

ALKALI BASALT FROM NYE COUNTY, NEVADA

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ABSTRACT

Large crystals of olivine, pyroxene and plagioclase in a hyalocrystalline mesostasis of alkali basalt composition are believed to represent intratelluric products of the early crystallization phases of a newly formed basalt magma. The habit of the crystals as well as the optical and chemical data of the crystalline and melt phases indicate that a moderate amount of crystal fractionation occurred as part of the cooling history of the magma. The physical distribution of the crystalline phases, on the other hand, suggests that eruption and chilling of the magma were rapid enough to prevent notable differentiation by crystal settling.

INTRODUCTION

If basaltic magma originates near the mantle-crust boundary, the stage and the rate at which it moves surfaceward prior to eruption should be of interest to petrologists. Unfortunately, evidence in congealed lavas is seldom explicit on these matters. Data from the study of a basalt flow, which occurs near Black Rock Summit in east central Nevada (Fig. 1), suggest that the ascent of the magma in question began just as differentiation by means of crystal settling was about to set in, and that rise, eruption, and cooling of the magma was exceedingly rapid.

The basalt flow is small—it covers an area 5 miles long and 3 miles wide and is located at longitude $116^{\circ} 00'$ west and latitude $38^{\circ} 28' 30''$ north, in the southwestern foothills of the Pancake Range in Nye County. The lava issued from a breach in the southwest wall of a small cinder cone, one of several located on a $N.20^{\circ} E.$ trending fissure. About 90 per cent of the lava issued from this crater; the remainder flowed from an orifice located near the northeastern extremity of the fissure. The vent of the crater is about 300 feet in diameter and is now filled with solidified lava up to the level of the breach in the wall. Within the crater the surface of the lava is covered with minor jagged protuberances; outside the crater it is dominantly pahoehoe type. Residual monolithic blocks of pyroclastic material, now scattered throughout the flow, may represent fragments from the breach in the crater wall. In the steep northwestern wall of a longitudinal depression in the lava three layers are exposed, each separated from the other by thin scoriaceous horizons. The thickness at this location exceeds 50 feet but the base of the lava was not observed anywhere within the confines of the perimeter and consequently the thickness could not be determined.

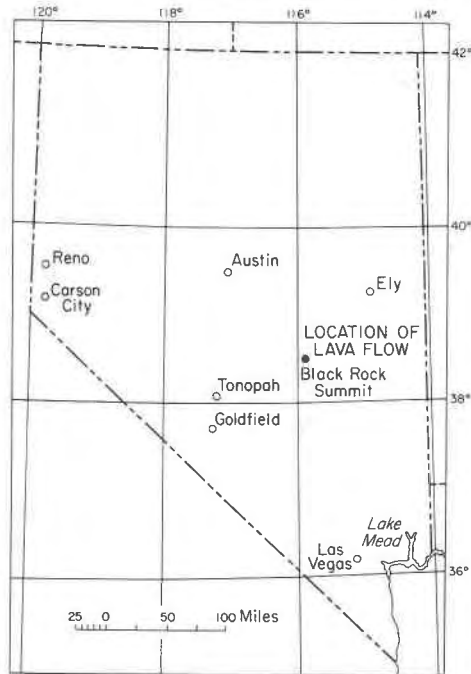


FIG. 1. Index map of Nevada showing the location of Black Rock Summit, near which the alkali flow occurs.

PETROGRAPHY

The rock is black, vesicular, and porphyritic except where marked oxidation attending vesiculation has colored it red. Its most striking characteristic is the large crystals of pyroxene, plagioclase, and olivine which make up 10–15 per cent of the mass. They are uniformly distributed throughout a porphyritic mesostasis¹ and range in size from less than 1.0 cm to 8.0 cm or more. The proportions of the various crystalline phases appear to have remained constant throughout crystallization, and there is flow alignment in the rock; the smaller crystals (1.0 to 1.5 cm) and most of the vesicles are distinctly oriented.

The mesostasis consists of vesicular brown glass, iron oxide, pyroxene, plagioclase, and olivine. Modal analysis of the mesostasis is as follows:

¹ The striking effect of the large crystals is to render crystals less than 2.0 mm in diameter inconspicuous. Thus, at first glance, the observer forms the impression of a sharper division between phenocrysts and mesostasis than actually is the case. Nevertheless, despite the apparent nature of this division, 2.0 mm was arbitrarily chosen, for the purposes of chemical analysis, as the dividing line between phenocrysts and mesostasis.

brown glass iron oxide mixture.....	48 per cent
pyroxene.....	16 per cent
plagioclase.....	14 per cent
olivine.....	12 per cent
clear brown glass.....	7 per cent
accessory minerals.....	less than 3 per cent
Total.....	100 per cent

Vesicle walls are occasionally lined with hydrous iron oxide, or with a buff colored material, part of which has an acicular habit, parallel extinction, and high birefringence—an *x*-ray powder pattern of some of the buff colored material indicates that it is a mixture of epsomite ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$); goslarite ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$), and possibly zinkosite (ZnSO_4).

A chemical analysis of the mesostasis (Table 1. no. 1.) shows notable quantities of CaO, MgO and Na_2O , whereas SiO_2 is definitely low. For comparison, the average analysis for 96 normal alkali basalts and dolerites (Nockolds, 1954) as well as the analysis of alkali basalt from a prehistoric flow, Hualalai, Hawaii, (Yoder and Tilley, 1962) are included in Table 1. The basalt from Nevada is higher in alumina and alkalis, but lower in silica, total iron, and titanium, than either the average analysis of Nockolds, or the alkali basalt from Hawaii. The alumina content is not, however, high enough to require classification as high-alumina basalt (anal. 4, Table 1). The mesostasis clearly has the composition of alkali basalt. It differs from most other alkali basalt in that it contains considerable glass, alkali basalts being almost invariably holocrystalline, with glass exceedingly rare (Yoder and Tilley, 1962). In most other respects the Nevada basalt and alkali basalts in general do not differ.

MINERALOGY

Pyroxene. Pyroxene crystals occur in two varieties; a greenish black type with fairly distinct cleavage and vitreous luster and a black type with subvitreous luster and subconchoidal fracture. The crystals are as long as 8 cm; the larger ones are subhedral, the medium and smaller ones are euhedral. The large and medium sized crystals are often partly resorbed and the grain boundaries have, as a result, a jagged sawtooth aspect. In all instances where resorption has occurred, the crystal remnants are in contact with iron oxide charged mesostasis. About 5 per cent of the crystals have been resorbed to such an extent that only narrow skeleton-like fragments with sawtooth edges remain.

Some of the pyroxene crystals are zoned and consist of a clear colorless core and exterior zone separated by a very narrow band charged with tiny mineral inclusions. Where measurements were taken, in the zoned pyroxene crystals, $Z/\lambda c$ was smaller for material in the core of the crystal than for the material in the outer zone.

TABLE 1. CHEMICAL ANALYSES AND NORMS OF BASALTS

	(1)	(2)	(3)	(4)
SiO ₂	44.8	45.78	46.53	48.27
Al ₂ O ₃	16.5	14.64	14.31	18.28
Fe ₂ O ₃	2.23	3.16	3.16	1.04
FeO	8.10	8.73	9.81	8.31
MgO	10.8	9.39	9.54	8.96
CaO	10.1	10.74	10.32	11.32
Na ₂ O	3.43	2.63	2.85	2.80
K ₂ O	1.76	0.95	0.84	0.14
TiO ₂	1.67	2.63	2.28	0.89
MnO	0.22	0.20	0.18	0.17
P ₂ O ₅	0.64	0.39	0.28	0.07
H ₂ O ⁺	0.23		0.08	0.15
H ₂ O ⁻			nil	0.17
Cr ₂ O ₃	—		0.06	n.d.
Total	100.48	99.24	100.24	100.57

(1) Basalt, mesostasis of lava flow from near Black Rock Summit, Nye County, Nevada. Analyst, M. Coller, Indiana University.

(2) Average of 96 normal alkali basalts and dolerites, Nockolds 1954, table 7, anal. IX, p. 1021.

(3) Alkali basalt, prehistoric flow, Hualalai, Hawaii, Yoder and Tilley 1962, table 2, anal. 20, p. 362-3. Analyst, J. H. Schoon.

(4) High alumina basalt, Warner Flow, Medicine Lake Highlands, California, Yoder and Tilley 1962, table 2, anal. 16, p. 362-3. Analyst, J. H. Schoon.

Norm: analysis (1)

<i>Mineral</i>	<i>Per cent</i>
orthoclase	10.4
albite	6.9
anorthite	24.3
nepheline	12.0
diopside	17.75
olivine	20.99
magnetite	3.2
ilmenite	3.2
apatite	1.4

Chemical analyses and optical data for the green as well as the black variety of pyroxene are given in Table 2 (anal. 1 and 2). The crystals analysed were selected because of difference in color and for no other special reason. Both varieties contain notable quantities of CaO and Na₂O, as well as minor amounts of K₂O. Compositional differences between the two are apparent in the content of SiO₂, Al₂O₃, MgO and total

iron. There is an inverse relationship between the MgO and total iron; where the former is high the latter is low and vice versa.

A chemical analysis of pyroxene from Hualalai, Hawaii (Table 2, anal. 3) is included for the purpose of comparison. The Hawaiian pyroxene contains less Al_2O_3 but more total Fe than either pyroxene in the basalt from Nevada. All the analyses contain considerable CaO.

TABLE 2. CHEMICAL ANALYSES OF PYROXENES FROM ALKALI BASALTS

	(1)	(2)	(3)
SiO ₂	47.6	50.2	48.61
Al ₂ O ₃	10.6	8.56	4.80
Fe ₂ O ₃	2.02	0.85	2.75
FeO	4.54	3.91	7.14
MgO	13.4	17.4	13.42
CaO	19.6	17.6	20.38
Na ₂ O	1.12	0.81	0.63
K ₂ O	0.01	0.04	0.11
TiO ₂	1.46	0.56	1.91
MnO	—	0.12	0.20
CO ₂	—	0.07	—
Cr ₂ O ₃	—	—	0.09
H ₂ O	0.09	0.04	0.03
Total	100.44	100.16	100.07
Z∧c	42°	41°	
α	1.685	1.695	
β	1.694	1.699	
γ	1.703	1.713	
2V	55°	54°32'	

* Chemical formulas calculated on the basis of 6 oxygens according to the method suggested by Stevens, 1946:

(1)* $(Ca_{38.7}Na_{4.0}Mg_{36.8}Fe_{9.8}Ti_{2.0}Al_{9.8})_{1.99}(Si_{86.2}Al_{13.8})_{2.01}O_6$; green variety. Analyst, M. Coller.

(2)* $(Ca_{34.3}Na_{3.1}Mg_{47.1}Fe_{5.9}Ti_{0.8}Mn_{0.2})_{1.98}(Si_{89.4}Al_{10.6})_{2.02}O_6$. black variety. Analyst, M. Coller.

(3) Pyroxene from alkali basalt, prehistoric flow. Hualalai, Hawaii, Yoder & Tilley 1962, p. 364, table 3, anal. 20. Analyst, J. H. Schoon.

Formulas for both varieties of pyroxenes were calculated on the basis of 6 oxygens according to the method suggested by Stevens (1946).

Plagioclase. Plagioclase crystals, almost invariably euhedral, range in size from microlites to phenocrysts 4.0 cm long (Fig. 2). The larger crystals are frequently broken and partly resorbed and the edges of the grains are in many instances well rounded. Polysynthetic twinning, with the com-

position face parallel to (010), is characteristic and is, in fact, the only form of twinning observed in all of the thin sections examined.

The compositional range has been obtained on the basis of determinations made on plagioclase crystals of several sizes. The composition of the microlites, for example, is An_{46-48} , that of the intermediate sized crystals (from 0.2 mm to 2.0 mm) An_{40-42} , and the optical and chemical data for the larger crystals, $Ab_{58} An_{36} Or_6$, are given in Table 3. Zoning was not observed in the large plagioclase crystals. The analysis of the largest crystal, however, was made on a composite sample of an entire crystal and is in essence representative of earliest plagioclase as well as latest. Plagioclase appears to have begun to crystallize soon after the ferromagnesian minerals did and it continued to crystallize until the final chilling of the residual magma.



FIG. 2. Plagioclase crystal in alkali basalt from near Black Rock Summit.

Olivine. Olivine occurs as single crystals and granular aggregates. The former are uniformly distributed throughout the flow, the latter on the other hand, were encountered only in the interior of the flow. The largest of the crystals measured $5\frac{1}{2}$ cm long (Fig. 3); the smallest, less than 0.1 mm in diameter. Within the body of the flow the crystals are deep green; in the outer fringes of the flow they have a yellow cast. In thin section, no apparent difference is discernible between the two types. Instead, about 98 per cent of the crystals are colorless and about 2 per cent have a faint lilac tint. A chemical analysis and the corresponding optical data for a composite sample of fragments from several large olivine crystals is given in Table 4. The chemical formula for the olivine was calculated by the method suggested by Stevens (1946). It was also calculated by the

TABLE 3. PLAGIOCLASE, BLACK ROCK SUMMIT, NEVADA

SiO ₂	59.6
Al ₂ O ₃	24.6
Fe ₂ O ₃	0.27
TiO ₂	0.56
CaO	5.53
MgO	0.13
Na ₂ O	7.07
K ₂ O	1.27
Total	99.03

α	1.537
β	1.530
γ	1.542
2V	82° ± 2°
Bxa	×
Ab ₅₈ An ₃₆ Or ₀₆	

Analyst, M. Coller

method suggested by Hess (1949). Differences between the two computations were minor.

Basal parting, accentuated by minute mineral inclusions, is present in some of the larger crystals. Occasionally larger crystals are shattered. A number of them are corroded or resorbed at the edges. Zoning is clearly noticeable in about 5 per cent of the large olivine crystals.

In an effort to determine, if possible, the extent of the compositional variation, if any, that exists between the core and the rim of the large olivine crystals, powdered samples from crystals of different diameters

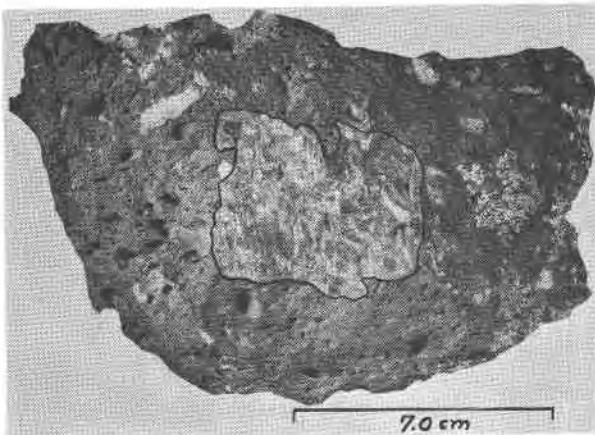


FIG. 3. Partly resorbed large olivine crystal in alkali basalt from near Black Rock Summit.

TABLE 4. OLIVINE, BLACK ROCK SUMMIT, NEVADA

SiO ₂	40.55
Al ₂ O ₃	1.62
Fe ₂ ×O ₃	n.d.
FeO	10.27
MgO	47.43
MnO	0.16
TiO ₂	n.d.
CaO	n.d.
H ₂ O	0.06
Total	100.09
α	1.6595
β	1.6725
γ	1.6930
2V	90° ± 2°

Formula (Mg₈₆ Fe₁₀ Al₂ Mn_{0.22})₂SiO₄ Analyst, M. Coller.

were prepared and *x*-rayed according to the method suggested by Yoder and Sahama (1957). Powdered silicon was used as an internal standard. On the assumption of normal conditions of crystallization during the cooling of the magma, the smaller the crystal the later the stage of crystallization at which it began to separate from the melt. In view of the fact that olivine appears to have continued crystallizing from the melt as long as crystals were forming, the composition of the smallest crystals and that of the outer portions of the large euhedral olivine crystals would presumably, be quite similar. Knowing this and the average composition of the larger crystals it would be possible to arrive at (a) the approximate composition of the core of the larger crystals, (b) the composition of the earliest olivine to crystallize from the melt, and (c) the degree of compositional variation in the olivine. The results, given in Table 5, are not necessarily proof, but they suggest that there is a range in composition of the olivine crystals along with a diminution in size. For the large crystals the *d*(130) value was 2.772, and the equivalent forsterite content, determined from the olivine *x*-ray determination curve, is 90.2 mol. per cent; for the smallest, 2.776, 84.0 mol. per cent. Based upon the above assumptions, and the results of the *x*-ray determinations, the composition of the earliest olivine to crystallize from the magma erupted near Black Rock Summit was approximately 96 mol. per cent forsterite. The variation in % Fo molecule appears to be negligible in the intermediate sized crystals but quite marked in crystals with diameters of 1.0 cm or less; the rate of % Fo impoverishment, therefore, appears to have accelerated in the later stages of olivine crystallization.

TABLE 5. COMPOSITION OF OLIVINE FROM BLACK ROCK SUMMIT, NEVADA,
BASED UPON $d(130)$ SPACINGS

Crystal diameter (cm)	$d(130)$	eq. Forsterite
0.25	2.7760	84.0
0.50	2.7743	86.8
1.0	2.7721	90.0
1.5	2.7719	90.5
1.5	2.7721	90.2

The olivine aggregates are not common. They have a maximum diameter, 12.5 cm., and consist of equidimensional grains, 0.1 mm in diameter, which are otherwise similar to the forsterite in the large crystals. Possibly they are relics of parental material of the magma but diagnostic evidence was not found.

DISCUSSION

The size of the crystals, their limited number, and the relative amount of glass in the mesostasis suggest intratelluric crystallization either for a short period of time in a volatile rich medium with few nucleation centers or for a longer time in a melt with low volatile content. Biotite and hornblende were not encountered in any of the thin sections examined. If it is assumed that sufficient volatiles were present in the crystallizing magma, any early formed volatile bearing minerals had to have been completely resorbed by the time crystallization ceased. Such a process apparently is possible, especially if the crystallizing magma rises from the magma chamber to the surface slowly (Yoder and Eugster, 1954), or in stages. Under such conditions, ample time might be available to resorb the earlier formed volatile bearing minerals and to produce additional olivine-basalt.

The complete lack of volatile bearing minerals and, to a limited extent, the lack of extensive resorption of the crystals present in the lava suggests that the magma must have been deficient in volatiles during the interval of intratelluric crystallization, at least, and that under these conditions anhydrous, early phase, high temperature minerals only were formed from the crystallizing magma. In fact, petrographic evidence appears to indicate that concentration of volatile constituents occurred in the very latest stage of cooling and then only at a stage when they could exert very little influence on the crystallizing mineral phases. Thus, although volatiles collected in sufficient quantity in the late stages of cooling to form gas bubbles in the rapidly solidifying lava, the glass in the mesostasis is devoid of volatile bearing minerals.

Olivine, pyroxene, and plagioclase, apparently crystallized from the

magma as coexisting phases throughout the intratelluric stage and possibly during part of the short-lived post-intratelluric stage as well. During much of the intratelluric stage the position of the point representing the composition of the melt from which the crystals were separating probably changed along a line representing the four phase curve of the system forsterite-albite-anorthite-clinopyroxene in a manner as outlined by Yoder and Tilley (1962). The range of composition traversed by this point could probably be related to the compositional change undergone by the large and intermediate sized crystals of the plagioclase. Eruption and final chilling of the melt probably began when the plagioclase composition stood near An_{40-42} , the composition of the intermediate size crystals. Melt and crystals appear generally to have co-existed under equilibrium conditions during crystallization except just prior to the start of the final chilling stage during which time much of the resorption observed probably occurred. The crystalline material when resorbed was converted to glass, rather than to a crystal phase stable at conditions of lower temperature and pressure, suggesting that the temperature of the melt was still high. It should be noted that despite the evidence of disequilibrium in portions of the cooling melt, as depicted by resorption in part of the larger crystals, elsewhere in the rock smaller crystals of olivine, pyroxene and plagioclase are not resorbed and, in fact, appear to have crystallized under equilibrium conditions from the residual liquid even in the very latest stages of crystallization.

The only evidence for differentiation by means of crystal fractionation in the particular system represented by the melt of the lava from Black Rock Summit is in the compositional differences and the variation of optical properties in individual crystals of plagioclase, olivine, and pyroxene. In this connection, some puzzling features have been noted. The per cent An in the plagioclase crystals, for example, is lowest in the large phenocrysts and highest in the microlites in the mesostasis. Carr (1954), in a study of the plagioclase of the Skaergaard intrusion, suggested that zoning in those crystals might be explained as a result of variation in hydrostatic pressure due to vertical movement of magma and crystals in convection currents and that crystallization giving simple normal zoning shown by the majority of the crystals is the result of increasing pressure during descent. Carr (1954) also points out, on the basis of existing data, that an increase of pressure possibly shifts the composition of crystallization at any given temperature toward a more albitic phase.

Whether or not the total volume of magma from which the Black Rock Summit lava was derived was large enough to support active convection currents is unknown. Assuming that it was not, an effect similar to that suggested for the Skaergaard intrusion might be possible if the magma

existed, for a time at least, as a column of unknown vertical dimension and the lava in question represented a fraction drawn off from some level of this column; perhaps by a fissure which opened to the melt. In such a column, plagioclase crystals, once formed, could begin to float in response to difference in density with respect to the residual liquid. Assuming a reasonable thickness for such a column of magma, it is conceivable that the pressure difference between successive levels in the column could account for the compositional differences exhibited by the plagioclase crystals in the lava and that variation in per cent An in the plagioclase crystals could be the result of crystallization at different levels in the column. Plagioclase crystals formed at higher temperature and pressure in the deeper parts of the column (the large phenocrysts) would, initially, contain less An than those formed a little higher in the lava column (the medium sized crystals) and the microlites, which probably formed near the top of the lava column or even just prior to and during eruption, would contain the highest per cent An. Upward movement of crystals during the intratelluric crystallization stage, even if only for a relatively short distance, might permit an earlier formed crystal to maintain a more or less uniform composition as crystallization proceeded. Resorbed crystals might be the result of a more rapid rate of rise locally; movement of this type might even account for some of the mixing of the different sized crystals. It is possible that the liquidus and solidus curves of the forsterite-fayalite system might be affected by a pressure gradient in a similar manner. Alternatively, Fo-rich crystals of olivine may have formed at an early stage and settled to some extent in the residual liquid, extracting magnesium from the latter, leaving it enriched in iron. The growth of pyroxene crystals which would have started soon thereafter, would tend to remove magnesium from the melt also and thus accelerate the iron enrichment process.

In general, the random distribution of crystals of the ferromagnesian minerals of all sizes in the lava, the nature of the resorption (*e.g.*, conversion to the glass phase) which has occurred on only some of the crystals in all the phases, the euhedral habit of many of the smaller crystals, and the absence of visible reaction between the two ferromagnesian silicate phases appear to suggest that at no time during crystallization of the magma did one crystalline phase become unstable to be replaced, through reaction with the residual liquid, by another. The order of crystallization of the various phases during cooling of the magma is not entirely clear and the presence of euhedral microlites of all the crystalline phases suggests some overlap of crystallization. Possibly the sequence of crystal growth did not follow the Bowen Reaction series exactly, for the solidified flow contains euhedral microlites, the last stage of crystallization, of all the

crystalline phases present in the flow. Despite the size and number of intratelluric crystals in the basalt, however, evidence of any degree of crystal settling is lacking. The reason for this is difficult to determine. Insufficient time, viscosity of the melt, or even turbulent convection would prevent settling. Although turbulence in the melt near the vent level may have redistributed earlier formed crystals, it is felt that insufficient time probably prevented large scale crystal segregation. Intratelluric crystallization apparently had proceeded to the point where crystal settling was imminent or had already begun, just as the melt and crystals were raised to the surface and erupted as lava. Rapid chilling, which undoubtedly set in almost immediately, with the attendant rapid increase of viscosity, prevented extensive differentiation. In this manner, the crystals remained uniformly distributed throughout the melt.

In overall composition, the basalt from near Black Rock Summit may represent the parent magma of much of the basalt in this part of Nevada.

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