

ADDITIONAL DATA ON FERROCARPHOLITE FROM
SULAWESI (CELEBES), INDONESIA

W. P. DE ROEVER, *Geological Institute, University of Amsterdam,
Nieuwe Prinsengracht 130, Amsterdam, The Netherlands*

AND

C. KIEFT, *Netherlands Organization for the Advancement of Pure
Research (Z.W.O.), Working Community for Analytical Chemical
Research of Minerals and Rocks (W.A.C.O.M.), c/o Free
University, Institute of Earth Sciences, De Boelleaan 1085,
Amsterdam-11, The Netherlands*

ABSTRACT

Four electron microprobe analyses are given of ferrocapholite, $(\text{Fe, Mg})\text{Al}_2(\text{OH})_4\text{Si}_2\text{O}_6$, a mineral chemically similar to chloritoid+quartz+water and probably a high-pressure/low-temperature equivalent of this assemblage in part of the glaucophane-schist facies and the lawsonite-albite facies. There is complete miscibility between divalent iron and magnesium in the range between the atomic ratios 0.82₅:0.16₅ and 0.55:0.43, with concomitant variation of the refractive indices and the optic axial angle.

INTRODUCTION

Ferrocapholite, $\text{FeAl}_2(\text{OH})_4\text{Si}_2\text{O}_6$, was first described by the senior author (W. P. de Roever, 1951). It is the ferrous iron analogue of carpholite proper, which contains manganese as the main divalent element. According to a crystal structure analysis by Caroline H. MacGillavry *et al.* (1956), ferrocapholite is an inosilicate with $(\text{SiO}_3)_n$ -chains very similar to those found in the pyroxenes.

In 1951 virtually manganese-free material with optic characteristics very near to those of carpholite was recognized in three samples collected in eastern central Sulawesi by the late Dr. W. H. Hetzel, member of the 1929 Celebes Expedition of the Netherlands Indies Geological Survey, and by its leader Prof. H. A. Brouwer. In the only sample that contained enough material for wet-chemical analysis according to conventional methods, the ferrocapholite appeared to be represented by a magnesian variety with the atomic ratio $\text{Fe}^{2+}:\text{Mg}:\text{Mn} = 0.79_5:0.20:0.00_5$; this sample (no. 15-161^x) was taken from a cobble of vein-quartz west of the village of Tomata (Fig. 1). Electron microprobe analyses of the ferrocapholite in the two other samples as well as of material erroneously described as carpholite in an earlier paper by W. P. de Roever (1947, p. 103-105), have now been performed by Kieft.

MODE OF OCCURRENCE

All three samples were taken from exposures of solid rock. In sample

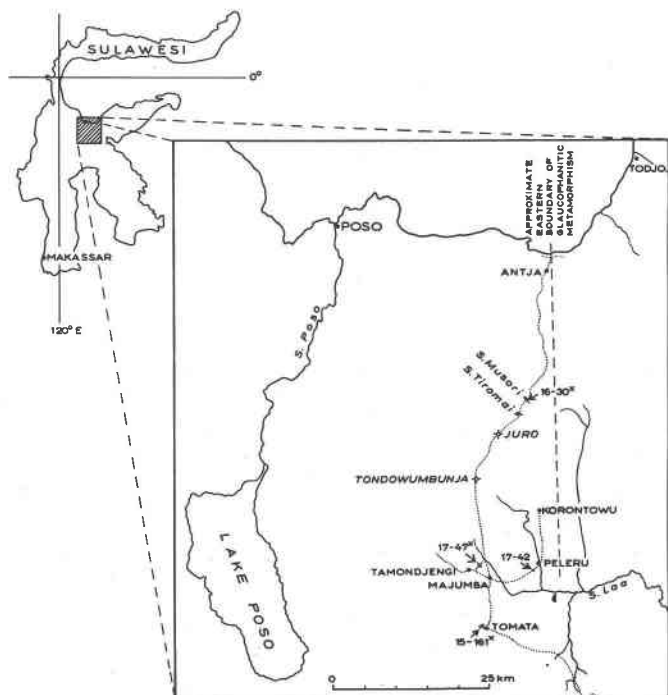


FIG. 1. Ferrocarcholite localities in Sulawesi, indicated by sample numbers.

17-47^x, a blastopsammitic sericite-quartzite collected east of Tamondjengi, north of the trail to Majumba, the mineral is also found in quartz-veins. In a metaconglomerate collected southwest of Peleru on the trail to Majumba (no. 17-42), it occurs as a rock-forming mineral in the mesostasis between the original pebbles, whereas in a blastopsammitic schistose ferrocarcholite-quartzite from the S. (Salo=river) Musori (no. 16-30^x) it is the main constituent of gray-green schistose layers alternating with layers colored red by hematite. All samples have been described rather elaborately in a previous paper by W. P. de Roever (1947, p. 103-111, 152-154).

Besides quartz, colorless mica, and hematite, the accompanying minerals are chlorite, leucoxene, rutile, tourmaline, zircon, and (?)biotite. The metamorphism shown by the rocks and causing the parallel arrangement of the ferrocarcholite crystals in sample 16-30^x is thought to be of Younger Mesozoic or Tertiary age, as it also affected radiolarian cherts and spilitic rocks considered to be of Mesozoic age. The main phase of this metamorphism was in the glaucophane-schist facies (Eskola's original nomenclature is preferred since common natural iron-bearing

glauco-phane requires considerable pressure for its formation, as lawsonite does, see de Roever, 1967; 1970). It could not be definitely determined whether the ferrocapholite was produced during metamorphism in this facies, or during slightly younger or older metamorphism in the green-schist facies, or in a facies characterized by the plentiful production of pumpellyite and actinolite apparently corresponding to Hashimoto's (1966) pumpellyite-actinolite-schist facies, or, more roughly, to the prehnite-pumpellyite-metagraywacke facies. According to its rather wide distribution (Fig. 1) and rather coarse grain-size, however, the ferrocapholite is most probably a product of metamorphism in the glaucophane-schist facies. Lawsonite, and jadeite accompanied by quartz (de Roever, 1955) have been found in a sample (no. 16-4^x) collected at a distance of a few kilometers from the ferrocapholite locality east of Tamondjengi. For the subfacies of the glaucophane-schist facies occurring in the area under consideration, which subfacies is characterized by the absence of epidote and garnet, the name lawsonite-glaucophane subfacies may be used (or lawsonite-glaucophanite subfacies as suggested by W. P. de Roever in 1947).

The only other part of the world where ferrocapholite has been found subsequently is Calabria, southern Italy (de Roever, de Roever, Beunk, and Lahaye, 1967). There the bulk of the mineral likewise occurs in quartz-bearing veins in an area also containing rocks with glaucophane, lawsonite, pumpellyite, aragonite, and jadeite (up to 80 percent Jd) associated with quartz, in the wider surroundings of Scalèa and between Scalèa and Mormanno (see also de Roever and Beunk, to be published). De Roever and Beunk came to the conclusion that the ferrocapholite of Calabria has been produced in part by metamorphism in the glaucophane-schist facies and in part by a metamorphism that may best be described in terms of Winkler's (1965) lawsonite-albite facies. A chemical analysis of a 98 percent-pure concentrate revealed a much larger proportion of magnesium, the atomic ratios $Fe^{2+}:Mg:Mn$ being 0.55:0.43:0.02.

In hand-specimen ferrocapholite resembles actinolite. Optically, however, it is rather easily recognized because of its parallel extinction and especially because of the tourmaline-like orientation of its pleochroism from yellow-green or green-yellow to very light blue-green or extremely light bluish green, with maximum absorption for vibrations normal to the elongation. It does not seem likely therefore, that the mineral has often been overlooked.

MICROPROBE ANALYSIS

Chemical analysis was performed with the aid of a Geoscan microprobe, with an accelerating potential of 20 kv. Standards used were wollastonite for Si, corundum, synthetic

TiO, Fe-metal, rhodonite for Mn, and olivine for Mg. For correcting mass-absorption and atomic number effects a modified version of the computer program of Springer (1967) was applied. In this modified program the mass-absorption coefficients of Heinrich (1966) are used. The Fe³⁺/Fe²⁺ ratio was determined by reducing the sum of the cation ratios, calculated on the basis of 8 O, to 5 and by compensating the resulting valence deficiency by assuming the presence of an appropriate amount of Fe³⁺. It is evident that inaccuracy of the analysis, especially in the Si-content, will result in errors in the Fe³⁺/Fe²⁺ ratio.

The results of four new electron-microprobe analyses are given in columns 1-4 of Table 1, together with the two previous analyses of ferrocapholite, made according to conventional methods (cols. 5 and 6).

All ferrocapholites hitherto analyzed contain an insignificant propor-

Table 1. Microprobe Analyses Of Ferrocapholite From Sulawesi Compared With The Other Analyses Of This Mineral

	Weight per cent				Atomic ratios						
	1	2	3	4	1	2	3	4	5	6	
SiO ₂	36.7	37.3 ₅	36.5	36.6 ₅	Si	1.99 ₅	2.02	2.00	2.03	2.03	2.01
Al ₂ O ₃	30.9	30.8	30.6 ₅	28.6 ₅	Al	1.98 ₅	1.96 ₅	1.98	1.87	1.87	1.90
TiO ₂	n.d.	<0.1	n.d.	n.d.	Ti					0.01	0.04
Total Fe as					Fe ³⁺	0.02	0.00 ₅	0.01 ₅	0.07	0.08 ₅	0.06
FeO	13.7	15.5	17.0	19.8	Fe ²⁺	0.60 ₅	0.69 ₅	0.76 ₅	0.85	0.81 ₅	0.57
MnO	0.2 ₅	0.1	0.3	0.2	Mn	0.01	0.00 ₅	0.01 ₅	0.01	0.00 ₅	0.02
MgO	4.7 ₅	3.9	2.7 ₅	2.0	Mg	0.38 ₅	0.31 ₅	0.22	0.17	0.20 ₅	0.45
Total	86.3	87.6 ₅	87.2	87.3	Total O	8	8	8	8		
γ		1	2	3	5						
		1.638	1.640	1.643	1.647						
β		1.633	1.636	1.639 - 1.640 (calc.)	1.644						
α		1.617	1.621	1.624	1.628						
2V _{oc}		60° - 61°	55° - 57°	51° - 52°	49°						
Birefringence		0.020-0.021	0.019	0.019	0.019 - 0.020						

1. Ferrocapholite, E of Tamondjengi, N of the trail to Majumba, eastern central Sulawesi, Indonesia, field number 17 - 47^x, museum number C 164, average of 9 measurements on 3 grains.
2. Ferrocapholite, SW of Feleru on the trail to Majumba, eastern central Sulawesi, Indonesia, field number 17 - 42, museum number B 3267, average of 5 measurements on 3 grains.
3. Ferrocapholite, S. Musori, on the trail from Mount Juro to Antja, N of the S. Tiramai, eastern central Sulawesi, Indonesia, field number 16 - 30^x, museum number C 141, average of 8 measurements on main mass of 3 grains. Optic constants determined by F. F. Beunk.
4. Extreme values obtained on narrow vein of no. 3 (inaccurate analysis due to bad measuring conditions within the vein).
5. Ferrocapholite, cobble W of Tomata, eastern central Sulawesi, Indonesia, field number 15 - 161^x, museum number C 98, wet-chemical analysis according to conventional methods by the 'Laboratorium voor Delfstoffenonderzoek van de Dienst van de Mijnbouw', Bandung (W. P. de Roever, 1951).
6. Ferrocapholite concentrate, about 98% pure, large block in tributary of T. Saracena near San Nicola Arcella, N of Scalba, province of Cosenza, southern Italy (R 164), wet-chemical analysis according to conventional methods by F. H. J. Lahaye (W. P. de Roever *et al.*, 1967).

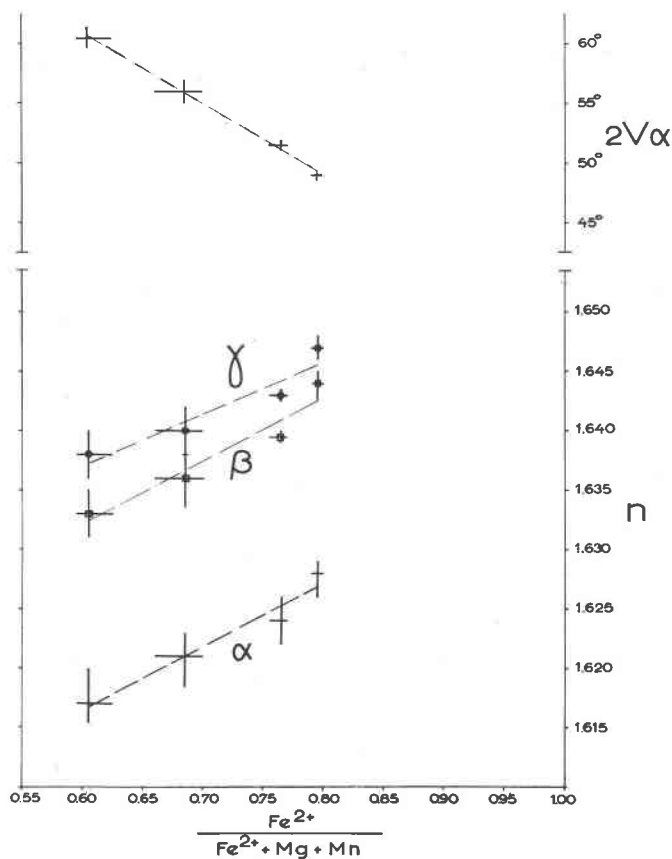


FIG. 2. Variation of refractive indices and optic axial angle with atomic ratio $Fe^{2+}:(Fe^{2+}+Mg+Mn)$, ferrocapholite from Sulawesi, Indonesia.

tion of Mn, the main variable being the ratio of divalent iron to magnesium. In carpholite proper, on the other hand, manganese is strongly dominant over either iron or magnesium. The results of the analyses indicate that ferrocapholite shows complete miscibility of divalent iron and magnesium in the range between the atomic ratios $0.82_5:0.16_5$ and $0.55:0.43$.

RELATION OF OPTICAL PROPERTIES TO CHEMICAL COMPOSITION

The refractive indices as well as the optic axial angle show a rather regular variation with the chemical composition as illustrated by Figure 2. An increase in the $Fe^{2+}:Mg$ ratio results in a gradual increase of the principal indices of refraction, and in a concomitant decrease of the optic

axial angle. In magnesium-rich ferrocapholites from Calabria currently being investigated by F. F. Beunk, however, the optic axial angle seems to be rather consistently 5° – 10° lower than indicated in the diagram for the ferrocapholite from Sulawesi (oral communication).

RELATION TO CHLORITOID

In view of the chemical similarity between ferrocapholite and chloritoid already recorded by W. P. de Roever *et al.* (1967) and illustrated by the equation



the ranges of substitution in ferrocapholite may be compared with those in chloritoid described by Halferdahl (1961) (Table 2). The sim-

TABLE 2. RANGES OF SUBSTITUTION IN FERROCARPHOLITE AND CHLORITOID

Substitution	Ranges in percent	
	Ferrocapholite	Chloritoid
Mg for Fe ²⁺	16 ₅ –43	0–42
Mn for Fe ²⁺	0 – 2	0–17
Fe ³⁺ for Al	3 – 4	0–14

ilarity between these ranges indicates that this reaction may indeed occur in nature. In this respect it is interesting to note that Fischer (1929) concluded that carpholite from the Harz Mountains was formed at the expense of ottrelite (see also Mügge, 1918).

Whereas ferrocapholite is found in rocks showing a comparatively low grade of metamorphism, chloritoid both in Sulawesi (W. P. de Roever, 1956) and in Calabria seems to be restricted to slightly higher-grade rocks, which would suggest that ferrocapholite is a low-grade equivalent of chloritoid (E. W. F. de Roever and Beunk, to be published). In view of the wide range of temperatures found for the formation of rocks of the glaucophane-schist facies by Taylor and Coleman (1968) with the aid of the $\text{O}^{18}/\text{O}^{16}$ method—which implies that part of the glaucophane-schist facies is a high-pressure equivalent of the greenschist facies—it seems safer, however, to restrict our conclusion to the statement that ferrocapholite is probably a high-pressure/low-temperature equivalent of chloritoid + quartz + water.

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