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IRON-RICH SERPENTINE AND CHAMOSITE FROM ELY, MINNESOTA

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ABSTRACT

Hydrothermal alteration of a femic igneous intrusive near Ely, Minnesota, has resulted in formation of an unusual assemblage of three iron-rich minerals. These minerals have been studied by means of Debye-Scherrer powder photographs, flat film fiber photographs, and chemical tests and have been determined to consist of clinochrysotile, antigorite, and a one-layered orthogonal mineral similar to lizardite and chamosite in *x*-ray patterns. This mineral is considered to be chamosite in this paper. Partial chemical analyses show that all three minerals are iron-rich. The considerable differences in d spacings and unit cell dimensions between these minerals and those previously published are attributed to high iron content.

Field and microscopic relationships show that antigorite formed during two stages, before and after formation of clinochrysotile. The relative time of chamosite formation could not be determined because no cross-cutting relationships were found.

INTRODUCTION

Hydrothermal alteration of an igneous intrusive near Ely, Minnesota, has resulted in the formation of an unusual assemblage of three minerals. The exact location (Fig. 1) is in NW$\frac{1}{4}$ NW$\frac{1}{4}$ Section 8, T63N R11W, Lake County, Minnesota. Available chemical and *x*-ray data for these minerals are presented in this paper.

GEOLOGIC SETTING

The mineral assemblage is found near the south margin of a tabular igneous intrusive striking approximately N. 75° E. This is about the same as regional strike. Neither the relationship of the intrusive to the intruded rocks nor the dip can be determined because the contact is covered by glacial drift. The intrusive seems to be mineralogically zoned, suggesting differentiation in place as in the case of the Palisades diabase (Walker, 1940). Intense alteration has made an accurate identification of igneous rock type extremely difficult; however, from its appearance it seems to have been highly mafic.

The minerals with which this paper is concerned are found in narrow veins and irregular masses which appear to be fracture fillings. Serpentine which is considered here to be a mixture of clinochrysotile and antigorite consists of splintery, blue-green to yellow-green bundles of fibers slightly twisted and deformed. Some portions are quite asbestiform whereas others are completely massive. In some cases, fibrous clinochrysotile-

Fig. 1. Location map.

antigorite mixtures have grown obliquely across former irregular fractures. A photomicrograph of the clinochrysotile-antigorite mixture is shown in Fig. 2. The massive mineral shown is massive antigorite which is found cutting across the fibrous mixture. Clinochrysotile also has replaced an original essential rock-forming mineral (Fig. 3), most likely olivine. It can be noted that fibers in the mixture (Fig. 2) are much coarser than those replacing olivine (Fig. 3). Readers will be interested in

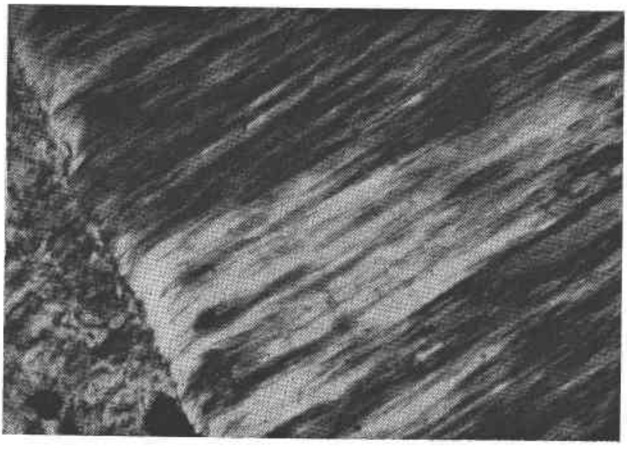

Fig. 2. Antigorite-clinochrysotile mixture (fibrous) cut by massive antigorite. Crossed polars, ×210.

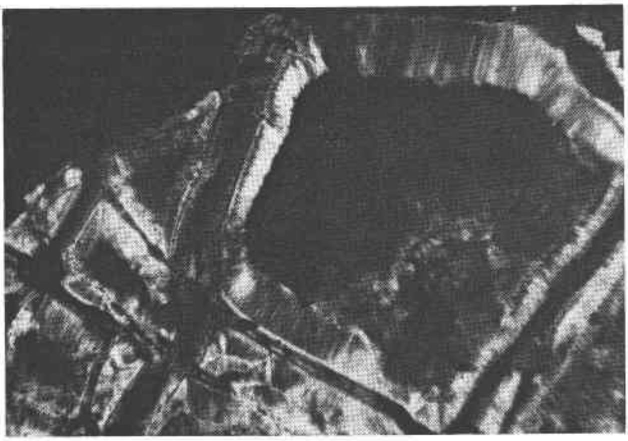

FIG. 3. Replacement of olivine (?) by clinochrysotile. Crossed polars, ×210.

comparing these photomicrographs with those by Faust and Fahey (1962).

The mineral considered to be chamosite in this paper is found in irregular masses having the appearance of fracture fillings. Chamosite consists of olive-green masses having the appearance of bent plates somewhat resembling slickensides. Microscopically, chamosite appears to consist of radiating fibers (Fig. 4). Chamosite and clinochrysotile-antigorite mixtures were not observed in contact with one another although the minerals were only separated by a few feet.

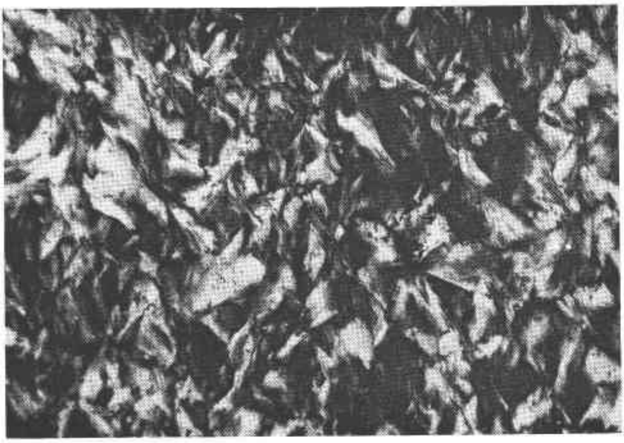

FIG. 4. Chamosite. Crossed polars, ×210.

EXPERIMENTAL PROCEDURES

Chemical tests. Nagy and Faust (1956) have shown that leaching chrysotile for one hour at 95° C. in 1N HCl results in structural collapse. To collapse the structure of antigorite, leaching in concentrated HCl for one hour is necessary. In this study, this test was used to determine roughly the amounts of antigorite and clinochrysotile in mixtures of these minerals.

Partial chemical analyses to determine per cents of magnesium and total iron were obtained on samples of chamosite, wall rock, and the clinochrysotile-antigorite mixture.

X-ray studies. All samples were examined with General Electric and Norelco recording diffractometers as well as by the Debye-Scherrer powder method. Because of preferred orientation, results in the case of the antigorite-clinochrysotile mixture were inconclusive. This mixture was studied by obtaining a fiber pattern of a bundle of fibers cleaved from the bulk sample using the flat-film front reflection method. Since the fibers consist of bundles of crystals with one axis in common and all other directions oriented, the effect of a single crystal rotation photograph is obtained without rotating the sample.

TABLE 1. UNIT CELL DIMENSIONS OF CLINOCHRYSOTILE

Whittaker and Zussman (1956)		Clinochrysotile, Ely, Minn.
a	5.34 Å	5.35 Å
b	9.2 Å	9.28 Å
c	14.65 Å	14.2 Å
β	93° 16′	94° 29′ ± 12′

RESULTS

The flat film fiber photograph shows that the fibrous mineral contains clinochrysotile with somewhat different unit cell dimensions than those given by Whittaker and Zussman (1956). A comparison is given in Table 1.

The small number of spots obtained, the diffuseness and weakness of the spots (especially on the upper layer lines), the two dimensional effects resulting from random layer stacking observed on Debye-Scherrer powder patterns, and the rather extensive development of arcs similar to a Debye-Scherrer pattern on the fiber photograph indicate that both fibering and layered structure are imperfect.

Debye-Scherrer powder photographs, using Straumanis film mountings and CoKα radiation were obtained for the clinochrysotile-antigorite mixture. The results are shown in Table 2. As can be seen from Table 2, many of the lines can be indexed on the basis of orthochrysotile, which was at first confusing, as the fiber pattern indicated that only clinochrysotile was present. In addition, Table 2 shows that the 202^1 line is weaker than the 202^2 line and that the lines which could be indexed on the basis of orthochrysotile are more abundant. All of this seems to indicate that clinochrysotile is less abundant than orthochrysotile, in seeming contradiction to the fiber pattern. Also, on the basis of the Debye-Scherrer diffraction line intensities, antigorite appears to be in higher concentration than chrysotile. This apparent anomaly was resolved by use of the acid leach. Partial diffractograms (Fig. 5) of untreated and 1N HCl treated samples show that peaks maintained their position and two-thirds of peak height (measured on a logarithmic scale) indicating that antigorite is present in greater amounts than chrysotile. Concentrated HCl caused complete structural collapse. It must be concluded that lines

TABLE 2. POWDER DATA FOR CHRYSOTILE AND ANTIGORITE FROM ELY, MINNESOTA

d	I/I	hkl antigorite	hkl chrysotile
7.216	100	001	002
4.577	15	020	020
3.961	1	$81\bar{1}$	022
3.626	50	102, $10\bar{2}$	004
2.968	1	14, 0, 1	024
2.771	1	magnesite line	
2.722	1	magnesite line	
2.521	70	16, 0, 1	202^2
2.457	20	$93\bar{1}$	202^1
2.161	25	17, 0, 1; $30\bar{3}$; 10, 3, 1	204^2
2.094	10+	17, 0, 2	204^1
1.794	1+	$93\bar{3}$	206^2
1.740	1+	17, 0, 3	310
1.671	1	21, 3, 1	028
1.617	1	23, 3, 1	207^2
1.556	20	24, 3, 0	
1.538	10	060	060
1.520	5	15, 0, 4; 16, 0, 4; 22, 3, $\bar{2}$	028^2
1.413	1		064

[1] Reflections from monoclinic chrysotile only.

[2] Reflections which may be indexed as orthorhombic chrysotile; however, they are probably rather due to antigorite (see text).

Fe-filtered Co radiation ($\lambda = 1.790$ Å) and a 114.59 mm camera were used.

that might be attributed to orthochrysotile probably belong on antigorite and the lack of antigorite reflections in the fiber pattern is due to mechanical separation during sample preparation. Furthermore, any antigorite remaining in the fiber specimen would not have many planes, if any, at the proper Bragg angle because it is not fibrous and the specimen was not rotated.

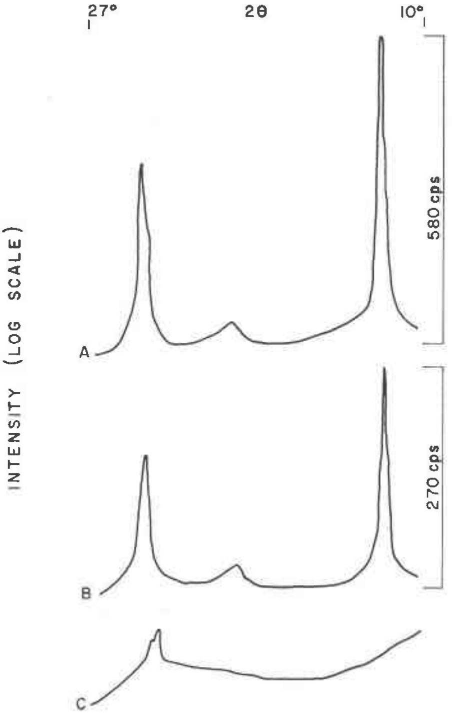

FIG. 5. Partial diffractograms for antigorite-clinochrysotile mixtures. Data were obtained with a General Electric recording diffractometer with Ni-filtered Cu radiation ($\lambda = 1.540$ Å). A—untreated; B—treated for one hour in 1N HCl at 95° C; C—treated for one hour in concentrated HCl.

Debye-Scherrer powder photographs of chamosite, using a Straumanis mounting and FeKα radiation, were kindly furnished by Dr. S.W. Bailey, Department of Geology, University of Wisconsin. Dr. Bailey also identified the mineral as a one-layer mineral with an orthogonal structure. Powder data for this mineral are given in Table 3. For purposes of comparison, powder data for lizardite and orthogonal chamosite are also given. It can be noted that the mineral bears resemblance to both chamosite and lizardite. The few reflections and the single reflection in the d

=1.55 region show that the mineral is orthogonal. The relatively small (001) dimension, 7.09 Å, suggests considerable substitution of aluminum for silicon. Therefore, the mineral most properly should be considered chamosite.

Since powder data and unit cell dimensions obtained in the *x*-ray studies differ considerably from those previously published by Whittaker and Zussman (1956), and a high iron content was suspected during *x*-ray studies, partial chemical analyses for magnesium and total iron were obtained. The results, shown in Table 4, indicate that the minerals are indeed iron-rich.

TABLE 3. POWDER DATA FOR LIZARDITE AND CHAMOSITE

Lizardite, Cornwall (Midgely, 1951)			Chamosite, Ely, Minnesota		Orthogonal chamosite (Brindley, 1951)		
d	hkl	I	d	I	hkl	d	I
7.36	001	10	7.09	8	001	7.04	10
4.62	020	7	4.60	3 bd	020	4.666	2
3.89	021	2			021	3.887	1
3.64	002	10	3.64	5			
					200	2.693	4
2.65	130	4					
2.495	201	8	2.53	10	201	2.516	9
2.299	040	2					
2.148	202	6	2.16	4	202	2.139	6
1.830	004	2	1.81	5			
1.794	203	4					
					203	1.769	4
1.737	310	4			241	1.710	?
1.695	024	1					
1.534	060	7	1.55	2	060	1.555	7
1.503	204	6	1.52	2	061	1.519	3
1.460	005	1	1.48	½	204	1.473	1
1.415	062	2			062	1.423	1
1.328	400	2			005	1.408	½
1.307	401	6			400	1.347	½

bd = broad and diffuse.
Mn-filtered Fe radiation ($\lambda = 1.937$ Å) and a 114.59 mm camera were used.

SUMMARY AND CONCLUSIONS

The flat film fiber method proves the presence of clinochrysotile with an imperfect structure in the fibrous mineral. Strong diffraction lines in power photographs at d = 2.52, d = 1.56, and d = 1.54 and the acid leach confirm the presence of antigorite in excess of clinochrysotile. The mixture probably consists of platy or massive antigorite dispersed among imperfect fibers of clinochrysotile. Microphotographs show that the mixture consists of unusually coarse fibers as compared to pure clinochrysotile. Antigorite did not appear on the flat film fiber photographs because antigorite was removed during sample preparation. In addition, antigorite remaining did not present many planes at the Bragg angle because it is not fibrous and the sample was not rotated.

Powder data for chamosite and antigorite-clinochrysotile mixture are very similar. Chamosite has comparatively few reflections and has only one reflection in the d = 1.55 (060) region.

TABLE 4. PARTIAL CHEMICAL ANALYSES OF SPECIMENS STUDIED

Mineral	% Mg	% MgO	% Total Fe	Total Fe as FeO
Antigorite-clinochrysotile	17.8	29.5	12.6	16.2
Chamosite	11.3	18.7	7.54	9.70
Wall Rock	9.46	15.6	13.8	17.75

Analyst: A. V. Novak, Department of Chemistry, Northern Illinois University, DeKalb. (Present address, Dept. of Chemistry, University of Illinois, Urbana, Illinois.)

The differences in unit cell dimensions for clinochrysotile and differences in d spacings for antigorite and chamosite from those previously published by Whittaker and Zussman (1956) are attributed to an unusually high iron content.

Photomicrographs show that at least a portion of the antigorite has formed after the fibrous antigorite-clinochrysotile mixture. Thus, there are two generations of antigorite. No relationships between chamosite and the serpentine minerals was found.

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