GARNET-CORDIERITE-ANTHOPHYLLITE ROCKS
AT RAT LAKE, MANITOBA

A THESIS PRESENTED TO
THE FACULTY OF GRADUATE STUDIES
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ABSTRACT

Anthophyllite - garnet - cordierite rocks occur in the PreCambrian of the Churchill province at Rat Lake, Manitoba. Texturally the rocks can be classified as granoblastites, porphyroblastites and schists. They occur in an area of deformed meta-sedimentary rocks that have been intruded by granodiorite, tonalite, granite and pegmatite. Three outcrops of the anthophyllite - garnet - cordierite rocks, covering and area of 200' x 90' were mapped on a scale of 1" ≑ 10' and ninety-seven samples were collected. Chemical analyses were obtained for 10 whole rock samples, also for garnets separated from seven samples, and one sample of cordierite. Compositions of other cordierite and anthophyllite specimens were determined by measuring optical properties.

Mineral relationships can be interpreted to have originated in two stages of metamorphism. An early high pressure, high temperature period of granulite metamorphism is evidenced by the relict mineral assemblage orthopyroxene - sillimanite - garnet - cordierite (?). A later retrograde garnet - cordierite grade of metamorphism of the uppermost amphibolite facies is indicated by the assemblage garnet - cordierite - anthophyllite - hercynite, (the garnet of this assemblage being a relict of the granulite grade metamorphism) plus textural evidence of reactions which are interpreted to be:

$$\text{Garnet} + \text{sillimanite} \longrightarrow \text{cordierite} + \text{hercynite} \quad (1)$$

$$\text{Orthopyroxene} + \text{quartz} + \text{water} \longrightarrow \text{anthophyllite} \quad (2)$$

$$\text{Anthophyllite} + \text{hercynite} \longrightarrow \text{cordierite} \quad (3)$$

The presence of relict bedding, and unusual rock compositions support a theory of origin of these rocks as a weathering deposit from basic rocks.

CHAPTER I

INTRODUCTION

Rat Lake is located approximately 80 miles N.W. of Thompson, Manitoba.

The location of anthophyllite - garnet - cordierite bearing rocks is shown in the inset of Plate No. 1 (pocket at back). Mapping of the outcrops and collection of samples was conducted during the summer 1969, while the author was employed by the Manitoba Mines Branch. The area was revisited in the summer of 1970.

In the Rat Lake area, pelitic rock of the Wasekwan series are overlain by arkosic rocks of the Sickle Series.

The rocks at Rat Lake are Archean in age and are complexly deformed. The oldest rocks in the area are a layered sequence of pelitic gneisses (meta-greywackes) that have been interpreted to belong to the Wasekwan series. The mineralogy of these rocks is quartz, plagioclase, biotite, garnet, cordierite, sillimanite $\pm$ graphite. Stratigraphically above the pelitic gneisses is a thin band of amphibolite; it is not continuously exposed, but correlation with magnetic maps indicates that it is persistent, and Campbell (1971) puts this unit in the lower part of the Sickle series. The Sickle rocks are a sequence of quartzo - feldspathic gneisses, generally red to reddish brown and dark brownish grey, their mineralogy is simple, quartz, alkali feldspar, biotite, $\pm$ sillimanite and garnet, and their regional metamorphic grade is upper amphibolite facies (Schledewitz, 1969, and Elphick, 1969).

The anthophyllite - garnet - cordierite rocks are located at the stratigraphic level of the amphibolite. Texturally these rocks are granoblastic, prophyroblastic and schists. In contrast to the surrounding rocks, the anthophyllite - garnet - cordierite rocks do not show complex deformation on micro or meso scale.

CHAPTER II

STRUCTURE

The deformation in the Rat Lake Area is very complex, and a complete account of the structure is given by Schledewitz (1971). In brief, evidence of an early deformation has been largely obscured by later complex deformational events. The earliest recognizable event consists of large scale, gentle, open folding, with an E-W axial plane. A second phase imposed on the first, is represented by tight isoclinal folding with a NW-SE axial plane. The basin and dome outcrop pattern of much of the area is the result of the interference effect of these folds. The third and most penetrative has an axial plane sub-parallel to the E-W direction of the first deformational event, and has produced a general E-W foliation in the Rat Lake Area. A late strong N-S shear direction is a prominent feature in the area.

The anthophyllite - garnet - cordierite rocks occur at the same stratigraphic horizon as the amphibolite that lies between the Wasekwan pelitic gneisses and the Sickle quartzo-feldspathic gneisses.

The outcrop (Plate 1) shows bedding, irregular folds and repetition of beds, which indicate a folded structure with an axial plane striking NW-SE; the plunge of this axis cannot be determined. An axial planar schistosity is well developed in the schists, units # 2, 3, and 5.

The anthophyllite - garnet - cordierite rocks do not display the penetrative foliation, associated with the third deformation, that is seen in the adjacent pelitic rocks. A ductility contrast may have existed between the two rock types, the anthophyllite rich rocks being more competent, and thus the later regional foliation is not developed.

CHAPTER III

MICROFABRICS

In contrast to the complex tectonic fabrics in the surrounding rocks, nematoblastic, porphyroblastic and granoblastic textures predominate in the anthophyllite - garnet - cordierite rocks. The microfabrics described below relate to the mineral assemblages within map units called schists, granoblastites and porphyroblastites (units # 2, 3, 5 to 14).

The anthophyllite - garnet - cordierite schists typically display a nematoblastic texture, with biotite and anthophyllite orientated with their greatest dimension (a-axis of biotite and c-axis of anthophyllite) parallel or sub-parallel to the schistosity (Fig. 1).

Most garnets are porphyroblastic and idioblastic (Fig. 2). Some xenoblastic crystals have an inclusion free core and an outer rim that is full of inclusions of anthophyllite, biotite and cordierite. These xenoblastic garnets generally have a reaction rim of cordierite ± hercynite surrounding them (Fig. 3). The texture in the reaction rim consists of granular cordierite, with some wormy intergrowths of quartz and/or hercynite and/or anthophyllite (Fig. 3-1). The development of this texture is interpreted to be due to a second period of recrystallization, (retrogression from granulite facies).

Cordierite knots are porphyroblastic with an internal granoblastic texture (Fig. 4). Hercynite in these knots is granoblastic (Fig. 4 and 5), and if sillimanite is present displays a wormy intergrowth with cordierite (Fig. 6). This texture is thought to represent the reaction(1), garnet + sillimanite ⟶ cordierite + hercynite. Figure 7 shows knots of cordierite associated with garnets of various sizes; garnet has reacted where sillimanite was included or adjacent to itl

Cordierite also occurs interstitially between anthophyllite and hercynite. Both minerals show corrosion edges (Fig. 8). Reaction (3) anthophyllite + hercynite ⟶ cordierite is interpreted from this relationship.

Cordierite in the quartzitic rocks (unit #1, Plate 1) contains inclusions of fibrolite. Numerous quartz inclusions were observed in one large poikiloblastic cordierite.

Polysynthetically twinned cordierite is abundant.

Anthophyllite is nematoblastic, except in units 11 and 12 where, in the presence of relict pyroxene, it has a feathery radial crystal growth. The pyroxene forms the nucleus from which the radial anthophyllite grows (Fig. 9). This is textural evidence for reaction (2), orthopyroxene + quartz + water ⟶ anthophyllite.

Magnetite is present as equidimensional grains disseminated throughout the rocks. One notable exception is Unit #7, a magnetite granoblastite. The rock has granoblastic texture with fine unidentified interstitial material filling the nearly sub-microscopic spaces between magnetite grains (Fig. 10).

No textural evidence was seen for proposing two periods of deformation, (i.e. cross-cutting relations in the microfabrics).

The presence of clear cores and inclusion riddled outer rims of garnets would be taken by some workers as evidence of two phases of garnet growth. Without knowing if there is a difference in the composition of the cores and rims, plus the absence of a secondary phase associated with the garnet, the author does not wish to propose two periods of garnet growth in these rocks.

Garnet porphyroblasts are highly fractured but not rolled. The absence of pull-apart structure of the schistose fabric by garnet porphyroblasts, the idiomorphism of the garnet and absence of inclusions (uncommon) indicate complete recrystallization of the rocks (Fig. 11).

Fig. 8; Relationship between hercynite and anthophyllite showing corrosion edges and interstitial cordierite. Sample FM-1- (X-Nicols; X 25).

CHAPTER IV

COMPOSITION AND PETROGRAPHY

The chemical composition of ten whole rock samples is given in Table 1, the Niggli norms of these samples are given in Table 2. Table 3 shows mineral modal analyses of the rocks. The locations of the ten rocks analysed are given in Fig. 12, and their composition plotted on Fig. 13.

The rocks (Table 1) are basic in composition, the SiO_2 content being less than 50%. The rocks are rich in MgO, FeO and Al_2O_3, with very little alkali component and negligible CaO. One analysis of vermiculite clay and one of a hypersthene gabbro are given for comparison. The SiO_2, Al_2O_3 and Fe_2O_3 values for the vermiculite clay are similar to the values for the rocks concerned with in this work, the FeO being low and MgO high. The SiO_2, Al_2O_3, FeO and MgO are in good agreement to those for phyersthene gabbro, but the Fe_2O_3 of the gabbro is low and CaO high. The high content of total iron in sample BH-5 (90% magnetite in the mode), and the relict bedding structure in this rock, unit #7, suggest that it is probably a metamorphosed sedimentary iron formation.

Table 1-1 shows analyses of two samples from table 1, plus Sample A, the average composition from 9 samples in table 1 (omitting sample BH-5), that have been recalculated to 100% after the addition of 5 wt.% CaO. Since basic igneous rocks contain an average of 5 wt.% CaO this amount was added to the analysis to determine the approximation of the rocks to a basic igneous rock composition. Sample R-524, B and C are put in for comparison. From the comparison it is seen that the chemistry of the Rat Lake rocks is similar to that of basic igneous rocks from which calcium and Na + K have been leached, although no evidence of such a process was observed.

The chemistry of the rocks is reflected by the mineralogy. Modally, anthophyllite, cordierite and garnet are the most abundant minerals present; anthophyllite $>$ cordierite $>$ garnet (Table 3). Biotite is the next most abundant mineral followed by hercynite, magnetite, pyroxene, sillimanite and zircon.

Anthophyllite:

The composition of five samples of anthophyllite was determined from measurements of the refractive index and $2V_z$ (Fig. 14). (Deer, Howie and Zussman, 1966).

Anthophyllite occurs as short, well formed prismatic crystals, commonly in a parallel orientation (nematoblastic), more rarely in radiating clusters. Its pleochroic formula is:

$\alpha = \beta$ = pale green - grey

γ = colorless to pale green.

Anthophyllite shows reaction textures when in contact with hercynite with the formation of a rim of cordierite between the two minerals. No other disequilibrium textures involving anthophyllite are present, except with hercynite.

Garnet:

Seven garnets were separated with heavy liquids (methylene iodide). Chemical analysis of the garnets is shown in Table 4. The location of the analyzed garnet samples is shown in Fig. 12.

The analysis shows that the garnets are almandine in composition, in terms of mole % end members the garnets are almandine 52% pyrope 38% and spessartite 10%.

TABLE 1

Chemical analysis (whole rock) in wt.% Done by X-Ray Fluorescence. Analyst K. Ramlal

Sample No.	FB-1	EF-3	BG-3	BH-5	G1-1	FM-10	10-2	IP-3	JR-7	HS-2	1	11
SiO_2	47.90	49.40	38.60	3.40	40.25	35.70	41.15	39.45	39.60	32.55	41.70	46.96
Al_2O_3	28.02	15.32	16.86	1.49	19.86	20.15	20.22	21.60	21.58	19.93	23.25	14.13
Fe_2O_3	2.91	4.68	6.59	61.69	4,84	7.40	3.88	3.85	5.48	11.38	6.05	0.76
FeO	10.44	12.48	13.28	27.62	15.80	15.56	14.84	14.68	13.56	15.84	0.75	14.95
MgO	8.30	14.40	20.20	3.40	14.70	16.70	15.00	14.80	15.10	15.70	28.35	15.97
CaO	0.00	0.00	0.00	0.00	0.03	1.10	0.02	0.50	0.10	0.11	-	2.32
Na_2O	0.16	1.00	1.04	0.03	1.06	1.48	1.52	1.40	1.40	1.32	-	0.35
K_2O	0.70	0.70	0.09	0.00	0.90	0.12	0.54	0.61	0.41	0.10	-	1.68
H_2O	0.52	1.52	1.86	0.75	1.14	1.26	1.62	1.62	1.55	1.84	-	1.33
CO_2	0.14	0.29	-	0.03	0.19	-	0.14	0.11	0.16	0.19	-	-
TiO_2	0.14	0.23	0.08	0.07	0.31	0.33	0.28	0.33	0.31	0.34	-	0.62
ZrO_2	0.07	0.08	0.03	0.00	0.12	0.09	0.08	0.09	0.08	0.09	-	-
S	0.00	0.00	0.119	0.01	0.01	0.34	0.01	0.01	0.00	0.04	-	-
MnO	0.10	0.10	0.14	0.07	0.07	0.13	0.08	0.07	0.07	0.08	-	0.93
Total	99.40	99.57	98.88	98.56	99.28	100.36	99.38	99.12	99.40	99.514	100.00	100.00

NOTE: See page 16 for sample description.

FB-1; Cordierite - garnet - biotite schist.

EF-3; Cordierite - garnet - anthophyllite schist.

BG-3; Magnetite - amphibole porphyroblastite.

BH-5; Magnetite granoblastite.

GI-1; Cordierite - garnet - anthophyllite porphyroblastite.

FM-10; Magnetite amphibolite.

IO-2; Garnet - cordierite - anthophyllite schist.

IP-3; Cordierite - garnet - anthophyllite porphyroblastite.

JR-7; Garnet - cordierite - anthophyllite schist.

HS-2; Magnetite - garnet - anthophyllite porphyroblastite.

1; Yelloish brown vermiculite, Corundum Hill, North Carolina (Chatard,1887) recalculated to 100% after removal of 22.47 wt. % H_2O.

11; Hypersthene Gabbro, Gunflint Minn. (From Clarke, F.W. 1924).

TABLE 1-1

Sample No.	EF 3	IO-2	A	R-524	B	C
SiO_2	47.23	39.42	39.77	45.7	35.56	30.24
Al_2O_3	14.65	19.37	19.90	11.45	11.25	16.83
Fe_2O_3	4.48	3.71	5.52	2.64	6.62	3.95
FeO	11.93	14.21	13.72	10.16	6.67	18.72
MgO	13.77	14.37	14.74	19.5	14.68	16.73
CaO	4.80	4.90	5.17	6.92	8.99	1.92
Na_2O	0.95	1.45	1.12	0.62	3.86	0.27
K_2O	0.07	0.51	0.39	NIL	1.70	0.02
H_2O	1.45	1.55	1.40	1.80	1.72	10.45
CO_2	0.27	0.14	0.16	0.41	-	0.08
TiO_2	0.21	0.27	0.24	0.29	8.03	0.58
ZrO_2	0.08	0.08	0.07	-	-	-
S	0.007	0.01	0.06	0.02	-	-
MnO	0.09	0.08	0.08	0.20	-	0.28

EF-3 Recalculated to 100% after addition of 5 wt.% CaO

IO-2 Recalculated to 100% after addition of 5 wt.% CaO

A Average of 9 analysis from Table 1, recalculated to 100% after addition of 5 wt.% CaO

R-524 Cortlandtite, Beresford Lake Area, Southeastern Manitoba; Ultramafic rocks of the Rice Lake Greenstone Belt; R. F. J. Scoates in Man. Mines Br. pub. 71-1 (in press).

B Melilite - Basalt; Hohenatoffeln, Hegau, baden, Grubenmann, analyst. Inaug. Dissert, Zurich, 1886, 35. (partial analysis)

C M. Vuagnat, Variolites et spilites, Archiv. Sci., Vol. 2, fasc. 2, p. 235, 1949. (partial analysis).

TABLE 2

NIGGLI NORMS

SAMPLE No.	FB-1	EF-3	BG-3	BH-5	GI-1	FM-10	IO-2	IP-3	JR-7	HS-2
Saturation Index	23.0	12.5	-6.0	-2.3	-2.4	-9.6	-2.7	-4.2	-1.6	-7.3
Differentiation Index	28.7	22.1	9.9	0.3	15.0	13.9	17.0	16.3	15.0	12.8
Colour Index	41.0	62.3	25.5	94.0	12.8	37.8	12.7	17.2	11.1	34.8
Calcite	-	-	-	-	0.06	-	0.040	0.281	0.200	0.225
Pyrite	-	0.026	0.314	0.035	0.026	0.884	0.026	0.026	0.026	0.107
Ilmanite	0.198	0.326	0.111	0.131	0.183	0.458	0.393	0.464	0.434	0.487
Orthoclase	4.227	0.423	0.536	-	5.415	0.708	3.227	3.651	2.443	0.609
Albite	1.464	9.168	9.392	0.363	9.671	13.255	13.774	12.706	12.648	12.204
Anorthite	-	-	-	-	-	5.453	-	1.808	-	-
Magnetite	3.097	4.988	6.918	86.153	5.133	7.704	4.087	4.062	5.755	12.231
Hematite	-	-	-	0.729	-	-	-	-	-	-
Corundum	30.049	15.158	16.524	2.120	19.010	16.964	18.875	19.838	20.924	19.837
Enstatite	23.558	40.930	-	-	-	-	-	-	-	-
Ferrosilite	14.198	16.036	-	-	-	-	-	-	-	-
Hypersthene	-	-	47.986	3.381	52.799	25.735	51.167	44.444	52.556	32.129
Quartz	23.024	12.565	-	-	-	-	-	-	-	-
Olivine	-	-	18.215	7.034	7.485	28.834	8.248	12.715	4.907	22.033

TABLE 3

Mineral Modes - Analysis by Point Counting

1,000 points per section

SAMPLE No.	FB-1	EF-3	BG-3	BH-5	GI-1	FM-10	IO-2	IP-3	JR-7	HS-2
Biotite	13.5	1.0	2.0		13.0	3.0	7.0	No section for this sample	6.5	1.0
Cordierite	73.0	39.0	.5		14.0	3.5	18.0		26.0	1.0
Garnet	2.5		2.0		7.0				26.0	0.5
Anthophyllite	9.0	60.0	79.0		65.0	62.0	63.0		34.0	72.5
Pyroxene			9.0	5.0		0.5				
Zircon			1.0		minor					
Hercynite			6.5	5.0	minor	31.0	12.0		herc + mt 7.0	25.0
Magnetite				90.0						
Sillimanite	2.0								0.5	

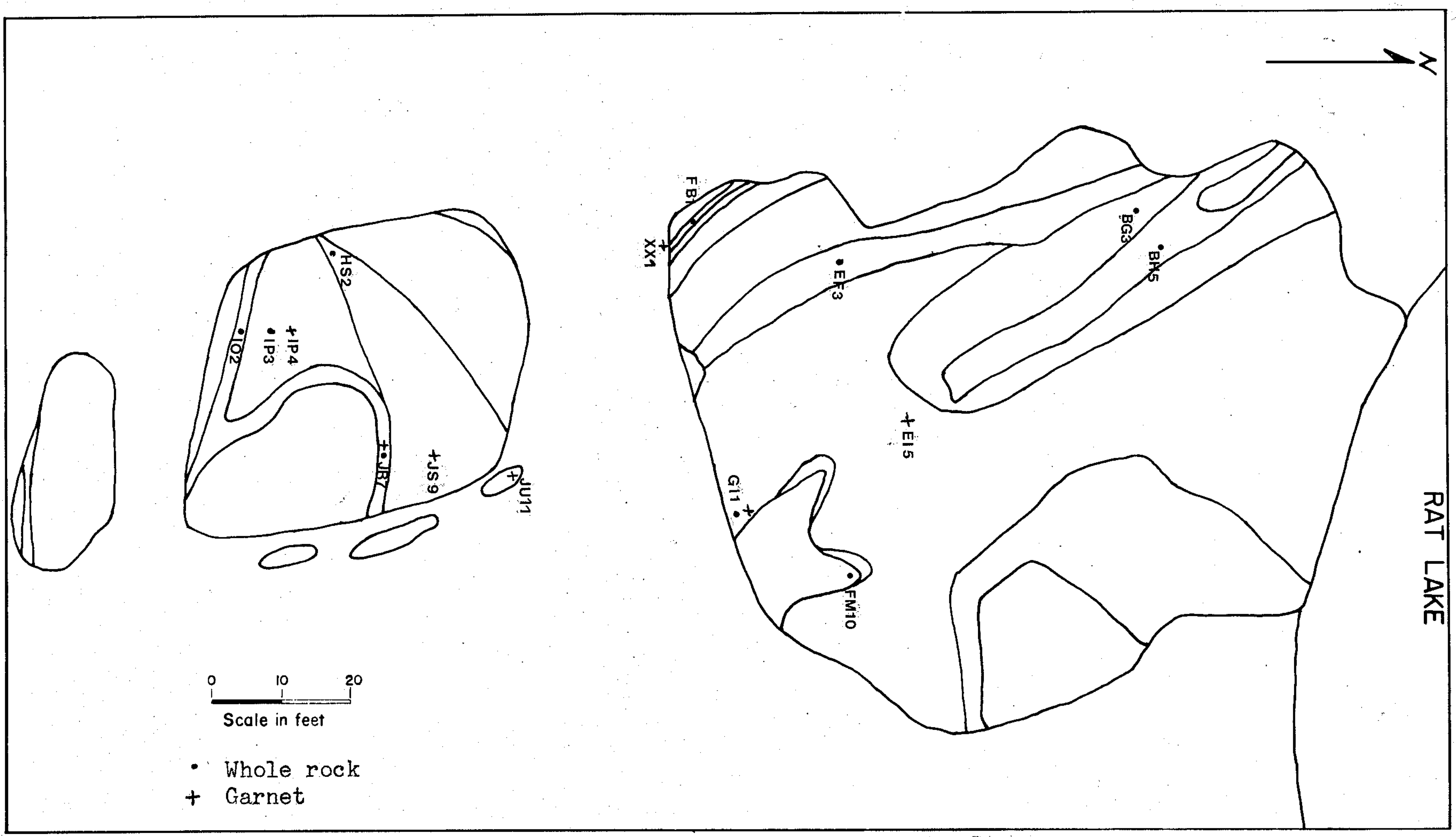

Fig.12; Location of samples for whole rock and garnet analysis

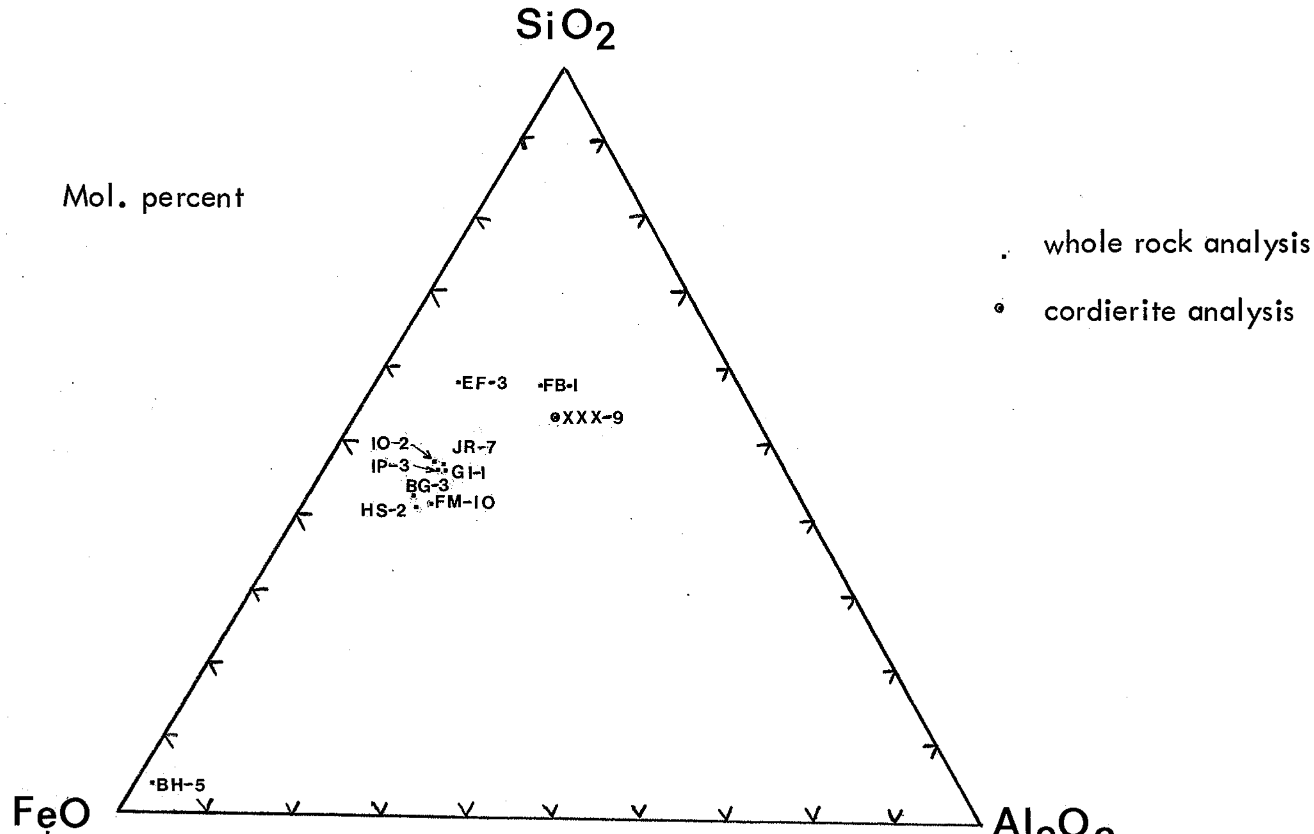

Fig. 13 Plot of chemical composition of ten whole rock analysis and one cordierite analysis.

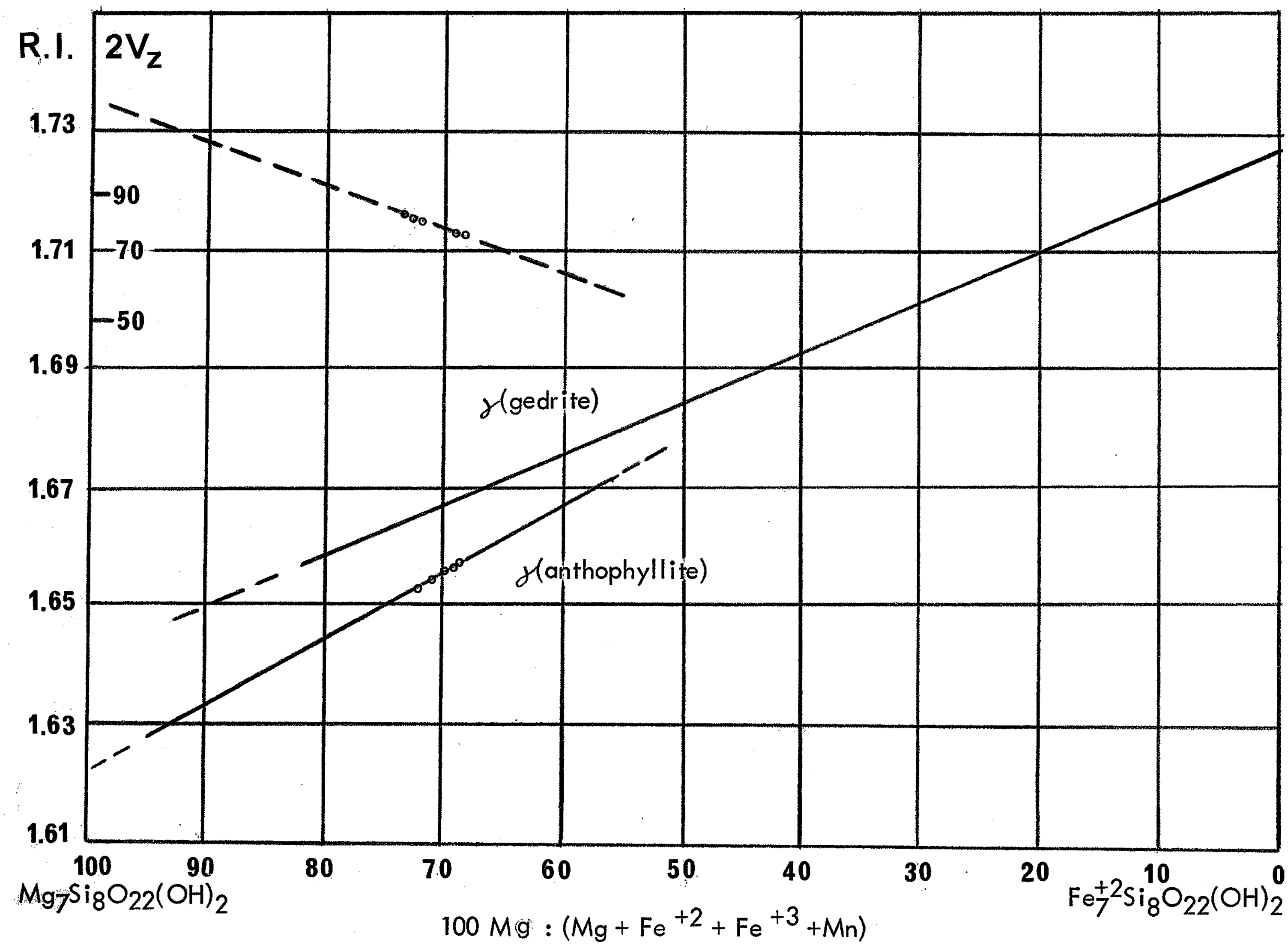

Fig. 14 Relation between the optical properties and chemical composition for anthophyllite. (After Deer, Howie, Zussman, 1966, in An Introduction to the Rock Forming Minerals, Longmans, London.)

TABLE 4

Chemical analysis of Garnet in wt.%

Sample No.	XX-1	IP-4	JR-7	JU-11	EI-5	GI-1	JS-9
SiO_2	37.45	37.15	38.10	38.15	37.15	36.40	36.50
Al_2O_3	20.40	20.36	20.36	20.22	22.72	20.76	20.84
FeO	25.63	24.24	24.60	24.84	25.16	25.02	24.22
CaO	0.00	0.00	0.00	1.34	0.26	0.10	0.40
MgO*	9.43	9.79	8.43	8.70	8.44	10.04	12.49
MnO*	4.25	5.98	4.47	4.01	3.47	4.90	2.85
TOTAL	94.46	97.52	95.96	97.26	97.20	97.22	97.30

* Analysis done by wet method. Other oxides done by X-Ray Fluorescence.

Analyst - M. Whitfield.