ALKALINE AND CALC-ALKALINE BASALTS FROM
CAPULIN MOUNTAIN, NORTHEASTERN
NEW MEXICO, U. S. A.

KEN-ICHIRO AOKI

*Institute of Mineralogy, Petrology and Economic Geology
Tohoku University, Sendai*

INTRODUCTION

From geologic, petrographic, and petrochemical studies, Aoki and Oji (1966) have emphasized that the calc-alkaline basalts in the alkaline province of southwestern Japan were derived from an alkali-olivine basalt magma which assimilated about 5 to 10% of its weight of granitic material in the early stages of fractionation. This type of basalt is found also in the Capulin Mountain, New Mexico.

The petrography and chemistry of the calc-alkaline basalt in Capulin Mountain, New Mexico will be described and discussed in this paper.

ACKNOWLEDGEMENTS

The author is indebted to Drs. Kazuo Kobayashi and Minoru Ojima of Geophysical Institute, University of Tokyo, for their kind assistance with the field work. He also wishes to thank Professor Yoshio Ueda of Tohoku University for kind advice with this work.

GEOLOGY AND PETROGRAPHY

In the Raton area, along the eastern foot of the Rocky Mountain Range of northeastern New Mexico, there are tremendous amounts of a series of Pliocene to Recent alkaline and peralkaline basaltic rocks accompanied by small amounts of calc-alkaline basalt-dacite association (Fig. 1). These Cenozoic volcanic rocks occupy the eastern border of the alkaline province of western United States, forming broad mesas, long narrow flows, and cones. Recently, the geology and the

Fig. 1. Index map showing the location of the basaltic rocks described in this paper. Black area: distribution of late-Tertiary to Quaternary basalts in New Mexico.

petrography of this area were studied in detail by Baldwin and Muhlberger (1959). According to them, these volcanic rocks are divided into the following groups (from oldest to youngest): 1. Raton basalt, 2. Sierra Grande andesite (similar to the Red Mountain dacite), 3. Clayton basalt and 4. Capulin basalt.

The petrography and chemistry of almost all of the basalts clearly show the nature of typical circum-oceanic alkaline suit which are characterized by high SiO_2 , Al_2O_3 and K_2O , and low TiO_2 . Any of the tholeiites or olivine-tholeiites saturated with silica have not been found in this area. This is an excellent contrast to the basalts belonging to typical olivine-tholeiite of the Taos area, western foot of Rocky Mountain Range, north central New Mexico (Aoki, 1967).

New analysis of nine volcanic rock samples from this area and their normative composition are given in Table 1. Some alkali basalts have normative quartz or hypersthene which is attributable to slight oxydation of the rocks after eruption.

The final stage of volcanic activities in this area is represented by

Table 1. Chemical analyses and norms of basaltic rocks

	1	2	3	4	5	6	7	8	9
SiO ₂	36.74	48.87	49.74	57.49	45.65	39.64	47.27	55.54	49.38
TiO ₂	1.83	1.13	1.15	0.90	1.42	1.83	1.59	1.00	1.18
Al ₂ O ₃	13.70	15.75	14.98	16.09	15.04	13.65	15.85	15.40	16.23
Fe ₂ O ₃	10.85	3.28	7.42	1.80	3.62	7.12	2.67	0.91	2.80
FeO	1.75	8.29	4.68	4.79	6.91	6.28	9.29	7.74	8.15
MnO	0.24	0.15	0.18	0.11	0.20	0.22	0.11	0.14	0.15
MgO	7.65	7.35	5.79	3.65	7.86	9.28	7.94	5.45	7.41
CaO	14.37	9.26	8.43	6.18	11.13	12.78	9.92	7.07	9.15
Na ₂ O	4.68	3.53	3.59	4.47	4.14	4.12	3.03	3.95	3.63
K ₂ O	1.90	0.85	1.25	2.36	1.49	1.50	0.71	2.05	1.36
H ₂ O+	1.42	0.55	1.40	1.37	1.19	0.84	0.45	0.39	0.28
H ₂ O-	1.35	0.19	0.46	0.19	0.47	0.47	0.28	0.07	0.00
F ₂ O ₅	2.87	0.50	0.53	0.60	0.72	1.66	0.59	0.40	0.57
SO ₃						0.32			
Total	99.35	99.70	99.60	100.00	99.84	99.71	99.70	100.11	100.29
O	—	—	2.18	4.87	—	—	—	0.16	—
Or	—	5.00	7.39	13.96	8.84	8.90	4.23	12.12	8.06
Ab	—	29.82	30.34	37.78	12.94	—	25.62	33.38	28.35
An	10.73	24.60	21.04	16.82	18.01	15.37	27.49	18.21	23.94
Lc	8.81	—	—	—	—	—	—	—	—
Ne	21.44	—	—	—	11.96	17.75	—	—	1.25
Wo	15.31	7.57	7.26	4.18	13.60	15.58	7.46	5.97	7.44
En	13.20	5.86	14.47	9.13	9.03	12.22	5.50	13.62	4.42
Fs	—	3.55	0.88	6.01	3.55	1.60	3.43	12.05	2.63
Cs	1.67	—	—	—	—	—	—	—	—
Fo	4.14	8.76	—	—	7.43	7.69	10.05	—	9.87
Fa	—	5.85	—	—	3.21	1.23	6.93	—	6.45
Mt	1.11	4.76	10.76	2.62	5.24	10.32	3.87	1.30	4.06
Hm	10.08	—	—	—	—	—	—	—	—
Il	3.48	2.14	2.19	1.72	2.71	3.48	3.02	1.90	2.23
Ap	6.79	1.18	1.24	1.41	1.71	3.93	1.41	0.94	1.34
Th	—	—	—	—	—	0.57	—	—	—

1. Oxidized olivine nephelinite (Raton basalt, Pliocene), Johnson mesa, 15 miles east of Raton, Colfax County.
2. Olivine alkali basalt (Raton basalt, Pliocene), Bartlett mesa near Raton.
3. Oxidized olivine alkali basalt (Raton basalt, Pliocene), Horse-shoe mesa near Raton.
4. Hypersthene bearing olivine augite calc-alkaline andesite (Sierra Grande andesite), 6 miles southeast of Des Moines, Union County.
5. Titanaugite olivine alkali basalt (Clayton basalt, Van Cleve flow, upper Pliocene), 8 miles east of Des Moines, Union County.
6. Hauyne nephelinite (Clayton basalt, upper Pliocene), 6 miles southeast of Des Moines.
7. Olivine alkali basalt (Clayton basalt, Clayton flow, upper Pliocene), 8 miles west of Clayton, Union County.
8. Hypersthene bearing augite olivine calc-alkaline basalt (Capulin basalt, Recent, B.C. 8,000–2,350), southern foot of Capulin Mountain, road cutting of HWY 64, Union County.
9. Titanaugite olivine alkali basalt, (Capulin basalt, Recent) scoria fall of Capulin Mountain erupted in the final stage.

eruption of the Capulin basalt during ca. 8,000 to 2,500 B.C. At first, lava flows and associated pyroclastics extended far north of Capulin town, forming the greater part of Capulin basalt. Then, several small cones which consist of basaltic cinder, scoria, bomb, and ash were formed on the uneven surface of the lava plateaus. Capulin Mountain which has been set aside as a National Monument is the largest and the most symmetrical of the cinder cones. Its conical form rises more than 300 m from its base to the highest point on the crater rim which has an elevation of about 2,740 m above sea level. The crater is 400 m in diameter at the top and 140 m in depth.

Two representative rock samples have been collected from the Capulin Mountain, one is a calc-alkaline basalt from lava flows erupted in the early stage, and the other is an alkali olivine basalt projected from the crater in the latest stage of eruption.

Calc-alkaline basalt In hand specimen, the rock is dark gray, porphyritic, and vesicular with scattered olivine, feldspar and quartz grains up to 3 mm in size set in a compact groundmass. Under the microscope, the phenocrysts are found to be mainly olivine (2.0%) and augite (0.5%). Hypersthene is quite rare (less than 0.1%). Olivine occurs in euhedral form, up to 2 mm in size. Weak zonal structure is observed only in the peripheral margin of each crystal. Olivine commonly displays weak undulating extinction, but does not have any translation lamellae. Minute octahedral grains of picotite are generally included. Augite is euhedral to subhedral, prismatic and attains a maximum length of 0.8 mm. Twinning on (100) is common. Hypersthene is always in parallel intergrowth with augite, and is always completely surrounded by it. It does not exceed 0.5 mm in length.

The groundmass is medium-grained and holocrystalline. It consists of plagioclase, augite, olivine, iron ore, apatite and anorthoclase and small amount of brown glass.

The rock is characterized by the presence of xenocrystic quartz (3.1%) and plagioclase (8.3%). The quartz xenocrysts are snow-white in color, generally rounded in outline and less than 2 mm in size. They are always surrounded completely by thick reaction rims (about 0.1 to 0.2 mm in width) of minute grains of augite or sometimes brown glass with scattered acicular crystals of augite. Small quartz grains are completely changed to augite by interaction with the host magma. Plagioclase xenocrysts are anhedral to prismatic in form and rounded in outline. Their compositions are vitrified in all

degrees toward the cores, and their fresh calcic thin mantles correspond in composition of the groundmass plagioclase.

Alkaline basalt The hand specimen of alkaline basalt is dark gray and porphyritic, with numerous small cavities and phenocrysts. The phenocryst which totals about 5 per cent of the whole rock is made up of olivine and plagioclase (up to 3 mm in size). The groundmass is compact and fine-grained. The rock also contains rare quartz xenocrysts.

Microscopically, it contains phenocrysts of plagioclase (3.6%), olivine (2.2%), and augite (1.3%). Olivine occurs in euhedral crystals; 0.2–2 mm long and tabular or elongated parallel to the c-axis. Minute octahedral picotite inclusions are not uncommon. Augite is stout prismatic euhedral to subhedral and is generally smaller than olivine. In the prismatic crystals the hour-glass structure is weakly developed. Plagioclase is long prismatic euhedral and reaches up to 1.5 mm in length. Zonal structure is scarcely perceptible in the cores of the plagioclase crystals, but is clear in the margin.

The groundmass is fine-grained and holocrystalline without any glassy base. It consists of plagioclase, potash-plagioclase, anorthoclase, augite, olivine, iron ore and apatite.

Quartz xenocrysts, not exceeding 1.5 mm across (0.8%), show the same occurrence as those of calc-alkaline basalt.

Petrographically, calc-alkaline basalt of Capulin Mountain is distinguished from alkaline basalt of the same place and of the Raton area by the following characteristics: (1) presence of hypersthene as phenocrysts, (2) common quartz and plagioclase xenocrysts, (3) absence of potash-plagioclase, (4) lath-shaped crystals with well developed faces of plagioclase in the groundmass instead of subhedral to anhedral form which are very common of the groundmass plagioclases in alkaline basalt owing to the high content of potash, and (5) dirty appearance of the groundmass texture. These characteristics of calc-alkaline basalt agree with those of Japanese calc-alkaline basalts in the alkaline province (Aoki, 1959, Aoki and Oji, 1966).

DISCUSSION

The genesis of calc-alkaline basalts and andesites is one of the most important problem in the petrology. Alternative hypotheses have been proposed concerning the origin of calc-alkaline volcanic suite. The principal hypotheses are summarized as follows; 1) frac-

Table 2. Groundmass composition of calc-alkaline basalt and average basalts.

	1	2	3	4	5
Number of analyses	9	1	1	43	16
SiO ₂	49.06	49.38	54.4	48.39	53.90
TiO ₂	1.39	1.18	1.2	2.10	1.39
Al ₂ O ₃	15.50	16.23	15.2	16.73	17.46
Fe ₂ O ₃	2.95	2.80	1.1	3.59	3.18
FeO	8.21	8.15	8.5	6.94	5.67
MnO	0.16	0.15	0.2	0.17	0.14
MgO	7.66	7.41	5.4	7.42	4.93
CaO	9.67	9.15	7.2	9.20	7.89
Na ₂ O	3.52	3.63	4.1	3.24	3.41
K ₂ O	1.17	1.36	2.3	1.66	1.72
P ₂ O ₅	0.70	0.57	0.5	0.56	0.31
Q	—	—	—	—	3.62
Or	6.89	8.06	13.3	9.84	10.17
Ab	28.51	28.35	34.6	26.57	28.82
An	23.02	23.94	16.4	26.16	27.22
Ne	0.68	1.25	—	0.45	—
Di	16.62	14.49	13.1	12.90	8.06
Hy	—	—	10.6	—	14.18
Ol	15.75	16.32	7.1	13.57	—
Mt	4.27	4.06	1.6	5.20	4.62
Il	2.64	2.23	2.3	4.00	2.64
Ap	1.65	1.34	1.3	1.31	0.74

1. Average alkali basalt of Raton area.
2. Alkali basalt from Capulin Mountain.
3. Calculated groundmass composition of calc-alkaline basalt from Capulin Mountain.
4. Average alkali basalt of southwestern Japan (Aoki and Oji, 1966).
5. Average calc-alkaline basalt of southwestern Japan (Aoki and Oji, 1966).

tionation of basaltic magmas contaminated by granitic rocks or siliceous sediments, 2) fractionation of basaltic magmas under high oxygen pressure, 3) mixing of basaltic and rhyolitic magmas, and 4) partial melting of quartz eclogite in the upper Mantle. Among these hypotheses Japanese petrologists have strongly supported hypothesis (1).

In the superimposed petrographic provinces of alkaline and calc-alkaline volcanic rock series, the study of the genetical relations between the two series is easier than that of superimposed tholeiite and calc-alkaline or high-alumina and calc-alkaline series. Because most of the circum-oceanic alkali basalt magmas are of slight undersaturation in silica, being plotted near the critical plane of undersaturation (Fo-Di-Pl) in the field of alkaline rocks, and the

Fig. 2. $\text{Na}_2\text{O} + \text{K}_2\text{O} - \text{SiO}_2$ diagram for all analyzed volcanic rocks in New Mexico. Solid circles, alkaline and peralkaline series. Open circles, calc-alkaline series. Half solid circle, groundmass composition of Capulin Mountain calc-alkaline basalt. Dashed line, boundary between alkaline and calc-alkaline series of the Japanese alkaline province (Aoki and Oji, 1966).

calc-alkaline basalts are saturated or oversaturated in silica, being plotted in the field of silica saturation or oversaturation, mafic mineral assemblages of such series are clearly different.

Calculated groundmass composition of calc-alkaline basalt from Capulin Mountain is given in Table 2. Averages of those Raton area and Japanese alkaline basalts and Japanese calc-alkaline basalts in the alkaline province are included for comparison. These alkaline basalts and calc-alkaline basalts are rather similar to each other and do not essentially show any chemical differences.

Fig. 2 is an alkali-silica diagram in which are plotted all the analysed volcanic rocks from Raton area (This paper and Baldwin and Muehlberger, 1959; old analyses are omitted). As shown in this diagram the alkaline and calc-alkaline series clearly differs from each other. Field boundary between the two series in the Japanese alkaline province is also given. The boundary between alkaline series and silica saturated series such as tholeiite, high-alumina or calc-alkaline series of Japan, Hawaii or Galapagos have been drawn by several investigators, and the lines lay at the same position in the diagram. The calc-alkaline basalt from Capulin Mountain is plotted near the boundary of the calc-alkaline and alkaline fields. Its groundmass composition, however, falls within the alkaline field, although still near the boundary. This shows a rather alkaline affinity for the groundmass. It should be stressed,

therefore, that the liquid composition is transitional between alkaline and calc-alkaline.

From the field occurrence, petrography and chemistry, it is concluded that the calc-alkaline basalt magma from the Capulin Mountain was developed at the top of a magma cupola or vent prior to the extrusion of the alkaline basalt magma which has assimilated granitic material. Before the digestion proceeded to completion, the calc-alkaline basalt magma was carried to the surface forming the basal part of the Capulin Mountain. Following this activity, alkaline basalt magma erupted successively from the same vent, resulting in the formation of the cinder cone.

APPENDIX

Constituent minerals of analyzed rocks given in Table 1 are as follows:

1. Fine-grained and holocrystalline, phenocryst; olivine, groundmass; nepheline, titanite, iron ore, olivine, phlogopite, analcime, sanidine.
2. Coarse-grained and holocrystalline, phenocryst; olivine, groundmass; olivine, augite, plagioclase, potash-plagioclase, anorthoclase, iron ore, apatite.
3. Coarse-grained and holocrystalline, phenocryst; olivine, groundmass; olivine, plagioclase, potash-plagioclase, augite, anorthoclase, iron ore, apatite.
4. Medium-grained and hypocrySTALLine, phenocryst; olivine, augite, hypersthene, plagioclase, magnetite, groundmass; plagioclase, augite, hypersthene, iron ore, apatite, brown glass.
5. Coarse-grained and holocrystalline, phenocryst; olivine, titanite, augite, groundmass; olivine, titanite, anorthoclase, plagioclase, potash-plagioclase, iron ore, apatite, analcime, xenolith; lherzolite inclusion up to 3 cm in size.
6. Fine-grained and holocrystalline, phenocryst; olivine, titanite, groundmass, hauyne, nepheline, olivine, titanite, iron ore, apatite, analcime.
7. Coarse-grained, phenocryst; olivine, groundmass; olivine, augite, plagioclase, anorthoclase, iron ore, apatite.

REFERENCES

- Aoki, K. (1959), Petrology of alkali rocks of the Iki Islands and Higashimatsuura District, Japan, Sci. Rep. Tohoku Univ. Ser. III, **6**, 261~310.
- (1967), Petrography and petrochemistry of latest Pliocene olivine-tholeiites of Taos area, northern New Mexico, U.S. A., Contr. Mineral. and Petrol., **14**, 190~203.
- and Oji, Y. (1966), Calc-alkaline volcanic rock series derived from alkali-olivine basalt magma, Jour. Geophys. Res., **71**, 6127~6135.
- Baldwin, B. and Muehlberger, W.R. (1959), Geologic studies of Union County, New Mexico, New Mexico Bur. Mines and Mineral Resources, Bull. No. 63.