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Sangu garnet deposit, Eastern Province, Zambia

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Abstract. Gem-quality garnet at the Sangu deposit occurs in plagioclase segregation veins confined to mafic granulite, as nodular crystals up to 10 cm in diameter. The colour is commonly red to brownish red in transmitted light, with a moderate brown hue. Faceted stones up to two-carats size have a pleasant strong red colour in incident light, but larger pieces show typically dark tone. Sangu garnet is pyrope-almandine with 46–47 mol% Prp, 39–40 mol% Alm, 9–10 mol% Grs, 2–3 mol% Adr, and 0.10 wt% TiO_2. Indices of refraction are 1.7597–1.7632 and specific gravity ranges from 3.87 to 3.94. This garnet is characterized by the presence of abundant acicular rutile crystals. Mine production primarily consists of fractured pieces 1–3 cm in size, 0.5–2 grams in weight.

Key words: gems, garnet deposits, granulites, veins, pyrope, almandine, Zambia

Introduction

Gem-quality garnets comprise a wide range of garnet compositions and types of deposits (Pearl 1975, Sinkankas 1961, 1972, Smith and Phillips 1972, Stockton and Manson 1982 and Webster 1983). A useful overview of gem garnets was given by Stockton and Manson (1985) and Stockton and Manson (1983) for specific colour ranges. Garnets exhibit broad chemical variability between the known end-members, the most common of which are pyrope, almandine, spessartine, grossular and andradite. There is a range of garnets, blood-red, brownish-red to violet-red in colour, which can neither be termed pyrope nor almandine, but are intermediate between them, and are called pyrope-almandine. This type of garnet is formed during the metamorphism of rocks. The localities for pyrope-almandine are distributed worldwide, but gem quality material is more restricted in its location. North Pare Mountains in Tanzania, North Carolina in USA, Fianarantsoa and Betroka in Madagascar and Beit Bridge in Zimbabwe are the best-known producers of pyrope-almandine garnet.

The finds of gem-quality pyrope-almandine garnet derived from batches of partial melt under granulite-facies conditions, such as Sangu deposit, are of much interest.

The Sangu area in Eastern Province hosts the only known commercial deposit of gem garnet in Zambia. In early 1990's, the transparent and facetable, gem-quality garnet of brownish red colour first appeared on the market in Lundazi, and the rough was transported out of Zambia. However, the notable commercial production was not being recorded before 2000. The deposit represents an interesting type of garnet mineralization, where large gem material occurs in plagioclase segregation veins confined to basic granulites. Petrology of the host rock, mineralogy, and gemology of garnet from Sangu deposit have not been previously studied.

Location

The Sangu garnet deposit is located approximately 57 km northwest of the town of Lundazi. It is accessible by the main road from Lundazi, 32 km to Chama, and further another 65 km by left crossing track in the direction to Chasefu School and the village of Chikwa (Fig. 1). The undulating terrain in the environs of the garnet deposit is covered by fairly thick bush vegetation and lies east of the Luangwa Valley Game Reserve (north).

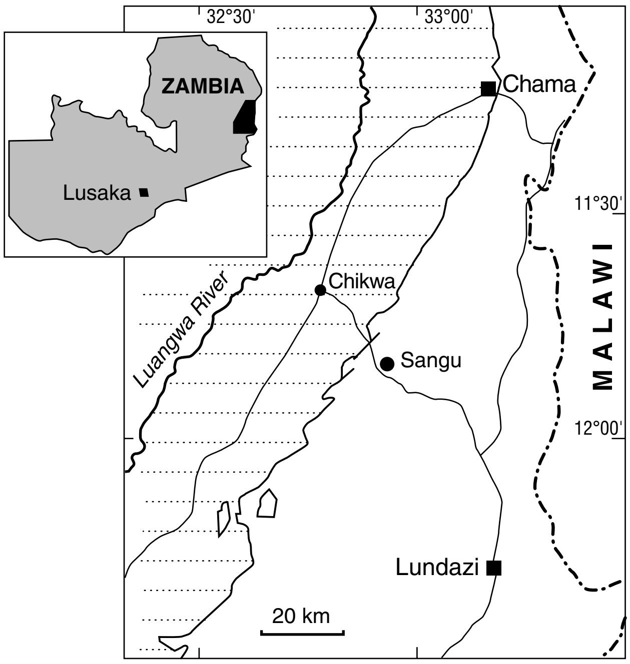

Fig. 1. Location of the Sangu deposit. Karoo sediments are shown by dot pattern.

Table 1. Composition of main rock types, Sangu deposit.

	Major elements, wt.%		Minor- and trace-elements, ppm			C.I.P.W. normative composition		
Sample	SA 3	SA 2		SA 3	SA 2		SA 3	SA 2
Rock type	Massive Hbl-Opx granulite	Foliated Hbl-Opx granulite		Massive Hbl-Opx granulite	Foliated Hbl-Opx granulite		Massive Hbl-Opx granulite	Foliated Hbl-Opx granulite
SiO_2	47.96	48.71	Ag	<0.08	<0.08	ab	13.5	11.2
TiO_2	0.65	0.69	Ba	348	262	an	22.3	23.9
Al_2O_3	15.63	16.45	Be	<0.8	1.6	or	1.3	1.1
Fe_2O_3	1.31	1.25	Bi	<0.05	0.06	di	5.6	5.7
FeO	8.04	7.41	Cd	<0.8	<0.8	hy	31.5	42.2
MnO	0.16	0.155	Co	65	52	ol	22.5	12.4
MgO	13.18	12.19	Cr	159	177	il	1.6	1.6
CaO	8.17	9.11	Cs	<10	<10	mt	1.6	1.5
Li_2O	0.015	0.012	Cu	27	219	ap	0.1	0.1
Na_2O	2.17	1.87	Mo	<5	<5	cc	0.0	0.3
K_2O	0.32	0.27	Ni	97	107	PlAn	63.5	69.3
P_2O_5	0.061	0.061	Pb	<10	10			
CO_2	0.06	0.07	Rb	6	11			
C	<0.005	0.015	Sr	214	238			
S	<0.005	0.01	V	139	151			
H_2O^+	1.4	1.19	Zn	77	79			
H_2O^-	0.12	0.14						
S -eq.	<0.001	0.002						
Total	99.26	99.61						

Major elements by wet analysis, minor- and trace-elements by ASA; Czech Geological Survey, Prague. Chief chemist Ing. V. Sixta

Geology

The area around the Sangu deposit is underlain by Palaeoproterozoic basement complex metamorphosed mainly during the Ubendian event (2.0–1.9 Ga). Metasedimentary biotite gneiss grading to migmatite, dark biotite+hornblende gneiss with abundant amphibolite and pyroxene granulite layers, and biotite (± sillimanite and cordierite) migmatite are the main rock types of the complex (Lewington 1987). Geological map 1 : 100,000 shows a complicated fold pattern imprinted during four successive deformation events. The metamorphic grade straddles the boundary between almandine amphibolite facies and granulite facies (Lewington 1987). This unit, widespread through much of the Lundazi District (O'Connors 1998), contacts sediments of the Karoo Supergroup in the Luangwa graben along NE–SW-striking faults (Fig. 1).

Mafic granulite hosting the garnet mineralization at Sangu is an integral part of the basement complex. The protolithic olivine norite, later transformed to mafic granulite, intruded the metasedimentary complex prior to the imprint of granulite-facies metamorphism; however, the emplacement age of norite has not been determined.

Correlation in the basement complex east of the Luangwa valley indicates Ubendian age of granulite-facies metamorphism (Lewington 1987, O'Connors 1998, Page 1978, Ring et al. 1997, Vrána et al. in print).

Table 2. Representative electron microprobe analyses of orthopyroxene, hornblende, biotite and plagioclase in sample SA 3, massive granulite.

Mineral	Opx	Hbl	Bt	Pl
SiO_2	53.53	44.37	38.20	53.86
TiO_2	0.06	1.26	3.54	0.05
Al_2O_3	3.11	14.19	17.30	29.45
FeOt	18.21	10.00	9.83	0.00
MnO	0.28	0.27	0.15	0.00
MgO	24.74	14.05	17.58	0.19
CaO	0.17	10.28	0.00	11.22
Na_2O	0.66	2.44	1.32	5.25
K_2O	0.00	0.25	8.47	0.07
Total	100.76	97.11	96.39	100.09
Number of atoms	(O=6)	(O,OH=24)	(O,OH=24)	(O=32)
Si^{IV}	1.937	6.427	5.473	9.721
Al^{IV}	0.063	1.573	2.527	6.265
T site	2.000	8.000	8.000	15.985
Al^{VI}	0.070	0.849	0.395	–
Ti	0.002	0.137	0.381	0.007
Fe^{2+}	0.551	1.211	1.178	–
Mn	0.009	0.033	0.018	–
Mg	1.335	3.034	3.755	0.051
Ca	0.007	1.595	–	2.17
Na	0.046	0.686	0.367	1.837
K	–	0.046	1.548	0.016

Mining and production

Although garnet from this deposit has been known since early 90's, the recent extensive exploitation represents the first gem-quality stones found in any significant quantities. The garnet deposit, owned by Mr. Mugala, was worked and then abandoned several times in the past (Fig. 2) due to the lack of financial resources and limited market. Local miners worked the mine on small scale, using only hammers, chisels and shovels. Since the time of greatest activity in 2000, about 50 people are involved in mining (Fig. 3). The mine is opened by a system of pits arranged in a line, which follows the plagioclase-garnet segregation veins. The exploited near-surface part of mafic granulite is moderately or weakly weathered allowing the use of shovels and chisels. Deeper parts of the exposed garnet accumulations are worked by drilling and blasting, and the extracted material is sorted by handpicking.

The deposit lies on eastern hilly slope along the garnet-bearing zone striking approximately N–S. The mineralized zone, composed of 2–3 veins of calcic plagioclase in mafic granulite, is about 300 m long, 5–10 m wide, and dips 80–85° to the west.

Garnet crystals occur embedded in calcic plagioclase veins and are either scattered, or form nodules up to 10 cm in diameter. Garnets are commonly found as fractured to equant and flat pieces 1–3 cm in diameter. Most of the production ranges between 0.5–2 grams in weight.

The authors estimate, from their personal experience, that the present annual production may reach about 400–500 kg of garnet. Of these stones, only up to 5% would be facet-grade. Most of the production is exported for faceting to India.

Methods and samples

All rock samples and the gem material studied were collected by the authors at the Sangu mine in 1999. Three typical samples of fresh rocks were selected for the study: SA3 – massive basic granulite, SA2 – strongly foliated rock similar to amphibolite with composition of basic granulite, and SA1 – moderately foliated basic granulite with 2 cm wide segregation of plagioclase and coarse garnet. Two fresh samples of the main rock types, SA3 and SA2, were analysed using wet analysis for major elements, and atomic spectral absorption analysis for some minor and trace elements in the accredited laboratory of the Czech Geological Survey, Prague.

Polished thin sections were prepared from five 1 cm-sized garnet crystals randomly selected from a larger lot. After microscopic examination, the chemical composition of garnet was analysed in three sections by an electron microprobe in the laboratory of the Czech Geological Survey, Prague, using a Camscan-Link-Isis operating in the energy-dispersion mode with the following conditions: 20 kV, beam current 3 nA, count time 80 s. Cobalt peak was used for calibration, standards included synthetic oxides and analysed minerals. Data reduction was done using the ZAF 4 program. Calculations of number of atoms were performed with the Mincalc program (Melín and Kunst 1992). All iron is given as FeO.

Gemmological testing was performed on three faceted stones: 5.8 ct square cut, 4.1 and 3.2 cross-modified cuts and three rough stones weighted 19.4 ct, 48.3 ct, and 136.5 ct (Fig. 4).

Refractive indices were measured by the method of minimal deviation with two-circle "Carl Zeiss" goniometer, using sodium light source and a special polished wedge of garnet crystal (the wedge angle of 45 degrees and three sets of repeated measurements). Specific gravity was determined hydrostatically (three to four sets of measurements). Fluorescence to ultraviolet light was observed in darkened room using a short-wave (2540 Å) UV lamp. The absorption spectra were recorded using a "Carl Zeiss" prism-type spectroscope, in a range from 350 nm to 800 nm. Internal features were examined using a SMZ-U "Nikon"-type stereomicroscope in conjunction with brightfield and dark-field illumination as well as polarizing filters.

Table 3. Electron microprobe analyses of garnet.

Sample No.	Garnet 2		Garnet 5	
	(n=6)	Range	(n=6)	Range
SiO_2	39.90	39.36–40.21	39.85	39.61–40.18
TiO_2	0.09	0.00–0.22	0.11	0.07–0.14
Al_2O_3	22.57	22.40–22.73	22.38	22.15–22.65
Cr_2O_3	0.07	0.00–0.16	0.05	0.03–0.09
Fe_2O_3	-	-	-	-
FeO	19.62	19.36–19.91	19.84	19.54–20.14
MnO	0.66	0.50–0.92	0.62	0.42–0.77
MgO	12.69	12.59–12.79	12.67	12.51–12.84
CaO	4.62	4.44–4.76	4.68	4.59–4.82
Total	100.22		100.20	
16 cations				
Si^{IV}	5.941		5.940	
Al^{IV}	0.059		0.060	
T site	6.000		6.000	
Al^{VI}	3.902		3.868	
Ti^{VI}	0.010		0.012	
Cr	0.008		0.006	
Fe^{3+}	0.080		0.114	
O site	4.000		4.000	
Fe^{2+}	2.363		2.359	
Mn^{2+}	0.083		0.078	
Mg	2.817		2.815	
Ca	0.737		0.747	
A site	6.000		6.000	
End-member molecules				
Alm	39.35		39.28	
Sps	1.39		1.30	
Prp	46.91		46.87	
Grs	9.90		9.24	
Ti-Grs	0.25		0.31	
Andr	2.00		2.85	
Uvar	0.21		0.15	

Petrology and mineralogy

In the excavation pits, the basic rock type carrying large garnet crystals is weakly foliated to massive medium-grained granulite (sample SA3) with aggregates of dark amphibole 1–2 cm in diameter, in whitish groundmass rich in plagioclase. Strongly foliated portions similar to amphibolite (sample SA2) and showing perfect planar fabric are less frequent. Transmitted-light microscopy of polished thin sections and microprobe analyses of mineral composition show that the rocks have completely recrystallized metamorphic textures and metamorphic mineralogy.

Table 4. Properties of garnet from the Sangu deposit.

Property	Red with brownish hue
Refractive index	1.7597–1.7632 ± 0.0002 standard deviation *
Specific gravity	3.87–3.94 ± 0.01
UV luminescence	None
Absorption spectrum	Lines at 576, 524, 506 and 460 nm
Inclusions	Acicular rutile and dot-like crystals

* Measured by Z. Taborský, Czech Geological Survey, Prague

Fig. 2. Abandoned and flooded Sangu deposit as photographed in 1999. Photo A. V. Seifert.

Fig. 3. View of the extensive workings at the Sangu garnet mine in 2000. Photo V. Žáček.

Whole-rock chemical and mineralogical composition

Analytical results (Table 1) show that both the massive and foliated rocks evolved from closely similar gabbroic protolith. Calculated values of C.I.P.W. normative composition (Table 1) provide insight in the probable original magmatic mineralogical composition. Significant quantities of normative olivine show the degree of rock undersaturation in silica. The strong prevalence of normative orthopyroxene above high-Ca pyroxene ("diopside", Table 1) indicates that the original rock should be classified as olivine norite. The small number of samples analysed cannot fully represent possible compositional variation of basic rocks at the Sangu deposit.

The composition of major minerals, i.e. plagioclase, pargasitic amphibole and hypersthene in the massive sample (SA3) is characterized by representative analyses in Table 2, selected from a large number of analyses. Mineral compositions in the strongly foliated rock (SA2) are closely similar. Textural criteria indicate that the granular mosaic of minerals corresponding to granulite-facies P-T conditions is in equilibrium.

Garnet crystals 1 cm to ca. 10 cm in diameter occur scattered in monomineral segregation veins of calcic plagioclase, which are several cm to about 30 cm thick. Plagioclase segregation in sample SA1 has the composition Ab 25, An 75, Or 0.1, but some compositional variation is probable, as plagioclase normative composition in samples SA3 and SA2 (Table 1) is An 64 and An 69, respectively.

Veins in the granulite host rock are either subvertical or show a moderate dip and relatively regular, quasi-planar geometry with some pinching-out, and irregular plagioclase–garnet segregations.

Discussion of petrology

The protolith rock to the basic granulite carrying large garnets is identified as original olivine norite. The rocks were completely recrystallized during granulitic metamorphism.

Compositional features (Table 1) show reasons for the dominance of low-Si amphibole – pargasite with ca. 44 wt% SiO_2 in the present granulitic mineral assemblage. Crystallization of additional metamorphic orthopyroxene or high-Ca clinopyroxene with SiO_2 contents of ~52 wt%, instead of pargasite, would require additional quantities of silica, which was not available. These compositional relations proved important for the absence of quartz inclusions in garnet and for the growth of gem-quality garnet.

The mineral assemblage of pargasite+hypersthene+plagioclase corresponds to basic granulite ("pyriclasite"). Rather uniform garnet composition with (mol%) 47 pyrope, 40 almandine and 10 grossular shows that garnet growth took place under high temperature of granulite facies. Garnet and plagioclase crystallization in the veins and segregations took place probably from relatively small batches of partial melt. These features classify the Sangu locality as a rather unusual type of gem-quality garnet deposit.

Data in the literature indicate that crystallization of large garnets in gabbroic or dioritic rocks metamorphosed under granulite facies conditions occurs at least at several locations worldwide. In Kohistan, NW Pakistan, granulitic metagabbros of the original ocean-floor provenance carry plagioclase veins and segregations with large garnets up to 10–20 cm in diameter. The veins are interpreted as a result of crystallization from local batches of partial melts formed under high-temperature granulite facies (Jan and Howie 1981, Jan and Karim 1995, Ringuette et al. 1999). It is not known whether some of these large garnets in Kohistan are of gem-quality. A major garnet deposit in the Adirondack Mts., U.S.A., i.e., the Barton mine (Russ 1997) has been commercially operated for over a century for production of a wide range of garnet abrasive materials. Some of the garnet is of gem-quality, but is not utilized commercially as a gemstone. Garnet crystals, frequently several cm in diameter (exceptionally up to 60 cm), showing successive rims of plagioclase and hornblende, occur in a granulitic metabasic rock, compositionally close to monzogabbro (Russ 1997). Garnets from this type of localities characteristically show pyrope-almandine compositions.

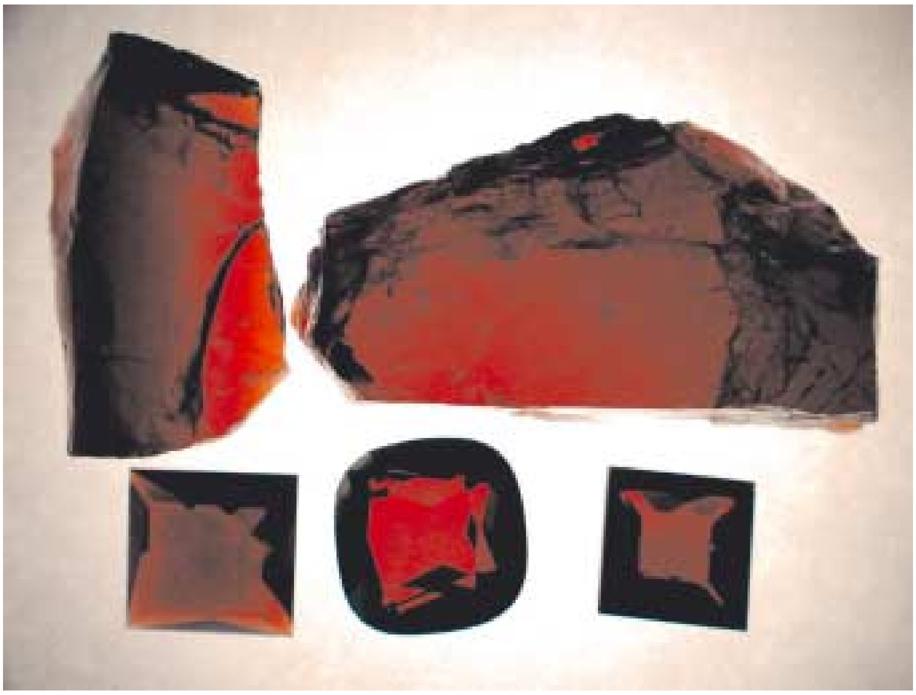

Fig. 4. Rough and faceted garnets from the Sangu mine. The largest rough stone shown here weights 48.3 ct. Photo V. Žáček, 2002.

Fig. 5. Fine faceted pyrope-almandine from the Sangu mine (5.8 and 3.2 ct) is typically dark red to brownish red. Photo V. Žáček, 2002.

Gemology

Garnet composition

Electron microprobe analyses of two garnet crystals are presented in Table 3. The chemical composition shows that pyrope component amounts to 46–47 mol% and slightly prevails over almandine (39–40 mol%); the grossular component displays minimum variation of around 10 %. The andradite molecule is calculated to 2–3 mol%.

Minor domains affected by later decompression reaction of garnet to microscopic-scale symplectite of anorthite + hypersthene + high-Ca clinopyroxene are documented in sample SA1. There is a significant small-scale compositional variation, with pyrope ranging from 28–38 %, and almandine from 42–51 mol%. The higher grossular content in SA1 (17 mol%) may reflect a different whole-rock composition of this sample, which also contains high-Ca pyroxene. However, the marginal, small-scale decompression reactions did not affect the composition of large crystals suitable for faceting. Reactions of this type are common in various granulite terrains, but in the case of Sangu they reached only a minor scale. This was a favourable circumstance in preserving the quality of large garnet crystals.

Gemological properties

The mineral is notably free of inclusions visible by free eye or 10 × triplet loupe. The colour of garnet is commonly red to brownish red with a moderate brown hue and dark tone (Fig. 5). Smaller faceted stones of two-carat size show a brilliant strong red colour in incident light of moderate intensity. The brownish shade comes to expression if the stones are observed in transmitted light.

The measured indices of refraction, 1.7597 to 1.7632, with standard deviation of 0.0002, specific gravity, and chemical composition (Table 4) correspond to the published relations of physical properties and composition (Winchell 1958). Several mm thick samples show moderate values of anomalous double refraction in the polariscope, but in thin sections, the garnet is isotropic. Strain and minor variation in composition probably contribute to the observed anisotropy of garnet. The variation in density of individual pyrope-almandine garnet crystals probably depends on a different ratio of pyrope and almandine molecules, besides minor grossular and andradite components.

Stones are almost free from internal inclusions, except acicular inclusions oriented in two directions meeting at an angle of about 60 degrees. These minute acicular rutile crystals disseminated throughout the stones are comparatively abundant, however, they are not observed in polished thin sections used for microprobe analyses, as these sections are only about 0.03 to 0.05 mm thick. Other inclusions seen in garnet are rare, scattered, very small, irregular dot-like crystals. A single case of a linear group 5 mm long of small quartz and chlorite inclusions, 10 to 30 μm long, was documented in several thin sections examined under the microscope. It is probable that these minerals were formed as a late product, due to infiltration of fluids along a brittle fracture. Very common are internal imperfections such as small fissures (feathers). Mineralogically, the garnet is referred to as iron-rich pyrope or pyrope-almandine, gemologically it is pyrope-almandine (Stockton and Mason 1985).

Conclusions

Strong red to brownish red garnet exploited at the Sangu deposit, Lundazi District, Eastern Province, Zambia, is a pyrope (47%) – almandine (40%) with a low (10 mol%) grossular content. Crystallization of this garnet is closely associated with metamorphic recrystallization of the host rock under granulite facies conditions. Petrochemical study indicates that the host-rock basic granulite evolved from a protolithic olivine norite. The large garnets crystallized together with plagioclase from small local batches of partial melt, as indicated by several similar occurrences worldwide.

As mafic pyroxene granulites occur at numerous locations in the Palaeoproterozoic basement complex of the general area (Lewington 1987, O'Connors 1998), there exists a fair chance of finding other localities of this type of garnet.

A strong brilliant red colour of Sangu garnet comes best to expression in faceted stones about two carats in weight or smaller. Large stones tend to be too dark.

Cheap labour available in the area, in combination with low-cost faceting in India, are important factors in economic viability of garnet mining at the Sangu deposit.

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