GRUNERITE IN WESTERN AUSTRALIA*

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INTRODUCTION

Recent studies of the older pre-Cambrian banded iron formations or banded ironstones, banded hematite quartzites, jaspilites or "jasper bars," as they are variously called in Western Australia, have revealed that where these have been subjected to high grade metamorphism, recrystallization is characterized by the development of the iron-rich amphibole, grunerite. This mineral has been found in many places throughout the State, and a description by the writer of its associated minerals and of the petrology of the rocks in which it occurs, will, it is hoped, be published shortly.

These metamorphosed banded iron formations in Western Australia show close affinities with the grunerite-bearing rocks of the Lake Superior Region in the United States. In the following pages is given brief descriptions of the occurrence of grunerite in several localities in Western Australia, together with an account of its mineralogy and chemical composition, and of its associated minerals.

DESCRIPTION OF OCCURRENCES

All specimens of grunerite so far recorded in Western Australia come from metamorphosed banded iron formations. Minerals with which it has been found most commonly associated are magnetite, quartz, blue-green hornblende, hedenbergite or iron-rich hypersthene, garnet, and to a much lesser extent, fayalite. The form, structure and mineral associations of the grunerite-bearing rocks of Western Australia usually indicate recrystallization of original banded ferruginous sedimentary material at high temperatures with little or no directed pressure, characteristic of contact thermal metamorphism (Fig. 3). However, some occurrences show evidence that recrystallization took place under fairly high directed pressures, indicative of regional metamorphic conditions (Fig. 4).

R. T. Prider (1)† has described the occurrence of a grunerite having optical properties indicating a composition near cummingtonite, from banded ironstone xenoliths in granite gneiss near Toodyay (Fig. 1). In another xenolith in this vicinity the place of grunerite is taken by iron-rich hypersthene.

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* Extracted from a portion of a thesis accepted in part fulfillment of the requirements for the degree of Doctor of Science in the University of Western Australia.

† Numbers in parentheses relate to references collected at the end of the paper.

At Bolgart, some 22 miles north of Toodyay, a very similar grunerite in banded magnetite-grunerite quartzite is also found occasionally intergrown with iron-rich hypersthene.

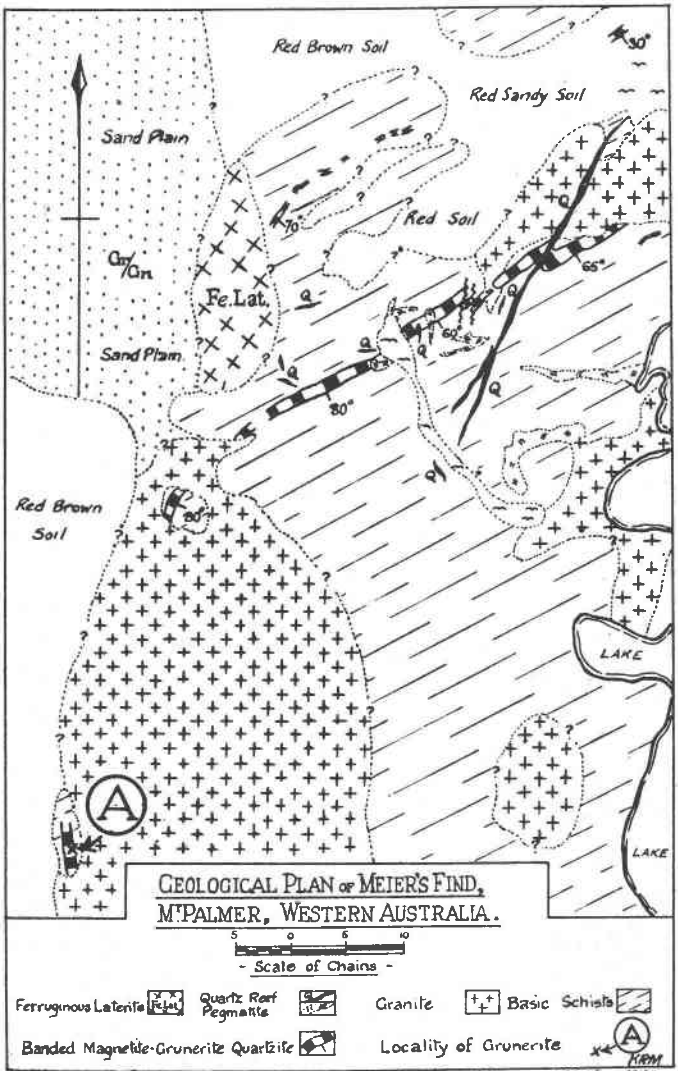
At Clackline, 12–13 miles to the south of Toodyay, is a series of metamorphosed banded ferruginous quartzites interbedded with garnetiferous and sillimanite-bearing mica schists. These ferruginous quartzites contain interbanded layers alternately rich in quartz and in cummingtonitic grunerite associated with magnetite, garnet (almandine), and a strongly pleochroic blue-green hornblende, which will be mentioned later.

FIG. 1. Locality map.

Banded iron formations or "jasper bars" are very abundant in the gold-bearing Older Greenstone Series in the Central Goldfields of Western Australia, and grunerite-bearing rocks are characteristic of the more highly metamorphosed regions. The best exposures of these rocks so far located are in the Mt. Palmer district of the Yilgarn Goldfield (Fig. 1). Here the beds of metamorphosed banded ironstone (meta-jaspilites) consist of banded magnetite-grunerite quartzites containing layers locally rich in hedenbergite and fayalite. These rocks are interbedded with recrystallized basic lavas and tuffs (amphibolite schists), ultra basic rocks (anthophyllite schists), and thin bands of argillaceous sediments (garnetiferous and andalusite-bearing mica schists), and intruded by numerous bodies of biotite granite and later quartz and pegmatite reefs. The rocks in this vicinity are for the most part comparatively fresh and unweathered and they provide excellent material for petrological investigations.

GRUNERITE FROM MEIER'S FIND, MT. PALMER

Material for analysis was selected from outcrops of banded magnetite-grunerite quartzite from the vicinity of Meier's Find, 3 miles south of Mt. Palmer. The geology of this area is illustrated in Fig. 2. The granite has completely engulfed portions of the banded ferruginous sediments



Compiled from Maps by K.R.Miles, 1940, and R.A.Hobson, 1936.

FIG. 2.

and associated basic amphibolite schists, leaving here and there small remnants or xenoliths of the older rocks.

The amphibole in these metamorphosed iron formations usually occurs in surface specimens as narrow bands of golden-brown to almost straw-colored silky lustred flakes and short prismatic crystals, associated with layers of black metallic iron ore. Occasionally fresher specimens are found, however, in which the amphibole is in masses of clear, rather grayish-green to light olive-green crystals.

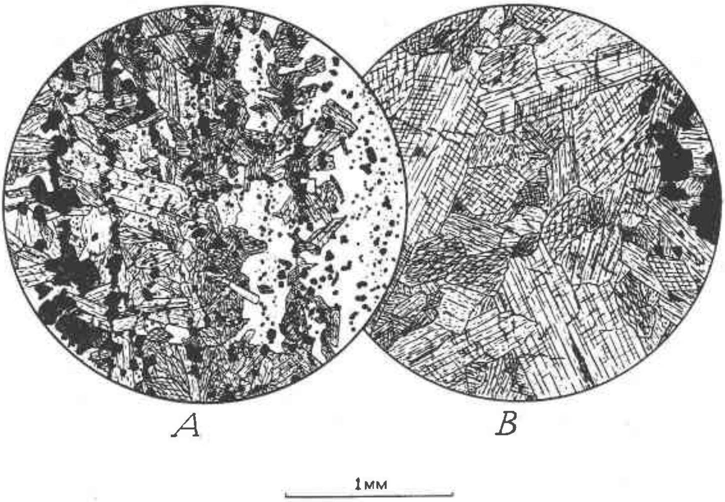


FIG. 3. Grunerite in banded magnetite grunerite quartzite, Meier's Find, Western Australia (Spec. 2/1740). *A*. Slice cut normal to banding. Note random orientation of the amphibole crystals. The original bedding is indicated by the parallel strings of magnetite crystals. *B*. Portion of a coarser grained grunerite-rich layer. Larger tabular plates of grunerite cut approximately parallel to (010) show well developed prismatic cleavage and characteristic fine cross striation parallel to (001).

The specimen from which grunerite for analysis was obtained came from a small outcrop partly enclosed by granite in the south west corner of the area, illustrated in Fig. 2. This rock is well banded, consisting of alternating layers of interlocking finely crystalline amphibole ranging from less than 1.5 mm. up to fairly coarsely crystalline bands over 20 mm. thick, enclosing thin bands of tiny black magnetite crystals and set in layers of glassy, clear to gray or brownish, fine grained quartz up to almost 5 mm. thick.

In thin section the rock appears granoblastic gneissic and the banded structure is well pronounced. The intercalated quartz bands form a clear mosaic often sprinkled with minute dust-like aggregates of iron ore. These alternate with bands rich in almost colorless grunerite, often associated with very minor quantities of a blue-green strongly pleochroic amphibole, and magnetite. The iron ore usually occurs in irregular parallel strings of loosely connected crystals passing evenly through the amphibole-rich bands (Fig. 3*A*) and also as narrow layers of grains ranging in size from minute particles up to idioblastic aggregates averaging .1–.2 mm. in diameter, enclosed in the quartz-rich bands. The iron ore grains in the different bands are more or less graded, the most coarsely crystalline masses usually being associated with the amphibole-rich layers.

The grunerite usually occurs in aggregates of interlocking short prismatic laths and diamond shaped basal sections, very light grayish-brown to colorless, lying in random orientation. The grain size of this amphibole varies somewhat in the different bands. For bands up to 1.5 mm. thick individual laths average .2–.3 mm. long, but in the coarser bands crystals may reach a length of over 2 mm. The typical random orientation of the crystals (decussate structure) and their characteristic form and cleavage are illustrated in Fig. 3*B*, which shows a portion of a coarse amphibole-rich band. Prism faces are usually well developed but the terminations of individual crystals are generally irregular. They show very good (110) cleavage and very characteristic well developed cross striations, which on sections cut approximately parallel to (010) make an angle of about 73° with the intersection of (110), and on sections parallel to (100) are approximately normal to (110). Thus these striations are apparently parallel to (001). Basal sections are characteristically diamond shaped with the perfect (110) cleavages intersecting at 56° and 124°. In no instance was any development of (010) faces seen. Prismatic sections frequently show irregular cross fractures.

The mineral is very weakly colored and feebly pleochroic with X = colorless to pale yellow; Y = pale yellow-brown to yellowish-gray; Z = pale yellow to pale green. Absorption $Y > Z > X$.

Many of the larger crystals show a grayish-brown cloudiness indicative of incipient oxidation, particularly along the cross fractures.

Twinning, both simple and multiple, on (100) as twin plane is very common, and very characteristic.

The refractive indices of this mineral were determined by the immersion method using mixtures of α-monobromnaphthalene and methylene iodide, with a sodium light. The indices of the mixtures were determined with the use of a tested Herbert Smith refractometer. These are:

$$\begin{aligned} \alpha &= 1.673 \pm .002 \\ \beta &= 1.694-{}^{*} \\ \gamma &= 1.711 \\ \gamma-\alpha &= .038 \\ Y &= b;\ Z\wedge c = 13\tfrac{1}{2}-14^{\circ} \end{aligned}$$

2V large (about 85°). Optical character −. Optical axial plane is parallel to (010). Dispersion is weak, r slightly $> v$.

Without a universal stage the writer was unable to determine the optic axial angle directly. From the refractive indices, however, using the approximate formula: $\cos V_\alpha = \sqrt{\beta-\alpha/\gamma-\alpha}$, we find that 2V = approximately 84°.

The above data indicate grunerite with a small amount of the cummingtonite molecule—probably containing about 83% of $FeSiO_3$. This conclusion is borne out by the chemical analysis (Tables 1 and 3).

In its optical properties this mineral appears to be intermediate in character between a specimen from Mt. Humbolt, Lake Superior, Michigan, described by S. Richarz in 1927 (2) and a mineral from La Mallière near Collobrières, France, analyzed by S. Kreutz in 1908 (3). It is very close optically to grunerite from Pierrefitte, Hautes-Pyrénées, France, described by H. V. Warren in 1931 (4) (Table 3).

The grunerite from the Meier's Find rock was isolated for analysis by crushing to pass a 150 mesh sieve, and by treatment with a strong hand-magnet to remove the bulk of the magnetic iron ore, and finally it was freed from the light minerals by repeated separations in bromoform (G. = 2.9). The remaining material was cleaned by boiling in a fairly strong hydrochloric acid solution. Inspection revealed that there still remained about 5 per cent impurity in the form of grains of a dark blue-green amphibole. These were removed by hand picking under a fairly high power lens. The analysis of the resulting pure sample of grunerite (Table 1) was made for the writer in the Western Australian Government Chemical Laboratory.

No fluorine estimation was made on this analysis but a subsequent determination by Mr. G. L. Miles in the Department of Chemistry, University of Western Australia, indicated $F < 0.05\%$. It being assumed then that the fluorine content was sufficiently low to be neglected, the analysis of this grunerite was arranged so that the constituents were in order of increasing effective radius and the structural formula calculated on a basis of 24 (O, OH, F) (Table 1). This gave the formula $(OH)_{2.36}(Fe'', Mg, Fe''', Al, Ca, Mn)_{6.75}(Si, Al)_8O_{22}$ which agrees fairly well with the ideal Warren formula for a monoclinic amphibole low in alkalies (5).

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* Owing to the difficulty of obtaining a perfectly oriented section there is some doubt as to the true value of β.

This gives the structural formula:

$$(OH)_{2.36}(Fe'', Mg, Mn, Fe''', Ca, Al)_{6.75}(Si, Al, P)_8O_{22}.$$

The chief points of difference are the slightly high (OH) value and the very slight deficiency in (Fe'', Mg, etc.). Possibly the slight excess of H_2O may represent an incipient hydration of the mineral whilst most of the small Fe_2O_3 content shown in the analysis has probably been formed due to oxidation, as it is impossible to avoid a slight cloudiness in even the freshest material analyzed.

TABLE 1. ANALYSIS AND CALCULATION OF GRUNERITE FROM MEIER'S FIND

	Wt. %	Molecular Proportions	Metal atoms on basis of 24 (O, OH, F)	Metal Groups
SiO_2	50.37	.838	7.969	8.00
P_2O_5	.02	.0002	.004	
Al_2O_3	.54	.005	$.095\left\{\begin{matrix}.027\\.068\end{matrix}\right.$	
Fe_2O_3	.56	.003	.057	6.75
MgO	4.47	.110	1.046	
FeO	40.08	.557	5.306	
MnO	1.07	.015	.142	
CaO	.83	.014	.133	
H_2O+	2.24	.124	2.858	2.36
H_2O-	.20			
	100.38			

In Table 2 the analysis of the Meier's Find mineral is compared with those of grunerite from different localities in North America and France, and one from Sweden. The essential characteristics of grunerite are the very low alkali content, the low alumina and ferric iron oxide, and the high ferrous iron oxide and silica contents. MgO replaces FeO in varying degrees while Al_2O_3 sometimes replaces a little of the silica, but always in very minor amounts. The analysis of Meier's Find grunerite demonstrates all these features clearly. The Swedish mineral (Table 2, No. 7) differs most from normal grunerite in that MnO and MgO have replaced a considerable quantity of the ferrous iron. This mineral should thus probably be called manganiferous cummingtonite or dannemorite. The grunerite from Rockport, Mass. (Table 2, No. 5) consists of almost pure ferrous silicate and approaches very close to the theoretical formula $H_2Fe_7(SiO_3)_8$ or $(OH)_2Fe_7\,Si_8O_{22}$.

Table 2. Analyses of Grunerite from Western Australia, North America, France and Sweden

	1.	2.	3.	4.	5.	6.	7.
SiO_2	50.37	48.53	47.17	46.42	47.54	50.79	50.74
Al_2O_3	.54	1.02	1.00	.25	.20	.34	.88
Fe_2O_3	.56	1.14	1.12	.09	.71	.89	1.80
FeO	40.08	39.20	43.40	42.60	47.25	38.43	24.13
MnO	1.07	.66	.08	2.23	2.14	1.12	7.38
MgO	4.47	4.06	2.61	3.12	.04	6.50	10.57
CaO	.83	1.31	1.90	1.51	Nil	Nil	2.00
Na_2O	Nil	1.06	.47	.70	.29	Tr	.22
K_2O	Nil	.19	.07	.43	.11	Nil	.08
H_2O+	2.24	1.71	2.22	1.78	1.55	2.00	1.94
H_2O-	.20	—	—	.14	—	—	—
TiO_2	Nil	—	—	.15	—	—	—
P_2O_5	.02	—	—	—	—	—	—
CO_2	Nil	—	—	—	—	—	—
C	—	—	—	.65	—	—	—
F_2	Nil	—	.07	—	.01	—	.07
	100.38	98.88	100.11	100.07	99.84	100.07	99.87
Sp. Gr.	3.45	3.44	3.518	—	3.597	3.443	3.337
Analyst	C. R. Le Mesurier	S. Richarz	S. Kreutz	E. G. Radley	Bowen & Schairer	A. Bygden	K. Johansson

1. Grunerite from 1 mile south of west corner Peg. G.M.L. 3647, Meier's Find, Yilgarn Goldfield, Western Australia.
2. Grunerite from ½ mile south of R.R. Station at Mt. Humbolt, Michigan (2, p. 151).
3. Grunerite from La Mallière near Collobrières, France (3, p. 910).
4. Grunerite (from schist). Pierrefitte, Hautes Pyrénées, France (4).
5. Grunerite from Rockport, Massachusetts (6, p. 545).
6. Grunerite from Cummington, Massachusetts (7).
7. Grunerite (dannemorite) from Uttersvik, Nävekvarn, Sweden (7).

The chemical and optical data for the Meier's Find grunerite agree fairly well with the results of previous work, and fit without serious discrepancy into the curves for iron-rich hydroxy-amphiboles of the grunerite series of Bowen and Schairer (6, Fig. 1), and for the manganese-poor grunerites and cummingtonites plotted by Sundius (7, Fig. 1).

Table 3 summarizes the optical data for the minerals whose analyses are given in Table 2. The molecular percentages of the principal constituents $FeSiO_3$, $MgSiO_3$, $MnSiO_3$ and $CaSiO_3$, neglecting the small percentages of other constituents, have also been added in this Table. These figures do not take into account the regular and definite quantities of combined water shown in the analyses of Table 1. Bowen and Schairer, in discussing this point recognized the hydroxyl as an essential constituent in these amphiboles (6, p. 548) and they have calculated the composition of the Rockport grunerite, etc., in terms of the two molecules $(OH)_2(Fe, Mn)_7(Si_4O_{11})_2$ and $(OH)_2Mg_7(Si_4O_{11})_2$. It may be noted that neither of these writers nor N. Sundius, who in 1931 compared the optical and chemical properties of the Mn-poor grunerites and cummingtonites with those of the Swedish manganiferous members (7), have considered lime as holding an essential place in the molecular structure of the grunerites.

The Pierrefitte and Mt. Humbolt minerals appear to be closest in both optical and chemical properties to the Meier's Find grunerite, the rather higher birefringence of the last probably being due to the slight increase of $FeSiO_3$ at the expense of $MnSiO_3$ compared with the former.

TABLE 3. COMPOSITION AND OPTICAL PROPERTIES OF THE GRUNERITES OF TABLE 2

	Meier's Find	Mt. Humbolt	Collobrières	Pierrefitte	Rockport	Cummington	Uttersvik
$FeSiO_3$	79.9	80.4	85.8	81.4	95.4	75.0	43.3
$MgSiO_3$	16.0	14.8	9.2	10.6	.1	22.8	34.1
$MnSiO_3$	2.0	1.4	.2	4.3	4.5	2.2	18.0
$CaSiO_3$	2.1	3.4	4.8	3.7	Nil	Nil	4.6
α	1.673	1.666	1.672	1.676	1.686	1.666	1.655
β	1.694–	1.684	1.697	1.693	1.706	1.684	1.672
γ	1.711	1.700	1.717	1.707	1.729	1.704	1.686
$\gamma-\alpha$	.038	.034	.045	.031	.043	.038	.030
2V	84° (Calc.)	85°	80–84°	85°15′	86°	90°	85.3°
$c:\gamma$	13½–14°	14–15°	10–11°	13°22′	10°	14°	15.4°

GRUNERITE FROM MT. WINDARRA

Near Mt. Windarra, about 14 miles north west of Laverton (Fig. 1) in the Mt. Margaret Goldfield, grunerite has been found in several beds of banded magnetite-grunerite quartzite enclosed in granitic gneiss.

The amphibole in slightly weathered surface specimens of this rock has a golden brown color, due apparently to a surface oxidation and hydration to limonite, since the powdered mineral, on treatment with hot HCl changes to a pale green, the surface stain being completely dissolved away. The grunerite occurs in narrow bands associated with granular magnetite intercalated between layers of quartzite. It is occasionally intergrown with a little blue-green pleochroic amphibole. Individual crystals of grunerite in these bands show a high degree of parallel alignment or orientation, indicative of growth under regional directed pressure (Fig. 4). The general form of the mineral is very similar to the Meier's

Find grunerite. Prismatic plates show perfect (110) cleavage and the characteristic (001) cross striation. An irregular cross fracture is also fairly common. Sections cut normal to the *c* axis (Fig. 4*A*) show the (110) cleavages intersecting at 56°, also occasionally a perfect (010) parting. Polysynthetic twinning on (100) is very common. Under the microscope it was noticed that the mineral here and there varied somewhat in its intensity of coloring from an almost colorless to a pale green, and in places it appeared that the colorless mineral was intergrown (sometimes in optical continuity) with the colored mineral.

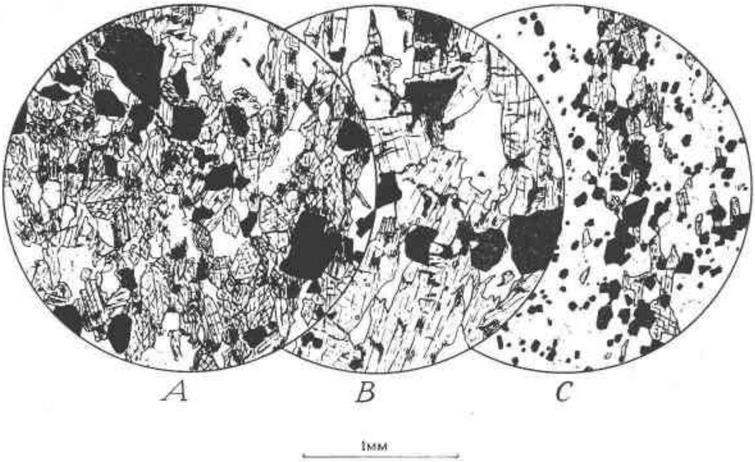

FIG. 4. Grunerite in banded magnetite grunerite quartzite, Mt. Windarra, Western Australia (Spec. L 180). Shows the form, structure and strongly oriented nature of the xenoblastic grunerite, indicative of growth under directed pressure (regional metamorphism). *A*. Slice cut normal to strike and dip of the banding (original bedding planes). Basal sections of grunerite predominate. Note the abundant twin planes on (100). *B*. Slice cut approximately parallel to strike and dip of bedding showing broad plates of grunerite cut parallel to (100). *C*. Slice cut approximately normal to the directions *A* and *B*, showing elongated ragged sections cut parallel to (010).

An attempt was made to separate these minerals for chemical analysis and after crushing to pass 150 mesh, extraction of magnetite with a hand magnet and removal of the light minerals by repeated bromoform separations, it was found that the resulting powder could be divided into two fractions by treatment with a strong electromagnet.

The magnetic fraction was a light straw color (gravity approx. 3.35). The non-magnetic powder was a pale green color (gravity about 3.25) and in the ratio non-magnetic to magnetic of about 8:3.

The lighter colored mineral was very weakly pleochroic with $X=$ colorless; $Y=$ pale yellowish; $Z=$ very pale greenish. Absorption $X<Y=Z$. Optics are:

$\alpha=1.663\pm.002$
$\beta=1.680$
$\gamma=1.696$
$\gamma-\alpha=\ .033$
$Z\wedge c=15\text{–}15\tfrac{1}{2}°$; $Y=b$. Optical character negative;
2V large (about 85°). Optic axial plane parallel to (010).
Dispersion not noticeable.

The above data indicate a grunerite near cummingtonite and probably containing approximately 65% $FeSiO_3$. Its optical properties appear fairly close to those of the Mt. Humbolt grunerite of Richarz and of the Cummington grunerite (Table 3), the principal difference being a slightly weaker birefringence.

A partial chemical analysis by G. L. Miles of the Department of Chemistry, University of Western Australia, gave the following:

$Fe_2O_3= 1.8$ %
$FeO =29.51$
$MnO = 1.6$
$MgO = 9.7$
$CaO = 1.7$
SiO_2 about 51%

Recalculated in terms of the molecular percentages of the four principal meta silicates—i.e. of Fe, Mn, Mg and Ca, this analysis gives:

$FeSiO_3$	58.2
$MnSiO_3$	3.2
$MgSiO_3$	34.4
$CaSiO_3$	4.2 (compare Table 3)

This indicates a grunerite very close to cummingtonite (i.e., 60% $FeSiO_3$) in which an appreciable amount of ferrous iron has been replaced by magnesium (compare with Tables 2 and 3). The Mt. Windarra mineral is distinctly higher in magnesia than the Meier's Find grunerite and in this respect more nearly approaches the Swedish Uttersvik mineral.

The darker green colored amphibole from Mt. Windarra differs from the lighter colored magnetic mineral principally in slightly stronger pleochroism and absorption colors, and in weaker refringence and birefringence. Approximate refractive indices determined were:

$\alpha=1.653\pm.002.$
$\gamma=1.673+$
$\gamma-\alpha=\ .020$; optical character negative;
$Z\wedge c=15\tfrac{1}{2}-16°$; $Y=b$.

These optical properties suggest an iron-rich actinolite, the principal discrepancy being a rather low value for the birefringence.

A partial analysis by G. L. Miles gave:

Fe_2O_3	1.0 %
FeO	19.10
MnO	0.63
MgO	7.38
CaO	5.95

This analysis bears out the optics and indicates an actinolite in which ferrous iron has replaced a portion of both the lime and the magnesia. As with the associated grunerite, the ferric iron content is low.

THE BLUE-GREEN AMPHIBOLE

Frequent mention has been made in the foregoing pages of the presence of a blue-green, strongly pleochroic amphibole associated with the grunerite in metamorphosed banded iron formations. This dark colored mineral is occasionally found moulded upon or growing in optical continuity with crystals of grunerite, though it more frequently occurs as small xenoblastic interstitial grains. In garnetiferous phases of the banded magnetite grunerite quartzites found at Clackline and near Mt. Palmer at Meier's Find and Heaney's Find (3 miles N.N.E. of Mt. Palmer), narrow bands rich in dark colored amphibole usually enclose clusters of dark red garnet, probably almandine. These bands probably represent thin clayey (aluminous) layers in the original ferruginous sediment.

This amphibole is jet black colored in mass. In thin sections it appears to have a form similar to the grunerite and usually occurs in subhedral plates showing perfect (110) cleavages, which in basal sections intersect at about 56° and 124°. Terminations on prismatic laths are usually irregular. The cross striation (001) on prismatic plates, so characteristic of the grunerite, is seldom seen. Simple twinning on (100) is uncommon and polysynthetic twinning is very rare.

Pleochroism is very strong; X = light green to yellowish-green; Y = dark olive green; Z = intense blue-green. The strong absorption masks interference colors, $Z \gtrequal Y > X$. Refractive indices of the mineral from Clackline gave:

$$\alpha = 1.673 \pm .002$$
$$\gamma = 1.701$$
$$\gamma - \alpha = .028$$
$$Z \wedge c = 21\text{–}22°;\ Y = b.$$

Optical character negative; 2V large (about 80°).

The strong blue-green color in amphiboles has been attributed to the presence of either appreciable quantities of iron in the ferric condition (8) (9) and (10), or of a considerable soda content.

To test these possibilities an attempt was made to isolate a small quantity of the blue-green amphibole from the heavy fraction of the Meier's Find grunerite described above. With the aid of a strong electromagnet it was found possible to remove most of the grunerite and magnetite leaving a fairly pure concentrate of blue-green amphibole. A micrometric analysis of the final product gave the following composition:

Blue-green amphibole 87.8%, grunerite 11%, magnetite (about) 0.5%, other minerals $<0.5\%$. Other minerals consisted of a few grains of quartz and zircon.

About .8 gram of the dark colored amphibole was so obtained. A partial analysis by G. L. Miles gave the following figures, after the necessary corrections for the impurities present had been made:

Fe_2O_3	8.7%
FeO	25.0
Na_2O+K_2O	< .1

The notable quantity of ferric iron and the almost total absence of soda confirm the opinion that the ferric iron is responsible for the strong blue-green coloration in this amphibole.

Finally, it may be of interest to note here that S. Richarz in 1927 recorded the presence of a variety of blue-green amphibole often found in parallel intergrowth with grunerite, in banded ferruginous amphibole-quartz rocks in the Lake Superior Region at Michigamme and Republic, Michigan (2, p. 154), and also from similar rocks in the Marquette District. According to Richarz this Lake Superior amphibole is strongly pleochroic with X=yellowish; Y=olive-green; and Z=blue-green, and has a birefringence about equal to that of common hornblende.

SUMMARY

In the foregoing pages a number of occurrences of the mineral grunerite in Western Australia have been described for the first time. Grunerite has been found only amongst the metamorphosed banded iron formations of the Older Greenstone Series of Western Australia. It has been formed as a result of the interaction of iron and silica during recrystallization of these rocks under conditions of both regional and contact thermal metamorphism. These metamorphosed banded iron formations in Western Australia appear very similar in mineralogical and chemical composition (and probably in origin) to the grunerite-bearing rocks of the Lake Superior Region.

The mineralogy, optical properties and chemical composition of several grunerites in Western Australia have been discussed in some detail, and a complete analysis and several partial analyses given. A brief description of a blue-green hornblende often associated with the grunerite in these rocks has also been added. The strong blue-green interference color displayed by this latter amphibole is shown to be due to a fairly high ferric iron content.

ACKNOWLEDGMENTS

The writer is much indebted to his brother, Mr. G. L. Miles of the Department of Chemistry, University of Western Australia, for his assistance in the preparation of a number of partial analyses included in the foregoing pages. He also thanks Dr. R. T. Prider of the Department of Geology, University of Western Australia, for many helpful discussions and suggestions during the determination of the optical data for this paper.

This work was carried out partly in the laboratories of the Geology Department, University of Western Australia, and partly in the Geological Survey of Western Australia, and the writer acknowledges his indebtedness to Professor E. de C. Clarke, and the Government Geologist, Mr. F. G. Forman, for making all facilities available to him.

Photographic reproductions of the text figures included in this paper were kindly prepared for him by Mr. H. J. Smith of the Geology Department, University of Western Australia.

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