CHAPTER III

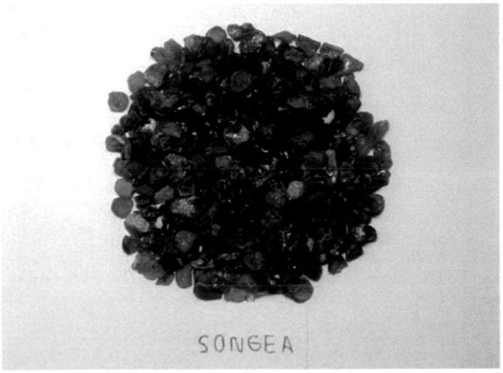
CHARACTERISTICS OF SOME SONGEA CORUNDUM

3.1 Introduction

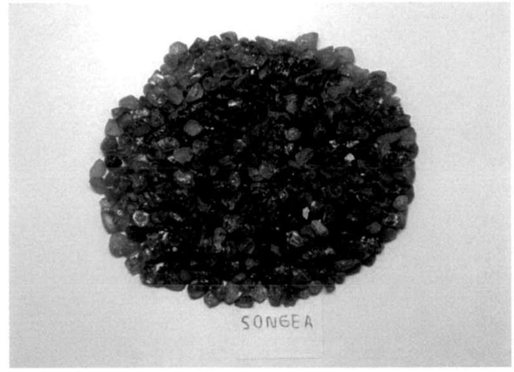
All characteristics observed from Songea corundum will be reported in this chapter. All fifty two corundum samples were selected to represent whole batch (more than 1000 grains) collections that were mostly provided by Thai traders. The selection was usually based on varieties of color of these samples. Subsequently, detailed color coding was carried out by comparing with the GIA Gem Set before the measurement and observation of other physical and gemological properties were consequently carried out. They include specific gravity, refractive index, luminescence and internal features. For spectroscopic studies and trace compositions, both aspects were also taken into account but these results will be reported in the next chapters. All properties mentioned above were carried out using basic gem testing equipments and some advanced instruments which details will be described in individual section.

3.2 Color

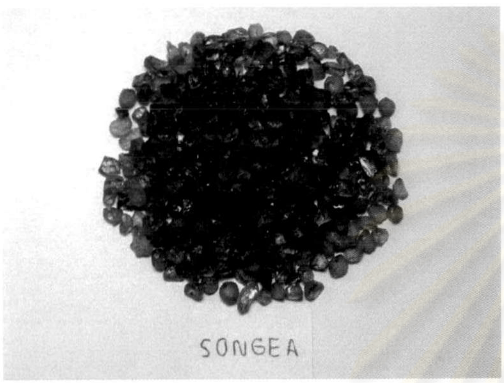
Gem corundums from this area usually have a wide range of color including red, orange, blue, violet, purple, yellow, green, colorless and every combination in between but do not appear to be quite in ruby color range. Mixed of colors in a single grain is a significant feature found in these samples. Therefore, Songea rubies may show orangy red, pinkish red, purplish red called "wine" or "burgundy" color (Kammerling et al., 1995). Subsequently, they were separated into 5 color varieties, i.e. red, purple, blue, yellow and colorless varieties (Figure 3.1). In addition, stones with various color patches are also distinguished (Figure 3.2). Representatives of each color variety were then selected for detailed study and comparison with GIA Gem Set.



Red variety



Purple variety

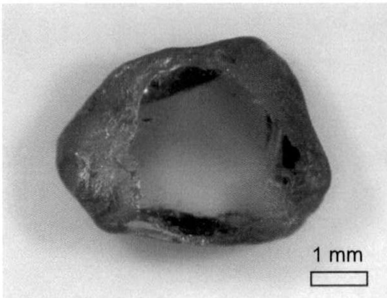


Blue variety

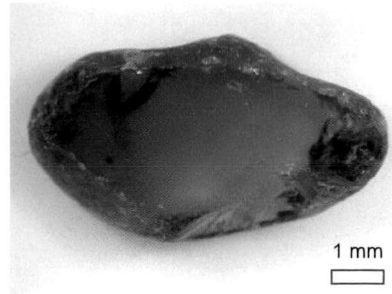
Mixed of yellow and colorless variety

Figure 3.1 Corundum samples from Songea were separated into 5 color varieties.

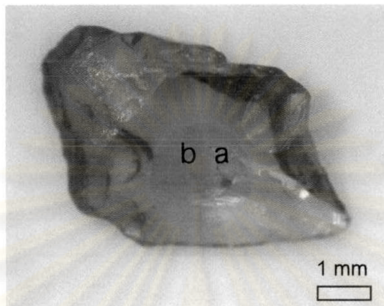
Color codes of representative samples obtained from comparison with the GIA Gem Set can be generally subdivided into 5 varieties. Red variety is composed of red (R), red orange (RO/OR) and orange (O). Purple variety contains violet (V), reddish purple (rP), bluish purple (bP), purple (P) and purple red (PR/RP). Blue variety is mostly blue (B) and violet blue (vB). Yellow variety is wildly characterized by yellow (Y), orangy yellow (oY), greenish yellow (gY), yellow green (YG/GY) green (G) and colorless variety (C). In addition, 16 samples have color patch or zoning; therefore they are not summarized in this category but they are shown in Appendix A. Consequently, samples of 5 initial color varieties were studied in details on gemological properties and other significant investigations.



sgb31: rim lvB7/3 core YG/GY2/1



sgb38: mdoR4/3 & lV8/1



sgb30: (a) PR/RP2/1, (b) patch or zoning R2/2

Figure 3.2 Color patch and zoning in Songea corundums in which their color codes are based on GIA Gem Set.

3.3 Physical and Gemological properties

Most of corundum samples in the collection are rounded pebble rough stones and are less than 1 carat, some red variety shows hexagonal shape. Besides, some red stones is fracture chips having fractures on the surfaces partly filled by iron stain. This character makes the stone look orange. Purple and yellow varieties are usually rounded grains which appear to have been transported; these features may refer to the alluvial deposit. Gemological properties of these stones are measured and presented mostly in Appendix A. However they are summarized in Table 3.1.

Purple and blue varieties exhibit a color change, ranging from weak to distinct. In purple variety, samples are purple/reddish purple in fluorescence light and are shifted to strong purplish pink in incandescence light (Figure 3.3). Blue variety shows blue color in fluorescence light and is shifted to weak purple color in incandescence light (Figure 3.4).

Luminescence characteristics of Songea samples under ultraviolet lamps are inert to moderate red under long wave and inert under shortwave as shown in Table 3.1. Moreover, the red variety of Songea corundums was examined using cathodoluminoscope (CL) model CLmk3A of CITL (Cambridge Image Technology Limited) at Department of General Science, Faculty of Science, Kasetsart University (Figure 3.5). Because study of cathodoluminescence is conventionally used for examination of ruby, only red variety samples were selected for this investigation. Samples appear very weak red only at the rims (Figure 3.6). Very weak cathodoluminescence may be related to iron contents in the samples. Luminescence in ruby under UV light is known to be suppressed by iron. The trace compositions obtained using Energy Dispersive X-ray Fluorescence (EDXRF) yield very high iron contents (1.04-1.45 wt%) in this variety of corundum (see next chapter). This may cause very weak cathodoluminescence in the red variety.

Figure 3.3 Purple variety showing purple/reddish purple in fluorescence light (left) and strong purplish pink in incandescence light (right).

Figure 3.4 Blue variety appearing blue rim and light yellow core in fluorescence light (left) and weak purple color in incandescence light (right).

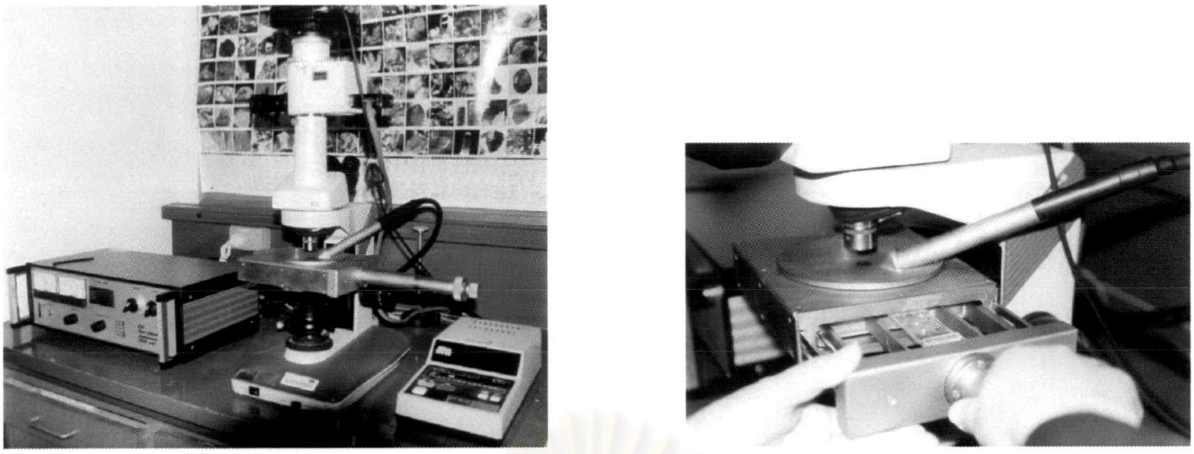


Figure 3.5 Cathodoluminoscope; model CLmk3A, Cambridge Image Technology Limited, based at Kasetsart University.

Figure 3.6 Image of a red variety of Songea corundum under cathodoluminoscope showing rather weak red luminescence.

Table 3.1 Summary of physical properties of representative corundums from Songea under this study.

Varieties	SG.	RI.		Birefringence	Luminescence (UV Light)	
		n_o	n_e		LW	SW
Red	33.89-4.02 (av. 3.99)	1.773-1.780	1.765-1.772	0.008	weak orange to moderate red	inert
Purple	3.85-4.02 (av. 3.91)	1.772-1.777	1.763-1.768	0.009	weak red	inert
Blue	3.92-3.98 (av. 3.95)	1.774-1.775	1.765-1.770	0.007	inert	inert
Yellow	3.92-4.08 (av. 4.02)	1.771-1.778	1.763-1.769	0.008	inert	inert
Colorless	3.74-3.83 (av. 3.78)	1.774-1.779	1.766-1.771	0.008	inert	inert

3.4 Internal Features

3.4.1 Microscopic Observation

Songea corundum samples were firstly examined under a binocular microscope (model SMZ-U) attached with FUJIX digital camera (model HC-300zi) at Department of General Science, Kasetsart University (Figure 3.7) for initial investigation of internal features. This examination is aimed at characterization of all internal features, including mineral inclusions. This fundamental information was crucial to design for further works (e.g. Raman spectroscopy and mineral chemistry of mineral inclusions etc). Finally, all data can be used for discussion on potential host rocks and perhaps origin of Songea corundum.

Internal features observed under microscope in Songea samples generally are fractures with iron stain, single or cluster of dark minute particles, short to long rutile needles intersecting at 60/120° directions, fingerprints and negative crystals (Figures 3.8 to 3.13). Besides, several types of mineral inclusions were additionally identified using Laser Raman Spectroscope. Subsequently, some representative's mineral inclusions were then selected for chemical analysis using Electron Probe Micro-Analyzer (EPMA). However, this chapter will report mineral types and their Raman spectra only; mineral chemistry of inclusions will be discussed in the last chapter.

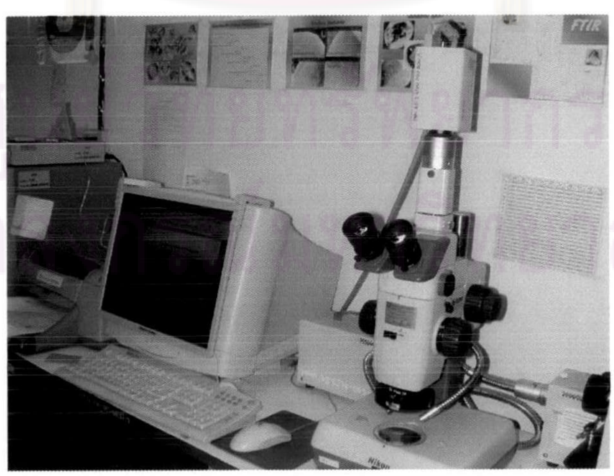


Figure 3.7 Microscope attached with digital camera at the Department of General Science, Kasetsart University were used for investigation of internal features.

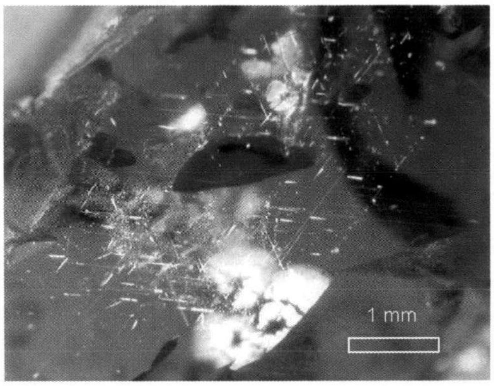


Figure 3.8 Iron-stained fractures and short rutile needles (sample sgb23 of red variety).

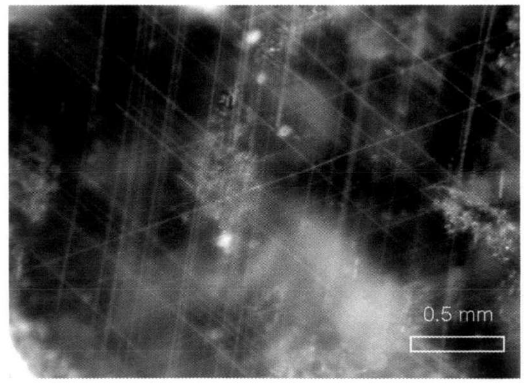


Figure 3.9 Long rutile needles set in 60/120^{o} directions with dust particles (sample sgb42 of purple variety).

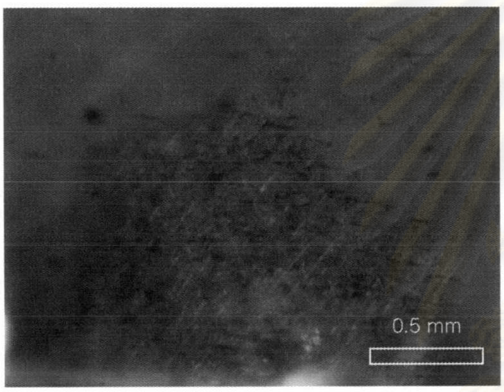


Figure 3.10 Short brown needles gathering in hexagonal form (sample sga14 of purple variety).

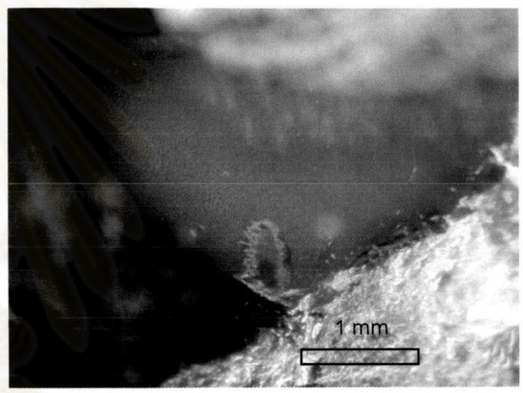


Figure 3.11 Fingerprints features found in Songea corundums (sample sgb40 of purple variety).

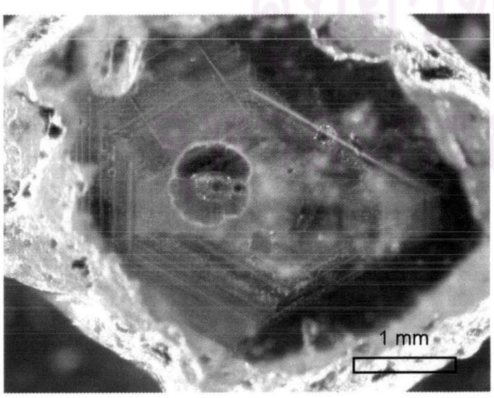


Figure 3.12 Hexagonal growths zoning (sample sgf143 of yellow variety).

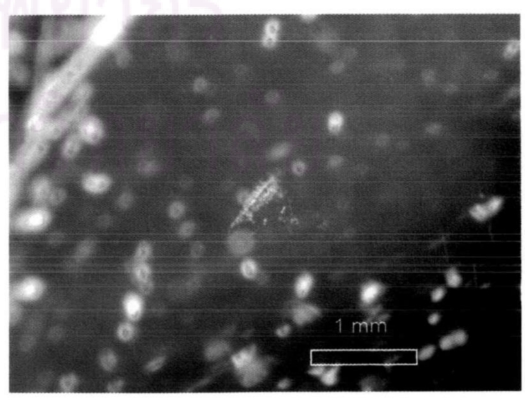


Figure 3.13 Negative crystals (sample sgb46 of purple variety).

3.4.2 Laser Raman Spectroscopic Determination

About thirty samples containing mineral inclusions were prepared and polished until those inclusions were exposed to the surfaces, and they were subsequently analyzed using Laser Raman Spectroscopy (Renishaw Ar LASER 514 nm, green with He-Ne LASER 621 nm, red) source at the Gem and Jewelry Institute of Thailand (GIT) (Figure 3.14).

Investigation of mineral inclusion indicates that the most common mineral inclusions in Songea corundum are apatite, epidote, feldspar, hematite, garnet, mica, paragonite and rutile.

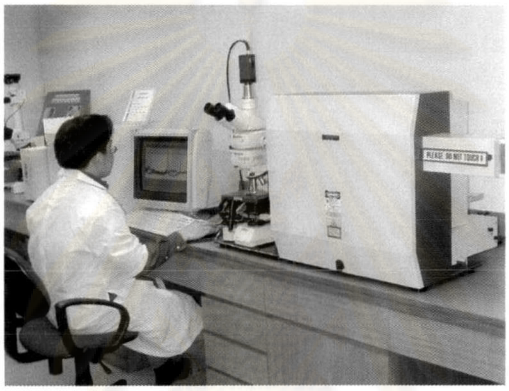


Figure 3.14 Laser Raman Spectroscope belonging to the GIT used for identification of mineral inclusion.

Rutile is the most dominant mineral inclusion which found in all color varieties in the forms of needle and crystals. Their colors are black, dark red brown, orange red and orange yellow colors. Black opaque rutile crystals contain largest size and are found particularly in purple variety. Dark red brown rutile inclusions present mostly in red and in some samples of yellow varieties, orange red rutile inclusions are found in red variety whereas small orange yellow rutile inclusions are mostly found in yellow variety. Black and brown rutile crystals are usually associated with fluid inclusions (Figure 3.15) whereas orange rutile inclusions show tension disc. Transparent epidote inclusions usually are colorless while some pale yellow, epidote inclusions are found as single/aggregate crystals in purple variety (Figure 3.16). Large inclusions of pinkish orange, orange, light brown and near-colorless garnets are usually found in purple corundum variety and sometimes in red variety that can be observed by naked eye (Figure 3.17). Feldspar inclusions are recognized in blue variety; they show aggregate, oval and transparent grains (Figure 3.18). Paragonite and apatite inclusions are rarely observed in Songea corundum. Paragonite inclusions are flat hexagonal shape and surrounded by crack and iron stain. Apatite inclusion present as small transparent crystals (Figure 3.19), mica inclusion is small transparent crystal in purple variety (Figure 3.20) and hematite is formed as brown to black opaque inclusions (Figure 3.21). All internal features found in each color variety of Songea corundums under this study are summarized in Table 3.3.

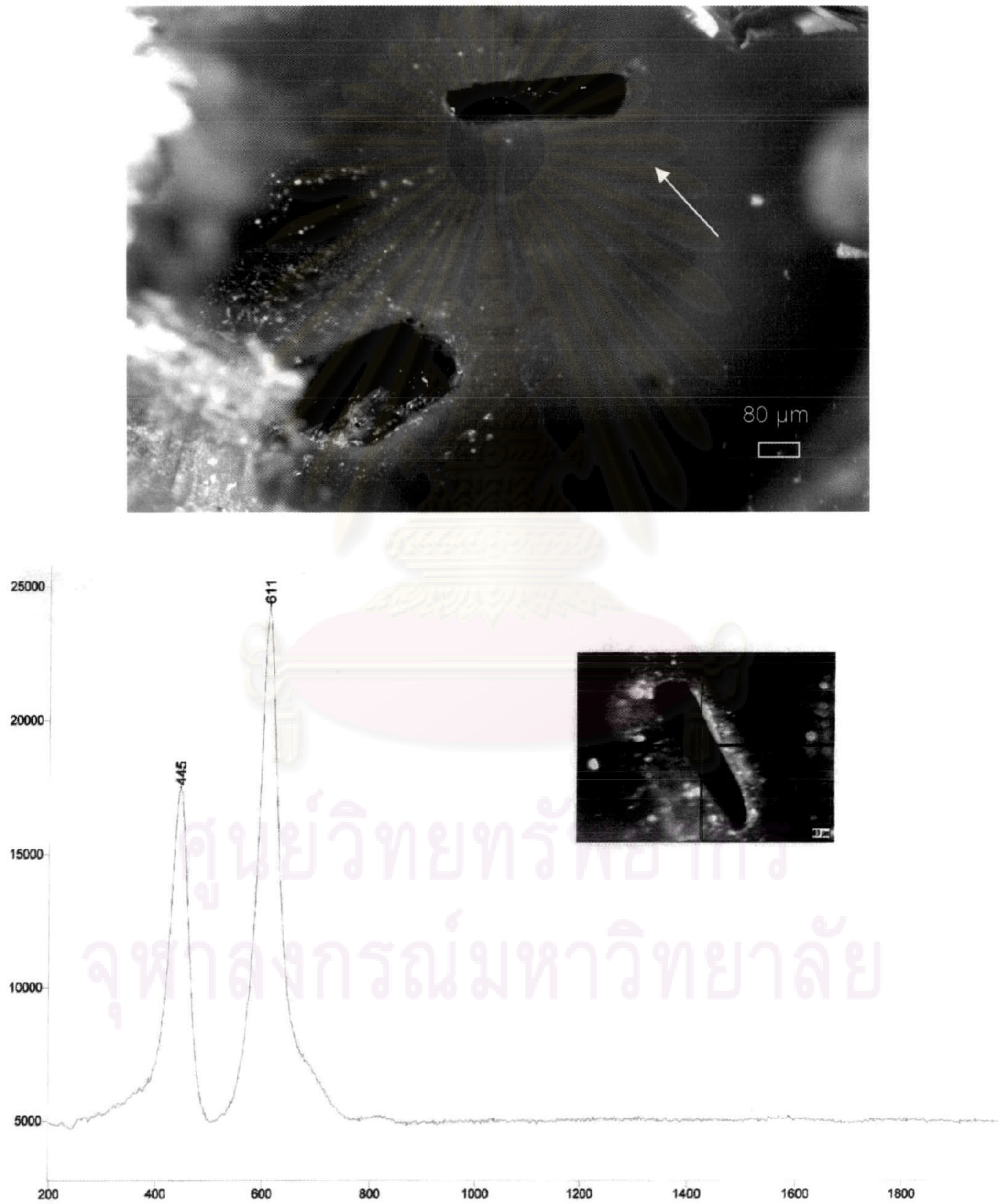


Figure 3.15 Large black opaque rutile inclusion closely associated with fluid inclusion in sample sgd92 of purple variety (top) and Raman spectrum (bottom) of rutile crystal as pointed by white arrow.

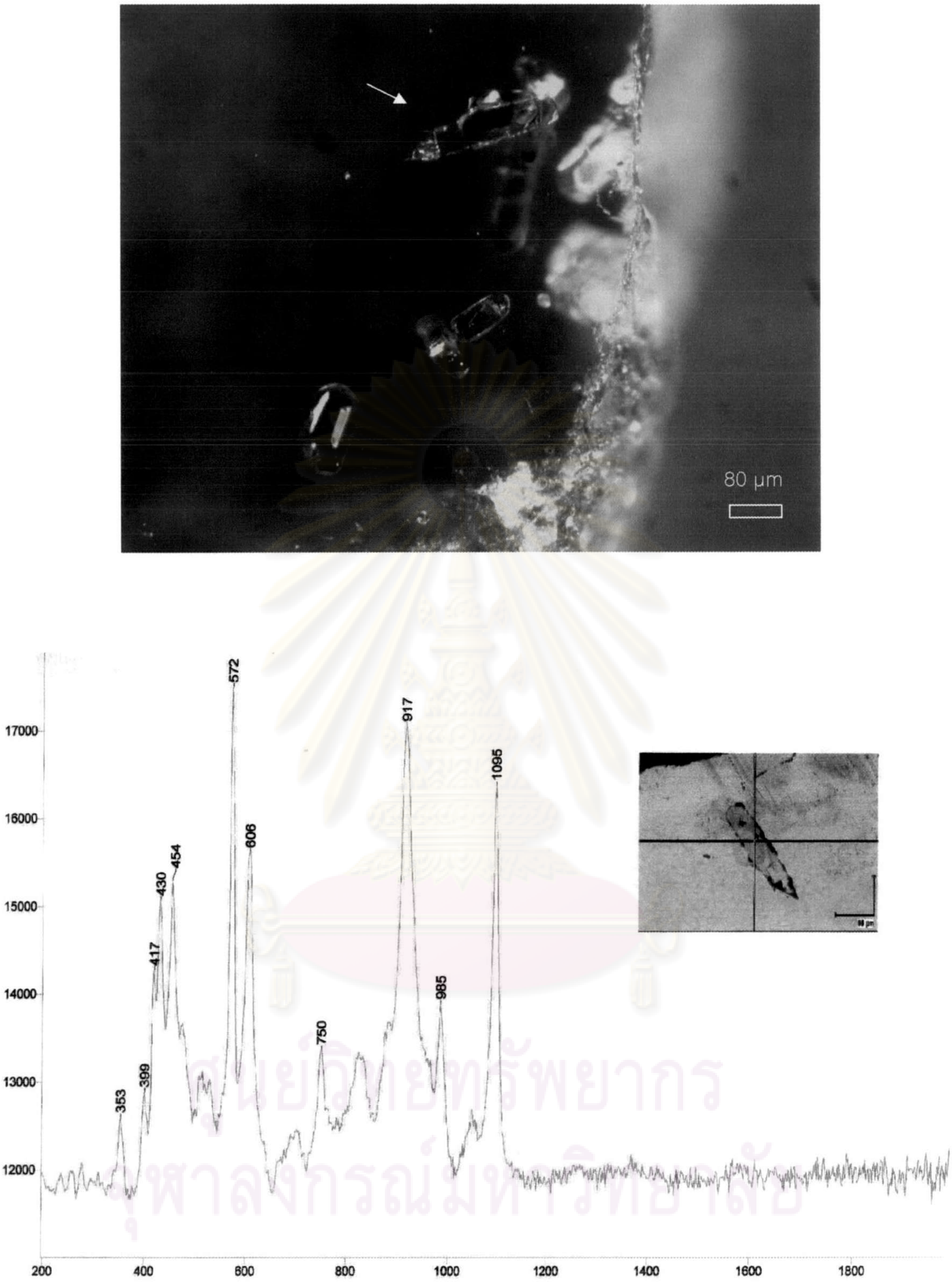
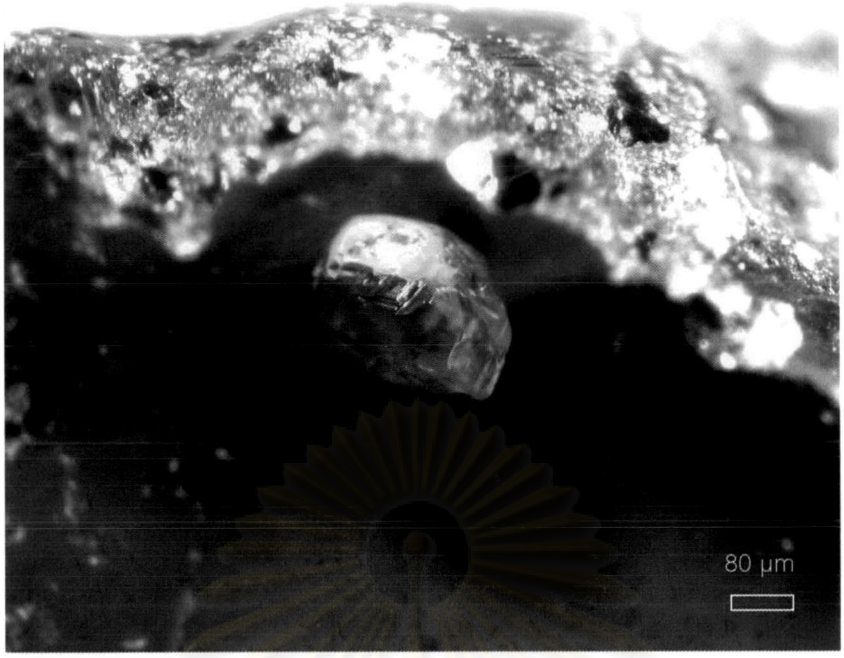


Figure 3.16 Single and aggregate crystals of epidote inclusion in sample sgd90 of purple variety (top) and Raman spectrum (bottom) of epidote crystal as pointed by white arrow.



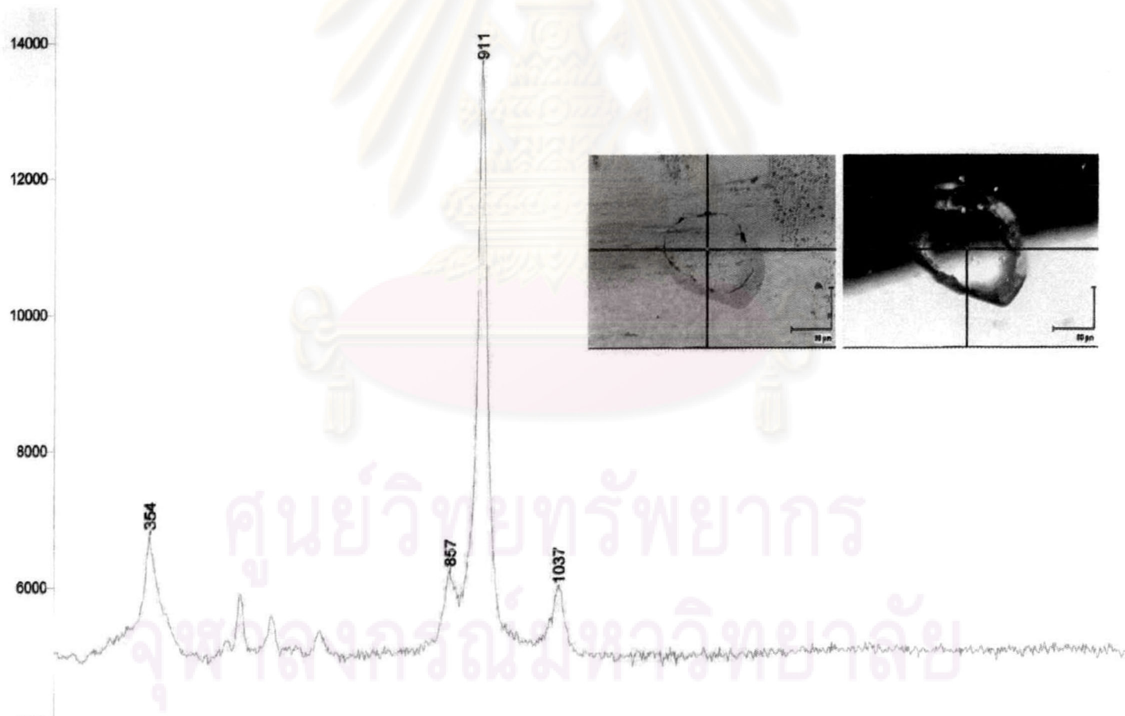


Figure 3.17 Large pinkish orange garnet found in sample sgd94 of purple variety (top) and Raman spectrum (bottom) of garnet crystal.

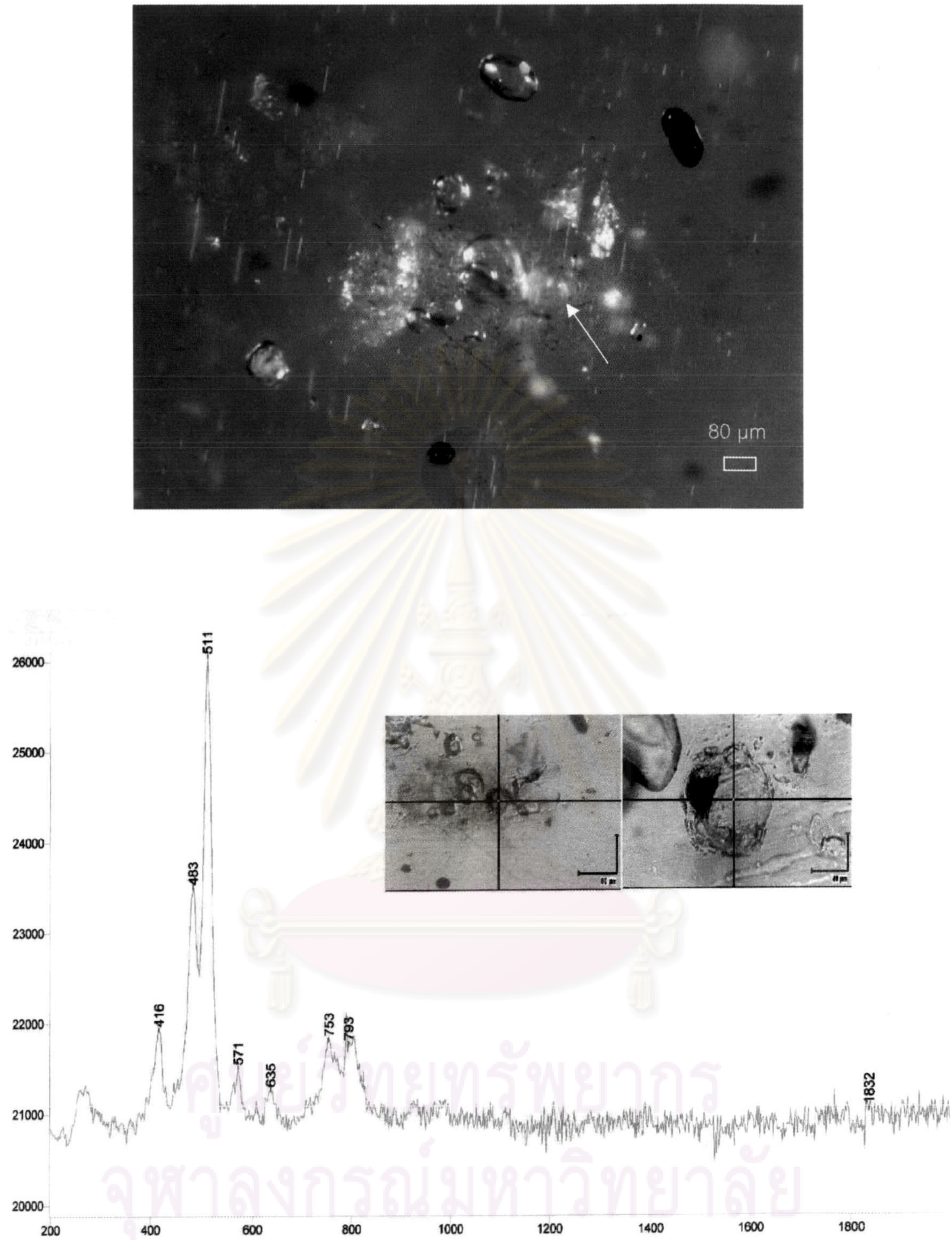


Figure 3.18 Transparent feldspar in sample sgd88 of blue variety (top) and Raman spectrum (bottom) of feldspar crystal as pointed by white arrow.

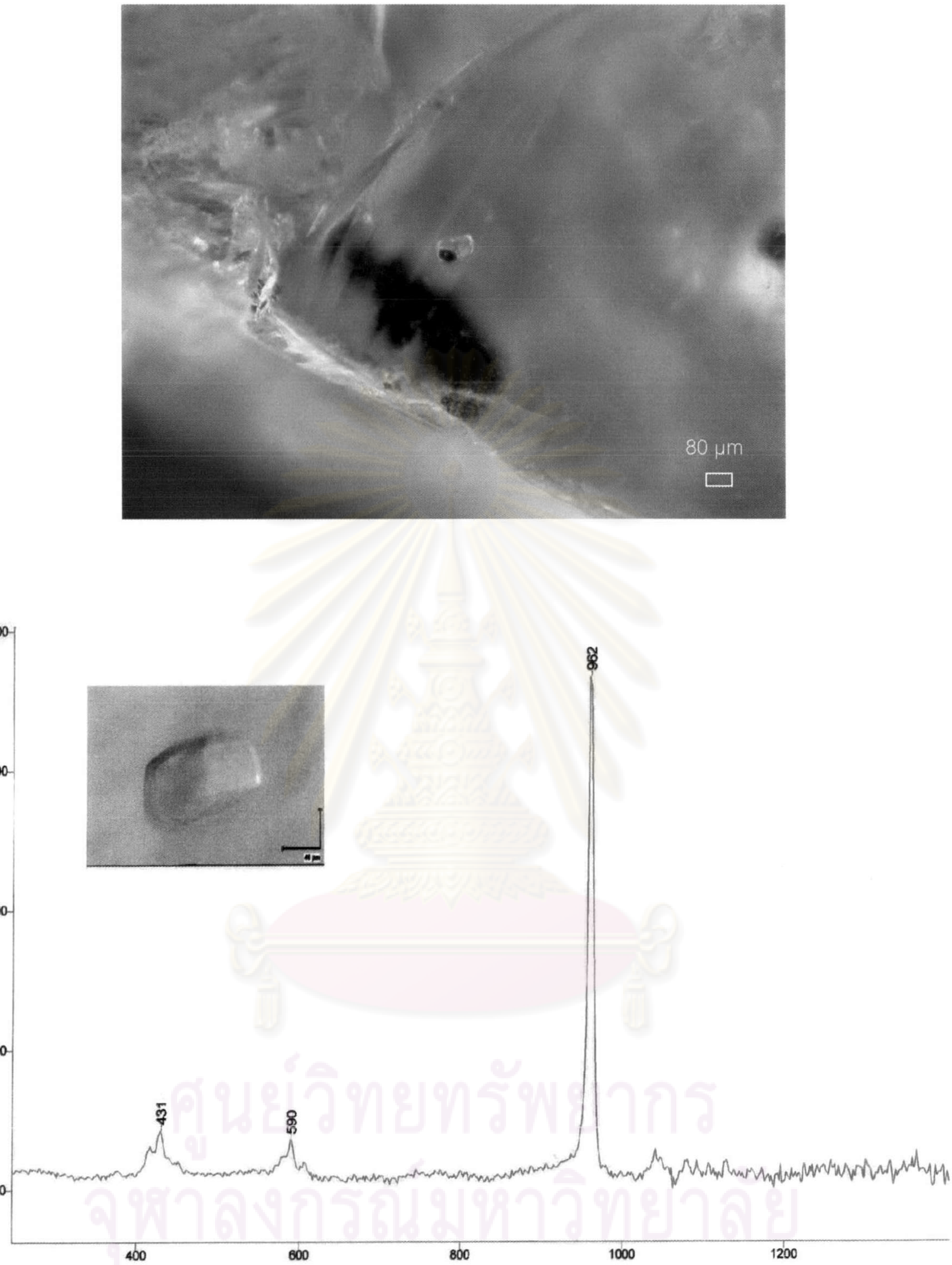


Figure 3.19 Small transparent apatite inclusion in sample sgd124 of yellow variety (top) and Raman spectrum (bottom) of apatite crystal.

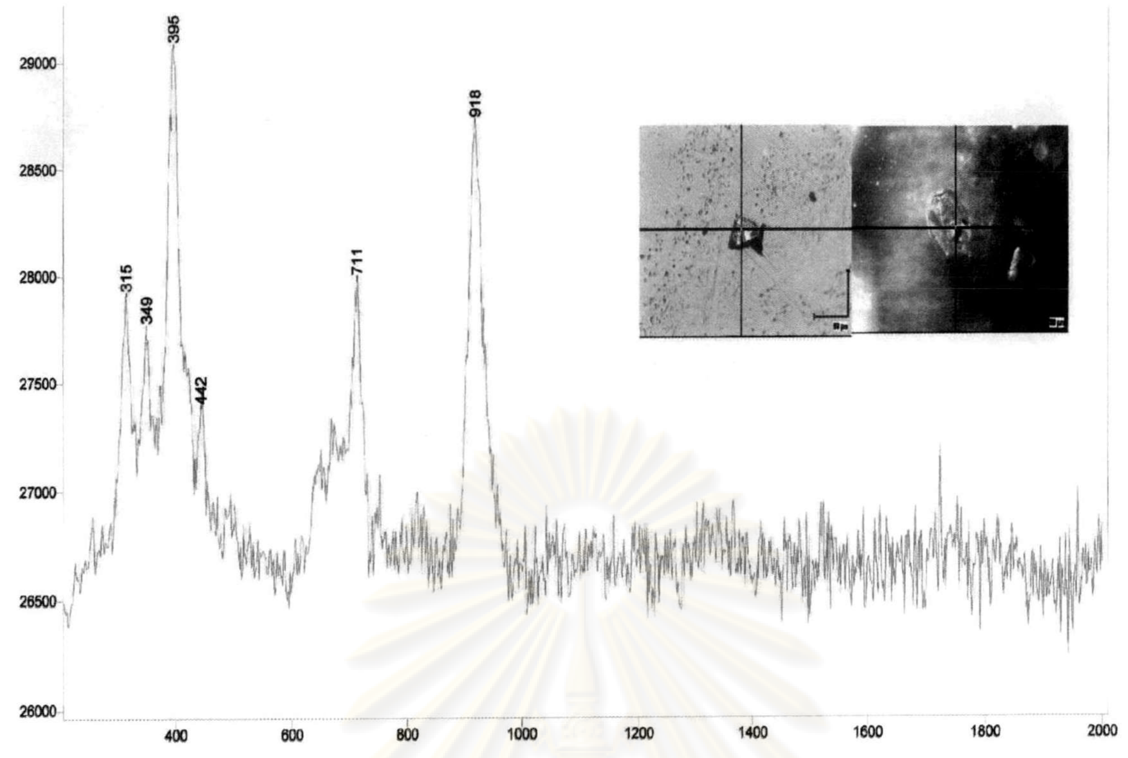
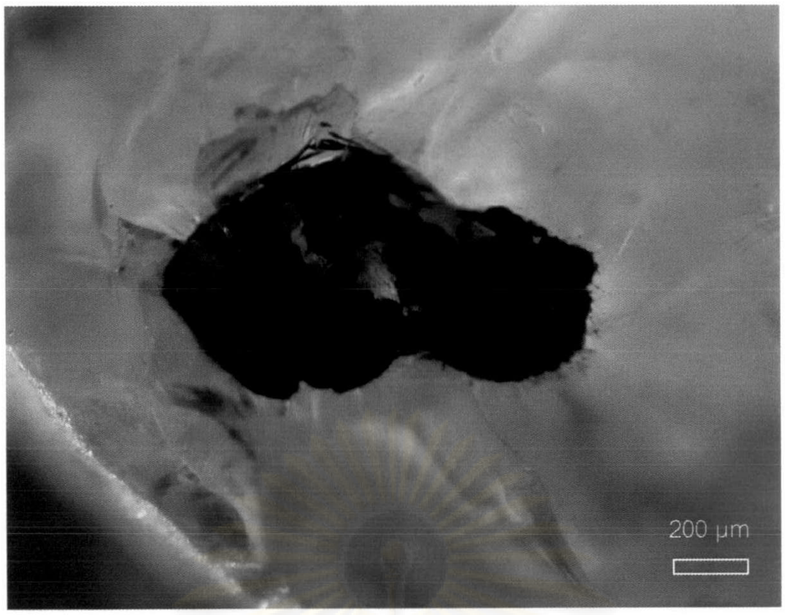


Figure 3.20 Small transparent mica inclusion in sample sgd91 of purple variety and its Raman spectrum.



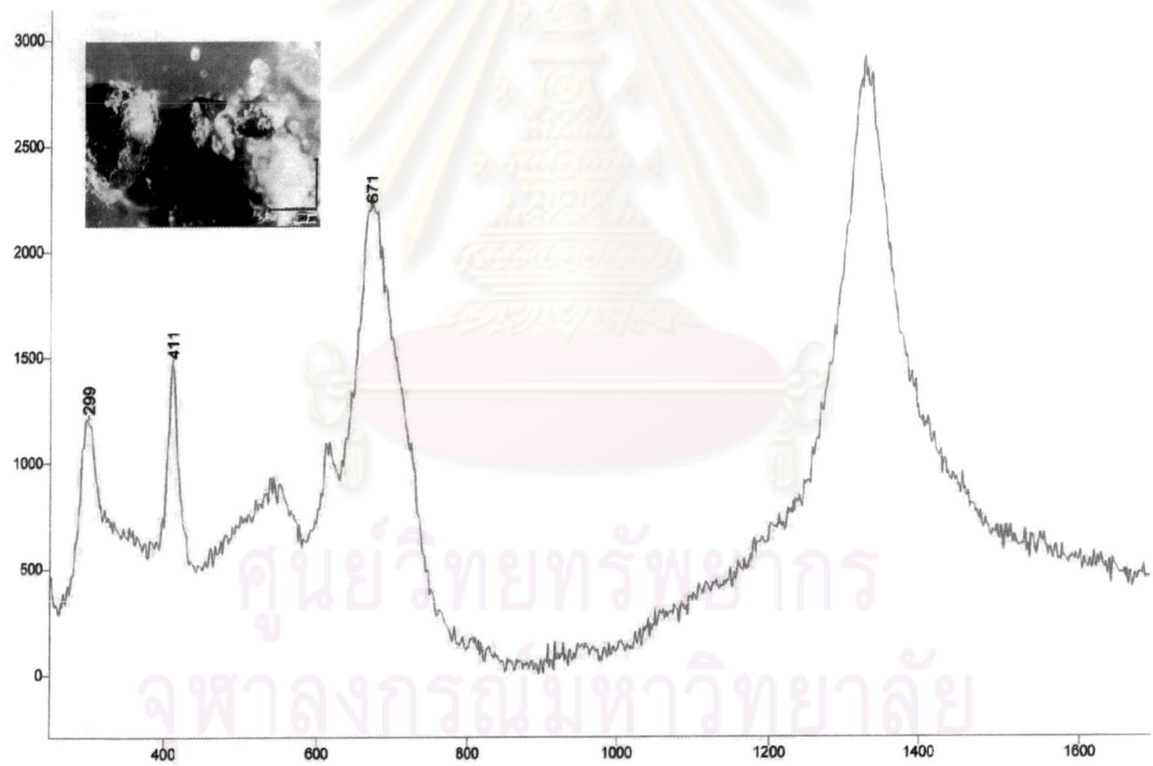


Figure 3.21 Small transparent hematite inclusion in sample sgd114 of red variety and its Raman spectrum (bottom).

Table 3.2 Internal features in Songea corundums discovered in this study.

Color varieties	Internal features
Red	Crystal inclusions: black and brown rutile with short and long needles, garnet, paragonite and hematite Crack, iron stain, minute particles
Purple	Crystal inclusions: black and orange rutile with short and long needles, epidote, garnet, paragonite and mica Minute particles, fingerprints
Blue	Crystal inclusions: black rutile crystals, rutile needles and feldspar Minute particles, fingerprint
Yellow	Crystal inclusions: short orange rutile, rutile needles and apatite Fine fingerprints
Colorless	Crystal inclusions: - fractures, minute particles, fingerprints

3.5 Chemistry of mineral inclusion

Electron Probe Micro-Analyzer (EPMA) at Macquarie University, Australia (Figure 3.22) was engaged to analyze mineral inclusions. Most mineral inclusions initially identified by Raman Spectroscopy were selected and prepared. Three to seven corundum grains containing mineral inclusions were placed into round mold, then they were filled by rasin (Figure 3.22). Subsequently, the samples inclusions were polished until inclusions were exposed to the surface. Unfortunately, some inclusions were gone during polished process. There were finally, garnet, feldspar, epidote and rutile available for analysis; moreover, quality of polished surface around exposed inclusions is sometimes very low. Some inclusions are quite tiny. These lead to low qualities of EPMA analyses (Table 3.3).

All available analyses were recalculated on basis of proper oxygen atoms such as 4(O) for feldspar, 13(O) for epidote, 2(O) for rutile and 24(O) for garnet (Table 3.3). These analyses not only confirm Raman analyses but also give more information that will be used for discussion in the last chapter. For instant, mineral chemistry of these inclusions indicate that garnet is rich in almandine component; feldspar yields about 40% Ca of mole fraction falling in andesine range (Figure 3.23); rutile and epidote are likely pure phases.

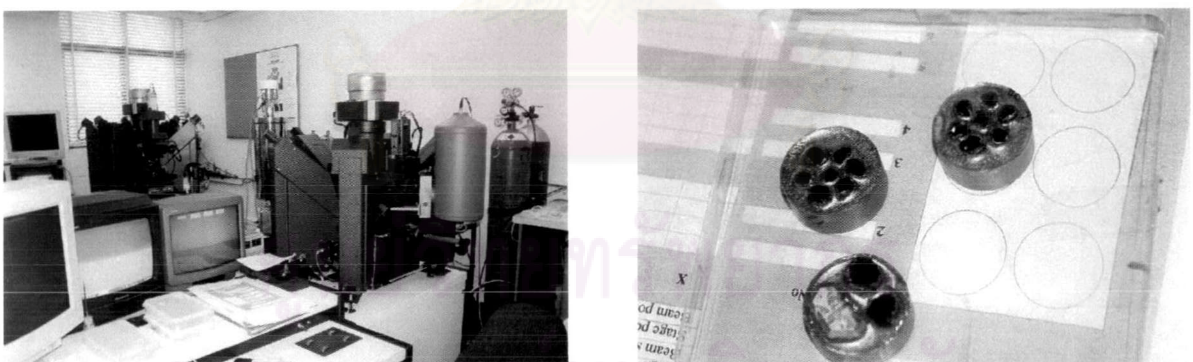


Figure 3.22 Electron Probe Micro Analyzer (EPMA) at Macquarie University, Australia (left) and sample preparation (right).

Table 3.3 EPMA Analyses of some mineral inclusions found in Songea corundums.

	sgd94 garnet	sgd88 feldspar1	sgd88 feldspar2	sgd90 epidote	sgd92 rutile1	sgd92 rutile2	sgd99 rutile3
SiO2	38.88	58.24	57.00	37.27	0.02	0.02	0.02
TiO2	0.07	0.00	0.02	0.24	97.19	96.14	97.65
Al2O3	21.91	26.24	26.20	27.06	0.00	0.00	0.23
Cr2O3	0.02	0.00	0.04	0.04	0.04	0.00	0.01
FeO	26.29	0.10	0.13	6.50	0.53	0.56	0.44
MnO	0.35	0.05	0.00	0.11	0.00	0.01	0.02
MgO	4.84	0.00	0.00	0.00	0.00	0.00	0.00
CaO	8.36	8.27	8.45	23.61	0.03	0.01	0.01
Na2O	0.04	6.84	6.91	0.01	0.05	0.00	0.07
K2O	0.00	0.28	0.07	0.02	0.03	0.02	0.00
NiO	0.00	0.00	0.02	0.03	0.01	0.00	0.00
P2O5	0.00	0.02	0.00	0.11	0.00	0.04	0.01
Cl	0.01	0.01	0.00	0.00	0.00	0.01	0.00
Total	100.75	100.04	98.83	94.98	97.89	96.80	98.46
Formula	24(O)	4(O)		13(O)	2(O)		
Si	6.017	2.608	2.586	3.154	0.000	0.000	0.000
Ti	0.008	0.000	0.001	0.015	0.996	0.996	0.994
Al	3.995	1.385	1.401	2.698	0.000	0.000	0.004
Cr	0.002	0.000	0.001	0.002	0.000	0.000	0.000
Fe2+	3.402	0.004	0.005	0.460	0.006	0.006	0.005
Mn	0.046	0.002	0.000	0.008	0.000	0.000	0.000
Mg	1.116	0.000	0.000	0.000	0.000	0.000	0.000
Ca	1.387	0.397	0.411	2.140	0.000	0.000	0.000
Na	0.011	0.594	0.608	0.001	0.001	0.000	0.002
K	0.000	0.016	0.004	0.002	0.000	0.000	0.000
Ni	0.000	0.000	0.001	0.002	0.000	0.000	0.000
P	0.000	0.000	0.000	0.002	0.000	0.000	0.000
Total	15.982	5.005	5.018	8.484	1.005	1.004	1.005

Note: sgd88 (feldspar1 = oval shape and lighter, feldspar2 = rounded shape and darker), sgd90 (colorless epidote), sgd92 (rutile1 = black and rod shape, rutile2 = black and oval shape), sgd94 (big pinkish orange garnet), sgd99 (rutile1 = small zone)

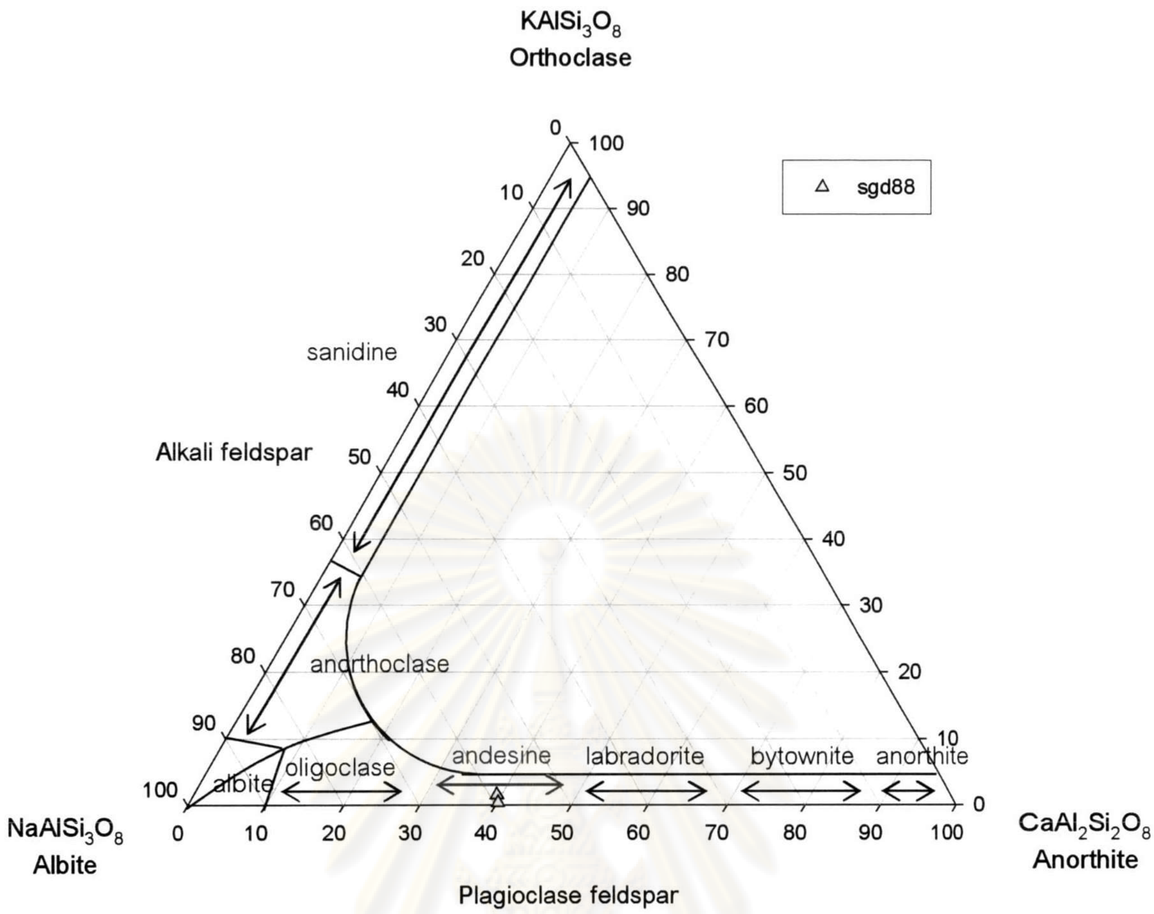


Figure 3.23 Feldspar nomenclature: orthoclase-albite-anorthite ternary plotting composition of feldspar inclusions in Songea corundum (modified from Klein and Hurlbut, 1977).