Geographic Origin Determination of Natural Yellow Sapphires: The Preliminary Study

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Introduction

Determining the geographic origin of yellow sapphires plays a critical role in the gem trade, as origin often dictates both perceived quality and market pricing. Yellow sapphires, a popular variety of corundum, form in diverse geological environments, each imparting unique internal features and chemical profiles. In today's market, where ethical sourcing and traceability are increasingly prioritized, reliable methods for origin determination are essential. Traditional gemmological approaches, such as analyzing inclusions, can offer helpful insights but are often insufficient—particularly when stones have undergone heat treatment or when inclusions appear similar across different mining regions. This research seeks to overcome these challenges by analyzing yellow sapphires from importantly global sources, including Sri Lanka, Madagascar, Tanzania, and Thailand. Through detailed geochemical profiling, the study aims to uncover distinguishing chemical traits that can serve as dependable indicators of geographic origin. The goal is to improve precision in origin determination, thereby reinforcing consumer trust, enhancing valuation, and promoting transparency across the gemstone supply chain.

Materials and Methods

In this investigation, a total of 151 yellow sapphire samples were analyzed. These originated from Sri Lanka (36 samples), Ilakaka, Madagascar (22), Tanga, Tanzania (45), and Bang Kacha, Chanthaburi, Thailand (50), with weights ranging from 0.23 to 4.30 ct and displaying various yellow colour tones (Figure 1). All samples had undergone traditional heat treatment, except for the Thai samples, which were treated using beryllium heat treatment. The gemmological properties of these samples were examined using both standard gemological tools and advanced analytical instruments, including Raman (Renishaw inVia Qontor Raman microscope), UV-Vis-NIR (PerkinElmer Lambda 1050), and LA-ICP-MS (LA: ESI Industrial NWR-213, ICP-MS: Thermo-Scientific iCAP™ RQ).

Figure 1: Representative samples of yellow sapphire from Sri Lanka, Madagascar, Tanzania, and Thailand ranging in weight from 0.23 to 4.30 ct (Photograph by M. Seneewong-Na-Ayutthaya)

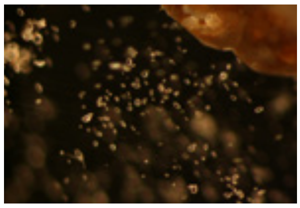
Results and Discussions

Internal features.

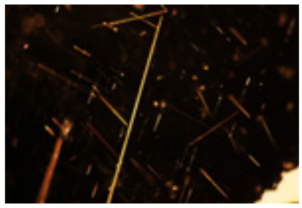
Sri Lankan yellow sapphires are frequently characterized by rectilinear, zigzag-shaped fingerprint inclusions (Figure 2a) and CO_2-filled negative crystals (Figure 2b) (Palke *et al.*, 2019). Additional commonly observed internal features include silk, various fingerprint patterns, needle-like inclusions, minute particles, milky clouds, twinning, as well as crystalline inclusions such as apatite and graphite. In contrast, yellow sapphires from Ilakaka, Madagascar typically contain abundant rounded zircon inclusions (Figure 2c) (Saeseaw *et al.*, 2020). Other diagnostic features in these samples include rutile needles (Figure 2d), silk, complex fingerprint patterns, iron staining, and mica inclusions. Tanzanian yellow sapphires are often distinguished by the presence of hematite silk (Figure 2e) and rose channels (Figure 2f). Additional inclusions observed in these stones include iron staining, hematite, zircon, amphibole, apatite, rutile, black inclusions, various crystalline phases, fingerprint patterns, silk, needles, clouds, and lamellar twinning. Notably, the zircon inclusions in Tanzanian sapphires may closely resemble those from Madagascar, complicating origin determination based solely on inclusion characteristics and necessitating further analytical investigation. Thai yellow sapphires frequently exhibit dissociated inclusions, particularly following high-temperature heat treatment (Figure 2g), along with angular bands of brownish particles (Figure 2h) (Saeseaw *et al.*, 2017). Other internal features include feldspar, crystals, negative crystals, minute particles, clouds, blue colour zones, fingerprint patterns, silk, needles, and iron staining.

a) Rectilinear zigzag fingerprint in Sri Lankan stone

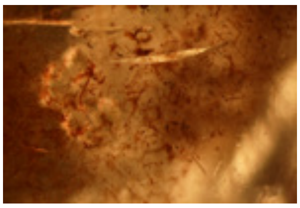
b) CO_2-filled negative crystals in Sri Lankan stone



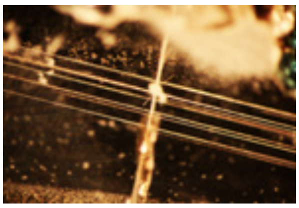
c) Cluster of rounded zircon inclusions in Madagascan stone



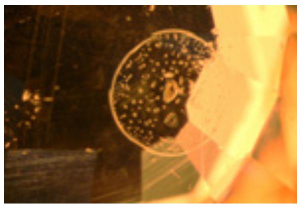
d) Rutile needle-like inclusions in Madagascar stone



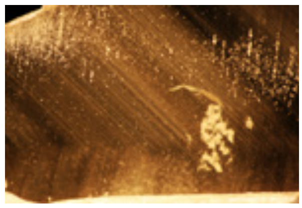
e) Hematite silk in Tanzanian stone



f) Rose channels in Tanzanian stone



g) Dissociated crystal (heat treatment) in Thai stone



h) Angular bands of brownish particles in Thai stone

Figure 2: Inclusions observed in yellow sapphire samples from various deposits examined in this study; field of view 3.8 mm (a, d, e, g), 2.8 mm (b), 1.8 mm (c), 4.5 mm (f) and 9 mm (h). (Photomicrographs by M. Seneewong-Na-Ayutthaya)

UV-Vis spectra.

Yellow sapphires exhibit characteristic UV/Vis/NIR spectra, with their colouration primarily attributed to two distinct mechanisms: colour centres (h•-Fe^{3+}) and the presence of the iron (Fe^{3+}) trace element (Dubinsky *et al*., 2020). Figure 3 illustrates the absorption spectrum of a yellow sapphire from Sri Lanka, which is representative of the colour produced predominantly by the colour centre chromophore. In contrast, for yellow sapphires with higher iron concentrations, such as those from Madagascar, Tanzania, and Thailand, their spectra are characterized by absorption features at approximately 378 nm and 450 nm attributed to Fe^{3+}/Fe^{3+} pairs, and an absorption band at approximately 387 nm indicative of isolated Fe^{3+} (Emmett *et al*., 2023; Dubinsky *et al*., 2020). These spectral features confirm the dominant role of iron (Fe^{3+}) as the primary chromophore for yellow colouration in these latter groups.

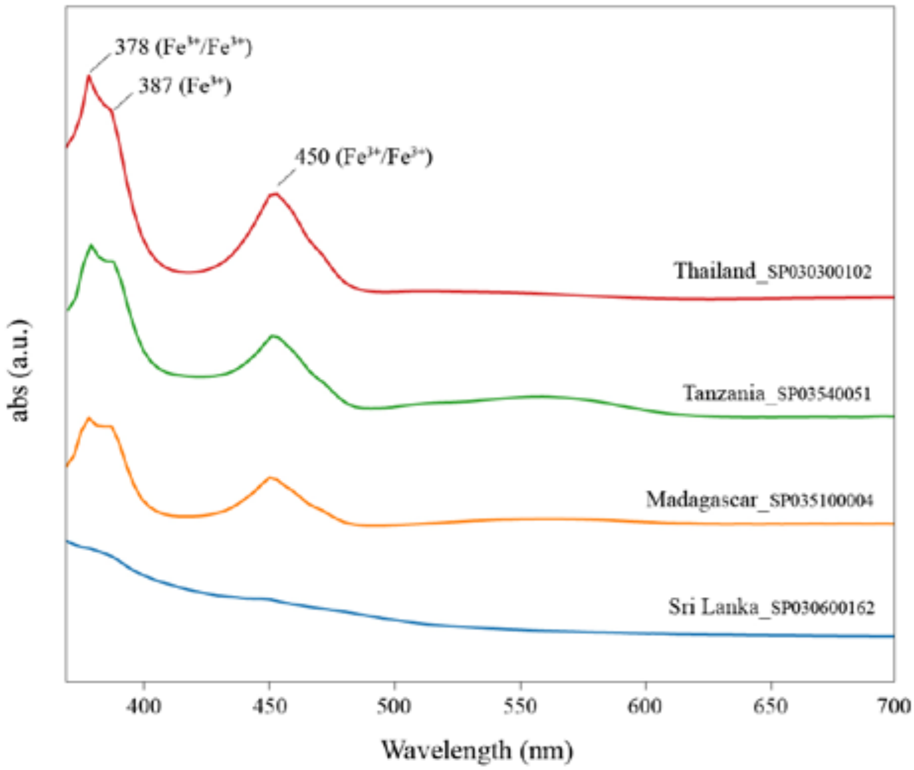


Figure 3: UV-Vis-NIR spectrum of yellow sapphire samples from various deposits examined in this study

Chemical analysis.

Chemical composition analysis of yellow sapphire samples using LA-ICP-MS revealed the presence of important trace elements, including Fe, Mg, Ga, Ti, Cr, and V. Yellow sapphires from Thailand exhibited the highest average Fe content (~15,000 ppm), followed by samples from Tanzania (~7,800 ppm), Madagascar (~4,500 ppm), and Sri Lanka (~440 ppm). The relatively high Fe content in Thai is attributed to their basalt-related geological origins, in contrast to Sri Lankan sapphires, which are typically associated with metamorphic rocks. As shown in Figure 4, 2D (Fe–Cr) and 3D (Fe–Mg–Cr) scatter plots clearly illustrate the differentiation of Sri Lankan yellow sapphires from those of other origins. Distinct clustering patterns were observed for each locality, enabling effective discrimination among samples from Sri Lanka, Madagascar, Tanzania, and Thailand. Among the trace elements, Fe, Mg, and Cr are identified as a key indicator for determining the geographical origin of yellow sapphires.

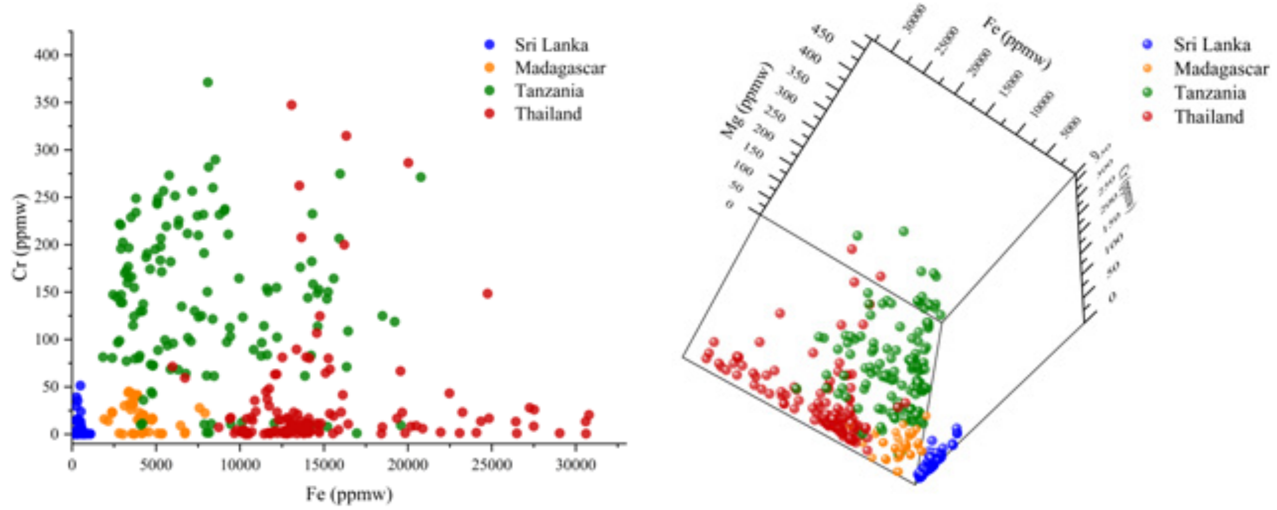


Figure 4: 2D and 3D scatter plots of trace element contents in yellow sapphires in this study.

Conclusion

This preliminary study demonstrates the potential for determining the geographic origin of yellow sapphires using a combination of various analytical techniques. The results highlight the ability to distinguish samples from Sri Lanka, Madagascar, Tanzania, and Thailand. Scatter plots of Fe-Cr and Fe-Mg-Cr concentrations show good clustering patterns, with Fe, Mg and Cr emerging as a key geochemical marker that reflects differences in geological formation. The integration of multiple methods, including inclusion observation, chemical analysis, and spectroscopic techniques, further enhances the accuracy of origin identification. For future research, increasing the sample size and incorporating a broader range of sample types and origins, colour variations, and treated stones from each locality will help strengthen and validate these findings.

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