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# NOTE ON LEUCITE-BEARING ROCKS FROM LEUCITE HILLS, WYOMING, U.S.A.

*by*

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(with 1 Text-figure and 2 Plates)

Contribution from the Department of Geology and Mineralogy, Faculty of Science, Hokkaido University. No. 1023

## Abstract

Leucite-bearing rocks from Leucite Hills are re-investigated. Petrographic descriptions are made on the wyomingite and orendite together with their xenoliths. Results of chemical analyses and a series of thermal experiments on these rocks are given. From the results of the present investigation the authors are led to the conclusion that the leucite-bearing rocks under consideration were derived directly from the partial melting of the upper mantle materials, probably mica periodotitic in composition, without the aid of assimilation of the granitic or other salic rocks.

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## 1. Introduction

Since the discovery of the leucite-bearing rocks from Leucite Hills, Wyoming almost seventy years ago, their genetic significance has been discussed by many workers, attaining to the widely different conclusions. The senior author had an opportunity to visit this locality some years ago. In view of the petrogenetic significance of these rocks, the re-investigation was made on the samples collected and the results are presented here with the hope to throw light on the genesis of the

leucite-bearing rocks. The senior author wishes to express his thanks to Mr. K. W. RITCHIE and Dr. O. G. KIM for their assistance in the field trip.

## 2. Mode of Occurrence

The Leucite Hills include several hills or mesas, remaining as monadonocks of various size on the flat plateau composed of the Tertiary and Cretaceous formations. The author visited one of the small cones, on the foot of which there was a quarry for pumiceous rocks. Although the workers of this quarry did not know the exact name of this cone, it is probably "Emmons Cone" judging from the description by CROSS (1897). The lower part of this cone is made largely of lava flows of dark purplish grey basaltic rock, which corresponds from its mineralogical composition to "wyomingite" named by CROSS. The rock shows remarkable flow banding through the presence of abundant reddish brown mica flakes. Besides light brownish yellow, porous or sometimes pumiceous rocks are found, especially on the top or the upper part of the cone. Sometimes the rocks contain small amount of sanidine and correspond to "orendite" as defined by CROSS. Although the direct relation of the two kinds of rocks could not be observed in the field, it seems likely that the porous orendite represents the upper part, while the massive lavas of wyomingite form the lower part of this cone.

## 3. Petrography

### Wyomingite

The rock shows parallel flow banding due to the plane arrangement of phlogopite flakes, and vesicular cavities are developed parallel to this flow banding. The rock is very fresh and free from secondary alteration. The sample collected from the lower part (No. 1101) is composed of leucite, augite, phlogopite, apatite, calcite and magnetite in the order of abundance (Table 1). Phlogopite is the only phenocrysts which are embedded in the groundmass consisting of other minerals. It is sometimes as large as 8 mm, but usually 0.4–1.0 mm in size. Parallel arrangement is commonly observed. Zoned structure is often distinct, usually the core being much deeper in color than the margin, with distinct pleochroism as follows:

X . . . . . pale yellow or nearly colorless  
 Y = Z . . . . . pinkish brown or pale pinkish brown  
 $\alpha = 1.561 \quad \beta \doteq \gamma = 1.597 \quad 2V(-) = 0^\circ - 34^\circ$

Sagenitic inclusions of deep brownish needles of unidentified minerals are fairly common, being distributed in the marginal parts. Rarely green spinel is enclosed in the core. From X-ray powder patterns the following lattice constants are obtained.

$$a_0 = 5.33, \quad b_0 = 9.32, \quad c_0 = 10.25 \pm 0.01 \text{ \AA} \quad \beta = 99^\circ 56' \pm 5'$$

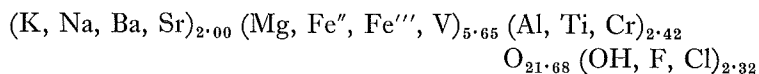
Table 1. Modal Composition of Leucite-bearing Rocks and their Xenoliths in Wt%, total being 100%.

|            | 1101                                                                              | 1102 | 1102A | 1101X | 1102X |
|------------|-----------------------------------------------------------------------------------|------|-------|-------|-------|
| Leucite    | 40.5                                                                              | —    | 34.5  | 47.8  | 38.9  |
| Sanidine   | —                                                                                 | —    | 4.1   | —     | —     |
| Phlogopite | 17.8                                                                              | 14.1 | 17.7  | 1.2   | —     |
| Biotite    | —                                                                                 | —    | —     | —     | 24.0  |
| Hornblende | —                                                                                 | 0.1  | —     | —     | 15.3  |
| Augite     | 39.6                                                                              | —    | 9.7   | 45.0  | 18.0  |
| Apatite    | 1.5                                                                               | —    | 1.4   | 1.1   | 0.5   |
| Magnetite  | 0.1                                                                               | 0.7  | —     | —     | 2.8   |
| Calcite    | 0.5                                                                               | —    | 1.1   | 0.9   | —     |
| Glass      | —                                                                                 | 85.1 | 31.5  | 4.0   | 0.5   |
| No. 1101   | Massive holocrystalline, dark grey wyomingite from the lower part of Emmons Cone. |      |       |       |       |
| No. 1102   | Porous, glassy, light brownish grey orendite from the upper part of Emmons Cone.  |      |       |       |       |
| No. 1102A  | More crystalline brownish yellow orendite from the top of Emmons Cone.            |      |       |       |       |
| No. 1101X  | Augite-leucite rock, a xenolith from wyomingite No. 1101.                         |      |       |       |       |
| No. 1102X  | Augite-hornblende-biotite-leucite rock, a xenolith from orendite No. 1102.        |      |       |       |       |

Table 2. Chemical Composition of Phlogopite from Wyomingite No. 1101.

| Wt. %                          |        | Atomic Number when<br>(O, OH, Cl, F)=24.00 |       |
|--------------------------------|--------|--------------------------------------------|-------|
| SiO <sub>2</sub>               | 41.33  | Si                                         | 6.00  |
| TiO <sub>2</sub>               | 1.45   | Ti                                         | 0.16  |
| Al <sub>2</sub> O <sub>3</sub> | 12.91  | Al                                         | 2.21  |
| Cr <sub>2</sub> O <sub>3</sub> | 0.46   | Cr                                         | 0.05  |
| Fe <sub>2</sub> O <sub>3</sub> | 2.27   | Fe'''                                      | 0.24  |
| FeO                            | 1.33   | Fe''                                       | 0.16  |
| MnO                            | n.d.   | Mn                                         | —     |
| MgO                            | 23.94  | Mg                                         | 5.22  |
| V <sub>2</sub> O <sub>3</sub>  | 0.29   | V                                          | 0.03  |
| CaO                            | tr.    | Ca                                         | —     |
| BaO                            | 0.84   | Ba                                         | 0.04  |
| SrO                            | 0.41   | Sr                                         | 0.03  |
| Na <sub>2</sub> O              | 0.47   | Na                                         | 0.14  |
| K <sub>2</sub> O               | 9.64   | K                                          | 1.79  |
| H <sub>2</sub> O+              | 1.79   | OH                                         | 1.73  |
| H <sub>2</sub> O—              | 1.07   | Cl                                         | 0.05  |
| Cl                             | 0.21   | F                                          | 0.54  |
| F                              | 1.17   | O                                          | 21.68 |
| SO <sub>3</sub>                | 0.008  |                                            |       |
|                                | 99.588 |                                            |       |
| O=F                            | 0.49   |                                            |       |
| O=Cl                           | 0.05   |                                            |       |
| Total                          | 99.048 | Analyst: H. Matsumoto                      |       |

Therefore the phlogopite belongs to the 1 M polymorph of phlogopite as defined by SMITH and YODER (1956). Chemical composition of the phlogopite separated from the host rock by an isodynamic separator is given in Table 2. Iron content, especially ferrous iron is very low, as compared with high MgO content. Rather high SrO and BaO are worthy of note in contrast to negligible content of CaO, while Na<sub>2</sub>O is very low too. F content is high, probably replacing appreciable amount of OH. The composition is very close to that obtained by HILLEBRAND (CROSS, 1897). The formula on the basis of 24 (O, OH, F, Cl) is as follows:



Leucite forms always slightly rounded granular crystals, usually 0.02–0.05 mm across, and rarely as large as 0.1 mm. It is always fresh and contains minute inclusions of isotropic glassy substance, showing concentric arrangement characteristic to leucite. But no skeletal growth is observed. Each crystal is separated from others by thin films of glass with rather high refractive index. The leucite shows neither birefringence nor twinning, being optically isotropic with  $n=1.514$ . Considerable effort was made to get pure sample of leucite by means of a magnetic separator and heavy liquid. Intimate association of leucite with augite and glassy films, however, made it impossible to obtain leucite sample pure enough for analysis.

Augite forms usually subhedral or anhedral crystals as interstices between leucite crystals, or euhedral crystals enclosing poikilitically the leucite crystals. It is usually 0.1–0.5 mm in size, attaining rarely to 1.5 mm in length. Colorless or pale greenish and non-pleochroic.

$$\alpha = 1.672, \quad \beta = 1.680\text{--}1.682, \quad \gamma = 1.710, \quad 2V(+) = 55^{\circ}\text{--}57^{\circ} \quad c\hat{Z} = 43^{\circ}$$

The composition estimated is Ca<sub>46</sub>Mg<sub>47</sub>Fe<sub>7</sub>, falling in the category of diopside. Rarely greenish margin is developed along the slightly pale brownish augite. It is interesting that the augite is continuous without any boundary with pale greenish glassy films between the leucite grains. Apatite is common, forming rather large euhedral, tabular or prismatic crystals up to 0.2 mm. Calcite is found filling the small vesicles as massive crystals, about 0.1–0.3 mm in size. Since the rock is free from secondary alteration, calcite is regarded to have formed at the later stage of crystallization, probably in the pneumatolytic stage. Its presence indicates the high CO<sub>2</sub> content in the original magma. Iron ores are very rare, small crystals of magnetite or hematite being only sporadically present in the matrix. Very rarely peculiar amphibole with the following pleochroism is found: X...pale yellow, Y...pale purple, Z...greenish yellow, but its exact nature could not be determined.

### Orendite

The rocks falling in this category are usually light brownish or yellowish grey, and porous or sometimes pumiceous. Shining flakes of phlogopite are distinct but no flow banding is observed. The samples collected vary in their crystallinity, from highly glassy rock (No. 1102) to rather crystalline one (No. 1102 A). The crystalline orendite (No. 1102 A) is composed of leucite, sanidine, phlogopite, augite, apatite, calcite and glass. The glass is filled with microlites of sanidine and augite. The minerals have nearly the same characteristics as those described above. Sanidine forms euhedral tabular crystals, usually less than 0.1 mm in size and Carlsbad twinning is common. In the glassy variety (No. 1102), phlogopite phenocrysts are set in the glassy groundmass, composed of pale brownish glass filled with abundant acicular microlites of augite. No leucite is observed. Sometimes minute acicular crystals of pargasitic hornblende less than 0.03 mm in length are lining the miarolitic cavities. It is pale green and almost non-pleochroic.

$$\alpha = 1.625, \quad \gamma = 1.643, \quad \hat{cZ} = 25^\circ$$

### Xenoliths

Small angular block of xenoliths, 2–5 cm in size, are rarely present in both wyomingites and orendites. Of these some representative samples will be described below.

Augite-leucite rock No. 1101 X from wyomingite No. 1101.

This type is generally enclosed in the massive wyomingite and is dark greenish grey in color. Under the microscope the rock is composed of leucite, augite, phlogopite, apatite, calcite and small amount of glass. Leucite is euhedral rounded crystals, much larger than that in the host rocks, ranging usually 0.1–0.5 mm in size. It is sometimes weakly birefringent, and shows characteristic polysynthetic twinning similar to microcline. Refractive index is 1.515. Contrary to the subhedral augite in the host rocks, the augite in the xenoliths is always euhedral, prismatic or tabular in shape, up to 1.0 mm in length. Radial aggregates are common. Zoned structure is noticed in the marginal parts and twinning on (100) is observed. Phlogopite is the same as that in the host rocks, except that it is usually less than 0.6 mm in size. Calcite is common as euhedral crystals in the cavity, and acicular apatite is also common.

Augite-hornblende-biotite-leucite rock No. 1102 X from orendite No. 1102.

Dark grey, rather compact xenolith is rarely enclosed in porous orendite. It is composed of mosaic aggregates of leucite, biotite, hornblende, augite, magnetite and apatite. Leucite, the most abundant mineral, forms equant or elongated tabular

crystals, 0.2–0.8 mm in size. Polysynthetic twinning and weak birefringence are usually observed in the larger crystals, in remarkable contrast to the small isotropic crystals in other rocks. Some leucite crystals are free from inclusions, while others are rich in characteristic, vermicular-shaped, small crystals of pale greenish augite, which have the same optic orientation. Hornblende is abundant, euhedral or subhedral, tabular, usually 0.5–2.0 mm in size, and rarely attains to 4 mm. Strong pleochroism is observed:

X...slightly greenish yellow, Y...yellowish brown, Z...deep reddish brown,  $\alpha = 1.683$ ,  $\gamma = 1.717$ ,  $2V(-) = 86^\circ$ ,  $\hat{c}Z = 4^\circ-6^\circ$

From these properties the hornblende is estimated to be kaersutitic in composition, rich in titan. Intense opacitization is observed especially along the margin, resulting in the aggregates of minute pyroxene, magnetite and colorless mineral. The hornblende is commonly surrounded by deep reddish brown biotite, which often shows well developed hexagonal plates.  $\gamma = 1.663-1.673$ ,  $2V(-) = 0^\circ-20^\circ$ , with strong dispersion of  $v > r$ . Pleochroism is X...pale yellow, Y = Z...deep reddish brown. Thus the biotite is regarded as titan biotite. Augite forms stout prismatic or slightly rounded grains, and the color varies from slightly purplish brown tinge to pale green, or rarely to grass green. Probably the augite includes both titaniferous and sodic augite.  $\alpha = 1.684$ ,  $\beta = 1.700-1.707$ ,  $\gamma = 1.720$ . It is interesting that some of the augite crystals are continuous to the minute skeletal crystals of pale green augite enclosed in the leucite crystals. The presence of abundant magnetite is worthy of note and this is the only rock in which considerable amount of magnetite is present.

#### 4. Petrochemistry

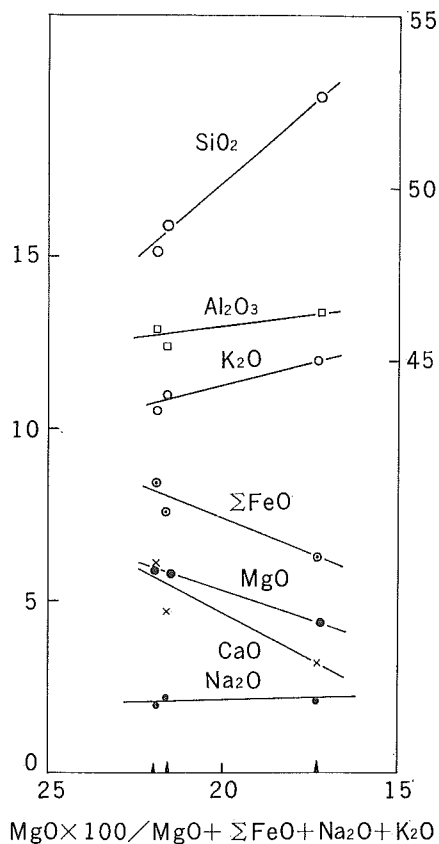
Chemical analyses of the wyomingite, orendite, and the xenolith No. 1101 X are given in Table 3, together with their normative composition. Xenolith 1102 X was too small to make analysis. The result is similar to the chemical composition of these rocks from other parts of the Leucite Hills analyzed by HILLEBRAND (CROSS, 1897). Extremely high potash content as compared with low soda content is the most remarkable feature. Rather high BaO and SrO are also worthy of note. F is also high, owing to the abundant phlogopite. The orendite is more felsic than wyomingite, and the ratio of the normative leucite and orthoclase is reversed in the two rocks. Since the orendite collected here is rather glassy, the modal sanidine is much less than normative orthoclase. The xenolith No. 1101 X is rather similar to, but slightly more mafic than, the host rock, i.e. MgO and CaO are higher, while the alkalis are lower in the xenolith. When the oxides are plotted against KUNO's solidification index— $MgO \times 100 / MgO + \text{total } FeO + Na_2O + K_2O$  (KUNO, 1953), the curves indicate the increase of  $SiO_2$ ,  $Al_2O_3$ ,  $K_2O$  and  $Na_2O$  and decrease of total FeO, MgO and CaO with the increasing solidification indices from the xenolith through the wyomingite to the orendite (Fig. 1).

Table 3. Chemical Composition and Normative Composition of the Leucite-bearing Rocks From Leucite Hills.

|                                | Weight % |        |        |          | Norm Wt. %   |       |       |
|--------------------------------|----------|--------|--------|----------|--------------|-------|-------|
|                                | 1101     | 1102   | 1101X  |          | 1101         | 1102  | 1101X |
| SiO <sub>2</sub>               | 48.94    | 52.64  | 48.22  | Or       | 15.57        | 35.03 | 21.13 |
| TiO <sub>2</sub>               | 1.76     | 1.72   | 1.78   | Lc       | 38.80        | 27.90 | 32.26 |
| Al <sub>2</sub> O <sub>3</sub> | 12.44    | 13.38  | 12.99  | Ne       | 1.42         | 1.14  | 4.26  |
| Cr <sub>2</sub> O <sub>3</sub> | 0.09     | 0.03   | 0.12   | Th       | 0.85         | 0.14  | 1.14  |
| Fe <sub>2</sub> O <sub>3</sub> | 4.28     | 5.19   | 2.81   | Ac       | 11.09        | 14.32 | 3.70  |
| FeO                            | 3.71     | 1.63   | 5.83   | Wo       | 7.66         | 4.29  | 9.28  |
| MnO                            | 0.10     | 0.09   | 0.10   | En       | 5.60         | 3.70  | 6.00  |
| MgO                            | 5.84     | 4.40   | 5.93   | Fs       | 1.32         | —     | 2.64  |
| V <sub>2</sub> O <sub>5</sub>  | 0.06     | 0.01   | n.d.   | Fo       | 6.30         | 5.18  | 6.16  |
| CaO                            | 4.77     | 3.16   | 6.16   | Fa       | 1.84         | —     | 3.06  |
| BaO                            | 0.81     | 0.37   | n.d.   | Mt       | 0.70         | 0.46  | 2.32  |
| SrO                            | 0.38     | 0.22   | n.d.   | Il       | 3.34         | 3.34  | 3.34  |
| Na <sub>2</sub> O              | 2.17     | 2.22   | 1.93   | Ap       | 1.01         | 1.01  | 1.34  |
| K <sub>2</sub> O               | 11.01    | 11.96  | 10.57  | Fr       | 1.40         | 1.01  | 1.40  |
| H <sub>2</sub> O+              | 1.43     | 1.87   | 1.36   | Cr       | 0.22         | —     | 0.22  |
| H <sub>2</sub> O—              | 0.54     | 0.44   | 0.56   |          |              |       |       |
| P <sub>2</sub> O <sub>5</sub>  | 0.47     | 0.44   | 0.50   |          |              |       |       |
| Cl                             | 0.05     | 0.03   | 0.05   |          |              |       |       |
| F                              | 0.71     | 0.54   | 0.69   |          |              |       |       |
| SO <sub>3</sub>                | 0.44     | 0.09   | 0.64   |          |              |       |       |
| Ni                             | 0.0007   | 0.0002 | n.d.   |          |              |       |       |
| Co                             | 0.0005   | 0.0002 | n.d.   |          |              |       |       |
| Cu                             | 0.0019   | 0.0012 | n.d.   |          |              |       |       |
| Zn                             | 0.011    | 0.007  | n.d.   |          |              |       |       |
|                                | 100.01   | 100.43 | 100.24 |          |              |       |       |
| O=F                            | 0.30     | 0.23   | 0.29   |          |              |       |       |
| O=Cl                           | 0.01     | 0.01   | 0.01   |          |              |       |       |
| Total                          | 99.70    | 100.19 | 99.94  | Analyst: | H. Matsumoto |       |       |
| S.I.                           | 21.6     | 17.3   | 21.9   |          |              |       |       |

## 5. Thermal Experiments

A series of thermal experiments has been made on the wyomingite, orendite and the xenolith, following the method described previously (YAGI, 1964), with the result shown in Table 4. It is interesting that pyroxene is always the liquidus phase, although augite is not phenocrystic constituent, and in the orendite augite is even occur in the glassy matrix. Probably pyroxene crystallized out in place of either phlogopite or the augite microlites in the glassy matrix. In these rocks the augite was usually preceded by leucite during the crystallization, but the order of crystallization of the two minerals is reversed in the experiments, partly owing

**Fig. 1**

Variation diagram against Solidification Index (S.I.) of the Leucite-bearing Rocks

to the absence of phlogopite in the dry experiments. Therefore the order of crystallization in these rocks cannot be estimated as in the case of Icelandic tholeiite basalts which are composed only of anhydrous minerals (YAGI, 1964).

It is also noticed that both wyomingite and its xenolith have nearly the same liquidus temperatures, which are much higher than the melting points of ordinary tholeiitic or alkali olivine basalts (TILLEY, YODER and SCHAIERER, 1964). The much lower melting point of the orendite than that of the wyomingite is in conformity with the increase in SiO<sub>2</sub>, iron and alkalis in the former. Although considerable amount of normative orthoclase is present in these rocks, the only felsic mineral observed in these experiments is leucite.

Table 4. Thermal Experiments on Wyomingite, Orendite, and Xenolith  
under 1 Atm Pressure.

| Temp.<br>°C         | Time<br>hrs | Results                                  | Index of<br>glass |
|---------------------|-------------|------------------------------------------|-------------------|
| Wyomingite No. 1101 |             |                                          |                   |
| 1325                | 1           | All glass                                | 1.557             |
| 1320                | 1           | Rare Px in glass                         | 1.556             |
| 1300                | 1           | Rare Px in glass                         | 1.556             |
| 1290                | 1           | Rare Px and very rare Lc in glass        | —                 |
| 1250                | 8           | Small amt. Px and small amt. Lc in glass | —                 |
| 1200                | 3           | Small amt. Px and lots Lc in glass       | 1.562             |
| 1150                | 24          | Lots Px and lots Lc in glass             | 1.562             |
| Orendite No. 1102   |             |                                          |                   |
| 1305                | 1           | All glass                                | 1.543             |
| 1300                | 1           | Rare Px in glass                         | 1.543             |
| 1290                | 1           | Rare Px in glass                         | 1.545             |
| 1230                | 16          | Small amt. Px in glass                   | 1.546             |
| Xenolith No. 1101 X |             |                                          |                   |
| 1320                | 1           | All glass                                | 1.561             |
| 1315                | 1           | Very rare Px in glass                    | 1.561             |
| 1295                | 10          | Rare Px in glass                         | 1.561             |
| 1290                | 1           | Rare Px and rare Lc in glass             | 1.565             |
| 1250                | 2           | Small amt. Px and mod. amt. Lc in glass  | —                 |
| 1220                | 2           | Mod. amt. Px and lots Lc in glass        | —                 |
| 1150                | 45          | Lots Px and lots Lc in glass             | —                 |

Px=Pyroxene      Lc=Leucite

## 6. Discussions

Occurrence of leucite-bearing rocks in the ocean is very limited. Of the five localities so far reported, i.e., Cape Verde Island, Kerguelen Archipelago, Utsuryo Island, Marquesas Island, and Tristan da Cunha, it was pointed out by BAKER et al (1964) that Tristan da Cunha is the only example of leucite-bearing rocks from truly oceanic island in the world. On the contrary leucite-bearing rocks are known from many localities on the continental regions. It is natural, therefore, that many petrologists prefer the hypothesis of assimilation of granitic rocks by the alkalic basalt for the origin of these highly potassic rocks (TURNER and VERHOOGEN, 1960). Fine examples of such reactions are given by GORAI (1940) and HOLMES (1945).

In the leucite-bearing rocks under consideration, however, evidence for such reaction between granitic rocks and basaltic magma has not been observed by the present authors. From the above-mentioned chemical and experimental data, it seems more likely that the xenolith No. 1101 X, wyomingite and orendite represent

the progressive stages of the differentiation from the parental magma. Though neither analysis nor thermal experiment is available for the xenolith No. 1102 X, its mineral composition suggests that it was formed in some part of the magma enriched in soda and titan. Therefore, all these rocks may be explained as the products of the crystallization differentiation of the common parental magma rich in potash.

When the  $K_2O/Na_2O$  ratio is calculated on the basaltic rocks presumably free from assimilation from both continental and oceanic regions, the ratio is always higher in the continental basalts than in the oceanic ones (YAGI, 1960 and unpublished data). Recently attention was called to the occurrence on the mid-Atlantic ridge or other parts of the Atlantic and Pacific ocean floors of extremely low-potash tholeiites (ENGEL and ENGEL, 1964). These facts seem to suggest that the continental basalts are always slightly higher in potash than the oceanic basalts. On the assumption that these basaltic rocks are direct derivatives of the upper mantle materials without the aid of contamination or assimilation of granitic or related sialic rocks, then the upper mantle under the continents could also be slightly more potassic than that under the oceans, even though the difference is very small. Recent geophysical investigation supports the concept of the inhomogeneity of the upper mantle. There is a possibility, therefore, that slightly more potassic phases, such as mica peridotite, may exist in the upper mantle under the continents. If such upper mantle material was subjected to the partial melting the resultant liquid will be more enriched in potash. Probably some geologic process resembling "zone melting" as advocated by HARRIS (1957) may have been effective to produce such highly potassic magmas. The present authors favor the view that some of the leucite-bearing rocks on the continents, or at least those of the Leucite Hills may have been derived by the crystallization differentiation from such parental potash-rich magma.

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**PLATE AND EXPLANATION 36**

## Explanation of Plate 36

- Fig. 1.** Large zoned phenocryst of phlogopite in the holocrystalline groundmass composed of leucite and augite. Wyomingite, No. 1101. Open nicols.  $\times 35$ .
- Fig. 2.** Phlogopite phenocrysts set in highly glassy vesicular groundmass. Orendite, No. 1102. Open nicols.  $\times 35$ .
- Fig. 3.** Tabular phenocrysts of phlogopite in the highly crystalline groundmass composed of augite and leucite. Orendite, No. 1102A. Open nicols.  $\times 35$ .
- Fig. 4.** Ditto. Birefringent crystals in the groundmass are augite, which shows sometimes poikilitic structure along the margins. Crossed nicols.  $\times 35$ .

Plate 36

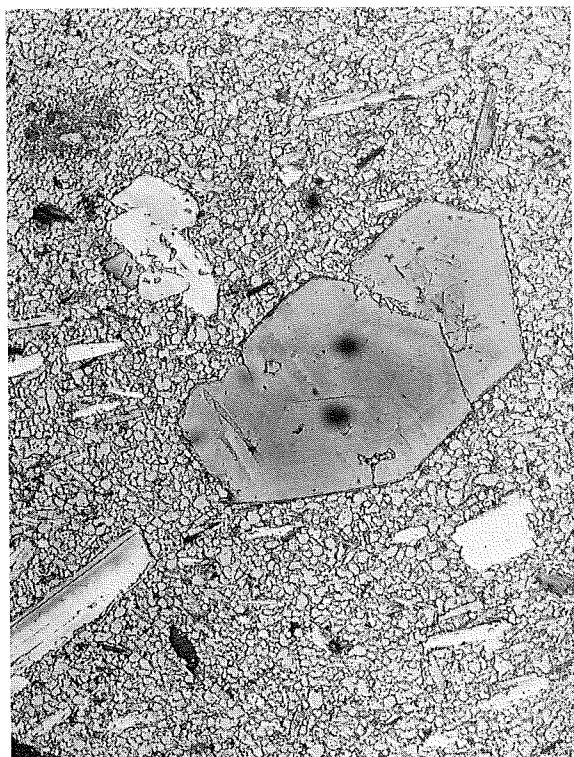


Fig. 1

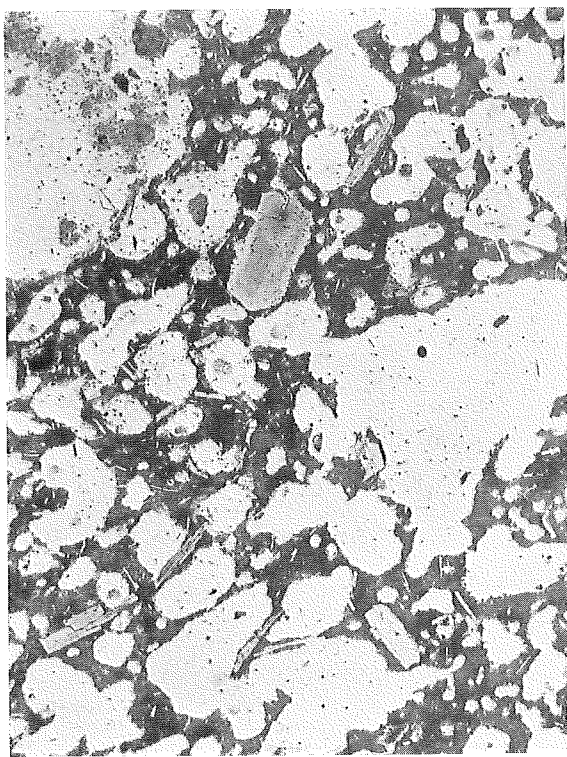


Fig. 2



Fig. 3



Fig. 4

**PLATE AND EXPLANATION 37**

## Explanation of Plate 37

- Fig. 1.** Augite-leucite rock, No. 1101X. Large euhedral augite crystals embedded in leucite grains and rare calcite (upper left corner). Open nicols.  $\times 35$ .
- Fig. 2.** Ditto. Note radial aggregates of augite. Crossed nicols.  $\times 35$ .
- Fig. 3.** Porous orendite, No. 1102A. Nice zoned phlogopite in the lower center, and large euhedral calcite crystal in vesicle in the center. Open nicols.  $\times 35$ .
- Fig. 4.** Augite-hornblende-biotite-leucite rock, No. 1102X. Large euhedral kaersutite phenocrysts, associated with large equant leucite and augite crystals. Open nicols.  $\times 35$ .

Plate 37

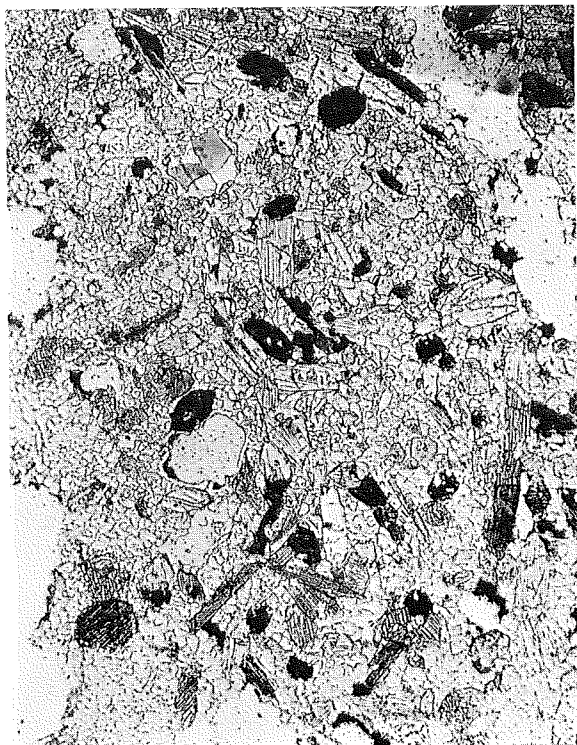


Fig. 1



Fig. 2

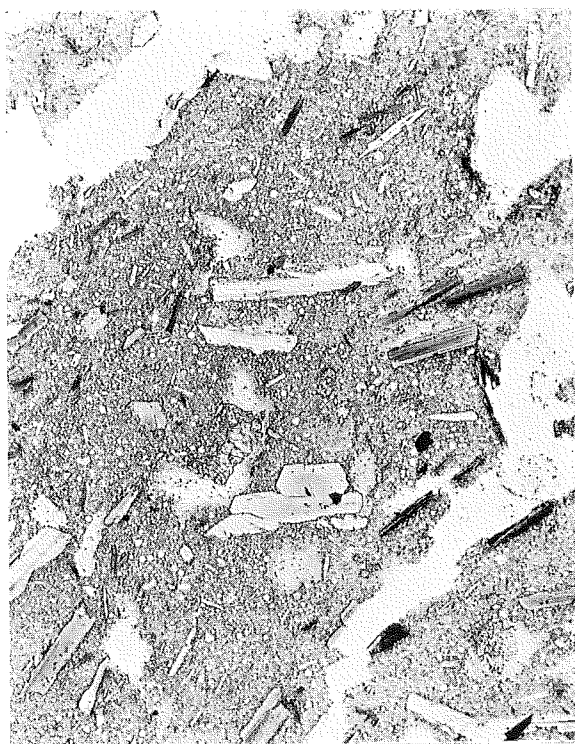


Fig. 3



Fig. 4