NOTES

CORRENSITE OF HYDROTHERMAL ORIGIN FROM VEITSIVAARA, EASTERN FINLAND

Corrensite was identified in a drill core sample from Veitsivaara in Hyrynsalmi, eastern Finland (see Figure 1). It occurs as a green material coexisting with calcite and filling a thin (~0.5 mm) fracture.

According to Bailey (1982) and Reynolds (1988), corrensite is a mixed-layer chlorite having ordered (Rl) interstratification and either a trioctahedral chlorite/vermiculite or chlorite/smectite 1:1 composition. Corrensite has been reported from a variety of geologic environments (Velde, 1977) including magmatic rocks and metamorphic rocks above the chlorite zone of regional metamorphism (Reynolds, 1988). Most reports, however, are of corrensite occurrences in diagenetic sedimentary environments (Furbish, 1975).

This is the first reported occurrence of corrensite from Finland. The present paper gives the results of several different analytical methods carried out on this material in an effort to correlate mineral structure and compositional parameters. The genesis of the corrensite is also discussed.

MATERIAL AND GEOLOGICAL SETTING

A drill core sample from 450.3 m depth of a corrensite-calcite vein crosscutting gray migmatite in Veitsivaara, Hyrynsalmi, eastern Finland, was collected for this study. The corrensite occurs as a thin layer on the vein walls, whereas calcite is mainly concentrated in the interior of the vein (Figure 2). Spherulitic textures, previously described in corrensite by Blatter *et al.* (1973), are present in the fine-grained matrix. The material studied was hand-picked under a stereomicroscope. Unfortunately a small amount of calcite could not be excluded.

In the Veitsivaara area the bedrock consists of late Archean banded and folded tonalite or trondhjemite containing relicts and inclusions of amphibolite (Luukkonen, 1987). Small exposures of granite porphyry, pegmatite granite, and metadiabase dikes are also present. About 1 km from the sampling site, the bedrock is intruded by a post-orogenic potassium granite stock, 6 km in diameter.

METHODS

X-ray powder diffraction (XRD) studies were made with a Philips wide-angle goniometer using Ni-filtered Cu radiation. Samples were prepared by grinding in acetone and then smeared onto a glass slide. The samples were then treated with ethylene glycol. The calcite in the samples was used as an internal standard after calibration against silicon. The 2θ range from $2°$ to $70°$ was scanned. Unit-cell dimensions and standard errors were calculated using the Appleman-Evans program revised by Benoit (1987). The coefficient of variation (CV) was calculated according to Bailey (1982).

A Perkin-Elmer 983 G infrared (IR) spectrophotometer was used. The KBr disc technique (1.5 corrensite/175 mg KBr) was used, and the transmittance was recorded between wavenumbers 4000 and 180 cm^{-1}.

Microprobe analyses of corrensite in a polished section were made with a JEOL Superprobe 733 using an accelerating voltage of 15 kV and a sample current of 20 nA. A beam diameter of 10 μm was used because of sample heterogeneity.

RESULTS AND DISCUSSION

Optical properties

The mineral was colorless in thin section and had no pleochroism. The mean index of refraction obtained with the immersion method was 1.56. Using the Michael-Levy chart, the birefringence was estimated to be <0.008.

XRD studies

The results of the XRD studies are presented in Table 1 and Figure 3. The superstructure d(001) spacing in the air-dried specimen expanded from 29.3 Å to 30.9 å on ethylene-glycol solvation. Heating the sample at 550°C for 1 hr caused the spacing to collapse to 23.8 Å.

The XRD pattern was similar to the corrensite pat-

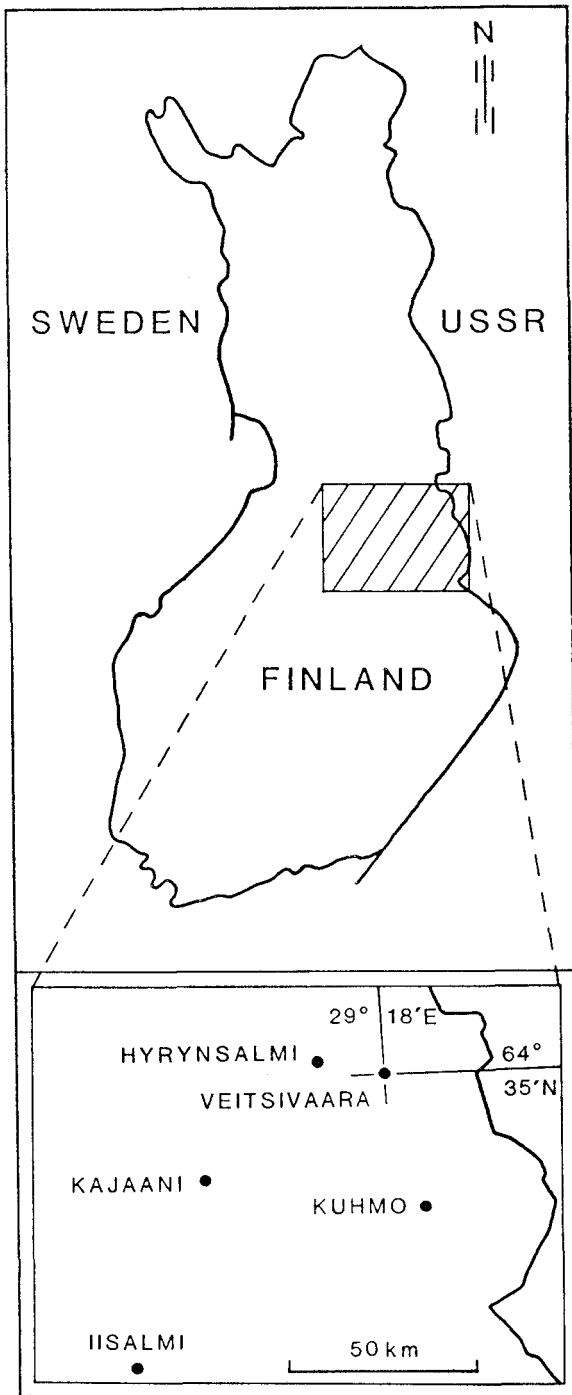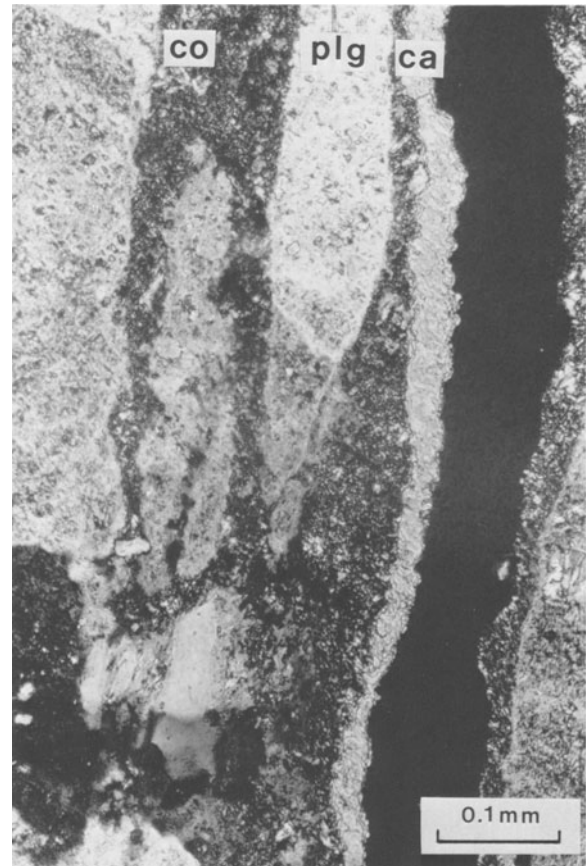Figure 1.   Location map of Veitsivaara, Finland.

Figure 2.   Thin section photomicrograph of fracture filling in core, Veitsivaara, eastern Finland. co = corrensite, plg = plagioclase, ca = calcite. Crossed polarizers.

Infrared studies

The IR-absorption spectrum is presented in Figure 4. In the OH-stretching region two strong bands are present, one at 3567 and the other at 3416 cm^{-1}. Weak-

tern listed on JCPDS file card 31-794 (JCPDS, 1986). An orthorhombic cell was chosen in accordance with this. The XRD data were in agreement with the criteria described by Wilson (1987). The 060 reflection at 1.537 Å confirmed a trioctahedral composition (Morrison and Parry, 1986).
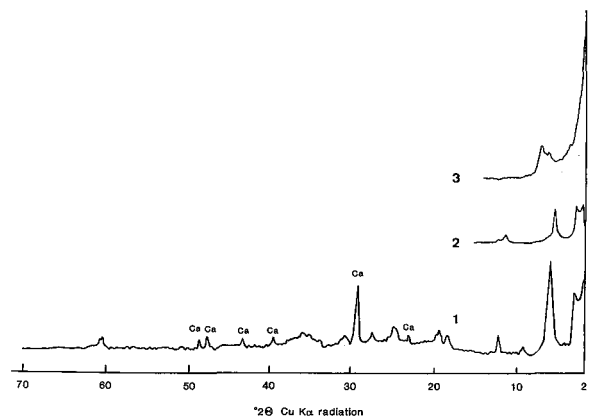

Figure 3.   X-ray powder diffraction pattern of corrensite from Veitsivaara; 1 = air-dried sample, 2 = ethylene-glycol treated sample, 3 = heated sample. Ca = calcite.

Table 1. X-ray powder diffraction data on corrensite from Veitsivaara.

h	k	l	Air dried			Ethylene-glycol treated	
			I	d_{obs} (Å)	d_{calc} (Å)	I	d_{obs} (Å)
0	0	1	30	29.26	29.12	100	30.90
0	0	2	100	14.54	14.56	100	15.20
0	0	3	5	9.64	9.71		
0	0	4	15	7.225	7.279	20	7.668
0	0	6	10	4.817	4.853	10	5.121
0	2	0	10	4.572	4.611		
0	0	8	10	3.603	3.640		
0	0	9	5	3.241	3.235	20	3.430
0	0	10	5	2.925	2.912		
0	6	0	10	1.537	1.537		
3	3	0	10	1.537	1.537		

Direct orthorhombic cell
$a = 5.322 \pm 0.002$ Å
$b = 9.222 \pm 0.002$ Å
$c = 29.12 \pm 0.07$ Å
$V = 1430.0 \pm 4.6$ Å^3
$CV^1 = 0.60$ $CV = 0.27$

[1] CV = calculated coefficient of variation.

er bands are present at 1638 and 1425 cm⁻¹. A main absorption at 1005 cm⁻¹ has a small shoulder at 875 cm⁻¹. Very weak shoulders are present at 820 and 760 cm⁻¹. Notable bands are also present at 673, 450, and 382 cm⁻¹.

The bands at 1425 and 875 cm⁻¹ are from the calcite impurity. The bands at 3567 and 3416 cm⁻¹ are attributed to OH groups in the hydroxide layer of chlorite in accordance with Bergaya *et al.* (1985). Hayashi and Oinuma (1967) reported trioctahedral chlorites to have two broad bands in the OH region, one at 3586–3560 cm⁻¹ and the other at 3436–3400 cm⁻¹. Bergaya *et al.* (1985) also obtained an additional band at 3685 cm⁻¹, which they attributed to OH groups in the silicate layers. Hayashi and Oinuma (1967) observed an absorption band at 3683 cm⁻¹ in Mg-chlorite, which they assigned to OH in talc layers in the chlorite structure. The corrensite of the present study showed no absorption bands near 3680 cm⁻¹. The band at 1638 cm⁻¹ was assigned to water-deformation according to Bergaya *et al.* (1985). Bands near 820 and 760 cm⁻¹ in
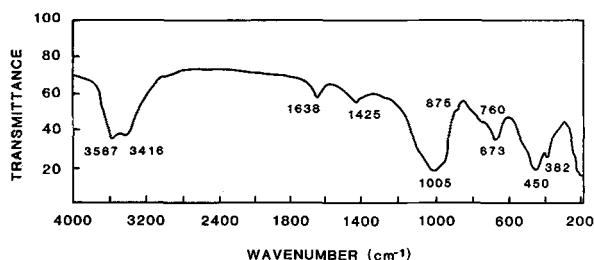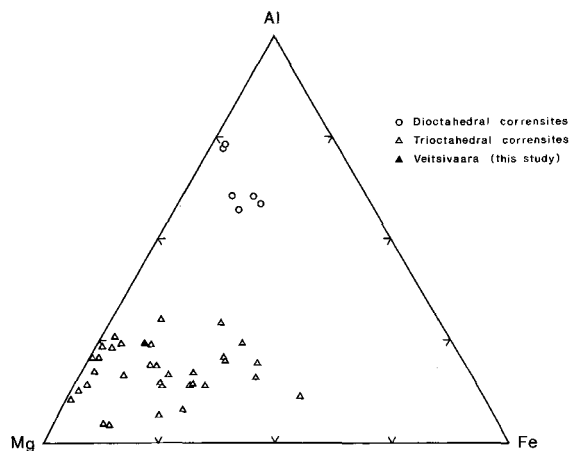
Figure 5. Triangular plot of octahedral occupancy for corrensite from Veitsivaara and data from Brigatti and Poppi (1984a) and Morrison and Parry (1986).

trioctahedral chlorites are associated with tetrahedral Al–O vibrations and increase in intensity with increasing Al-for-Si substitution (Farmer, 1974). The Veitsivaara corrensite showed only a diffuse shoulder at 820 cm⁻¹ and a weak shoulder at 760 cm⁻¹, indicating only a limited amount of Al-for-Si substitution. Additionally, Farmer (1974) reported that the band at 820 cm⁻¹ is lost as the Fe^{2+} content increases. The near absence of this band in the present study would thus indicate both a limited Al-for-Si substitution and the existence of Fe in the sample as Fe^{2+}. Hayashi and Oinuma (1965) found that the wavenumber of the Si–O absorption in the region 620–692 cm⁻¹ decreases with increasing Mg and Fe in octahedral position. The wavenumber of this band for the Veitsivaara sample, 673 cm⁻¹, indicates only a small amount of octahedral Mg and Fe, in agreement with the calculated octahedral site occupancy
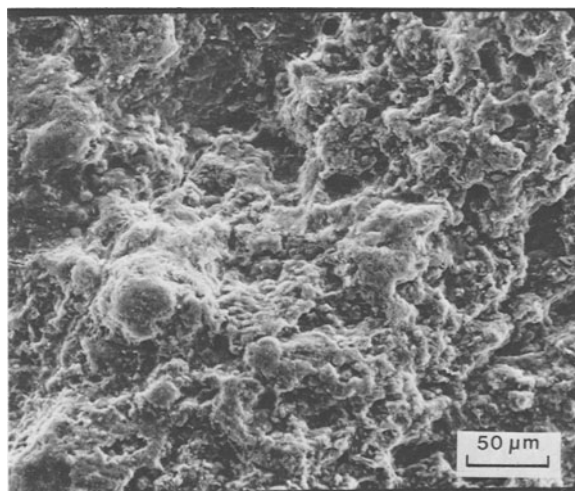
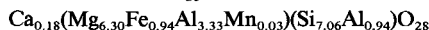Figure 4. Infrared spectrum of corrensite from Veitsivaara. KBr-disc technique (1.5 mg of corrensite/175 mg KBr).

Figure 6. Scanning electron micrograph of corrensite from Veitsivaara, Finland.

Table 2. Electron microprobe analyses of corrensite from Veitsivaara.[1]

Analysis	SiO₂	TiO₂	Al₂O₃	FeO[2]	MnO	MgO	CaO	Na₂O	K₂O	Sum
1	39.26	0.03	22.22	5.24	0.09	21.06	1.05	0.04	0.06	89.05
2	37.95	0.00	19.02	6.76	0.23	21.83	1.18	0.01	0.10	87.08
3	38.06	0.00	20.63	6.63	0.21	22.97	0.94	0.04	0.04	89.52
4	37.28	0.00	15.03	4.29	0.14	27.58	0.72	0.03	0.04	85.11
5	34.87	0.00	17.82	9.36	0.35	23.33	0.60	0.02	0.02	86.37
6	39.97	0.01	22.23	4.12	0.11	19.35	0.90	0.04	0.02	86.75
Average	37.90	0.01	19.49	6.07	0.19	22.69	0.90	0.03	0.05	87.31

Formula based on $O_{20}(OH)_{10}$:

$Ca_{0.16}(Mg_{5.62}Fe_{0.84}Al_{2.12}Mn_{0.03})(Si_{6.30}Al_{1.70})O_{20}(OH)_{10}$

Formula based on O_{28}:
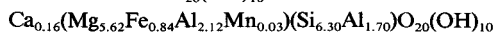
$Ca_{0.18}(Mg_{6.30}Fe_{0.94}Al_{3.33}Mn_{0.03})(Si_{7.06}Al_{0.94})O_{28}$

[1] Analyst = B. Johanson.
[2] $FeO = Fe_{tot}$.

(Figure 5). The bands at 1005 and 450 cm⁻¹ were generally assigned to Si–O stretching and Si–O bending vibrations.

Electron microprobe analysis

The corrensite had a flaky habit, as seen in the scanning electron micrograph (Figure 6). Representative microprobe analyses are listed in Table 2. An averaged analysis is thought to describe the material best, and therefore it has been used in the formula calculations. For the purpose of comparison, mineral formulas were calculated on the basis of $O_{20}OH_{10}$ (Brigatti and Poppi, 1984a; Morrison and Parry, 1986) and O_{28} (Bettison and Schiffman, 1988; Dudoignon *et al.*, 1988). Table 2 shows variation among multiple analyses. In particular, the Al_2O_3, FeO, MgO, and CaO contents vary markedly, possibly due to the calcite impurity; however, a rough positive CaO-SiO₂ covariation (Table 2)
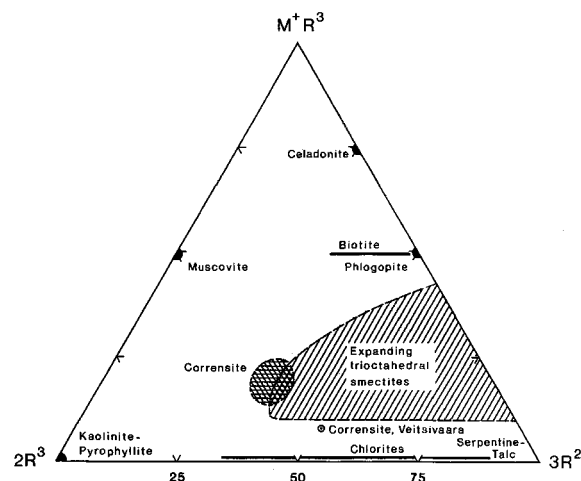

Figure 7. Velde diagram showing corrensite from Veitsivaara compared to other phyllosilicates (Velde, 1985) and corrensite samples (Dudoignon *et al.*, 1988). $M^+R^3 = Na + K + 2Ca$, $2R^3 = (Al-M^+R^3)/2$, $3R^2 = (Mg + Fe)/3$ (in atomic proportions, normalized to 1).

argues against major calcite contamination and, suggests instead, a small degree of corrensite heterogeneity.

Calcium substitution in chlorite structure is limited. A value >0.10 Ca/28 oxygens indicates the presence of a smectite component (Bettison and Schiffman, 1988). The value of 0.18 obtained for the Veitsivaara corrensite, thus, indicates a smectite component. Figure 5 shows the octahedral population of the Veitsivaara corrensite compared with data from other studies (Brigatti and Poppi, 1984a; Morrison and Parry, 1986). The Veitsivaara corrensite falls within the trioctahedral field and contains only a small amount of Mg and Fe; this was also shown in the IR studies. In trioctahedral corrensite, Al constitutes <30% of the octahedral sites, and Fe/(Fe + Mg) < 0.5 (Brigatti and Poppi, 1984a).

The Veitsivaara corrensite is plotted in Figure 7 on a Velde diagram (Velde, 1985) and comparison with other phyllosilicate minerals from Velde (1985) and eight corrensite samples from Dudoignon *et al.* (1988). The Veitsivaara corrensite plots between the chlorite field and the field of expanding trioctahedral smectites, closer to the 3R²-corner compared, with corrensite studied by Dudoignon *et al.* (1988). Relative to other trioctahedral corrensites, the Veitsivaara sample is relatively poor in Mg + Fe (Figure 5); however, Figure 7 shows that the Veitsivaara corrensite contains more Mg + Fe than those analyses in the corrensite field of Dudoignon *et al.* (1988). This suggests that the corrensite samples of Dudoignon *et al.* (1988) are dioctahedral, which have octahedral Al/(Al + Fe + Mg) > 0.3 (Brigatti and Poppi, 1984a).

Origin and temperature of formation

The corrensite of the present study probably formed during interaction of a relatively Fe- and Mg-rich hydrothermal fluid with the wall-rock. High Mg- and Fe-contents of the fluid may have originated from interaction with metadiabase dikes at elevated temperatures.

Chamley (1989), in his description of hydrothermal fracture fillings and wall-rock minerals, lists corrensite among the minerals formed by interaction of hydrothermal fluids with host rocks. The mineral grains of the wall rock in the present study are locally corroded and commonly occur within the corrensite matrix (see Figure 2), suggesting interaction between a hydrothermal fluid and the wall rock. Alteration products of ophiolitic rocks commonly contain corrensite; here the wall-rock material supplied the Mg, Fe, and Al necessary to form corrensite (Brigatti and Poppi, 1984b). The wall-rock minerals in Veitsivaara could not have supplied the Mg and Fe needed. Parneix *et al.* (1985), in their study on alteration of biotite to chlorite in altered granites, concluded that Mg and Fe needed for the alteration must have been supplied by hydrothermal fluids. This is thought to apply also for the Veitsivaara corrensite. The temperature of formation of the Veitsivaara corrensite is estimated at 100°–250 °C. Velde (1985) found the temperature of formation of hydrothermal corrensite to be 100°–250°C. Calcite coexisting with corrensite probably was the last precipitate of the hydrothermal fluid. The unit-cell volume of this calcite is 367.1 ± 0.7 Å^3 and the a axis is 4.994 ± 0.004 Å, giving a calcite temperature of formation $\leq 100°C$ (Carlson, 1983). The Veitsivaara corrensite undoubtedly formed at a higher temperature.

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