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CHROME MICA-CLAY, TEMPLE MOUNTAIN, UTAH

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ABSTRACT

Chrome mica-clay occurs at Temple Mountain, Utah in association with uranium mineralization. It contains approximately 0.4 to 0.6 per cent Cr_2O_3 and consists of mixed $2M_1$ and 1M mica polymorphs. These mixed polymorphs differ from the well-crystallized single polymorph chrome micas, mariposite and fuchsite. At Placerville, Colorado a similar chrome mica-clay contains as much as 20 per cent interlayered expanding lattice material. Recorded data on synthesis suggest that a likely source of these chrome mica-clays would be hydrothermal chromium-bearing solutions.

INTRODUCTION

The rigorous application of *x*-ray diffraction and allied mineralogical techniques to the fine fractions of clays has gained momentum during recent years. As a result, somewhat indefinite clay material long ago recognized as hydromica (Galpin, 1912) and later described as illite (Grim, Bray and Bradley, 1937) is becoming better understood. Grim, Bray and Bradley recognized the uncertain nature of this mineral when they said that illite " . . . is not proposed as a specific mineral name, but as a general term for the clay mineral constituent of argillaceous sediments belonging to the mica group."

The material differs from the other mica minerals in composition, occurrence and origin. Following its introduction, "illite" became widely used as a general term which was applied to the mica clay minerals from argillaceous sediments as well as to those from other environments. However, as long ago as 1928, Mauguin demonstrated by means of *x*-ray diffraction the existence of polymorphism in the mica group. Shortly after the original description of illite, Hendricks and Jefferson (1939) identified 7 crystalline modifications (polymorphs) among 100 specimens of mica, and in 1949 Axelrod and Grimaldi described a 3-layered monoclinic muscovite polymorph which is dimorphous with the more common 2-layered muscovite polymorph. Recently, Smith and Yoder (1956) published the results of an experimental and theoretical study on the structure and relations of the possible mica polymorphs. The simplest polymorphs are classed as 1M, $2M_1$, $2M_2$, 3T, 2O and 6H, but it is noted that more complicated types can be developed. Thus, in the investigation of the mica-clays, the presence of these various polymorphs must be considered. Grim, Bradley and Brown (Brindley, 1951) note that the demonstration of polymorphism in the micas shows that the original characterization of illite as a derivative of 2M muscovite crystallization is not entirely precise. In their investigation of the upper stability limits of muscovite, Yoder and Eugster (1954) synthesized a randomly stacked one-layer monoclinic muscovite (1Md illite) and thus demonstrated that the 2M structure is not unique to the illites. In 1955 Levinson recognized the existence of the 1Md, 1M and 3T mica polymorphs in nature by an *x*-ray diffraction investigation of a number of specimens labeled illite or hydrous mica. Yoder and Eugster (1955) conclude that the material known as "illite" may be ascribed to polymorphs of muscovite, solid solutions close to muscovite or to mixed-layer structures. They summarized the status of the term "illite" by suggesting that it " . . . be used only as a field term as Grim *et al.* originally proposed. When identification is made of the material or materials, the polymorph of the mica should be specified, and note made of the clay mineral with which it may have formed mixed layers."

The terms fuchsite and mariposite have been applied to chromium-bearing micas as defined on the basis of optical and chemical evidence (Kerr, *et al.*, 1951). The varietal names chromium muscovite and chromium phengite were introduced by Whitmore, Berry and Hawley (1946) as a better definition of these chromium-bearing micas. Chrome mica-clay as it occurs at Temple Mountain, Utah and Placerville, Colorado is herein identified as a fine-grained mixture of $2M_1$ and 1M mica polymorphs which may be associated with interlayered expanding material, and in which chromium is an essential constituent. It is less well crystallized than the single polymorph chrome micas. Brindley (1951) uses "clay mica" in referring to this type of material. However, "mica-clay" or "clay-mica" are applied interchangeably (Levinson, 1955). In this investigation and that of Kelley and Kerr (1957) mica-clay is preferred since it emphasizes the essentially micaceous nature of the material.

Recently, Mauguin (1956) reported the results of M. Stangatchilovitch's re-examination of "avalite" from Mt. Avala, Yugoslavia. He concludes that this material, which was originally described by Losanitsch (1884) as an alumino silicate of chromium and potassium and has been placed in the muscovite group or redefined as fuchsite (Ramdohr, 1948), "is neither a particular mineral species nor a fuchsite, but a chrome illite with a small amount of kaolin impurity." Optical examination of a specimen labeled muscovite (avalite), Mt. Avala, Servia from the Egleston Collection, Columbia University shows an impure, fine-grained green aggregate with indices of refraction which lie within the range of Temple Mountain and Placerville chrome mica-clays. It seems likely that this material might be redefined in terms of chrome mica polymorphs rather than "illite." However, a sample sufficiently pure to yield an *x*-ray diffraction pattern free from extraneous lines was not obtained.

Occurrence

Green chrome mica-clay is believed to be a significant alteration product at Temple Mountain, Utah. Field relations suggest precipitation from ascending solutions carrying chromium as an accompaniment of the primary introduction of uranium. The green mineral is localized in the vicinity of collapse areas (Kerr, Bodine and Kelley, 1957). More elevated temperatures probably prevailed near these areas than in the main uranium mining areas some distance away.

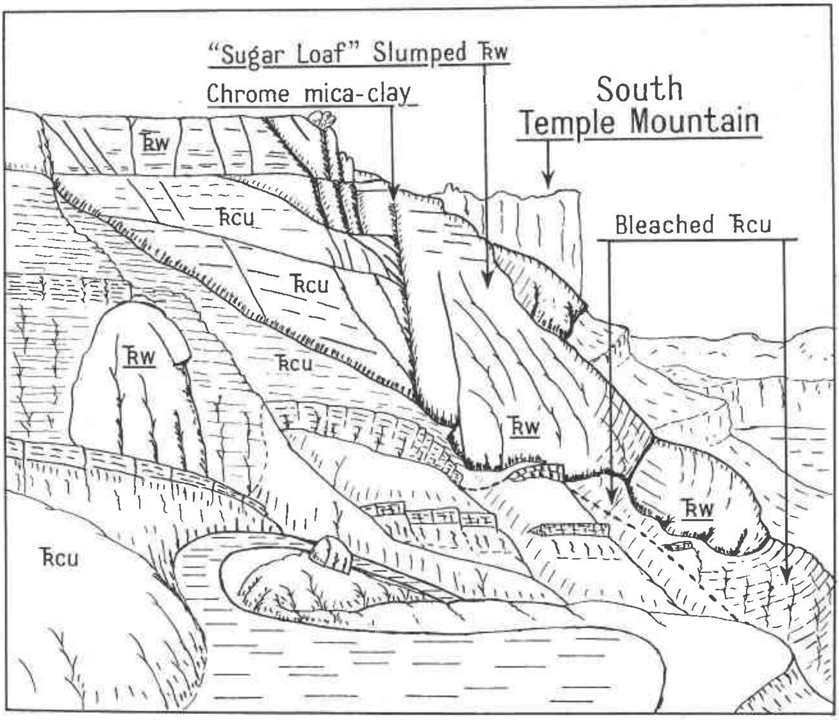

Fig. 1. Chrome mica-clay zone, Temple Mountain, Utah. Mica-clay is distributed in and near fractures in a slumped block of Wingate sandstone (Trw). The block rests upon differentiated Chinle (Trcu).

Surface exposures and drill cores indicate that the mica-clay penetrates strata over a vertical range of 1,200 feet from the upper part of the Wingate formation (Triassic) to the Kaibab formation (Permian). A vertical exposure of nearly 100 feet occurs on the west side of Temple Mountain (Fig. 1), where a collapsed block of Wingate sandstone is stained by the green mica-clay. This material is found in drill cores cut many hundreds of feet below, and also occurs 2.6 miles west in a collapse near Flattop Mesa. It is abundant on the east slope of South Temple Mountain at the base of the Wingate formation, and appears along the eastern margin of the Temple Mountain collapse area. At the Eagle's Nest prospect on the north escarpment of North Temple Mountain, mica-clay shows the greatest depth of color and highest chromium content noted.

The mica-clay occurs in veinlets along bedding planes and dispersed through sediments. Table 1 gives the principal mineral content of these chrome mica-clays. They are found close to areas of dolomitization of the Wingate sandstone, but apparently not within the dolomite. The chromium is an introduced element since the original chromium content of the host rock is negligible. For comparison, chrome mica-clay from Placerville, Colorado—another Plateau uranium locality (Kerr, Rasor and Hamilton, 1951)—has been restudied. In their study of chrome micas from various localities, Whitmore *et al* (1946)conclude that most of the constituents and particularly the chromium, had their origin in solutions derived from some magmatic source. The occurrence of chrome-illite ("avalite") reported by Mauguin (1956) is of interest. This material is present in dolomitic and quartzitic masses in the Mount Avala chromite-bearing serpentine. It is ascribed to hydrothermal action associated with the Tertiary andesitic eruptions which were responsible for the alumina in the mica as well as the alteration of chromite to free the chromium.

TABLE 1. MINERAL CONTENT OF CHROME MICA-CLAYS

Eagle's Nest	*Incline No. 1*
$2M_1 > 1M$ mica	$2M_1 - 1M$ mica
quartz	quartz
calcite	feldspar
kaolinite	jarosite
	kaolinite
Drill Hole V-7	*Placerville*
$2M_1$ mica	$2M_1 > 1M +$ montmorillonite
quartz	quartz
apatite	pyrite
calcite	
pyrite	

It is interesting that at the Mi Vida uranium mine in San Juan county, Utah, Gross (1956) notes the occurrence of a vanadium clay as the principal cementing material of the ore samples. The material is described as "a probable mixed-layer montmorillonite-hydromica with substitution of vanadium in one or both lattices." The possible relation of this material to the chrome mica-clay is worthy of further investigation.

TABLE 2. X-RAY DIFFRACTION OF CHROME MICA-CLAY AND MARIPOSITE
(Cu-radiation; Ni-filter)

Eagle's Nest $2M_1>1M$		Drill Hole V-7 $2M_1$		Drill Hole V-7 (leached) $2M_1>1M$		Incline No. 1 $2M_1-1M$		Placerville, Col. $2M_1>1M+$Mont.		Mariposite Mother Lode Fault, Mariposa Co., Calif. Heinrich and Levinson (1955) 1M		Mariposite Carson Hill, Calveras Co., Calif. Heinrich and Levinson (1955) $2M_1$	
d(Å)	I	d(Å)	I	d(Å)	I	d(Å)	I	d(Å)	I	d(Å)	I	d(Å)	I
10.3	10							10.39[e]	6				
		9.90	10	9.82	10	9.93	10	9.91	10	10.0	s	10.0	s
4.951	5	4.954	4	4.924	1	4.993	5	4.954	3	4.99	m	4.99	m
4.462	3	4.460	5	4.436	8	4.473	6	4.480	5	4.48	s	4.49	s
												4.32	vw
								4.112	1			4.11	vw
		3.863	1			3.948	3	3.844	½			3.88 $2M_1$	m
3.767[g]	½	3.720	2	3.705	3	3.736	4	3.705	1			3.73 $2M_1$	m
3.608	½					3.631	4	3.616	½	3.67 1M	m		
3.501	3	3.504	3	3.477	2	3.517	4	3.477	2			3.49 $2M_1$	m
3.336	10	3.336*	>10	3.322*	>10	3.346*	>10	3.336*	>10	3.35	s	3.33	s
3.241	3	3.241	3	3.230	2	3.249[z]	7	3.247	2			3.20 $2M_1$	m
3.066	½					3.076[y]	5	3.076	½	3.08 1M	m		
2.985[c]	6	2.976	1	2.976	2	2.976	3	2.976	1			2.99 $2M_1$	m
2.883[g]	4	2.873	1	2.838	1			2.847	1			2.86 $2M_1$	m
2.838	3	2.795[a]	>10					2.768	1	2.84	vvw	2.78 $2M_1$	mw
								2.696	½	1M			
2.562[x]	3	2.561	7	2.550	7	2.568[x]	5	2.561	4	2.57	s	2.57	s
2.526	2	2.493	½					2.493	1			2.48 $2M_1$	mw
2.459	2	2.448	3										
2.377	½	2.383	2			2.371	4	2.383	1	2.39	m	2.39	m
		2.341	1	2.330	3	2.318	3						
2.283[x]	4	2.240[a]	4	2.252	2					2.26	w	2.25	w
		2.204	1					2.199	1			2.20	w
2.130[x]	2	2.125[a]	3	2.111	1			2.120*	4	2.13	w	2.13	m
				2.021	3	2.077	3			2.00	m	1.99	s
1.995	1	1.988[a]	3	1.970	½			1.980*	7				
										1.72	vw	1.72	vvw
		1.651	1			1.645	3	1.648	1	1.66	w	1.65	m
1.631	1	1.637[a]	1	1.639	2			1.629	1				
												1.60	vvw
												1.56	vvw
1.497	2	1.499[a]	4	1.494	2	1.502	4	1.499	3	1.51	s	1.50	ms

* Mica masked by quartz.
[a] Mica masked by apatite.
Mica masked by calcite.
[e] Expands to 11.62 with ethylene glycol.
[g] Mica line masked by gypsum.
[x] Mica line masked by kaolinite.
[y] Mica line masked by jarosite.
[z] Mica line masked by feldspar.

X-RAY DIFFRACTION

The *x*-ray diffraction spacings for 1M and $2M_1$ mariposite (Heinrich and Levinson, 1955) are given in Table 2 for comparison with the Temple Mountain and Placerville chrome-bearing materials. These reflections, especially of the polymorphs, are sharp and well defined in contrast to the weak, diffuse and asymmetric lines of Temple Mountain mixed polymorphs. The 2.696 Å, 1M reflection which is missing from the mariposite used for comparison, does appear in the Placerville mica-clay.

The separation of the mica-clay fraction for *x*-ray diffraction study was made by collecting material which remained in suspension in distilled water for six to eight hours. *X*-ray patterns were obtained with a Philips diffraction outfit and chemical data with an *x*-ray spectrographic unit. The intensities (Table 2) were recalculated proportional to 10 for the most intense 10.0 Å reflection. Reflections due to impurities are omitted unless they mask or interfere with mica reflections as indicated. The principal polymorph shown by these patterns is based upon the presence and relative intensity of characteristic reflections (Yoder and Eugster, 1955). Three polymorph forms appear which are described as $2M_1 > 1M$, $2M_1 - 1M$. In addition, $2M_1 > 1M +$montmorillonite is found. On the basis of the *x*-ray diffraction data given by Mauguin (1956), this chrome illite does not appear to correlate with any of the polymorphs.

Drill Hole V-7

The *x*-ray difffraction pattern (Table 2) indicates essentially a $2M_1$ polymorph, although the reflections are somewhat diffuse and weak compared with the better crystallized $2M_1$ reference mariposite. The minor development of the 1M polymorph is indicated by the asymmetric 3.72 Å line. It is significant that after leaching with dilute HNO_3 (in order to remove apatite) this line increases in intensity and shifts to 3.705 Å, an approach to the 3.6 Å-1M spacing. However, this may also be caused by the breakdown of the $2M_1$ to 1M polymorph by acid action as the 3.88 Å and 2.48 $2M_1$ spacings disappear. These particular polymorph reflections seem generally weak or missing in the Temple Mountain chrome mica-clays, and the definition of this 3.705 Å reflection may result from purification. The 2.838 Å$-2M_1$ line appears after removal of the apatite in addition to the following mica lines: 2.252 Å, 2.111 Å, 1.970 Å, 1.639 Å and 1.494 Å. The dominance of the $2M_1$ structure is of interest since it occurs at depth and represents a more stable type formed at higher temperatures.

Apatite, quartz and gypsum are fine grained impurities. The gypsum was removed during washing, but apatite is intimately associated and has approximately the same particle size. Hence, it persists unless it is leached out by acid. Before leaching, aggregate fragments which are approximately 100 microns in diameter removed from thin section yield persistent apatite and mica-clay reflections with the *x*-ray micro-camera. The apatite particles yield sharp, well defined reflections compared with those from chrome mica-clay of corresponding size. Thus the diffuseness of the mica-clay is an inherent reflection feature and not due entirely to small particle size.

Eagle's Nest

The *x*-ray diffraction pattern of this material shows contamination by gypsum, calcite and kaolinite. The lines of these impurities are well defined compared with the more diffuse mica-clay lines. The mica-clay consists of mixed $2M_1 > 1M$ polymorphs. The 3.608 Å and 3.066 Å$-$1M spacings are equally developed and distinct although definitely weaker than the 3.501 Å and 3.241 Å$-2M_1$ reflections. Since the 3.8 Å$-2M_1$ line is missing and the 3.767 Å$-2M_1$ line is weak (although enhanced by a gypsum reflection), this mixture is believed to contain significant 1M mica-clay. However, it is less abundant than the $2M_1$ polymorph.

It is significant that this material which shows the highest chromium content (3 per cent) among the chrome mica-clays at Temple Mountain also has a relatively prominent 1M structure. This may reflect the most intense hydrothermal activity, although not necessarily the highest temperature of formation, as presumably the 1M polymorph would be less prominent.

Incline No. 1

Quartz, jarosite and feldspar are impurities which interfere with some of the mica-clay reflections. The presence of feldspar explains the intensity of the 3.249 Å spacing which is considerably more intense than would be expected from the $2M_1$ mica reflection only. Since the 3.631 Å and 3.076 Å 1M spacings have the same intensity as the 3.736 Å and 3.517 Å $2M_1$ reflections, the material is interpreted as a more or less equal mixture of $2M_1$ and 1M polymorphs.

The chrome-bearing micaceous clays from Temple Mountain, therefore, are essentially mixed $2M_1$ and 1M polymorphs which show a slight range in proportions. Diamond drill hole V-7 from deep in the collapse shows the best development of the $2M_1$ polymorph, whereas Incline No. 1 and the Eagle's Nest have more 1M. It is also noted that V-7 shows a much stronger tendency to orient when settled from suspension than do the other specimens which contain more of the mixed 1M polymorph. On the other hand, this orientation may result from more rapid settling of the larger and better crystallized $2M_1$ fraction, whereas the finer, possibly 1M particles, remained in suspension.

Placerville, Colorado

A re-examination of the Placerville, Colorado chrome-bearing mica-clay has been made in view of its similarity with the Temple Mountain occurrence. On the basis of chromium content and optical properties, this material was called fuchsite (Kerr *et al.*, 1951). However, recently purified material gives an *x*-ray diffractometer pattern (Table 2, p. 12) which shows the presence of interlayered montmorillonite. The asymmetric (001) reflection has two distinct peaks (10.39 Å and 9.91Å). After orientation and glycolation the 10.39 Å peak shifts to 11.62 Å, and the 9.91 Å remains in the same position. The 3.336 Å peak increases in intensity after glycolation which indicates that the (005) spacing of the expanded layers has moved closer to the (003) reflection of the 10 Å layers. This may signify the presence of as much as 20 per cent expanded layer material (Weaver, 1956). The pattern also shows $2M_1 > 1M$ mixed polymorphs and is therefore similar to the material from Eagle's Nest at Temple Mountain except for the relatively large content of associated interstratified montmorillonite. The 3.616 Å and 3.076 Å 1M lines are of equal intensity, but weaker than the $2M_1$ reflections.

McConnell (1953) has described volkonskoite as a chromium montmorillonite from the Morrison formation near Thompson, Utah which contains about 2 per cent Cr_2O_3. This material is associated with a non-chrome mica, whereas at Placerville an interlayered relation exists. It appears possible that the expanding material in the interlayer position at Placerville also contains chromium.

Glycolated Temple Mountain Chrome Mica-Clay

Due to asymmetry the (001) 9.90 Å reflection exhibits a steep slope on the high angle side and a moderate slope on the low angle side. This suggests interlayered montmorillonite. However, oriented specimens either heated in an ethylene glycol saturated atmosphere (Brunton, 1955), or soaked with the liquid, show no expansion toward the low angle region, and only a slight tendency toward a more symmetrical peak as indicated by a somewhat more gentle slope toward the high angle area. This is confirmed by slowly scanning the peak. There is also a slight increase in the amplitude of the 3.33 Å spacing. If interlayered expanding material is present, it amounts to less than 10 per cent (Weaver, 1956). Yoder (oral communication) suggests that this lack of expansion with ethylene glycol may be explained by the position of this chrome mica-

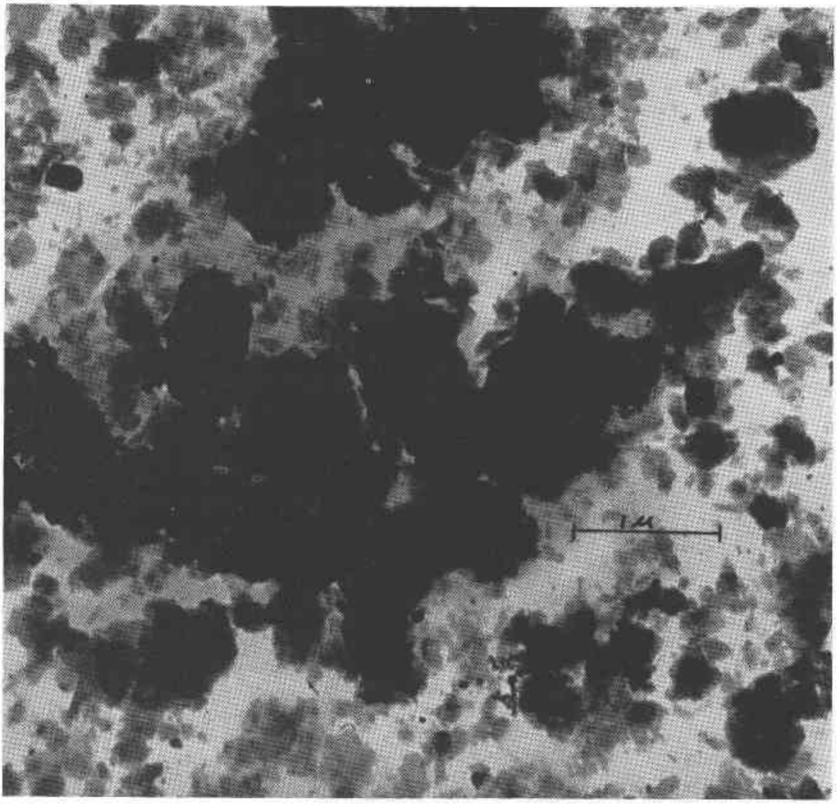

FIG. 2. Electron micrograph of chrome mica-clay from Temple Mountain, Utah. Specimen drill hole V-7 shows a particle size distribution which ranges from approximately 0.1 to 1 micron.

clay near celadonite in the muscovite, celadonite, pyrophyllite series. It is also possible that the association of mixed $2M_1$ and $1M$ polymorphs as well as the variation (approximately 0.1 to 1 micron) in particle size as seen in the electron micrograph (Fig. 2) may contribute to the asymmetry of this reflection.

X-Ray Spectrograph

Notwithstanding the presence of fine grained impurities, *x*-ray spectrographic data yield a fair estimate of the Cr_2O_3 content. Three reference mounts containing 1 per cent, 3 per cent and 5 per cent Cr_2O_3 mixed with SiO_2 were prepared and scanned with the Norelco *x*-ray spectrograph. The amplitudes of the $K\alpha$ and $K\beta$ reflections were plotted against per cent Cr_2O_3 and from these the values for the chrome mica-clays were estimated (Table 3). *X*-ray spectrographic examination of bromoform separated fractions indicates that the chromium is concentrated in the lighter micaceous fraction rather than in the heavier pyrite-rich material. Iron is also present and varies inversely with chromium. In the Drill Hole V-7 specimen (leached with dilute HNO_3 to remove the apatite) the Cr_2O_3 content increases with purification which indicates that the chromium is concentrated in the mica-clay.

TABLE 3. Cr_2O_3 IN SOME MICA-CLAYS

	Cr_2O_3 per cent
Drill Hole V-7	0.37–0.68
Drill Hole V-7 (leached)	0.55–0.85
Incline No. 1	0.55–0.85
Eagle's Nest	3.07–3.30
Placerville	3.40–3.60

For comparison, in fuchsite analyses (Whitmore *et al.*, 1946) Cr_2O_3 ranges from 0.27 per cent to 4.81 per cent, whereas in mariposite the Cr_2O_3 ranges between 0 and 0.78 per cent. At Temple Mountain the 1M polymorph suggests the higher chromium content since the Eagle's Nest and Incline No. 1 samples contain more chromium than samples from Drill Hole V-7 where the $2M_1$ polymorph is more prominent. The interlayered expanding material at Placerville is believed to contain chromium as well as the associated mica-clay.

DIFFERENTIAL THERMAL ANALYSIS

Although the published DTA curves of muscovite differ, they exhibit a distinct range at variance with the mica-clays. In his investigation of the decomposition of muscovite, Roy (1949) found that there are no marked changes up to 940° C., but he structure is destroyed within the relatively narrow range between 940° C. and 980° C. However, some vari-

TABLE 4. ENDOTHERMIC PEAKS OF MUSCOVITE

Grim and Bradley (Brindley, 1951) Coarse grained (10–20 microns)	800–900° C.
Grim and Rowland (1942)	750–950° C. 300–400° C.
Grim (1953)	850° C. and 900° C.
Grim (1953)	720° C.

ation probably is due to the time factor. Grim and Rowland (1942) note the variations (Table 4) in the muscovite curves and suggest they may be due to grain size, since the coarse flakes permit only a small amount to be packed loosely in the specimen holder. Grim and Bradley (Brindley, 1951) note that a decrease in the particle size of muscovite is accompanied by a reduction in the temperature of the start of the endothermic reaction, and an increase in the interval during which it occurs.

The typical DTA curve for "illite" (Kerr, Kulp and Hamilton, 1949) shows three endothermic reactions. The first corresponds to the loss of interlayer water between about 120 and 220° C. Grim (1953) says this differs from the well crystallized micas as "a consequence of fewer interlayer actions, less bond between layers, less uniform orientation of successive layers and smaller particle size, and/or a difference in composition within the silicate layer itself."

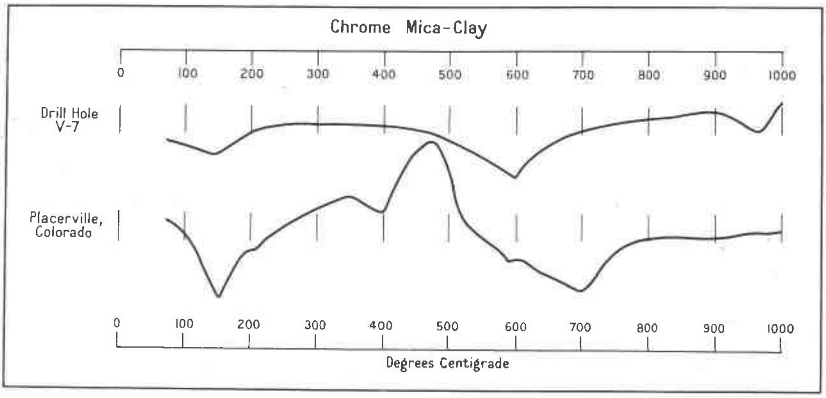

FIG. 3. DTA of chrome mica-clay. In drill hole V-7, the mica-clay is similar to illite with a trace of calcite. The Placerville, Colorado, sample represents an assemblage of mica-clay, montmorillonite, pyrite and quartz.

The second endothermic peak in "illite" is sharp and occurs at about 500° C.–600° C. This is caused by the loss of hydroxyl water. The sharpness of this reaction compared with that in muscovite is attributed by Grim (1953) to differences in particle size. The third endothermic reaction occurs between about 850° C. and 950° C. and represents the complete destruction of the lattice. An exothermic reaction frequently is present between 900° C. and 1000° C., and reflects the crystallization of spinel.

The DTA of the chrome mica-clay shows some of the characteristics of both mica-clay ("illite") and muscovite. V-7 (Fig. 3) has an adsorbed water peak at about 150° C., which corresponds to the loss of adsorbed water in the mica-clays, and a single endothermic peak at about 600° C., which is thought to represent the loss of hydroxyl lattice water, and is also typical of the mica-clays. However, the subsequent endothermic-exothermic effects which are present in "illite" are missing, which is more characteristic of muscovite. The endothermic peak at 960° C. is probably due to some minor associated calcite. Mauguin (1956) gives somewhat similar results for the DTA of "chrome-illite," namely a well defined endothermic peak at 130° C. and another at 570° C. The exothermic effect reported at 830° C. does not appear in the chrome-micas of this investigation, and it is somewhat anomalous for "illite," since it is low in temperature and not preceded by an endothermic effect. Perhaps this is due to an unidentified impurity.

The DTA curve of the Placerville material distinctly shows the presence of the more reactive interlayered montmorillonite. Thus, there are double dehydration peaks between 150° C. and 220° C. rather than the more usual single reactions in the mica-clays as well as an endothermic peak at about 700° C. which corresponds to a similar one in montmorillonite. This peak is particularly broad since the reaction begins at about 500° C. and is believed to include or mask that of the associated mica-clay. However, the usual higher temperature endothermic-exothermic peaks of both "illite" and montmorillonite are missing in the micas. A prominent 470° C. exothermic peak is due to pyrite and the small, sharp endothermic peak at about 580° C. superimposed on the broad endothermic flexure reflects the presence of associated quartz as an impurity.

OPTICAL PROPERTIES

The green chrome mica-clay at Temple Mountain occurs in thin veinlets, layers and streaks disseminated through quartz sand. Although it imparts a general green or gray-green appearance to the rock, in thin section the color is generally tan or pale bluish-green. The darker green bands appear to represent 1M mica-clay derived by later, lower tem-

TABLE 5. OPTICAL DATA ON CHROME MICA-CLAY

	α	β	γ	Birefringence	2V	Optic sign
Eagle's Nest	1.553	1.584	1.587	.034		
V-7 626 feet	1.554	1.585	1.592	.038	ca. 30°	—
Incline No. 1	1.554	1.582	1.589	.035		
Placerville	1.559	1.582	1.590	.031		
Fuchsite (Whitmore, *et al.*)	1.5590–1.5695		1.5973–1.6115	.035–.042	32°–46°	—
Mariposite (Whitmore, *et al.*)	1.56 –1.58		1.60 –1.63	.033–.040	0°–40°	—
Illite (Grim, 1953)	1.545 –1.63		1.57 –1.67	.022–.055	small	—
"Avalite"	1.554	1.582	1.592	.038		
Muscovite (Rogers and Kerr, 1942)	1.556 –1.570	1.587–1.607	1.593 –1.611	.037–.041	30°–40°	—

perature chromium-bearing solutions acting on and causing the breakdown of earlier $2M_1$ mica-clay. Micro-camera x-ray diffraction patterns of both tan and pale green materials removed from thin section are similar, but the significant polymorph lines may be too weak to register. The optical properties given in Table 5 are compared with reference material. The indices of refraction of the Temple Mountain samples are somewhat lower than those given for fuchsite and mariposite and agree more closely with illite (Grim, 1953). The birefringence of the Placerville specimen is lower than the birefringence of the Temple Mountain material. This is probably due to the presence of interstratified montmorillonite. It appears from the specimens examined that the higher chrome content of Eagle's Nest, Incline No. 1 and Placerville correlates with a lower birefringence. This may be due either to the presence of the 1M polymorph or to interstratified montmorillonite.

TEMPERATURE CONDITIONS

Hydrothermal synthesis by Yoder and Eugster (1955) has indicated that the transition of 1M to $2M_1$ mica polymorphs occurs between 200° C. and 350° C. at 15,000 p.s.i. water pressure. Under natural conditions the effects of catalysts and other variables which include temperature, pressure and ion concentration are not known. If the data of synthesis are applicable, the presence of the $2M_1$ polymorph at Temple Mountain indicates a corresponding temperature of formation.

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REFERENCES

AXELROD, J. M., AND GRIMALDI, F. S. (1949), Muscovite with small optic angle: *Am. Mineral.*, **34**, 559–572.

BRINDLEY, G. W., ed. (1951) *X*-ray identification and crystal structures of clay minerals: Min. Soc. Great Britain Monograph, Chap. V, 138–172.

BRUNTON, G. (1955), Vapor pressure glycolation of oriented clay minerals: *Am. Mineral.*, **40**, 124–125.

GALPIN, S. L. (1912), Studies of flint clays and their associates: *Amer. Ceramic Soc. Trans.*, **14**, 301–346.

GRIM. R. E. (1953), Clay mineralogy: McGraw-Hill Book Co., Inc., 384 p.

GRIM, R. E., BRAY, R. H., AND BRADLEY, W. F. (1937), The mica in argillaceous sediments: *Amer. Mineral.*, **22,** 813–829.

GRIM, R. E., AND ROWLAND, R. A. (1942), Differential thermal analyses of clay minerals and other hydrous materials: *Amer. Mineral.*, **27,** 801–818.

GROSS, E. B. (1956), Mineralogy and paragenesis of the uranium ore, Mi Vida mine, San Juan county, Utah: *Econ. Geol.*, **51,** 623–648.

HEINRICH, E. W., AND LEVINSON, A. A. (1955), Studies in the mica group: polymorphism among the high silica sericites: *Amer. Mineral.*, **40,** 983–995.

HENDRICKS, S. B., AND JEFFERSON, M. E. (1939), Polymorphism of the micas: *Amer. Mineral.*, **24,** 729–771.

KELLEY, D. R., AND KERR, P. F. (1957), Clay alteration with uranium mineralization; Moss Back ore member, Temple Mountain, Utah: *Bull. Geol. Soc. Am.* (In press).

KERR, P. F., BODINE, M. W., JR., AND KELLEY, D. R. (1957), Collapse features, Temple Mountain uranium area, Utah: *Bull. Geol. Soc. Amer.* (In press).

KERR, P. F., KULP, J. L., AND HAMILTON, P. K. (1949), Differential thermal analyses of reference clay mineral specimens: *A. P. I. Proj.* **49,** Columbia Univ., New York, N. Y., 48 p.

KERR, P. F., RASOR, C. A., AND HAMILTON, P. K. (1951), Uranium in the Black King prospect, Placerville, Colorado: *Ann. Rep't July 1, 1950–June 30, 1951, U. S. Atomic Energy Comm., RMO-797*, 25–43.

LEVINSON, A. A. (1955), Studies in the mica group: polymorphism among illites and hydrous micas: *Amer. Mineral.*, **40,** 41–49.

LOSANITSCH, S. M. (1884), Die Analyse eines neuen Chrom-minerals (Avalit): *Berichte der deutschen chemischen Gesellschaft*, **17(2),** 1774–1775.

MAUGUIN, M. C. (1928) Étude des micas au moyen des rayons *X*: *Soc. française de mineralogie*, **51,** 285–332.

MAUGUIN, M. C. (1956), Sur la presence d'illite chromifère dans le gisement de cinabre d'Avala, près de Belgrade: (Note de M. Stangatchilovitch présentée par M. C. Mauguin): *Comptes rendus*, **242,** 145–147.

MCCONNELL, D. (1953), An American occurrence of volkonskoite: Clays and clay minerals: Proceedings of the Second National Conf. on Clays and Clay Minerals, *Nat'l Academy of Sciences Nat'l Research Council Publication* **327,** 152–157.

RAMDOHR, P. (1942), Klockmann's Lehrbuch der Mineralogie, Stuttgart, 632.

ROGERS, A. F., AND KERR, P. F. (1942), Optical mineralogy, McGraw-Hill Book Co., Inc., New York, 335.

ROY, R. (1949), Decomposition and resynthesis of the micas: *Amer. Ceramic Soc. Jour.*, **32,** 202–209.

SMITH, J. V., AND YODER, H. S. (1956), Experimental and theoretical studies of the mica polymorphs: *Min. Mag.*, **31,** 209–235.

WEAVER, C. E. (1956), The distribution and identification of mixed-layer clays in sedimentary rocks: *Am. Mineral.*, **41,** 202–221.

WHITMORE, D. R. E., BERRY, L. G., AND HAWLEY, J. E. (1946), Chrome micas: *Am. Mineral.*, **31,** 1–21.

YODER, H. S., AND EUGSTER, H. P. (1954), Synthesis and stability of the muscovites: *Am. Mineral.*, **39,** 350–351.

YODER, H. S., AND EUGSTER, H. P. (1955), Synthetic and natural muscovites: *Geochemica et Cosmochimica Acta*, **8,** 225–280.

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