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ANTHOPHYLLITE WITHIN THE ALBITE-EPIDOTE HORNFELS FACIES, FREMONT COUNTY, COLORADO

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ABSTRACT

Aluminian ferroanthophyllite is present abundantly in distinctive Precambrian quartz-albite metasedimentary rocks in western Fremont County, Colorado. The metamorphic grade of these albitic quartzites—the albite-epidote hornfels facies—differs sharply from nearby medium to high-grade Idaho Springs metamorphic rocks, and the name Mitchell Gulch formation is proposed for them. The occurrence of anthophyllite within these low-grade contact rocks results from their unusual bulk composition, and the apparent instability of paragonite within the albite-epidote hornfels facies.

INTRODUCTION

During the summer of 1958 an investigation of the Precambrian rocks north of the Arkansas River between Howard and Cotopaxi in south-central Colorado, disclosed a well-exposed isolated Precambrian albitic-quartzose metasedimentary rock group, three miles northeast of Howard (Salotti, 1962). These metasediments exhibit a markedly lower metamorphic grade than do the more widespread Idaho Springs metamorphic rocks, although both rock units are older than the Middle Precambrian Pikes Peak granite. These light-colored quartzitic rocks crop out over four square miles, and the name, Mitchell Gulch formation, is proposed for them, after Mitchell Gulch, the most prominent drainage in the area. Included among the rock types is a quartz-albite-anthophyllite schist. The presence of anthophyllite is interesting because the environment of the Mitchell Gulch formation was low intensity regional metamorphic, modified by considerable contact effects—the greenschist and albite-epidote hornfels facies of Turner (1958). Apparently this represents the first authenticated record of anthophyllite within this facies.

GEOLOGY

The Mitchell Gulch paraschists occur along the southwestern flank of the Pikes Peak granite batholith, which has been intruded into them. They are broadly folded with low to moderate dips into a poorly defined northeast-trending anticline, which plunges southwest at a low angle. Locally, metamorphic foliation transects original sedimentary compositional banding. This feature is particularly noticeable in thinly laminated schists with alternating quartz-albite and mica layers. The estimated thickness of these rocks is 2,000+ feet; probably the original thickness was considerably in excess of this amount. Permian-Pennsylvanian sedi-

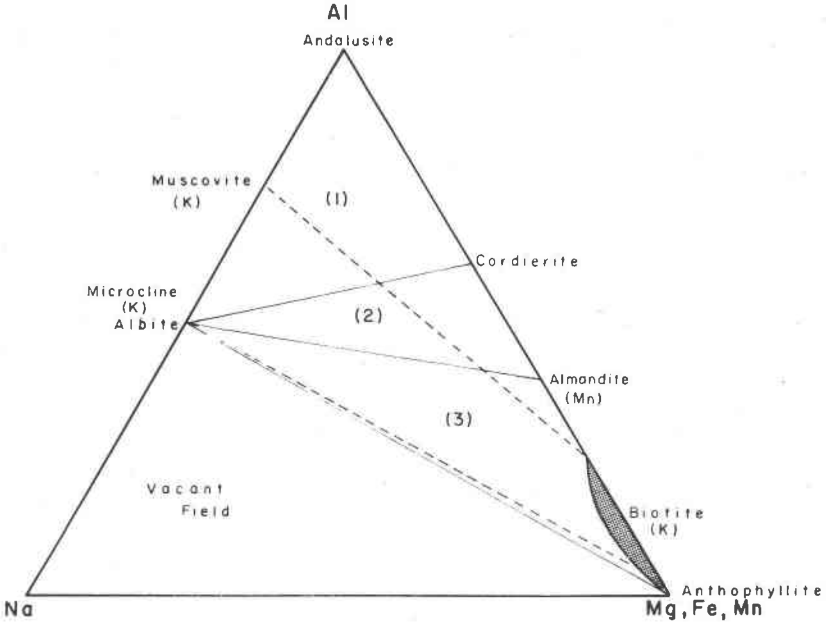

FIG. 1. Albite-epidote-hornfels facies. ANF diagram for assemblages with excess SiO_2. Dashed field indicates assemblages high in K_2O.

ments lie in fault contact along the western boundary; the southeast margin of the formation grades into migmatite and medium- to coarse-textured Pikes Peak granite and to the northeast into aplitic Pikes Peak granite. Granitic injection is minor, and only locally has migmatite been developed. Small unzoned pegmatites are not uncommon, and cross-cutting, generally uncontorted aplite dikes are rare.

PETROGRAPHY

The mineral composition of the Mitchell Gulch formation and the relation of the anthophyllite-bearing members are best demonstrated by reference to a ternary diagram of the system Na-Al-Mg, Fe, Mn, which contains excess silica (Fig. 1).

Microscopic examination of the rocks shows them to be petrographically separable into the following assemblages:

1. Quartz-albite-andalusite-cordierite-epidote group-mica
2. Quartz-albite-almandite-cordierite ± epidote group-mica
3. Quartz-albite-almandite-anthophyllite ± mica
4. Quartz-albite-microcline-mica

Disregarding retrograde alterations, the close adherence of the assemblages to the mineralogic phase rule indicates that Mitchell Gulch rocks crystallized under equilibrium conditions. Before discussing the anthophyllite-bearing unit specifically and the origin of all members in general, an account of their petrology is in order.

Quartz-albite-andalusite-cordierite-epidote-mica rock

Quartz-albite-mica schist with knots of accessory andalusite, cordierite, epidote minerals and randomly distributed zircon, rutile and magnetite is the commonest type. The rock, distributed throughout the formation, is light gray to blue gray and commonly well foliated, especially mica-rich varieties. Mica "eyes" are not uncommon.

The rock is characterized microscopically by interlocking, fine-grained equigranular quartz and albite with sub-parallel mica, which is largely responsible for the foliation. Some quartz-albite-mica schist shows a distinct sequence of thin (up to 30 per inch) quartz-feldspar bands alternating with micaceous layers. Such layered rocks appear more schistose than their non-banded counterparts. In some specimens the orientation of the mica transects the mineralogic banding.

The commonest mineral is generally quartz, although rocks in which quartz is subordinate to albite are not unusual. The grain size varies from 0.2–0.5 mm. with locally coarser grains up to 1 mm.

Plagioclase ranges from Ab_{88} to Ab_{95}; rarely is it slightly less sodic than Ab_{90}.

Normally biotite predominates over muscovite, but in leucocratic varieties muscovite and/or sericite is present almost to the exclusion of biotite. Biotite is commonly concentrated as clusters or knots in which andalusite, clinozoisite and rarely cordierite also occur.

Two generations of muscovite are present: the early is finer-grained and contributes to the foliation; coarser-grained, late muscovite transects the foliation and is commonly symplektitic with quartz. In some rocks late muscovite has resulted in the development of of a conspicuous maculose texture. Rutile, the most extensively distributed accessory mineral, generally occurs as small scattered euhedra somewhat altered to leucoxene. Anhedral to subhedral zircon is sparingly present. Magnetite occurs as small scattered euhedra and subhedra.

Andalusite, an epidote mineral, and cordierite are closely associated in or near biotite clusters. Andalusite is generally anhedral and not pronouncedly poikiloblastic. Skeletal cordierite is almost entirely altered to pinite.

Quartz-albite-almandite-cordierite-mica ± epidote rock

Garnet is a conspicuous component of this schist, and andalusite is absent. Biotite is invariably essential. Garnet-bearing rocks occur interlayered throughout the commoner rock types. Porphyroblasts of garnet up to 2 cm occur within biotite haloes. The garnet is a pyralspite type containing approximately 11% pyrope, 56% almandite and 33% spessartite (Table 1) (Sriramadas, 1957; Winchell, 1958).

TABLE 1. PHYSICAL AND CHEMICAL PROPERTIES OF GARNET FROM THE MITCHELL GULCH FORMATION

Semiquantitative spectrochemical analysis	Index of refraction (5750 Å)	a	G
Major components: Fe, Al, Mn, Si Ca, Mg (<5%)	1.807±0.003	11.548 Å	4.18

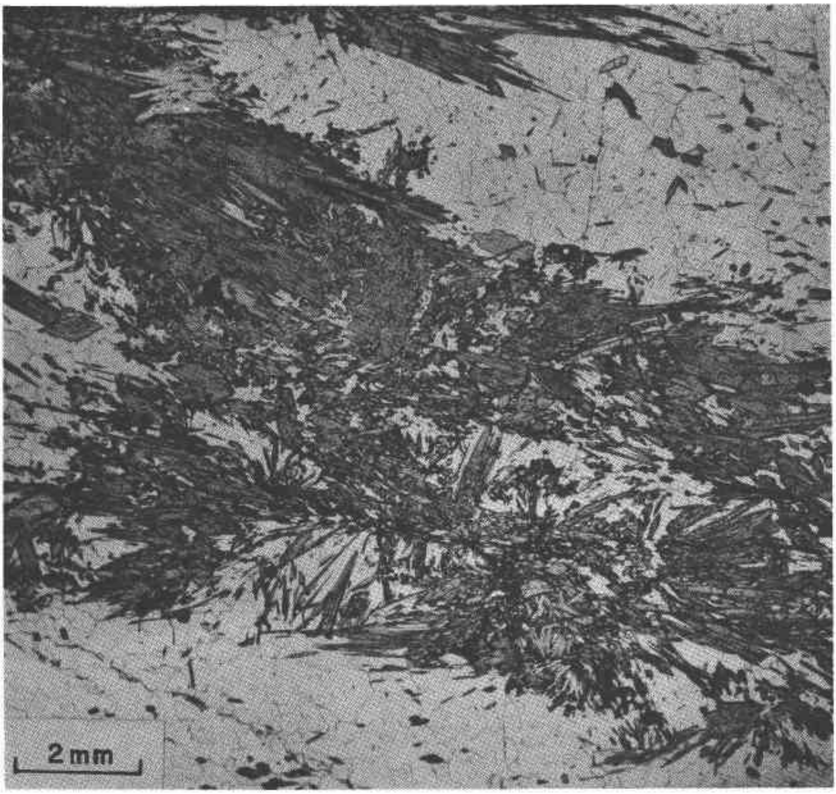

FIG. 2. Sheaf-like cluster of anthophyllite in quartz-oligoclase-anthophyllite schist. Matrix consists of nearly equal amounts of quartz and oligoclase (Ab_{89}). The opaque mineral is rutile in part altered to leucoxene. Mitchell Gulch formation, near center sec. 30, T. 49 N., R. 11 E., Fremont County, Colorado. Plane polarized light.

Quartz-albite-almandite-anthophyllite-mica rock

Anthophyllite-bearing rocks, which are less abundant than the other rock types, occur throughout the formation. The anthophyllite content ranges from 41 per cent to accessory amounts. Some hand specimens are estimated to contain approximately 75 per cent anthophyllite. These highly anthophyllitic rocks are dark silky green. Rocks containing radial clusters of anthophyllite are tough and compact, if fresh, but form relatively poor outcrops. Anthophyllite-poor rocks are light-colored and generally better foliated than anthophyllite-rich varieties. Sheaf-like anthophyllite clusters are more characteristic of anthophyllite-rich varieties (Fig. 2). Amphibole-poor rocks tend to have similarly oriented individual anthophyllite euhedra (Fig. 3). In the field this change in habit can be traced from amphibole-poor to amphibole-rich rocks. A "feather amphibolitic" texture is not uncommon in anthophyllite-poor rocks with individual euhedra randomly oriented within the foliation.

The texture of the fine-grained quartz-albite matrix is similar to that of other units. The

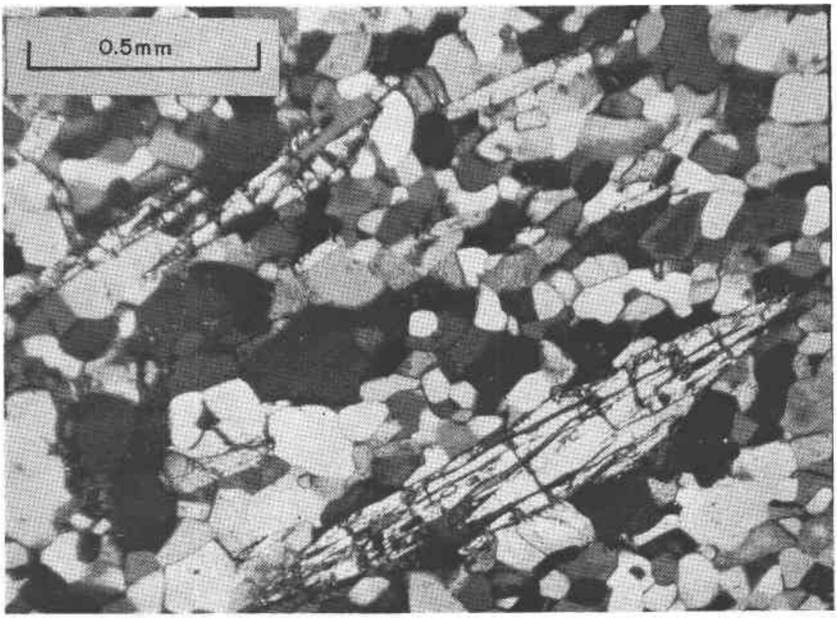

FIG. 3. Quartz-albite-anthophyllite schist in which anthophyllite occurs as separate parallel euhedra. Albite (Ab_{95}) is distinguished from quartz by its turbid appearance and poorly developed albite twinning. Mitchell Gulch formation, near center sec. 30, T. 49 N., R. 11 E., Fremont County, Colorado. Crossed polars.

presence of radial and/or euhedral anthophyllite, and the absence of andalusite, cordierite, epidote and microcline distinguish it from other rock types. Accessory minerals are magnetite, zircon, garnet and rutile.

Plagioclase, ranging in composition from Ab_{88} to Ab_{95}, is generally albitic and may exceed quartz in volume (Table 2). The amount of pale tan to greenish-tan biotite varies inversely with anthophyllite.

Quartz-albite-microcline-mica rock

Microcline-bearing rocks are rare within the formation. Texturally they closely resemble quartz-albite-mica schist, the chief difference is the microscopic presence of microcline. Almandite is rare, and rutile, zircon and magnetite are ubiquitous accessories.

ANTHOPHYLLITE

Optically the anthophyllite of these rocks is atypical (Table 3); however, *x*-ray analyses confirm the identity (Table 4). The characteristic clove brown to pale tan pleochroism is not present. Most anthophyllite is strongly pleochroic in shades of blue-green (γ) to greenish yellow-tan (α or β). The absorption is $\alpha=\beta<\gamma$. Both optically (+) and (−) anthophyllite are present; most specimens examined on a universal stage were (+). 2V in (−) anthophyllite is generally greater but it is large for both.

TABLE 2. MODES OF QUARTZ-ALBITE ROCKS FROM THE MITCHELL GULCH FORMATION, COTOPAXI-HOWARD AREA, COLORADO[1]

	1	2	3
Quartz	43.2	36.9	30.4
Plagioclase	51.3(Ab_{92})	56.7(Ab_{95})	27.6(Ab_{89})
Muscovite	5.4	—	—
Biotite	—	2.8	—
Anthophyllite	—	3.3	41.1
Accessories	Tr	0.2	0.9
Total	99.9	99.9	100.0

1. Quartz-albite-mica schist, sec. 30, T. 49 N., R. 11 E., Fremont County, Colorado.
2. Quartz-albite-anthophyllite schist, sec. 30, T. 49 N., R. 11 E. Fremont County, Colorado.
3. Quartz-albite-anthophyllite schist, sec. 19, T. 49 N., R. 11 E. Fremont County, Colorado.

[1] Rosiwal analysis by means of Hunt-Wentworth micrometer.

The γ index, varying even within specimens, generally lies between 1.68 to 1.69. According to Rabbit's chart (1948, p. 295) these indices suggest a substitution of from 25–29 wt. % of $FeO+Fe_2O_3+TiO_2+MnO$ for MgO. The chemical analysis (Table 6) is in good agreement with this figure. This correlates well with the unusually strong pleochroism, because, in general, the pleochroic intensity increases with increasing iron content (Rabbit, 1948). Anthophyllite shows varying degrees of alteration to a highly pleochroic green chlorite with low normal interference colors. *X*-ray and optical examination show it to be ripidolite.

The anthophyllite used for the chemical and *x*-ray analysis was separated by pulverizing and collecting the fraction screened between 60 and 140 mesh. Quartz and feldspar were removed in bromoform and chlorite and mica in methylene iodide. The anthophyllite-rich fraction was fur-

TABLE 3. OPTICAL PROPERTIES AND SPECIFIC GRAVITY OF ANTHOPHYLLITE FROM THE MITCHELL GULCH FORMATION

$\gamma=c,\ \beta=b$

$\alpha,\ \beta=$ yellow-green to greenish tan
$\gamma=$ blue-green

$\gamma=1.691\pm.002$
$\beta=1.681\pm.002$
$\alpha=1.674\pm.002$
$G=3.36$

$\gamma-\alpha=.017$

$2V=80°(+)$

Filtered white light 5750 Å.

TABLE 4. *X*-RAY DIFFRACTION DATA

1 Gedrite		2 Anthophyllite		3 Anthophyllite	
d Å	I/I_1	*d* Å	I/I_1	*d* Å	I/I_1
8.99	50	8.9	30	8.92	16
8.28	70	8.26	55	8.24	100
7.19	50	7.48	7	—	—
—	—	5.04	13	5.01	16
—	—	4.62	13	4.65	17
4.45	30	4.50	25	4.45	21
4.11	30	4.13	20	4.12	12
3.87	15	3.90	13	3.88	14
3.63	50	3.65	35	3.64	21
3.32	30	3.36	30	3.35	35
3.21	85	3.24	60	3.22	70
3.04	100	3.05	100	3.05	85
2.87	50	2.87	20	2.87	18
2.81	50	2.84	40	2.83	25
2.74	50	2.74	20	2.747	20
2.66	50	2.68	30	2.672	37
2.56	50	2.590	30	2.570	40
2.53	50	2.540	40	2.545	38
2.49	50	2.434	13	2.500	36
2.31	30	2.318	20	2.319	17
—	—	2.290	20	2.307	17
—	—	2.252	13	2.279	17
—	—	2.174	9	2.156	17
2.14	30	2.142	30	2.137	19
2.06	15	2.074	9	2.071	16
—	—	1.991	15	1.992	17
—	—	1.875	11	1.876	10
—	—	1.734	30	1.732	12
—	—	1.693	13	1.700	11
—	—	1.618	30	1.618	14
1.51	50	—	—	1.513	21

1. Glen Urquhart, Scotland, ASTM 7-289.
2. Georgia, 19.5 mol. per cent Fe, ASTM 9-455.
3. Fremont Co., Colo.

ther concentrated on a Franz separator. Optical examination indicated that the impurities were less than 1 per cent, mostly as rare, fine scaly hematite coatings and as small chlorite patches. The diffractometer pattern shows none of the prominent hematite reflections. Because the composition of ripidolite is close to that of anthophyllite, and the amount

TABLE 5. CHEMICAL ANALYSIS OF ANTHOPHYLLITE FROM THE MITCHELL GULCH FORMATION, FREMONT COUNTY, COLORADO

SiO_2	44.00%	CaO	0.00%
Al_2O_3	19.20	Na_2O	2.57
FeO	23.00	K_2O	0.27
MgO	8.38	MnO	1.70

Analyst: Law and Company, Atlanta, Georgia.

of hematite is so small, the chemical analysis (Table 5) is uncorrected for these contaminants.

In the original chemical analysis, total iron was reported as ferric iron; however, examination of the iron in solution during analysis showed it to be almost entirely ferrous iron. A small amount of ferric iron present likely resulted from oxidation during analysis; therefore, all iron was recalculated as ferrous iron.

Ignition at 1000° C. was the only method available to determine water of constitution. In view of the questionable accuracy of such a figure and the likely oxidation of some ferrous iron, this determination is not included.

THE FACIES CLASSIFICATION AND ORIGIN OF THE MITCHELL GULCH FORMATION

The facies classification of Mitchell Gulch rocks is best determined by the absence of lime-bearing plagioclase, proxied for by albite-epidote. The presence of andalusite and cordierite, along with the field relations, indicate a contact-metamorphic origin. The absence, toward the granite, of a hornblende-hornfels facies does not preclude the development of an albite-epidote hornfels facies (Turner and Verhoogen, 1960).

With the exception of garnet and anthophyllite, the mineralogic composition of Mitchell Gulch rocks agrees well with assemblages listed by Turner (1958) for the albite-epidote hornfels facies. In the writer's opinion, the appearance of these two minerals results from the unusual chemical composition of the original rock. In rocks of appropriate composition, the generation of manganoan garnet is commonplace at or before the appearance of biotite (Tilley, 1926). Tilley (1926) further noted that during contact metamorphism of regionally metamorphosed schists, almandite became unstable and a manganoan garnet is developed. Wright (1938) found that garnet associated with contact action on siliceous rocks averaged 30.7 per cent spessartite. The Mitchell Gulch garnet contains about 33 per cent spessartite, and the writer suggests that this lowered the stability of the garnet enough to allow it to be stable within the albite-epidote facies. It appears that at temperatures associated with the formation of rocks of this facies Mn behaves in part as a distinct thermodynamic component, separate from Mg and Fe^{2+} and does not readily enter biotite (Hall, 1941; Ramberg, 1952) or anthrophyllite (Rabbit, 1948).

The unusually high iron and aluminum content of the anthophyllite likely has lowered its stability field so that it too is stable in the albite-epidote hornfels environment. Bowen and Tuttle (1949) reported that magnesian anthophyllite is metastable in the presence of water vapor, and Yoder (1952) concluded that magnesian anthophyllite is only stable below 660° C. and in a water-deficient environment. Ramberg (1944) suggests that the stability relation between talc and anthophyllite is dependent in part upon the Fe:Mg ratio of the anthophyllite—the higher the ratio, the lower the inversion temperature. By analogy with other iron-magnesium silicates, in general, a limited increase in iron relative to magnesium probably would not result in any new minerals or the destruction of present minerals, but would lower the stability field of the affected phases. Barth (1952) places the upper limit of iron replacement for magnesium in anthophyllite at 50 per cent; beyond that point he believes that grunerite occurs. However, Seki and Masao (1957) report an aluminian ferroanthophyllite in which magnesium is essentially absent and with a significant substitution of AlAl for (Mg,Fe)Si. The substitution of Fe for Mg and AlAl for (Mg,Fe)Si, along with a low PH_2O would all favor the formation of anthophyllite over talc ($>H_2O, <Fe, <Al$), cummingtonite ($<Al$) and actinolite ($<Al$). The rarity of the association, albite-epidote-anthophyllite, reflects the unusual rock composition necessary for anthophyllite to be stable within the facies.

Six rocks containing andalusite and high in light-colored mica and albite were run on the diffractometer to check for paragonite. The results were negative in all cases. Apparently paragonite does not form in the albite-epidote hornfels facies. If paragonite were stable, then albite and andalusite would be incompatible, and Al and Si could form a sodium rather than a potassium mica, thus making potassium available to react with cordierite and anthophyllite to form biotite.

Which of the four mineral assemblages that formed (Fig. 1) depended upon the bulk composition of the rock. In rocks with excess potassium (microcline), anthophyllite, cordierite and andalusite were not observed; only manganoan almandite is present. This, as previously discussed, likely indicates the selective acceptance by garnet over biotite of the manganous ion.

In andalusite-bearing rocks, the ratio of MgO, FeO: Al_2O_3 is low enough to allow the formation of andalusite.

Anthophyllite and andalusite are incompatible, and Tilley (1937) found in the anthophyllite-cordierite rocks of the Lizard the relation:

$$\text{andalusite} + \text{anthophyllite} \rightarrow \text{staurolite} + \text{cordierite}$$

In the lower intensity Mitchell Gulch rocks, it appears that

$$\text{andalusite} + \text{anthophyllite} \rightarrow \text{almandite (Mn)} + \text{cordierite}$$

The association cordierite-anthophyllite does not occur in the same thin section. In view of the world-wide association of this pair, its apparent absence is a cause for concern. The writer can only suggest that the pair may be present but are not represented in the rocks examined, or as Eskola (1914) has pointed out, their co-presence may depend upon the overall composition of the rock, particularly the MgO: FeO ratio and the Al_2O_3 content. In this case high Al_2O_3 would presumably favor cordierite and garnet, whereas less Al_2O_3 would favor anthophyllite-garnet.

CONCLUSION

The chemical composition of index minerals used to establish metamorphic intensity must be taken into consideration. Because most of these "key" minerals are solid solutions, their composition will depend to a large part upon the bulk composition of the original rock. The appearance of anthophyllite in the low-grade Mitchell Gulch rocks results largely from the unusual composition of the rocks, and from the apparent instability of paragonite within the albite-epidote hornfels facies.

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REFERENCES

ANDERSON, A. L. (1931), Genesis of the anthophyllite deposits near Kamiah, Idaho. *Jour. Geol.* **39**, 68.

BARTH, T. F. W. (1934), Polymorphic phenomena and crystal structure. *Am. Jour. Sci.*, **27**, 283.

——— (1952), Theoretical Petrology. John Wiley & Sons, N. Y.

BOWEN, N. L. (1920), Optical properties of anthophyllite. *Wash. Acad. Sci. Jour.* **10**, 411–414.

——— AND O. F. TUTTLE (1949), The system $MgO-SiO_2-H_2O$. *Geol. Soc. Am. Bull.* **60**, 439–460.

BRINDLEY, C. Q. AND S. Z. ALI (1950), Thermal transformations of magnesian chlorites, *Acta Cryst.* **3**, 25–30.

DUNN, J. A. (1932), Reaction minerals in a garnet-cordierite gneiss from Mogok. *Geol. Survey India, Rec.* **65**, 445–456.

ESKOLA, PENTTI (1914), On the petrology of the Orijarvii region in southwestern Finland. *Comm. Geol. Finlande Bull.* **40**, 1–277.

——— (1936), A paragenesis of gedrite and cummingtonite from Isopaa in Kalvola, Finland. *Geol. Soc. Finlande Comptes R.* **9**, 1.

——— (1950), Orijarvii re-enterpreted. *Bull. Comm. Geol. Finlande* **150**.

FOLINSBEE, R. E. (1941), The chemical composition of garnet associated with cordierite. *Am. Mineral.* **26**, 50–53.

FRANCIS, G. H. (1955), Gedrite from Glen Urquhart, Inverness-shire. *Mineral. Mag.* **30**, 709–716.

FYFE, W. S., F. J. TURNER AND J. C. VERHOOGEN (1958), Metamorphic reactions and metamorphic facies. *Geol. Soc. Am. Mem.* **73**.

HARKER, ALFRED (1950), Metamorphism. Methuen, 3d ed.

JAHNS, R. H. (1939), Clerici solution for the specific gravity determination of small mineral grains. *Am. Mineral.* **24**, 116–122.

JOHANSSON, K. (1930), Vergleichende Untersuchungen an Anthophyllit, Grammatit und Cummingtonit. *Zeit. Krist.* **73**, 31–51.

JURRINEN, AARNO (1956), Composition and properties of staurolite. Acad. Diss., Univ. Helsinki.

LINDGREN, WALDEMAR (1925), The cordierite-anthophyllite mineralization at Blue Hill, Maine and its relation to similar occurrences. *Natl. Acad. Sci. Proc.* **11**, 1–4.

MILTON, D. J. AND J. ITO (1961), Gedrite from Oxford Co., Maine. *Am. Mineral.* **46**, 734–740.

PRIDER, REX T. (1940), Cordierite-anthophyllite rocks associated with spinel-hypersthenites from Toodyay, Western Australia. *Geol. Mag.* **77**, 364–382.

RABBIT, J. C. (1948), A new study of the anthophyllite series. *Am. Mineral.* **33**, 263–323.

RAMBERG, H. (1944), Petrological significance of subsolidus phase transitions in mixed crystals. *Norsk. Geol. Tids.* **24**, 42–74.

——— (1952), The Origin of Metamorphic and Metasomatic Rocks. Univ. Chicago Press.

SALOTTI, CHARLES A. (1962), Petrology and structure of Precambrian metasedimentary rocks near Howard, Colorado (abs.). *Geol. Soc. Am., Spec. Paper* **68**, 259.

SEKI, YOTARO AND YAMASAKI MASAO (1957), Aluminian ferro-anthophyllite from the Kitakami Mountains Land, Northeastern Japan. *Am. Mineral.* **42**, 506–520.

SHAND, S. J. (1943), Notes on cordierite: (a) Cordierite crystals from a glass furnace; (b) Cordierite from Horns Nek, Transvall. *Am. Mineral.* **28**, 391–395.

SKINNER, B. J. (1956), Physical properties of end-members of the garnet group. *Am. Mineral.* **41**, 428–436.

SRIRAMADAS, A. (1957), Diagrams for the correlation of unit cell edges and refractive indices with the chemical composition of garnets. *Am. Mineral.* **42**, 294–298.

Tilley, C. E. (1923), Paragenesis of the minerals of the three-component system MgO-Al_2O-SiO_2 in thermal metamorphism. *Geol. Mag.* **60,** 101–107.

——— (1926), On garnet in pelitic contact zones. *Mineral. Mag.* **21,** 47–50.

——— (1937), Anthophyllite-cordierite-granulites of the lizard. *Geol. Mag.* **74,** 300–309.

——— (1957), Paragenesis of anthophyllite and hornblende from the Bancroft Area, Ontario. *Am. Mineral.* **42,** 412–416.

Turner, F. J. and J. C. Verhoogen (1960)), Igneous and Metamorphic Petrology. McGraw-Hill, 2d Ed.

Warren, B. E. (1930), The structure of anthophyllite $H_2Mg_7(SiO_3)_8$. *Zeit. Krist.* **75,** 161–178.

Winchell, A. N. (1938), The anthophyllite and cummingtonite-gruenerite series. *Am. Mineral.* **23,** 329–339.

——— (1958), The composition and physical properties of garnet. *Am. Mineral.* **93,** 595–600.

Wright, W. J. (1938), The composition and occurrence of garnets. *Am. Mineral.* **23,** 436–445.

Yamada, H. (1943), On rhombic amphibole and biotite in metamorphosed slate from Wariyama, Iwate Prefecture. *Imper. Acad. Japan. Proc.* **19,** 579–581.

Yoder, H. S., Jr. (1952), The MgO-Al_2O_3-SiO_2-H_2O system and the related metamorphic facies. *Am. Jour. Sci., Bowen Vol.*, 569–627.

Manuscript received, April 6, 1962.