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NOTE

CLINOCHLORE FROM THE SILVER STAR DISTRICT, MADISON COUNTY, MONTANA

Key Words—Chemical analysis, Chlorite, Clinochlore, Hydrothermal vein, Sericite.

Almost monomineralic clinochlore is mined at the Golden Antler mine, about 40 km southeast of Butte, Montana, in the Silver Star district, a district where gold, silver, copper, and lead were formerly mined. The chlorite mine is in the SW¼ sec. 14, T2S, R6W, in Madison County and is leased by Cyprus Industrial Minerals Company. The author identified clinochlore from this deposit in 1975, and open-pit mining on a small scale began in 1977 (Berg, 1983). The light-colored and high-grade nature of the clinochlore from this deposit allows it to be used in some of the same applications as talc. The present note reports the physical and chemical properties of this unusual chlorite mineral.

GEOLOGY OF THE DEPOSIT

At the Golden Antler mine, near-vertical clinochlore veins strike north–south and range in thickness from several centimeters to approximately 10 m. These veins are near the southeast edge of the Silver Star mining district, about 1 km southeast of the closest of the metalliferous veins. The host rock for the clinochlore veins and most of the metalliferous veins is quartzofeldspathic gneiss of Archean age which is in fault contact with Paleozoic sedimentary rocks to the northeast. The Rader Creek pluton of the Cretaceous-age Boulder batholith has intruded the Paleozoic units about 3 km northeast of the Golden Antler mine; the Hell Canyon pluton, also considered to be part of the Boulder batholith, has intruded the Archean metamorphic rocks about 3 km southwest of the mine. The clinochlore veins are perpendicular to the foliation of the quartzofeldspathic gneiss, which has an east–west strike and near vertical dip.

The average modal composition of 13 specimens of unaltered quartzofeldspathic gneiss collected at this deposit is: quartz, 26.5%; oligoclase, 65.7%; K-feldspar, 2.6%; biotite, 5.0%; magnetite, 0.2%; and zircon and apatite in trace concentrations. In the poorly defined zone of propylitic alteration surrounding the chlorite veins, oligoclase in the gneiss has altered to albite with the formation of clinozoisite, and biotite has altered to chlorite with the formation of rutile. A zone of sericitic alteration surrounds the clinochlore veins and extends outward for a distance typically at least equal to their exposed widths. In this zone, replacement of feldspar by sericite and of biotite by chlorite has produced a white rock. Rutile is a trace constituent of this rock. Within a few centimeters of the clinochlore vein, chlorite has replaced the sericite forming a rock composed mainly of clinochlore and quartz. The relatively sharp contact between the zone of sericitic alteration and the pale green clinochlore vein is generally gradational over a distance less than 1 cm. In thin section small veinlets of clinochlore can be seen extending into quartz grains. There is no evidence of introduced quartz in the zone of sericitic alteration.

MATERIALS AND METHODS

Analyses were performed on representative samples of clinochlore collected from the Golden Antler mine. The scanning electron micrograph was taken by R. B. Hall, U.S. Geological Survey, Denver, Colorado, using a Cambridge Stereoscan Model 180 instrument.

Samples were ground by hand and loosely packed in metal sample holders for X-ray powder diffraction (XRD) analyses using a Norelco wide-range goniometer equipped with a AMR 3-202 focusing monochromator. Estimates of peak intensities were made from a trace scanned at 1°2θ/min using Ni-filtered CuKα radiation from a fine-focus tube with 1° divergence and receiving slits. Peak intensities were estimated from peak areas computed using a digital processor.

The metal oxide analyses were obtained using an Applied Research Laboratories 3400 induction-coupled, argon-plasma emission spectrometer to analyze

Figure 1. Scanning electron micrograph of clinochlore from Silver Star District, Montana, taken by R. B. Hall, U.S. Geological Survey, Denver, Colorado.

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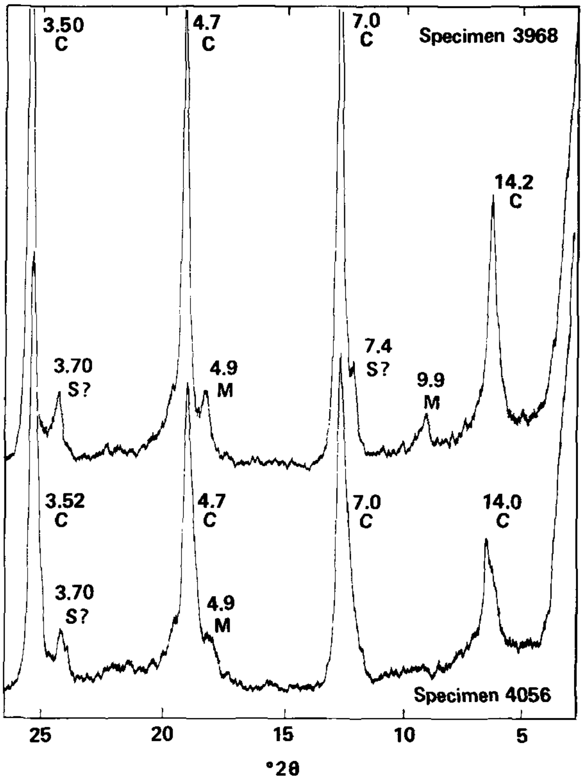

Figure 2. X-ray powder diffraction patterns of clinochlore specimens 3968 and 4056; CuKα radiation; scan rate = 2°2θ/min. C = clinochlore, M = mica, S? = probably serpentine.

solutions prepared from lithium meta-borate fusions of the pulverized samples. Ferrous iron was determined by a modification of the procedure described by Maxwell (1968, p. 417). Total water was determined by the Penfield method (Hillebrand *et al.*, 1953, pp. 827–828). H_2O- was determined by drying 1 g of sample at 105°C for 1.5 hr; H_2O+ was calculated from the difference between total water and H_2O- values. All chemical analyses were performed by the Analytical Division, Montana Bureau of Mines and Geology.

CLINOCHLORE

The veins consist essentially of clinochlore, greenish gray (5G 6/1) in hand specimen, but almost colorless when examined with a hand lens on a freshly broken surface. Rutile, zircon, and limonite are trace constituents. An unidentified anisotropic mineral with very low birefringence and average index of refraction of about 1.48 is a trace constituent recognized only in thin section. This mineral may be a zeolite. Most of the clinochlore is very fine grained (less than 2 μm) and is cut by microveinlets containing individual crystals as long as 0.1 mm (Figure 1). The average index of refraction of individual grains of clinochlore is 1.583 ± 0.003.

XRD analysis of samples from this deposit confirm

Table 1. X-ray powder diffraction data for chlorites.

	1		2	
(hk*l*)	d (Å)	I/I_0	d (Å)	I/I_0
001	14.00	42	14.15	8
002	7.0	100	7.05	10
003	4.72	74	4.72	6
02,11	4.58	8	4.60	2
004	3.52	80	3.54	10
005	2.84	21	2.83	4
$20\bar{1}$	2.66	7	2.66	1½
$20\bar{2}$	2.58	17	2.59	5
201	2.54	44	2.54	8
$20\bar{3}$	2.44	30	2.44	7
202	2.38	14	2.38	4
$20\bar{4}$	2.24	12	2.255	4
$20\bar{5}$	2.07	2	2.06	1½
007	2.025	5	—	
204	2.000	28	2.00	6
$20\bar{6}$	1.880	10	1.88	2½
205	1.823	9	1.82	2½
15,24,31	—		1.74	1
207	—		1.715	½
206	1.66	4	1.66	1½
$20\bar{8}$	1.567	27	1.565	3
060	1.538	29	1.538	7
062	1.500	9	1.503	2½
063	1.45	5	1.462	½
00,10; 064	—		1.414	1
208	1.394	20	1.392	2½

1. Golden Antler mine clinochlore, sample 4056 loosely packed in sample holder; quartz used for calibration.
2. IIb chlorite from Buck Creek, North Carolina (Brown and Bailey, 1962, p. 839).

Table 2. Chemical analyses of clinochlore from Montana and California.

	Specimen				
	3968	4056	1451	3316-6	38
SiO_2	29.79	29.93	31.54	32.41	30.5
TiO_2	0.21	0.22	1.47	n.d.	n.d.
Al_2O_3	22.03	21.83	18.59	18.16	17.3
Fe_2O_3	1.03	0.78	0.74	0.61	2.9
FeO	1.95	2.55	3.74	6.16	6.1
MnO	0.07	0.08	n.d.	n.d.	n.d.
MgO	29.49	29.80	31.70	31.24	32.8
CaO	0.09	0.11	0.17	0.04	n.d.
Na_2O	0.09	0.03	0.01	0.01	n.d.
K_2O	0.16	<0.01	0.02	0.01	n.d.
P_2O_5	0.05	<0.05	n.d.	n.d.	n.d.
H_2O+	13.6	13.5	12.16	12.73	11.5
H_2O-	0.04	<0.01	0.62	0.31	0.8
Total	98.60	98.99	100.76	101.68	101.9

Analyses of samples 3968 and 4056 (Golden Antler mine) performed by the Analytical Division, Montana Bureau of Mines and Geology. Samples 1451 and 3316-6 = clinochlores associated with talc in southwestern Montana (Berg, 1979, p. 8). Sample 38 = clinochlore from the Taft Hill area, California (Post and Plummer, 1972, p. 279).

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the high concentration of a chlorite, with mica being the most commonly identified additional constituent (Figure 2). Small flakes of colorless mica can be recognized in a thin section of specimen 3968.

Both specimens 3968 and 4056 appear to contain a serpentine-group mineral in low concentration as suggested by the 7.4- and 3.7-Å peaks in the XRD patterns. Although grain mounts and thin sections were searched for serpentine-group minerals, none were detected indicating that if in fact serpentine is present in these specimens, it must be one of the platy varieties easily confused with a fine-grained chlorite. Clinochlore from this deposit is of the IIB polytype reported to be typical of metamorphic rocks and medium and high temperature veins (Brown and Bailey, 1962, p. 845). XRD data for a sample of clinochlore from the Golden Antler deposit are presented in Table 1.

Chemical analyses of two representative specimens from this deposit are given in Table 2. Analyses of two slightly more Mg-rich specimens of clinochlore associated with talc deposits in southwestern Montana are included for comparison, as is an analysis of clinochlore from the Flagstaff Hill area of California (Post and Plummer, 1972, p. 279). The higher K_2O content reported in specimen 3968 can be attributed to the mica (sericite?) found in this specimen. Because of the higher purity of specimen 4056, a structural formula was calculated from the analysis of this specimen. The TiO_2 reported in these analyses is attributed to rutile recognized in thin section and is not included in the calculation. The half-cell structural formula as calculated by the method of Foster (1962, pp. A-2 to A-3) follows:

$$(Al_{1.35}Fe^{3+}_{0.06}Fe^{2+}_{0.02}Mg_{4.27})(Al_{1.13}Si_{2.87})O_{10}(OH)_8$$

Following the nomenclature of Bayliss (1975), this chlorite would be considered to be clinochlore.

Samples of clinochlore from this deposit may be obtained from the author.

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