The sapphirine–ruby connection: new occurrence in an ornamental rock named ìTutti-Fruttiî

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For many years, petrologists have described relationships between corundum as ruby and the rare mineral sapphirine. Sapphirine has been described in several geological context, including eclogites and high-temperature magnesian schists. Until know, occurrences of sapphirine with ruby were known in low-silica alumina-rich rocks that formed under high-grade metamorphism, as a result of the hydratation of gabbros or troctolites. Such rocks are mostly pargasite amphibolites.

In this paper we describe pluricentrimetric sapphirine crystals from an unknown source probably located in Southern Kenya, in a vein-like metasomatic rock consisting mainly of calcic plagioclase, green Cr-pargasite and Mg-tourmaline, blue Cr-kyanite and ruby. This uncommon color melange prompted the use of the name “Tutti-Frutti”! These metasomatic veins are hosted in serpentinised ultramafic rock and show phlogopite-spinel salbands.

The sapphirine prisms in contact with phlogopite are rimmed by a ruby polycristalline shell. Ruby in contact with pargasite is rimmed by spinel. Such mineral assemblages are reminiscent of those observed in sapphirine-bearing metagabbros, however in this case the relationships of the different rocks, and their structure, points towards a metasomatic origin.

Introduction

Sapphirine has been described in a range of rocks including Al-rich granulites (Arima and Barnett, 1984; Droop and Bucher-Nurminen, 1984; Currie and Gittins, 1988; Kriegsman and Schumacher, 1999); corundum-bearing amphibolites or anorthosites (Forestier and Lasnier, 1969; Herd et al, 1969; Haapala et al, 1971; Pamic et al, 1973; Janardhanan, 1974; Lasnier, 1977; Nicollet, 1986; Tenthorey et al, 1996), aluminous xenoliths in igneous rocks (Harley and Christy, 1995), Al-Mg schists (Segnit, 1957; Seifert, 1974), and vein-like metasomatized rocks around ultramafic intrusions (Currie and Gittins, 1988). It has also been described as part of a xenolith in alkali basalts from Australia (Sutherland and Coenraads, 1996), and as an inclusion in a ruby from an alkali basalt field in Thailand (Koivula and Fryer, 1987). Sapphirine occurs as an accessory mineral in ruby- and dravite-bearing desilicated rocks of Southern Kenya (Austromineral GmbH, 1978; Mercier et al, 1999; Simonet, 2000a).

The range of P-T conditions at which sapphirine forms has been summarised by Christy (1989) and spans from 650 to more than 1000 C, and from 3 to more than 12 kbar. In most of the rocks mentionned above, sapphirine occurs with corundum and other aluminous minerals.

The sapphirine-bearing rocks described here are unique since to the best of our knowledge, the paragenesis has never been described before. The samples were brought to the Laboratory of Gemmology of the University of Nantes in 1995. Their geographic origin is unknown, although the type of alteration of the rock, as well as information provided by the samples owner, suggest that it comes from East Africa.

Petrography and mineralogy

The sapphirine-bearing rock, christened “Tutti-Frutti” owing to the wide range of colours of the minerals constituting it, appears as a vein-like material. These veins, as one can judge from the few samples available, are 10 to 40 cm thick, and are hosted by serpentinized ultramafic rock. The vein material is separated from its host rock by a 2 to 10 cm thick micaceous salband. It consists basically of plagioclase, phlogopite and sapphirine, with varying amounts of corundum, dravitic tourmaline, kyanite, pargasitic amphibole, spinel, cordierite, graphite and altered sulphides. The texture is coarse, pegmatoid (Figure 1). The salbands consist mostly of phlogopite with scattered spinel grains, with minor amounts of carbonates, altered pyrite and graphite.

Sapphirine appears as large, euhedral to anhedral crystals, up to 10 mm wide and 40 mm long (Figure 2). In sections parallel to the main axis of the crystals, colour zonation is apparent with a light grey core circled by a darker purplish grey rim. Sapphirine belongs to the earliest paragenesis, and is in contact with either plagioclase, phlogopite or pargasite, and in most cases rimmed by corundum (Figure 2). When sapphirine is in contact with phlogopite, the corundum lamellae are parallel to the cleavages of the phlogopite, which suggests that both minerals originated from the breakdown of sapphirine. In some samples, sapphirine is separated from phlogopite by a rim of a fine grained chlorite pseudomorphosing an other mineral, possibly cordierite.

The structural formula is $(Si_{1.4}\ Al_{4.6})(Al_{4.5}\ Mg_{3.4})O_{20}$, and is close to the 7:9:3 formula (Figure 3). This sapphirine contains up to 1.8 wt% Cr_2O_3, which explains its red cathodoluminescence coolour. Cr-bearing sapphirines have been described in different locations (see Nicollet, 1986), and their Cr_2O_3 content can reach up to 7.4 wt% (Friend, 1982). Limited substitution of Fe^{2+} with Mg, and Fe^{3+} with Al, is known to occur (Seifert, 1974), but most sapphirine analysis published, especially for samples originating from Al-rich metapelites, contain significant amounts of Fe (e.g. Arima and Barnett, 1984; Droop and Bucher-Nurminen, 1984; Kriegsman and Schumacher, 1999). The absence of Fe in the Tutti-Frutti sapphirine is unusual, but is consistant with the high XMg recorded in dravite and amphibole (see further below). This sapphirine is rather similar to sapphirine from anorthosites (compare with sample a24 of Nicollet, 1986 and to sapphirine symplectites from meta-troctolites of North Carolina (Tenthorey et al, 1996). Its composition is also close to that of relictual sapphirine from the Aquamines ruby deposit in Kenya, where the same type of reaction involving corundum, phlogopite and sapphirine has been observed (Mercier et al, 1999; Simonet, 2000). On a power X-ray diffractogram (figure 4), peaks for both 1Tc and 2M polytypes are present, a fact commonly observed in many natural sapphirines (Christy, 1989)

Corundum. Three different type of corundum have been identified. The first type appears as millimetre size granules or lamellae forming rims around the sapphirine crystals (Figure 1 and 2). These crystals have a red colour in thin section.

The second type consits of anhedral to euhedral crystals of larger size (up to 5 mm across). These crystals typically show a colour zonation, with a colourless core and a red rim. The core is also often partly occupied by minute epitaxic inclusions of rutile drawing a hexagonal pattern (Figure 5). Type 1 and 2 can be present in the same sample and at least part of type 2 corundum seems to originate from the recrystallisation of type 1 corundum. The red colour of the mineral, as usual with ruby, is owed to the presence of Cr traces.

The third type, more rare, consits of rounded crystals hosted in kyanite blades, at the expense of which they appear to have grown. These crystals also show a colour zonation, although the amount of rutile inclusions is lower.

Phlogopite is present in the vein itself, and is also the main constituant of the salbands were it is more fine grained. Its structural formula is $(Si_{2.64-2.76}Al_{1.24-1.36})(Al_{0.01-0.28}Mg_{2.47-2.65}Ti_{0.03}Cr_{0.01-0.03})(K_{0.78-0.87}Na_{0.06})\ O_{10}\ (OH)_2$. This mineral has a XMg =1, and as a result is colourless in thin sections. This phlogopite is chemically similar to that of the ruby-bearing rocks of the Aquamines ruby deposit in Kenya (Simonet, 2000a).

Spinel appears as anhedral grains scattered in the phlogopite of the salbands. It is colourless in thin section and bright red in hand specimen. A qualitative microprobe analysis showed that it is mostly constituted of Al and Mg, and is therefore spinel s.s. The colour is owed to traces of Cr.

In one sample that does not contain sapphirine, Cr-spinel appears as anhedral grains at the contact between corundum crystals and pargasite. This type of spinel is of orange-brown colour in thin sections. Its structural formula is $(Al_{1.2-1.5}Cr_{0.6-0.8})(Mg_{0.8}Fe_{0.1}Zn_{0.1})O_4$. So far spinel has not been observed in direct association with sapphirine, although reactions involving sapphirine and spinel have been noted in sapphirine-bearing rocks (Forestier and Lasnier, 1969; Lasnier, 1977; Tenthorey et al, 1996).

Anorthite (An_{97}) appears as large porphyroclasts and as smaller recrystallised neoblasts with a granuloblastic structure, and seems to be, with sapphirine, the earliest mineral in the rock. The anorthite matrix is locally invaded by phlogopite.

Dravite. Poeciloblastic tourmaline is present in some samples in association with anorthite, kyanite and corundum. It is bright emerald green in hand specimen. Chemically, it is a solid solution of dravite and uvite (61-64 mol % dravite), with a XMg =1. Cr traces, together with the absence of Fe, are responsible for its green colour and for its red cathodoluminescence. Its chemical composition is similar to that of gem-quality dravite-uvite solutions from East Africa associated or not to ruby deposits (Key and Ochieng, 1989; Simonet, 2000a and 2000b) . On a diagram of Henry and Guidotti (1985), it plots in the field of tourmalines associated to low Ca ultramafites and Cr-V metasediments (Figure 6). In the absence of B analysis, normalisation of the formula was done on the basis of 15 cations in T, Z and Y sites, following the recommendations of Henry and Dutrow (1996) for Li-deficient tourmalines. The obtained formula is:

$$(Si_{5.8}Al_{0.2})(Al_{6.4}Cr_{0.1}Mg_{2.5})(Ca_{0.3}Na_{0.5})(BO_3)_3(OH)_4$$

Al appears to be present in the T site (0.2 a.p.f.u.), and Mg is also deficient, which is likely to be partly the results of a Si+Mg <-> 2Al substitution. This observation reinforces the aluminous character of the mineral assemblage.

Pargasite. Clino-amphibole occurs as deformed porpyroclasts, particularly between anorthite and plagioclase, and appears to be a relict. It is bright green both in hand specimen and in thin section. Its empirical formula is $(Si_{5.9-6.2}Al_{1.8-2.0})(Al_{0.9}Cr_{0.2}Mg_{3.8})(Ca_{1.9}Na_{0.1})(Na_{0.4-0.5}K_{0.2})O_{22}(OH)_2$. This formula is close to the ideal formula of pargasite (Leake, 1978). As for the tourmaline, its green colour is due to the absence of Fe and to the presence of Cr. The XMg=1 is exceptionnal for a natural pargasite. Its chemical composition is overwise close to that of pargasite from corundum- and/or sapphirine-bearing amphibolites (Figures 7, 8, and 9), except that the content of Al_{IV} is lower.

Kyanite, of a bright blue colour, has been observed in some samples, in association with ruby and tourmaline. Such association is common in metasomatic ruby deposits of Southern Kenya, particularly at the John Saul Mine (Key and Ochieng, 1989). Cr content is up to 0.01 p.f.u. Cr has been described as a trace element in kyanite (White and White, 1967), and Ibarguchi et al (1991) have decribed kyanite crystals containing about 4 wt% Cr_2O_3.

Cordierite. Altered cordierite crystals have been observed in some samples, in close association with sapphirine. This mineral could not be analysed due to its high degree of alteration.

Pyrite and hematite. Hematite is a common accessory mineral in all rock samples, where it replaces and pseudomorphoses pyrite. Pyrite cores are still observable in some samples. Alteration of pyrite to hematite is secondary.

Graphite is a common accessory mineral in all samples. It usually occurs as flakes aggregates in the plagioclase matrix, and flakes are sometimes included in corundum and in pargasite. Graphite flakes are also present in the phlogopite salbands.

Carbonates have been observed as accessory minerals in both the vein material and in the salbands. Qualitative microprobe analysis show that is is Mg-calcite. It is likely to be a result of superficial alteration of the rock and it is difficult to ascertain wether it as part of the original assemblage. They are closely associated to graphite flakes aggregates.

Apatite has been observed as an acessory mineral, particularly in phlogopite and as an inclusion in sapphirine.

Petrology

Textural evidences suggest that anorthite and sapphirine were among the first phases to crystallise in the rock, and that part of the corundum grew at its expense. Relationships with neighbouring minerals suggest that a reaction involving the breakdown of sapphirine into corundum (type 1) and phlogopite took place. Such a reaction would imply an external input of K^+, and the production of SiO_2 (that is, a desilication, see figure 10) Similar reaction and texture have been observed in a metasomatic ruby-bearing rock at the Aquamines deposit in the Mangare area, Southern Kenya (Simonet, 2000a). Phase relationships of phlogopite in the system K_2O-MgO-CaO-Al_2O_3-SiO_2-H_2O have been studied by Modreski and Boettcher (1973). These authors found that at temperatures in excess of 1000C for 10 kbar (in the presence of water), phlogopite + corundum melt incongruently, producing spinel. The breakdown of sapphirine into chlorite, spinel and corundum (Seifert, 1974) was not observed in the Tutti-Frutti. While type 2 corundum possibly originates from the recrystallisation of type 1 corundum, type 3 corundum grew at the expense of kyanite. Such textures and phenomena have been described in corundum deposits of the Mangare area in Southern Kenya (e.g. Key and Ochieng, 1989), and are thought to be the result of metasomatic desilication of kyanite (Simonet, 2000a).

Relations between spinel, corundum, and pargasite have been noted in other types of corundum-bearing rocks such as ruby amphibolites. At Longido and Lossongonoi in Tanzania, spinel is present as inclusions in pargasite, close to or at the contcat with corundum (Simonet, 2000). In corundum-bearing amphibolites of Southern Vohibory (Madagscar), Nicollet (1986) also observed the marginal transformation of corundum into spinel. In most corundum-bearing amphibolites where both spinel and sapphirine are present, these minerals do not belong to the same paragenesis (e.g. Lasnier, 1977; Tenthorey et al, 1996).

Discussion

Vital information concerning the rocks hosting the "tutti-frutti" is lacking. From the available samples, it can only be stated that it occurs as veins within an ultramafic rock. Such a geological context is common for sapphirine and/or ruby-bearing rocks. Simonet (2000a) has shown that there are two main types of ruby-bearing rocks directly associated to ultramafic rocks. These are:

- Metamafic rocks (ruby-bearing amphibolites) that result from the hydration in granulite facies of gabbros or anorthosites. The mafic protolith is part of a mafic-ultramafic sequence (ophiolite, anorthositic complex, etc...). The genesis of these rocks involves mostly metamorphic reactions.
- Metasomatic rocks resulting from the desilication of a felsic rock coming into contact with an ultramafic rock (pegmatite, gneiss, etc). Such rocks are common in East Africa, and result from severe metasomatic phenomena.

Observations done on the Tutti-Frutti triggers immediate comparisons with the metasomatic rocks of the Mangare area in Southern Kenya (see Key and Ochieng, 1989; Mercier et al, 1999; Simonet, 2000a). Particularly, reactions involving sapphirine and ruby are similar to those observed in the Aquamines ruby deposit of this area. The transformation of sapphirine into corundum and phogopite, and of kyanite into corundum, as well as the strongly aluminous character of all minerals present, implies a desilication of the rock. The presence of tourmaline in an ultramafic environement is not consitant with a purely metamorphic origin, since B normally does not originate from ultramafic rocks. This points towards an at least partially metasomatic origin of the rock. Although textural relationships between minerals are not clear, the earliest assemblage recorded includes sapphirine and anorthite. It is difficult, in this case, to ascertain the type of protolith of the rock. In the Mangare area, similar rocks have been found to have a pegmatitic protolith (Simonet, 2000), but they have not suffered such a drastic alteration as the Tutti-Frutti did. However, the sharp contact between the veins and their host ultramafic rocks suggest that the protolith could also be pegmatitic in this case. Sapphirine in vein-like metasomatised veins associated to ultramafic rocks has been described by Currie and Gittins (1988) from Wilson Lake in Labrador.

Another striking characteristic of the Tutti-Frutti is the high XMg of normally ferro-magnesian minerals, that is sapphirine, dravite, pargasite and phlogopite. This is not due to the absence of Fe from the rock, since pyrite is found as a common accessory mineral in the rock. It has recently been suggested by Simonet et al (2000) that in graphite-rich, Fe-poor gem-bearing rocks of East Africa, the partionning of Fe between sulphides and silicates could be very strong due to the highly reducing environement. This would lead to all available Fe to be trapped in the sulphides, thus being unavailable for silicates. This hypothesis has heavy implications on the genesis of some gem minerals such as ruby, Mg-tourmaline, kornerupine, enstatite, tsavorite, tanzanite, and is still under investigation.

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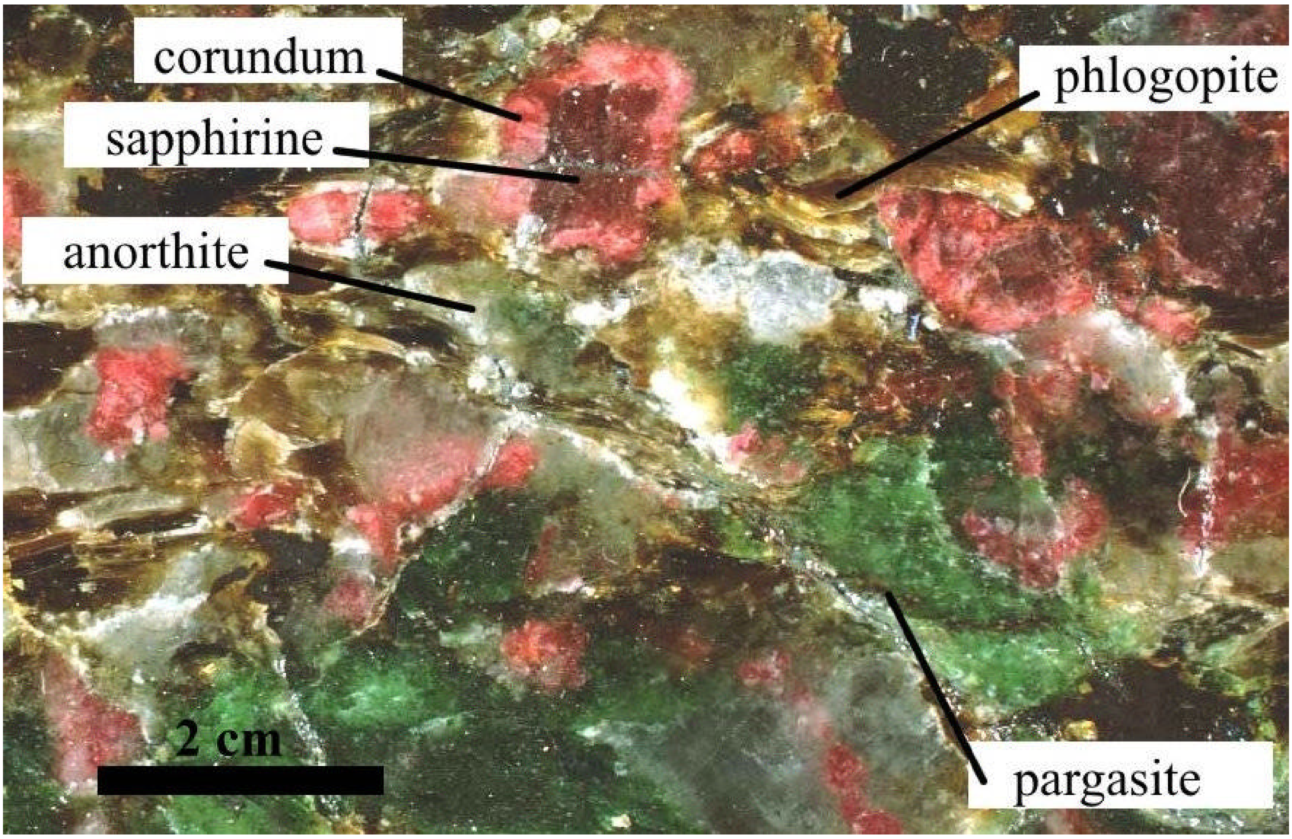

Figure 1. Photograph of a polished section of the Tutti Frutti. Note corundum rims around sapphirine crystals.

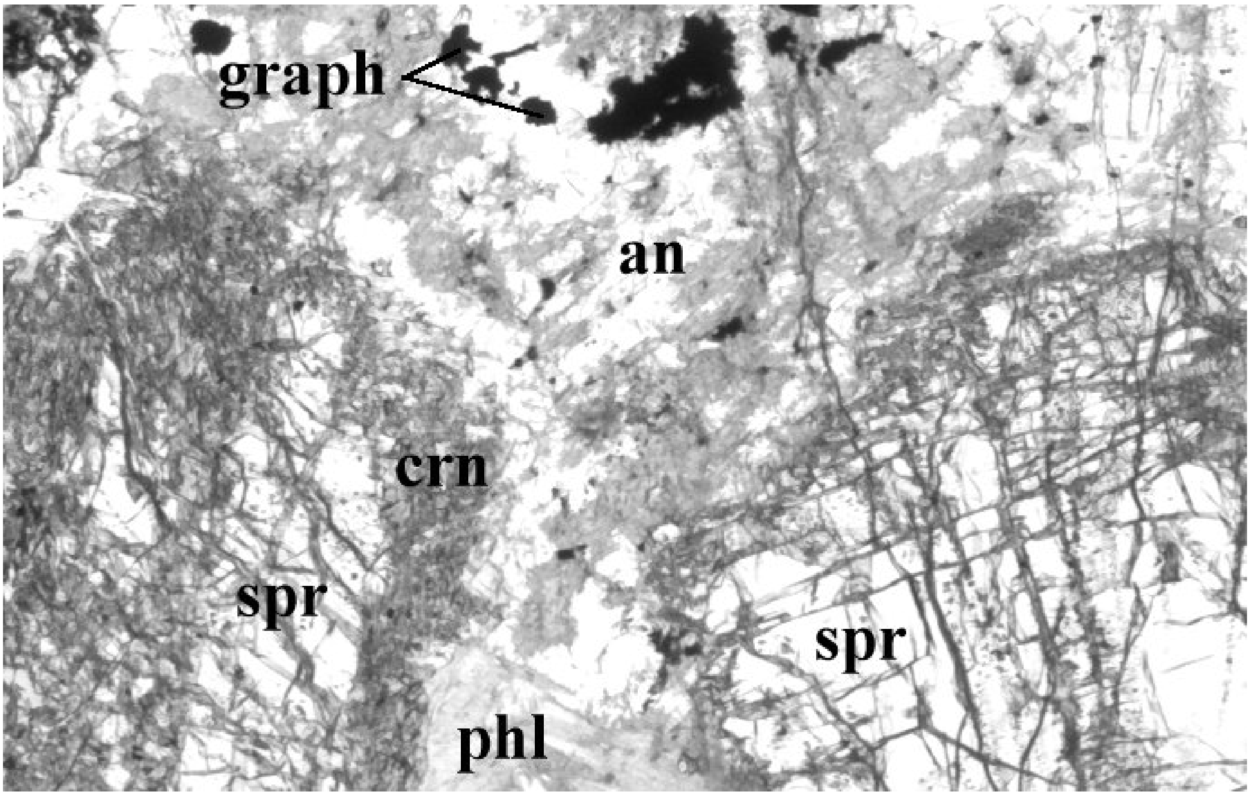

Figure 2. Photograph of a thin section showing the relations between sapphirine (spr) and type 1 corundum (spr). Note the presence of graphite flake aggregates. The area depicted is about 1 cm wide.

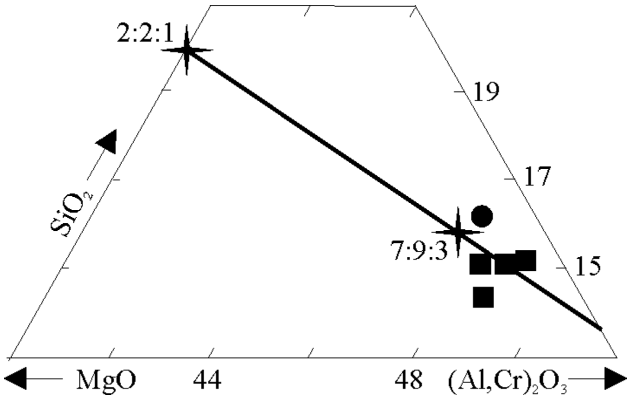

Figure 3. Chemical composition of the Tutti-Frutti sapphirine (squares) compared with that of sapphirine from Aquamines (circle). Stars indicate ideal compositions 2:2:1 and 7:9:3.

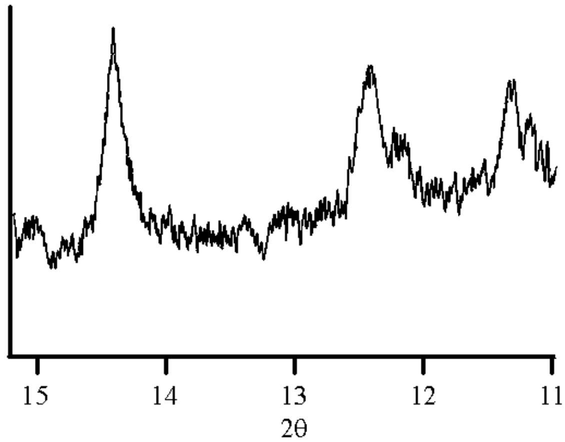

Figure 4. Powder X-ray diffractogram of a crystal of sapphirine (outer and inner zone mixed). Peaks between 2θ = 11 and 2θ = 15 indicate both 1Tc and 2M polytypes.

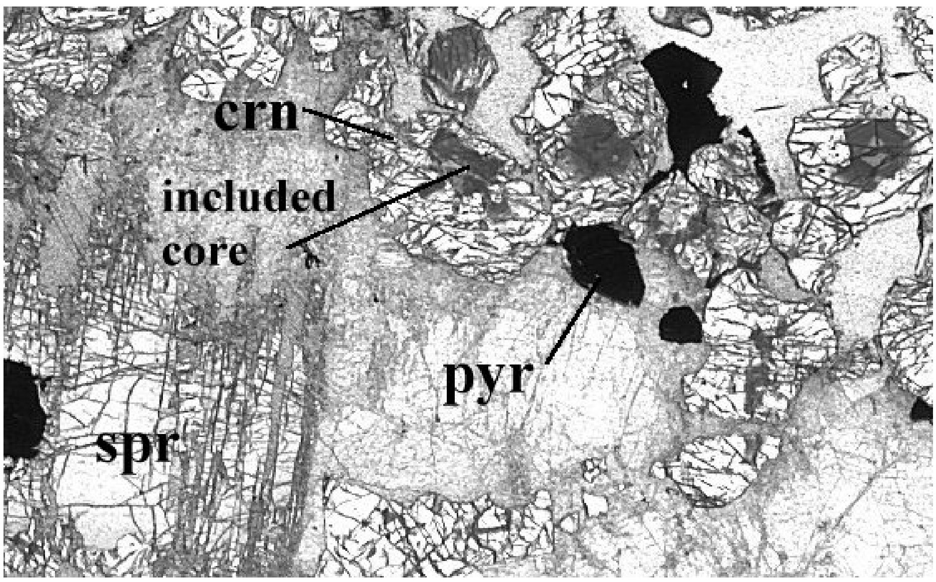

Figure 5. Photograph showing type 2 corundum. Note the cores heavily opacified by epitaxic rutile inclusions.

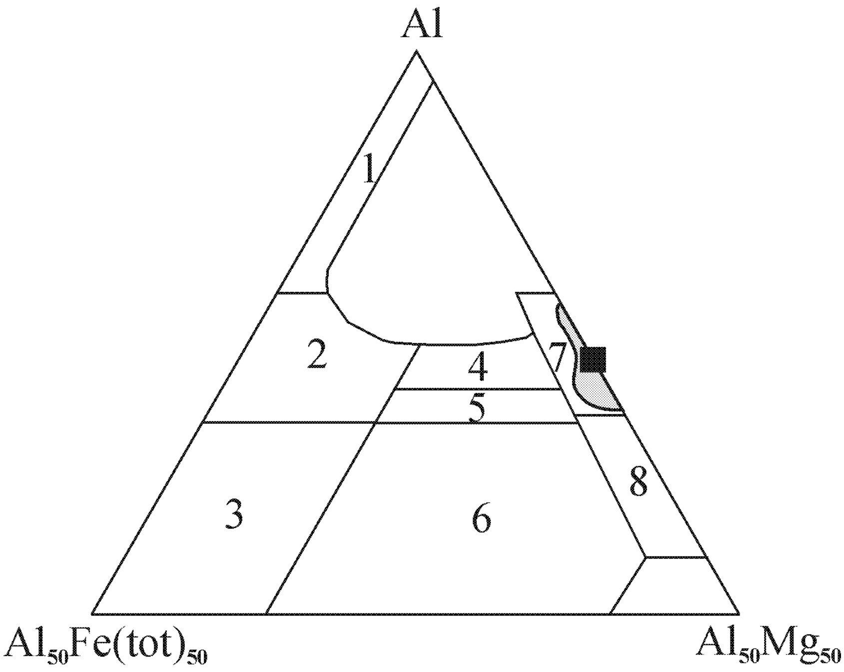

Figure 6. Diagram of Henry and Guidotti (1985). Al, Fe, and Mg in molecular proportions. Square: dravite from the Tutti-Frutti. Grey area: field of gem-quality dravite-uvites from East Africa (Simonet, 2000b).

Fields:1-Li-rich granitoid pegmatites and aplites; 2- Li-poor granitoid and their associated pegmatites and aplites; 3- Fe3+-rich quartz tourmaline rocks (hydrothermally altered granites); 4- Metapelites and metapsammites coexisting with an Al-saturating phase; 5-Metapelites and metapsammites not coexisting with an Al-saturating phase; 6- Fe3+-rich quartz-tourmaline rocks, calc-silicate rocks, and metapelites; 7- Low-Ca ultramafics and Cr, V-rich metasediments; 8- Metacarbonates and meta-pyroxenites. Fields 4 and 5 overlap with field 7.

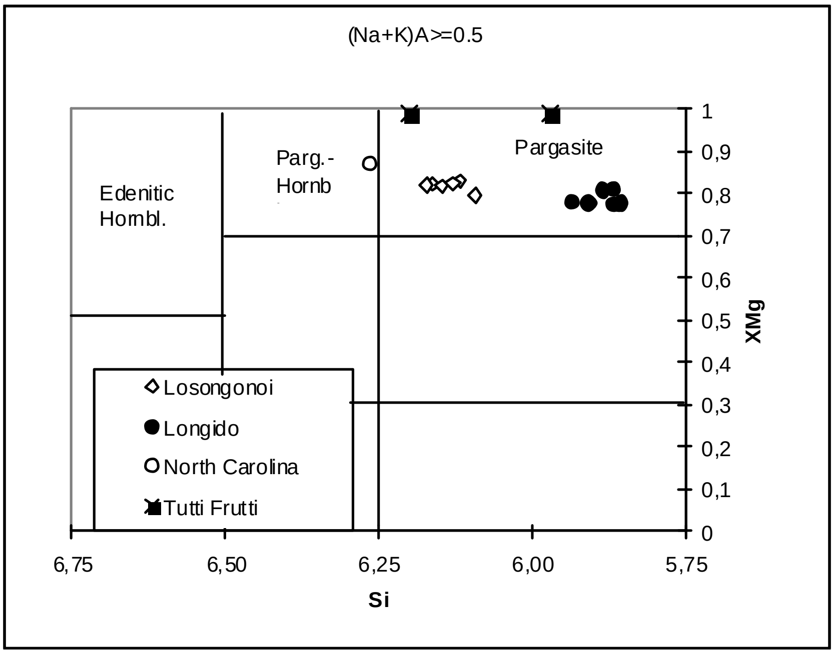

Figure 7. Diagram of Leake (1978) showing the composition of pargasite from the Tutti-Frutti compared to that of amphiboles from ruby-bearing amphibolites. Data for Longido and Lossongonoi from Simonet (2000a). Data for North Carolina from Tenthorey et al (1996).

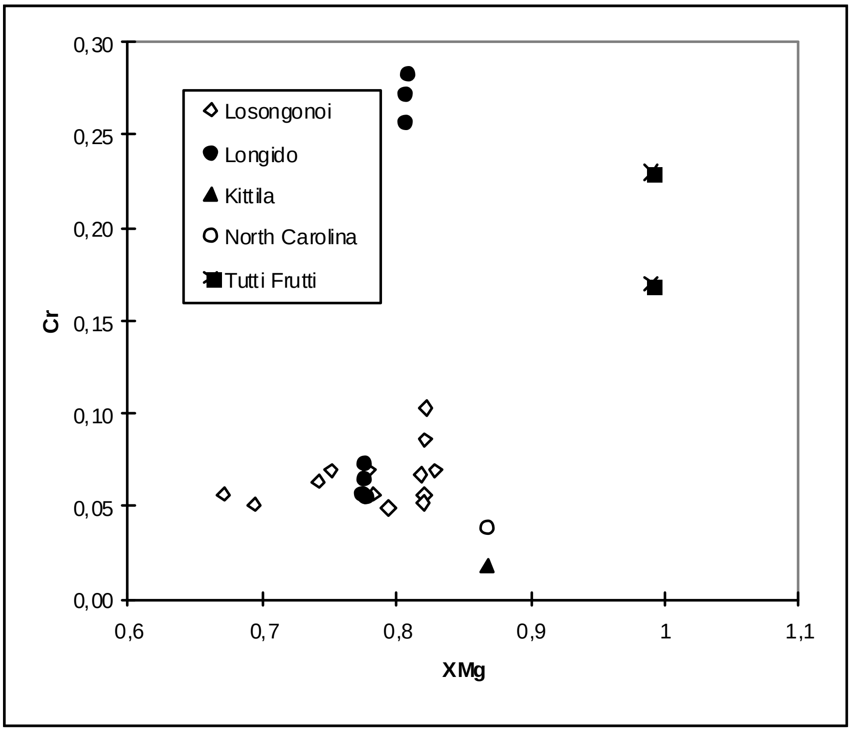

Figure 8. XMg vs Cr content for pargasite from the Tutti-Frutti and from various ruby-bearing amphibolites. Data for Longido and Lossongonoi from Simonet (2000a). Data for North Carolina from Tenthorey et al (1996). Data for Kittila from Haapala et al (1971). Note the exceptionnaly high XMg of the Tutti-Frutti amphiboles.

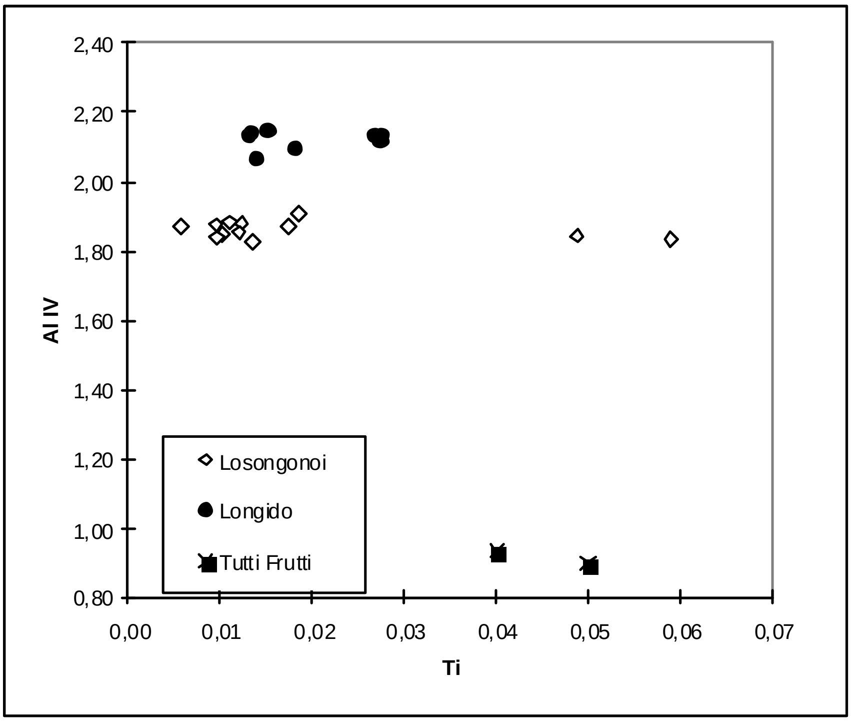

Figure 9. Al_{IV} vs Ti content for pargasite from the Tutti-Frutti and from various ruby-bearing amphibolites. Data for Longido and Lossongonoi from Simonet (2000a).

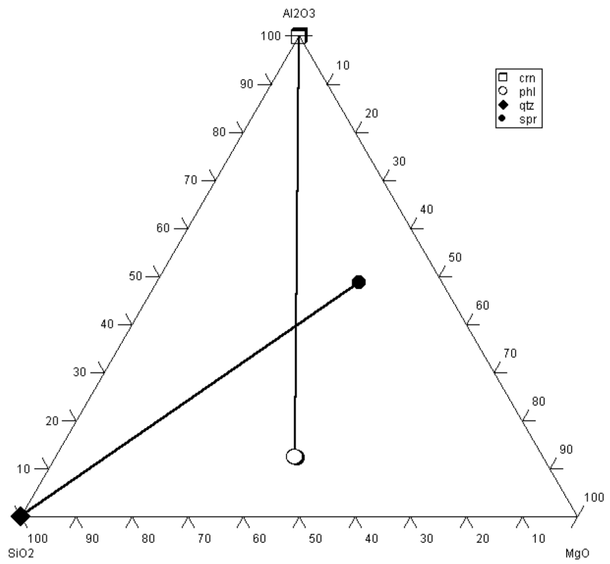

Figure 10. Chemical composition (molecular proportions) of the phases involved in the formation of the corundum rims around sapphirine crystals.

samp. no.	1	2	3
SiO2	11,9	12,1	12,0
Al2O3	66,7	66,5	65,0
Cr2O3	1,7	1,8	1,6
MgO	20,0	19,6	19,2
tot	100,2	100,0	97,8
Si	1,4	1,4	1,4
Al	4,6	4,6	4,6
Al	4,4	4,5	4,5
Mg	3,4	3,4	3,4
Cr	0,2	0,2	0,1
O	20,0	20,0	20,0

Table 1. Chemical composition of sapphirine samples from the Tutti-Frutti. Formula normalised at 20 O a.p.f.u.