DISCUSSION

Pumpellyite plus quartz reacts to form anorthite plus clinopyroxene at temperatures slightly above 500°C at 1000 atmospheres and 530°C at 3000 atmospheres. The decomposition curve for this dehydration reaction appears to have a very steep, positive slope. These *p-T* conditions may vary with different oxidation conditions, or with starting material of a different composition. In natural rock systems, it is unlikely that pumpellyite persists to temperatures as high as 500°C; in nature it is replaced by other lime-bearing minerals (*e.g.*, epidote and ca-amphibole) long before the appearance of metamorphic ca-plagioclase.

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MICA PERIDOTITE, WYOMINGITE, AND ASSOCIATED POTASSIC IGNEOUS ROCKS IN NORTHEASTERN UTAH

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An association of highly potassic, silica-poor igneous rocks has been discovered east of Salt Lake City, Utah, near the junction of the east-west trending Uinta Arch and the north-south trending Wasatch Mountains, both uplifted during the Cretaceous-Tertiary Laramide Orogeny. The occurrence of mid-Tertiary granitic plutons and extrusive andesitic rocks, mostly pyroclastic, in this same area has been known for several decades, but the potassic rocks have been discovered only in recent years, in part through areal mapping by students of the University of Utah. The rather widely scattered (Fig. 1) potassic rocks range in age from Upper Eocene to Lower Pliocene. They comprise two small plugs or dikes of mica peridotite and two centers of minor intrusions and flows of phlogopite-diopside-analcime or sanidine rocks similar to those found in the Leucite Hills of Wyoming, about 150 miles to the northeast and in the Fitzroy Basin of northwestern Australia.

Mica peridotite occurs as dikes (now inaccessible) in underground workings of the Park City mining district (Boutwell, 1912). Through the generosity of the U.S. National Museum a small specimen of this peridotite was obtained for study. In thin section it appears nearly identical to Boutwell's description. Chemical analysis (wst-16, Table 1) discloses a low content of SiO_2 but appreciable K_2O; the Fe_2O_3/FeO ratio is rather high.

A search in the field for the small plug of "biotite olivinite" referred to by Larsen (1954) was unsuccessful. But, in about the same area at the head of Smith-Morehouse Canyon, several pieces of float of an ultramafic rock were found scattered within an area about twenty feet in diameter, and located about 300 feet southeast of the surveyed marker at the northwest corner of section 32 in T1S, R8E. The ultramafic rock (wst-15) contains scattered clots of aggregated phlogopite up to one centimeter in diameter. In thin section the rock is a strongly porphyritic mica peridotite, with anhedral phenocrysts of olivine (20 modal percent) and melilite (2 percent) set in a fine groundmass of very pale orange, poikilitic phlogopite flakes, clinopyroxene granules, minor sanidine laths and dust-like opaques. Chemical analysis (Table 1) shows low SiO_2 and very high MgO and K_2O; the Fe_2O_3/FeO ratio is high. The normative minerals include many that are highly undersaturated in SiO_2.

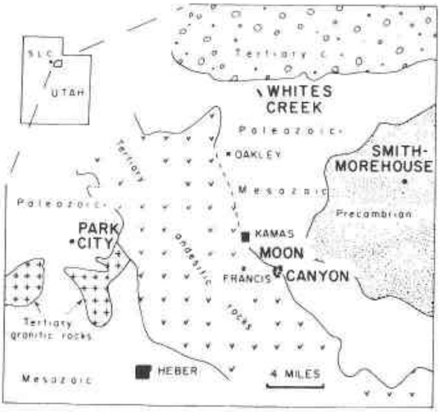

FIG. 1. Geologic sketch map of the area east of Salt Lake City, Utah showing the location of known occurrences (names in large print) of mica peridotites and lamproites. Precambrian rocks are quartzites; Paleozoic-Mesozoic rocks are shales, sandstones and carbonates; Tertiary rocks are shales, sandstones, and conglomerates.

At the head of Whites Creek, about 5 miles north-northeast of Oakley, Utah, Morris (1953) discovered three irregular elongate bodies of rock

TABLE 1. CHEMICAL COMPOSITIONS (WT. %) OF MICA PERIDOTITES AND LAMPROITES OCCURING EAST OF SALT LAKE CITY

	Mica peridotites		Lamproites		
	wst-15	wst-16	WC-2	MC-1	MC-72
SiO_2	37.68	39.08	50.46	55.56	55.73
TiO	0.64	2.12	2.12	2.40	2.82
Al_2O_3	7.33	10.15	11.73	10.50	10.72
Fe_2O_3	3.99	4.33	3.11	3.93	3.73
FeO	5.36	5.75	1.84	1.20	0.95
MnO	0.19	0.15	0.09	0.08	0.08
MgO	20.61	11.01	10.78	5.79	6.96
CaO	12.15	13.24	4.62	3.88	3.85
SrO	0.30	0.38	0.14	0.04	0.06
BaO	0.04	0.14	0.82	0.37	0.35
Na_2O	0.71	0.74	1.02	3.23	1.21
K_2O	5.33	2.86	9.53	3.86	10.49
H_2O+	3.44	7.35	1.67	7.27	1.14
H_2O-	1.24	1.28	0.21	0.13	0.89
P_2O_5	0.78	1.25	1.67	1.48	1.13
Total	99.79	99.83	99.81	99.72	100.11

Analyst: K. Aoki
wst-15, 300 feet SE of NW corner of section 32 in T1S, R8E.
wst-16, underground workings, Park City mining district (see Boutwell, 1912).
WC-2, head of Whites Creek, 5 miles NNE of Oakley.
MC-1, 72, Moon Canyon, 3 miles E of Francis.

which he called melteigite. In all of the specimens (such as WC-2), phenocrysts of phlogopite are clearly visible in a gray-brown aphanitic matrix. In one of the bodies pale green anhedral phenocrysts (up to one centimeter) of olivine ($Fo_{97.5}$) are jacketed by smaller, randomly oriented flakes of phlogopite. The phenocrysts of phlogopite are fairly euhedral with pleochroic orange cores and narrow red-brown rims. The other major constituents are subradiating, blocky, untwinned sanidine and colorless euhedral diopside. Much smaller flakes of red-brown phlogopite and needles of apatite, diopside (some with a green tint), and rare brown amphibole are scattered about in the rock.

East of Francis and mostly within Moon Canyon, detailed mapping has disclosed a complex of several separate dikes, plugs, and flows of phlogopite-bearing rock within andesitic pyroclastics and late Paleozoic shales and quartzites. Phlogopite-bearing flows are interstratified with bedded to massive andesite tuffs and breccias, and fragments of phlogopite-bearing rock occur locally in the pyroclastic rocks. The flows range

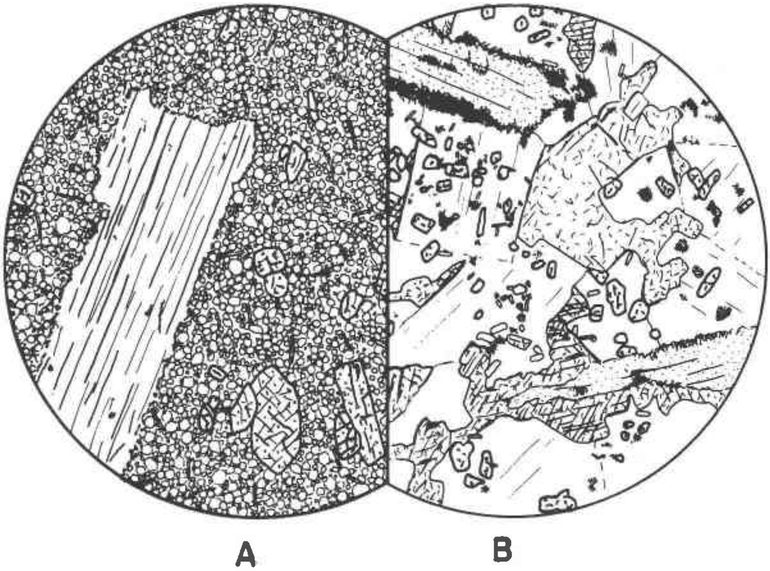

FIG. 2. A, analcime wyomingite, sample MC-12, from Moon Canyon, Utah. Large phenocryst of phlogopite and microphenocrysts of diopside are surrounded by a matrix of minute analcimes, a few shreds of phlogopite, and interstitial pale brown glass. B, "trachyte," sample MC-67, from Moon Canyon, Utah. Blocky sanidines poikilitically enclose small prisms of diopside and apatite; interstitial amphibole partially surrounds a corroded phlogopite (bottom) and another phlogopite with dark sagenitic borders is at top of view. Diameter of A is one mm and of B is two mm.

from a scoriaceous layer about 5 to 10 feet thick to a flow about 30 feet thick with vesicular rock at the top and bottom and central coarser grained non-vesicular rock. Borders of minor intrusions are also vesicular and the larger ones have relatively coarse (0.5 mm) rock in the central parts. Phlogopite phenocrysts of 1-cm size are plentiful and in some exposures their strong flow orientation imparts a high degree of schistosity.

The finer grained rocks (Fig. 2A) have euhedral phenocrysts of diopside and completely serpentinized (?) pseudomorphs of rarer olivine in addition to the larger phlogopites. In the groundmass are tiny blebs of analcime ($n=1.495$; $a=13.706\pm0.001$ Å), needles of diopside, and shreds of phlogopite, all enclosed in a pale brown glass ($n=1.543$). Somewhat coarser-grained varieties have much the same character but the felsic constituents are subradiating to randomly oriented blocky grains of sanidine with local, marginally located, blebs which appear to be analcime. Borders of phlogopite phenocrysts are darker and more turbid (because of disseminated iron oxide) than in the glassy rocks; some have crude marginal sagenite webs. Interstitial to the sanidines are irregular grains of amphibole (pleochroic from honey-yellow to pink-brown with $2V_x 22°–26°$), presumably magnophorite. The coarsest grained phlogopitic rocks (*e.g.*, MG-72) contain no analcime or glass (Fig. 2B). The blocky sanidines are untwinned, have the optic axial plane (010) and contain substantial Fe^{3+} substituting for Al. Chemical analysis (Table 2) discloses 14 molecular percent of iron-feldspar. Carmichael (1967) found 9.6 to 18.4 percent in ferriferous sanidines in rocks of the Leucite Hills, Wyoming. Small prisms of diopside and apatite are poikilitically enclosed in sanidines. Magnophorite is abundant, mainly interstitial to sanidine, and commonly mantles irregular and less abundant corroded phlogopites as if in a reaction relationship.

TABLE 2. COMPOSITION AND OPTICAL PROPERTIES OF FERRIFEROUS SANIDINE IN "TRACHYTE," MC-7, MOON CANYON

Weight percent oxides		Molecular percent	
SiO_2	62.88	Or	77.0
TiO_2	0.50	FeOr	14.0
Al_2O_3	15.53	Ab	7.5
Fe_2O_3	3.83	An	11.5
FeO	0.16		
MgO	0.20	Optical properties in Na light	
CaO	0.26		
BaO	n.d.	α	1.528
Na_2O	0.78	β	1.531
K_2O	14.66	γ	1.531
H_2O^+	0.74	$2V_x$	56
H_2O^-	0.10		
Total	99.64		

Analyst: K. Aoki.

There is little variation in five chemically analyzed phlogopite-bearing rocks from Whites Creek and Moon Canyon (Table 1). All have an intermediate content of SiO_2, nearly as much K_2O as Al_2O_3, and a very high Fe_2O_3/FeO ratio. The Na_2O/K_2O ratio and the H_2O content in the one analyzed glassy rock (MC-1) are much higher compared to the holocrystalline rocks. Preliminary analysis of other hypocrystalline samples yields essentially the same results as for MC-l. The olivine-bearing sample from Whites Creek (WC-2) is lower in SiO_2 and higher in MgO than the essentially olivine-free rocks from Moon Canyon.

In comparison with the chemically and mineralogically similar rocks from the Leucite Hills of Wyoming (Cross, 1897; Carmichael, 1967) and

TABLE 3. X-RAY POWDER DIFFRACTION DATA FOR FERRIFEROUS SANIDINES FROM "TRACHYTES," MOON CANYON

hkl	MC-7		MC-67	
	d(Å)	I	d(Å)	I
$\bar{2}01$	4.238	40	4.239	40
111	3.952	20	3.955	20
130	3.794	60	3.793	60
$\bar{1}31$	n.d.	20	3.621	20
$\bar{2}21$	n.d.	10	3.563	10
$\bar{1}12$	3.466	30	3.4651	30
220	3.326	60	3.3284	60
$\bar{2}02$	3.2891	40	3.2923	40
040	3.2641	25	3.2609	25
002	3.2328	100	3.2340	100
$\bar{1}31$	3.001	40	3.0008	40
132	2.770	10	2.771	10
$\bar{2}41$ $\bar{2}21$	2.584	20	2.584	20
060	2.175	15	2.174	15
a (Å)	8.608±0.000		8.621±0.004	
b (Å)	13.065±0.000		13.052±0.006	
c (Å)	7.199±0.000		7.200±0.003	
β	116.00 ±0.00		116.02 ±0.02	

Si (a=5.4307 Å) was used as an internal standard. Unit-cell parameters were determined on only the more accurately measured lines by a least-squares refinement computer program written by M. H. Mueller and LeRoy Heaton of the Argonne National Laboratory.

from the Fitzroy Basin of northwest Australia (Wade and Prider, 1940; Prider, 1960) the phlogopite-bearing rocks in Utah are generally richer in SiO_2 and Al_2O_3 but substantially poorer in TiO_2 and BaO. The Utah rocks generally have a "cleaner" groundmass, compared to rocks from Wyoming and especially Australia which have a turbid, chloritic groundmass. Perovskite and leucite, very common constituents of the Wyoming and Australian rocks, have not been found in the Utah rocks.

Cross (1897) coined the term *wyomingite* for the rock whose constituents are phlogopite, diopside, leucite, and glass and the term *orendite* for an assemblage of sanidine-leucite-phlogopite-diopside. The Utah rocks are close enough in texture, mineralogy and chemistry to apply these names, with an appropriate modification to account for the presence of analcime instead of leucite. Broadly speaking, the relatively coarse sanidine-amphibole-diopside-phlogopite rock from Utah is a trachyte, yet its unusual chemical and mineralogical composition, in addition to its

Table 4. The Results of Duplicate K-ar Age Determinations on Phlogopites from Three Lamproites and on One Whole Rock Sample of Mica Peridotite

Sample	Percent K	Percent Ar^{40R}	Age (my)
MC-66, Moon Canyon	7.60	64	40.4
"trachyte" plug	7.60	74	39.4
MC-104, Moon Canyon	8.10	70	36.5
analcime wyomingite flow	8.10	65	37.4
WC-2, Whites Creek	8.00	34	13.7
"trachyte" dike	8.00	40	12.8
wst-15, Smith-Morehouse mica peridotite	4.60	80	38.7

very close affinity to wyomingite and orendite, might justify a more specific name. Lamproite is a useful name applied by Prider (1960) to the whole suite of highly potassic and magnesian rocks of extrusive and hypabyssal character.

In the K-Ar age determinations of four samples (Table 4) at Rice University, argon was determined by isotope dilution on a Nier-type 6-inch mass spectrometer, using argon-38 spikes. Potassium was determined by both tetraphenyl boron precipitation and flame atomic absorption. The values of constants used in the age calculations were:

$$\lambda_K = 0.585 \times 10^{-10}\ \text{yr.}^{-1}, \qquad \lambda_\beta = 4.72 \times 10^{-10}\ \text{yr.}^{-1},$$
$$K^{40}/K\ 1.10 \times 10^{-4}\ \text{mole/mole}.$$

The age data in Table 4 indicate at least two episodes of lamproitic magma activity about 22–28 my apart. The ages for the Moon Canyon rocks are slightly greater than K-Ar ages for nearby andesitic and granitic rocks (Crittenden and Kistler, 1966) which range from 33 to 37 my and 25.5 to 37.0 my, respectively.

It appears plausible, on the basis of the preliminary chemical data and the age determinations, that mica peridotite magma could have differentiated to form lamproite magmas, as postulated by Prider (1960) for the Australian lamproites. Experimental data (Seifert and Schreyer, 1966; Luth, 1967) on analogous but more simple compositions appear to be compatible with this relationship. The contrasts in mineralogical composition within the Utah lamproites are related in part to contrasts in rate and temperature of crystallization. The relation of the lamproite magmas to andesite magmas of nearly the same age has yet to be learned.

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MINERALOGY OF A ZONED REPLACEMENT BODY FROM THE BLUE MOUNTAIN LITCHFIELDITE, PETERBOROUGH COUNTY, ONTARIO

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This note describes the mineralogy of a zoned, approximately spherical replacement body, about 16 inches in diameter from the Blue Mountain litchfieldite of Methuen Township, Peterborough County, Ontario. Hewitt (1960) has described the geology of this area. Although the prin-