

ON THE COMPOSITION OF SOME INDIAN GARNETS. BY
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10.)

I. Introduction.

In 1912 it was arranged that an investigation into the chemical composition of Indian garnets should be undertaken by Mr. S. N. Godbole, M.Sc., who has since become Assistant Professor of Chemistry in the Victoria College of Science, Nagpur. I accordingly selected for him from our collection 9 specimens of Indian garnet, illustrating various modes of occurrence of this group of minerals in India. The original intention was that, on completion of the analysis of this first batch of material, a further series of specimens should be sent illustrating other modes of occurrence; pressure of work has, however, prevented Mr. Godbole from continuing his analyses.

In each analysis the constituents usual in garnet were determined, but some of the analyses totalled to a little over 96 and 97 per cent. only. It was then suggested that perhaps alkalis were present; but after a careful search Mr. Godbole failed to detect their presence, as also the presence of titania. As Mr. Godbole's duties preclude any further work on this material, these analyses have to be utilised as they stand, and, although four of them total to too small a figure, indicating either that there is some other constituent present, or that some constituent has been underestimated, yet Mr. Beckett, Principal of the College, who supervised the work, accepts the responsibility for its being careful and conscientious work, the results of which can be safely utilised. Mr. Godbole has kindly consented to my discussing his analyses from the geological and mineralogical point of view.

II. Description of Material used.

The specimens sent for analysis were examined by me before despatch and their descriptions recorded. Thin sections have been cut from duplicate material and examined under the microscope.

These descriptions with the data elicited under the microscope follow :—

J. 371. Orange-red or mahogany-red garnet from the garnet mines, Sarwar, Kishengarh State, Rajputana.

Under the microscope this garnet is practically colourless, and shows numerous inclusions of three sorts. The most abundant are minute needles arranged in several parallel sets, oriented presumably with some reference to the crystallographic habit of the mineral; but as the specimen sectioned showed no crystal faces this relationship is not obvious. The refractive index of these needles is greater than that of garnet; the polarisation tints range up to blue of the first order, the extinction is oblique, ranging from 15° up to 39° with reference to the long axis of the needles, the ray nearest the vertical axis being sometimes that of lesser and sometimes that of greater elasticity. The colour of these needles is very pale yellowish. The second kind of inclusion is in broader needles, polarising in first order grey. There are also a few grains of a mineral of lower refractive index than the garnet and very low birefringence and probably apatite. The above list of inclusions sounds formidable, but the total amount is exceedingly small.

I. 16. Three cut garnets from Jaipur, Rajputana. Light crimson colour.

A small cut gem was sacrificed for microscopical examination. As the slice is rather thick, the garnet is of very pale pink tint and looks almost perfectly pure. There are no cracks or signs of alteration: but there are an exceedingly few very minute doubly refracting grains.

F: 367. "Spessartite", dodecahedron from mica-schist, Kulu. Attached mica scratched off.

One rhombohedral dodecahedron was sacrificed for the preparation of a thin slice. In this the garnet is very pale pink and shows a small quantity of included black and brown oxides which would be impossible to eliminate. In addition there are a few very minute pleochroic grains of negative elongation and absorption at right angles to length. They may be brown tourmaline with the following pleochroism. O nearly colorless, E brownish; $O > E$.

13/546. From a pegmatite dyke, Biradavole, Nellore district, Madras. General colour mahogany: orange-red to fiery red on thin edges. The garnet was trapezohedral modified by the rhomb-dodecahedron.

In thin section under the microscope this garnet is pale pink with perhaps an orange tinge. Under the low power the garnet appears pure except for a very few tiny inclusions of quartz (with colorless mica in one case). But under the high powers the garnet is seen to contain numerous minute needles arranged in thin parallel sets mainly at angles of 60° . These needles are usually so thin as to appear

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opaque, but where slightly thicker they are seen to be of positive elongation and straight extinction—properties possessed by both sillimanite and rutile. As rutile is coloured and of higher refractive index than garnet, whilst sillimanite is colourless and of lower refractive index than garnet, it ought to be possible to refer these needles to one or other of these two, but I find it difficult to decide these points on such thin needles.

17/63. Trapezohedral spessartite from pegmatite cutting Gondite Series, Bichua, Chhindwara district.

Under the microscope this garnet is very pale yellowish, with perhaps an orange tinge. It contains a very little quartz and a colorless substance, mainly occupying minute cracks, which is possibly a micaceous mineral. There is also a little secondary iron-ore.

18/582. Garnet-rock from Nautan-Barampur, Ganjam district, Madras. Considerably blackened in patches: in others of light buff or crimson colour. Some pale blue apatite grains. Thought to be mangan-grandite. From Kodurite Series.

Under the microscope this is seen to be a granular rock composed mainly of practically colourless garnet (? a yellowish tinge), with a moderate amount of scattered quartz. There is much secondary iron oxide along the boundaries of the garnet grains with some black oxide as well, presumed to be an oxide of manganese.

18/912. Piece of a large trapezohedral crystal from Satak, Nagpur district, C. P. Dark yellow-brown to yellowish liver-coloured, probably partly altered: orange when fractured. From Gondite Series.

Under the microscope this garnet is light sulphur-yellow with numerous scattered tiny included grains of red hematite and of some black oxide, presumably manganese oxide. The distribution of these inclusions causes the crystal to be zoned parallel to the crystal faces. Some shells are nearly free from inclusions. These inclusions could not however be excluded from the material taken for analysis. In addition there is a large patch of microcline and one of black ore, both easily rejected.

18/482 (233). Spandite-rock from Kodur, Vizagapatam district, Madras. Chocolate-brown, due to secondary oxidation along boundaries. Fiery red where transparent. From the Kodurite Series.

Under the microscope this is seen to be a mono-mineralic granular aggregate of orange-yellow garnet, with black oxide along the boundaries of the grains, forming a black network and to a certain extent along cracks extending into the interior. In the medial zone of the black bands of the network there is often a thin streak of a light greyish substance. The interiors of the grains are perfectly fresh, but

traversed by a network of minute cracks. The material picked from this could not have been completely pure.

M. 1538. "Calderite" from Hazaribagh district, Chota Nagpur. Massive, brownish black to orange-brown (resin-coloured) where thin. From the metamorphic crystalline complex of Hazaribagh.

Under the microscope this rock is composed almost entirely of light brownish garnet, evidently in large crystal units, but much cracked. It is very fresh, however, except for very thin brownish fibres along some of the cracks: it contains a few light green pyroxene grains of quite large size.

In forwarding this material to Nagpur directions were given concerning the picking of the material to be actually used for analysis.

III. Methods and Results of Analysis.

In each case the material was, if necessary, picked, and in the case of 18/482 the garnet was treated with cold dilute hydrochloric acid to remove coatings and films of black oxide of manganese.

The specific gravity was in each case determined on the material used for analysis, the method of direct weighing in air and water being used for the larger material, and the specific gravity bottle for the smaller-sized material such as 18/482.

The analytical procedure followed by Mr. Godbole was as follows:—

After estimating the silica, iron and aluminium were separated from manganese, calcium, and magnesium by the usual methods. The manganese was then estimated as sulphide, the calcium precipitated as oxalate and the magnesium as phosphate. Iron and aluminium were estimated together as oxides, and the iron estimated volumetrically, so that the amount of aluminium was determined by difference.

Ferrous iron was separately estimated. Equal quantities of the mineral and calcium fluoride were treated with hydrochloric acid on a water bath in an atmosphere of inert gas (*i.e.* out of contact with air). After the reaction ferrous iron was estimated volumetrically.

Owing to the deficit in the totals of some of the analyses, attempts were made to estimate alkalis if present. But the results showed absence of alkalis.

The results of analysis are collected in the following table:—

TABLE NO. I.—*Results of analysis of 9 specimens of garnet.*

Specimen No.	Sp.Gr.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	TOTAL.
J-371 .	3.64*	30.01	22.25	7.87	17.56	0.95	10.64	2.42	100.70
I-16 .	4.24	30.47	22.81	2.84	20.97	0.31	8.82	1.85	100.07
F-367 .	4.00†	37.66	20.22	..	21.00	4.63	2.76	3.07	99.03
13/546 .	4.15	34.81	22.87	14.77	0.38	11.67	..	2.00	96.20
17/63 .	3.95‡	36.02	19.79	5.93	5.98	26.00	1.85	5.06	100.10
18/582 .	3.54§	33.61	17.91	8.75	3.02	28.51	2.18	1.95	98.03
18/912 .	4.18	34.73	22.40	4.51	1.63	35.30	..	0.97	99.60
18/432(233).	3.72	32.76	7.92	18.54	1.23	11.77	0.69	24.43	97.34
M-1533 .	3.73	37.43	8.39	19.86	3.85	2.80	0.81	24.40	97.63

* This result is obviously too low and is not used further. A duplicate piece of J-371 of malogany brown colour gave G=3.98 in the Geological Survey of India laboratory, and another of purplish rose colour gave G=3.95. The former figure is used in later tables.

† Other crystals of this number gave in the Geological Survey of India laboratory results ranging from 4.11 to 4.16 (Mem., Geol. Surv. Ind., XXXVII, p. 175).

‡ Another crystal was found by me to have a specific gravity of 4.02 (*L.o.*).

§ Obviously too low: not used further.

IV. Interpretation of the Results.

In Table No. 2 these 9 analyses have been rearranged in terms of their constituent garnet molecules, amongst which it has, in one of the analyses, been necessary to assume the existence of the molecule $3\text{FeO}.\text{Fe}_2\text{O}_3.3\text{SiO}_2$. It will be seen that the total percentage of garnet molecules ranges from as high as 98.48 per cent to as low as 79.97 per cent.

The excess over the garnet molecules has been shown as sillimanite, quartz, surplus alumina and ferric oxide and, in one analysis, as lime, whilst in most cases there is a surplus of oxygen, due probably, at least in part, to the difficulty of estimating exactly the amounts of FeO and Fe_2O_3 in an insoluble silicate, but possibly in some cases to slight oxidation of the garnet. To ascertain if any of these impurities were microscopically visible, I had thin sections cut of each of these garnets (not, of course, of the pieces actually analysed), and the results of the examination of these have been given in pages 192 to 194.

A comparison of the impurities shown in table No. 2 with those noticed under the microscope is of interest. Sillimanite is shown in three analyses. I.16 is, however, too pure to contain nearly 8 per cent. of impurities, unless in solid solution, which seems improbable. F.367 contains no visible sillimanite and only a very small quantity of other inclusions. The specimen analysed must have been much less pure than that examined by me. 13/546, which should contain over 7 per cent. of sillimanite, does in fact show, under the microscope, numerous minute needles that may be either sillimanite or rutile, and also a little quartz. But the amount of inclusions cannot be nearly as high as 7 per cent.¹ Quartz in appreciable quantity should be shown by 18/582 and M.1538. Such proved to be the case. Surplus ferric oxide should be, according to the analyses, shown by four of the garnets. Of these J.371 does not show ferric oxide, but shows other inclusions.

¹ That sillimanite does actually occur inside garnet I proved to my satisfaction by examining the garnets in two thin slices of khondalite, one being Dr. T. L. Walker's original khondalite from Kalahandi (4239-15/181) of which the garnet is represented in the table on p. 200 and the other a slice of this rock (5339) from Nantan-Barampur in Ganjam, collected by myself.

17/63 does show a little secondary iron-ore: 18/912 shows numerous scales of red hematite and grains of a black ore (? manganese-ore) in certain shells: whilst 18/482 shows much black oxide in the unpicked mineral. There are no visible impurities nor inclusions corresponding to the surplus alumina in 18/912 or the surplus lime in 18/482.

These discrepancies are possibly in part due to material being held in solid solution in garnet, and, in three analyses, probably to the fact that there is a deficit in the analysis.

The tendency of garnet to enclose other minerals is exemplified by the descriptions on pages 192-3, and is well-known¹; nevertheless, in order to ascertain whether Mr. Godbole's results departed from the theoretical composition of garnet to a greater extent than usual, I selected from Dana's "System of Mineralogy" one analysis of each of the five chief species of garnet (omitting uvarovite), and recalculated them also into terms of garnet molecules. The analyses selected were as follows (omitting water, alkalis, etc.) :—

TABLE No. 3.

	G.	SiO ₂ .	Al ₂ O ₃ .	Fe ₂ O ₃ .	FeO.	MnO.	MgO.	CaO.	TOTAL.
Grossularite, . No. 9, Vesuvius.	3.572	39.83	20.16	1.03	1.21	0.40	0.97	35.42	99.08
Pyrope, No. 6, Elle Ness.	4.124	40.92	22.45	5.46	8.11	0.46	17.85	5.04	100.20
Almandite, No. 4, Zillertal.	4.04	39.12	21.08	0.00	27.28	0.80	..	5.76	100.04
Spessartite, No. 14, Glen Sklag.	4.125	35.99	16.22	8.64	23.27	15.24	0.47	0.40	100.23
Andradite, No. 10, East Rock.	3.740	35.09	tr.	20.15	2.40	0.86	0.24	32.80	100.13

On recalculation into garnet molecules these analyses can be rearranged as follows :—

¹ Sir T. H. Holland's paper "On the Aqueous Inclusions in Indian Garnets," *Rec., Geol. Surv. Ind.*, XXIX, pp. 16-19, (1896), is of interest in this connection.

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TABLE NO. 4.

	Pyrope.	Alman- dite.	Spessar- tite.	Grossu- larite.	Andra- dite	3FeO. Fe ₂ O ₃ . 5SiO ₂ .	3MnO. Fe ₂ O ₃ . 5SiO ₂ .	Total Garnet.	SURPLUS.					
									Sillima- nite.	Quartz.	Fe ₂ O ₃ .	CaO.	MgO.	O.
Grossularite	3.24	2.80	1.06	81.92	3.25	..	..	92.25	2.92	..	3.35	..	..	..
Pyrope	59.30	23.47	1.03	10.79	3.11	..	..	97.75	..	2.19	..	..	..	0.23
Almandite	..	75.36	1.89	15.48	..	..	..	92.63	3.79	..	..	..	..	0.60
Spessartite	1.33	41.60	35.49	..	1.22	19.67	..	99.57	0.40	0.26
Andradite	86.05	6.41	0.93	93.39	2.07	..	4.41	0.24

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In two of the garnets the molecule $3\text{FeO} \cdot \text{Fe}_2\text{O}_3 \cdot 3\text{SiO}_2$, again appears, as well as the molecule $3\text{MnO} \cdot \text{Fe}_2\text{O}_3 \cdot 3\text{SiO}_2$ in one case. The departures of these analyses from the theoretical composition of garnet are comparable with those of Mr. Godbole's analyses, and apparently such departures must be regarded as normal for garnet.

V. Other Analyses of Indian Garnets.

Besides the 9 analyses of garnets by Mr. Godbole the only other analyses of Indian garnets of which I am aware are two of "calderite" by Piddington and Tween,¹ and the analyses of Indian manganese-garnets by Messrs. T. R. Blyth, J. Coggin Brown, and the Imperial Institute, given in my memoir on the manganese ore deposits of India.² In addition the composition of the garnet in khondalite can be calculated from the analysis of this rock by Dr. T. L. Walker, assuming the iron to be in the ferrous condition.³ These 8 analyses, are as follows:—

TABLE NO. 5.

	G.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	BaO	TOTAL.
1030 (18/371)—Chargaon.	..	34.71	8.05	8.38	n.d.	88.83	5.40	4.07	tr.	100.34
10/984—Wagora .	4.24	37.73	21.26	..	9.94	24.48	3.48	3.11	..	100.00 ⁴
A.219 (18/378)—Garbhani.	4.02	35.24	6.48	23.00	n.d.	16.37	2.04	15.29	0.18	99.41
A.233 (18/392)—Kotaharra.	..	37.57	18.98	3.47	7.45	16.50	0.23	15.80	..	100.00 ⁴
A.134 (18/557)—Bolarai.	3.76	38.18	14.22	11.41	2.16	2.68	0.65	30.70	..	100.00 ⁴
Hazribagh . . .	3.735	37.44	6.27	19.38	5.24	tr.	1.40	30.93	..	100.66
Katksandi, Hazaribagh.	3.65	46.35	0.35	30.18	..	21.00	..	1.00	..	100.00 ⁴
15/181—Kalahandi .	..	37.74	21.24	..	34.06	..	4.01	2.95	..	100.00 ⁴

On calculation into terms of garnet molecules these analyses can be rearranged as follows:—

¹ See 'A Manual of the Geology of India,' Pt. IV, 'Mineralogy' by F. R. Mallet, pp. 80-90, (1887); and my discussion of calderite in *Mem., G. ol. Surv. Ind., XXXVII*, pp. 182-186.
² *Mem., G. ol. Surv. Ind., XXXVII*, pp. 167-168, (1900).
³ *Mem., G. ol. Surv. Ind., XXXIII*, Part III, p. 9, (1902).
⁴ Calculated from rock analysis.

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TABLE No. 6.

No.	Pyrope.	Alman- dite.	Spessart- dite.	Grossu- larite.	Andra- dite.	FeO. FeO. 3SiO ₂ .	3MnO. MnO. 3SiO ₂ .	3FeO. FeO. 3SiO ₂ .	Total Garnet.	SURPLUS.		
										O.	Fe ₂ O ₃ .	SiO ₂ .
1080—Chargaon	18.04	..	10.98	..	15.38	..	12.80	..	96.05	0.97	5.37 (MnO)	..
16/984—Wagers	11.65	22.92	57.08	8.35	..	..	..	..	100.00	..	..	..
A.219—Garbham	6.79	..	23.13	..	46.08	5.40	16.79	0.48	88.67	0.23	0.61 (MnO)	..
A.233—Kotakara	0.77	17.24	38.50	32.43	11.06	..	..	..	100.00	..	..	..
A.134—Borani	2.18	4.99	6.25	50.13	31.45	..	..	..	100.00	..	..	..
Hazaribagh	4.69	4.59	..	18.28	73.12	..	..	..	100.69	0.36	..	0.31
Katksandl . . . . .	..	..	1.69	..	3.00	19.50	52.76	..	76.95	6.84	..	21.07
15/181 Kalabandi	13.31	78.80	..	7.89	..	..	..	..	100.00	..	..	..

In two cases again the molecule $3\text{FeO} \cdot \text{Fe}_2\text{O}_3 \cdot 3\text{SiO}_2$, appears and in three cases the molecule $3\text{MnO} \cdot \text{Fe}_2\text{O}_3 \cdot 3\text{SiO}_2$, and in one case the molecule $3\text{MnO} \cdot \text{Mn}_2\text{O}_3 \cdot 3\text{SiO}_2$.

VI. Molecular Composition of Indian Garnets.

These eight additional analyses have been assembled in one table (No. 7) with Mr. Godbole's results, the order adopted being that of composition. Although this table contains 17 analyses it is not as comprehensive in the garnets represented as would have been the case had Mr. Godbole been able to deal with the second set of garnets as originally proposed. In particular it is defective in not containing analyses of the garnets of the Indian marbles and calciphyres, usually essonite or andradite, nor of the pink garnets of the garnet-amphibolites.

On scanning this table it will be observed that the *pyrope molecule* is present in quantity (>20%) only in one garnet, which is one of the precious garnets of Rajputana. The *almandite molecule* is present to the extent of over 20% in the first 6 garnets, of which the first 4 are derived from the crystalline schists—mica-schists and khondalite. The *spessartite molecule* occurs to the extent of over 20% in 8 garnets, of which one is from a pegmatite in the Nellore district, 6 are from the Gondite and Kodurite Series of the Central Provinces and Madras respectively, and one is from a pegmatite cutting the Gondite Series.

The *grossularite molecule* is found in quantity only in 2 garnets, both of which come from kodurites, one from Vizagapatam and one from Ganjam. The *andradite molecule* is found in quantity in five garnets, three of which come from the Kodurite Series of Madras and two from the massive garnet rocks of Hazaribagh.

In addition there are shown by these analyses to be three other molecules that must be considered, namely, $3\text{FeO} \cdot \text{Fe}_2\text{O}_3 \cdot 3\text{SiO}_2$, $3\text{MnO} \cdot \text{Fe}_2\text{O}_3 \cdot 3\text{SiO}_2$ and $3\text{MnO} \cdot \text{Mn}_2\text{O}_3 \cdot 2\text{SiO}_2$. The first of these occurs in quantity in the calderite of Hazaribagh and in small amount in two manganese-garnets from the Kodurite Series of Ganjam and Vizagapatam. It also occurs to the extent of nearly 20% in the "spessartite" garnet of Glen Skiag in Scotland. We must, it appears, accept this molecule as existing in some garnets. It requires, therefore, a name, and as the Indian locality Katkam-sandi is unsuitable this garnet may perhaps be called *skiagite* after the Scottish locality.

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TABLE NO. 7.

No. of specimen.	Locality.	Rock in which found.	G.	Fyropo (Py).	Almandite (Al).	Spessartite (Sp).	Grossularite (Gr).	Andradite (An).	3FeO Fe ₂ O ₃ 3SiO ₂ (Sk).	3MnO Fe ₂ O ₃ 3SiO ₂ (Ca).	3MnO Mn ₂ O ₃ 3SiO ₂ (Bl).	Name adopted.	Colour.
J.371	Sarwar, Kishengarh.	Schist .	3.98	36.10	55.04	2.26	6.60	..	..	..	..	Pyralmandite.	Orange-red.
L.16	Jaipur .	Schist .	4.24	12.05	81.74	0.80	5.41	..	..	..	..	Almandite.	Light crimson.
15.181.	Kalahandi .	Khondalite .	..	13.31	78.80	..	7.29	..	..	..	..	Almandite	Red.
F.367 .	Kulu .	Mica-schist .	4.09 (4.11-4.16)	11.53	62.70	13.47	12.30	..	..	..	..	Mangan-almandite.	Brown-red.
13/546	Biradavole, Nellore.	Pegmatite .	4.15	..	59.87	31.18	3.95	..	..	..	..	Spalmandite.	Orange-red to fiery red.
16/984	Wagora, Chhindwara.	Gondite .	4.24 ¹	11.65	22.92	57.08	8.35	..	..	..	..	Ferro-spessartite.	Cinnamon.
17/63 .	Bichua, Chhindwara.	Pegmatite in gondite.	3.95 (4.02)	4.65	18.20	62.73	11.68	2.69	..	..	..	Spessartite.	Orange-brown.
18/582	Nautan-Barampur, Ganjam.	Apatite-spessartite rock	..	7.70	17.31	65.30	..	6.24	3.45	..	..	Spessartite.	Light-buff.
18/912	Satak, Nagpur .	Gondite Series	4.13	..	10.58	86.66	2.76	..	..	..	..	Spessartite.	Yellow-brown.
A.238 .	Kotakarra, Vizagapatam.	Opalised kordurite.	..	0.77	17.24	38.50	32.43	11.06	..	..	..	Calc-spessartite.	..
18/482	Kodur, Vizagapatam.	Spandite rock (kordurite Series).	3.72	2.53	3.16	30.46	5.40	53.42	..	..	..	Spandite.	Fiery-red.
A.219 .	Garbbam, Vizagapatam.	Spandite-rock	4.02	6.88	..	23.44	..	46.70	5.47	17.02 +0.49 (Ba Fe)	..	Spandite.	Rich-red.
M.1538	Hazaribagh.	Massive garnet rock in metamorphic rocks.	3.73	2.94	14.15	7.11	16.50	59.30	..	..	..	Mangan-grandite	Brownish black to orange-brown.
..	Hazaribagh .	Do.	3.735	4.66	4.56	..	18.15	72.63	..	..	..	Andradite (grandite).	Yellow brown to black.
A.134	Bozani, Ganjam.	Opalised kordurite.	3.76 ¹	2.18	4.99	6.25	50.13	36.45	..	..	..	Grandite.	Light brown.
1030 .	Chargaon, Nagpur	Gondite Series	4.15-4.2	19.78	..	17.68	..	16.01	..	12.81	34.72	Magnesia-blythite.	Orange-red to orange.
..	Kakamsandi, Hazaribagh.	Massive quartz garnet rock,	4.02 ¹	..	..	2.20	..	3.90	25.34	68.56	..	Calderite (ferro-calderite).	Dark brown to black.

¹ Calculated from known analysis and specific gravity of rock.

The second molecule, $3\text{MnO}\cdot\text{Fe}_2\text{O}_3\cdot 3\text{SiO}_2$, occurs in large quantity in the analysis of calderite from Katkamsandi in Hazaribagh. This particular analysis has always been considered open to doubt and attempts to repeat Piddington's results, represented in the table by the other two analyses of garnet from Hazaribagh by Mallet and Mr. Godbole respectively, have failed to disclose the large percentage of manganese found by Piddington. However, the existence of this molecule in one example of spandite from Garbham in the Vizagapatam district (17%) and in one example of spessartite from Chargaon in the Central Provinces (13%) is proved by the two analyses A.219 and 1030, which were by competent analysts. We must therefore accept this molecule also as present in some garnets, and the appropriate name for it seems to be *calderite*, as has previously been suggested.¹

The third additional molecule is $3\text{MnO}\cdot\text{Mn}_2\text{O}_3\cdot 3\text{SiO}_2$, found only in one Indian garnet, at Chargaon in the Nagpur district, C. P. This garnet has hitherto been treated as a spessartite, but the abundant manganese is present as 18% of spessartite, 13% of calderite and 35% of $3\text{MnO}\cdot\text{Mn}_2\text{O}_3\cdot 3\text{SiO}_2$, the balance being pyrope and andradite. The analysis was very carefully carried out by the late Mr. T. R. Blyth, for many years Assistant Curator to the Geological Survey of India, on very carefully picked material. Mr. Blyth was known for his accurate analytical work and we must therefore accept the result as returned by Mr. Blyth as accurate. The amount of material used in the analysis was only $\frac{1}{2}$ gramme, so that it was not possible to determine the state of oxidation. Consequently the proportions of FeO , Fe_2O_3 , MnO , and Mn_2O_3 , had to be calculated on the assumption that the mineral conformed to the general garnet formula $3\text{RO}\cdot\text{R}_2\text{O}_3\cdot 3\text{SiO}_2$. Owing to the small amounts of alumina (8.05%) and Fe_2O_3 (8.38%), assuming all the iron as being in the ferric condition, there appears to be no escape from the $3\text{MnO}\cdot\text{Mn}_2\text{O}_3\cdot 3\text{SiO}_2$ molecule. In my memoir on the manganese-ore deposits of India, already cited, no attention was directed to this point and the presence of the Mn_2O_3 molecule in the garnet did not prevent my calling it spessartite. It seems to me desirable, however, to have a name for the molecule itself, and I propose to call it *blythite* after Mr. Blyth.

¹ *Mem., Geol. Surv. Ind.*, XXXVII, p. 184.

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From this table it is seen that few of the garnets contain a high enough percentage of one molecule to be designated by that name alone. If names are to be used for the remainder, compound names seem inevitable. I find it difficult to devise any systematic method of compounding these names; but I have attempted to allow for any molecule present to the extent of 20% or over, either by amalgamating two names (pyralmandite, spalmandite, spandite, grandite), or by prefixing the name of a prominent chemical constituent (mangan-almandite, ferro-spessartite, calc-spessartite, mangan-grandite).

It is possible, of course, to devise formulæ to indicate the composition of complex garnets. Thus Uhlig¹ assigns the symbol of a chemical element to each garnet, indicating the principal distinguishing chemical characteristic thereof, and builds up formulæ according to the molecular proportions of the various garnets. Pentti Eskola² uses formulæ indicating the atomic percentages of the elements separately in each group of isomorphous constituents, preferring this method because in an isomorphous mixture one cannot ascertain how the protoxides are combined with the sesquioxides. As, however, one speaks of the various garnet molecules as if they exist, a conformable idea of the composition of any given garnet can be given by a formula built up of symbols indicating the various garnet molecules. Using the symbols Py, Al, Sp, Gr, An, Sk, Ca, Bl, for the 8 garnet molecules considered in this paper (see table No. 7), the 17 garnets in table 7 could be represented by formulæ of which the following are examples:—

J.371 Pyralmandite	Py ₅₉ Al ₅₅ Sp ₂ Gr ₇
18/912 Spessartite	Al ₁₁ Sp ₃₇ Gr ₃
A. 219 Spandite	Py ₇ Sp ₂₃ An ₄₇ Sk ₅ Ca ₁₇
M.1538 Mangan-grandite	Py ₃ Al ₁₄ Sp ₇ Gr ₁₆ An ₆₉
1030 Magnesia-blythite ("Spessartite")	Py ₁₀ Sp ₁₈ An ₁₆ Ca ₁₃ Bl ₂₅

Some form of diagram may prove useful in indicating the relationships of a number of garnets. For a series of garnets containing as many as 8 molecules the diagrams used by Ford³ and

¹ *Verh. d. Naturh. Ver. d. Rheinl. u. Westf.*, Vol. 67, pp. 307-403, (1910); consulted in abstract in *Neues Jahrb. fur. Min. Geol. u. Pal.*, Band I, 1912, p. 22.

² On the Eclogites of Norway, *Videnskaps. Skrifter*, I, Mat-Naturv. Klasse, 1921, No. 8, p. 8.

³ *Amer. Jour. Sci.*, XL, pp. 33-40, (1915).

HAZARIBAGH
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Eskola in the papers cited are unsuitable; and instead the type of diagram constructed in Plate 10 may be used. This diagram, which is constructed on a molecular basis, is not uninformative, as it shows a general relationship between mode of occurrence and composition. The almandite molecule is seen to be specially characteristic of the argillaceous crystalline schists, and of pegmatite: the spessartite molecule is characteristic of the Gondite and Kodurite Series and of a pegmatite cutting the Gondite Series: the andradite and grossularite molecules are abundant in some members of the Kodurite Series and the massive garnet-rocks of Hazaribagh whilst the additional molecules skiaigite, calderite, and blythite occur sporadically in the Gondite Series, the Kodurite Series, and the Hazaribagh massive garnet-rocks.

VII. Specific Gravity of Indian Garnets.

In his paper on the relations existing between the chemical, optical, and other physical properties of the members of the garnet group,¹ W. E. Ford makes a study of the relationship between specific gravity and chemical composition, using 64 analyses of garnets in which the difference between the observed and calculated specific gravities does not exceed 0.1. Adopting the following specific gravity values for the pure garnets:—

Pyrope	3.510
Almandite	4.250
Spessartite	4.180
Grossularite	3.510
Andradite	3.750

Ford found that the average difference between the measured and calculated specific gravities of his 64 garnets was 0.045, or if the plus and minus signs were taken into consideration, it was only +0.002: he deduces therefrom that the values assigned above to the specific gravities of the various pure garnets must be nearly correct.

Using Ford's values for pure garnets, and taking only those Indian garnets that are free from the three new garnets, of which the specific gravity is unknown, we may compare the specific gra-

¹ *Amer. Jour. Sci.*, XL, pp. 33-49, (1915).

vity values given in Table No. 7 with those calculated from the pure garnets. This is done in the following table:—

TABLE No. 8.

	Values from Table No. 7.	Calculated from values for pure garnets.
J.371	3.98	3.90
I. 16	4.24	4.09
F.367	4.09 (4.11.4.16)	4.04
13/546	4.15	4.15
16/984	4.24	4.04
17/63	3.95 (4.02)	4.06
18/912	4.13	4.17
233	3.72	3.87
M.1638	3.73	3.79
Hazaribagh	3.735	3.72
A.134	3.76	3.075

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The diagram is intended to show the type of garnets which are used. This diagram is not intended to show the range of occurrence and distribution of the garnets, but to show the relative positions of the different series. The diagram is intended to show the relative positions of the different series. The diagram is intended to show the relative positions of the different series.

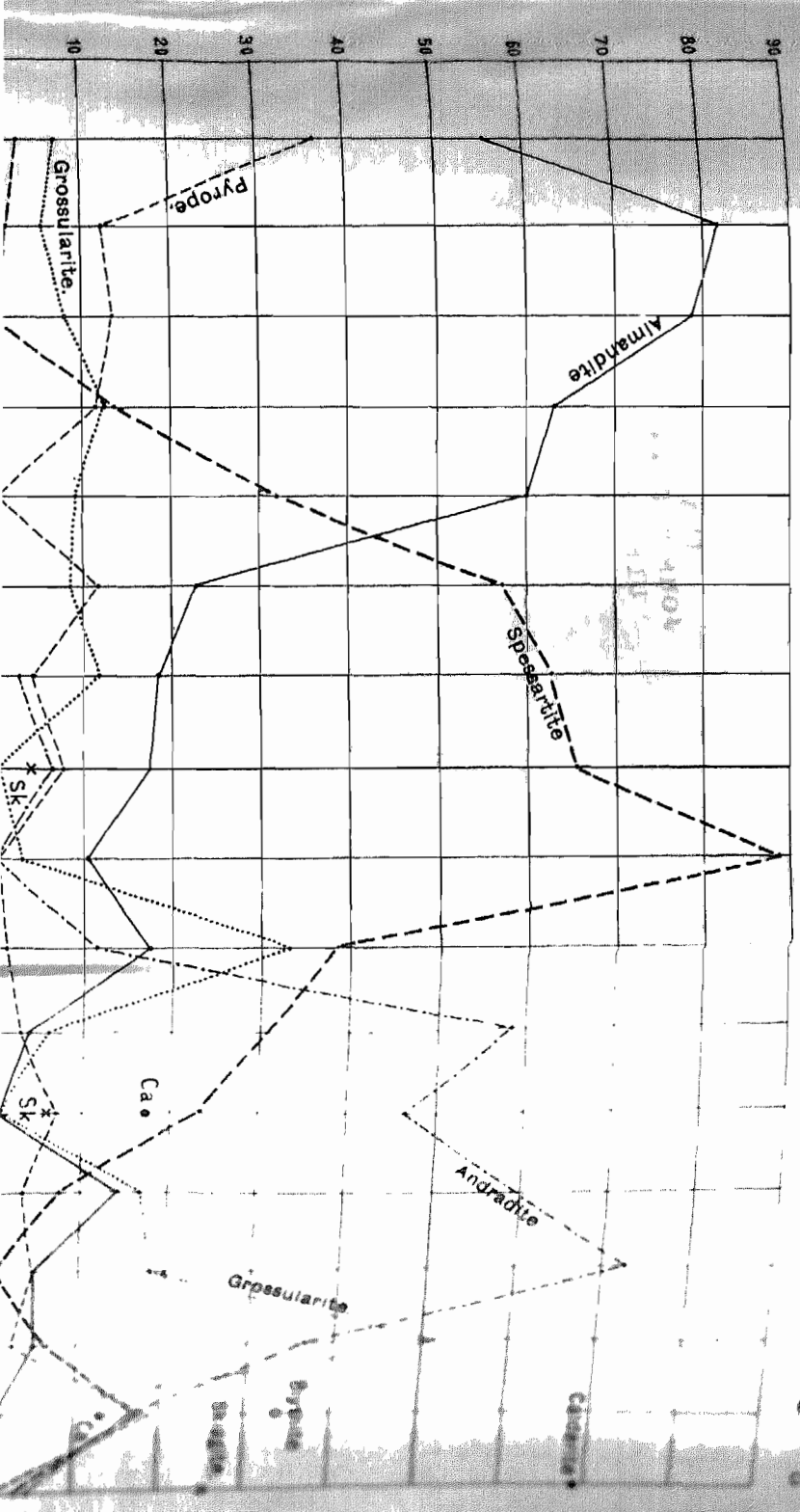
VII. Specific Gravity of Indian Garnets.

The specific gravity of the garnets is given in the following table. The specific gravity of the garnets is given in the following table. The specific gravity of the garnets is given in the following table.

3.510
4.250
4.150
3.610
3.750

The specific gravity of the garnets is given in the following table. The specific gravity of the garnets is given in the following table. The specific gravity of the garnets is given in the following table.

Table 33-49, (1915)



- Pyralmandite ... Mica-schists.
- Almandite ... Mica-schists.
- Almandite ... Khondalite.
- Mangan-alm andite ... Mica-schist.
- Spalmandite ... Pegmatite.
- Ferro-spessartite ... Gondite series.
- Spessartite ... Pegmatite in gondite.
- Spessartite ... Kodurite series.
- Spessartite ... Gondite series.
- Calc-spessartite ... Kodurite series.
- Spandite ... Kodurite series.
- Spandite ... Kodurite series.
- Mangan-grandite ... Hazarbagh crystalline schists.
- Andradite (grandite) ... Hazarbagh crystalline schists.
- Grandite ... Kodurite series.
- Magnesian-orthite ("Spessartite") ... Gondite series.
- Calcandite (ortho-calcandite) ... Hazarbagh crystalline schists.

ARGILLACEOUS SCHISTS.

GEOLOGICAL SURVEY OF INDIA.