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Green micas in the Archaean Isua and Malene supracrustal rocks, southern West Greenland, and the occurrence of a barian-chromian muscovite

R. F. Dymek, J. L. Boak and M. T. Kerr

Abstract

Chemical analyses of green micas from the Archaean Isua and Malene supracrustal rocks of southern West Greenland reveal an exceedingly large compositional range from nearly pure muscovite to types with up to ~ 17 wt % Cr_2O_3 and ~ 8 wt % BaO. Large variations in the concentrations of MgO and FeO^T (up to ~ 3 wt % each), TiO_2 (up to ~ 2 wt %) and Na_2O (up to ~ 1 wt %) were also noted. These Ba- and Cr-rich micas are unlike previously reported analyses of 'fuchsite', and may constitute a new species of mica, the confirmation of which awaits additional mineral-chemical and crystallographic study.

Ba-substitution on the mica interlayer- or A-site occurs continuously up to ~ 0.22 cations/formula (11 oxygen normalization), whereas Cr-substitution on the octahedral sites occurs continuously up to ~ 0.45 cations/formula, followed by a compositional hiatus to types with ~ 0.90 cations/formula. This hiatus may indicate a miscibility gap in the Cr-Al series.

Ba-substitution $[Ba^{A}Al^{IV} = K^{A}Si^{IV}]$ is approximately balanced by Mg- and Fe-substitution $[(Mg, Fe)^{VI}Si^{IV} = Al^{VI}Al^{IV}]$ so that the tetrahedral site is $\approx Si_3Al$. Whether this lack of Al-enrichment is a crystal-chemical effect or represents bulk composition control is unclear.

The Ba- and Cr-enrichment in these micas is a distinct geochemical anomaly, the origin of which is problematic. The Ba and Cr may have evolved from detrital chromite and sedimentary barite components in the sedimentary protolith, or be related to secondary processes such as deposition from circulating hydrothermal fluids.

Introduction

Schists and gneisses containing green mica, commonly referred to in the field as 'fuchsite quartzite', constitute a widespread, but minor component in the Archaean supracrustal rocks of southern West Greenland. Because of their striking green color, such rocks comprise easily recognizable marker horizons that aid in geological mapping. Throughout the Godthåbsfjord-Ameralik region, there is an overall spatial association between green mica rocks in the > 3000 Ma Malene supracrustal suite and adjacent Amîtsoq gneiss. In fact, Chadwick & Nutman (1979) have suggested that Malene green mica rocks in the northwest Buksefjorden region may mark the position of an originally unconformable supracrustal-gneiss contact. In the ~ 3800 Ma Isua supracrustal belt, green mica rocks are not associated with quartzofeldspathic orthogneiss, although ultramafic bodies (talc schist/serpentinite) commonly occur nearby.

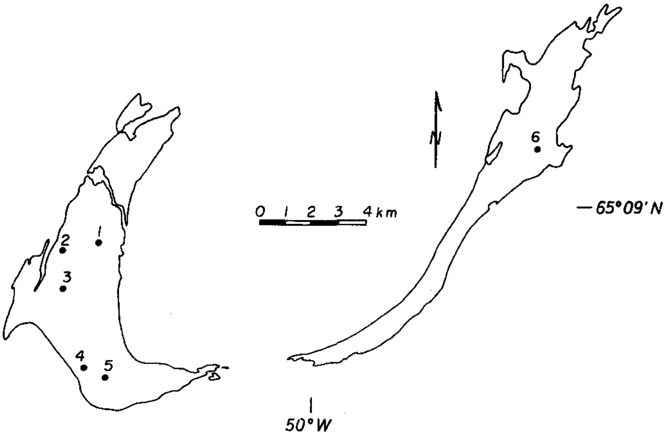

Fig. 1. Sketch map of the Isua supracrustal belt illustrating locations of green mica rocks. (1) IW801–2A, (2) GGU 173193. (3) IW807–4B, 4D, 5, 5A; GGU 173184. (4) IW811–11; GGU 168262. (5) GGU 173274. (6) ID25–12; ID999; GGU 173137.

Despite abundant field observations on the occurrence of green mica rocks, it is exceedingly difficult to assess their stratigraphic and petrogenetic significance since virtually nothing is known about their mineralogy and chemistry.* For example, although the green micas are termed 'fuchsite', previous analyses by one of us on a sample collected in Ameralik fjord indicated that it was ordinary muscovite with a low Cr-content (< 0.4 wt % Cr_2O_3).

In an attempt to clarify the nature of these rocks and to place some constaints on their origin, we summarize in this paper the principal mineral-chemical characteristics of green micas found in both the Isua and Malene supracrustals based on the results of a recently-completed electron microprobe study. We have found an unanticipated large range in chemical composition, and report here the discovery of an unusual barian-chromian muscovite which may constitute a new mica species.

Occurrence and sample description

Isua supracrustals

Samples of green mica rock were studied from six localities within the Isua supracrustal belt (fig. 1). The most common type is a fine-grained, dense, emerald-green quartzite known locally as 'grønlandit'. These rocks are typically laminated on a millimetre-scale, and contain 5–10% disseminated mica plates that are faintly pleochroic from colorless to pale-green. In some quartzitic samples, green micas are restricted to discrete thin laminae, which impart a striped pattern to the rock, whereas other samples are dull green schists comprised of >

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* Ghisler (1976) has reported a green mica with ~ 1.9 wt % Cr_2O_3 collected from a shear zone in anothosite from the Fiskenæsset region. This occurrence is distinctly different from the ones considered here.

90% mica containing scattered sugary white quartzite lenses. All gradations exist between the bright green quartzites and dull green schists. The overall appearance of these samples suggests that they are metamorphosed cherts which contained variable amounts of clay-rich layers. Locally, these types are associated with outcrops of banded ironstone.

Green micas also occur in quartz-rich lenses in biotite schist, containing abundant accessory tourmaline and rutile. These mica-bearing lenses have a characteristic 'vein-shape' elongated parallel to compositional layering, and are secondary in origin, as the micas demonstrably replace plagioclase of the host biotite schist. The genetic significance of these replacement textures are unclear at the present time.

Most occurrences of green mica rocks and associated quartzites form discontinuous pods and lenses in a rather uniform sequence of amphibolites. Although these appear to be metasedimentary interlayers, the possibility that the green mica rocks are xenoliths or inclusions in the amphibolites cannot be ruled out completely. However, pods of ultramafic rock crop out within a few hundered meters (or less) of each green mica locality. In one case, the green mica rocks are found less than 10 m from a contact with talc schist.

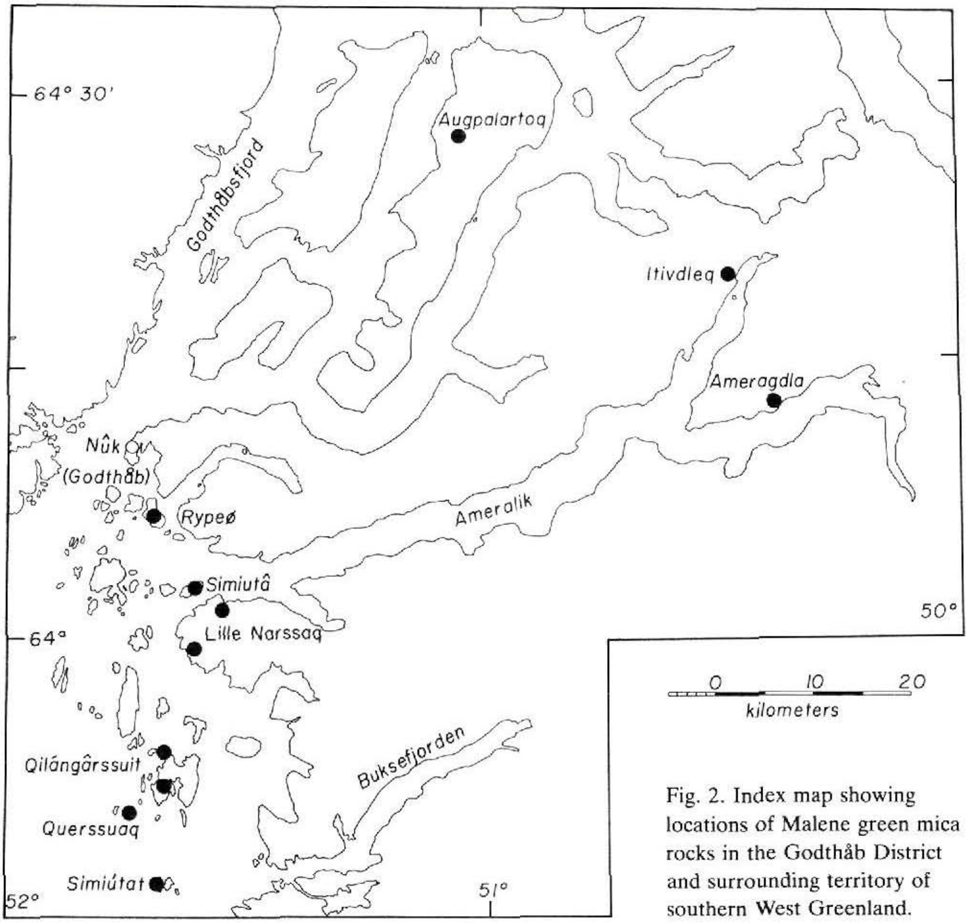

Fig. 2. Index map showing locations of Malene green mica rocks in the Godthåb District and surrounding territory of southern West Greenland.

Malene supracrustals

A total of 27 occurrences of green mica rocks were sampled at the eight localities illustrated in figure 2. In general, the Malene green mica rocks can be divided into four principal types:

(1) massive to laminated, coarsely-crystalline quartzite containing only a trace of mica flakes ($\leq \sim 1\%$). The mica in this association ranges from bright emerald green to grass green, and may occur with plagioclase, microcline, sillimanite, rutile, zircon and sulfide;

(2) fine-grained sugary to medium-grained granular quartzitic schists with well-defined layering. These contain up to 50% pale to bright green mica, and traces of rutile, zircon, feldspar, sillimanite and sulfide;

(3) quartz + biotite + plagioclase ± sillimanite schists with scattered (up to $\sim 2 \times 25$ mm) laminae of kelly green mica. Bright red garnet occurs in two samples from this group;

(4) quartz + biotite + plagioclase ± microcline + muscovite ± garnet gneisses in which some of the muscovite forms clots surrounding sillimanite. Accessory zircon, sulfide and

Table 1. Microprobe analyses of Isua green micas

		1	2	3	4	5	6	7
	SiO_2	46.71	46.04	46.51	45.02	41.85	40.78	42.32
	Al_2O_3	34.65	35.87	34.44	31.98	32.00	29.05	33.64
	Cr_2O_3	0.76	1.29	0.98	1.43	1.63	3.21	0.48
	TiO_2	0.29	0.49	0.51	1.25	1.38	1.40	1.09
	MgO	0.82	0.40	0.83	1.39	1.31	1.82	1.11
	FeO*	1.07	0.84	1.33	1.52	1.62	2.96	1.86
	ZnO	0.00	0.05	0.00	0.22	0.00	0.87	0.11
	MnO	0.02	0.00	0.02	0.02	0.01	0.08	0.02
	CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	BaO	0.36	0.39	0.63	2.93	6.52	7.76	6.91
	Na_2O	0.56	0.79	0.61	0.39	0.52	0.46	0.41
	K_2O	10.17	9.70	10.01	9.52	8.39	7.68	8.13
	F	0.05	0.05	0.00	0.00	0.00	0.31	0.00
	Cl	0.02	0.00	0.00	0.01	0.00	0.02	0.02
	Total†	95.45	95.89	95.87	95.68	95.23	96.27	96.10
					FORMULA PROPORTIONS BASED ON 11 OXYGENS			
IV	Si	3.107	3.047	3.092	3.070	2.950	2.929	2.947
	Al	0.893	0.953	0.908	0.930	1.050	1.071	1.053
VI	Al	1.825	1.845	1.792	1.642	1.610	1.390	1.710
	Cr	0.040	0.068	0.052	0.077	0.091	0.182	0.026
	Ti	0.015	0.024	0.026	0.064	0.076	0.076	0.057
	Mg	0.081	0.039	0.082	0.141	0.138	0.195	0.115
	Fe	0.060	0.046	0.074	0.087	0.096	0.178	0.108
	Mn	0.001	0.000	0.001	0.001	0.001	0.005	0.001
	Zn	0.000	0.002	0.000	0.011	0.000	0.046	0.006
A	Ca	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Ba	0.009	0.010	0.016	0.078	0.180	0.218	0.189
	Na	0.072	0.101	0.079	0.052	0.071	0.064	0.055
	K	0.863	0.819	0.849	0.828	0.755	0.704	0.722

1. IW801-2C 2. 173137 3. 173193 4. 173274 5. IW811-11B 6. IW807-4B 7. 168262

**Total iron as FeO.*

†Minus oxygen for F and Cl.

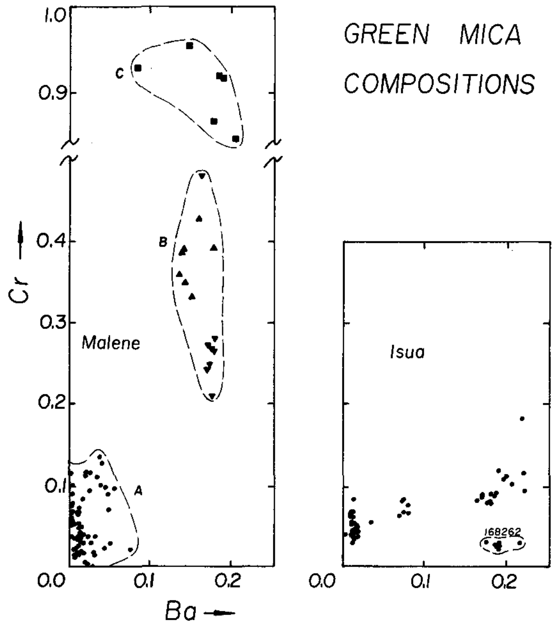

Fig. 3. Formula proportions Cr and Ba in green micas from the Isua and Malene supracrustal rocks based on an 11 oxygen normalization. For the Isua samples, there is a general increase of Cr with increasing Ba; the data for sample 168262 – which is nearly 100% mica – depart from this trend. For the Malene samples, three types are distinguished: Type A – low Ba and Cr; Type B – high Ba and Cr; Type C – high Ba and extreme Cr.

rutile minerals occur in all samples. The mica ranges in color from pale mint green to olive green, and is transitional to ordinary schists with colorless muscovite.

Group (1) associations are invariably found in direct contact with Amîtsoq gneiss, and include localities noted by Chadwick & Nutman (1979). Group (2) typically occurs as isolated layers in brown biotite-rich paragneiss, and together with groups (3) and (4), are found in Malene units that abut against Amîtsoq gneiss.

The green micas in the more quartz-rich lithologies appear to be the primary products of prograde metamorphism although rare inclusions of sillimanite suggest that some micas are secondary. Textural features in group (4) samples, in which the muscovite replaces sillimanite, indicate a retrograde origin for much of the mica.

Chemical composition

Isua Supracrustals

Representative analyses of Isua green micas are listed in Table 1, which shows that the compositions depart considerably from end-member muscovite: $KAl_2 \square Si_3AlO_{10}(OH)_2$. The concentrations of MgO (~ 0.4–1.9 wt %), FeO (~ 0.9–3.0 wt %) and TiO_2 (~ 0.4–1.4 wt %) in each sample are relatively high. MnO and ZnO are typically low (< 0.1 wt %), although one sample contains ~ 0.9 wt % ZnO. Na_2O contents are in the range 0.4–0.8 wt %, but there is no detectable CaO.

Most noteworthy, however, are the high concentrations of Cr_2O_3 (up to 3.2 wt %) and BaO (up to ~ 8 wt %). These data on Ba and Cr are summarized in figure 3, which suggests an overall trend of increasing Ba with increasing Cr. The circled data points that depart from this trend are from a single sample (168262), which consists of > 98% mica.

Malene Supracrustals

Representative analyses that span the range of measured compositions are listed in Table 2. In general, the Malene green micas have compositional characteristics broadly similar to the Isua ones, and include types rich in Ba and Cr.

The Ba- and Cr-contents of the Malene green micas are illustrated in figure 3, which distinguishes three types. Type A is characterized by low to moderate BaO and Cr_2O_3 (~ 0.1–1.7 wt % and ~ 0.1–2.5 wt % respectively), and includes samples from all the field groups described previously. Interestingly enough, even those micas with the very lowest Cr_2O_3 have the characteristic Kelly green color ascribed to 'fuchsite'. Types B and C contain higher BaO (~ 4–6 wt %) and Cr_2O_3 (~ 5–17 wt %), and are found only among field group (1), the coarsely-crystalline quartzites.

Table 2. Microprobe analyses of Malene green micas

		1	2	3	4	5	6	7	8
	SiO_2	46.37	46.03	45.72	47.70	45.48	42.61	41.41	40.80
	Al_2O_3	36.00	35.66	34.37	28.60	32.89	25.86	33.25	23.47
	Cr_2O_3	0.15	0.30	0.70	2.19	0.41	8.51	5.06	16.79
	TiO_2	0.43	0.13	1.68	1.34	0.55	0.81	0.48	0.16
	MgO	0.63	0.84	0.89	1.83	1.56	2.77	0.55	0.77
	FeO*	0.54	1.16	0.91	2.90	2.85	0.06	0.00	0.23
	ZnO	0.11	0.00	0.00	0.00	0.00	0.47	0.00	0.21
	MnO	0.00	0.00	0.01	0.02	0.00	0.04	0.02	0.05
	CaO	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.00
	BaO	0.35	0.35	0.27	0.75	1.66	5.72	6.42	5.10
	Na_2O	1.10	0.56	0.62	0.27	0.41	0.48	0.53	1.02
	K_2O	8.83	10.53	9.63	10.21	10.41	8.47	8.29	8.49
	F	0.09	0.00	0.07	0.00	0.16	0.39	0.14	0.00
	Cl	0.01	0.01	0.00	0.00	0.02	0.01	0.02	0.01
	Total†	94.60	95.57	95.05	95.81	96.33	96.03	96.11	97.09
				FORMULA PROPORTIONS BASED ON 11 OXYGENS					
IV	Si	3.081	3.063	3.052	3.222	3.072	3.025	2.892	2.929
	Al	0.919	0.937	0.948	0.778	0.928	0.975	1.108	1.071
VI	Al	1.902	1.861	1.758	1.500	1.692	1.190	1.630	0.916
	Cr	0.008	0.016	0.037	0.117	0.022	0.478	0.279	0.953
	Ti	0.021	0.007	0.084	0.068	0.028	0.043	0.025	0.009
	Mg	0.062	0.083	0.089	0.184	0.157	0.293	0.057	0.082
	Fe	0.030	0.065	0.051	0.164	0.161	0.004	0.000	0.014
	Mn	0.000	0.000	0.000	0.001	0.000	0.002	0.001	0.011
	Zn	0.005	0.000	0.000	0.000	0.000	0.025	0.000	0.003
A	Ca	0.000	0.000	0.015	0.000	0.000	0.000	0.000	0.000
	Ba	0.009	0.009	0.007	0.020	0.044	0.159	0.176	0.143
	Na	0.141	0.072	0.080	0.035	0.054	0.066	0.072	0.142
	K	0.742	0.894	0.820	0.880	0.897	0.767	0.739	0.778

1. OGA-16, Type A, Ameragdla
2. GRD-142, Type A, Qilángârssuit
3. GRD-704A, Type A, Augpalartoq
4. GRD-197, Type A, Querssuaq
5. GRD-1678D, Type A, Lille Narssaq
6. GRD-1679, Type B_1, Lille Narssaq
7. GRD-1679, Type B_2, Lille Narssaq
8. GRD-1679, Type C, Lille Narssaq
**Total iron analyzed as FeO.*
†Minus oxygen for F and Cl.

The data for types (B) and (C) includes analyses from zoned single crystals. For example, in sample GRD 1679, pleochroic azure cores (~ 13–17 wt % Cr_2O_3) are separated from paler green rims (~ 5–8 wt % Cr_2O_3) by a sharp optical discontinuity. In addition, type (B) and (C) micas are intergrown with Ba-rich microcline (~ $Or_{60}Ab_{10}Cn_{30}$). Therefore, the Ba-contents of these micas should approach a saturation limit for the conditions of formation of these samples.

Discussion

In the previous sections, we have described the different occurrences of green micas in supracrustal rocks from West Greenland, and summarized the large range of compositions found. In this section, we continue the discussion on the chemical compositions as it relates to cation substitutions. In addition, we compare our results to previous studies of 'fuchsite' and speculate as to the origin of the green micas in our samples.

Cation substitutions

An important substitution in the green micas involves replacement of Al^{3+}(0.530Å) by Cr^{3+}(0.615Å) on octahedral sites (ionic radii from Shannon, 1976). This substitution not only causes expansion of the octahedra to accommodate the larger cation, but also involves distortions of the basic mica sheet structure. The large range of Cr-content found in the green micas from West Greenland permits some constraints to be placed on the crystal-chemical aspects of Cr-substitution.

In the samples from Isua, Cr-contents ranges continously from ~ 0.02 to ~ 0.15 cations/formula (fig. 3). We anticipate that analyses of other samples will not alter the observed trends.

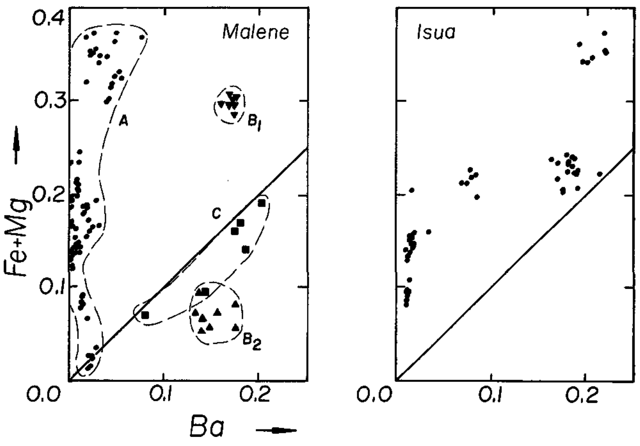

Fig. 4. Formula proportions (Fe + Mg) and Ba in green micas from the Isua and Malene supracrustal rocks based on an 11 oxygen normalization. For the Isua samples, (Fe + Mg) increases with increasing Ba. Type A Malene green micas have uniformly low Ba, but a substantial range of (Fe + Mg). Type B Malene green micas include two varieties: subtype B_1 with (Fe + Mg) > Ba, and high TiO_2 (~ 0.9 wt %), and subtype B_2 with (Fe + Mg) < Ba, and low TiO_2 (~ 0.4 wt %). Type C has (Fe + Mg) ≈ Ba and low TiO_2 (~ 0.2 wt %).

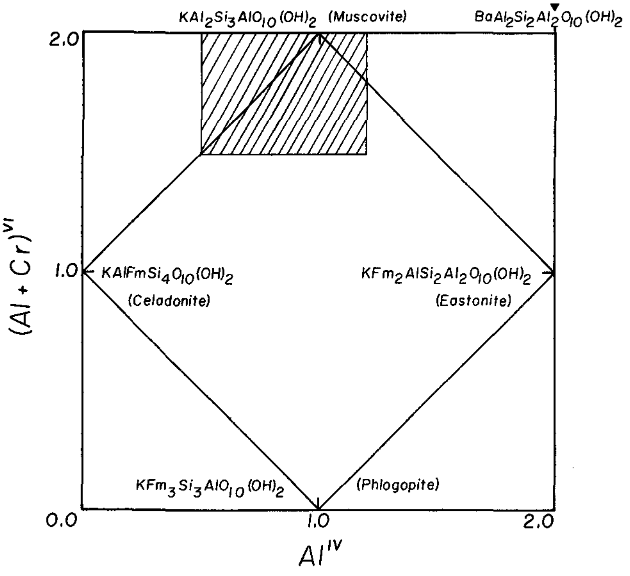

Fig. 5. Schematic Al^{VI}-Al^{IV} variation diagram for micas illustrating the general relationship between end-member Muscovite [$KAl_2\square Si_3AlO_{10}(OH)_2$], Ba-mica [$BaAl_2\square Si_2Al_2O_{10}(OH)_2$], and Celadonite [$KFmAl\square Si_4O_{10}(OH)_2$]. For the sake of completeness, the compositions of Phlogopite-Annite [$KFm_3Si_3AlO_{10}(OH)_2$] and Eastonite [$KFm_2AlSi_2Al_2O_{10}(OH)_2$] are also shown. The hachured area is expanded in Figure 6. (Fm = Mg + Fe + Mn + Zn).

In the Malene samples, the low-Ba micas (type A; fig. 3) contain up to ~ 0.13 cations Cr/formula, whereas the high-Ba micas fall into two groups: type B and C contain ~ 0.20–0.47 and ~ 0.84–0.95 cations Cr/formula respectively. The dramatic compositional hiatus in these Cr-rich micas corresponds to the optical discontinuity observed in thin section. Thus, complete Cr-Al solid solution does not occur, and it is possible that these data reflect a miscibility gap.

Substitution of Ba^{2+}(1.61Å) for K^{+}(1.64Å) on the mica interlayer or A-site should not be inhibited from the standpoint of cation size, but requires charge compensation according to the relationship: $Ba^{A} + Al^{IV} = K^{A} + Si^{IV}$. Therefore, incorporation of large amounts of Ba into muscovite should cause a distinct increase in the amount of tetrahedral Al. On the other hand, substitution of Mg^{2+} and Fe^{2+} into muscovite, which can be described by the relationship: $(Mg, Fe)^{VI} + Si^{IV} = Al^{VI} + Al^{IV}$, will cause tetrahedral Al to decrease. Since the Greenland micas contain substantial Ba, Fe and Mg (Tables 1 and 2), the amount of Al^{IV} will be determined by the way in which the two above-mentioned substitutions balance each other.

These relationships are summarized in figure 4, which illustrates formula proportions (Fe + Mg) plotted against Ba. In the Isua micas, (Fe + Mg) exceeds Ba in all cases suggesting that an increase of Al^{IV} associated with Ba is compensated by Mg and Fe*. The data for the Malene green micas are somewhat more complex: Type A has $(Fe + Mg) > Ba$, whereas type B has $(Fe + Mg) \gtrless Ba$, and type C has $(Fe + Mg) \approx Ba$.

Figure 6 illustrates formula proportions $(Al + Cr)^{VI}$ and Al^{IV}; this diagram describes the combined effects of Ba, Mg, and Fe on the Al-content of muscovite, as shown schematically in figure 5. Isua green micas display a trend of decreasing $(Al + Cr)^{VI}$ with slightly increasing

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* This figure and discussion assumes that all iron is Fe^{2+}. This conclusion must be modified to the extent that some of the iron occurs as Fe^{3+} directly replacing Al^{3+} on octahedral sites.

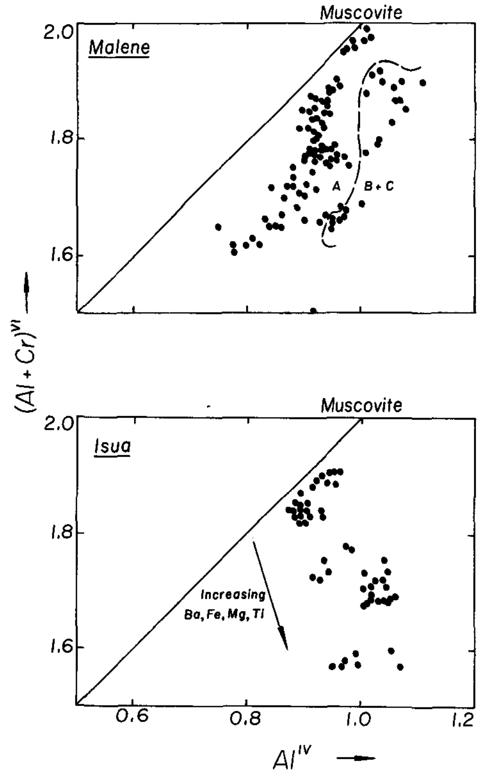

Fig. 6. Formula proportions Al^{IV} and $(Al + Cr)^{VI}$ in green micas from the Isua and Malene supracrustals based on an 11 oxygen normalization. The Isua data suggest a trend of increasing Al^{IV} with decreasing $(Al + Cr)^{VI}$, whereas in the Malene green micas, Al^{IV} and $(Al + Cr)^{VI}$ both decrease. (See text for discussion).

Al^{IV}. The fact that $Al^{IV} \approx 1$ (total range 0.88 to 1.07) affirms the suggested balance between Ba and (Fe + Mg) alluded to previously. The marked decrease of $(Al + Cr)^{VI}$, also caused by substitution of (Fe + Mg), correlates with increasing Ti, consistent with a substitution of the type $[(Mg, Fe) + Ti)]^{VI} = [2(Al + Cr)]^{VI}$.

Type A Malene green micas have Al^{IV} in the range ~ 0.75 to ~ 1.02, consistent with their low Ba and relatively high (Fe + Mg) contents (cf. fig. 4). The Ba-rich type B and C micas are systematically shifted towards higher Al^{IV}. $(Al + Cr)^{VI}$ in these analyses is also decreased by Ti, which ranges up to ~ 0.10 cations/formula.

Comparison with earlier work

Several papers reporting on the chemical compositions of green micas have appeared within the last few years (e.g. Chen & Lee, 1974; Sadashivaiah & Karisiddaiah, 1976; Ghisler, 1976; Devaraju & Murthy, 1978; Cooper, 1980), but in general the literature on 'fuchsite' is sparse and incomplete, especially in view of the high Ba-contents reported here, as most previous investigators either neglected to analyze for that element or did not report a measurement. The original analysis of 'fuchsite' from the type locality (Schwartzenstein, Zillerthal, Austria) lists more than 5 Wt % Cr_2O_3 (Dana, 1892). Other published analyses of 'fuchsite' indicate a large range of Cr_2O_3-content, with the vast majority in the range 0.8

to 4.6 wt %; the highest previously recorded value being 6.08 wt % (Wherry, 1916). However, Dana (1892, p. 617) describes avalite, a green 'mica' with ~ 14 wt % Cr_2O_3 occurring "...in earthy aggregates of thin crystalline scales in the quartzyte of Mt. Avala, near Belgrade". (Clifford, 1967). However, the analysis was carried out on impure material containing chromite and quartz, and the status of avalite as a pure mineral is exceedingly doubtful.

Whitmore (1947) suggested that muscovite with Cr_2O_3-contents > 1 wt % be called 'fuchsite', and those with lesser amounts be refferred to as 'chromiferous muscovite'. In view of the fact that our results indicate that only small amounts of chromium (~ 0.10 wt %) are needed to impart the characteristic kelly green color to this mineral, an analysis and due caution are needed before the name 'fuchsite' can be applied.

The contents of MgO (~ 0.7–5.0 wt %) and FeO + Fe_2O_3 (~ 1–6 wt %) in published analyses are highly variable, but mostly in the 2–3 wt % range. TiO_2 ranges up to 2%, but most investigators neglected to report a measurement. BaO is likewise rarely analysed for, although Matthews (1967) and Hutton (1942) reported 1.07 and 0.15 wt % respectively. The Ba-rich mica, oellacherite, contains 4–6 wt % BaO, but no Cr_2O_3 (Strunz, 1970). However oellacherite has a 1M structure, in contrast to the $2M_1$ structure that characterizes the green micas from Greenland which we have studied crystallographically.

This brief review of previous work certainly suggests that the barian-chromian micas from West Greenland have compositions unlike any reported in the past. In particular, type C Malene green micas (see Table 2, No. 8), have high Ba and Cr $\approx$ Al, and may constitute a new species of dioctahedral mica. However, the lack of data on Ba in green micas from other localities makes such a conclusion tentative, and we are following up this study with a general investigation of fuchsite in order to evaluate this possibility.

Origin of barium and chromium enrichment

Perhaps the most intriguing aspect of our mineral-chemical study involves the origin of the Ba and Cr in these micas, especially since Ba-Cr is not usually considered a geochemically coherent element pair. Two equally plausible models are considered:

(1) Ba and Cr were fixed in mica during metamorphism of protolith containing detrital chromite and sedimentary barite; and,

(2) barian-chromian micas were deposited from circulating hydrothermal fluids.

Malene type A green micas occur in clastic metasediments (quartzitic to psammitic schists), and it is not unreasonable to attribute the modest amounts of Cr in them to an originally detrital chromite component. The Ba-content ranges to higher values than are found in musovite from typical pelitic metasediments (e.g. Guidotti, 1974), and special circumstances appear necessary to explain its presence.

Similarly, for Malene type B and C green micas, which occur in massive quartzites, a detrital chromite component also seems reasonable. As noted previously, these micas are exceedingly Ba-rich and some coexist with barian microcline. It is interesting to note in this regard that on Qilângârssuit, an island ~ 40 km south of Godthåb (fig. 2), green mica schists (including ones with Cr-rich green garnet and epidote) are associated with a small outcrop of calcite marble that contains microcline. Hence, there is at least one Malene supracrustal locality where there is a spatial association between green mica schists and chemical sediments.

We suggest that the chemical characteristics of the Malene green micas are explained adequately by invoking chromite as a source for Cr, and sedimentary barite, which was mixed into the clastic rocks, as a source for Ba. The interlayered 'fuchsite' schist – barite deposits described recently by Devaraju & Murthy (1978) in Archaean rocks from the Chitradurga District, India may be a direct analogue to the Malene occurrences. Unfortunately, these authors did not report Ba analyses of their green micas. In the Malene supracrustals, any barite that was present originally could have broken down during high-grade metamorphism ($T > 525°C$) by a reaction of the type:

$$\begin{array}{ll} 2\,BaSO_4 + FeCr_2O_4 = FeS_2 + 2\,BaO + Cr_2O_3 + 7/2\,O_2 \\ \text{barite} \quad + \text{chromite} = \text{pyrite} + \text{`mica'} \end{array}$$

It is interesting to note that pyrite occurs in virtually every Malene green mica rock.

At Isua, the green mica rocks occur with quartzitic gneisses that we interpret to be metamorphosed ribbon cherts. The close spatial association with ultramafic rocks may be fortuitous, but these could have provided a source of Cr. In general, an origin by mixing of detrital chromite and clay with sedimentary chert and barite is consistent with many of the data and field observations.

However, in some Isua samples, the green micas occur in quartzitic veinlets replacing biotite schist. These 'vein' associations are otherwise indistinguishable from more massive, homogeneous green mica quartzites, and suggest a secondary and possibly external source for the green micas. Although this feature could simply be due to local remobilization, the formation of all the green micas (Isua *and* Malene) by deposition from circulating hydrothermal fluids should be considered. We envision the situation in which Cr is leached from chromite, pyroxene, etc., and Ba is leached from feldspar; these are carried in solution and deposited as a mica (or clay precursor) in a 'favorable' environment. Except for the unusual mica compositions, this process is identical to sericitic alteration caused by hydrothermal solutions in a multitude of geological environments. However, any further conclusions on this model are premature, as the relevant solubility data (particularly for Cr) and the conditions necessary for Ba and Cr transport in hydrothermal solutions (pH, f_{O_2}, complexing etc.) are meager to non-existent.

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Department of Geological Sciences,
Harvard University,
Cambridge, Massachusetts 02138,
USA.