

Hydrous cordierite with isotopically light oxygen from granulites, Strangways Range, Central Australia

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SUMMARY. Two new analyses of magnesian cordierites ($MgO \sim 12\%$) reveal about 1% by weight of H_2O+ , and one sample contains $15 \times 10^{-5} \text{ cm}^3 \text{ STP/gm}$ argon, which is twenty times in excess of argon expected for its age. Host granulites contain unexpectedly light oxygen, and three cordierites have $\delta^{18}O$ values of 2.0, 2.8, and 3.1 ‰ , respectively.

CORDIERITE is a common mineral in the quartz-rich granulites that make up a large proportion of the granulite terrane of the Strangways Range, about 70 km NE. of Alice Springs in the Pre-Cambrian Arunta Block of central Australia (fig. 1). The first granulite metamorphism (1860 Ma—Iyer, 1974; Iyer *et al.*, 1976) was synorogenic, and quartz and cordierite are commonly elongate and crystallographically oriented. Hypersthene and/or phlogopite are cogenetic minerals in many of these rocks.

Several later metamorphisms have affected the region, and it is common to find rocks in which the effects of two or more metamorphisms are obvious. A later granulite metamorphism (essentially thermal and metasomatic rather than dynamic) affected portions of the Strangways Range at about 1470 Ma (Iyer *et al.*, 1976), and several other episodes (including retrogressions) are being recorded (Woodford *et al.*, 1975; A. Allen, pers. comm.; Black, 1975).

The purpose of this short paper is to draw attention to some of the geochemical features of cordierites of the Strangways Range.

The cordierites of the hypersthene-cordierite-quartz granulites

Cordierites from hypersthene-cordierite-quartz granulites at Yambah and Woolonga (fig. 1) have been studied by Iyer (1974) and Woodford (1974), respectively, and details are being prepared for

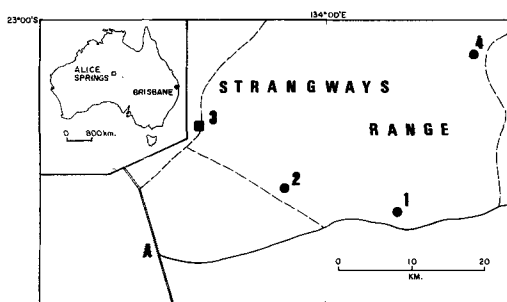


FIG. 1. Locality plan of the Strangways Range, central Australia, showing the location of Johannsen's Phlogopite Mine (1), Harry Creek Copper Prospect (2), Yambah Homestead (3), and Woolonga Bore (4). A is 43 km N. of Alice Springs.

publication. These granulites are taken to be highly metamorphosed magnesian or pelitic quartzites.

The cordierites from these granulites are very magnesian, with $100 \text{ Mg}/(\text{Mg} + \Sigma\text{Fe})$ commonly about 86. They are very similar to those described below from the large lensoid bodies. A probe analysis of a very similar cordierite from a hypersthene-cordierite-quartz granulite collected near Johannsen's Phlogopite Mine (fig. 1) has been published by Vernon (1975)—Table 1. It is very magnesian $100 \text{ Mg}/(\text{Mg} + \Sigma\text{Fe}) = 89.8$, and similar to the cordierites analysed by Woodford (1974) and Iyer (1974). Oxygen from a similar hypersthene-cordierite-quartz granulite (PM230) from the same locality has been studied isotopically. The oxygen of the 'whole rock' is very light, $^{18}O/^{16}O = 2.7 \text{ ‰}$ (Wilson and Baksi, in press). As the cordierite from this rock is the same optically as cordierite in the other hypersthene-cordierite-quartz granulites from Johannsen's Phlogopite Mine, its chemical composition should be close to those shown in Table 1.

TABLE I. *Chemical and physical data for cordierites from Strangways Range*

Sample	PM131	NT-17/252	PM86	PM131	NT-17/252	PM86
SiO ₂	50.18	50.86	49.49	Numbers of ions on anhydrous basis of 18 oxygens		
TiO ₂	tr	0.00	tr	Si 5.014	5.006	4.925
Al ₂ O ₃	33.14	34.66	34.73	P 0.005	—	6.000
Fe ₂ O ₃	0.09	—	0.04	Al ^{iv} 0.981	0.994	1.075
FeO	2.87	2.41†	3.10	Al ^{vi} 2.922	3.027	2.999
MnO	tr	0.00	—	Ti —	—	—
MgO	12.12	11.89	11.97	Fe ³⁺ 0.007	—	0.003
CaO	0.18	0.07	tr	Mg 1.805	1.744	1.775
Na ₂ O	0.27	0.08	0.01	Fe ²⁺ 0.240	0.198	0.258
K ₂ O	0.08	0.00	tr	Mn —	—	—
P ₂ O ₅	0.06	—	—	Ca 0.019	0.007	—
H ₂ O+	1.09	—	1.00	Na 0.052	0.015	0.002
H ₂ O-	0.04	—	tr	K 0.010	—	—
CO ₂	nil	—	nil			
Sum	100.12	99.97	100.33*	Mg value = 87.99	89.80	87.23
				$\gamma (\pm 0.002) = 1.542$	—	1.543
				$2V_{\alpha} = 95^{\circ}$	—	88^{\circ}

* Add traces (ppm) in PM86: Cr₄, Ti₅₈, V n.d., Co₇, Zn₉₀, Rb₃, Sr n.d., Zr₁₆₇, Pb₃, Cu₈, Ni₄. (n.d. = not detected.)

† Total Fe as FeO.

X-ray data			
Sample	PM131	PM86	H367
Cell <i>a</i>	9.733	9.721	9.733
Size <i>b</i>	17.006	17.050	17.036
Å <i>c</i>	9.332	9.336	9.336
Distortion index:			
Δ	0.25	0.255	0.255

Cordierites from large lensoid bodies within the granulite terrane

Johannsen's Phlogopite Mine. At Johannsen's Phlogopite Mine the hypersthene-cordierite-quartz granulites enclose a complex synform of very coarse-grained rocks containing a wide range of combinations of many minerals, some of which occur in several forms and compositions. The minerals recognized so far are: cordierite, orthopyroxene, clinopyroxene, olivine, anthophyllite, gedrite, phlogopite, biotite, chlorite, muscovite, microcline, orthoclase, anorthite, spinel, magnetite, sapphirine, pargasite, clinohumite, hōgbomite (Wilson, 1977), garnet, actinolite, corundum, staurolite, apatite, calcite, tourmaline, zircon, monazite, rutile, ilmenite, and sphene.

These minerals are grouped into several distinct parageneses, and at least five metamorphic episodes ranging from granulite to greenschist facies have been recognized. Papers describing these minerals and the various metamorphic episodes are in preparation.

The possibility is being investigated that these silica-deficient highly magnesian and aluminous rocks may represent relics of ancient soil horizons. Lenticular bodies of similar rocks, easily recognized by their distinctive mineral suites, have been

found in a similar stratigraphic position in several widely separated parts of the Strangways Range.

Sapphirine is developed in many cordierite-bearing rocks, and several new analyses of that mineral are being prepared for publication. An unusual sapphirine paragenesis has already been described (Hudson and Wilson, 1966).

Cordierite PM131 is a very pure sample free from alteration products and was prepared from an outcrop about 220 m SSE. from the main shaft (now abandoned). The host rock is a coarse polygonally textured rock in which sapphirine and a clear green spinel are important second metamorphism minerals.

The analysis, Table I, shows that this cordierite, which is cogenetic with the aluminous mineral bytownite, is slightly less aluminous than the other two analysed cordierites, whose host rocks contain little or no plagioclase. However, this cordierite has significantly higher trace amounts of Ca, Na, and K.

The formula for cordierite was calculated on an anhydrous basis of 18 (O), as in a normal procedure assuming that H₂O+ is fairly loosely held within the cyclosilicate channels. However, the H₂O+ is in fact tightly held, for the total dehydration did not take place until well above 1000 °C. It is interesting to note that both cordierites from Johannsen's

Phlogopite Mine contain about the same amount of tightly held water ($H_2O + = 1.09\%$ and 1.00% for PM131 and PM86, respectively). Facilities are unavailable to enable an appraisal of the relative importance of molecular H_2O and the replacement of oxygen by (OH), as was noted by Schreyer and Yoder, 1964. Until this can be done the formula for cordierites will continue to be written on an anhydrous basis.

Cordierite PM86 was collected from coarse-grained greasy pale-brown cordierite masses, which adjoin sapphirine-bearing spinel-bronzite-gedrite rocks. The cordierite masses are about 61 m SE. of the main shaft (now abandoned). As the cordierite masses are almost mono-mineralic, it is not difficult to prepare from a sample, such as PM86, a very pure mineral fraction that is completely free from alteration products, pleochroic haloes, and zircon inclusions. During mineral preparation small samples of phlogopite and calcic plagioclase ($\sim An_{90}$) cogenetic with the cordierite were prepared. Other accessories, and the alteration products along the edges of the coarse polygonal grains of cordierite, include a secondary orthoamphibole, kyanite, rutile, monazite, corundum, and ilmenite. Description of these is outside the scope of this paper, for it is believed that the analysed mineral separate of cordierite has not suffered chemically from these secondary metamorphic effects.

Chemically this cordierite PM86 is very similar to the others cited in Table I. CaO and K_2O occur as traces $< 0.01\%$, and the Fe is unusually reduced. Eleven trace elements were determined by W. Swiney using XRF methods. Zn (90 ppm) is high and consistent with high Zn values in many minerals in the Strangways Range (Wilson, 1977; Woodford and Wilson, 1976).

The X-ray diffraction data are set out in Table I. The cell size was determined from powder photographs and the distortion index (Δ) = 0.255 was measured from an expanded diffractogram. Both PM131 and PM86 are subdistortional cordierites, which are defined by Miyashiro (1957) as $0.29 > \Delta > 0$. The distortion indices of all three cordierites of Table I are identical.

Harry Creek copper prospect

A small copper prospect 16 km WNW. of Johannsen's Phlogopite Mine shows several petrological similarities to rocks in the vicinity of the mine (fig. 1). The most obvious differences between the two localities are: orthopyroxene is not common at this locality; sapphirine has not been found.

At the western end of the bold ridge of clino- and orthoamphibole rocks and gedrite-cordierite-quartzites there are masses of coarse-grained

brownish-grey cordierite and spinel-bronzite-gedrite rocks, which are remarkably like those of Johannsen's Phlogopite Mine.

Sample H367 is a portion of an almost mono-mineralic cordierite mass and it is similar in texture and mineralogy to sample PM86. The coarsely polygonal grains show 'fibrolitic' alteration products, which comprise mostly felted masses of gedrite and sillimanite (rather than kyanite, as at Johannsen's Phlogopite Mine). Tiny dusty particles of a black spinellid have exsolved throughout the cordierite. During mineral preparation a sample containing these dusty inclusions was prepared because it is assumed that this would closely correspond in bulk composition to the original cordierite prior to spinellid exsolution. The sample as finally prepared contained no hydrous alteration products.

A later metamorphic phase has caused the growth of rare, very small, staurolite grains (up to 0.2 mm long) in some cordierite grains. Discussion of the metamorphic and chronological significance of the staurolite, which is common in the more deformed granulites of the main range of mountains to the north, is outside the scope of this paper.

A chemical analysis of this cordierite was not undertaken, but optical properties of the material clear of exsolved spinellids suggest that this clear material now has an Mg value of ≈ 93 . However, the likely original cordierite would have been slightly more Fe-rich, i.e. Mg value ≈ 85 . The distortion index $\Delta = 0.255$ is identical to that of the cordierites from Johannsen's Phlogopite Mine (Table I).

Excess argon

Dr. D. C. Green analysed argon in cordierite sample PM131 by isotope dilution using a ^{38}Ar tracer and making the usual blank corrections. The amount of ^{40}Ar recorded, $15 \times 10^{-5} \text{ cm}^3 \text{STP/gm}$, is about twenty times in excess of argon that would be generated by the 0.08% K_2O of the cordierite, whose age is 1460 Ma, as inferred from Rb/Sr work on associated rocks (Iyer *et al.*, 1976). This quantity of argon in cordierite is consistent with the finding of excess argon elsewhere in the Strangways Range, where some phyllosilicates show $5.9 \times 10^{-5} \text{ cm}^3 \text{STP/gm } ^{40}Ar$ (Woodford *et al.*, 1976, p. 392). Very similar quantities of argon have been recorded in cordierites of comparable Precambrian ages by Damon and Kulp (1958) who found large excesses of Ar in some samples.

Abundant helium is also present in cordierite sample PM131. However, in the absence of a helium tracer, a quantitative measure was not possible. Damon and Kulp (*op. cit.*) record very much more He than Ar in cordierite.

Experimental isotope techniques

Oxygen was extracted by means of the bromine pentafluoride method described by Clayton and Mayeda (1963). Our procedures, however, differ from other laboratories in that no conversion to CO₂ is made, as has been reported in earlier papers (Wilson *et al.*, 1970; Wilson and Green, 1971). Our data are tied to SMOW by repeated analyses of NBS Quartz 28, which we are currently accepting to be $\delta = 9.5 \text{ }^0_{\text{00}}$ (Matsuhisa, 1974).

Results are reported as δ values, defined as:

$$\delta = 1000(R_{\text{sample}} - R_{\text{SMOW}})/R_{\text{SMOW}}$$

where $R_{\text{sample}} = {}^{18}\text{O}/{}^{16}\text{O}$ in the sample, and $R_{\text{SMOW}} = {}^{18}\text{O}/{}^{16}\text{O}$ in Standard Mean Ocean Water (Craig, 1957).

We found $\delta {}^{18}\text{O} \text{ }^0_{\text{00}}$ for PM86 1.97 (2 anals.); for PM230 2.79 ± 0.10 (8 anals.); for H367 3.11 ± 0.07 (2 anals.).

Significance of isotope data

The present study of the oxygen was exploratory, for there seem to be no other oxygen data for cordierite. The problem with oxygen isotope studies of cordierite is that ${}^{18}\text{O}/{}^{16}\text{O}$ values (as above) must represent a mixture composed of oxygen from the cyclosilicate structure itself as well as oxygen held within the channels of cyclosilicates as 'H₂O', CO₂, etc. As preliminary tests have shown that CO₂ is absent, it is assumed that no other oxygen-bearing phase other than H₂O is present in the channels of these cordierites.

The ${}^{18}\text{O}/{}^{16}\text{O}$ data show that these rocks contain unusually light oxygen. Cogenetic quartz, cordierite, and hypersthene from one of the rocks (PM230) combine to give a calculated 'whole-rock' ${}^{18}\text{O}/{}^{16}\text{O}$ value of $2.7 \text{ }^0_{\text{00}}$, whereas chemically similar metasediments on other continents commonly have much heavier oxygen with whole-rock values of $8\text{--}10 \text{ }^0_{\text{00}}$. A possible explanation for the light oxygen in these cordierite-bearing metasediments may involve high-latitude Precambrian meteoric waters that were heated by non-igneous means in deep aquifers long before their granulite facies metamorphism (Wilson and Baksi, in press).

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