CONTRIBUTIONS TO THE MINERALOGY OF NORWAY

No. 26. Chromian muscovite in meta-anorthosite.

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Abstract. Chromian muscovite occurs in veins or pockets in meta-anorthosite at widely scattered localities in the Caledonides of Norway and contains 0,15—0,45% Cr, 0,001—0,008% V, and 1—5% Fe. Chlorite, epidote, biotite, hornblende, and kyanite are the most common associated minerals while a highly ordered sodic plagioclase, zoisite, muscovite, and paragonite are the most common minerals of the host rocks. The vein minerals belong to a late hydrothermal stage of the alteration of the anorthosites.

Introduction

Anorthosites in the Caledonides of Norway are often metamorphosed into schists with sodic plagioclase, epidote group minerals, and usually considerable amounts of white mica. In addition to the white mica which C. F. KOLDERUP (1903, p. 33) attributed to alteration from plagioclase, a very conspicuous bright-green mica is found in veins and small pockets in the strongly saussuritized anorthosites. This green mica is mentioned as "fuchsite" (KOLDERUP and KOLDERUP, 1940, p. 81 and OFTEDAL, 1960, p. 26) from the Bergen Arcs. Green mica in meta-anorthosites has also been noted in the Oppdal area (personal communication by P. Holmsen) and in the Sunnfjord and Nordfjord area (present work by the author). During the study of the green micas from the latter area, I felt the need to supply my material with samples from the Bergen Arcs and the Oppdal area. The present paper, therefore, gives some data on the composition and paragenesis of green micas in meta-anorthosites from widely scattered localities.

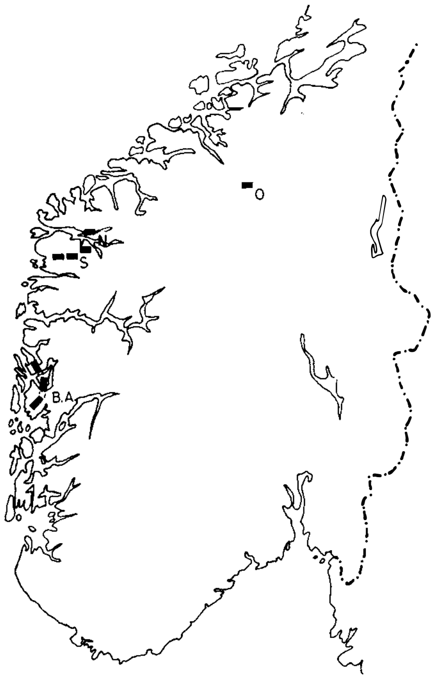

Fig. 1. Key map. Location of the described chromian muscovites in meta-anorthosite. (B.A.: Bergen Arcs, S: Sunnfjord area, N: Nordfjord area, O: Oppdal area).

Names like "fuchsite", "mariposite", and "chromiferous muscovite" have been used for green muscovite containing chromium. WHITEMORE, BERRY, and HAWLEY (1946) studied these micas and concluded that fuchsite is structurally identical with muscovite while mariposite appears to be a chromian phengite. In older literature, fuchsite has been used for green micas with more than 1% Cr_2O_3, but Whitemore, Berry, and Hawley prefer the varietal name *chromian muscovite*. The structural identity of chrome micas with muscovite has recently also been established by Lasarenko (1955) from the study of x-ray data, optical properties, and thermal dehydration curves. The term *chromian muscovite* will therefore be preferred for muscovites with an appreciable amount of chromium.

Chromium muscovite in meta-anorthosite.

The green mica occurs in aggregates of 1/2—2 mm broad flakes in irregular veins and pockets, or as thin folia parallel to the schistosity of the altered anorthosites. The border to the host rock is either

Table 1. Physical properties and mineral associations of chromian muscovite in meta-anorthosites. Minerals encloced by brackets occur in very small amounts.

Locality	b_0 ±0,02Å	$2V_x$ ±1°	β ± 0,002	Association	
				In vein	In host rock
Espevoll, Haus, Bergen Arcs	8,99	39°	1,592	Chlorite Calcite Biotite	Andesine, An 30 Zoisite Paragonite (muscovite, calcite, chlorite)
Fyllingsnes Lindåslandet, Bergen Arcs	9,01	35°	1,599	Chlorite Epidote Kyanite Biotite	Andesine, An 36 Zoisite Muscovite (biotite, calcite)
Fleslandveien Fana, Bergen Arcs	9,01	38°	1,600	Hornblende Chlorite Epidote	Andesine, An 40 Hornblende Zoisite Phlogopite
Nordal, Sunnfjord	9,01	37°	1,592	Chlorite Calcite	Albite, An 5 Zoisite Muscovite (paragonite)
Sunndalsvatn Sunnfjord	9,02	36°	1,598	Chlorite Epidote Calcite	Albite, An 8 Zoisite Muscovite (chlorite, calcite)
Lote-tunnel Nordfjordeid Nordfjord	9,01	35°	1,601	Chlorite (sagenitic) Epidote Biotite	Andesine, An 47 (chlorite, biotite, epidote, muscovite, calcite)
Rognkleiv, Hyen Nordfjord	9,02	36°	1,599	Chlorite Calcite	Andesine, An 30 Zoisite Muscovite (paragonite, chlorite).
Kvitådalen Oppdal	9,04	36°	1,600	Chlorite Epidote Calcite	Oligoclase— Andesine An 25—35 Epidote Muscovite (calcite)

sharp or transitional; hornblende on the borders of transecting veins from Fleslandveien, Fana even appears to have inclusions of green mica. The bright-green colour is conspicuous in the field, and it appears that the green mica is preferentially developed in strongly tectonized zones. Formation of the green mica probably took place at a late stage during the tectonization of the anorthosite.

The green veins consist mainly of muscovite and subordinate chlorite, epidote, biotite, and kyanite. The associated minerals indicate that muscovite formed under the conditions of the greenschist facies. The mica flakes are sometimes interleaved with chlorite, biotite, or kyanite. Thick cleavage fragments have pleochroism: Y pale yellow green and Z pale grass green, but colour and pleochroism are only slightly noticable in thin sections. Physical properties and mineral associations are listed in Table 1.

X-ray powder analysis was performed by a 22,92 cm quadruple camera with quartz and $Pb(NO_3)_2$ as internal standards. Basal reflexions indicate rather constant $d_{(002)}$ dimensions at 10,03 Å, while the (060) reflexions and the derived b_0 dimensions vary somewhat.

Axial angles were determined by U-stage on powder mounts.

The x-ray investigation revealed that the mica is a 2 M muscovite. Presence of chromium was first demonstrated spectrochemically by Prof. I. Oftedal. Later H. J. Bollingberg made spectrometrical determinations of chromium, vanadium, and total iron (Table 2):

Table 2. Spectrochemical determinations of Cr, V, and Fe in green muscovites (Analyst: H. J. Bollingberg, Mineralogisk Museum, Copenhagen).

Locality	Cr	V	Fe
Espevoll, Haus, B. A. . . .	0,40%	0,001%	1%
Fleslandsveien, B. A.	0,45%	0,006%	2—5%
Nordal, Sunnfjord	0,15%	0,005%	1,4%
Sunndalsvatn, Sunnfjord . . .	0,30%	0,008%	2—5%
Kvitådalen, Oppdal	0,20%	0,001%	1%

The determinations of Cr were made with Pb_{3234} as internal standard and are probably correct within $\pm$ 10%. The colour of the muscovite appears to be related to the chromium content because the highest Cr-values are found in bright-green micas and the lowest Cr-values are found in rather pale-green micas. It should be noted, however, that also iron and vanadium are strong pigmenting agents which might cause green colour in muscovite. The spectrochemical determinations of iron are rather rough estimates, but they indicate that the muscovite is n o t an iron-muscovite, and this is confirmed by the indices of refraction and by the b_0 dimensions which are lower than for iron-muscovite (FOSTER, BRYANT and HATHAWAY, 1960). Vanadium might also contribute to the green colour (DIETRICH, 1958) but appears to have negligible influence in this case.

Associated minerals in the green-mica veins.

A notable occurrence of green mica associated with corundum has been reported by KOLDERUP and KOLDERUP (1940, p. 81) at Rebnor, Fosnøy in the Bergen Arcs. This corundum is a ruby variety, and the reported association with chromium muscovite is similar to the green mica-kyanite veins which cut ruby pegmatite at Froland, Arendal South Norway (OFTEDAHL, 1963).*

Corundum has not been found in the veins of chromian muscovite which I have investigated, but might belong to the association. The major mineral associations in the veins are:

Chromium muscovite-epidote-chlorite-biotite-kyanite
Chromium muscovite-epidote-hornblende-chlorite
Chromium muscovite-epidote-chlorite
Chromium muscovite-chlorite

Epidote forms aggregates of about 2 mm long, irregular columns. The colour is either unnoticable or pale yellow with the yellow hue most distinct along the Z vibration direction. Some sections show anomalous blue interference colours. Highest normal interference colours are about 0.15, the axial angle is large, and the axial plane is transverse to the cleavage.

Hornblende usually form aggregates where the individual grains are about 1—5 mm. In the border-zone of a chromium muscovite vein transversing hornblende-rock near Flesland, muscovite seems to be inclosed in hornblende. Pleochroism is distinct: X colourless or pale yellow, Y (pale) green and Z (pale) blue-green. Maximum extinction Z/C is 22° and indices of refraction on cleavage fragments are about 1,661 and 1,652. These properties indicate that the hornblende might have about 23 mol % (Fe'', Mn, Ti) molecule (PARKER, 1961).

* According to personal information from N.-H. Kolderup, the ruby at Rebnor may belong to the host-rock mineral association.

Chlorite occurs in flakes up to a couple of mm in length or in thin blades interleaved with pale biotite or muscovite. Polysynthetic twinning may be noticed on sections with favourable orientation. A pale-green colour may be seen in thin section, but the flakes are usually colourless and have normal low interference colours. Optic angle is very small and elongation either positive or negative. Sagenitic inclusions are common in chlorite from the Lote-tunnel.

Biotite from a muscovite-epidote-chlorite-kyanite vein between Fyllingsnes and Eikangervåg is intimately interleaved with chlorite and muscovite. The pleochroism, X colourless, Y and Z pale brown ochre might indicate a low iron content.

Kyanite occurs as usually less than 1/2 mm grains which sometimes are interleaved with muscovite. Pleochroism is not distinct in thin section, but well defined in powder mount: X colourless, Y pale blue, Z pale blue. Crushed fragments have a bright-blue colour. Indices of refraction are rather high: $\alpha' = 1{,}718$, $\beta = 1{,}726$ and $\gamma = 1{,}732$, which perhaps is due to a slight content of chromium replacing aluminium in the lattice. Kyanite may show partial alteration into an aggregate of pale-brown scales which appear to be biotite. The alteration proceeds irregularily from the border and is most distinct at hornblende contacts.

Accessory minerals. Both biotite and kyanite occur in such small amounts in the green-mica aggregates that they might be termed accessory minerals. Other minerals which are present in accessory amounts are *rutile, sphene, zircon, pyrite, magnetite* and sometimes also *quartz* and *calcite*.

Minerals in the host rock.

Some of the minerals of meta-anorthosites are impossible to distinguish optically, and the host rocks of the investigated green micas and some purified minerals were finely ground and studied by x-ray diffractometer.

Feldspar. The feldspar is a sodic plagioclase which is thoroughly recrystallized and usually devoid of polysynthetic twinning. The composition, determined by indices of refraction on cleavage fragments, varies from albite to calsic andesine. Order-disorder relations have been evaluated by the method given by SLEMMONS (1962), who defined the "intermediacy index" for plagioclases as a number varying from 0 in extremely disordered types to 100 in the thoroughly ordered types. The intermediacy index was evaluated for the plagioclases of meta-anorthosites by the separation of the (131) and ($1\bar{3}1$) reflexions. The only slightly altered meta-anorthosite from the Lote tunnel, Nordfjord, has an intermediacy index of about 60, while the thoroughly altered meta-anorthosites have intermediacy indices about 100. The feldspar associated with abundant epidote-group minerals and white mica in meta-anorthosite therefore is a highly ordered sodic plagioclase.

Epidote group minerals. Epidote minerals appear in thin section as columns with a highly preferred orientation in the foliation plane. Sometimes a poikiloblastic texture and zonal differences in interference colours can be noted. The axial angle of an epidote group mineral from Fyllingsnes with zonation is about + 35° and axial plane is transverse to the cleavage plane. X-ray techniques (SEKI, 1959) revealed that it is a β-zoisite, and this mineral is more frequent than epidote (or possibly clino-zoisite) in the meta-anorthosites which I have studied.

White mica. White mica forms irregular, tiny inclusions in feldspar in the least altered anorthosites and several-millimetres-broad flakes which curve around the other minerals in the more strongly recrystallized types. Muscovite is the major white mica in most of the investigated samples and paragonite is the major white mica in one sample. Both types of white mica are present in three samples, and both are of the 2 M type. Separation of the basal reflexions is easily recognizable and basal spacing was determined from the (006) reflexion:

Muscovite, $d_{(002)}$ 9,92 Å (Espevoll, Haus).
Paragonite, $d_{(002)}$ 9,63 Å

(Quartz was added as an internal standard; limits of error are less than ± 0,03 Å).

Paragonite is reported to have very small optical angle (ROSENFELD, 1956; DIETRICH, 1956), but the well crystallized paragonite from Espevoll has $2\,V_x = 42°$ (± 1°) and $\beta = 1{,}600$ (± 0,002) and corresponds closely with the mica described by Harder (HARDER, 1956). The Espevoll paragonite therefore cannot be distinguished optically from muscovite. Margarite, with nearly the same X-ray pattern as paragonite, but readily identifiably by the high index of refraction, has not been identified in the meta-anorthosites.

Chlorite. Dark-green chlorite is only an accessory mineral in white meta-anorthosite but may be abdudant in dark layers and even relatively pure in veins or small aggregates. A chlorite separated from a hornblende-rich dark layer at Nordal had basal spacing at d = 14,3 and relatively weak first and third basal reflexions. These proporties might indicate that the chlorite is relatively rich in iron (BRINDLEY, 1961, p. 261).

Accessory minerals. Chlorite is present in very small amounts in the white meta-anorthosites and only a few of the diffractometer charts have the characteristic 7 Å reflexion. Biotite and calcite might be noted in some diffractometer charts while rutile and sphene only can be noted in powder mounts or thin sections.

Formation of chromian muscovite.

Anorthosites often have a high content of aluminia which results in the formation of corundum (CARLSON, 1957). The anorthosites of the Bergen Arcs have garnet, corundum, spinel, høgbomite and staurolite (N.-H. KOLDERUP, 1936) associated with pyroxene and hornblende. These minerals seem to disappear when the anorthosites are transformed into rocks with sodic plagioclase, epidote minerals, and mica. The surplus of aluminia in meta-anorthosites obviously is present in the mica.

The formation of white and green mica probably took place at different stages during the metamorphism of the anorthosites. Veins of green mica often cut folia of white mica in the schistosity surface, and give the impression of a late hydrothermal origin. Inclusions of green mica in hornblende and *vice versa* and intimate mixtures of the minerals of the green veins with those of the host rock indicate, however, that tectonization and formation of secondary minerals in the anorthosites was more or less contemporaneous.

Chromium for the green mica was derived either from the anorthosites themselves or from external sources. In the first case it might be concentrated during some stage of alteration of anorthosites:

1. Saussuritization of plagioclase
2. Sericitization of plagioclase
3. Decomposition of original dark minerals into amphibole or chlorite.

The ionic-radius of Cr^{3+} is close to the radius of Al^{3+}, and diadochy for chromium therefore is possible. But plagioclase has aluminium in 4-coordination, and this structure cannot permit entry of chromium for aluminium (RANKAMA and SAHAMA, 1950, p. 662). Alteration of plagioclase therefore is not likely to give any chromium available for formation of green mica.

Decomposition of the dark minerals is more likely to give a surplus of chromium. Chromium replace aluminium if there are AlO_6-groups in the structure, and also Fe^{3+}, Ti^{4+}, Fe^{2+} and Mg^{2+} in the structure of the dark minerals. The derivation of chromium therefore might be linked to some stage of alteration of the dark minerals.

Extensive study of chromium in the dark minerals of anorthosite has been beyond the scope of this work, but the following data have some significance:

Table 3. Spectrometrical determinations of chromium in some dark minerals in meta-anorthosite, Florevikja, Nordal, Sunnfjord. (Analyst H. J. Bollingberg, Mineralogisk Museum, Copenhagen).

	Cr
Hornblende, Nordal, Sunnfjord	0,015%
Magnetite, — ...	0,24 %
Chlorite, — ...	0,02 %

The Cr-determinations are too few to permit any conclusions, but it is interesting that chlorite and hornblende have a low content of chromium. Chlorite and hornblende are probably alteration products of other dark minerals like pyroxene and garnet in the anorthosite, and some chromium might have been concentrated in the intergranular fluids during the alteration.

Addition of chromium from external sources must also be considered. The great amount of muscovite in some meta-anorthosites and the veins of relatively pure green mica represent a high concentration of potassium and is indicative of potassium metasomatism during metamorphism. The veins of green mica therefore probably belong to a late hydrothermal stage with components partly derived from decomposition of dark minerals in the anorthosite itself and partly from external sources.

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