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Authigenic Magnesioarfvedsonite from the Green River Formation, Duchesne County, Utah[1]

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Abstract

Fibrous authigenic sodic amphibole (similar to magnesioarfvedsonite in composition) from the Green River Formation of Utah has been analyzed, the first analysis of a diagenetic amphibole to be reported. Intimate intergrowth of the fibers with dolomite, silica, and organic material—a fact not realized at first—presented unusual problems for analysis. A formula, $Na_{0.488}K_{0.275})(Mg_{3.323}Fe^{2+}_{0.318}Fe^{3+}_{1.076}Al_{0.069}Ti_{0.034})(Na_{1.845}Ca_{0.155})Si_{8.059}O_{22.000}(OH)_{2.441}F_{0.470}$, which corresponds to the generally accepted structural amphibole formula, $(Alk.)_{0.000\text{-}1.000}X_{5.000}Y_{2.000}Z_{8.000}O_{22.000}(O,OH,F,Cl)_{2.000}$, was obtained by removing and analyzing the organic matter separately. The composition of this organic matter approximates $C_{38}H_{57}O_6N$, similar to that for organic matter from a different Green River locality and paragenesis and for the general composition of the Green River organic matter called kerogen.

The X-ray powder pattern of fibrous Utah magnesioarfvedsonite is very similar to that of synthetic and other (igneous-metamorphic) magnesioriebeckites; partly because of this similarity, the Green River amphibole has been heretofore termed magnesioriebeckite instead of the more correct magnesioarfvedsonite.

Blue amphibole also occurs as overgrowths on brown detrital hornblende in sandy phases of the Green River Formation; these will be described in a second report.

Introduction

Since sedimentary authigenic amphiboles were first reported from the Green River Formation (Milton and Eugster, 1959), no chemical analyses have been reported although there has been considerable interest in and attempts to determine the precise identity of the amphiboles. Unlike the acmitic pyroxenes of the Green River (Milton and Eugster, 1959), which occur in crystals of almost ideal purity (Clark, Appleman, and Papike, 1969), these amphiboles are characteristically associated with or intergrown with other minerals and, as a result, separation of material suitable for analysis is generally a problem. However, it is possible, as will be shown, to analyze the imperfectly purified mineral and, by appropriate treatment of the analytical data, to arrive at a reasonable composition for the amphibole. Because of the virtual impossibility of obtaining pure samples of these amphiboles, we have described in some detail the nature of the analyzed samples, the analytical procedures, and the treatment of the analytical data.

Occurrence

Authigenic Green River amphibole occurs in two distinct forms. It occurs as microscopic blue overgrowths on common brown detrital igneous hornblende (Milton and Eugster, 1959; Milton, Chao, Fahey, and Mrose, 1960) in numerous outcrops in Utah, in sandy phases of the Green River Formation, as well as in cores and cuttings from Utah and Wyoming. This report, however, is confined to the second and more frequent mode of occurrence as asbestiform blue-gray aggregates, as much as a centimeter across, usually seen in a brown dolomitic marlstone ("oil shale") matrix. Similar aggregates on a microscopic scale occur in various carbonate minerals of the formation. Except for a single occurrence, the one described here (from the head of Avintaquin Canyon, Duchesne County, Utah, where it was found in outcrops as conspicuous bright blue splotches), all samples of this type of amphibole are from cores or cuttings.

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[1] Publication authorized by the Director, U.S. Geological Survey.

Figures 1 and 2 illustrate the two modes of occurrence of authigenic sodic amphibole in the Green River Formation.

Method of Analysis

Two separate analyses (Table 1) of the apparently cleanest material, both samples of which were from the same locality but one was somewhat more gray than blue, gave very similar results—about what might be expected in duplicate analyses of a single sample. It was concluded that the slight color difference did not indicate significant chemical variation and therefore, in the following procedures, only the analysis of the grayish amphibole was examined.

FIG. 1. Thin section, ordinary light. Brown detrital hornblende peripherally altered to blue magnesioarfvedsonite which, with detrital plagioclase, accounts for most of the surrounding area. This alteration and diffusion of the alteration product is characteristic of the sandy layers of the Green River dolomitic marlstone; in contiguous fine-grained dark-brown "oil shale" layers, the amphibole has segregated into discrete spheroids (Fig. 2). Conoco Duchesne 688-1, about 2700 ft, Duchesne County, Utah.

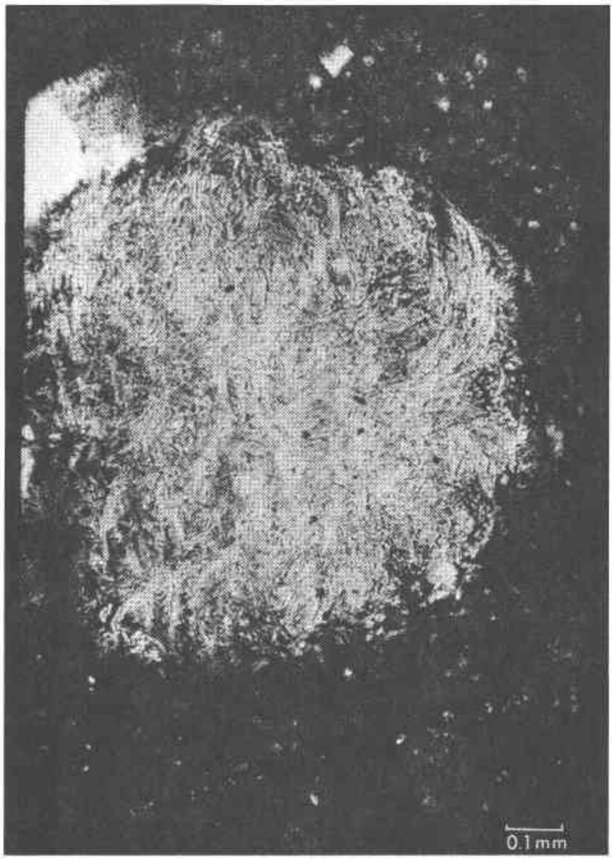

FIG. 2. Thin section, ordinary light. Blue-gray magnesioarfvedsonite spheroid in dark-brown oil shale. Such fibrous masses are found in outcrop in Avintaquin Canyon, Utah. Conoco Duchesne 638-1, 2748 ft, Duchesne County, Utah.

However, neither analysis as reported was amenable to calculation of a formula because of a considerable but unknown quantity of organic matter in the sample. (Later study also revealed the presence of silica and dolomite.) Analysis of the separated organic matter (Table 2) permitted recalculation of the amphibole analysis.

Chemical Analysis of Organic Matter

The considerable amount of total carbon as CO_2 (Table 1), 11.4 and 13.6 percent, and, in part, the high H_2O^+ values, 6.0 and 6.8 percent, result from the admixed carbonate and organic matter in the amphibole. The brown organic matter was therefore separated from the amphibole, as described below, and, after drying under vacuum, analyzed separately (Table 2). Also in Table 2 is analytical data for organic matter from a different source and paragenesis in the Green River Formation (Mahogany Ledge, Colorado; sample is "insoluble in nahcolite."

TABLE 1. Analysis (percent by weight) of Magnesioarfvedsonite from Avintaquin Canyon, Duchesne County, Utah*

	Sample				Spectrographic Analyses**	
Constituent	16920 blue-gray	16921 blue	Footnotes	Constituent	16920 blue-gray	16921 blue
SiO_2	53.0	51.9	a	Mn	0.01	0.01
MgO	14.8	14.2	b	Ag	0.00003	0.00003
CaO	1.2	1.4	b	B	0.007	0.007
Fe_2O_3	9.4	9.8	b,c	Ba	0.003	0.003
FeO	2.5	3.0	c	Be	0.00007	0.00007
Al_2O_3	0.36	0.31	b	Co	0.0005	0.0007
TiO_2	0.28	0.29	b	Cr	0.003	0.003
Na_2O	7.9	7.5	b	Cu	0.002	0.003
K_2O	1.4	1.4	b	Mo	0.0007	0.0007
H_2O^-	0.38	0.38	d	Ni	0.002	0.002
H_2O^+	6.0	6.8	d	Pb	0.0005	0.0007
F	0.99	0.88	e	Sc	0.0005	0.0007
Total C as CO_2	11.4	13.6	d	Sr	0.007	0.007
				V	0.02	0.03
				Zr	0.005	0.005
CO_2 as carbonate (by acid evolution)	0.36	not detd.	f			
Specific gravity	2.73	2.70	g			

*Blanche Ingram, U. S. Geological Survey, analyst.

**Analyst, Helen W. Worthing, U. S. Geological Survey. "Results are reported in percent to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, and 0.1, etc., which represent the approximate midpoints of group data on a geometric scale. The assigned group for semi-quantitative results will include the quantitative value about 30 percent of the time."

As, Au, Bi, Cd, Ce, Ga, Ge, Hf, Hg, In, La, Li, Nb, P, Pd, Pt, Re, Sb, Ta, Te, Th, Ti, U, W, Y, Yb, Zn not found in either sample.

(a) Approximately 5 mg of sample was fused with NaOH in gold crucibles. The melts were dissolved in HCl, and SiO_2 was determined spectrophotometrically by a molybdenum-blue procedure using a solution of 1-amino-2-naphthol-4-sulfonic acid-sodium-sulfite as reducing agent.

(b) Approximately 20 mg of sample was decomposed with $HF-HClO_4$. Aliquots of the solution were used to determine Mg, Ca, total Fe, Al, Ti, Na, and K. Mg, total Fe, Al, and Ti were determined spectrophotometrically: Mg with thiazole yellow, total Fe with o-phenanthroline, Ti with tiron, and Al with alizarin red S after a cupferron separation. Na, K, and Ca were determined flame photometrically.

(c) To determine FeO, approximately 20 mg of sample was decomposed with HF at room temperature in the prescence of an excess of standard $NaVO_3$ solution. The $NaVO_3$ reacting with Fe^{+2} was measured by titrating the excess $NaVO_3$ with standard $Fe(NH_4)_2(SO_4)_2$ solution. The FeO and total iron values were used to calculate Fe_2O_3.

The FeO reported may have been affected to an unknown extent by the organic contaminant of the amphibole; however, the determinations were made by a cold-solution procedure, not likely to dissolve much (if any) of the organic. In any case, the effect (if any) of the organic would be to increase, not decrease, the apparent FeO, and therefore there can actually be no more than that reported. Thus the magnesioarfvedsonite is characteristically a ferric, rather than ferrous, iron mineral.

(d) A 50 mg sample was dried at 110°C and weighed to determine H_2O^-. The sample was then mixed with V_2O_5 and ignited in a combustion train at 900°C in a stream of oxygen. Water (H_2O^+) and CO_2 were absorbed and weighed.

(e) A 5-mg sample was fused with Na_2CO_3-ZnO and leached with H_2O. Fluorine was distilled from the leachings at 150°C in a $HClO_4-H_3PO_4$ medium using a micro-still. Fluorine was determined spectrophotometrically on the distillate with thoron.

(f) A 50-mg sample was treated with HCl and heated. The CO_2 evolved was absorbed and weighed. There was not sufficient sample for this determination in 16921.

(g) Specific gravity was determined with a specific gravity bottle and toluene.

Specimen supplied by J. Dyni, U. S. Geological Survey).

An attempt to separate the organic and inorganic constituents of the sample on the basis of their specific gravities was unsuccessful. Ultrasonic agitation of a suspension of the finely ground powder in carbon tetrachloride produced an organic float still containing about 50 percent ash. Acid treatment of powdered sample (1/1 hydrochloric acid)—on the assumption that metallic salts or complexes were present—was also unsatisfactory, as the organic separate (after drying the product and floating it in carbon tetrachloride) also contained about 50 percent ash. Microscopic observation of the powdered sample indicated a fine intergrowth of birefringent mineral matter with the organic material. On the assumption that silica or silicates were present, the sample was treated with 1/1 hydrochloric acid and hydrofluoric acid for removal of silica. This procedure was successful in reducing the ash content of the product to an acceptable value of 4.6 percent (Table 2) and indicated the presence of intergrown silica or (less likely) silicates.

Computation of Formula

With the data of Tables 1 (sample 16920) and 2 (Utah dry, ash-free sample), we compute a magnesioarfvedsonite formula as follows:

From Table 1 the percents by weight are:

Total C as CO_2 in sample	11.4
CO_2 as carbonate (by acid evolution)	0.36
Therefore, organic CO_2 in sample	11.04
Organic C in sample	3.01

The 73.4 percent C in the ash-free organic matter (Table 2) is thus equivalent to 3.01 percent C in the sample as a whole. By this same ratio—73.4:3.01—the 9.8 percent H, 2.3 percent N, and 14.5 percent O equate to, respectively, 0.402, 0.094, and 0.595 percent in the sample as a whole. The total weight percent of organic matter—that is, C+H+N+O or 3.01 + 0.402 + 0.094 + 0.595—thus equals 4.10.

H 0.094 is equivalent to 3.62 H_2O, leaving 2.38 H_2O for the amphibole ($H_2O^+ = 6.0$; Table 1).

TABLE 2. Chemical Analysis (percent by weight) of Organic Matter in Samples from Utah and Colorado*

	Utah		Colorado
	dry	dry, ash-free**	dry, ash-free
C	70.0	73.4	74.2
H	9.3	9.8	10.1
N	2.2	2.3	2.2
O (by difference)	13.9	14.5	13.5
Ash	4.6	--	--
Total	100.	100.	100.

*John C. Chandler, U. S. Geological Survey, analyst.

**This composition approximates $C_{38}H_{57}O_6N$.

To the 0.36 CO_2 (by acid evolution) present in dolomite (the carbonate of analyses), we allot 0.23 percent CaO and 0.18 percent MgO, deducting these amounts from the figures reported in Table 1 (see Table 3).

The computed 4.10 percent organic matter is intergrown with silica, perhaps another percent or two; this has been disregarded in the following computation of the amphibole analysis.

Finally, there is a correction for $F_2 = O$, −0.42 percent from the summation.

The recomputed analysis, after these adjustments for occluded organic matter and dolomite, is given in Table 3; the formula of the amphibole (magnesioarfvedsonite) is derived in Table 4.

Infrared Analysis

An infrared analysis of the Colorado organic isolate showed the presence of silica at approximately 1000 cm^{-1}. This peak nearly disappeared in the acid-treated organic isolate. Other features of the infrared absorption curve indicate the strong aliphatic character of the material (also indicated by its high hydrogen content) and the low aromatic character. Strong carboxyl (−COOH) and carbonyl (=CO) absorptions were also noted. The material may be somewhat unsaturated; from its composition and infrared absorption spectrum, it appears to have been derived from aquatic organic matter (plankton and algae) rather than terrestrial humic substances derived from decaying plants, which tend to be highly aromatic in their chemical structure and to contain about half as much hydrogen.

TABLE 3. Recalculation of Chemical Analysis (percent by weight) of Sample 16920

	16920	dolomite	amphibole	amphibole to 100 percent
SiO_2	53.0	--	53.0	56.26
MgO	14.8	0.18	14.62	15.55
CaO	1.2	0.23	0.97	1.03
Fe_2O_3	9.4	--	9.4	9.98
FeO	2.5	--	2.5	2.65
Al_2O_3	0.36	--	0.36	0.38
TiO_2	0.28	--	0.28	0.30
Na_2O	7.9	--	7.9	8.39
K_2O	1.4	--	1.4	1.49
H_2O^-	0.38	--	0.38	0.40
H_2O^+	6.0	--	2.4	2.55
F	0.99	--	0.99	1.05
Total C as CO_2	11.4	--	--	--
CO_2 as carbonate (by acid evolution)	0.36	0.36	--	--
Total		0.77	94.20	100.0
organic matter	4.10	--	--	--
dolomite	0.77	--	--	--
Less $O = F_2$			0.42	0.45
Total			93.78	99.55

Sample 16920 is computed to 93.8 percent amphibole, 4.1 percent organic matter, and 0.8 percent dolomite, and a small (neglected) amount of silica.

TABLE 4. Computation of Magnesioarfvedsonite Formula

	Recomputed analysis (amphibole to 100 percent, Table 3)	atoms per half unit cell		Ionic charge	
SiO_2	56.26	Si	8.059	32.228	
MgO	15.55	Mg	3.323	6.646	
CaO	1.03	Ca	0.155	0.310	
Fe_2O_3	9.98	Fe^{+3}	1.076	3.228	
FeO	2.65	Fe^{+2}	0.318	0.636	
Al_2O_3	0.38	Al	0.069	0.207	
TiO_2	0.30	Ti	0.034	0.136	
Na_2O	8.39	Na	2.333	2.333	
K_2O	1.49	K	0.275	0.275	
H_2O^-	0.40	--	--	--	45.999 (+)
H_2O^+	2.55	OH	2.441	2.441	
F	1.05	F	0.476	0.476	
Total	100.00		ɔ (22)	44.000	
Less $O = F_2$	0.45				46.917 (−)
Total	99.55				

The sites are filled according to the standard scheme
$AX_5Y_2Z_8O_{22}(OH,F)_2$,

A		X_5		Y_2		Z_8		O_{22}		$(OH,F)_2$	
Na	0.488	Mg	3.323	Na	1.845	Si	8.059	O	22.00	$(OH)_2$	1.220
K	0.275	Fe^{2+}	0.318	Ca	0.155		--		--	F_2	0.238
	--	Fe^{3+}	1.076		--		--		--		--
	--	Al	0.069		--		--		--		--
	--	Ti	0.034		--		--		--		--
Total	0.763		4.820		2.000		8.059		22.00		1.458

This yields the formula
$(Na,K)_{0.76}(Mg,Fe^{2+},Fe^{3+},Al,Ti)_{4.82}(Na,Ca)_{2.00}Si_{8.06}O_{22.00}[(OH,F)_2]_{1.46}$

Optical and Physical Data

Optically, because of the matted fibrous habit of the magnesioarfvedsonite, only α can be readily determined; it appears to be close to 1.634. The Green River magnesioarfvedsonite has about 16 percent magnesioriebeckite ($\alpha = 1.668$), about 8 percent tremolite ($\alpha = 1.606$), and about 6 percent magnesioarfvedsonite ($\alpha = 1.633$). However, substitution of F for OH would lower the indices of refraction; the intergrown organic material and silica would have a similar effect.

Pleochroism varies from bluish gray (*X*) to olive brown (*Y*, *Z*); Tröger (1971) gives bluish green to bright bluish green and bright yellow green. However, in different specimens of Green River amphibole, a wide variation in blue, green, and yellow-brown tints may be observed.

The observed density 2.73 (Table 1, sample 16920) is considerably lower than the values cited by Deer, Howie, and Zussman (1963) for magnesioarfvedsonites: 3.166, 3.196, and 3.231. Admixture of organic matter and dolomite as noted above

TABLE 5. X-ray Powder Patterns of Utah Magnesioarfvedsonite, Madagascar Torendrikite, Synthetic Magnesioriebeckite, and Synthetic Magnesioarfvedsonite

Magnesioarfvedsonite, Utah (blue) sample 16921		Torendrikite (Lacroix, 1920) XRPD 20-656		Magnesioriebeckite (synthetic) (Ernst, 1960)			"Magnesium arfvedsonite" (synthetic)* (Korytkova et al., 1968) XRPD 22-1387		
I	d	I	d	I	d	hkℓ	I	d	hkℓ
--	--	8	9.03	12	9.30	020	--	--	--
vs	8.453	100	8.45	100	8.45	110	--	--	--
vw_b	4.783	4	4.88	--	--	--	--	--	--
s	4.486	16	4.50	25	4.506	040	40	4.54	040
--	--	12	4.21	--	--	--	--	--	--
vvw	4.046	--	--	--	--	--	--	--	--
vvw	3.854	2	3.88	25	3.860	$\bar{1}31$	--	--	--
vvw	3.604	--	--	--	--	--	--	--	--
msb	3.411	--	--	65	3.420	131	50	3.41	131, 041
--	--	8	3.37	--	--	--	--	--	--
s	3.269	--	--	60	3.280	240	30	3.29	240
vvs	3.130	90	3.12	90	3.135	310	50	3.13	310, 201
--	--	--	--	14	2.926	$\bar{1}51$	--	--	--
--	--	60	2.890	--	--	--	--	--	--
s	2.810	--	--	30	2.807	330	20	2.81	330
vs	2.702	30	2.714	80	2.724	151	100	2.72	151
--	--	--	--	20	2.699	$\bar{3}31$	--	--	--
ms	2.583	10	2.593	30	2.596	061	40	2.58	002, $20\bar{2}$+
--	--	14	2.536	--	--	--	80	2.52	170
w	2.498	--	--	40	2.513	$\bar{2}02$	--	--	--
vvw	2.442	--	--	--	--	--	--	--	--
vw_b	2.395	6	2.379	--	--	--	--	--	--
--	--	8	2.327	--	--	--	--	--	--
--	--	4	2.313	10	2.317	$\bar{3}51$	20	2.32	112, $17\bar{1}$
w	2.303	4	2.296	18	2.293	$\bar{1}71$	--	--	--
w	2.261	4	2.269	--	--	--	30	2.28	080
--	--	--	--	10	2.248	--	--	--	--
--	--	2	2.182	20	2.178	$\bar{2}61$	--	--	--
--	--	12	2.168	--	--	--	50	2.17	$33\bar{2}$, 261
ms	2.145	--	--	--	--	--	--	--	--
--	--	--	--	10	2.082	202	--	--	--
--	--	4	2.065	--	--	--	--	--	--
vvw	2.043	--	--	--	--	--	--	--	--
--	--	8	2.025	--	--	--	--	--	--
vw	2.006	4	2.008	--	--	--	--	--	--
vw	1.976	--	--	--	--	--	--	--	--
w	1.930	8	1.892	--	--	--	--	--	--
w_b	1.836	4	1.813	--	--	--	--	--	--
vvw	1.801	--	--	--	--	--	--	--	--
vvw	1.777	2	1.737	--	--	--	--	--	--
vvw	1.669	4	1.683	--	--	--	--	--	--
vvw	1.645	14	1.655	--	--	--	--	--	--
s	1.621	8	1.635	--	--	--	30	1.658	$2\underline{10}\bar{1}$, $24\bar{3}$+
--	--	6	1.613	--	--	--	--	--	--
s	1.587	8	1.585	--	--	--	--	--	--
vvw	1.569	2	1.569	--	--	--	--	--	--
--	--	4	1.526	--	--	--	--	--	--
vw_b	1.501	4	1.517	--	--	--	70	1.511	$48\bar{2}$+
--	--	4	1.508	--	--	--	--	--	--
vvw_b	1.484	6	1.502	--	--	--	--	--	--
vvw_b	1.443	--	--	--	--	--	--	--	--
vvw_b	1.429	--	--	--	--	--	80	1.432	$37\bar{3}$
vvw_b	1.373	--	--	--	--	--	--	--	--
vvw_b	1.350	--	--	--	--	--	--	--	--
vvw_b	1.331	--	--	--	--	--	--	--	--
vvw_b	1.304	--	--	--	--	--	--	--	--
vvw_b	1.283	--	--	--	--	--	70	1.286	482, 353+
vvw_b	1.260	--	--	--	--	--	--	--	--
vvw_b	1.217	--	--	--	--	--	--	--	--
vvw_b	1.185	--	--	--	--	--	--	--	--

* Only the most intense lines are given for this pattern.

would reduce the observed density, but the major difference probably reflects the considerable preponderance in our sample of magnesium over ferrous iron.

Nomenclature of Green River Amphibole

The formula of this amphibole may be considered (Malcolm Ross, written communication, 1973) with reference to a generalized alkali amphibole formula

$$A_{1-x}(R^{2+}{}_{4-x+y}R^{3+}{}_{1+x-y})(\mathrm{Na}_{2-y}\mathrm{Ca}_y)\mathrm{Si}_8\mathrm{O}_{22}(\mathrm{OH})_2$$

where $R^{2+} = \mathrm{Mg}+\mathrm{Fe}^{2+}$ and $R^{3+} = \mathrm{Fe}^{3+} + \mathrm{Al} + \mathrm{Ti}$;

when $x = 1$ and $y = 0$,

we have $\mathrm{Na}_2R^{2+}{}_3R^{3+}{}_2\mathrm{Si}_8\mathrm{O}_{22}(\mathrm{OH})_2$ riebeckite;

when $x = 0$ and $y = 0$,

we have $\mathrm{Na}_3R^{2+}{}_4R^{3+}\mathrm{Si}_8\mathrm{O}_{22}(\mathrm{OH})_2$ arfvedsonite;

when $x = 1$ and $y = 2$,

we have $\mathrm{Ca}_2R^{2+}{}_5\mathrm{Si}_8\mathrm{O}_{22}(\mathrm{OH})_2$ tremolite.

In these terms, the analysis (Table 4) computes

$$A_{1.00-0.24}(R^{2+}{}_{3.64}R^{3+}{}_{1.18})(\mathrm{Na}_{2-0.155}\mathrm{Ca}_{0.155})\cdot\mathrm{Si}_{8.06}\mathrm{O}_{22.00}[(\mathrm{OH},\ \mathrm{F})_2]_{1.46}$$

from which $x = 0.24$ and $y = 0.155$; $y = 0.155$ corresponds to ~8 percent tremolite and $x = 0.24$ corresponds to ~76 percent arfvedsonite or leaving ~16 percent riebeckite in the amphibole, for which the term magnesioarfvedsonite is therefore appropriate.

This accords with the terminology of Deer, Howie, and Zussman (1963), whose discriminant between magnesioriebeckite and magnesioarfvedsonite is the occupancy of the *A* sites—empty in magnesioriebeckite, full in magnesioarfvedsonite. Thus, in five magnesioriebeckite analyses, Ca + Na + K varies from 1.73 to 2.31, mean 1.92; for three magnesioarfvedsonites, Ca + Na + K varies from 2.88 to 3.22, mean 3.07 (Deer, Howie, Zussman, 1963). (In the Utah mineral, it is 2.74.) They further cite three magnesioarfvedsonites with $(\mathrm{Fe}^{2+} + \mathrm{Mn}^{2+})/\mathrm{Mg}$ ranging from 0.27 to 0.75; in the Green River magnesioarfvedsonite, the ratio is 0.10, reflecting a great preponderance of Mg, which Tröger (1969, p. 456) notes as extremely rare.

X-ray Powder Data

Ernst (1958) notes that the powder pattern of synthetic magnesioriebeckite varied very little over a wide range of iron oxidation and resembled that of a natural magnesioriebeckite from Bolivia (U. S. National Museum 4980). The Green River magnesioarfvedsonite is also quite similar to Ernst's (1960) synthetic (Table 5) and to XRPD 20-656 torendrikite (Lacroix, 1920; Table 5), as well as to other magnesioriebeckites–magnesioarfvedsonites.

Fibrous magnesioarfvedsonite with composition

$$(\mathrm{Na}_{2.94}\mathrm{Ca}_{0.06})(\mathrm{Mg}_{4.27}\mathrm{Fe}^{2+}{}_{0.03}\mathrm{Fe}^{3+}{}_{0.68})_{4.98}\cdot(\mathrm{Si}_{7.96}\mathrm{Al}_{0.02}\mathrm{O}_{22})(\mathrm{OH})_{1.92}\mathrm{F}_{0.25}$$

was synthesized hydrothermally from olivine (MgO 45.79 percent, FeO 11.30 percent) by Korytkova, Fedoseyev, and Makarova (1968).

Table 5 shows the similarity in the powder patterns of the blue Utah magnesioarfvedsonite (sample 16921), torendrikite [Lacroix (1920), which Deer, Howie, and Zussman (1963, p. 369) call magnesioriebeckite], synthetic magnesioriebeckite (Ernst, 1960), and synthetic "magnesium arfvedsonite" (Korytkova, Fedoseyev, and Makarova, 1968); all four patterns are similar.

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