two origins. In detail, the study of Myanmarese spinels initially focused on mineralogical, gemological, and chemical characteristics [1,3,4,6]. Subsequently, studies began to explore the identification of thermally treated spinels in relation to synthetic ones [7–11]. As the research progressed over the years, experts and scholars studied the inclusions of Myanmarese spinels [12–15]. Researchers launched some preliminary investigations on inclusions, trace elements, and the gemological characteristics of Tajikistani spinels [3,6,16]. However, further comparisons, excluding the color factor, are needed to clearly distinguish the spinels from these two regions. In this paper, we describe the gemological characteristics of spinels from Myanmar and Tajikistan by a series of conventional gemological tests and we also compare the Raman spectra of their inclusions. Therefore, this study aims at providing important assistance in distinguishing between the spinels of the two origins.

2. Geological Settings

The gem-quality spinel deposits of Myanmar and Tajikistan are both located within the Himalayan orogenic belt and are associated with the third great collision of the Indian subcontinent and Eurasia, which is known for its high temperature metamorphism and deformation [6,17]. The most famous spinel deposit in Tajikistan is the Kuh-i-Lal (Figure 1). The occurrence of ultramafic rock is a feature of this deposit. The ultramafic rocks contain talc, +kyanite, ±phlogopite. The Kuh-i-Lal deposit is located in a magnesian skarn of the enstatite–forsterite rock. Spinels are associated with enstatite, magnesite, phlogopite, pyrrhotite, pyrite, rutile, and graphite [18]. In addition, Myanmarese spinel deposits are mainly located in the "Mogok Metamorphic Belt". The "Mogok Gem Belt" is located in the Mandalay region (Figure 1) [19,20]. Spinels are associated with ruby, phlogopite, muscovite, margarite, scapolite, pyrite, sphene, and graphite [17].

Figure 1. Map of spinel sources in Myanmar and Tajikistan (modified from Google Earth).

3. Materials and Methods

3.1. Materials

A total of 20 spinels from Myanmar and Tajikistan, ranging from 0.20 to 3.70 ct, were analyzed for the study (Figure 2), including 10 samples from Myanmar (M-1–M-10) and 10 from Tajikistan (T-1–T-10). The M-1–M-10 samples were fragments and rough spinels with good crystal shape, while the T-1–T-10 samples were transparent spinels.

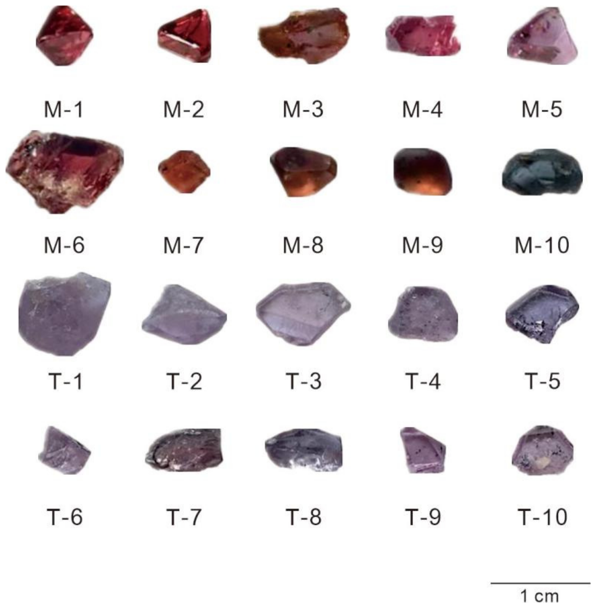

Figure 2. The twenty different samples of spinels studied. (M—Myanmar; T—Tajikistan.)

3.2. Methods

The gemological tests for the samples were conducted at the Gemological Research Laboratory of the China University of Geosciences (Beijing). All the samples were investigated with a refractometer, polariscope, diffraction grating spectroscope, long-wave (365 nm) and short-wave (254 nm) UV lamp, and an apparatus for hydrostatic weighing testing. Internal and external features were observed with a GI-MP22 gemological photographic microscope using darkfield, brightfield, and top illumination.

Raman spectra were collected with a Horiba HR Evolution-type micro-confocal laser Raman spectrometer (Horiba, Ltd., Kyoto, Japan) in the Gemological Research Laboratory of the China University of Geosciences (Beijing). Laser source: 532 nm. Laser power: 30–40 mW. Laser spot size: 1 μm (Figure 3). Resolution: 4 cm^{-1}. Scan time: 20 s. The Raman shifts were calibrated using monocrystalline silicon before the test, with a tolerance of $\pm$0.5 cm^{-1}. After placing the sample, the appropriate objective was selected according to the size of the inclusions in the sample and the inclusions were located. When the spot was minimized, the focus was complete and the test began.

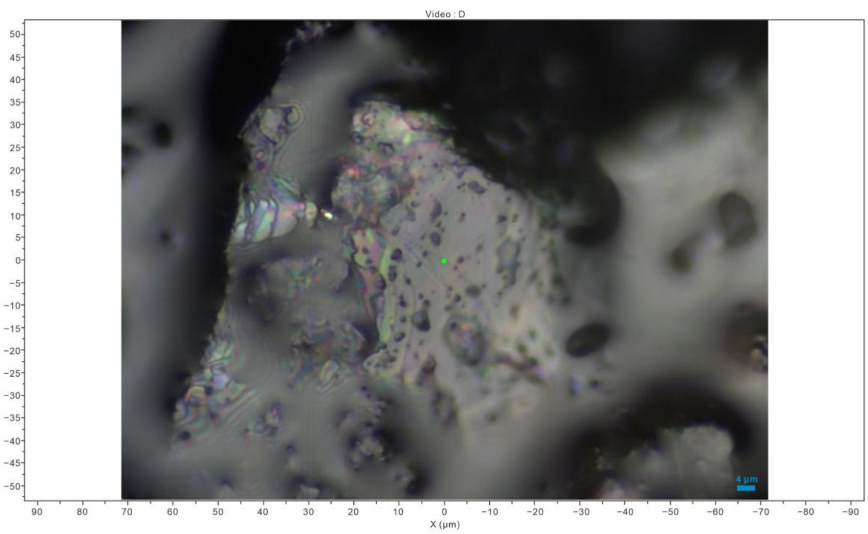

Figure 3. The laser spot size with a scale (magnification: 500×).

Laser Raman spectroscopy is widely used for the routine identification of materials, allowing the differentiation of spinel subspecies from characteristic spectra without any information on composition or structure [21–23]. Currently, Raman spectroscopy plays an essential role in the differentiation of spinel subspecies and spinel inclusion components. Spinels contain abundant inclusions, and many differences are observed between the inclusions in Myanmarese and Tajikistani spinels. These can be distinguished by observing the appearance of common inclusions by using Raman spectroscopy on the different components of inclusions.

4. Results

4.1. Conventional Gemological Properties

The studied spinels from Myanmar were deep red, light purplish red, brownish red, pink, brownish orange, light purplish red, grayish blue, and had a transparent appearance. Some of the spinels from Myanmar were formed as octahedrons (Figure 4a) or spinel twins (Figure 4b), which look like flat triangles with notches at the corners, known as re-entrant angles (Figure 4c). Other spinels from Myanmar were water-worn pebbles or fragments with a conchoidal fracture. The spinel samples from Tajikistan were blue-purple, purple, light purple, brownish purple, grayish purple and were octahedral distorted crystals or slabs (Figure 4d).

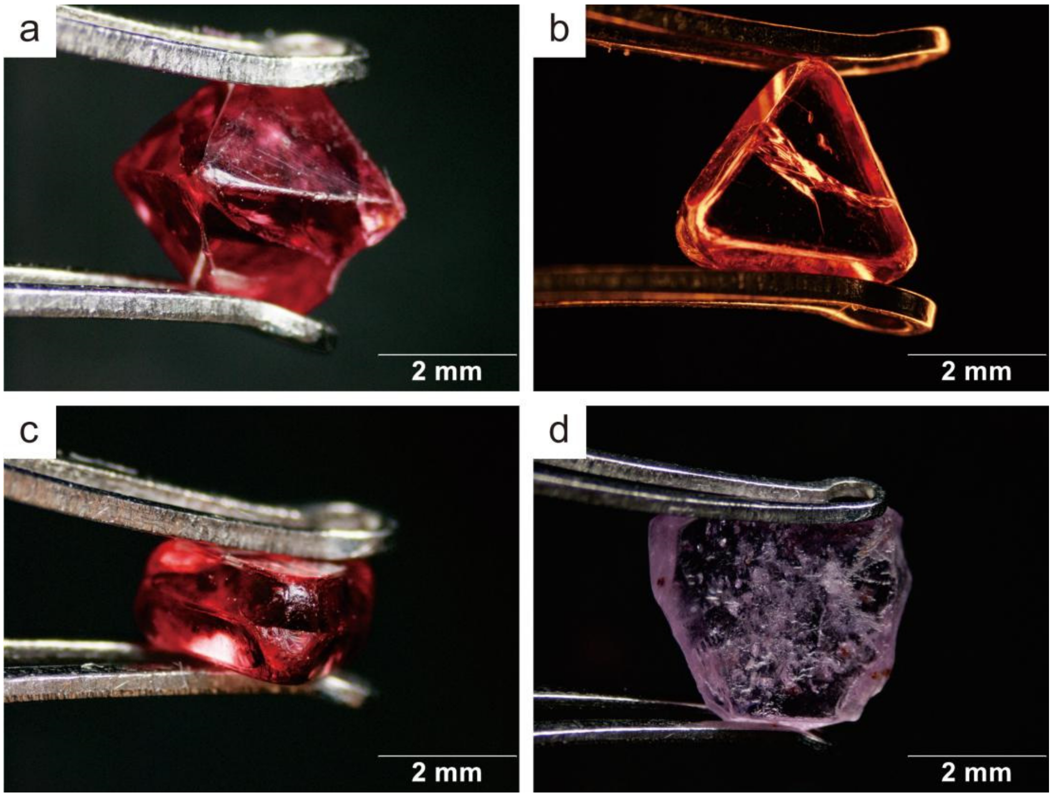

Figure 4. (**a**) Octahedral spinel from Myanmar (M−1). (**b**) Spinel formed as spinel twins from Myanmar (M−2). (**c**) Spinel formed as spinel twins with re-entrant angles from Myanmar (M−2). (**d**) Slab spinel from Tajikistan (T−4).

Most spinels from Myanmar showed a stable refractive index of 1.718, but some samples had refractive indices as low as 1.716. The spinels from Tajikistan had a refractive index of 1.712–1.713. The red and pink spinels from Myanmar showed an obvious Cr spectrum.

All the grayish blue spinels from Myanmar were typically inert to long-wave and short-wave UV radiation, but red and pink spinels showed strong red fluorescence under long-wave radiation. The purple and orange spinels from Myanmar with different saturations also show different fluorescence. This phenomenon may be associated with the coloring elements of spinel. The spinels from Tajikistan showed faint red fluorescence or non-fluorescence under long-wave radiation and faint yellow fluorescence under short-wave radiation.

4.2. Inclusions under the Gem Microscope

4.2.1. Myanmarese Spinel Inclusions

In the 10 Myanmarese spinel samples studied with a gemological microscope, we observed some solid and gas–liquid inclusions. These inclusions showed rounded crystals and black flake inclusions and were probably made up of apatite (Figure 5a), calcite, graphite, or ilmenite. However, slightly rounded apatite crystals associated with black flake graphite or ilmenite are a unique characteristic of Myanmarese spinels [24]. Therefore, these previous findings are in good agreement with the observations of the current study. We observed a long columnar inclusion containing a black mineral (Figure 5b), but the black mineral was too small to detect with the Raman spectroscope. According to previous studies, it was presumed to be graphite or ilmenite [25].

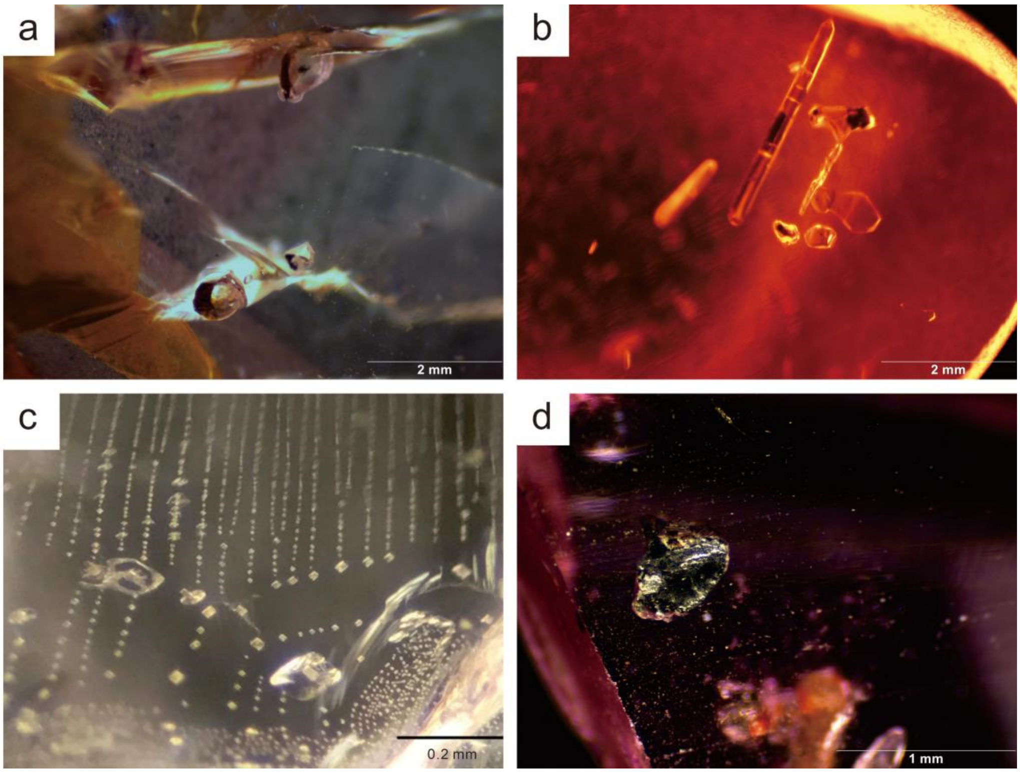

Figure 5. (**a**) Rounded crystal inclusions (apatite) in a Myanmarese spinel (M−3). (**b**) Long columnar inclusion containing a black mineral (graphite or ilmenite) in a Myanmarese spinel (M−4). (**c**) Octahedral negative crystals (calcite) arranged in very neat rows in a Myanmarese spinel (M−10). (**d**) Brassy yellow metallic luster inclusion (pyrite) in a Myanmarese spinel (M−5).

These inclusions were approximately arranged in the shape of fingerprint outlines (when viewed parallel to the c-axis of the host, indicating that crystal growth occurred mostly along the basal planes). This is another characteristic of Myanmarese spinels [24]. These types of inclusions were also observed in the M-10 sample (Figure 5c). These octahedral inclusions had obvious boundaries, indicating that the sample and inclusions had different refractive indices.

Pyrite inclusions are uncommon in spinels and are generally primary inclusions with an idiomorphic crystal form. An idiomorphic brassy yellow pyrite inclusion could be seen in the pink spinel sample P-10 which had been ground out of the surface (Figure 5d).

4.2.2. Tajikistani Spinel Inclusions

In the 10 Tajikistani spinel samples studied with a gemological microscope, we observed some solid and gas–liquid inclusions. These inclusions showed octahedral crystals with healing fissures and were probably made up of magnesite. A black opaque mineral inclusion exposed to the surface was found in the sample T-5, and this inclusion was identified as rutile by Raman analysis (Figure 6a). Many colorless crystals generally appeared in two sizes, and these crystal inclusions were clustered together (Figure 6b). The larger ones were approximately 80 μm in diameter and rounded in shape. The smaller ones were approximately 20 × 5 μm and columnar in shape. They could be easily distinguished by shape and size. In some cases there were large crystal inclusions containing small crystal inclusions, indicating that they were formed sequentially, and it can generally be deduced that small crystals form before large ones. These inclusions were probably made up of apatite and zircon.

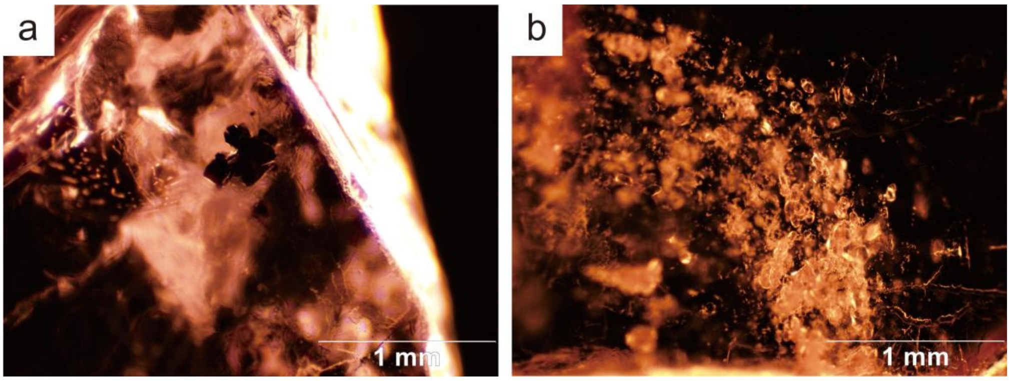

Figure 6. (**a**) Black inclusions (rutile) in a Tajikistani spinel (T−5). (**b**) Colorless crystals (apatite and zircon) in two size clusterings in a Tajikistani spinel (T−3).

4.3. Raman Spectra Characteristics

4.3.1. Comparison of the Raman Spectra of the Myanmarese and Tajikistani Spinels

By comparing the Raman spectra of the spinels (M-6, M-9, T-9, T-10) with those in the literature [11], we found the following characteristic peaks in the range of 200–900 cm^{-1}: a strong absorption peak at 407 cm^{-1} (E_g) caused by the Mg symmetric bending vibration within the tetrahedron; an absorption peak at 311 cm^{-1} ($T_{2g}(1)$) caused by a jump of Mg in the tetrahedral position; an absorption peak at 766 cm^{-1} (A_{1g}) caused by Mg-O symmetric stretching vibrations within the tetrahedron; while the attribution of the Raman signal at 655 cm^{-1} ($T_{2g}(2)$) is still controversial [9]. Therefore, these previous findings are in good agreement with the observations of the current study, which revealed that these samples are composed of $MgAl_2O_4$ [9,11]. The peak positions and attributions of the Myanmarese and Tajikistani spinels studied in this paper are shown in Table 1.

Table 1. Peak positions and attribution of the Myanmarese and Tajikistani spinels (cm^{-1}).

Sample Number	Origin	$T_{2g}(1)$	(E_g)	$T_{2g}(2)$	A_{1g}	Date Source
		A Jump of Mg in the Tetrahedral Position	Mg Symmetric Bending Vibrations within the Tetrahedron	—	Mg-O Symmetric Stretching Vibrations within the Tetrahedron	
M-6	Myanmar	309	405	663	764	this paper
M-9	Myanmar	311	407	665	766	this paper
T-9	Tajikistan	312	405	665	766	this paper
T-10	Tajikistan	312	405	663	766	this paper
$MgAl_2O_4$	—	311	407.8	671	772	[9]

4.3.2. Raman Spectra Comparison of Common Inclusions in the Myanmarese and Tajikistani Spinels

The spinels from both Myanmar and Tajikistan contained apatite, zircon, and carbonate inclusions, but the Raman spectra, appearance, and distribution of these inclusions were slightly different.

Raman analyses revealed that the cylindrical inclusions containing a black mineral in Myanmarese spinel (M-9) and colorless crystal inclusions in Tajikistani spinel (T-3) were apatite (peaks at 964 and 1123 cm^{-1}). Apatite inclusions were present in both Myanmarese spinel (M-9) and Tajikistani spinel (T-3).

Figure 7a shows two positions in a cylindrical inclusion containing a black mineral: the end of the cylindrical inclusions (P1) and the black mineral (P2). The results of the separate Raman analysis are shown in Figure 7b: Raman spectra in P1 and P2 both had the characteristic absorption peak for spinel (E_g, $T_{2g}(2)$, A_{1g}) and the characteristic absorption peak for apatite. In addition, Raman spectra in P1 had an absorption peak at 964 cm^{-1} caused by a vibrating belt of $P0_4$, which is the vibrational absorption peak for apatite [26,27]. Raman spectra in P2 had an absorption peak at 1123 cm^{-1} caused by the replacement of PO_4 by SO_4 [27]. The black mineral was too small to detect with the Raman spectroscope. According to previous studies, it was presumed to be graphite or ilmenite [24,25].

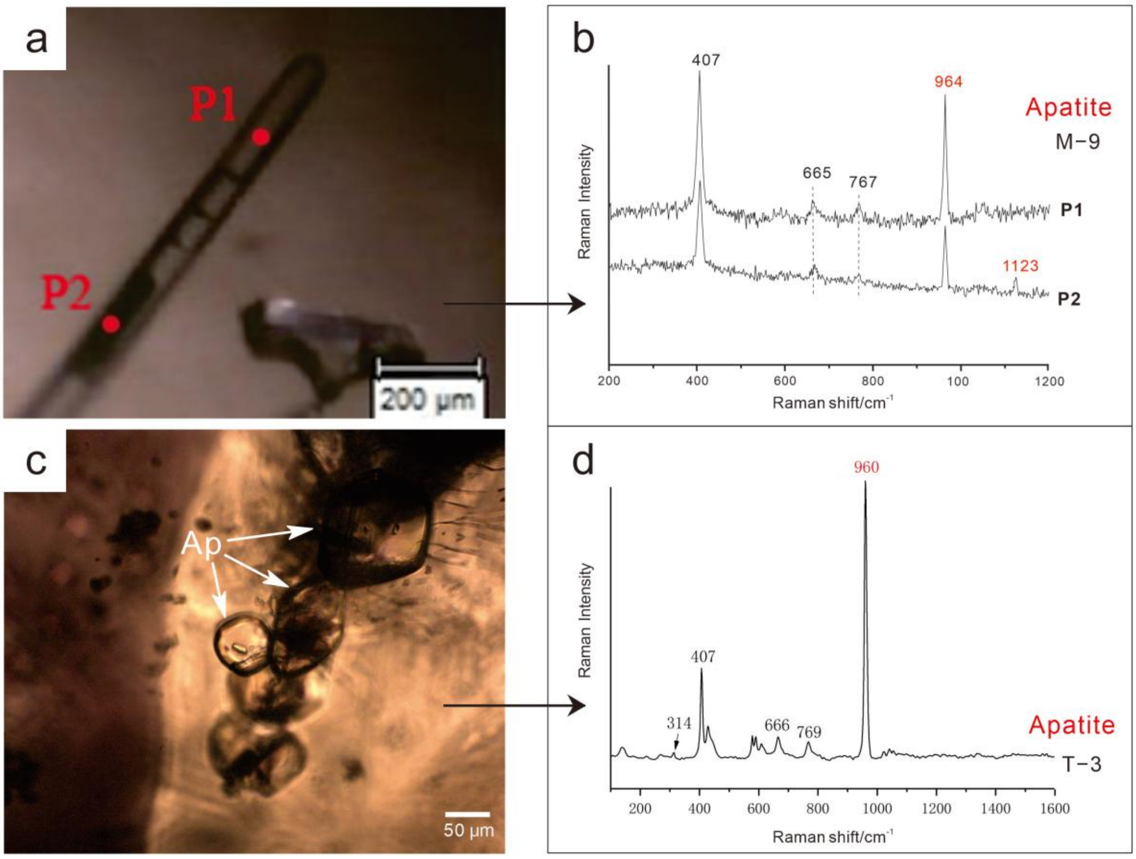

Figure 7. (**a**) Apatite inclusions in Myanmarese spinel (M−9) and (**b**) their (M−9) Raman spectra. (**c**) Apatite inclusions in Tajikistani spinel (T−3) and (**d**) their (T−3) Raman spectra.

The colorless crystal inclusions in T-3 were divided into large and small sizes (Figure 7c): the larger ones (80 μm in diameter) were generally rounded in shape, while the smaller ones (20 × 5 μm) were approximately columnar. These inclusions were usually clustered together. Raman spectroscopy of these crystal inclusions showed that the larger, rounded, colorless crystal inclusions were apatite (Figure 7d).

Raman analyses revealed that a small columnar crystal inclusion within the apatite inclusion (peaks at 961 cm^{-1}) (Figure 8a) in a Tajikistani spinel (T-3) was made up of zircon (peaks at 201 cm^{-1}, 225 cm^{-1}, 357 cm^{-1}, 440 cm^{-1}, 961 cm^{-1}, and 1011 cm^{-1}) (Figure 8b) [28]. Some small columnar zircons were included within the apatite, and some occured singly or in clusters. The results were consistent with previous studies that found zircon to be associated with apatite [13]. Zircons are frequently found in spinel from Tajikistan but are rare in spinel from Myanmar. We did not find zircon in our spinel samples from Myanmar, which was mentioned by Phyo [14] and Themelis [29] in spinel from Mogok. They found tiny accessory zircon inclusions (maximum size of 50 µm, minimum size of 10 µm) in a few spinels from Kyauksin and Kyauksaung [13,14,29]. By comparing the Raman analysis results for other zircons in T-3, it was found that the half-height width of the B1g characteristic absorption peak (1009 cm^{-1}) was concentrated in the range of 4–7 cm^{-1}, which indicated that it had well-crystallized [30].

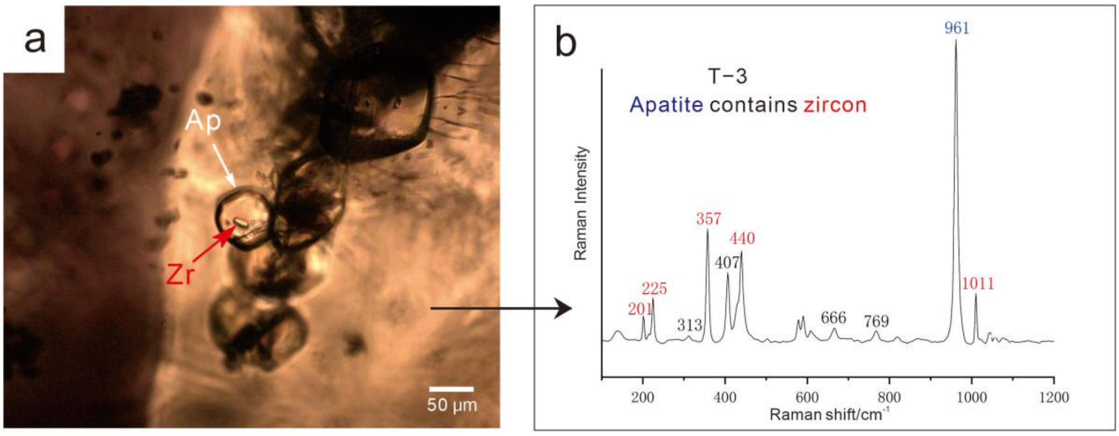

Figure 8. (**a**) Zircon inclusion in Tajikistani spinel (T−3) and (**b**) its (T−3) Raman spectrum.

The spinels from both Myanmar (M-8, M-10) and Tajikistan (T-2) contained carbonate inclusions. Raman analyses revealed that the inclusions with similar shapes and sizes in Myanmarese spinel (M-8) were made up of magnesite (peaks at 328, 737, 1093, and 1762 cm^{-1}), while octahedral negative crystals in Myanmarese spinel (M-10) were dolomite (peaks at 177, 300, and 1099 cm^{-1}) and calcite (peaks at 155, 282, 712, and 1086 cm^{-1}). The transparent crystal inclusions in Tajikistani spinel (M-10) were magnesite (peaks at 330, 738, 1096, and 1765 cm^{-1}).

Sample M-8 had a large number of inclusions of similar shape (Figure 9a) and size (approximately 20 µm), and the Raman spectrum of one of them (Figure 9b) showed the absorption peak of magnesite [31]. Sample M-10 showed a lot of octahedral negative crystals, usually arranged in very neat rows, and this phenomenon is a unique feature of Myanmarese spinel [24]. Three octahedral negative crystals were labeled as C1, C2, and C3 (Figure 9c) and subjected to separate Raman analysis. The results are shown in Figure 9d and exhibit the characteristic peaks of dolomite [12,32–34]. Moreover, another octahedral negative crystal in M-10 (Figure 9e) was tested by Raman spectroscopy, and Figure 9f shows characteristic peaks of calcite [12,35–38]. Therefore, the octahedral negative crystals of the Myanmarese spinel samples containede dolomite and calcite components.

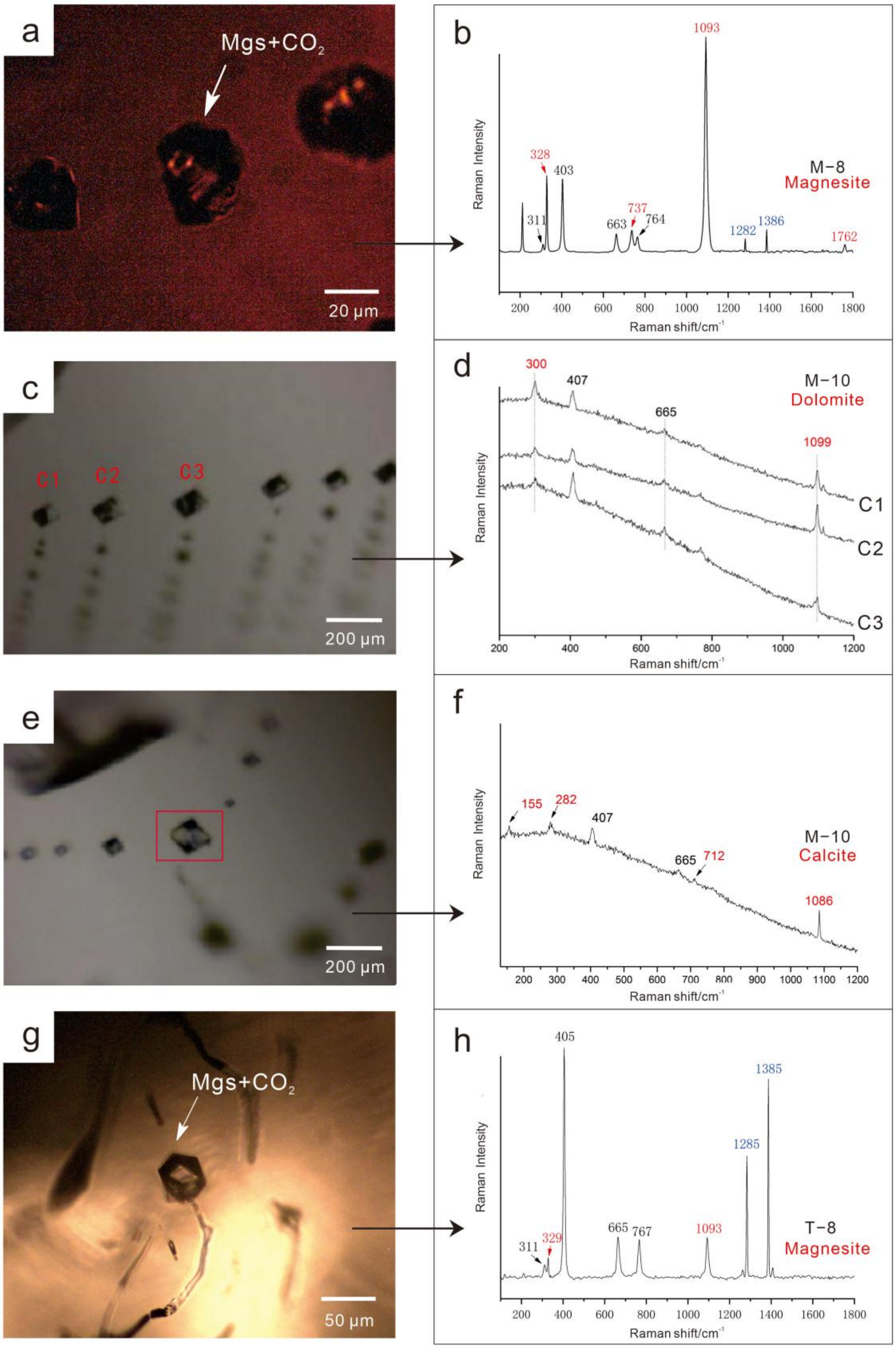

Figure 9. (**a**) Magnesite inclusion in Myanmarese spinel (M−8) and (**b**) its (M−8) Raman spectrum. (**c**) Dolomite inclusions in Myanmarese spinel (M−10) and (**d**) their (M−10) Raman spectra. (**e**) Calcite inclusion in Myanmarese spinel (M−10) and (**f**) its (M−10) Raman spectrum. (**g**) Magnesite inclusion in Tajikistani spinel (T−8) and (**h**) its (T−8) Raman spectrum.

Carbonate crystal inclusions (Figure 9g) are also common in Tajikistani spinel (T-8), but only magnesite was detected in this study. Figure 9h shows the characteristic peaks of magnesite.

In short, we observed three types of carbonate inclusions in Myanmarese spinel: calcite, dolomite, and magnesite, while Tajikistani spinel showed only one (magnesite).

4.3.3. Comparison of the Raman Spectra of the Different Inclusions in the Myanmarese and Tajikistani Spinels

Spinels of different origins have specific inclusions. For example, Myanmarese spinels contain pyrite, while Tajikistani spinels contain rutile and talc inclusions. The origins of spinels can be determined from the Raman spectra of these inclusions.

Raman analyses revealed that the brassy yellow inclusion with complete crystalline shape in Myanmarese spinel (M-5) was made up of pyrite (peaks at 342 cm^{-1} (E_g), 378 cm^{-1} (A_g), and 428 cm^{-1} (T_g)). Actually, pyrite inclusions are rare in Myanmarese spinel and are generally primary inclusions with complete crystalline shape. An et al. [39] argued that pyrite be divided into types I, II, and III. The brassy yellow pyrite inclusion in the Myanmarese spinel M-5 (Figure 10a) was tested by Raman spectroscopy with the characteristic absorption peak of pyrite (Figure 10b). Comparing the relative intensity of the absorption peaks led to the conclusion that $I_{Eg} \approx I_{Ag} \gg I_{Tg}$. Therefore, the pyrite was considered a type I pyrite [36].

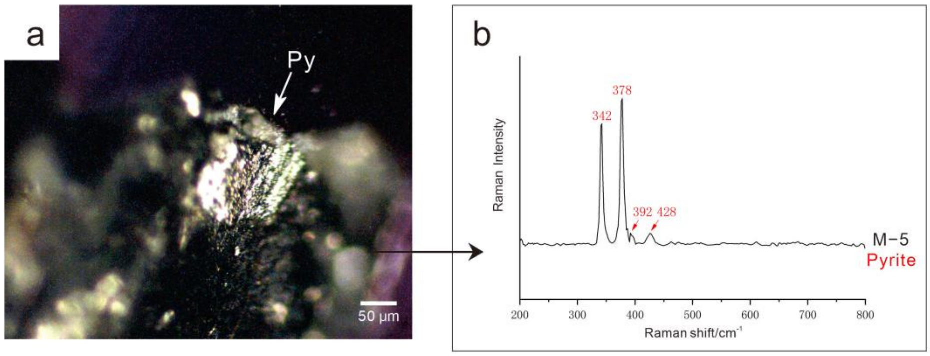

Figure 10. (**a**) Pyrite inclusion in Myanmarese spinel (M−5) and (**b**) its (M−5) Raman spectrum.

Black, slightly transparent to opaque massive rutile inclusions are commonly found in spinels from Tajikistan. Raman analyses revealed that the black opaque mineral inclusions (Figure 11a) in Tajikistani spinel (T-5) were rutile (peaks at 248 cm^{-1}, 437 cm^{-1}, and 611 cm^{-1}) (Figure 11b).

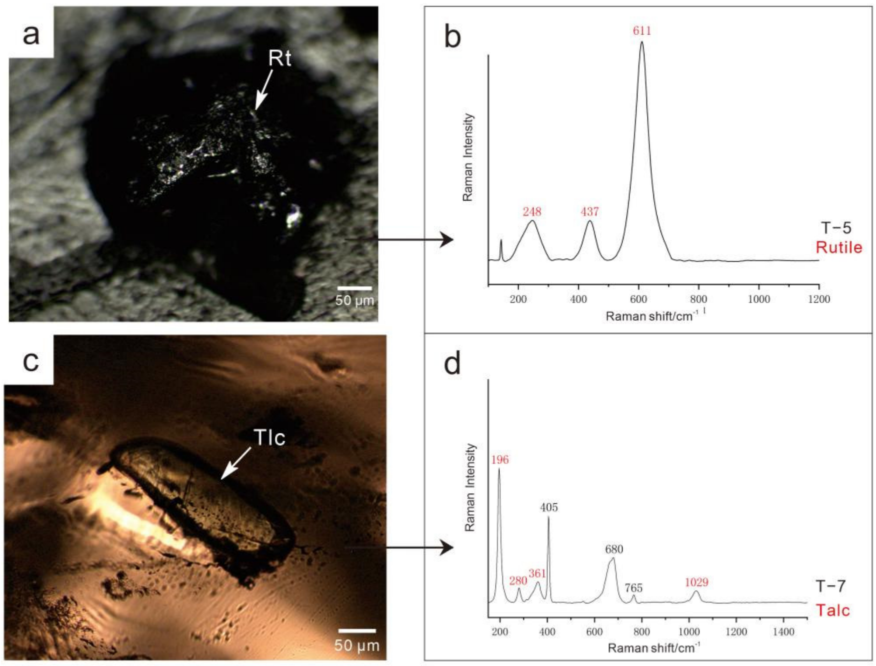

Figure 11. (**a**) Rutile inclusion in Tajikistani spinel (T−5) and (**b**) its (T−5) Raman spectrum. (**c**) Talc inclusion in Tajikistani spinel (T−7) and (**d**) its (T−7) Raman spectrum.

Raman analyses revealed that colorless columnar crystal inclusions (Figure 11c) in Tajikistani spinel (T-7) were talc (peaks at 196 cm^{-1}, 280 cm^{-1}, 361 cm^{-1}, and 1029 cm^{-1}) (Figure 11d). The results are consistent with previous studies that showed that the spinel in Tajikistan was produced in talc–kyanite rocks [3]. The mineral inclusions in gemstones can record the history of gemstone formation [40,41].

5. Discussion

5.1. Gemological Characteristics

The spinel samples from Myanmar and Tajikistan have excellent transparency and a constant refractive index [24]. Most red and pink Myanmarese spinels have a complete crystalline form, such as octahedral or contact twin, while those from Tajikistan are often slabbed or octahedral distorted crystals (rarely). The red and pink spinels from Myanmar show a distinct Cr spectrum on a diffraction grating spectroscope. Under long-wave radiation, red and pink Myanmarese spinels show strong red fluorescence, while grayish blue spinels typically show inertness. However, there is a unique feature of Tajikistani spinel, with some samples showing very weak yellow fluorescence with short-wave UV radiation [42].

5.2. Comparison of the Characteristics of Inclusions in Spinels from Myanmar and Tajikistan and Their Raman Spectra

Firstly, apatite, zircon, and carbonate inclusions occur in both provenances. Although samples from both sources contain apatite inclusions, these inclusions are considerably different in appearance and distribution. The columnar apatite inclusion of Myanmarese spinel containing a black mineral (graphite or ilmenite) is a unique feature of Myanmarese spinel. The analysis in this paper did not detect its specific composition but based on previous studies it is speculated that it could be graphite or ilmenite [25]. The Tajikistani spinel apatite inclusions are rounded and do not contain black minerals. These crystal inclusions of different sizes are usually clustered together.

Zircons are frequently found in spinel from Tajikistan but are rare in spinel from Myanmar. Zircon inclusions occur in a few spinels from Myanmar as tiny accessory inclusions (maximum size of 50 μm, minimum size of 10 μm) [13,29]. Many colorless crystals in Tajikistani spinels generally occur in two sizes; the larger ones are rounded (80 μm in diameter), while the smaller ones are columnar (20 × 5 μm). Sometimes they are clustered together and sometimes the larger crystal inclusions contain smaller crystal inclusions. Raman spectroscopy revealed that the large, round inclusions were apatite and the small, columnar inclusions zircon. Moreover, the zircon inclusions in Tajikistani spinel are well-crystallized, as shown by the half-height widths in the Raman spectroscopy. Therefore, zircons are rarely found in Myanmarese spinels as tiny accessory inclusions but frequently occur in Tajikistani spinels in columnar shapes and clustered with apatite inclusions.

Carbonate inclusions are common in Myanmarese spinels, usually calcite, dolomite, and magnesite. Carbonate inclusions also frequently occur in Tajikistani spinels, but, unlike those from Myanmar, only one type of carbonate inclusion (magnesite) was found in the Tajikistani spinels. In addition, calcite and dolomite were the main components of octahedral negative crystals in Myanmarese spinels, which were determined by Raman analysis. The octahedral negative crystals arranged in very neat rows were characteristic of inclusions in Myanmarese spinels. Gübelin and Koivula [25] proposed that these octahedral negative crystals were formed when metallogenic hydrothermal fluids entered the fissures, causing recrystallisation of the host crystals and residual hydrothermal fluids filled the holes. Therefore, it could be concluded that the octahedral negative crystals are secondary or pseudo-secondary inclusions formed by fluids filling crystal cavities and producing dolomite, calcite, or a mixture of both, which appears consistent with previous studies [12,25,43,44].

Secondly, spinels of different origins include special inclusions. Pyrite is found in Myanmarese spinels. Dark rutile inclusions and talc inclusions are also common in Tajikistani spinels.

Both Myanmar and Tajikistan are located in the Himalayan orogenic belt, and the results of the comparison of inclusions of spinels from the two sources are shown in Table 2. Previous findings are in good agreement with the observations of the current study [6,14,45].

Table 2. Comparison of inclusions in Myanmarese and Tajikistani spinels.

Mineral Names	Myanmar	Tajikistan
Apatite	Common	Common
Calcite	Common	None
Dolomite	Common	None
Graphite	Sometimes	Sometimes
Magnesite	Common	Common
Phlogopite	Sometimes	None
Pyrite	Rare	None
Rutile	None	Sometimes
Zircon	Rare	Common
Talc	None	Rare

6. Conclusions

Spinel has excellent gemological properties and is a popular colored gemstone. Spinels from Tajikistan and Myanmar are abundant and of high quality, and most of the spinels on the jewellery market therefore come from these two regions. Consequently, the study of spinels from these two origins is of great scientific importance and of considerable commercial value.

Both Myanmarese spinels and Tajikistani spinels have apatite, zircon, and carbonate inclusions, but they are slightly different in terms of appearance and distribution. The apatite inclusions in Myanmarese spinels contain black minerals, while those in Tajikistani spinels do not. In addition, zircon inclusions occur in a few spinels from Myanmar as tiny accessory inclusions, while they frequently occur in Tajikistani spinels in columnar crystal form. These zircon inclusions are often gathered with apatite inclusions in Tajikistani spinels. Three different types of carbonate inclusions were observed in the Myanmarese spinels, consisting of calcite, dolomite, and magnesite, while in the Tajikistani spinels only one was observed, consisting of magnesite. In addition, spinel from Myanmar contains pyrite while that from Tajikistan contains rutile and talc.

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