THE COMPOSITION AND OCCURRENCE OF GARNETS[*]

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Introduction

During the last seventy-five years several hundred chemical analyses of garnets have been made by chemists and mineralogists throughout the world. This paper is an effort to collect and arrange all these analyses in order to show which particular garnet is characteristic of each rock type.

Two new chemical analyses of garnets from mica schists were made by the writer; one from Amisk Lake, Saskatchewan, and a second from Alaska.

In addition the writer estimated the composition of 23 garnets from various rock types by determining in each case the index of refraction, specific gravity, and the quantitative amount of ferrous iron. A qualitative test was also made for manganese.

Estimation of the Chemical Composition of Garnets by Physical and Chemical Methods

Studies by Ford,[1] Stockwell[2] and Fleischer[3] on the relation between physical properties and chemical composition of garnets show that a very close connection exists between index of refraction, specific gravity, *x*-ray pattern and chemical composition. Ford demonstrated from his study that if the index of refraction, specific gravity, and various tests for the chief components are made, it is nearly always possible to determine fairly closely the chemical composition of the garnet.

Table 1 gives the index of refraction, specific gravity, ferrous iron content and the presence, or absence, of manganese of the garnets listed. From these data the proportions of the various molecules present in garnet can be estimated. These compositions are plotted in Figs. 1 to 8.

Table 2 records the chemical analyses made by the writer of two garnets obtained from mica schists.

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[*] Abstract of a thesis submitted in partial fulfillment for the degree of Doctor of Philosophy, University of Minnesota, Minneapolis, Minnesota.

[1] Ford, W. E., A study of the relations existing between the chemical, optical and other properties of the garnet group: *Am. Jour. Sci.*, 4th. Series, pp. 33–49, **1915.**

[2] Stockwell, C. H., *Am. Mineral.*, vol. **12,** p. 327, 1927.

[3] Fleischer, M., *Am. Mineral.*, vol. **12,** p. 751, 1937.

Table 1. Composition of Garnets from Various Rock Types

No.	Index	Specific Gravity	% FeO	Mn. Present or Absent	Estimated Composition				
					Sp	Gr	Py	Al	An
1.	1.795	4.08	31.4	Present	10		8	72	10
2.	1.803	4.20		Present	70	5	5	20	
3.	1.802	4.09	32.0	Present	5	6	15	74	
4.	1.795	4.02	31.9	Present	4	10	15	71	
5.	1.805	3.97	29.1	Trace	2	5	15	68	10
6.	1.775	3.90	17.8	Absent		35	15	46	4
7.	1.779	3.92	20.7	Absent		16	35	49	
8.	1.792	4.00	31.6	Absent		10	10	73	7
9.	1.802		27.5	Present	6	15	15	64	
10.	1.798	4.00	29.3	Present	3	5	15	67	10
11.	1.809	4.10	33.6	Present	6	5	10	79	
12.	1.873			Absent		10		5	85
13.	1.783	3.88	21.9	Absent		20	30	50	
14.	1.739			Absent		25	55	20	
15.	1.888	3.78		Absent		5	5		90
16.	1.808			Absent		60	5	5	30
17.	1.736			Absent		85	10		5
18.	1.866	3.75		Absent		10		10	80
19.	1.804			Absent		50	5	5	40
20.	1.809			Absent		45	5	10	40
21.	1.804			Absent		50	5	5	40
22.	1.783	3.99	26.0	Absent		30	5	60	5
23.	1.887	3.81		Absent		5		5	90

Sp = Spessartite
Gr = Grossularite
Py = Pyrope
Al = Almandite
An = Andradite

Description and Location of Rocks from Which Garnets of Table 1 Were Taken.

1. A few grains of garnet found in clusters in biotite in a pegmatitic granite boulder from Jellicoe, Ontario.
2. Garnet enclosed in muscovite flakes of pegmatite from Connecticut.
3. Garnetiferous gneiss from New Hampshire.
4. Garnet-biotite gneiss from Sturgeon River, Saskatchewan.
5. Garnet-andalusite schist from Amisk Lake, Saskatchewan.
6. Sillimanite-garnet gneiss from Burgess, Ontario.
7. Garnet-biotite-hornblende schist from Markstay, Ontario.
8. Light gray sedimentary gneiss from Lake Harbour, Baffin Land.
9. Chlorite schist from Minnesota, Sec. 16, T 27, NR, 67 W.
10. Garnet crystal in biotite schist from Western Ontario.
11. Garnet crystal in biotite schist from Connecticut.
12. Garnet in greenstone from Minnesota.
13. Garnet from anorthosite boulder, Adirondacks, New York.
14. Garnet from eclogite, Bavaria.

15. Garnet from iron formation, East Mesabi, Minnesota.
16. Garnet from aplite dolomite contact, Potgietersrust, Bushveld, South Africa.
17. Garnet from limestone, Ariege.
18. Garnet from limestone, Broadway mine, south end of Boulder Batholith, Montana.
19. Garnet from limestone, Bannack, Montana.
20. Garnet from limestone, Puy de Pegnires, Hautes Pyrenees.
21. Garnet from limestone, Bannack, Montana.
22. Garnet from limestone, Franklin, North Carolina.
23. Garnet from limestone, Pass between Tincup and Pitkin, Colorado.

TABLE 2. CHEMICAL ANALYSES OF TWO GARNETS FROM BIOTITE SCHISTS

Number 1. From Amisk Lake, Northern Saskatchewan.

	%	Mol.	Per cent molecules by weight	
SiO_2	36.00	613	Spessartite	4.6
Al_2O_3	22.61	221	Grossularite	6.5
Fe_2O_3	2.67	016	Pyrope	7.4
FeO	32.12	446	Almandite	81.5
MgO	2.19	054		
CaO	2.36	042		
MnO	1.86	025		
Total	100.01			

Number 2. From Alaska.

	%	Mol.		
SiO_2	39.86	664		
Al_2O_3	21.76	213		
Fe_2O_3	.68	004	Spessartite	3.7
FeO	29.98	416	Grossularite	4.8
MgO	4.63	115	Pyrope	16.4
CaO	1.66	029	Almandite	75.1
MnO	1.44	020		
Total	100.61			

Method Employed in Collecting and Presenting Analyses

The literature was searched for analyses of garnets which were accompanied by petrographic descriptions of the rocks or mineral associations from which they were taken. Many were rejected because there was no report on the character of the rock. All analyses were discarded that contained considerable amounts of elements that are unusual to the garnet molecule. The study was confined to the five common members of the garnet group, namely: spessartite, grossularite, pyrope, almandite and andradite. The compositions are expressed by weight of the garnet molecule and calculated to one hundred per cent. They are tabulated in Table 3.

Table 3

No.	Sp	Gr	Py	Al	An	No.	Sp	Gr	Py	Al	An
1.	50.5		2.8	46.7		47.			17.2	79.8	3.0
2.	89.1	3.0	4.6	3.3		48.	5.3		.9	91.4	2.4
3.	59.8			37.2	3.0	49.	17.3		7.0	71.4	4.3
4.	88.5	1.8		9.7		50.	20.7		6.8	68.5	4.0
5.	41.0	2.5	1.7	50.0	4.8	51.	9.0	6.8	4.4	80.8	
6.	59.9	1.3	2.8	36.0		52.	55.7			40.9	3.4
7.	68.5	.8	.5	30.2		53.	10.8		13.0	73.0	3.2
8.	37.3		4.5	46.3	11.9	54.	65.5	1.9		31.5	1.1
9.	42.0		1.0	53.3	3.7	55.	58.0	4.0		38.0	
10.	84.1			15.9		56.	10.1		11.7	73.8	4.4
11.	62.8	11.7	4.6	18.2	2.7	57.	34.9	17.5		38.2	9.4
12.	33.0		3.4	63.6		58.	45.9		7.3	35.5	11.3
13.	77.4			16.0	6.6	59.	34.8	4.5	5.7	55.0	
14.	79.9	3.1		17.0		60.	17.0			83.0	
15.	21.0	4.3	4.7	70.0		61.	7.3		3.6	84.6	
16.	16.0	7.9	4.1	72.0		62.	16.4		3.3	74.6	5.7
17.	21.2	4.8	5.3	67.7		63.	48.9	12.7	10.2	28.2	
18.	33.9	7.0		59.1		64.	58.5	1.9	2.8	36.8	
19.	51.8	4.7	6.7	36.8		65.	46.4	5.7		47.9	
20.	2.7		26.5	70.8		66.	15.6	5.8	16.0	62.6	
21.	32.5	5.8		54.3	7.4	67.	10.5		4.5	81.0	
22.	11.8	2.8	12.0	73.4		68.	50.5			49.5	
23.	20.0	2.0	4.5	73.5		69.	13.3	3.2	6.0	77.5	
24.	31.2	8.9		59.9		70.	12.4		9.5	70.7	7.4
25.	89.5			8.0	2.5	71.	7.1			88.3	4.6
26.	51.9	4.7	6.9	36.6		72.	18.0	8.0	16.0	58.0	
27.	54.0		6.5	34.5	5.0	73.	7.7	6.0	16.3	70.0	
28.	4.4		16.6	74.1	4.9	74.	5.0	5.9	16.9	65.0	7.2
29.	1.4	15.7	29.0	53.9		75.			29.1	67.0	3.9
30.	61.3	2.6	.5	35.6		76.	3.0	9.8	16.2	71.0	
31.	11.8		11.8	73.5	2.9	77.	7.8	10.9	6.7	67.1	7.5
32.	68.2	8.0		23.8		78.		4.8	7.8	87.4	
33.	90.0	4.8	.8	4.4		79.		6.3	7.0	86.7	
34.	45.1	4.0		50.9		80.	2.7	4.1	12.4	80.8	
35.	39.8	2.5		57.7		81.	3.2	5.8	8.6	82.4	
36.	21.7	2.6		75.7		82.	3.6	5.6	16.8	74.0	
37.	66.9	.5		32.6		83.	2.2	3.8	14.7	78.3	1.0
38.	33.7	1.9	2.9	60.5		84.	2.3	2.8	20.3	74.6	
39.	34.8			65.2		85.	1.6	1.8	25.2	71.4	
40.	36.8	2.9	3.3	57.0		86.	4.9	4.6	17.1	73.4	
41.	67.5			32.5		87.	2.2	11.1	5.8	80.9	
42.	52.0	6.4		41.6		88.			10.2	76.3	13.5
43.	78.4	1.5	1.0	19.1		89.		2.6	10.9	86.5	
44.	71.0			20.0		90.	18.0	8.0	16.0	58.0	
45.	64.0	1.0		31.0	4.0	91.	1.8	8.8	.6	72.2	16.6
46.	4.8	4.0	11.3	79.9		92.	.9		27.5	65.5	6.1

TABLE 3 (*Continued*)

No.	Sp	Gr	Py	Al	An	No.	Sp	Gr	Py	Al	An
93.	4.9	8.6	8.5	78.0		141.		33.0	36.0	31.0	
94.	8.8	10.6	7.8	74.8		142.		33.0	49.0	18.0	
95.		19.8	23.0	57.2		143.		17.4	48.6	34.0	
96.	16.1		4.0	71.8	8.1	144.		12.7	63.2	24.1	
97.	2.0	9.2		88.8		145.		13.3	51.5	25.2	
98.	1.7	18.2	13.4	66.7		146.		11.5	66.9	21.6	
99.	2.0	31.0	17.3	49.7		147.			67.2	19.8	13.0
100.		29.7	14.5	54.8		148.			65.7	19.4	14.9
101.	6.5	17.2	12.9	63.4		149.		13.6	67.3	19.1	
102.		28.3	12.7	59.0		150.			64.7	17.7	17.6
103.		15.7	38.0	46.3		151.	2.0		64.6	16.8	16.6
104.	12.5	8.0	10.6	47.0	21.9	152.	1.0	16.0	83.0		
105.	8.9	9.4	13.4	59.0	10.3	153.	.4		76.6	15.1	7.9
106.	1.4	10.6	48.0	39.4		154.		12.5	87.5		
107.	3.7	13.9	29.6	53.0		155.		14.8	85.2		
108.	1.0	5.1	38.3	55.6		156.		10.0	81.9		8.1
109.	2.0	17.5	36.6	43.9		157.		13.3	85.4		1.3
110.	1.2	36.6	49.2	13.4		158.		13.0	87.0		
111.	2.0	12.0	25.0	61.0		159.	.9	5.2	71.6	14.7	7.6
112.	4.4	16.0	15.0	65.0		160.		81.0	10.0		9.0
113.	1.5	30.0	8.5	60.0		161.		95.3	1.8	1.2	1.7
114.		19.0	20.0	51.0	10.0	162.	1.5	6.7	28.0	55.8	8.0
115.	12.0	22.0	19.0	47.0		163.	3.0	13.7	24.3	59.0	
116.		21.0	16.0	48.0	15.0	164.	1.1	85.3	1.3	1.1	11.2
117.		29.1	27.7	43.2		165.	1.5	84.0			14.5
118.			74.9	18.7	6.4	166.	3.9	5.3	9.6	81.2	
119.			56.3	43.7		167.	.5			.7	98.8
120.			62.9	23.0	14.1	168.		18.2	39.6	42.2	
121.			51.1	34.2	14.7	169.		18.0	53.0	29.0	
122.		5.7	33.4	46.5	14.4	170.		18.0	50.0	32.0	
123.		11.4	60.4	28.2		171.		18.0	50.0	32.0	
124.	2.4	30.0	16.8	50.8		172.		22.0	40.0	38.0	
125.		13.8	37.6	48.6		173.		18.0	44.0	38.0	
126.		23.5	13.3	63.2		174.			30.8	48.8	30.4
127.		21.5	43.4	35.1		175.		29.2		7.6	63.2
128.		19.0	37.7	43.3		176.		85.9	6.9		7.2
129.		21.1	44.4	34.5		177.		19.1		1.0	79.9
130.		26.6	30.3	43.1		178.		24.5		.6	74.9
131.		20.5	14.4	65.1		179.		19.7		1.9	78.4
132.		12.4	30.9	56.7		180.		94.3			5.7
133.	2.6	41.4	20.7	35.3		181.		93.5	.5		6.0
134.		12.6	81.5	5.6		182.		60.3	1.8	1.7	36.2
135.	2.0	9.0	34.5	34.0	20.5	183.		44.4	1.3	3.1	51.2
136.	2.3	31.8	19.1	46.8		184.		84.0	4.0		12.0
137.	.5	36.0	50.9	12.6		185.	1.5	27.9		8.0	62.6
138.	8.0	20.7	48.0	8.0		186.				11.3	88.7
139.		30.0	10.0	56.0	4.0	187.				5.0	95.0
140.	1.0	6.0	17.8	63.8	11.9	188.		84.4		3.6	12.0

TABLE 3 (*Continued*)

No.	Sp	Gr	Py	Al	An	No.	Sp	Gr	Py	Al	An
189.	1.8	26.3		6.1	65.8	207.		98.4	1.4		
190.		23.7	12.7	63.3		208.	.8	72.2	6.7	20.1	
191.		3.9		9.0	87.1	209.	3.5	54.5		8.0	34.0
192.	.2	85.0	1.1	.5	13.2	210.					100.0
193.		83.5	2.4		14.1	211.		39.5			60.5
194.				3.4	96.6	212.		65.2			34.8
195.	.7	63.4	1.0	1.7	33.2	213.		38.6			61.4
196.	2.1	91.7	2.1		4.1	214.		35.7			64.3
197.		97.2	2.8			215.	1.4	63.4		9.9	25.3
198.	.9	88.7	2.3	8.1		216.	.5	57.8		4.2	37.5
199.	1.5	59.0		39.5		217.	.5	84.3			15.2
200.	1.0	8.8	.6	72.8	16.8	218.					100.0
201.		29.8	7.3		62.9	219.			5.7		94.3
202.	1.5	72.9	6.0		19.6	220.		92.5			7.5
203.		99.2	.8			221.	1.4	77.4	1.4		19.8
204.	1.0	44.3	4.2	.5	50.0	222.	1.0	30.5		4.5	64.0
205.		46.2			53.8	223.		70.8			29.2
206.	3.2	96.8									

INDEX TO TABLE 3

Numbers 1– 35, garnets from pegmatites.
Numbers 36– 53, garnets from granites.
Numbers 54– 73, garnets found associated with contact action on siliceous rocks.
Numbers 74– 96, garnets from biotite schists.
Numbers 97–116, garnets from amphibole schists.
Numbers 117–147, garnets from eclogites.
Numbers 148–159, garnets from kimberlites and peridotites.
Numbers 160–174, garnets from other basic rocks; such as gabbro, anorthosite and basalt.
Numbers 174–223, garnets from calcareous contact rocks.

SUMMARY OF TABLES

The average proportion of the major molecules of garnets in the rock types are:

Rock Type	Spessartite	Grossularite	Pyrope	Almandite	Andradite
Pegmatite	47.1			41.8	
Granite	36.0			56.8	
Garnets associated with contact action on siliceous rocks	30.7			56.4	
Biotite schists		6.0	13.8	73.0	
Amphibole schists		20.7	20.3	53.6	
Eclogites		18.5	37.4	39.1	
Kimberlites and peridotites		9.0	72.3	13.4	
Various basic rocks		28.7	20.7	34.4	15.6
Calcareous contact rocks		51.5			40.8

Sources of Analyses in Table 3

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The percentage of each molecule is plotted on a triangular diagram. The two corners at the base of the triangle each represent 100% of the major or essential molecules present. The top, or third corner, represents the remaining or accessory molecules. The location of the small circle shows the proportions of the essential components and the sum of the accessory molecules. This circle is plotted by first scaling off the percentages of the two components on the base. From the points obtained lines are drawn parallel to the sides opposite the angles containing the two major molecules, to an intersection. The intersection locates the point. The percentage of each of the three accessory molecules is represented by the length of lines drawn to scale from the circle. There are eight such diagrams; one for garnets from each of the following rock types: 1. Granites and pegmatites; 2. Garnets associated with contact action on siliceous rocks; 3. Biotite schists; 4. Amphibole schists; 5. Eclogites; 6. Kimberlites and peridotites; 7. Various basic igneous rocks; 8. Calcareous rocks.

Conclusions

1. This study shows the remarkable constancy of one variety of garnet in each rock type. Also this observation demonstrates that the recognition of the rock type is an important aid in determining the chemical composition of garnets by physical methods.

2. Spessartite and almandite constitute 85–90% of the molecules of garnets from pegmatites and granites. In general, if one of the major constituents is known, either spessartite or almandite, the other can be estimated within a reasonable error, with 5–15% left for the remaining molecules. This can be accomplished quickly by determining the amount of almandite through a ferrous iron determination.

3. Since grossularite and andradite represent over 90% of the garnet molecules in calcareous contact rocks, it is possible to estimate the composition by determining the index of refraction alone. Winchell's[4] diagram shows that the index of pure grossularite is 1.734, while that for andradite is 1.895. A straight line diagram represents the proportions of the two garnets. The range of index is so wide and the amounts of other garnet molecules so small that it is nearly always possible to estimate very closely the percentage of grossularite and andradite in garnets from calcareous contact rocks.

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[4] Winchell, *Optical Mineralogy*, Part 2, p. 257.

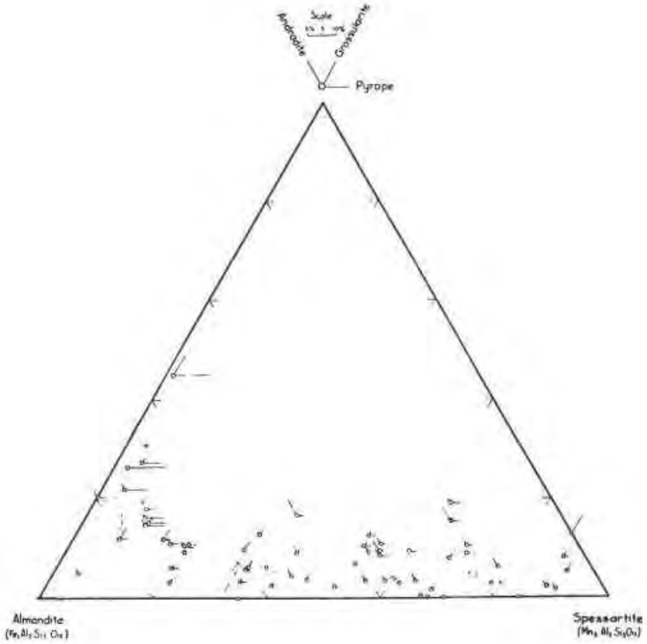

FIG. 1. Garnets from pegmatites and granites.

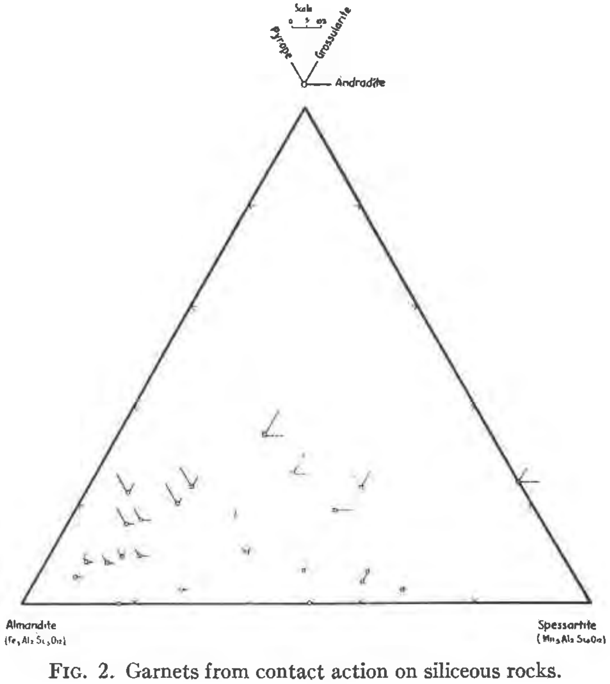

FIG. 2. Garnets from contact action on siliceous rocks.

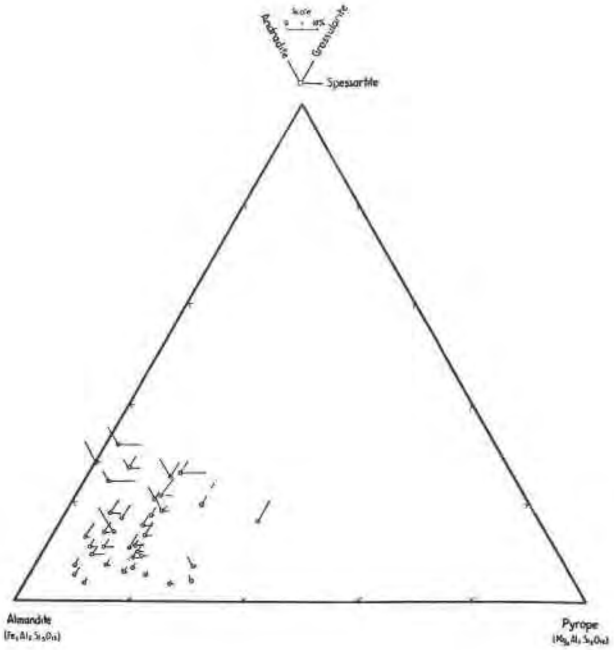

FIG. 3. Garnets from biotite schists.

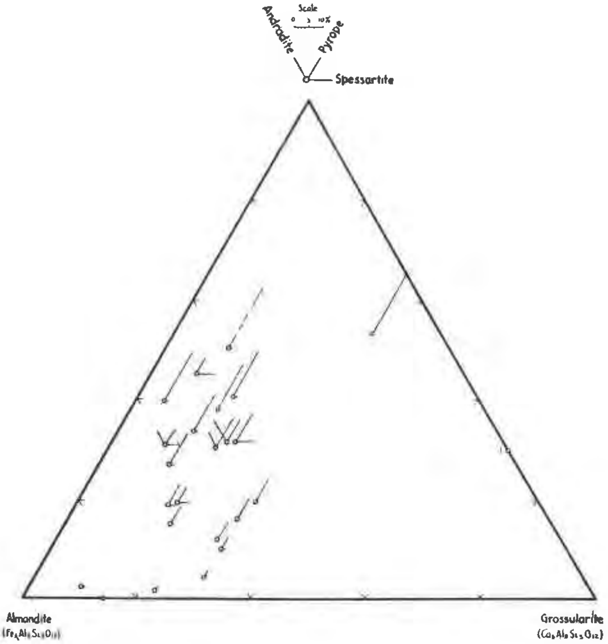

FIG. 4. Garnets from amphibole schists.

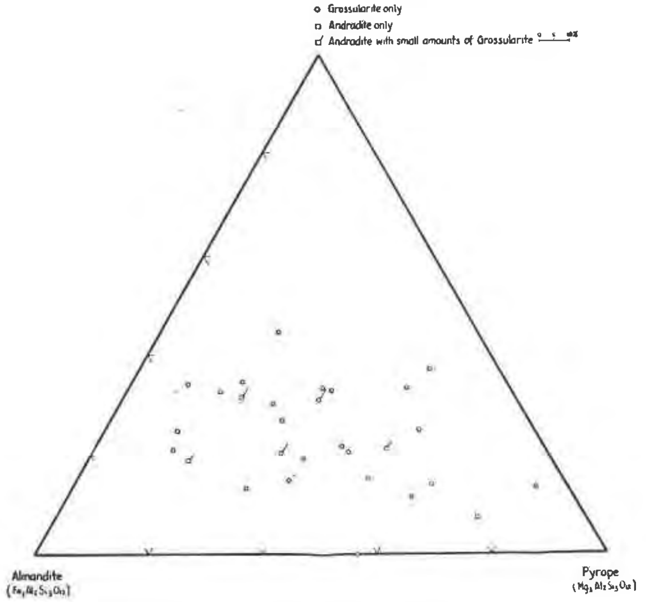

FIG. 5. Garnets from eclogites.

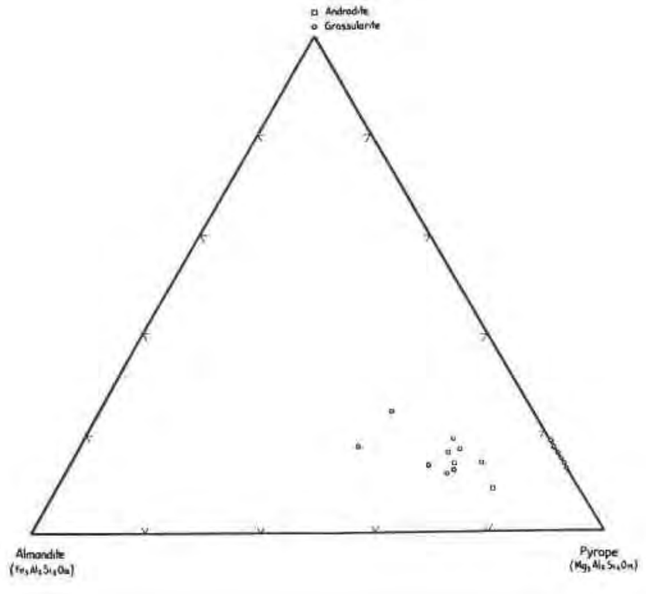

FIG. 6. Garnets from kimberlites and peridotites.

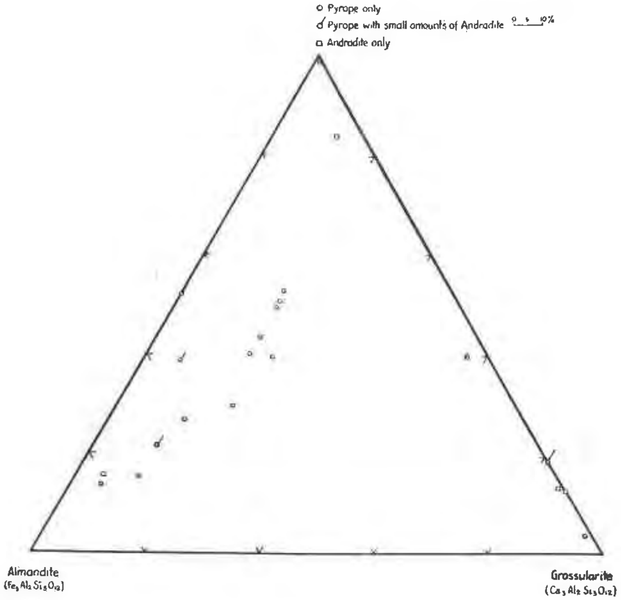

FIG. 7. Garnets from basic igneous rocks.

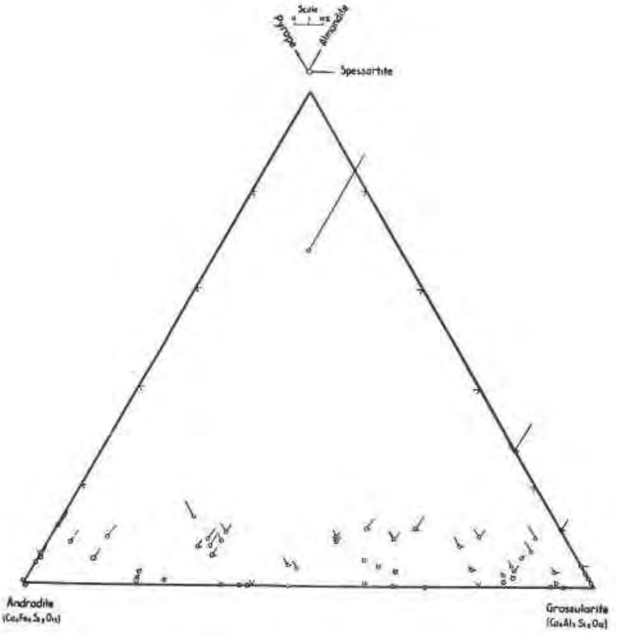

FIG. 8. Garnets from calcareous rocks.