Garnet, corundum and other gem minerals from Umba, Tanzania

P. C. Zwaan

Zwaan, P. C. Garnet, corundum and other gem minerals from Umba, Tanzania. Scripta Geol., 20 : 1-41, 24 figs., 10 tables, Leiden, February 1974.

Both rhodolite and almandine garnets occur in Umba. The rhodolites have no special properties by which they can be distinguished from other garnets in the pyrope-almandine series, except their rose-red colour. Hence a distinctive name is unnecessary. Rutile appears to be the most frequent mineral inclusion in rhodolite, whereas in almandine both apatite and rutile are common. Corundums of different colours occur. Green corundums owe their colour to iron, while blue corundums have a high Ti and a low Cr content. Common inclusions are rutile, pyrrhotite and apatite, whereas graphite especially is found in deep violet corundums. The inclusions in both the garnets and the corundums are not characteristic of this locality. The properties of emerald green and orange-brown tourmalines are given, as well as those of brownish orthopyroxenes, a light green clinopyroxene, yellow scapolite, reddish brown zircon and turquoise.

P. C. Zwaan, Rijksmuseum van Geologie en Mineralogie, Hooglandse Kerkgracht 17, Leiden, The Netherlands.

Introduction

The material described here originates from the Umba gem mine, a small location in the jungle, situated in the northeastern part of Tanzania on the Kenya border. The name of the mine is taken from the Umba river, flowing in the area. The mine produces a number of minerals of gem quality, especially garnet, corundum and tourmaline. According to Solesbury (1967) these minerals occur in metamorphic rocks of Precambrian age.

Since 1967 a number of papers describing minerals from the Umba area have been published. The area, therefore, is well known now to many mineralogists and gemmologists.

During a visit to the mine in July 1967, the author was given a number of mineral specimens, mainly pebbles, for scientific research. The author also collected garnets and corundums, both crystals and fragments as well as pebbles, all from secondary deposits.

Production at the mine is from open pits, drilled and dug to a depth of about 15 m in vermiculite pegmatites and amphibole gneisses.

In connection with theft of material at the mine, a common problem at small gem workings, the manager was anxious to know whether the minerals occurring at the Umba mine had properties that were characteristic of the locality. From the scientific point of view the minerals are very interesting indeed. The garnets are both almandines and very nice so-called rhodolites. The corundums have different colours. Besides red and blue there are deep violet and parti-coloured stones, such as blue with yellow, red with blue, and red with green. Orange-coloured corundums are also found, locally named "golden sapphire". The tourmalines are characterized by their very nice emerald-green colour, although some are yellowish brown and orange.

On a small scale some other minerals are found: a brownish orthopyroxene,

a green clinopyroxene, yellow scapolite, turquoise and zircon. They all are more or less of gem quality.

This paper will look into the reasons for the colour of the tourmaline and the corundum, and consider whether a special name for the "rhodolite" garnets is necessary.

All specimens as well as the X-ray powder photographs are stored and registered in the Rijksmuseum van Geologie en Mineralogie, Leiden (numbers prefixed with RGM).

The minerals have been studied by optical methods and by X-ray diffraction.

The specimens have been provided with one, or often two polished flat faces to facilitate the optical examination and to measure the refractive indices on a gemstone refractometer. For this purpose a Rayner standard refractometer was most often used in combination with sodium light. In some cases a refractometer provided with a diamond prism was applied. The microscopic examination was done using methylene iodide and monobromonaphtalene as immersion liquids. This procedure was also suitable to make photomicrographs of the inclusions.

The absorption spectra were observed with a Rayner prism spectroscope and measured by means of a Hartridge Reversion Spectroscope. The accuracy of the last-named instrument is not very great for broad bands, and the readings may be incorrect up to 10 Å.

Specific gravity measurements were carried out by means of a hydrostatic balance using ethylene dibromide as an immersion liquid and coils of silver wire to hold the specimens.

The X-ray investigation was done by means of powder photographs, using Fe-radiation and a Debye-Scherrer camera with a diameter of 114.6 mm.

Identification of inclusions was made by means of X-ray powder photographs. Use was made of the so-called "sphere" method of Hiemstra (1956), because only very small amounts of material were available. The samples were obtained by scraping down with a steel needle part of an inclusion extending to the surface of the host specimen. In the past the author has used this method with great succes to identify solid inclusions in Ceylon minerals (Zwaan, 1965 and 1967).

The unit cell dimensions of the garnets were calculated using a method described by the author in a paper dealing with the identification of pyrope-almandine garnets (Zwaan, 1961). This method is based upon the measurement of the distance (e) in mm between the corresponding α_1-lines of the reflections 10 4 0, 10 4 2 and 880 on an X-ray powder photograph of the garnet. The function between a and e (4 Θ with the camera used) can be derived from the formula, to be used for minerals crystallizing in the cubic system:

$$\sin^2 \Theta = \frac{\lambda^2}{4a^2} (h^2 + k^2 + l^2)$$

in which: Θ is the glancing angle,
λ is the wavelength of the used radiation,
a is the length of the unit cell.

Acknowledgements

The author is much indebted to Dr C. Kieft of the WACOM, a working group for analytical geochemistry subsidized by the Netherlands Organisation for the Advancement of Pure Research (ZWO) at Amsterdam for microprobe analyses of eight garnets; to Dr P. Maaskant of the Institute of Earth Sciences of the Free University at Amsterdam for the determination of trace elements in two corundums and a tourmaline and to Mr K. M. Stephan of the "Geologisch en Mineralogisch Instituut" of Leiden University for his analytical work on three almandine garnets to determine the Fe^{+2} / Fe^{+3} ratio, on an orthopyroxene and on a turquoise.

Rhodolite garnet

PREVIOUS WORK

The name rhodolite was proposed by Hidden & Pratt (1898) for a garnet with a "delicate rose-like colour" from North Carolina. Chemical analyses of two samples were given together with the specific gravity determinations, 3.837 and 3.838. These data indicated that the garnet contained two molecules of pyrope on one molecule of almandine.

Trumper (1952) described this material as a garnet with a specific gravity of 3.837 and a refractive index of 1.76, showing the characteristic absorption spectrum of almandine. He also mentioned a find of rhodolite garnet in Greenland.

According to Deer et al. (1962) rhodolite is a rhododendron pink variety of pyrope with Mg: Fe approximately 2: 1, known from North Carolina and elsewhere. Data reported by Webster (1972) are very similar.

Objections against the name are raised, amongst others, by Anderson (1959) and Campbell (1972), because it is so similar in sound and spelling to that of the manganese silicate mineral rhodonite. Campbell suggests that the name "rhodomacon" garnet be considered. The first syllable relates to the colour and the second one to the fact that this variety was first discovered in Macon County, North Carolina.

Martin (1970) notes that the refractive indices of a number of rhodolites of unknown origin (probably Tanzania) are well below that of a specimen from North Carolina. Their average refractive index is 1.747 while that of the "Carolina stone" is 1.758. The average value is near the middle of the range for pyrope, yet the stones are of an entirely different colour (rose-red to pale violet). Spectroscopy reveals the three main absorption bands of almandine, and these are of moderate intensity.

In a paper on rose-red garnets from Tanzania, Bank & Nuber (1969) state that since 1964 large numbers of garnets from this area have been sold as rhodolites. Most of the specimens are round so that no crystal forms can be recognized. The material is apparently from secondary deposits. The refractive indices vary from 1.745 to 1.755; the densities from 3.79 to 3.80. The unit cell dimension of these rhodolites is 11.5034 ($\pm$ 0.0003) Å. Chemical examination indicates that these garnets have a high Fe content, little Mn and traces of Rb and Pb. These

authors, too, conclude that rhodolites are intermediate types in the pyrope-almandine series.

Campbell (1972) made a comparative study of what has proved to be rhodolite garnet of known Rhodesian origin. He examined 12 rough stones having no particular form. The refractive indices measured are between 1.750 and 1.760, with an average of 1.755. The densities lie between 3.83 and 3.89, the average being 3.85. All the specimens have an almandine absorption spectrum, varying in intensity from very weak to medium. The refractive indices of another 50 cut stones also vary from 1.750 to 1.760. Comparing these results with the data in the literature Campbell notes that the only difference between rhodolite garnet and other garnets in the pyrope-almandine series is "colour and colour alone".

PROPERTIES

The properties of 29 pebbles of rhodolite are given in Table 1 in ascending order of refractive index. All specimens have a pleasant rose-red colour.

First it is seen that the properties of these garnets vary widely. The lowest figures for refractive index and specific gravity are from one sample; the same is true of the highest. A linear function between these properties generally holds true, as was to be expected. A comparison of these data with those given by previous workers indicates that most of them are higher, although all lie in between the properties of pyrope and almandine towards the pyrope end-member.

From the figures for the length of the unit cell it can be seen that there is a variation from 11.497 to 11.532 Å, which cannot be due simply to the substitution of Fe for Mg, because there is no regularity. Samples with low refractive index and density may have larger unit cells than samples with higher properties and vice versa. It is an obvious fact that Ca, and to a lesser extent Mn, have a great influence on the size of the unit cell.

To ascertain this, microprobe analyses of four specimens have been made. The samples selected were those with the lowest and highest refractive index and specific gravity, and those with the smallest and greatest length of the unit cell. The results are given in Table 2. These specimens appeared to be somewhat inhomogeneous. Variations in the chemical composition to a maximum of relatively 10 per cent were observed. The analyses represent the average of three or four measurements per sample.

First it can be seen that the garnet with the lowest refractive index and density has the highest Mg and the lowest Fe content, while the one with the highest figures has the highest almandine and the lowest pyrope content. In other words, the ratio Mg : Fe can be derived from the properties mentioned.

Regarding the size of the unit cell it is seen that the rhodolite with the highest Ca content (RGM 163 138) has the largest *a*, while the one with the lowest *a* value (RGM 163 166) has a low Ca content in combination with little Mn. The rhodolite with the lowest Ca content (RGM 163 164) has a larger unit cell, which probably is due to its higher Mn content. Thus, both Ca and Mn may affect the size of the unit cell to a large extent.

Both the Ti and Cr contents of these garnets are too low to have a significant influence on these properties.

Another observation worth mentioning is that all X-ray powder photographs of these rhodolites have a pattern characteristic for pyrope, that is, almost equal

Table 1. Properties of 29 rhodolite garnets from Umba, Tanzania.

sample no.	original weight in carats	n	D	a in Å	no. X-ray powder photograph
RGM 163 175	3.56	1.749	3.790	11.521	RGM 201 567
" 163 171	4.65	1.750	3.827	11.511	" 201 531
" 107 196	3.61	1.751	3.809	11.504	" 201 512
" 163 176	3.62	1.751	3.828	11.514	" 201 568
" 107 205	4.08	1.753	3.831	11.499	" 201 520
" 107 209	4.66	1.753	3.851	11.510	" 201 566
" 163 163	1.46	1.753	3.858	11.506	" 201 523
" 163 137	1.42	1.754	3.855	11.525	" 201 518
" 163 166	1.75	1.756	3.861	11.497	" 201 526
" 163 167	2.01	1.756	3.863	11.502	" 201 527
" 163 136	2.90	1.757	3.831	11.508	" 201 517
" 163 134	4.79	1.757	3.852	11.512	" 201 515
" 163 168	1.38	1.757	3.854	11.501	" 201 528
" 163 179	2.65	1.758	3.847	11.518	" 201 573
" 163 178	2.40	1.759	3.879	11.515	" 201 572
" 163 162	1.80	1.759	3.883	11.501	" 201 522
" 163 133	4.16	1.760	3.849	11.520	" 201 514
" 163 132	3.00	1.760	3.863	11.521	" 201 513
" 163 135	3.49	1.760	3.865	11.523	" 201 516
" 163 182	2.04	1.760	3.871	11.523	" 201 576
" 163 180	1.99	1.760	3.872	11.508	" 201 574
" 163 177	4.38	1.761	3.869	11.523	" 201 569
" 163 181	2.02	1.762	3.880	11.524	" 201 575
" 163 138	1.42	1.762	3.883	11.532	" 201 519
" 163 169	1.40	1.762	3.890	11.510	" 201 529
" 163 161	2.05	1.762	3.891	11.507	" 201 521
" 163 165	1.87	1.767	3.907	11.514	" 201 525
" 163 170	1.63	1.768	3.898	11.514	" 201 530
" 163 164	1.34	1.769	3.908	11.509	" 201 524

intensities of the diffraction lines 332, 422 and 431. With almandine garnets the intensity of 332 is rather faint in comparison with those of 422 and 431. This difference between pyrope and almandine was first mentioned by Stockwell (1927).

In contrast with this observation, the absorption spectrum is a pattern characteristic for almandine. All rhodolites show the three main absorption bands of almandine with more or less intensity depending on the depth of the colour of the sample.

From the data given here, it can be concluded that the rhodolites described are garnets with a composition between pyrope and almandine. They have no special properties by which they can be distinguished from either pyrope or almandine, except their rose-red colour. Finally, this conclusion may also be drawn from the X-ray powder diffraction data for two rhodolites and two almandines from Umba, given in Table 3. The differences, extremely small, are apparently due to normal isomorphous replacement.

Table 2. Microprobe analyses of four rhodolite garnets from Umba, Tanzania.

	RGM 163 175	RGM 163 166	RGM 163 138	RGM 163 164
SiO_2	41.7	40.7	40.8	39.7
Al_2O_3	22.7	23.0	22.6	22.7
TiO_2	0.03	0.035	0.03	0.03
Cr_2O_3	0.12	0.06	0.21	0.03
Fe_2O_3	---	---	---	---
FeO	10.7	17.6	17.8	21.9
MnO	5.2	0.6	2.8	1.6
MgO	16.8	15.9	13.1	12.6
CaO	2.9	2.0	3.1	1.8
Total	100.15	99.895	100.44	100.36
n	1.749	1.756	1.762	1.769
D	3.790	3.861	3.883	3.908
a (Å)	11.521	11.497	11.532	11.509
	Numbers of ions on the basis of 12 (O)			
Si	3.03 } 3.03	2.99 } 2.99	3.02 } 3.02	2.98 } 2.99
Al	--- }	--- }	--- }	0.01 }
Al	1.94	1.99	1.96	2.00
Ti	0.002 } 1.949	0.002 } 1.995	0.002 } 1.972	0.002 } 2.004
Cr	0.007	0.003	0.01	0.002
Fe^{+3}	---	---	---	---
Fe^{+2}	0.65	1.08	1.14	1.37
Mn	0.32 } 3.02	0.04 } 3.02	0.17 } 3.00	0.10 } 3.03
Mg	1.82	1.74	1.44	1.41
Ca	0.23	0.16	0.25	0.15
	Mol. per cent. end-members			
almandine	21.52	35.76	38.00	45.20
andradite	---	---	---	---
grossular	7.61	5.30	8.33	4.97
pyrope	60.27	57.62	48.00	46.53
spessartine	10.60	1.32	5.67	3.30
uvarovite	---	---	---	---

Regarding the name "rhodolite" and the new name "rhodomacon" proposed by Campbell (1972), it is clear that from the mineralogical point of view the logical step would be to discard both, unless it appears from further studies that one or another trace element, only occurring in this type of garnet, is responsible for the special colour, something that is very unlikely. This is a nomenclature problem within the scope of the Commission on New Minerals and Mineral Names of the International Mineralogical Association.

Table 3. X-ray powder diffraction data for four garnets from Umba, Tanzania.

	rhodolite RGM 163 179		rhodolite RGM 163 138		almandine RGM 163 158		almandine RGM 163 156	
hkl	d (obs.)	I	d (obs.)	I	d (obs.)	I	d (obs.)	I
222	3.33	2	3.32	½	3.33	1	3.32	½
400	2.88	8	2.88	8	2.87	8	2.88	8
420	2.58	10	2.57	10	2.57	10	2.58	10
332	2.46	6	2.46	6	2.45	4	2.46	4
422	2.35	6	2.35	6	2.34	6	2.35	6
431	2.26	6	2.26	6	2.25	6	2.26	6
521	2.10	6	2.10	6	2.10	6	2.11	6
440	2.04	2	2.04	1	2.03	4	2.04	2
611	1.870	6	1.867	7	1.863	6	1.870	7
620	1.822	2	1.824	½	1.818	2	1.827	1
444	1.663	5	1.664	6	1.660	5	1.667	6
640	1.596	8	1.598	8	1.595	8	1.601	8
642	1.540	9	1.541	9	1.537	9	1.543	9
732	1.464	1	1.465	½	1.459	½	1.465	½
800	1.440	5	1.441	5	1.438	4	1.445	5
741	1.419	1	1.420	½	1.417	½	1.425	½
653	1.373	1	1.371	½	1.374	½	1.382	½
752	1.300	1	1.302	½	1.302	½	1.308	½
840	1.286	6	1.287	5	1.287	5	1.292	6
842	1.255	7	1.256	7	1.255	6	1.261	7
761	1.240	1	1.241	½	1.241	1	1.245	½
664	1.226	6	1.227	5	1.227	5	1.232	6
851	1.213	2	1.214	1	1.213	1	1.219	2
853	1.162	5	1.163	4	1.163	4	1.168	5
1011	1.139	½	1.140	½	1.138	½	1.144	½
1020	1.129	3	1.130	2	1.128	3	1.134	3
943	1.118	½	1.119	½	1.118	½	1.124	½
952	1.097	½	1.097	½	1.096	½	1.102	½
1040	1.069	8	1.071	8	1.070	8	1.075	8
1042	1.052	7	1.053	7	1.052	7	1.057	7
880	1.019	7	1.020	7	1.018	7	1.023	7
972	0.9956	½			0.9948	½	1.002	½
1060	0.9880	½			0.9876	½	0.9928	½
1141	0.9809	½			0.9807	½		
1062	0.9739	½			0.9734	½		

From the commercial point of view it will be practically impossible to eliminate the name "rhodolite", because it has become part and parcel of the language. It would therefore create confusion to introduce another name designating the specific colour. Moreover, there is every chance that a new name would be used to introduce a "new gemstone". It is advisable that the name "rhodomacon" should be considered by the International Confederation of Jewelry, Silverware, Diamonds, Pearls and Stones (CIBJO).

INCLUSIONS

Microscopic examination of all rhodolites indicates that they are generally rather clean. In this respect they have much in common with pyrope garnets.

Rutile appears to be the most frequent solid inclusion. It occurs in both long and short prismatic needles, either running in three directions making an angle of 60°, or isolated (see Figs. 1, 2 and 3).

In specimen RGM 163 171, black, somewhat rounded crystals are found. They have a short prismatic habit and, therefore, look as if they are isometric (see Figs. 4, 5 and 6). In reflected light a submetallic lustre may be observed. One of them, extending to the surface of the garnet, was identified as rutile by means of an X-ray powder photograph (RGM 201 337).

In specimen RGM 107 205 inclusions are present that resemble the "smooth tubes with rounded ends" described by Campbell (1972). They have parallel extinction, although they resemble two-phase inclusions (see Fig. 7). Their identity is not certain but they can be rutile needles because they have much higher refractive indices than the surrounding garnet and rather high interference colours.

In three specimens zircons with haloes can be seen. More or less rounded crystals occur in two other samples which from their habit and interference colours could be apatite. In specimen RGM 163 161, there are inclusions with a platy habit that might belong to the mica group of minerals. Two rhodolite garnets contain liquid feathers similar to those occurring in Ceylon garnets.

From these observations one may conclude that the inclusions found in these rhodolite garnets are not unique for this locality. Even pseudo-isometric rutile crystals, as detected in specimen RGM 163 171, have been found in an almandine garnet from Ceylon (Zwaan, 1967). The other inclusions frequently occur in garnets from other localities.

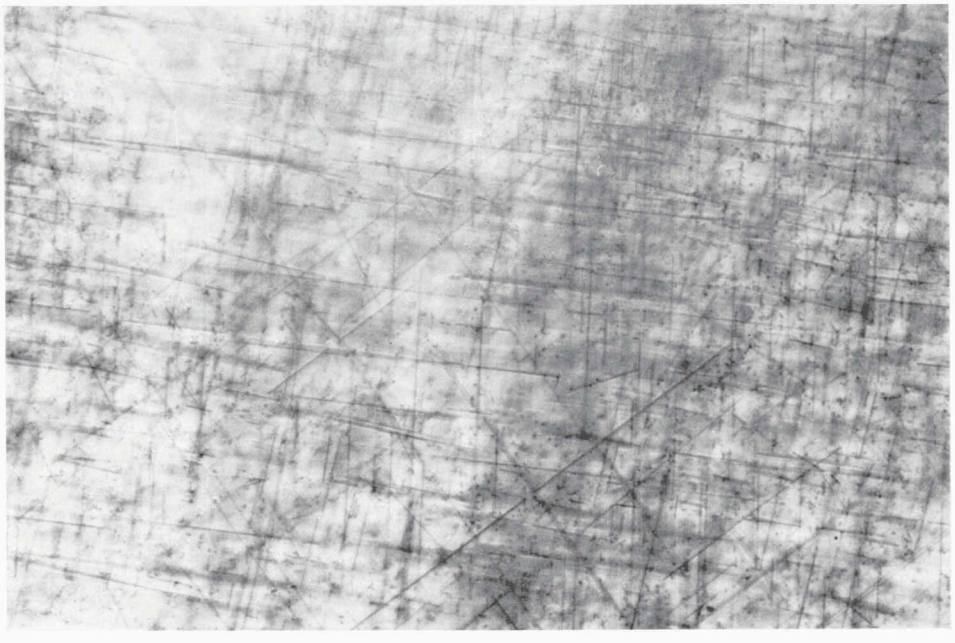


Fig. 1. Rutile needles in rhodolite garnet RGM 163 178, 60x.

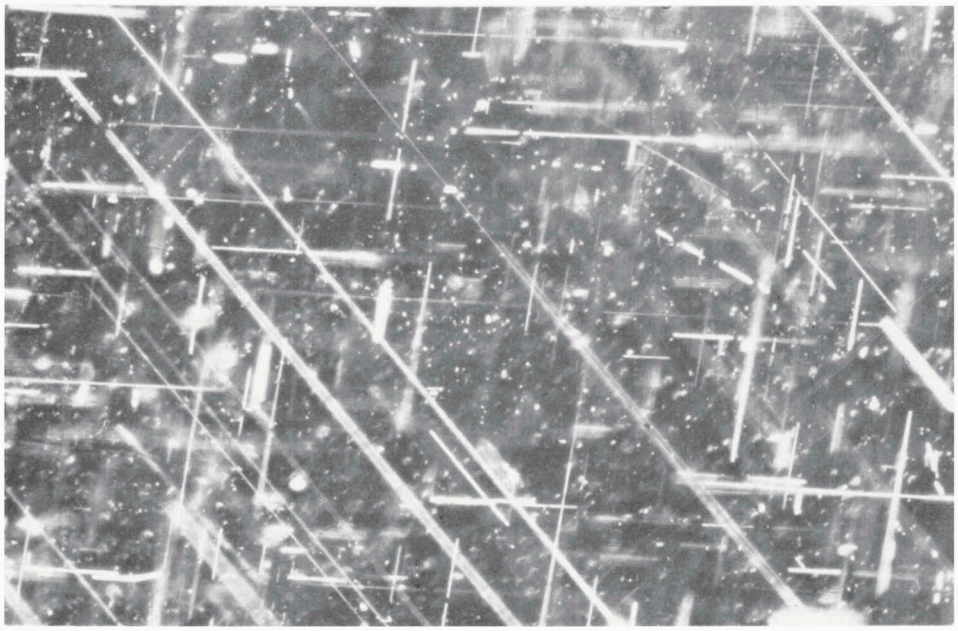
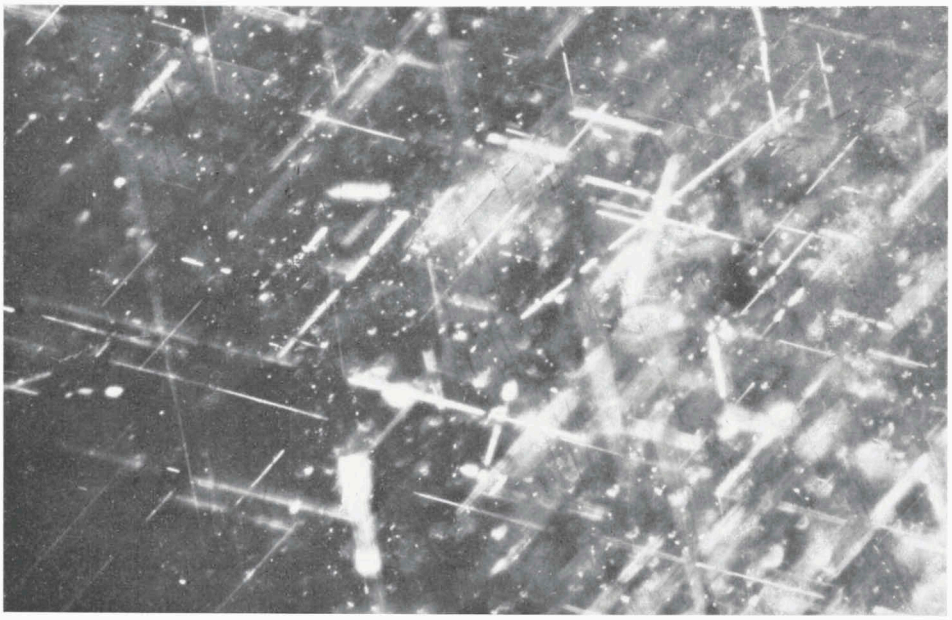


Fig. 2. Rutile needles in rhodolite garnet RGM 163 178, 60x, reflected light.

Fig. 3. Rutile needles in rhodolite garnet RGM 107 209, 80x, reflected light.



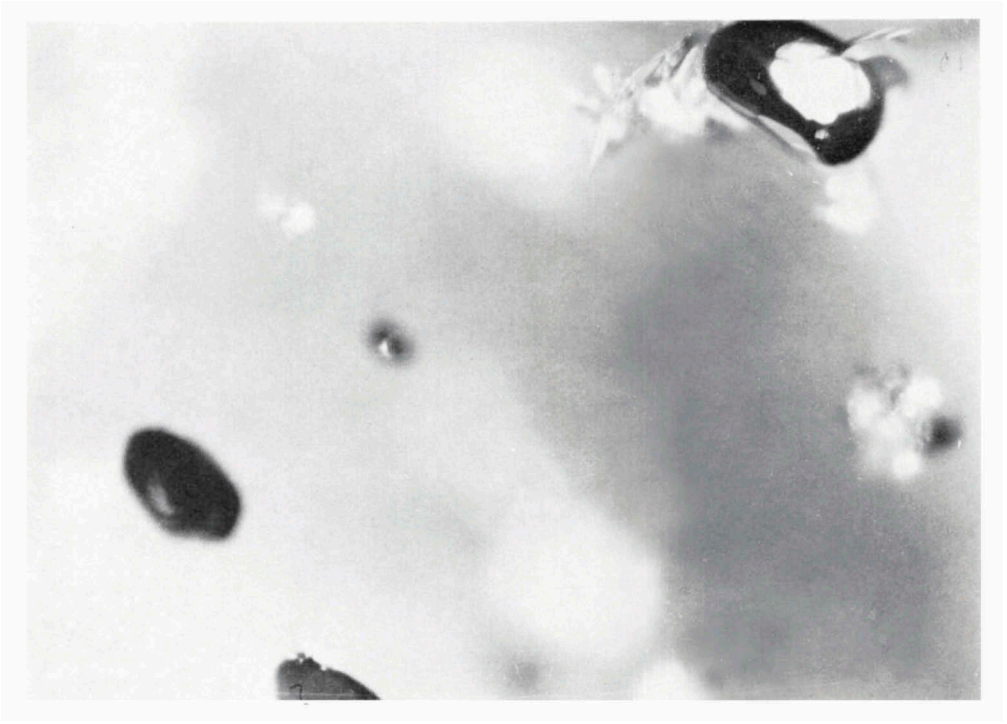


Fig. 4. Rutile crystals in rhodolite garnet RGM 163 171, 65x, reflected light.

Fig. 5. Rutile crystal in rhodolite garnet RGM 163 171, 150x, both reflected and transmitted light.

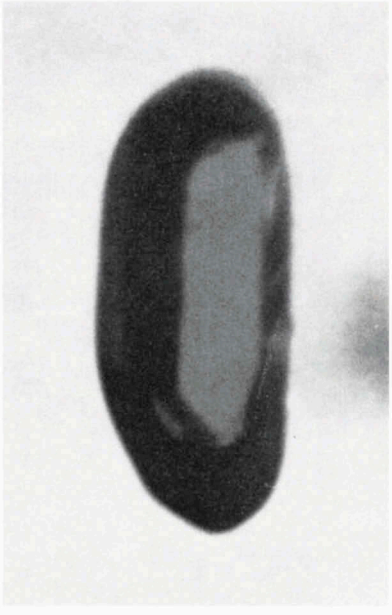
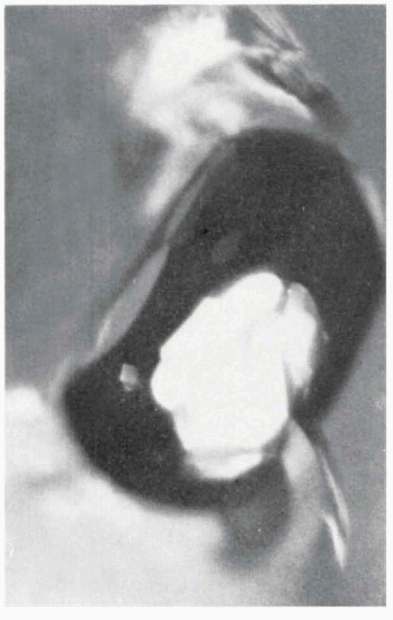


Fig. 6. Rutile crystal in rhodolite garnet RGM 163 171, 150x, reflected light.



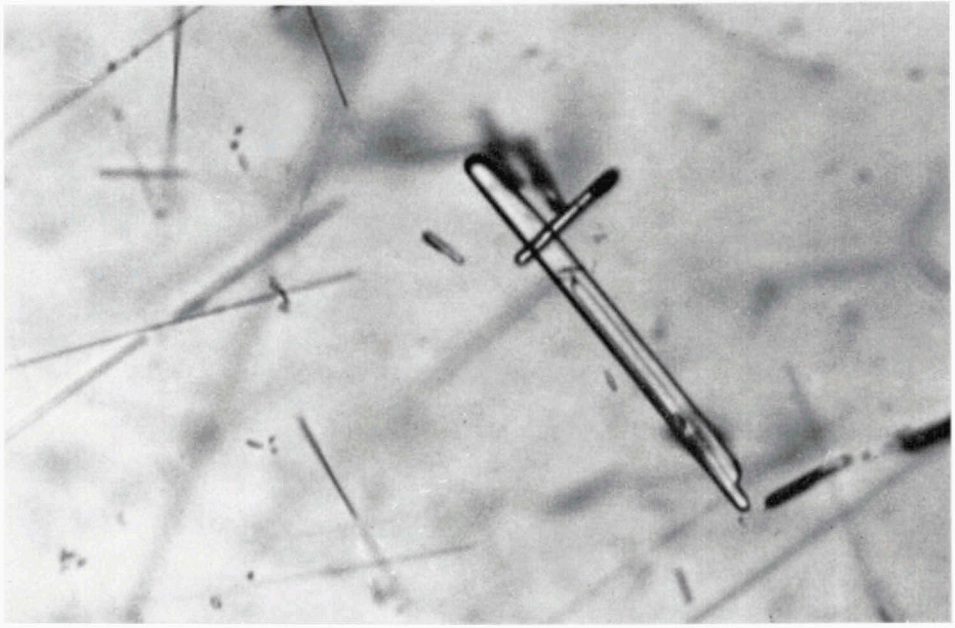


Fig. 7. Smooth tubes with rounded ends, probably rutile, in rhodolite garnet, RGM 107 205, 120x.

Almandine garnet

PROPERTIES

Many specimens of almandine garnet were available for examination. All have a pleasant red to brownish red colour and most of them are of gem quality. All samples are parts of crystals, but no crystal forms could be observed. Those having interesting inclusions were selected for description. Their properties are given in Table 4 in ascending order of refractive indices.

Although two of these garnets have properties lying in the field of the rhodolites, the remaining five show higher values for *n*, D and *a*. A linear function between refractive index and specific gravity is present, but there is no consistent relation between these data and the length of the unit cell; in other words the variation of *a* is not due alone to the substitution of Fe for Mg. It is obvious that both the Ca-ion and the Mn-ion play an important part here. This can be seen in Table 5 in which microprobe analyses of four almandine garnets are given. As with the rhodolites, a selection was made of those specimens having the lowest and the highest refractive indices and densities, as well as those with the minimum and maximum values for the size of the unit cell. Since the elements Cr and Ti, as well as trivalent Fe were not determined, the molecular percentages of the end-members andradite and uvarovite are not given. The analyses represent the average of three measurements per sample. No indications of inhomogeneity are found in these garnets.

It is seen from these analyses that the garnet with the highest Ca content

Table 4. Properties of seven almandine garnets from Umba, Tanzania.

sample no.	original weight in carats	n	D	a in Å	no. X-ray powder photograph
RGM 163 155	30.00	1.750	3.798	11.511	RGM 201 716
" 163 157	39.25	1.758	3.856	11.493	" 201 718
" 107 203	19.43	1.771	3.910	11.543	" 201 333
" 163 158	6.73	1.772	3.931	11.523	" 201 719
" 163 156	3.53	1.775	3.929	11.576	" 201 717
" 163 160	7.56	1.775	3.964	11.528	" 201 721, 201 723
" 163 159	9.38	1.787	4.037	11.537	" 201 720, 201 722

Table 5. Microprobe analyses of four almandine garnets from Umba, Tanzania.

	RGM 163 155	RGM 163 157	RGM 163 156	RGM 163 159
SiO_2	40.4	40.3	38.7	38.15
Al_2O_3	23.45	23.2	21.9	21.75
Fe_2O_3	---	---	---	---
FeO	15.0	18.8	22.65	27.15
MnO	1.1	0.3	1.05	3.4
MgO	17.0	16.35	7.9	6.85
CaO	2.65	0.6	7.5	2.65
Total	99.60	99.55	99.70	99.95
n	1.750	1.758	1.775	1.787
D	3.798	3.856	3.929	4.037
a (Å)	11.511	11.493	11.576	11.537
	Numbers of ions on the basis of 12 (O)			
Si	2.96 } 2.985	2.98 } 2.99	2.98 } 2.98	2.995 } 3.00
Al	0.025 }	0.01 }	--- }	0.005 }
Al	2.00 } 2.00	2.00 } 2.00	1.99 } 1.99	2.005 } 2.005
Fe^{+3}	--- }	--- }	--- }	--- }
Fe^{+2}	0.92 }	1.16 }	1.46 }	1.78 }
Mn	0.065 } 3.04	0.02 } 3.025	0.07 } 3.05	0.22 } 3.02
Mg	1.85 }	1.80 }	0.90 }	0.80 }
Ca	0.205 }	0.045 }	0.62 }	0.22 }
	Mol. per cent. end-members			
almandine	30.26	38.35	47.87	58.95
andradite	---	---	---	---
grossular	6.75	1.49	20.33	7.28
pyrope	60.85	59.50	29.50	26.49
spessartine	2.14	0.66	2.30	7.28
uvarovite	---	---	---	---

Table 6. Chemical analyses of three almandine garnets from Umba, Tanzania. (Analyst: Miss H.Bontje).

	RGM 163 155	RGM 163 157	RGM 163 159
SiO_2	41.88	41.01	39.04
Al_2O_3	22.93	22.40	21.14
TiO_2	0.00	0.64	0.00
Fe_2O_3	1.14	4.22	3.01
FeO	13.88	14.88	23.78
MnO	1.32	0.37	3.39
MgO	16.51	15.46	6.83
CaO	2.89	0.65	2.79
Na_2O	0.20	0.20	0.23
K_2O	0.00	0.00	0.00
P_2O_5	0.03	0.05	0.00
Total	100.78	99.88	100.21
n	1.750	1.758	1.787
D	3.798	3.856	4.037
a (Å)	11.511	11.493	11.537
	Numbers of ions on the basis of 12 (O)		
Si	3.03 } 3.03	3.01 } 3.01	3.02 } 3.02
Al	--- }	--- }	--- }
Al	1.95	1.93	1.93
Ti	0.00 } 2.00	0.04 } 2.00	0.00 } 2.00
Fe^{+3}	0.05	0.03	0.07
Fe^{+2}	0.88	1.11	1.64
Mn	0.08	0.02	0.22
Mg	1.78 } 2.98	1.69 } 2.88	0.79 } 2.89
Ca	0.23	0.05	0.23
Na	0.01	0.01	0.01
	Mol. per cent. end-members		
almandine	29.7	38.5	56.7
andradite	2.4	3.8	3.8
grossular	5.1	---	4.5
pyrope	60.1	57.0	27.4
spessartine	2.7	0.7	7.7
uvarovite	---	---	---

(RGM 163 156) has the highest *a*, while the one with the lowest value for *a* has the lowest Ca content (RGM 163 157).

The two almandine garnets with equal Ca content (RGM 163 155 and 163 159) have different unit cell dimensions, which may be ascribed to their different Mn content.

The conventional analyses given in Table 6 do not differ very much from the analyses obtained by the microprobe. It is seen that the andradite percentage is not high in these garnets, and that the Fe content is mainly due to divalent iron.

The relation between the Mg or Fe content and the figures of *n* and D can be observed in both Tables 5 and 6. The higher the pyrope content the lower *n* and D, the higher the almandine content the higher these properties.

Although the X-ray powder photographs of these almandine garnets are very similar, it is seen that two of them, made from the samples RGM 163 155 and 163 157 have a pattern characteristic for pyrope. The remaining five have an almandine pattern, which means that the intensity of the diffraction line 332 is rather faint in comparison with those of 442 and 431.

In Table 3 X-ray powder diffraction data for two almandine garnets from Umba are given. As might be expected the mutual differences are only small, just like the differences between them and the powder data for the rhodolites, also given in this table.

Regarding the absorption spectra, all specimens have an almandine spectrum. The three main absorption bands of almandine can easily be observed. It is striking that this spectrum also dominates in the two garnets having properties in the pyrope field. Apparently even a low Fe content in garnets of the pyrope-almandine series is sufficient to eliminate the broad absorption band in the yellow-green centred near 5750 Å, characteristic for pyrope. Moreover it should be interesting to examine the relationship between the intensity of the reflection 332 on X-ray powder photographs and the Mg/Fe ratio. The data found indicate that these garnets, except two of them, have higher properties than the rhodolites. They belong to the pyrope-almandine series and are generally situated in the region towards the almandine end-member.

INCLUSIONS

Sample RGM 107 203 contains numerous more or less rounded crystals, both large and small, having low polarization colours, parallel extinction and a lower refringence than the surrounding garnet (Fig. 8). One of them, extending to the polished surface of the almandine, was identified by X-ray powder photograph RGM 201 340 as apatite. No orientation of these apatite crystals was observed.

In specimen RGM 163 155 groups of apatite crystals occur (X-ray powder photograph RGM 201 334). In Fig. 9 some of them can be seen. They have the same habit as those occurring in the garnet described above. In addition, rutile can be seen, oriented in three directions making an angle of 60° with one another. The needles are sparsely spread through the stone but concentrated around the clusters of apatite. Small zircon crystals with haloes can be seen throughout the garnet. Finally, a well-developed liquid feather is present.

Rather small rounded crystals of apatite (X-ray powder photograph RGM 201 335) occur in sample RGM 163 156 (Fig. 10). They are concentrated in one part of the garnet. The characteristic habit of apatite crystals, when included in other minerals, is shown in Fig. 11. In addition, a few rutile needles can be observed in this garnet.

Specimen RGM 163 157 contains a great number of black opaque, more or less rounded crystals, arranged in groups without any orientation (Fig. 13). In reflected light they have a submetallic high lustre. (Fig. 12). By means of an X-ray powder photograph (RGM 201 336) one of them was found to be rutile. In rhodolite garnet RGM 163 171, similar crystals were included. Besides the rutile crystals, the almandine garnet contains a few long rutile needles.

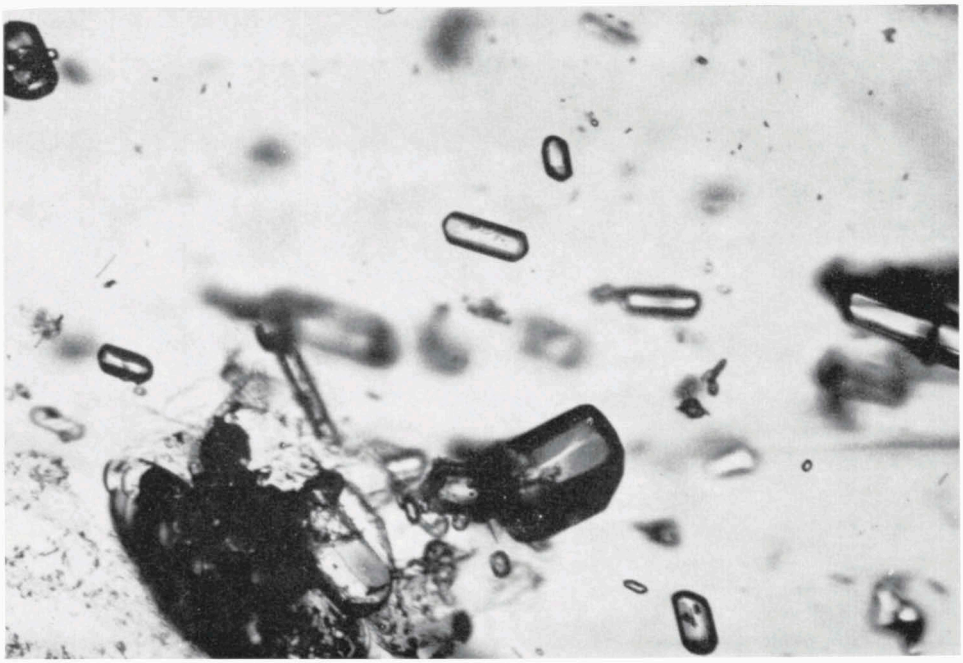


Fig. 8. Apatite crystals in almandine garnet RGM 107 203, 65x.

Fig. 9. Apatite crystals in almandine garnet RGM 163 155, 80x.

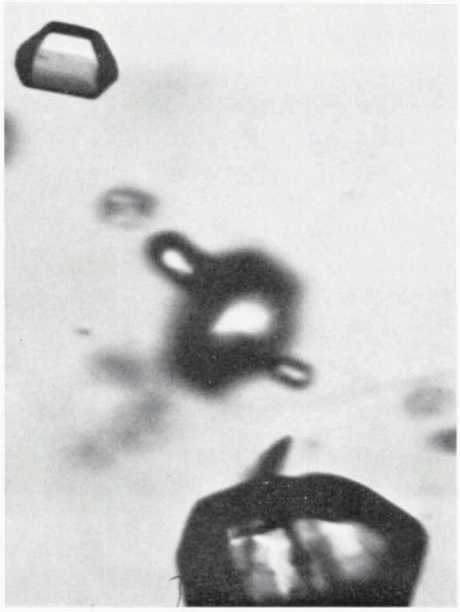
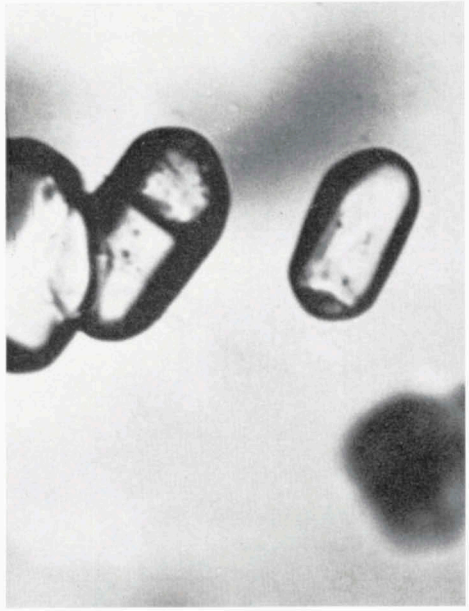


Fig. 10. Apatite crystals in almandine garnet RGM 163 156, 180x.



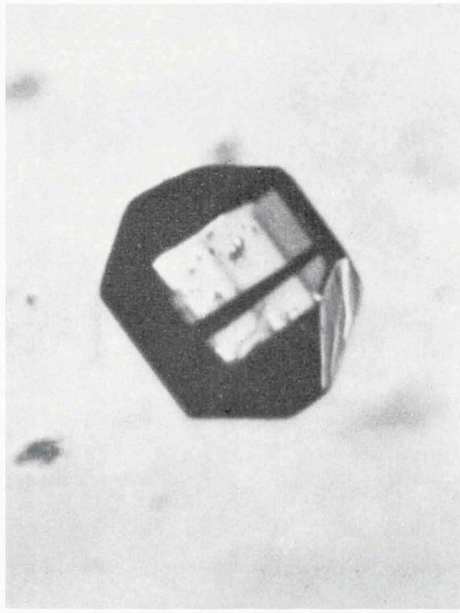


Fig. 11. Apatite crystal in almandine garnet RGM 163 156, 110x.

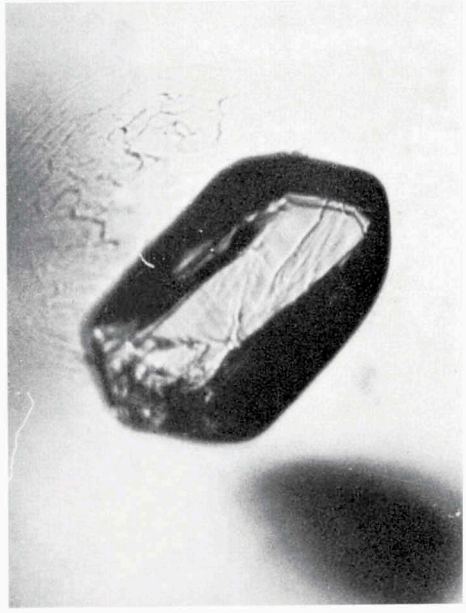


Fig. 12. Rutile crystal in almandine garnet RGM 163 157, 110x, both reflected and transmitted light.

Fig. 13. Rutile crystals in almandine garnet RGM 163 157, 40x.

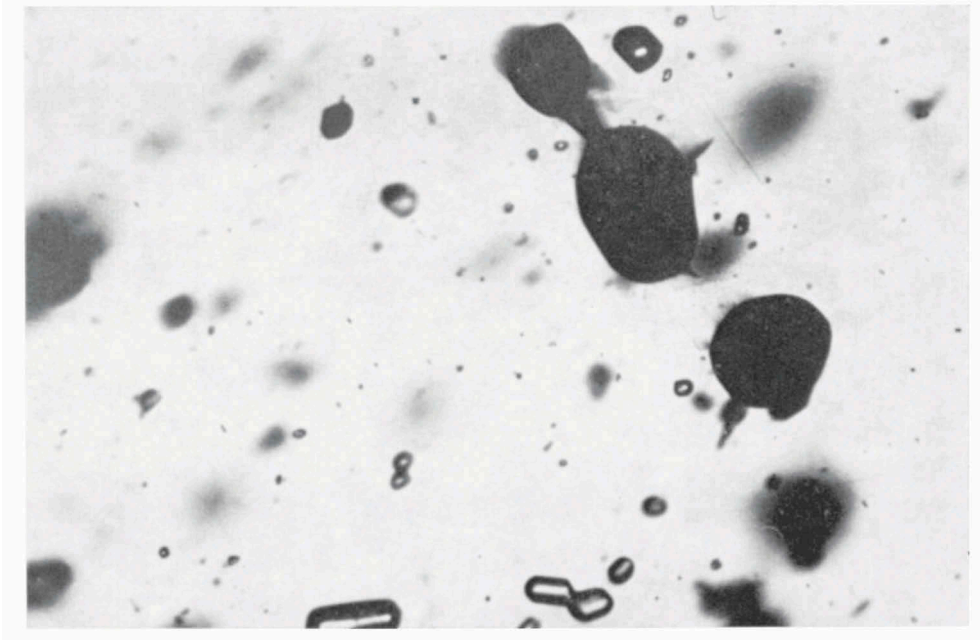


Fig. 14. Pyrrhotite and apatite crystals in almandine garnet RGM 163 158, 40x.

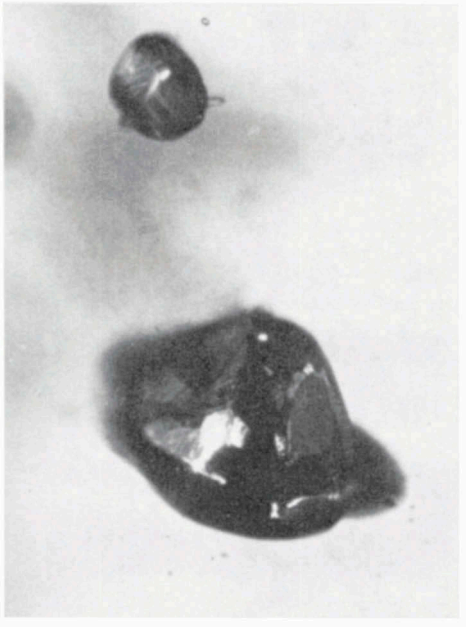


Fig. 15. Pyrrhotite crystals in almandine garnet RGM 163 158, 90x, both reflected and transmitted light.

Black opaque crystals, most often rounded and sometimes with a hexagonal shape, occur in sample RGM 163 158 (Figs. 14 and 15). In reflected light they have a bronzy yellow colour. One of them, touching the surface of the garnet, was identified as pyrrhotite (X-ray powder photograph RGM 201 324). In addition, both long and short prismatic colourless transparent crystals occur without any orientation throughout the stone. They resemble the apatite crystals included in the above mentioned almandine garnets, having the same optical properties as far

as these can be examined. Needles of rutile, arranged in the well-known three directions, are concentrated around the larger crystals of pyrrhotite and apatite.

In specimen RGM 163 159 some groups of apatite crystals are present, all crystals having properties similar to those found in the other almandine garnets described here. Moreover, some black crystals with a high lustre are included, which resemble the rutile crystals found in sample RGM 163 157.

In garnet RGM 163 160 no solid inclusions can be observed but two very well developed liquid feathers occur.

From these data it is obvious that apatite and short prismatic rutile crystals are common inclusions in almandine garnets from Umba. These inclusions cannot be considered diagnostic for the locality, as the same inclusions are found in almandine garnets from Ceylon. Pyrrhotite is also known from Ceylon stones (Zwaan, 1967), while there is no question that zircons with haloes are commonly found in garnets from other sources.

Corundum

VARIETIES

The most striking property of the corundums from Umba is the variation in colour. Therefore, the available material will be described first according to the colours and subsequently according to the properties.

Ruby – (RGM 107 193, 107 202, 107 207, 107 210, 107 225, 163 172, 163 173 and 163 183). Red corundum was available in rather large quantity, the colour being violet-red to a paler orange-red. Most of the material consists of crystal fragments, sometimes with one or two basal pinacoid faces. There are a few specimens, however, having distinct crystal forms. Sample RGM 107 225, for instance, is a vermiculite-bearing rock in which four ruby crystals are to be seen. These are hexagonal prisms with basal pinacoid faces. The largest one has a length of 15 mm and a diameter of 13 mm.

RGM 107 202 consists of two parallel-grown hexagonal prisms, the joining plane being in the direction of the basal pinacoid. Both prisms have a length of 5 mm approximately, the diameters being 9 and 8 mm respectively.

Although the colours of these rubies are rather good, they are too brittle and so impure as to be almost translucent, and therefore are not of gem quality.

Sapphire – (RGM 163 188 to 163 191). These four crystals have a pleasant blue colour with a light violet hue. They are hexagonal prisms with basal faces, a tabular habit which is quite unusual for sapphire. The size of RGM 163 188 is 17 x 11 mm, RGM 163 189 is 11½ x 14½ mm, RGM 163 190 is 6 x 18 mm and RGM 163 191 is 4 x 18 mm, the first figure corresponding to the length and the second to the diameter. The prism faces are corroded, the pits being filled with vermiculite flakes. It is very likely therefore that these crystals originate from a vermiculite rock similar to that described above (RGM 107 225).

Greenish corundum – RGM 107 198, 163 141 to 163 144). Many large crystal

fragments with basal pinacoid faces were available for investigation. They have a greenish to yellow-brown colour and tend to be reddish in artificial light, a colour change very much like that of an alexandrite. The specimens are mainly almost translucent, hence are not of gem quality.

Pinkish corundum – (RGM 107 206, 107 214 and 107 224). Sample RGM 107 206 consists of a number of rather large crystal fragments, all intergrown with a greenish black amphibole which will be described later on. The corundums have a flattened habit by which the basal pinacoids are well developed. Diameters up to 20 mm are observed.

In sample RGM 107 214 a number of crystal fragments without any crystal faces are present. They are pinkish with a distinct violet hue. Some of them have a pink core surrounded by violet in hexagonal zoning. Parts of the stones are almost colourless.

RGM 107 224 is a rock specimen in which large crystal fragments, up to a size of 50 x 40 x 20 mm, are intergrown with kyanite.

Violet corundum – (RGM 107 201, 107 204, 163 153 and 163 154). Three specimens have a deep violet colour resembling that of good quality amethyst. One of them, RGM 107 201, is a corroded hexagonal prism of 8 mm with a diameter of 15 mm. Included black submetallic flakes may be seen with the naked eye.

Another one, RGM 163 153, also has a hexagonal prism habit with a length of 10 mm and a diameter of 11 mm. Its original weight is 14.62 carats. The same inclusions as seen in the above mentioned crystal may be observed. They are oriented parallel to the basal pinacoid.

The third one, RGM 163 154, has an irregular shape with basal pinacoids only, its original weight being 8.82 carats. With the naked eye numerous included transparent colourless crystals may be seen together with the same black flakes as included in the other two specimens mentioned above.

RGM 107 204 consists of about 20 corroded hexagonal prisms, partly covered with vermiculite. All crystals have a tabular habit and are much lighter violet than the above mentioned corundums. Moreover they are almost translucent, due to impurities. The largest one has a length of 7 mm and a diameter of 19 mm.

Yellow-orange corundum – (RGM 107 208 and 163 174). One of the two specimens, RGM 107 208, is a parallel growth of two well crystallized flat hexagonal prisms. The total size is 6 x 13 mm, the latter figure being the diameter.

RGM 163 174 is a crystal fragment which, on account of its colour, is called "golden sapphire" in the Umba area.

Parti-coloured corundum – (RGM 107 199, 107 217, 163 145 to 163 148 and 163 184 to 163 187). Among them are five specimens with violet-pink and blue colours in which some areas are almost colourless. RGM 163 145 is a corroded hexagonal prism, covered with vermiculite, with a length of 15 mm and a diameter of 30 mm. This crystal is sapphire blue with a pinkish coloured core.

Three others (RGM 163 146 to 163 148) are crystal fragments with a blue core changing to pink towards the outside of the specimens.

Sample RGM 107 199 is a fragment of a crystal that originally had a violet-pinkish core changing into pale yellow and almost colourless, and then into blue at the exterior. Electron microprobe determinations have been carried out in this

specimen, the results of which will be given below on page 22 and in Table 7.

RGM 107 217 is a corroded hexagonal prism with a length of 10 mm and a diameter of 20 mm. It is mainly blue with an orange-pink core.

RGM 163 184 is a flat corroded slab of a hexagonal prism, about 55 mm thick, with a diameter of 21 mm. The main colour is blue, the edges and a small part of the core are yellow to colourless.

RGM 163 185 is a part of a hexagonal prism with a thickness of almost 11 mm. Perpendicular to the c-axis it has a violet-pink colour. Parallel to this axis the centre is blue but the rest of the stone has orange edges changing to yellow. The specimen is covered by vermiculite, while the same mineral is also included.

RGM 163 186 is about half of a hexagonal prism with a thickness of 9 mm and a diameter of 14 mm. The corroded prism faces are covered with vermiculite. Perpendicular to the c-axis its colour is mainly orange-yellow but parallel to this axis the centre is yellowish and the outside is violet-pink. Colour zoning is very distinct.

RGM 163 187 is an irregular shaped crystal fragment having basal pinacoid faces only. Its thickness is about 7 mm. The different colours that are visible are orange, blue and pink, the blue being predominant.

PROPERTIES

Density – The specific gravity of several corundums was measured, especially of those which may be confused with other minerals. The green corundum RGM 163 143 was found to have the lowest density (3.975), while another green one (RGM 163 142) has the highest figure of 3.993. All other densities are between these two figures.

Optical properties – The refractive indices lie between 1.760 and 1.765 for ε and between 1.768 and 1.774 for ω. These figures are obtained from a large number of stones. They do not deviate from data given by Bank (1972). The higher values, mentioned by Bank (1970) for orange corundums from Umba were not found with RGM 163 174. This orange specimen has ε 1.765 and ω 1.774.

Although many specimens have normal extinction, there are many showing anomalous interference colours in polarized light, which apparently is due to impurities, cracks, parting, etc. Depending on the depths of their colours, all corundums have distinct to strong dichroism, the rubies in tones of yellow-orange and deep red, the sapphires in pale blue and deep blue, the orange stones in yellow and orange-red. The greenish corundums (RGM 107 198 and 163 141 to 163 144) have both bluish and yellowish tints; in artificial light the yellow changes into a reddish yellow colour. The corundums of other colours are dichroic in pale and deep tones of the same colour.

As might be expected, the nature of the absorption spectra is strongly dependent on the colour of the stone. The red corundums have an absorption spectrum which is apparently due to Cr, with lines and bands, characteristic of rubies, and therefore, their spectrum will be called the ruby spectrum.

The blue corundums have the characteristic sapphire absorption spectrum, due to Fe. The same spectrum is shown by the yellow and the green material, as well as the blue with yellow and the green with yellow parti-coloured corundums.

The orange material has a more complex spectrum, being a combined ruby and sapphire spectrum. Both Cr and Fe lines may be observed. The deep violet corundums have a similar absorption spectrum.

In a number of the parti-coloured stones the absorption spectrum changes with the colour from a ruby to a sapphire pattern by moving the stone from one side to the other under the spectroscope, for instance from red to blue and from red to green.

With respect to the intensities, the corundums with deep colours have the most distinct spectra, while those of paler-tinted stones have moderate to weak intensity. In the pale violet corundums the sapphire spectrum dominates while the ruby spectrum is weak. The same is true with the orange material.

Under both long- and short-wave ultra-violet light most of the corundums are inert. The yellow variety specially is not fluorescent, which is in contrast with yellow corundums from Ceylon. The latter have an apricot yellow colour under long-wave ultra-violet light. Under this irradiation the red variety of the Umba corundums will give a red fluorescence while the violet to pink corundums are weak orange-red. The deep violet stones are distinct red, the paler violets give a dull red. Under short-wave ultra-violet light they have the same colour, however with less intensity.

Chemical properties – To find out which elements are responsible for the colour of the corundums, electron microprobe determinations have been carried out by Dr P. Maaskant on the green corundum RGM 163 144 and the parti-coloured specimen RGM 107 199. Particular attention was paid to those elements which may occur in corundum, as can be seen in analyses given by Deer et al. (1962). Spectrometer 2Θ-scanning only revealed the presence of Fe, Ti and Cr, which elements are, according to Harder (1969), responsible for the colours of corundums.

Table 7. Electron microprobe determinations of two corundums and one tourmaline from Umba, Tanzania (in weight %).

	corundum RGM 163 144 green	corundum RGM 107 199 red part	corundum RGM 107 199 blue part	tourmaline RGM 107 197 emerald-green
Fe	1.08 (1.06-1.10)	0.42 (0.41-0.43)	0.42 (0.41-0.43)	0.005
Ti	0.015 (0.011-0.019)	0.012 (0.009-0.018)	0.019 (0.010-0.025)	0.35
Cr	0.005	0.023 (0.014-0.030)	0.020 (0.012-0.030)	0.16
V	<0.05 *	<0.05 *	<0.05 *	0.46
Ca	<0.001*	<0.001*	<0.001*	1.46
Mn	0.002*	<0.0005*	<0.0005*	± 0.010

* if present

As these corundums were embedded in the same mould as tourmaline RGM 107 197, Mn, Ca, and V were also analysed in the corundums. Electron microprobe determinations were performed with a Cambridge Instrument Co. Geoscan operated at accelerating potentials of 25 and 30 kV. As standards were used diopside (Fe), Ti0 and pyrope (Ti), pyrope (Cr), olivine (Mn), diopside (Ca) and V_2O_5 for Vanadium. Apparent concentrations, only corrected for dead-time and background, obtained from the average value of three arbitrarily chosen spots, are given in Table 7.

The Fe content of the green corundum RGM 163 144 is extremely high in comparison with the data given by Harder (1969), for a green sapphire from Umba. Moreover, the Ti and Cr contents are about twice as high as those mentioned by Harder. The high Fe content of this corundum may be the cause of its green colour, while its reddish hue in artificial light may be due to the rather high Cr content, though it is much lower than that of the parti-coloured corundum RGM 107 199. The data for the reddish part of the latter indicate a high Fe content in comparison with results given by Harder for rubies.

As already mentioned, however, this corundum is not deep ruby-red but more pinkish brown-red changing into pale orange-yellow and finally pale blue to violet-blue. Hence the high Fe content of the reddish part is explicable. The Ti and Cr contents of this part are in good agreement with those found by Harder.

The bluish part of this corundum has a high Cr content compared with data given by Harder (1969) for a blue sapphire from Umba. It fits better, however, with his data on violet corundums from the same area. This may be due to the fact that there is distinct violet present in the blue part of the specimen. The data for both Fe and Ti are within the range given by Harder for blue sapphires.

Individual spot analyses of simultaneously measured Ti and Cr contents in the red part (left) and the blue part (right) of the parti-coloured corundum indicated a possible relationship between these two elements. A more detailed investigation of this relationship is shown in Fig. 16: six continuous scanning profiles for Ti- and Cr-$K\alpha$ radiation across the parti-coloured corundum and more or less perpendicular to the red-blue boundary.

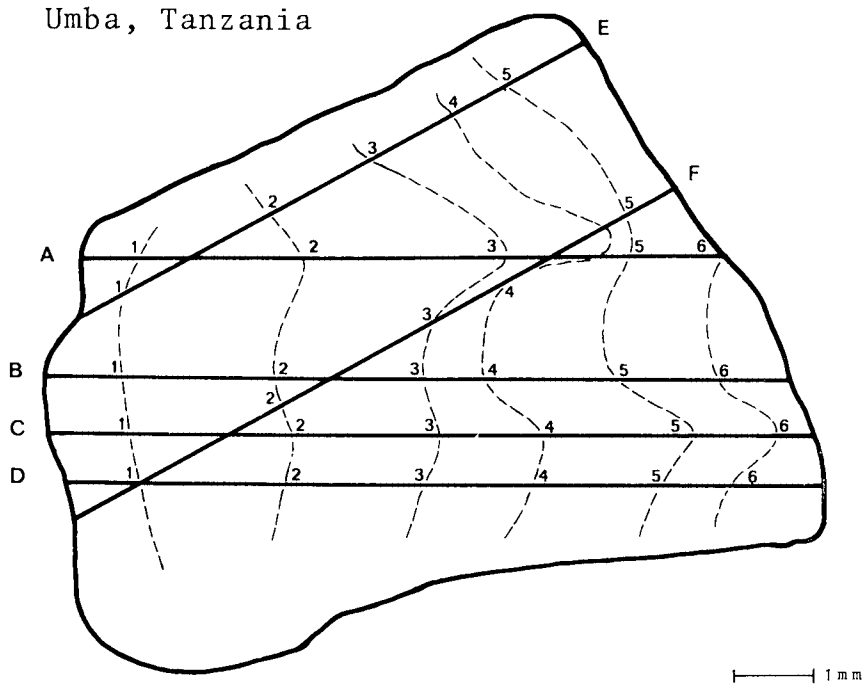
The six sections have a striking similarity, especially when the Cr content is taken into consideration. The numbers in the figure represent comparable situations in the sections: 1 corresponds with the first Cr minimum, 2 is the second Cr minimum. 3 is a Cr minimum just before one or two Cr maximums, followed immediately by a Cr level at 4. The end of this level is 5, while 6 is the second Cr maximum after the Cr level. At the point of intersection between A and F the Cr level in section A is missing. Here the red part of the corundum is penetrating into the blue.

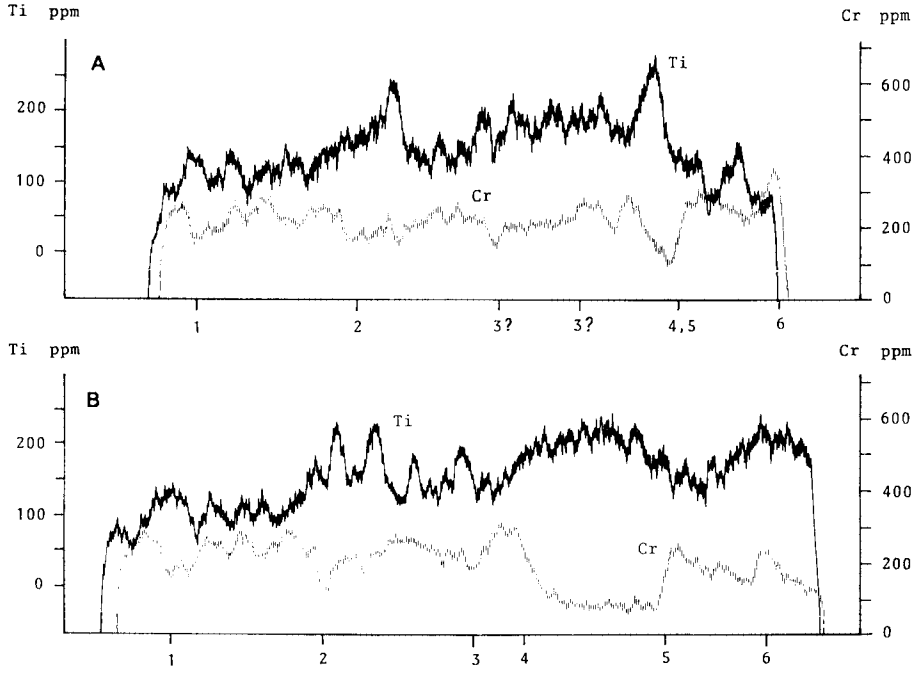
From the data obtained, it may be concluded that the blue colour of this specimen may be due to a higher Ti and a lower Cr content, whereas in the red part the Cr content is higher and the Ti content is lower.

Harder (1969) points out that X-ray fluorescence is more convenient than the microprobe to detect trace elements. Differences in concentration, however, can better be measured with the aid of the last-named instrument. A disadvantage of the microprobe is that the Fe^{+3} / Fe^{+2} ratio cannot be detected.

It is very unlikely that blue sapphires owe their colour to Co, as mentioned by Solesbury (1967). Harder (1969) does not mention Co. We did not find this element in the blue corundums described here. Their absorption spectra, moreover, do not have any absorption bands which can be ascribed to cobalt.

C O R U N D U M R G M 107 199





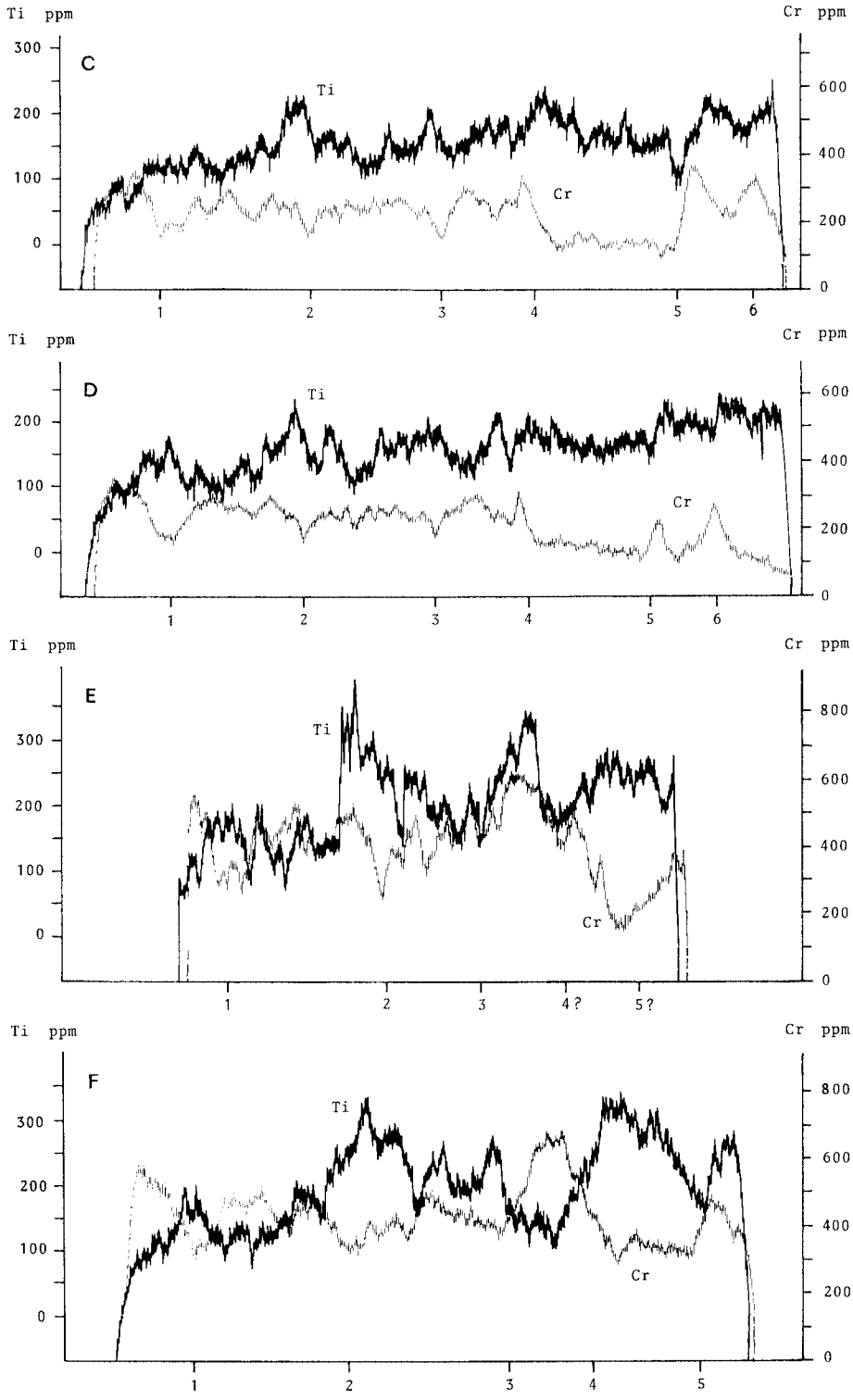


Fig. 16. Continuous scanning profiles for Ti- and Cr-$K\alpha$ radiation across the corundum RGM 107 199.

INCLUSIONS

As usual with corundum, many inclusions can be observed. Most of them are solid and represent various minerals.

Rutile – Rutile is a common inclusion in many of the corundums. In the green stone RGM 163 141 it occurs as long needles, oriented in two directions (Fig. 17). In the same way needles are found in rubies RGM 163 172, 163 173 and 107 210. Moreover, short needles of rutile, oriented in three directions, are present in many other specimens, as in the deep violet corundum RGM 163 154 and concentrated at several places in the parti-coloured stone RGM 163 184.

According to Eppler (1972) elongated needles occur in corundums from Umba, which seem to be similar to rutile needles but in fact are corundum. It is difficult to identify these needles by use of optical methods only. It is quite possible, therefore, that the material described here also contains corundum needles together with or instead of rutile needles.

In the four sapphire crystals (RGM 163 188 to 163 191), 'needles' occur which may be ascribed to a kind of dislocation, a possibility mentioned by Schubnel (1972).

Pyrrhotite – A rather common inclusion in ruby is pyrrhotite. In Fig. 18 somewhat rounded crystals may be seen included in ruby RGM 163 172. They have a bronzy yellow colour with a metallic lustre. X-ray powder photographs (RGM 201 277, 201 278 and 201 330) indicate that it is pyrrhotite. Many of the rubies belonging to sample RGM 163 173, and the rubies RGM 107 210 and 163 183 contain similar crystals. Material scraped from the latter was found to be strongly magnetic.

Apatite – Almost colourless crystals with the same habit as the apatite crystals found in the described almandine garnets from Umba occur in a number of corundums. Fig. 21 illustrates these apatite crystals (X-ray pawder photograph RGM 201 328), included in the deep violet corundum RGM 163 154. In the green corundums RGM 163 141 and 163 142 these apatite crystals are well developed (X-ray powder photographs RGM 201 339 and 201 332). In Figs. 19 and 20 some of the apatite inclusions in these corundums may be seen.

In a number of the specimens belonging to the parcel of rubies RGM 163 173, as well as in the parti-coloured corundum RGM 163 186, similar crystals are included. Their identity has not been checked by X-ray analysis but their optical properties give strong indications that they are apatite crystals as well.

Graphite – In some of the corundums, especially in the deep violet specimens, many black submetallic flakes, visible to the maked eye, have been identified as graphite (X-ray powder photographs RGM 201 325 and 201 329). They occur in layers parallel to the basal face. Fig. 22 illustrates these inclusions in sample RGM 163 153.

Similar flakes occur to a lesser extent in violet corundum RGM 163 154, and the violet crystal RGM 107 201. Finally, in a number of the stones in the parcel of rubies RGM 163 173, flakes can be observed, which are probably graphite.

Zircon – Many somewhat rounded, colourless and transparent crystals occur in the yellow-orange corundum RGM 163 174. In polarized light they have haloes.

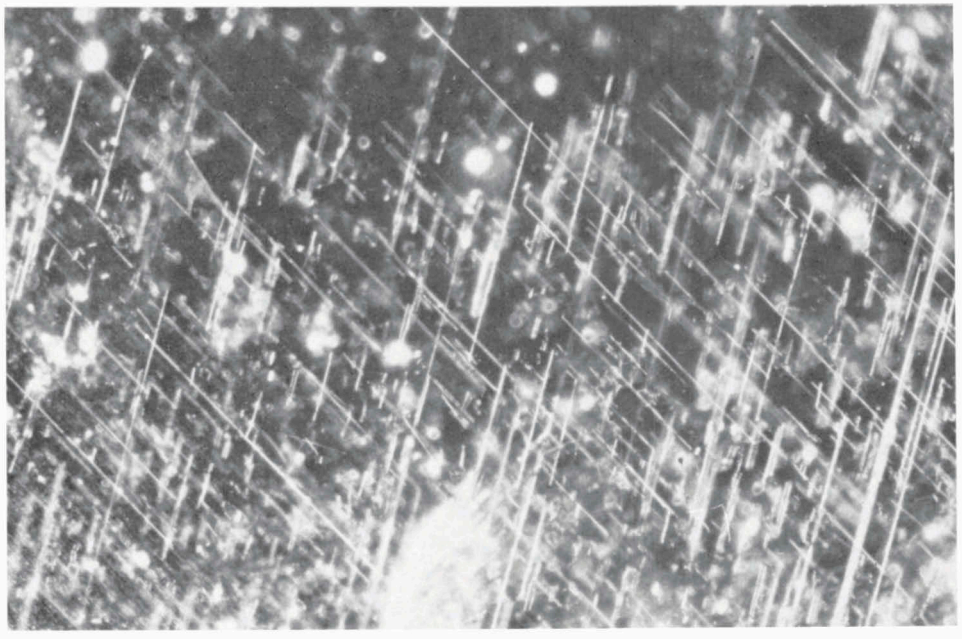


Fig. 17. Rutile needles in green corundum RGM 163 141, 70x, reflected light.

Fig. 18. Pyrrhotite crystals in ruby RGM 163 172, 60x, both reflected and transmitted light.

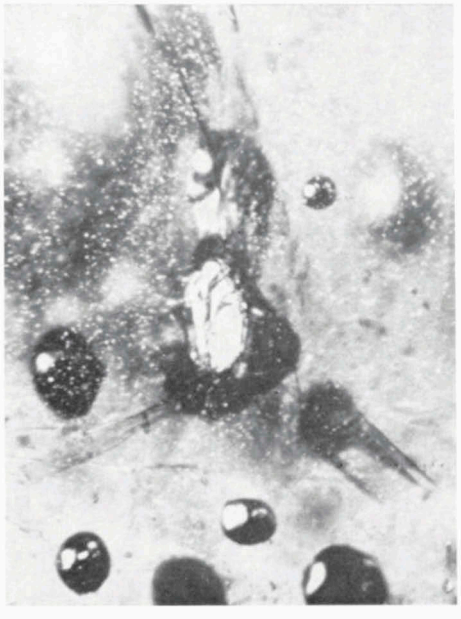
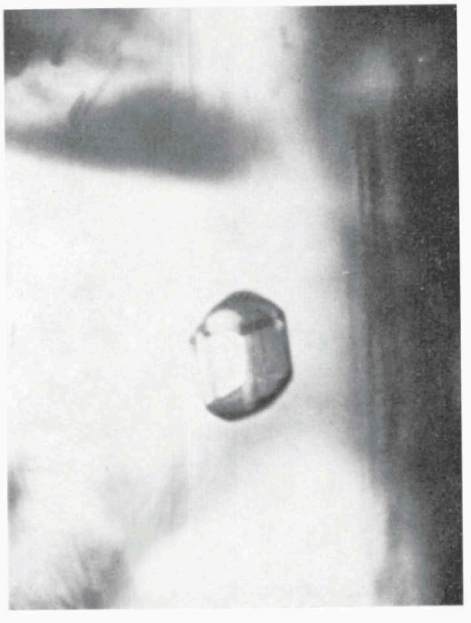


Fig. 19. Apatite crystal in green corundum RGM 163 142, 150x, both reflected and transmitted light.



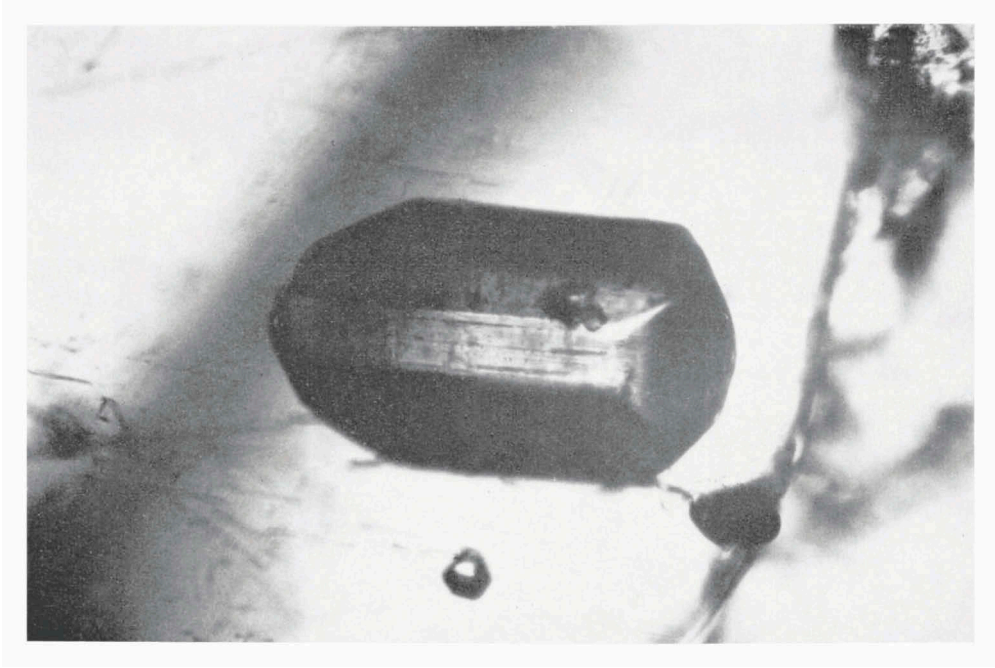
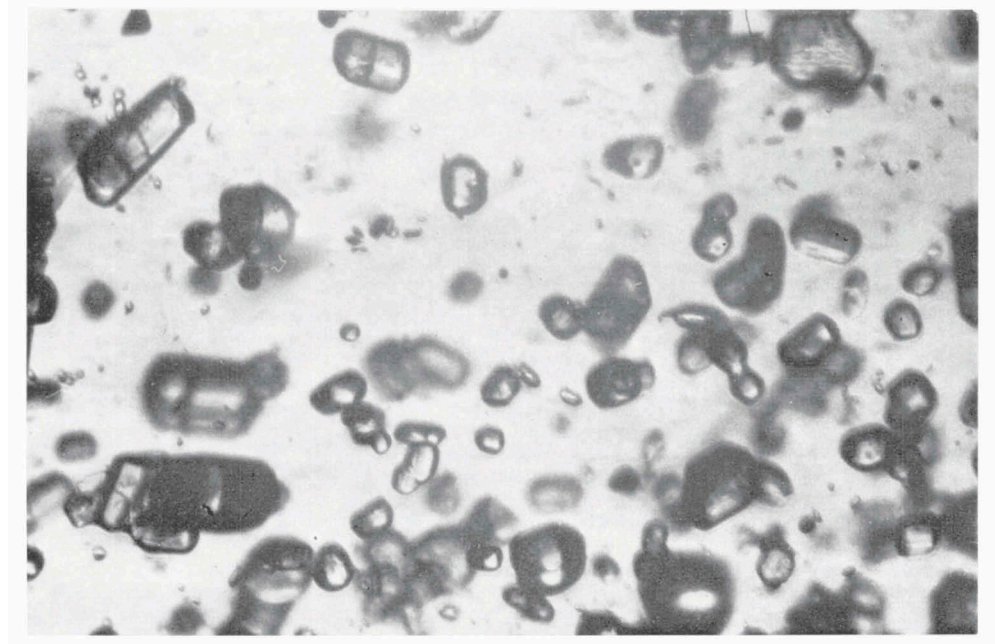


Fig. 20. Apatite crystal in green corundum RGM 163 142, 90x.

Fig. 21. Apatite crystals in violet corundum RGM 163 154, 45x.



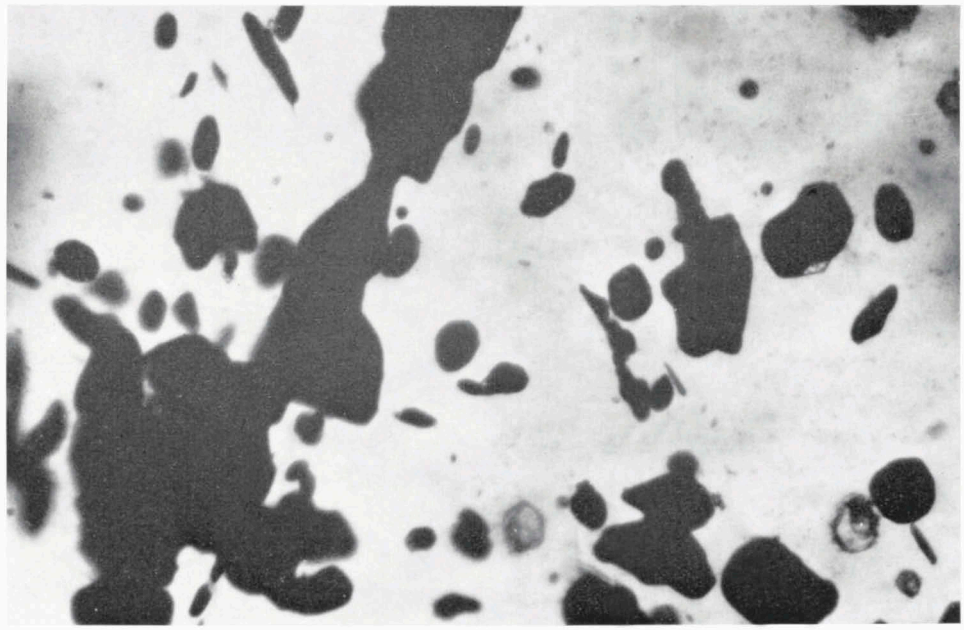


Fig. 22. Graphite flakes in deep violet corundum RGM 163 153, 60x.

One of them, touching the surface of the corundum was identified as zircon (X-ray powder photograph RGM 201 345). Similar crystals with haloes are included in the four sapphire crystals RGM 163 188 to 163 191.

Recently, Schubnel (1972) has also mentioned zircon inclusions in violet and blue corundums from this area.

Spinel – In ruby RGM 107 193 some black to dark greenish blue inclusions can be seen, with a habit that is generally isometric, though elongated and flattened crystals also occur. One of them was found to be spinel (X-ray powder photograph RGM 201 775).

Vermiculite – Many of the corundums, but especially the violet to pink specimens of sample RGM 107 214, include flakes of a mica-like mineral, in planes parallel to the basal face of the host crystal. Their colour is brownish green to a pleasant olive green. They are probably vermiculite because they are very similar to the material covering many of the corundums that is identified by X-ray powder photographs RGM 201 331 and RGM 201 338. The parti-coloured specimen RGM 163 185 also contains a number of vermiculite flakes.

Liquid feathers – Liquid feathers are a common feature in many of the Umba corundums described here. A well developed one can be observed in the parti-coloured stone RGM 163 187. These feathers resemble closely those usually found in Ceylon sapphires.

CONCLUSIONS

From these observations it is obvious that rutile and apatite are common inclusions in corundums from Umba, while pyrrhotite is common in the rubies. Included graphite seems to be distinctive for the deep violet corundums.

These inclusions, with the exception of graphite, cannot be considered diagnostic for the locality as the same inclusions may occur in Ceylon corundums (Zwaan, 1967). Graphite is, up to now, only found in Umba corundums.

The orientation and the habit of the inclusions might be characteristic of a locality, but for Umba corundums it has not yet been recognized.

Tourmaline

VARIETIES

Only eleven tourmalines were available for investigation. On the basis of colour they can be divided into two groups, one with emerald green colour and the other with reddish brown and orange colour (see Table 8). The stones, listed in this table, were cut from rough material presented by the manager of the Umba mine.

As the tourmalines described here were found in the weathered portion of the deposit, their primary origin is unknown. The author collected a crystalline limestone (RGM 107 190) in which small graphite flakes occur together with minor amounts of pale green tourmaline (X-ray powder photograph RGM 201 209). It is quite possible that the emerald green crystals originate from the same type of rock. As the emerald green specimens are of particular interest because of their colour, they will be described first.

Emerald green tourmaline – From the crystallographic point of view the rough specimens are most interesting. RGM 107 219 has a flattened prismatic habit. The best developed form is $\{02\bar{2}1\}$. Subsequently both $\{11\bar{2}0\}$ and $\{10\bar{1}0\}$ are well developed. Other forms present are $\{0001\}$, $\{10\bar{1}1\}$ and $\{01\bar{1}2\}$. The crystal is about 10 mm across the prism and about 7 mm in depth.

RGM 107 220 has the same unusual habit. The order of development of the forms is also the same. The basal pinacoid faces are absent, however. Perpendicular to the c-axis, the size is 30 mm, while the depth is about 21 mm.

The crystal RGM 107 197 has a prismatic habit, the prism faces being well developed and vertically striated. Moreover, the form $\{02\bar{2}1\}$ can be observed. The length of the crystal is 7 mm, across the prism it measures 4 mm.

Some properties of both the rough specimens and the cut stone are given in Table 8. Due to the perfect crystallization, it was possible to measure the refractive indices of the crystals on a refractometer using the rhombohedral faces. The refractive indices and the densities are in good agreement with those given by Webster (1961) and Bank & Berdesinski (1967) for green tourmalines from Tanzania.

All four specimens have a strong dichroism. The dichroic colours, yellow-green and deep bluish green, closely resemble those of a good quality emerald. Under the Chelsea colour filter they show a deep red colour, just as emerald normally does. The big crystal RGM 107 220 even has a red colour in transmitted artificial light, a phenomenon also mentioned by Webster (1961) for a dark green tourmaline from Tanzania.

Regarding the absorption spectrum all four crystals have the same pattern, the intensity being the highest in RGM 107 220. In the red part, a weak line may

Table 8. Properties of ten tourmalines from Umba, Tanzania.

sample no.	colour	original weight in carats	ε	ω	D	remarks
RGM 107 197	emerald green	1.01	1.620	1.642	3.027	crystal
" 107 219	emerald green	4.01	1.620	1.642	3.040	crystal
" 107 220	emerald green	115.42	1.620	1.642	3.051	crystal
" 151 262	emerald green	1.02	1.618	1.638	3.054	emerald cut
" 107 192	orange	5.31	1.620	1.642	3.053	pebble
" 163 130	orange	2.74	1.621	1.643	3.055	pebble
" 151 259	yellow-orange	2.12	1.627	1.648	3.057	oval mixed cut
" 163 131	yellow-brown	1.15	1.621	1.646	3.036	pebble
" 151 260	reddish brown	1.93	1.620	1.643	3.044	oval mixed cut
" 151 261	reddish brown	13.53	1.626	1.648	3.042	cushion cut

be observed at 6995 Å, while at about 6765 Å a doublet is present. A broad absorption band centred between 6105 and 6070Å is shown by these stones as well as a general absorption of the violet part of the spectrum. These observations are very similar to data given by Crowningshield (1967/68) and Anderson (1971). The author agrees that the absorption spectrum may be due to Cr, although V as a source should also be taken into account (Anderson, 1971).

For that reason Dr P. Maaskant carried out a partial electron microprobe analysis on sample RGM 107 197. The results are given in Table 7. From the data, it is very likely that both vanadium and chromium cause the emerald green colour of this tourmaline, although it is not impossible that the high Ti content might also influence this colour in one way or another.

Under long-wave ultra-violet light these tourmalines are inert but a mustard yellow glow is seen under short-wave conditions.

The typical liquid inclusions often seen in tourmalines occur in the three rough specimens. Moreover, in the crystal RGM 107 219 large well-formed crystals may be observed, having much in common with those described by Webster (1961). Fig. 23 shows one of these crystals which from the habit and interference colours, could be apatite.

Orange and brownish tourmaline – This group consists of three specimens in which an orange colour is predominant. The refractive indices and densities are given in Table 8. It is striking that the variation in the densities is small, the lowest is 3.053, the highest 3.057. Apart from those of two emerald green stones, these values are higher than any of the remaining samples.

All three have a very distinct to strong dichroism in tones of pale yellow and yellow-orange. Their absorption spectra are not very characteristic, a general absorption of the blue and violet parts only may be observed. Under long-wave ultra-violet light no fluorescence can be seen, but they have a dull yellow glow under short-wave ultra-violet light.

The liquid inclusions, normally seen in tourmalines, occur in all three.

As stated in Table 8 two of the brownish tourmalines are reddish brown and one is yellow-brown. Their refractive indices are generally slightly higher than those of the green tourmalines mentioned in this table. Their densities are between the lowest and highest data measured for the green stones, but distinctly lower than those of the orange stones.

The yellow-brown specimen RGM 163 131 is strongly dichroic, the colours being pale yellow and brownish orange. The two reddish brown cut stones have

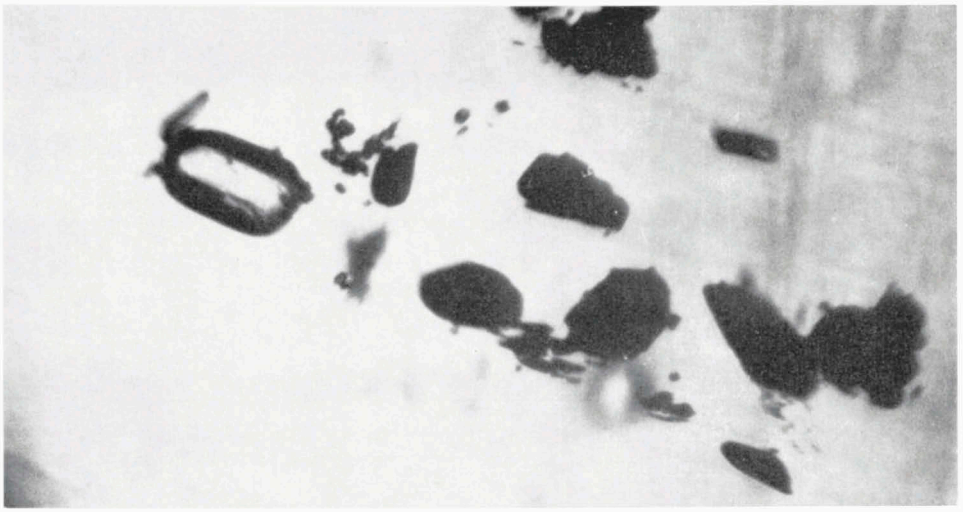


Fig. 23. Liquid and crystal inclusions in emerald green tourmaline RGM 107 219, 70x.

a very strong dichroism in tones of greenish yellow and reddish brown.

Regarding their absorption spectra they have much in common with red tourmalines. A broad absorption band in the green, centred near 5200 Å, together with weak lines near 4600 and 4500 Å in the blue and a narrow band at 5370 Å in the green part of the spectrum, may be seen.

These tourmalines glow a dull yellow under short-wave ultra-violet light but are inert under long-wave irradiation. They contain the liquid inclusions normally seen in tourmalines. Fig. 24 illustrates these inclusions in the yellow-brown stone RGM 163 131, together with two-phase inclusions occurring only in this specimen.

CONCLUSIONS

Although far too little material was available for examination, the data obtained give sufficient indication to conclude that the two groups of tourmalines described differ in chemical composition. The emerald green specimens possibly are related to uvite, while the orange and brownish stones could contain a high content of elbaite.

Other gem minerals

PYROXENE

Orthopyroxene – (RGM 107 200, 163 149 to 163 152). Although only a few specimens were available for investigation it is worth while to pay attention to them on account of their properties. Their colour is a deep yellowish brown. With the naked eye no inclusions may be observed. They therefore are certainly of gem quality and interesting as collector's items.

Fig. 24. Liquid and two-phase inclusions in yellow-brown tourmaline RGM 163 131, 110x.

Two specimens (RGM 163 149 and 163 150) are strongly corroded almost complete crystals with a short prismatic habit. The first one had an original weight of 23.56 carats and has been partly used for a chemical analysis (see Table 9). RGM 163 150 weighs 19.09 carats, measuring 16 x 14 x 9 mm.

The remaining samples are crystal fragments, the perfect cleavage giving rise to cleavage planes having a bronzy lustre.

The average density of all specimens available is 3.291; ranging from 3.267 for the crystal RGM 163 150 to 3.310 for sample RGM 163 149.

Regarding the refractive indices, α varied from 1.662 to 1.670, while γ varied from 1.672 to 1.678. Sample RGM 163 152 appeared to have the highest birefringence (0.012).

Using a Universal Stage a great number of measurements were carried out to find the optic axial angle of sample RGM 107 200. The average value found was $2V\gamma = 86°$.

All specimens have a strong pleochroism in tones of red-brown and yellowish

Table 9. Chemical properties of orthopyroxene RGM 163 149 from Umba, Tanzania. (Analysts: Miss H.Bontje and L.Belfroid "Geologisch en Mineralogisch Instituut" of Leiden University).

Chemical analysis		Numbers of ions on the basis of 6 (O)		
SiO_2	57.00	Si	1.984	2.000
TiO_2	0.01	Al	0.016	
Al_2O_3	0.70	Al	0.013	1.994
Fe_2O_3	0.53	Fe^{+3}	0.013	
FeO	7.69	Fe^{+2}	0.224	
MnO	0.20	Mn	0.006	
MgO	33.12	Mg	1.717	
CaO	0.54	Ca	0.021	
Na_2O	---			
K_2O	---	Mg	86.7	
P_2O_5	---	Fe	12.3	
H_2O^+	0.03	Ca	1.0	
H_2O^-	---			
Total	99.82	$100Mg/(Mg+Fe^{+2}+Fe^{+3}+Mn)$		87.6

brown-green. Their absorption spectrum is characterized by a strong narrow band at 5060 Å in the green, while weaker bands are to be seen at 5480, 4830 and 4500 Å. Very vague bands can be seen at 5115 and 5045 Å, while the violet part of the spectrum is generally absorbed. This spectrum is apparently due to ferrous iron and is similar to the absorption spectrum of brownish orthopyroxenes from India.

The orthopyroxenes from Umba are rather clean. Some of them have needle-like inclusions which could be exsolution lamellae, common in orthopyroxenes of plutonic rocks. Recently Lorimer and Champness (1973) described such lamellae in an orthopyroxene from the Stillwater Complex, Montana, and found them to be augite.

A chemical analysis was made of specimen RGM 163 149. The results are given in Table 9. The Mg content is in agreement with what could be expected from the optical data mentioned above. Moreover a method, described by Zwaan (1955), was used to determine the molecular percentage of enstatite in specimen RGM 107 200. The relative distances between the diffraction lines 10 3 1 and 060 on X-ray powder photographs RGM 201 207 and RGM 201 495, of this specimen, were measured and found to be 0.90 mm. This corresponds with a mol. % of enstatite of 87.

From the above data it may be concluded that the orthopyroxenes available

for investigation have very similar properties, with the Mg content between 87 and 88. It depends on the nomenclature used whether the name enstatite or bronzite applies to this orthopyroxene. As a bronzy lustre may be observed, especially on cleavage planes, the name bronzite may have the preference.

Clinopyroxene – Only one specimen (RGM 163 139), a crystal fragment weighing 3.89 carats, was available for investigation. Its colour is a lively light green. Under the Chelsea colour filter the same colour may be observed. In the absorption spectrum two lines of about equal intensity can be seen at 5080 and 5050 Å in the green, while a very weak line is present in the red at about 6900 Å.

The density is 3.255. In order to avoid damage to the specimen no accurate measurements of the refractive indices have been carried out. Using the distant vision method the mean refractive index of 1.68 was observed on a refractometer. The birefringence is rather strong because doubling of internal cracks can distinctly be seen.

The pattern of X-ray powder photograph RGM 201 748 of this specimen is very similar to that of a diopside from Zillertal, Austria.

It is very likely, by virtue of its properties, that this clinopyroxene is a member of the diopside group. As no inclusions can be observed, apart from some internal cracks, the material is of gem quality. Its colour resembles that of the new green variety of grossular garnet recorded from the same area (Bank et al., 1970). It would be wise to be alert to the appearance of this clinopyroxene on the market.

SCAPOLITE

As the author described this material in detail in a special issue of the Journal of Gemmology on the occasion of the 70th anniversary of Mr B. W. Anderson (Zwaan, 1971), it will suffice here to give a summary.

There were only two specimens available for investigation, a rough one (RGM 107 194) and a stone cut from a rough crystal fragment (RGM 151 264).

RGM 107 194 has a yellow colour and weighs 7.23 carats. Its density is 2.659, ω is 1.562, ε is 1.543. A very distinct dichroism in tones of straw-yellow and almost colourless may be observed, while no characteristic absorption spectrum has been detected. It has a weak yellowish orange fluorescence under long-wave ultra-violet light and glows a rather strong similar colour under short-wave irradiation. Natural etching figures are observable on one of the natural faces of the stone. From the centre of these triangular depressions needle-like inclusions emanate.

The X-ray powder photograph (RGM 201 714) of this stone appeared to be characteristic for scapolite. The observed X-ray powder data are compared with those of three other scapolites, that is, one from Mozambique, one from Madagascar and a marialite from an unknown locality. These data agree best with those of the marialite. Its optical properties, however, indicate a scapolite in the dipyre field. Anyway, this scapolite seems to have a chemical composition in which the molecular percentage of marialite is predominant.

RGM 151 264 is an oval-shaped faceted stone of 7.51 carats, of light yellow colour and containing needle-like inclusions, which are in fact hollow tubes with a prismatic habit.

The density is 2.671, ω is 1.567, ε is 1.548. Its dichroism is distinct in tones of pale yellow and almost colourless. No characteristic absorption bands could be observed. Under long-wave ultra-violet light the stone has a weak reddish orange fluorescence, while under short-wave irradiation the glow is much stronger in the same colour.

These properties indicate a scapolite somewhere between dipyre and mizzonite.

ZIRCON

The zircons available for investigation may be divided into two groups, one of four distinct crystals or parts of crystals and one of 26 small pebbles.

In the first group, RGM 107 195 is a part of a crystal with a fine reddish brown colour, its weight is 7.89 carats, its size approximately 9 x 8 x 7½ mm. The habit is prismatic, which is due to the fact that the form {110} is the best developed one. Moreover the forms {111}, {331} and {311} may be observed, together with conchoidal fractures at several places.

RGM 163 192 is also a reddish brown crystal, having a pyramidal habit. The best developed form is {311}. Other forms observed are {111} and {101}. The weight of this crystal is 2.73 carats, its size is 8 x 7½ x 5 mm. The fracture is conchoidal.

RGM 163 193 is a complete reddish brown crystal with the same habit as RGM 163 192. Its weight is 2.79 carats, the size is 7½ x 6 x 6 mm.

RGM 163 194 is a reddish brown crystal fragment on which only one crystal face can be seen. Conchoidal fractures are well developed. Its weight is 3.12 carats, the size 10½ x 6 x 3½ mm.

In the second group, RGM 163 195 consists of 19 small pebbles, all reddish to yellowish brown. The total weight is 10.33 carats, the smallest weighing 0.42 carats and the largest 0.75 carats.

RGM 163 196 consists of seven small pebbles, all pale yellow-brown to colourless. Their total weight is 3.88 carats, the smallest pebble being 0.40 carats, the largest one weighing 0.65 carats.

The lowest density found is 4.667 for the crystal fragment RGM 163 194, while sample RGM 163 193 appeared to have the highest specific gravity of 4.684. For both lots of small pebbles the density of the whole lot was measured, giving 4.675 for RGM 163 195 and 4.683 for RGM 163 196. All zircons described here have refractive indices far above that of methylene iodide and a high birefringence. The last property could be derived from the fact that, especially with the four larger specimens, distinct doubling of crystal face edges or internal cracks was observed when looking through the stone.

All zircons have a characteristic absorption spectrum. Strong narrow bands (lines) can be seen at 6910, 6625, 6590 and 6535 Å in the red, 5895 Å in the yellow, 5625, 5375 and 5150 Å in the green, 4840 Å in the blue and 4325 Å in the violet part of the spectrum. Weaker lines are observable at 6830 Å in the red, 6210 and 6150 Å in the orange and 4600 Å in the violet. It must be noted that the four larger specimens have a more distinct spectrum than the small pebbles.

As usual with zircon of gem quality, these specimens are free or almost free from inclusions.

The properties indicate that these zircons are of the so-called high type. The

Table 10. Chemical analysis (Analyst: L.Belfroid) and X-ray powder diffraction data for turquoise RGM 107 191 from Umba, Tanzania.

		d(obs.)	I	d(obs.)	I
CuO	4.60	9.11	½	2.13	1
Al_2O_3	35.08	6.73	6	2.06	1
Fe_2O_3	3.26	6.17	8	2.02	2
FeO	0.78	4.77	3	1.902	2
MgO	0.51	4.06	½	1.842	2
CaO	0.06	3.67	10	1.814	1
P_2O_5	31.69	3.43	5	1.782	1
H_2O	19.66	3.29	4	1.673	1
CO_2	< 0.10	3.08	4	1.608	1
insol.	3.16	2.89	9	1.545	1
Total	98.90	2.51	3	1.491	3
		2.40	1	1.476	½
		2.30	2	1.391	½
		2.23	2		

reddish brown variety, having much in common with the colour of certain tourmalines, will certainly be well received as a gemstone. The pebbles, however, are too small for cutting. Only when larger samples with this colour are produced by the mine will it be worth while to pay attention to them.

TURQUOISE

In 1967 some prospecting for turquoise was done in a limonite bearing clay, alternated by sandy layers. These sediments are apparently derived from aluminous rocks. Veins of turquoise with a waxy lustre, up to one centimetre in thickness, are embedded in the sediments. The colour of the material varies from yellowish green to bluish green. Good quality turquoise was not found, except for minor quantities. The material is generally massive, although crusts with concretionary shapes occur.

In Table 10 a chemical analysis from material (RGM 107 191) collected by the author is given. When compared with analyses of turquoise from other sources, the relatively low Cu content is striking.

It was impossible to measure the refractive indices accurately, due to the cryptocrystalline to fine-granular state, but by means of optical examination in immersion media a mean value of 1.64 was found in grain preparates. Moreover, a weak pleochroism in tones of bluish green and yellowish green to almost colourless could be observed. The density, too, could not be measured easily, the

material being too impure. Data indicate a mean value not far above 2.63. In Table 10, X-ray powder data, calculated from X-ray powder photograph RGM 201 276, are given.

Associated minerals

AMPHIBOLE

A brownish black, long prismatic mineral is intergrown with pinkish corundum RGM 107 206. Crystals up to 20 mm in length without terminal faces can be observed. In thin section it has a weak pleochroism with α yellowish, β yellowish brown and γ bluish green. The mineral has a parallel extinction. Various measurements of the optic axial angle give a mean value of $2V\gamma = 84°$. The refractive indices are α 1.645, β 1.652 and γ 1.662. X-ray powder photographs RGM 201 496 and 201 853 have a pattern similar to that of the amphiboles of the anthophyllite group. From these data and its occurrence with corundum, it may be concluded that this mineral is a member of the orthoamphiboles. It is very likely that it will be a gedrite, rich in iron.

Moreover, minor quantities of another amphibole can be observed in this sample, having a greenish black colour and properties indicating a member of the common hornblende group (X-ray powder photograph RGM 201 852).

Not occurring with one of the gem minerals, but still worthy of mention is a handspecimen consisting of amphibole in a lateritic rock (RGM 107 189). Many almost black, long prismatic to needle-like crystals, up to 20 mm in length, are visible. In thin section the mineral is bluish green, and has a distinct pleochroism in tones of α yellowish green, β pale yellow-green and γ bluish green. The mean extinction angle $\gamma \wedge c$ is 18°, the mean optic axial angle $2V\alpha = 82°$. The refractive indices are α 1.631, β 1.647 and γ 1.653. The average value obtained from density measurements is 3.099. The patterns of the X-ray powder photographs RGM 201 828 and 201 829, taken of this amphibole, have much in common with that of the members of the actinolite group. The mineral therefore may be considered an amphibole belonging to this group.

KYANITE

Kyanite appears to be a common mineral in the Umba mine, occurring abundantly, intergrown with corundum and garnet. The author was given both loose crystals and handspecimens. RGM 107 188 consists of a great number of long bladed crystal fragments up to 45 mm. These have a light blue colour but in parts are colourless. In thin section the mineral is colourless. Optic axial angle measurements gave an average of $2V\alpha = 81°$. The refractive indices are α 1.713, β 1.722 and γ 1.728. Density measurements gave a mean value of 3.639

The remaining specimens (RGM 107 222 to 107 224. 107 228), are mainly composed of kyanite together with almandine garnet, pale orange-pink corundum and vermiculite. RGM 107 228, the biggest sample, is about 50 x 35 mm. It has a greenish blue colour, resembling that of aquamarine. Parts of the mineral are of

gem quality. In thin section it is almost colourless, its pleochroism extremely weak in tones of pale blue and colourless. The mean value of the optic axial angle $2V_\alpha$ was found to be 82°, its refractive indices are α 1.714, β 1.723 and γ 1.730. X-ray powder photograph RGM 201 765 (specimen RGM 107 222) has a pattern characteristic for kyanite.

VERMICULITE

Although most of the specimens described in this paper are coated with vermiculite, there are few samples in which the mineral occurs in important quantities (RGM 107 216, 107 222, 107 223, 107 225 and 107 228). It has been found together with corundum, especially with ruby as in sample RGM 107 225, and with kyanite. The size of the laminae may vary up to a diameter of about 35 mm, as in specimen RGM 107 216.

The mineral has a golden brown colour. In thin section it is almost colourless, its pleochroism therefore being weak. The optic sign is negative, 2V being very small. The refractive indices are α 1.526, β 1.546 and γ 1.548. By rapid heating the mineral exfoliates with much swelling. X-ray powder photograph RGM 201 338, taken of specimen RGM 107 225, was found to be a pattern characteristic of vermiculite with strongest diffraction lines 14.32(10)-4.55(7)-3.58(6)-2.85(7)-2.62(5)-2.55(4)-2.39(7) and 1.530(7).

Summary

A description is given of various gem minerals from the Umba area in Tanzania. The refractive indices and densities of the rhodolite garnets vary widely, but all lie between the properties of pyrope and almandine towards the pyrope end-member. The size of the unit cell varies mainly in relation to both the Ca and Mn contents, as can be derived from microprobe analyses. The X-ray powder patterns are similar to that of pyrope, whereas their absorption spectra show bands characteristic of almandine. The results indicate that these rhodolites have no special properties by which they can be distinguished from either pyrope or almandine, except their rose-red colour. It is very unlikely that one or another trace element will only occur in this type of garnet and will be responsible for its special colour. Therefore it would be logical to discard the name. Both needles and short prismatic crystals of rutile are the most frequent mineral inclusions in rhodolite. These are not distinctive for the locality.

The almandine garnets generally have higher refractive indices and densities than the rhodolites. From both microprobe and wet analyses it is obvious that their unit cell dimensions vary mainly with the Ca and Mn contents. Both apatite and short prismatic rutile are common inclusions in these garnets, and pyrrhotite and zircon are present occasionally. These inclusions are not diagnostic for the locality.

The diversity of the colours of the corundums is fascinating. Not only ruby and sapphire, but also green, pink, deep violet, golden yellow and parti-coloured specimens occur. Most of the properties are normal for corundum. The absorption

spectra, however, are either ruby or sapphire spectra or a combination of the two, depending on the colour of the specimen. Electron microprobe determinations of green corundum indicate a high Fe content which may be the cause of its colour. Blue corundum may owe its colour to Ti, whereas the red variety has a high Cr and a low Ti content. Rutile and apatite occur frequently as inclusions while, especially in deep violet corundums, graphite is found. Pyrrhotite is rather common in ruby. Apart from the above mentioned graphite, which up to now has only been found in Umba corundums, these inclusions are not distinctive for the locality.

Tourmalines, having a very attractive emerald green colour, show a deep red under the Chelsea colour filter. The absorption spectrum can be ascribed to chromium and vanadium. Electron microprobe determinations confirm that both Cr and V cause the emerald green colour. Besides liquid inclusions, as normally seen in tourmaline, crystals are enclosed which could be apatite. The properties of the green tourmaline have much in common with those of uvite.

Orange and brownish tourmalines have properties similar to those of elbaite. They only contain the tell-tale liquid inclusions.

Orthopyroxenes with a deep yellowish brown colour appeared to be Mg rich, their molecular percentage of enstatite being about 88. The absorption spectrum can be ascribed to ferrous iron. A light green clinopyroxene of gem quality was found to have much in common with the members of the diopside group.

Yellow scapolites from the Umba area have somewhat varying properties. Both marialite-rich and dipyre to mizzonite members were found.

Zircons with reddish brown to yellowish colours occur. From the gemmological point of view the reddish brown specimens are very attractive. All samples examined are high type zircons.

On a small scale turquoise occurs. A chemical analysis indicates a relatively low Cu content. Most of the material is of poor to moderate quality.

Amongst the associated minerals kyanite attracts attention. Both light blue and sea green varieties are found together with corundum and garnet. Part of the material might be used for cutting. A description is given of various amphiboles and of vermiculite. The last named minerals occur with corundum, the vermiculite especially with ruby.

References

Anderson, B. W., 1959. Properties and classification of individual garnets. - Jour. Gemmology, 7, 1: 1-7.

——, 1971. Gem. Testing. - Butterworth & Co Ltd., London: 1-384.

Bank, H., 1970. Hochlichtbrechender orangefarbiger Korund aus Tansania. - Zt. Dt. Gemmol. Ges., 19, 1: 1-3.

——, 1972. Violette Edelkorunde aus dem Umba-Gebiet von Tansania. - Ibidem, 21, 2: 126-127.

Bank, H. & W. Berdesinski, 1967. Chromhaltiger Turmalin. - Z. Dt. Ges. Edelsteink., 61: 30-32.

Bank, H., W. Berdesinski & J. Ottemann, 1970. Durchsichtiger smaragdgrüner Grossular aus Tansania. - Z. Dt. Gemmol. Ges., 19, 1: 4-7.

Bank, H. & B. Nuber, 1969. Rosarote Granate aus Tansania. - Ibidem, 18, 2: 69-72.

Campbell, I. C. C., 1972. A comparative study of Rhodesian rhodolite garnet in relation to other known data and a discussion in relation to a more acceptable name. - Jour. Gemmology, 13, 2: 53-64.

Crowningshield, R., 1967-68. Developments and Highlights at the Gem Trade Lab in New York. - Gems Gemology, 12, 8: 242-243.

Deer, W. A., R. A. Howie & J. Zussman, 1962. Rock-forming Minerals. - Longmans, London: 1: 1-333 and 5: 1-371.

Eppler, W. F., 1972. Needles in corrundum other than rutile. - Jour. Gemmology, 13, 2: 41-44.

Harder, H., 1969. Farbgebende Spurenelemente in den natürlichen Korunden. - N. Jb. Miner. Abh., 110, 2: 128-141.

Hidden, W. E. & J. H. Pratt, 1898. On rhodolite, a new variety of garnet. - Am. Jour. Sci., 4, 5: 294-296.

Hiemstra, S. A., 1956. An easy method to obtain X-ray diffraction patterns of small amounts of material. - Amer. Mineral., 41: 519-521.

Lorimer, G. W. & P. E. Champness, 1973. Combined Electron Microscopy and Analysis of an Orthopyroxene. - Ibidem, 58: 243-248.

Martin, B. F., 1970. A study of rhodolite garnet. - Jour. Gemmology, 12, 2: 29-36.

Schubnel, H. J., 1972. Pierres précieuses dans le monde. - Horizons de France, Paris: 1-192.

Solesbury, F. W., 1967. Gem corundum pegmatites in N. E. Tanganyika. - Economic Geology, 62: 983-991.

Stockwell, C. H., 1927. An X-ray study of the garnet group. - Amer. Mineral., 12: 327-344.

Trumper, L. C., 1952. Rhodolite and the pyrope almandine series. - Gemmologist, 21, 246: 26-30.

Webster, R., 1961. Tanganyika Tourmaline. - Ibidem, 30, 356: 41-45.

——, 1972. Gems, Their Sources, Descriptions and Identification. - Butterworth & Co Ltd, London: 1-838.

Zwaan, P. C., 1955. On the determination of pyroxenes by X-ray powder diagrams. - Leidse Geol. Meded., 19: 167-276.

——, 1961. Some notes on the identification of the pyrope-almandine garnets. - Proc. Kon. Ned. Acad. Wet. B, 64, 2: 305-312.

——, 1965. Apatite crystals in a Ceylon spinel. - Jour. Gemmology, 9, 12: 434-440.

——, 1967. Solid inclusions in corundum and almandine garnet from Ceylon, identified by X-ray powder photographs. - Ibidem, 10, 7: 224-234.

——, 1971. Yellow scapolite, another gem-mineral from Umba, Tanzania. - Ibidem, 12, 7: 304-309.

Manuscript received 9 November 1973.