Pegmatitic Trachyandesite Plugs and Associated Volcanic Rocks in the Saline Range–Inyo Mountains Region, California

GEOLOGICAL SURVEY PROFESSIONAL PAPER 614–D

Prepared in cooperation with the California Department of Conservation Division of Mines and Geology

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By DONALD C. ROSS

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

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PEGMATITIC TRACHYANDESITE PLUGS AND ASSOCIATED VOLCANIC ROCKS IN THE SALINE RANGE–INYO MOUNTAINS REGION, CALIFORNIA

By Donald C. Ross

ABSTRACT

Two small late Tertiary volcanic plugs (made up of intermediate plagioclase, sanidine, clinopyroxene, olivine, and metallic opaque minerals) on the west flank of the Saline Range grade from fine-grained pilotaxitic trachyandesite at their margins to coarse-grained, miarolitic, pegmatitic rocks at their cores. The plugs intrude layers of cinder, ash, and tuff that lie immediately beneath a vast volcanic cap which covers about 125 square miles and whose black olivine-bearing rocks are dominantly trachyandesites that contain about 2 percent K_2O.

Chemical analyses and semiquantitative spectrographic analyses were determined for 16 volcanic specimens from the area. These chemical data are supplemented by determinations of the index of refraction of fused-glass beads from 54 volcanic specimens. Potassium-argon determinations from K-feldspar and clinopyroxene of one of the plugs and from three whole-rock samples of the capping flows give uppermost Pliocene ages.

These new chemical data extend the large area in the Sierra Nevada and western Great Basin where late Cenozoic mafic volcanic rocks seem to be typically alkaline and particularly rich in K_2O.

INTRODUCTION

On the west flank of the Saline Range, a window in a vast field of upper Cenozoic trachyandesitic volcanic rocks exposes two small plugs that have coarse-grained pegmatitic cores that grade marginally into a fine-grained pilotaxitic rock. The purpose of this report is to describe these rather unusual rocks and their volcanic associates and to present the chemical and petrographic data that have been accumulated on these volcanic rocks during the geologic mapping of a cross section of the Inyo Mountains (Independence and Waucoba Wash 15-minute quadrangles). Location of the volcanic rocks of this region is shown on plate 1. Geologic maps of and reports about the two quadrangles already published (Ross, 1965, 1967a, b) show their distribution in more detail and also contain brief descriptions of these units.

Published chemical data on volcanic rocks of this region are scarce. It therefore seems particularly desirable to get chemical data on the volcanic rocks of the Inyo Mountain-Saline Valley region into the literature, as field examination and even thin-section determination is insufficient to ascertain the chemical characteristics of these largely aphanitic rocks. As the chemical data slowly accumulate, it is becoming apparent that there is a large alkalic province of Cenozoic volcanic rocks in this region that might go undetected without such data.

The great bulk of the volcanic rocks cover most of that part of the Saline Range that is within the Waucoba Wash quadrangle and adjoining parts of the lower east slopes of the Inyo Mountains. These volcanic rocks are dominantly a great caprock flood of trachyandesite flows and agglomerate. A window on the west flank of the Saline Range exposes the unusual fine to coarse-grained intrusive rocks of the plugs as well as cinder beds, tuff, and tuffaceous sedimentary rocks that underlie the volcanic caprock. Beneath the capping trachyandesite elsewhere in the Saline Range are a few exposures of more felsic volcanic rocks and alluvial deposits with ash and pumice-rich layers. Volcanic rocks are absent at higher altitudes in this part of the Inyo Mountains, but low on the western slopes there are several patches of dark basaltic ash and cinders, in part mixed with alluvial material that originated from a small volcanic center just north of the area of plate 1*A* at the west base of the Inyo Mountains or that originated from volcanic centers at the east base of the Sierra Nevada to the west. The volcanic rocks shown in Owens Valley are the ends of basaltic flows that originate along faults (marked by alined cinder cones) along the east front of the Sierra Nevada (Moore, 1963).

GENERAL NAME FOR THE SALINE RANGE CAPROCKS

The flood of black volcanic rocks capping the Saline Range, which commonly contain visible phenocrysts of olivine and (or) pyroxene are, by field classification, basalt. As can be seen from table 1, however, these rocks do not have the chemical composition of typical basalts (see, for example, table 2 in Yoder and Tilley

TABLE 1.—*Analyses, in percent, of volcanic rocks in the northern Inyo Mountains–Saline Range region*

[Chemical analyses by rapid rock method; analysts: P.L.D. Elmore, S. D. Botts, Gillison Chloe, Hezekiah Smith, Lowell Artis, and J. L. Glenn. Semiquantitative spectographic analyses by J. D. Fletcher, Marcelyn Cremer, and Chris Heropoulos. Results are reported in percent to the nearest number in a series 1, 0.7, 0.5, 0.3, 0.2, 0.15, and so on, which represent approximate midpoints of interval data on a geometric scale. The assigned interval for semiquantitative results will include the quantitative value for about 30 percent of the results. Looked for but not found: As, Au, Bi, Cd, Ge, Hf, Hg, In, Li, Pd, Pt, Re, Sb, Ta, Te, Th, Tl, U, W, Zn, Pr, Sm, Eu. Also looked for but not found in samples 6 and 7: Gd, Tb, Dy, Ho, Er, Tm]

	Trachyandesite caprocks, Saline Range					Intrusive trachyandesite					Other volcanic rocks, Saline Range				Trachybasalt, Owens Valley	
	1	2	9	13	14	3 Margin →	4	5	6	7 Core	11	8	10	12	15	16
Chemical analyses																
SiO_2	56.3	51.6	47.2	47.0	48.4	51.1	47.4	46.8	49.0	47.6	53.0	60.3	74.0	70.1	48.6	48.7
Al_2O_3	17.0	18.1	16.6	17.0	17.4	15.5	16.1	15.5	14.5	14.0	16.1	17.2	13.2	15.2	16.5	14.9
Fe_2O_3	5.1	3.7	4.6	6.0	3.4	8.4	8.2	8.4	7.4	10.2	2.6	4.7	.25	1.6	2.5	2.9
FeO	1.8	5.3	5.8	2.6	5.9	.04	1.9	2.0	3.8	2.7	4.4	.34	.28	.16	6.0	5.6
Total Fe as FeO	(6.4)	(8.6)	(9.9)	(8.0)	(9.0)	(7.6)	(9.3)	(9.6)	(10.6)	(11.9)	(6.7)	(4.5)	(0.5)	(1.6)	(8.2)	(8.2)
MgO	4.1	4.6	7.7	6.3	2.5	6.3	6.9	6.9	4.0	4.1	5.8	2.0	.1	.1	9.0	11.0
CaO	6.8	7.5	9.9	11.7	9.1	7.5	10.5	9.5	8.1	8.1	7.4	3.2	1.0	1.3	9.1	10.1
Na_2O	4.0	4.0	3.5	4.2	5.1	4.9	3.8	3.8	4.9	4.1	4.4	5.6	4.9	4.9	3.3	2.9
K_2O	2.7	2.0	1.4	.73	1.6	2.5	1.2	1.3	2.8	2.8	2.1	3.6	4.1	5.3	1.9	1.4
H_2O-	.12	.32	.12	.73	.17	.45	.52	1.2	.14	.33	.84	.71	.19	.33	.10	.13
H_2O+	.66	.84	.63	1.6	2.7	.55	.45	1.6	.40	.46	1.1	.89	1.5	.58	.59	.24
TiO_2	1.1	1.7	1.8	1.5	1.9	1.7	1.8	1.7	2.8	3.1	1.5	1.0	.11	.34	1.5	1.3
P_2O_5	.41	.61	.89	.48	.80	.65	.74	.74	1.5	1.6	.50	.34	.02	.09	.66	.54
MnO	.12	.14	.17	.12	.12	.11	.12	.12	.13	.15	.10	.05	.05	.02	.15	.15
CO_2	.26		.14	.11	.14	.19	.24	.08	.18	.08	.14		.05	.05	<.05	<.05
Total	100.47	100.41	100.45	100.07	99.23	99.89	99.87	99.64	99.65	99.32	99.98	99.93	99.75	100.07	99.90	99.86
CIPW norms																
Q	5.8											5.7	28.7	19.3		
or	16.0	11.9	8.3	4.4	9.8	14.9	7.2	7.9	16.7	16.8	12.7	21.6	24.7	31.6	11.3	8.3
ab	34.0	34.1	26.0	24.7	33.0	38.4	28.6	30.3	33.7	33.6	38.0	48.2	42.3	41.8	23.8	23.1
an	20.5	25.7	25.5	26.0	20.6	13.1	23.6	22.1	9.4	11.7	18.3	11.4	2.0	3.9	24.8	23.6
Normative An	(An_{38})	(An_{43})	(An_{49})	(An_{51})	(An_{38})	(An_{25})	(An_{45})	(An_{42})	(An_{22})	(An_{26})	(An_{33})	(An_{19})	(An_{5})	(An_{9})	(An_{51})	(An_{51})
ne			2.0	6.3	6.4	1.9	2.1	1.5	4.4	.9					2.4	.9
wo	3.8	3.2	7.1	12.3	8.3	5.7	9.5	8.8	8.4	7.5	6.2	.2	1.1	.5	6.8	9.7
en	10.2	9.6	5.3	10.6	4.4	4.9	8.2	7.6	7.3	6.5	9.5	5.1	.3	.3	4.8	7.2
fs		3.5	1.2		3.6						2.4		.2		1.4	1.6
fo		1.4	9.8	3.8	1.4	7.7	6.4	7.1	2.0	2.7	3.7				12.5	14.3
fe		.5	2.4		1.3						1.0				4.1	3.5
mt	3.0	5.4	6.7	4.5	5.1		1.3	2.0	4.6	.2	3.8		.4		3.7	4.2
hm	3.0			3.0		8.5	7.4	7.3	4.3	10.2		4.8		1.6		
il	2.1	3.3	3.4	2.9	3.7	.3	3.5	3.3	5.4	6.0	2.9	.8	.2	.4	2.9	2.5
ap	1.0	1.5	2.1	1.2	2.0	1.6	1.8	1.8	3.6	3.8	1.2	.8	.05	.2	1.6	1.3
cc	.6		.3	.3	.3	.4	.6	.2	.4	.2	.3		.1	.1		
Total	100.0	100.1	100.4	100.0	99.9	[1] 100.0	100.2	99.9	100.2	100.1	100.0	[2] 100.0	100.05	[3] 100.0	100.1	100.2
Niggli numbers																
Si	163.4	135.6	105.8	108.6	129.8	129.9	109.4	110.9	127.0	122.5	141.8	214.3	439.7	350.8	109.6	104.3
Al	29.1	28.0	21.9	23.2	27.5	23.2	21.9	21.6	22.2	21.2	25.4	36.0	46.2	44.8	21.9	18.8
Fm	33.5	37.3	44.7	37.4	30.4	40.3	41.9	43.6	38.4	41.6	38.4	24.3	3.7	7.5	46.1	50.1
C	21.1	21.1	23.8	29.0	26.2	20.4	26.0	24.1	22.5	22.3	21.2	12.2	6.4	7.0	22.0	23.2
Alk	16.3	13.5	9.6	10.5	16.0	16.1	10.3	10.7	16.9	14.8	15.0	27.5	43.8	40.7	10.0	7.9
Q	−1.6	−18.6	−32.6	−33.3	−34.2	−34.6	−31.7	−31.9	−40.8	−36.8	−18.2	4.5	164.7	88.0	−30.2	−27.4
K	.31	.25	.21	.10	.17	.25	.17	.18	.27	.31	.24	.30	.36	.42	.27	.24
Mg	.53	.48	.58	.58	.33	.59	.57	.56	.40	.38	.60	.44	.24	.10	.66	.70

Rittmann numbers and rock names

k	0.31	0.25	0.21	0.11	0.18	0.25	0.17	0.18	0.28	0.31	0.24	0.30	0.36	0.42	0.28	0.24
an	.28	.34	.38	.37	.26	.17	.36	.33	.12	.17	.25	.13	.02	.04	.36	.4
p	55.0	53.6	50.8	51.5	48.2	45.0	50.8	49.7	40.5	50.2	51.5	51.0	54.4	52.3	51.5	53.6
Rittmann rock name	Trachy-andesite	Olivine-trachy-andesite	Olivine-andesine basalt	Andesine basalt	Andesite	Olivine-andesine trachy-basalt	Andesine basalt	Andesine basalt	Dark phonolitic nephelite tephrite	Dark phonolitic nephelite tephrite	Trachy-andesite	Latite	Soda rhyolite	Soda rhyolite	Olivine-andesine trachy-basalt	Andesine basalt (almost on trachy-basalt line)

Semiquantitative spectrographic analyses

Ag						0.0001										
B	0.002	0.0015	0.0015									0.001	0.005	0.002		
Ba	.1	.1	.1	0.07	0.1	.1	0.1	0.1	0.2	0.2	0.1	.2	.01	.15	0.1	0.1
Be	.0003	.0001	.0001		.00015	.00015		.0001	.00015	.00015	.0001	.00015	.0005	.0002	.00015	.0001
Ce	.02	.02	.02	.015	.015	.015	.015	.015	.03	.02		.02		.02	.015	
Co	.002	.002	.003	.003	.003	.003	.005	.005	.003	.003	.003	.001		.0005	.005	.005
Cr	.007	.002	.02	.03	.02	.03	.03	.03	.0007	.0003	.05	.0015		.0007	.05	.07
Cu	.005	.005	.005	.005	.005	.005	.0015	.003	.005	.01	.005	.001	.0001	.0003	.007	.007
Ca	.001	.0015	.001	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	.002	.0015	.0015	.0015	.0015
La	.01	.005	.01	.007	.01	.01	.01	.01	.02	.02	.005	.007		.02	.007	.005
Mo													.0007			
Nb	.0015	.001	.001	.001	.0015	.0015	.0015	.0015	.002	.003	.001	.0015	.002	.001	.0015	.001
Ni	.007	.002	.02	.01	.01	.015	.015	.015	.003	.003	.015	.001		.0005	.03	.05
Pb	.002	.0005	.0007									.005	.005	.005		
Sc	.002	.003	.003	.005	.003	.003	.005	.005	.005	.005	.003	.001		.0005	.003	.005
Sn	.0007	.0005	.0005													
Sr	.2	.2	.2	.1	.1	.07	.07	.07	.07	.07	.07	.07	.002	.02	.2	.2
V	.015	.02	.02	.05	.05	.03	.05	.05	.07	.07	.03	.015		.003	.02	.02
Y	.003	.003	.003	.003	.005	.003	.005	.005	.007	.007	.003	.002	.0015	.002	.003	.003
Yb	.0002	.0003	.0003	.0003	.0003	.0003	.0005	.0005	.0005	.0007	.0003	.0002	.00015	.0002	.0003	.0003
Zr	.03	.03	.03	.015	.02	.02	.02	.02	.03	.03	.02	.03	.007	.03	.03	.02
Nd							.015	.015	.03	.02						
Bulk density	2.49	2.74	2.83	2.85	2.76	2.70	2.75	2.79	2.67	2.74	2.71	2.44	2.05	2.32	2.53	2.74
Specific gravity, powder	2.82	2.93	3.00	2.90	2.95	2.85	2.95	2.85	3.00	3.00	2.75	2.64	2.45	2.55	2.95	2.95

[1] Includes 2.6 percent pf. [2] Includes 1.4 percent tn. [3] Includes 0.3 percent tn.

Specimen localities, parentheses enclose California Grid System coordinates, Zone 4	*Quadrangle*
1. T. 11 S., R. 38 E., (2,346,700 E., 607,800 N.).	Waucoba Wash quadrangle.
2. T. 11 S., R. 38 E., (2,340,000 E., 598,300 N.).	Do.
9. T. 11 S., R. 39 E., (2,364,100 E., 583,200 N.).	Do.
13. NW¼ sec. 6, T. 13 S., R. 39 E. (2,358,300 E., 552,400 N.).	Do.
14. T. 12 S., R. 37 E., (2,314,000 E., 559,200 N.).	Do.
3. T. 11 S., R. 38 E., (2,335,800 E., 596,700 N.).	Do.
4. Same as 3.	Do.
5. Same as 3.	Do.

Specimen localities, parentheses enclose California Grid System coordinates, Zone 4	*Quadrangle*
6. Same as 3.	Waucoba Wash quadrangle.
7. T. 11 S., R. 38 E., (2,336,800 E., 596,300 N.).	Do.
11. T. 12 S., R. 38 E., (2,359,200 E., 568,400 N.).	Do.
8. T. 12 S., R. 38 E., (2,353,300 E., 585,600 N.).	Do.
10. T. 12 S., R. 39 E., (2,364,300 E., 574,000 N.).	Do.
12. T. 12 S., R. 38 E., (2,357,000 E., 557,200 N.).	Do.
15. S. edge sec. 15, T. 11 S., R. 34 E., (2,219,400 E., 602,200 N.).	Independence quadrangle.
16. SE¼ sec. 3, T. 11 S., R. 34 E., (2,223,300 E., 582,300 N.).	Do.

1962, p. 361–363). The Saline Range volcanic rocks are high in alkalis and low in magnesia, as compared with basalts of similar silica content. Also, coarse-grained intrusive phases of these rocks contain modal K-feldspar. Normative plagioclase is generally andesine, less commonly oligoclase, and is labradorite in only one of the 11 chemically analyzed specimens. By using the rock-classification system of Rittmann (1952), various names apply to these rocks (table 1), but andesine basalt and trachyandesite are the most common. By using the classification of MacDonald and Katsura (1964, p. 88–89), the Saline Range volcanic rocks are all part of the alkalic suite, and the less silicic varieties are alkalic basalts or alkalic olivine basalts. Some specimens more nearly fit hawaiite, as they contain both normative and modal andesine. Some specimens with more than 5 percent normative, but no modal nepheline, are basanitoid.

No one name from a chemical classification will apply equally well to all the somewhat variable Saline Range volcanic caprocks. It seems, however, that the name "trachyandesite" best reflects the general chemical nature of this suite, which is high in alkalis and has a normative plagioclase of less than An_{50}. For the purposes of this report, the entire suite of caprocks and their presumably intrusive equivalents will be referred to as the trachyandesite of the Saline Range. The medium to coarse-grained cores of the plugs might more precisely be called syenodiorite. The bulk of the intrusive rocks, however, are not much coarser grained than the trachyandesitic caprocks of the volcanic field. To help focus attention on the fact that these plugs are closely related to the extrusive volcanic rocks, the term "trachyandesite" will be used to refer to all these intrusive rocks, regardless of grain size. The terms "pegmatitic" and "diabasic" as here used for these intrusive rocks refer solely to texture and have no compositional connotation.

INTRUSIVE TRACHYANDESITE

The intrusive plugs and related dikes of these rocks, which crop out over an area of only about one-tenth of a square mile, are shown on plate 1*B*. These plugs are in part sill-like and intrude a sequence of cinder layers, tuff, and tuffaceous sedimentary rocks (fig. 1). In part, these intrusive rocks are coarse grained and miarolitic; they contain primary K-feldspar along with olivine and clinopyroxene and have a texture that can best be described as pegmatitic. As far as I know, this occurrence of pegmatitic rocks in a mafic volcanic suite in this region is unique. The northernmost pegmatitic plug is isolated from the capping trachyandesite, but the southern mass appears to be overlain by the caprock sequence. The rapid gradation in these plugs from dense volcanic rock to pegmatitic cores within the space of a few tens of feet (figs. 2, 3) suggests that the plugs were very shallow intrusions that were sealed off, and thus the volatile-rich fluid of the core was permitted to crystallize to a pegmatitic and miarolitic texture. Even though the plugs are near the surface, however, an erosion interval seems to separate their emplacement from the extrusion of the capping flows, as coarse-grained core rock of the south plug directly underlies caprock (see also p. D17). These plugs and the associated pile of cinder layers suggest proximity to a volcanic center. Also, the window that exposes the plugs and cinder layers spans one of several northeast-trend-

FIGURE 1.—View to the west from north of the northernmost plug of trachyandesite in dominantly pink to white tuff beds, which are thin bedded in part and may be lacustrine. Red cinder and ash beds cap the tuff.

FIGURE 2.—Crudely bedded red ash and cinder deposits and sill-like part of north intrusive body of trachyandesite (outlined on photograph) exposed in window in Saline Range volcanic field.

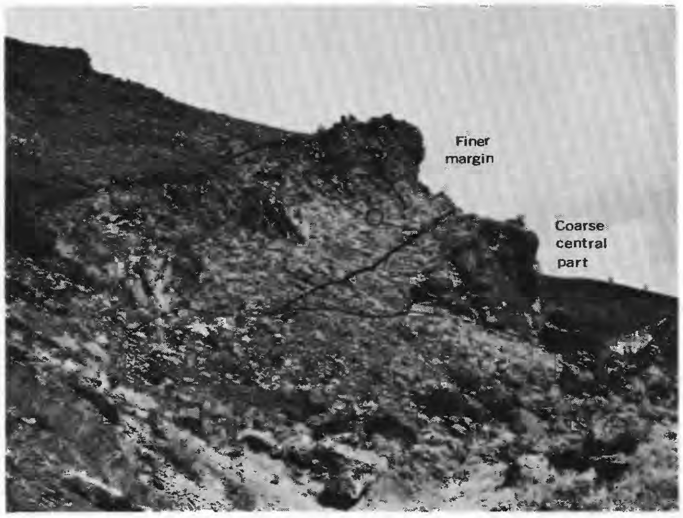


FIGURE 3.—Closer view of trachyandesite intrusive of figure 2. Contact of marginal rocks with cinder beds is sharp. Contact between marginal and pegmatic core rocks is gradational, but relatively abrupt. Specimens 3, 4, 5, and 6 were collected approximately where indicated by open circles.

ing faults that traverse the caprocks and that may reflect cracks that were a source of feeders for this volcanic sequence.

FIELD DESCRIPTION AND RELATIONS

The rocks of the plugs are generally medium gray to medium dark gray, but some of the finer grained marginal facies are reddish gray. In both plugs and in the smaller associated dikes, a range in grain size is notable from margin to core. The marginal rocks look much like the trachyandesite of the flows, though they are lighter in color than the caprocks. The cores of thin dikes that are only a few feet thick are fine to medium grained and have a prominent network of platy euhedral feldspar crystals separated by open pore space. The cores of the plugs are coarse grained, the largest crystals being 5–10 mm in maximum dimension. Coarse reticulate platy feldspar crystals are most conspicuous. The core rocks have much open pore space into which terminated crystals of clinopyroxene and olivine extend. These miarolitic cavities locally contain calcite and other secondary minerals.

The north plug is grossly sill-like in its southern part, but markedly cuts across the intruded tuff beds near its northern end. A marginal envelope of fine-grained rock grades abruptly into a core of coarse pegmatitic and miarolitic rock (figs. 2, 3).

The south plug markedly cuts across the intruded cinder beds. In contrast to the simple envelope and core of the north plug, the south plug is typified by veins several inches to several feet thick of coarse-grained, miarolitic core rock intruded into the finer-grained marginal rock (fig. 4*A*) and by many patchy areas of coarse-grained, spongy core rock (fig. 4*B*,*C*). The south plug shows clearly that the core rocks are coarse spongy equivalents of the marginal rocks and not a separate later intrusive pulse.

MICROSCOPIC DESCRIPTION

The finer grained marginal rocks of the plugs and dikes have a pilotaxitic (felty) texture, and some are trachytic; some specimens are also weakly porphyritic. These rocks are generally dense, but some are vesicular. The plagioclase laths are as much as 0.2 mm long; dark minerals and opaque clots are as large as 0.8 mm in largest dimension, but more commonly are 0.1–0.2 mm. The marginal rocks grade in grain size into a rock with a diabasic or intergranular texture with grains generally from 1 to 3 mm in longest dimension. Further coarsening of grain size produces rocks that approach a pegmatitic texture with crystals 5–10 mm in length. The medium-grained (diabasic) rocks are only in part miarolitic, whereas the coarser varieties are invariably miarolitic. None of these rocks contain micrographic (micropegmatitic) interstitial material, which seems so widespread and common in mafic pegmatitic differentiates in other areas. The textural gradation from margin to core can be seen in the photomicrographs of figure 5*A*–*C*. Figure 6 shows some of the representative rocks of the trachyandesite plugs in hand specimen. What is probably the most abundant rock type of both plugs is illustrated by photomicrographs in figure 5*D* and *E* and by hand specimen in figure 6*A*. Figures 6*B* and 6*C* show the general appearance of the coarser grained core rocks, figure 6*D* shows the rapid grain-size change from margin to core.

The mineralogy of these rocks is grossly the same from the fine-grained margin to the coarse-grained core. Intermediate plagioclase is dominant, both clinopyroxene and olivine are abundant, and metallic opaques are also common. K-feldspar, probably sanidine, forms a mantle on plagioclase crystals in the coarsest grained varieties (fig. 5*G*). Attempts to distinguish the plagioclase from the K-feldspar by staining of slabs and thin sections were generally unsuccessful. Sanidine, unlike the other K-feldspars, does not seem to take a good stain. The one thin section (specimen D) stained well enough to permit a distinction by point counting showed about three times as much plagioclase as K-feldspar. This 3:1 ratio, which is generally compatible with the normative composition of the intrusive trachyandesite, is at least the correct order of magnitude for the feldspar content. Probably K-feldspar (sanidine) is present as 10–15 percent of these rocks. Small amounts of biotite and amphibole are also found. Table 2 shows the modes of seven specimens of these intrusives;

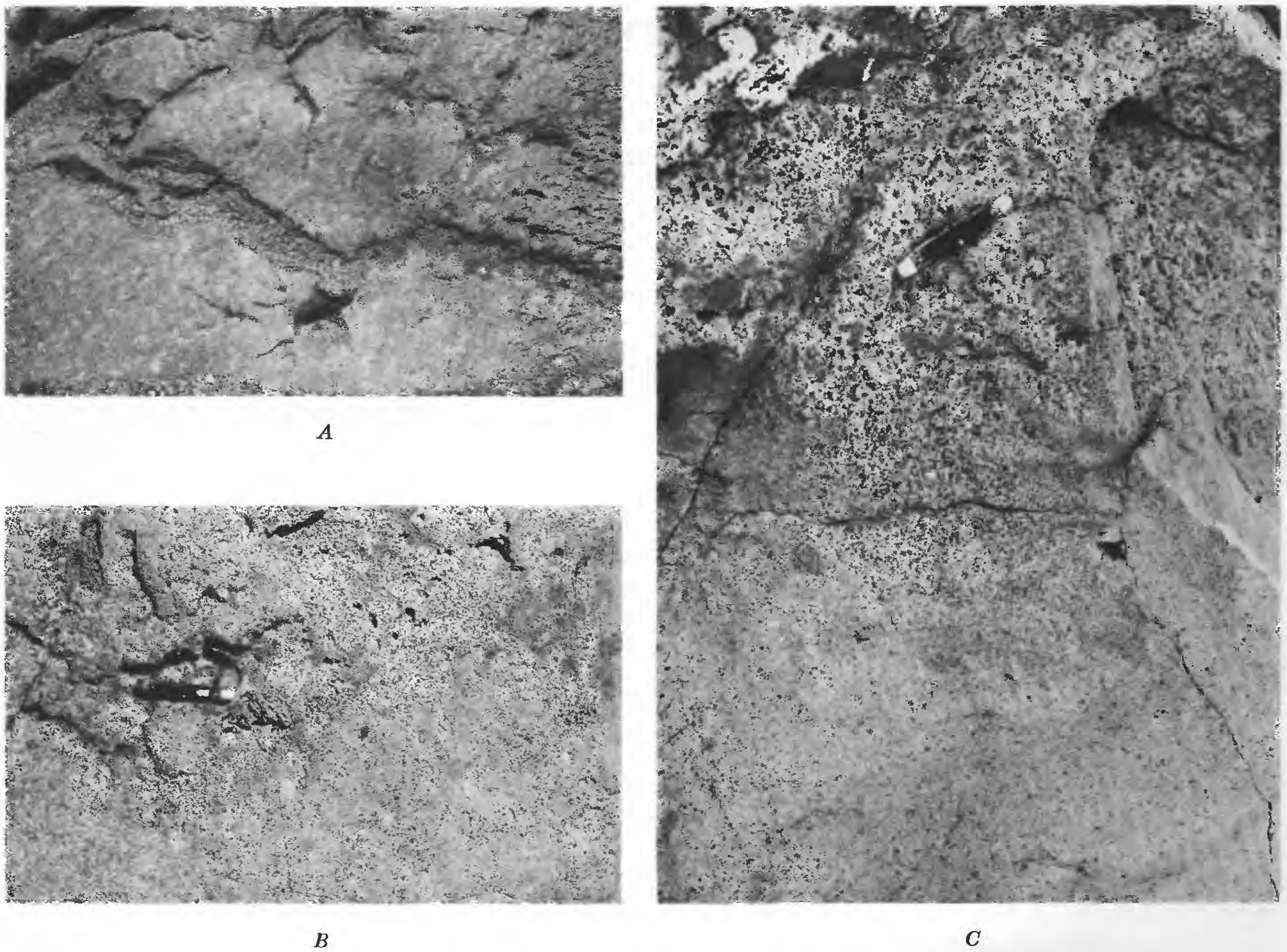


FIGURE 4.—Relations of pegmatitic core rocks to marginal rocks in the southern trachyandesite plug. Finer grained phases are similar to specimens C and D, shown in photomicrographs 5*D*, *E*. Coarser grained phases are similar to specimens 6, 7, and G shown in photomicrographs 5*C*, *F*, and *G*. Knife used for scale in all views. *A*, Relatively sharp-walled pegmatitic vein. *B*, Patchy gradational contact. *C*, Gradational, but abrupt grain-size change. Coarse phase here extremely miarolitic.

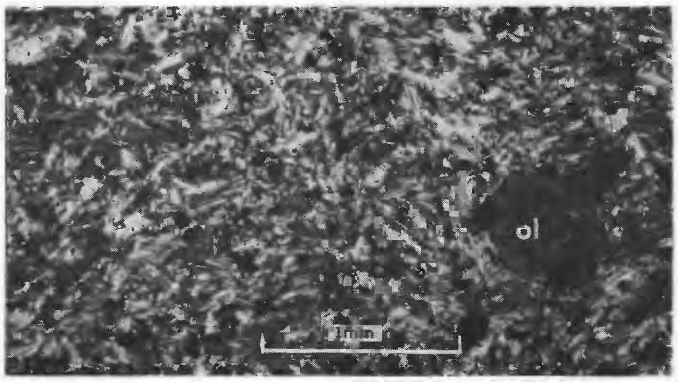
specimens 5, C, D, and E are from the medium-grained (diabasic) phase; specimens 6, F, and G are from the pegmatitic core rocks. Two of the coarsest grained specimens (6 and G) are notably poorer in olivine and richer in feldspar than the other specimens; they also contain amphibole. The other coarse specimen (F), however, is very similar to the medium-grained rocks.

Plagioclase is the most abundant constituent of these rocks; most is calcic andesine to sodic labradorite. There appears to be no noticeable difference between plagioclase of the marginal and core rocks except grain size.

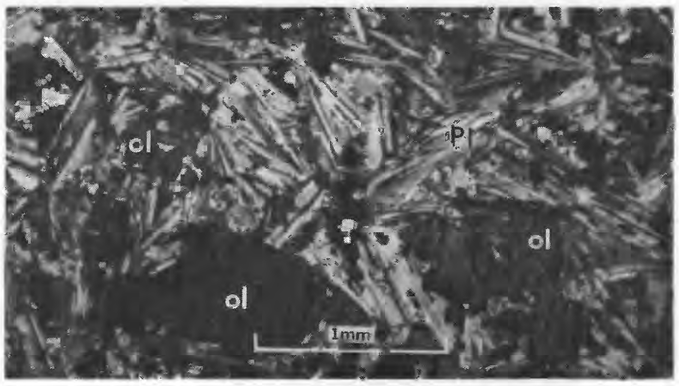
K-feldspar is present in some of the medium- and coarse-grained rocks as interstitial grains and as mantles on the plagioclase; it is not conspicuous in the fine-grained marginal rocks. The index of refraction of the K-feldspar is about: $n_x=1.527$, $n_z=1.535$. The $2V$ is negative and ranges from near 0° to 30°. A pure-mineral separate from specimen 7 has a K_2O content of 6.5 percent; its X-ray diffraction pattern is shown in figure 7. This mineral probably is mostly sanidine.

Olivine, where fresh, is in pale-yellow crystals that have a $2V$ of near 90° and a birefringence of about 0.035–0.04—features that suggest magnesian olivine of the variety chrysolite. In most specimens olivine is intensely or completely altered to iddingsite(?) and iron oxides. Some black metallic masses seem to be pseudomorphing olivine.

Clinopyroxene, which is deep green in grains, is pale green to colorless in thin section. A pure mineral separate made from specimen 7 has the following properties: indices of refraction, $n_x=1.700$, $n_y=1.708$, $n_z=1.725$; $r>V$ distinct; and $2V(+)$, moderate. The X-ray diffrac-



A



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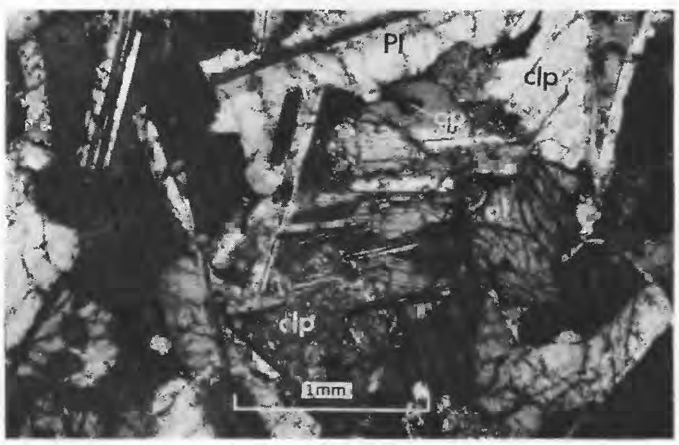

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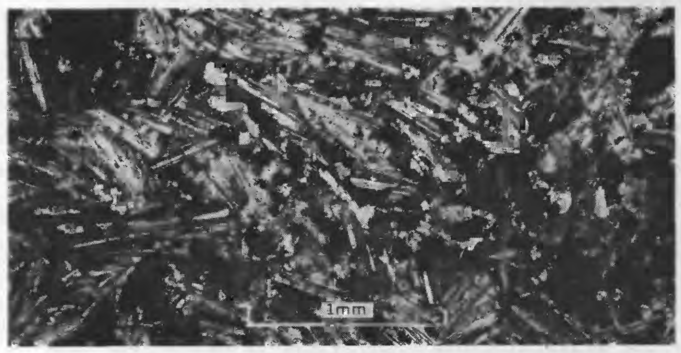

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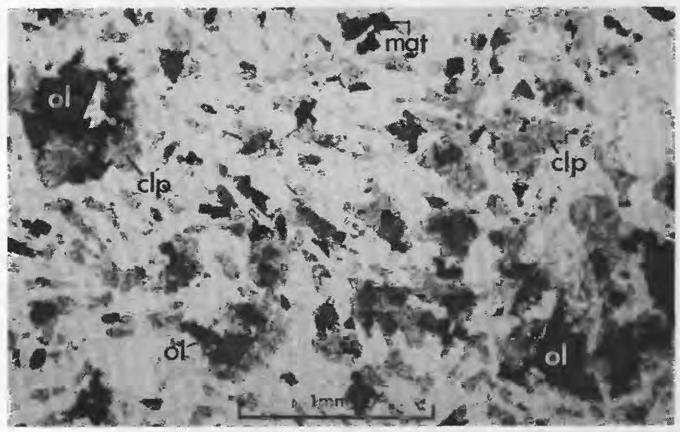
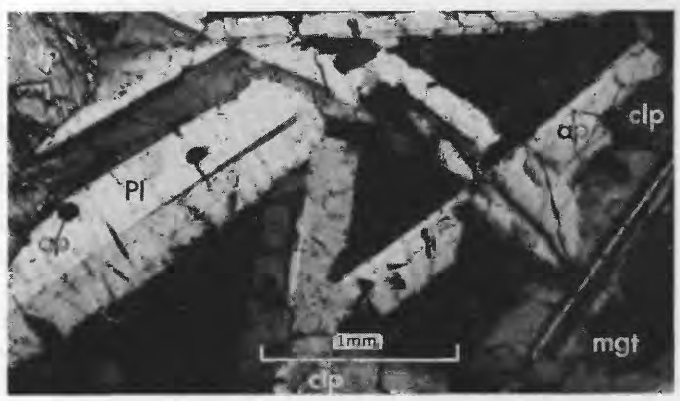
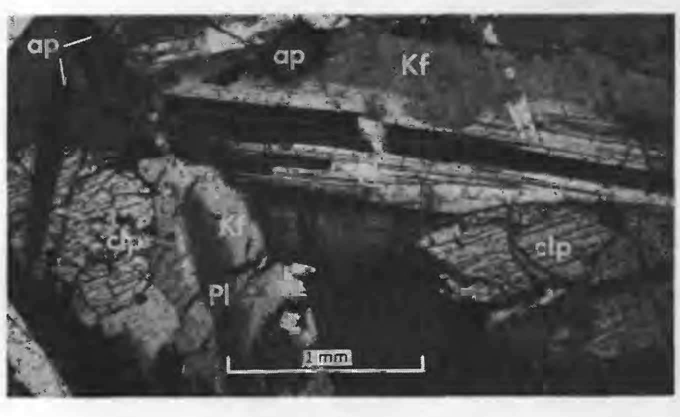


E



F



G

FIGURE 5.—Photomicrographs of rocks from intrusive trachyandesite plugs. *A*, Pilotaxitic texture near contact with wallrock cinder layers of north plug. *B*, Diabasic texture intermediate between contact and core rocks of north plug. *C*, Pegmatitic core rock of north plug. *D*, Diabasic-textured rock, the most common type in south plug. Crossed-nicols view to emphasize plagioclase laths and texture. *E*, Same view as *D* under plane light to emphasize clinopyroxene, olivine, and magnetite. *F*, Pegmatitic core rock of south plug. View dominated by coarse blades of plagioclase and triangular-shaped miarolitic cavities. *G*, Pegmatitic core rock of south plug showing K-feldspar coating plagioclase and filling large interstitial spaces. Symbols used: ap, apatite; clp, clinopyroxene; Kf, K-feldspar; mgt, magnetite; ol, olivine; Pl, plagioclase.

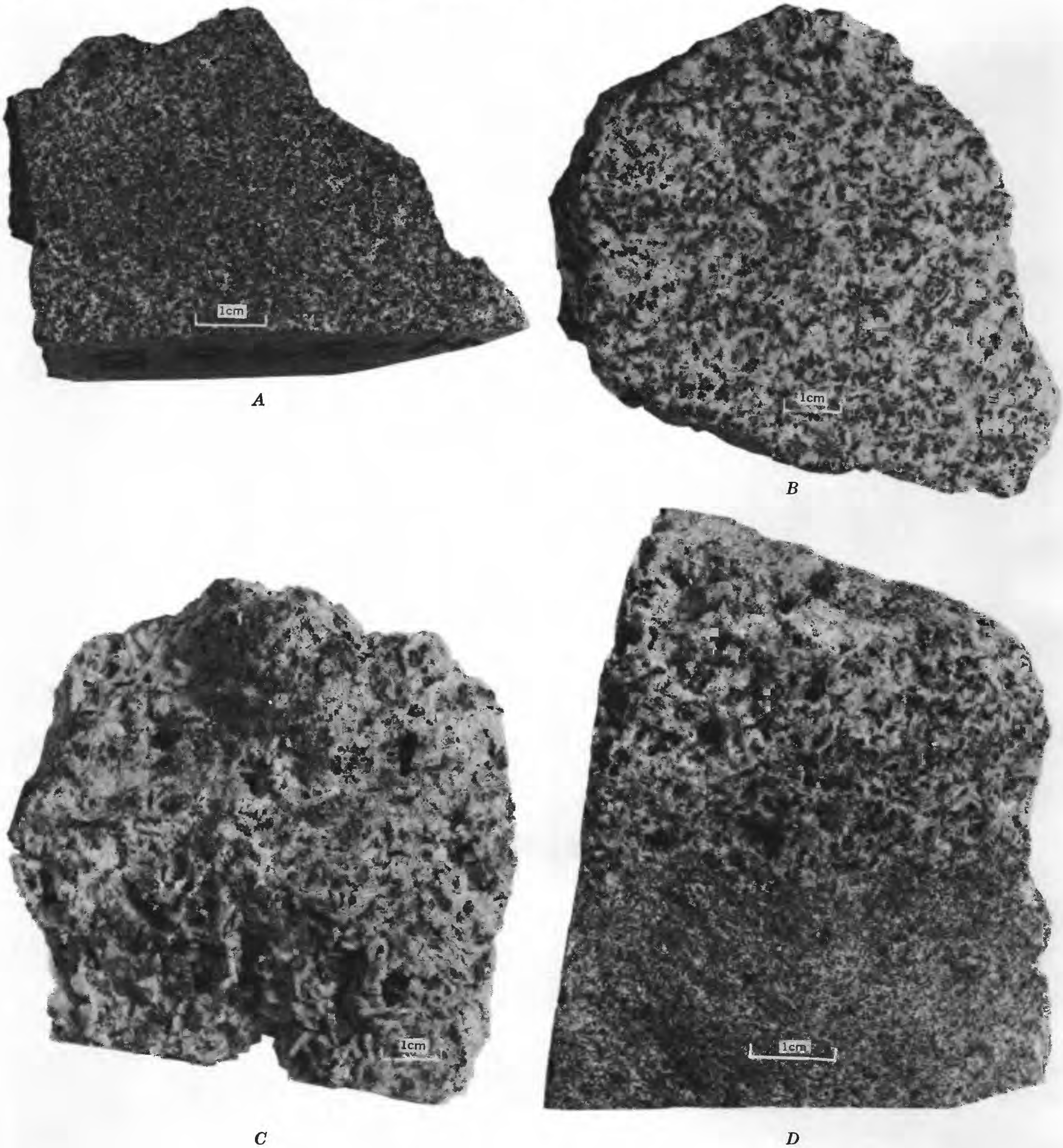


Figure 6.—Photographs of selected hand specimens from intrusive trachyandesite plugs. *A*, Diabasic marginal rock (similar to rock in figures 5*D* and *E*). *B*, Pegmatitic core rock (sawed surface). *C*, Bladed feldspar and miarolitic cavities of pegmatitic core rock. *D*, Gradational, but rapid grain-size change at contact between marginal rock like rock in figure 6*A* and pegmatitic miarolitic rock like rock in figure 6*C*.

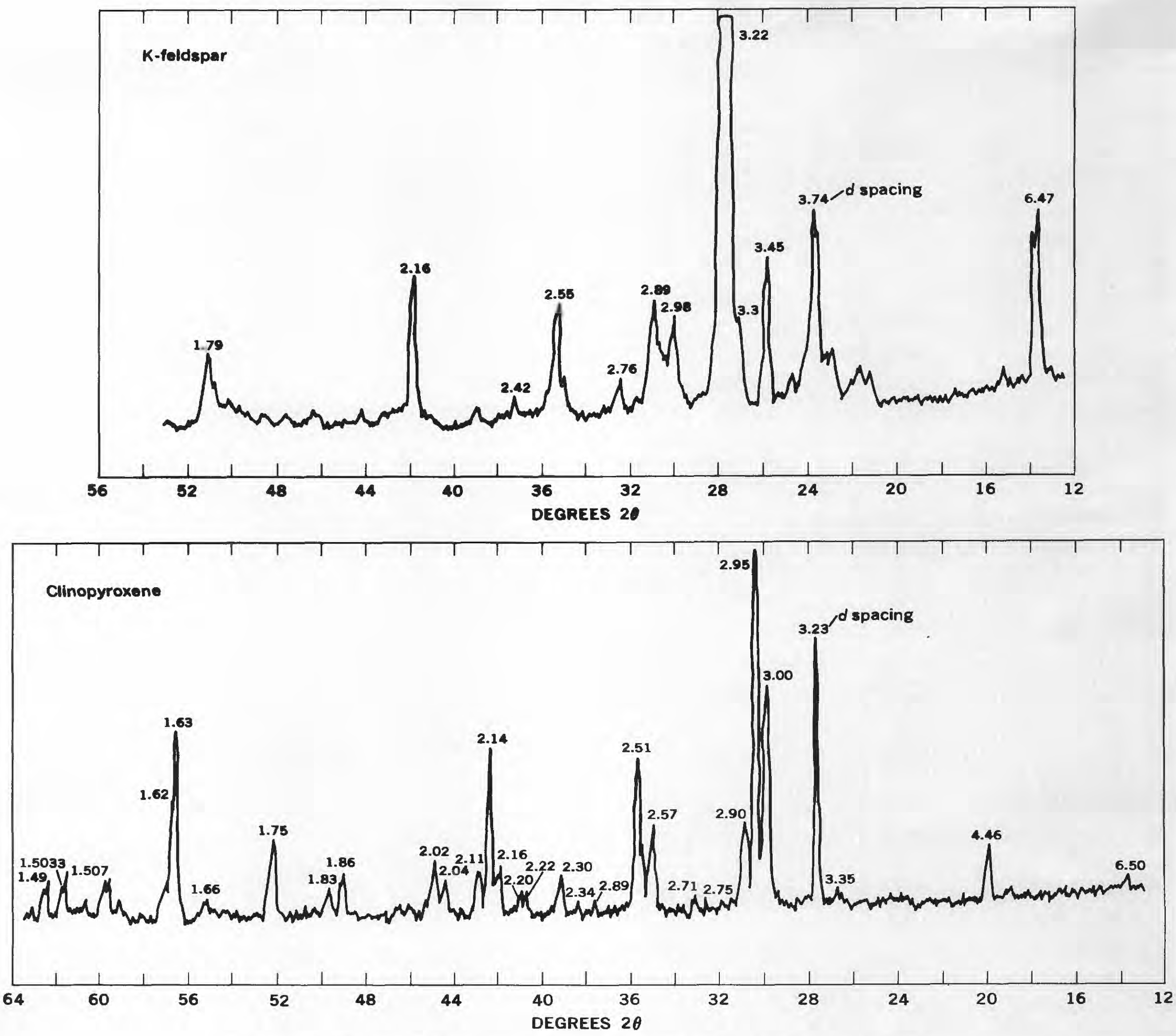


FIGURE 7.—X-ray diffraction patterns of selected minerals from specimen 7.

tion pattern for this sample also is shown in figure 7, Locally, pale clinopyroxene is rimmed by moderate-green to dark-yellowish-green clinopyroxene(?), which is pleochroic from light olive brown to moderate green.

Trace amounts of light-brown amphibole and red-brown biotite are fairly widespread. Apatite is an abundant colorless accessory mineral. Metallic opaque minerals are abundant and make up some of the largest crystals and crystal aggregates in the coarser grained rocks. Magnetite is common, but some of the "metallic" aggregates are presumably ilmenite, as they are not attracted to a hand magnet.

CHEMICAL DATA

The five specimens (3, 4, 5, 6, and 7) that were chemically analyzed (table 1) were selected to provide a sample from the margin to the core of these intrusive rocks. Specimens 3, 4, 5, and 6 were collected from the west contact of the north plug as shown in figure 5: at the contact, 20 feet below the contact, 40 feet below, and about 60 feet below, respectively. Specimen 6 is representative of the coarse core of the north plug; specimen 7 is a coarse variety from the south plug, presumably a coarser crystallized phase of rocks like specimen 6.

The chemical analyses do not show as much chemical variation as I had expected for rocks with such a radical textural variation. The sampling was neither systematic nor detailed, but the specimens selected looked typical and represented the textural range of these rocks as they were studied in the field. The most consistent trend is in total Fe as FeO, which shows a consistent increase to the core—a relationship that was guessed from field relations. Somewhat as expected, TiO_2 follows total Fe and is concentrated in the core relative to the margin. MgO is less common in the core rocks, which seems to correlate with a lower amount of olivine in these rocks. Less directly tied to predictable trends from field observation are the decrease coreward of Al_2O_3 and the increase coreward of P_2O_5.

COMPARISON OF PEGMATITIC CORE ROCKS WITH SIMILAR ROCKS OF OTHER AREAS

The pegmatitic trachyandesite intrusive rocks are a rather startling textural variate of the typical volcanic rocks of this region. Pegmatitic variations in basaltic and diabasic rocks, particularly in intrusive sheets, however, are rather widely referred to in the literature.

Lacroix (1928) briefly described three localities from France, Polynesia, and China of what he called "Les pegmatitoides des roches volcaniques á facies basaltique." He described coarse-grained segregation veins composed of labradorite, titaniferous augite, olivine, and magnetite with groundmass orthoclase and reported chemical analyses of the basaltic rocks and their pegmatitic derivatives.

Shannon (1924) described the mineralogy and petrology of an intrusive diabase at Goose Creek, Va., that has pegmatitic phases. These pegmatitic rocks are characterized by labradorite, titaniferous augite, and large skeletal crystals of "iron ore" (as large as 5 mm). Interstitial micropegmatite with orthoclase is common. These rocks become quite coarse-grained, and although chemically they are much less alkalic than the Saline Range rocks, they have a similar physical appearance (Shannon, 1924, pls. 1–3).

Kennedy (1933, p. 244–247) described some general characteristics of late differentiates of basaltic magmas, noting "that many lava flows and minor intrusions of basaltic composition show a remarkable tendency to segregate contemporaneous veins which differ in composition from the parent rock." He divided the differentiates into two types: (1) those from tholeiitic basalts that have calc-alkaline derivatives, and (2) those from olivine basalts that give alkaline derivatives. The latter are characterized by the absence of quartz, abundant K-feldspar associated with basic plagioclase, and abundant iron ores. Kennedy (1933, p. 245) has tabulated eight analyses of these alkaline derivatives, including those reported by Lacroix (1928, p. 324), that have the following average oxide percentages: SiO_2, 49.2; Al_2O_3, 14.7; $FeO+Fe_2O_3$, 10.7; MgO, 3.6; CaO, 7.9; Na_2O, 4.2; K_2O, 2.9; and TiO_2, 3.2. These values are closely comparable to the alkaline pegmatitic rocks of the Saline Range area (table 1). Kennedy made the point (1933, p. 246) that his examples characteristically show a marked decrease in MgO coupled with a strong increase in alkalis in the differentiates and that the parent rocks are not from originally alkaline magma but are "normal olivine basalt." By contrast, the visible parent rocks of the Saline Range rocks are themselves alkaline; of course we cannot be sure that the entire Saline Range suite is not already differentiated from a less alkaline parent, but this seems unlikely for the large volume of volcanic rocks involved. The end-member pegmatitic rocks of the Saline Range volcanic suite are similar chemically to alkaline differentiates from parent rocks of much lower total alkali value in other areas.

Walker (1953, p. 41–44) described the field occurrence of "pegmatitic differentiates of basic sheets." He noted that such rocks occur as schlieren, patches, and crosscutting veins or dikes. The examples he cited from many localities are generally much less alkaline than the Saline Range rocks, but their textures and general mineralogy appear grossly similar. Walker noted (1953, p. 43) that most dolerite (diabase)-pegmatite is in sharp unchilled contact with adjacent dolerite (diabase). In contrast, many of the contacts in the small plugs in the Saline Range are gradational (figs. 4*B*, *C*), even where grain-size variation is considerable. The general appearance suggests that the coarse spongy core rock was a late crystallizing volatile-rich pegmatitic phase relative to the fine- to medium-grained (diabasic) matrix rock. Even some of the more distinctive veins (fig. 4*A*) are gradational and blend with the matrix rock. This probably mainly reflects crystallization in place for the core rocks of the Saline Range plugs and only minor squirting around of vein material. Apparently, in other areas there is more mobility of later juicy pegmatitic phases, which creates more crosscutting, dikelike relations.

Thick sheets and transgressive bodies of dolerite (diabase) from Tasmania have been described by McDougall (1962). These rocks are more silicic than the Saline Range rocks, and they all seem to have abundant modal quartz in the coarse-grained differentiates. Even though they are chemically dissimilar, the appearance of the hand specimens is remarkably similar (McDougall, 1962, following p. 302) to some of the Saline Range differentiates.

This brief summary of some reported occurrences of mafic, coarse-grained, and pegmatitic differentiates points out their textural similarity to the alkalic rocks of the Saline Range. But it also points out that alkalic differentiates like the coarse-grained pegmatitic core rocks of the Saline Range plugs can be derived from parent rocks that have a considerable range in composition.

OTHER OCCURRENCES OF INTRUSIVE TRACHYANDESITE

The rather unique character of the pegmatitic plugs in the window on the west flank of the Saline Range is further pointed out by the presence of dikes, sills, and small plugs elsewhere in this area that have not developed coarse miarolitic cores. Along the east base of the Inyo Mountains and in the large outcrop area of Paleozoic rocks in the Saline Range are dikes and sills, generally only a few feet thick, that at least in part penetrate the capping trachyandsite flows. Similar dikes have been seen within the capping flow sequence. Some of these dike rocks, particularly the long southernmost dike in the Inyos and the several dikes in the north part of the large Paleozoic outcrop area in the Saline Range, are so altered and weathered that their composition and relation to the caprock sequence is difficult to determine. Fresher dikes and the sill-like intrusives in the area of specimen 11 and dikes near the locality of specimen 14 in the Inyo Mountains appear to intrude and feed the caprock sequence. All the dikes and sills outlined above are believed to be genetically related to the capping trachyandesite sequence.

These intrusive rocks, where fresh, look much like the capping trachyandesite. They are composed of labradorite, clinopyroxene, olivine, and minor apatite and ilmenite-magnetite. Typical of the altered dikes are chloritic pseudomorphs after ferromagnesian minerals that are chiefly pyroxene, iddingsite pseudomorphs after olivine, and clouds of sericitic material replacing plagioclase. Some of the dikes are vesicular and amygdaloidal, and one (fig. 8) has a sharply chilled margin against quartz monzonite wallrock.

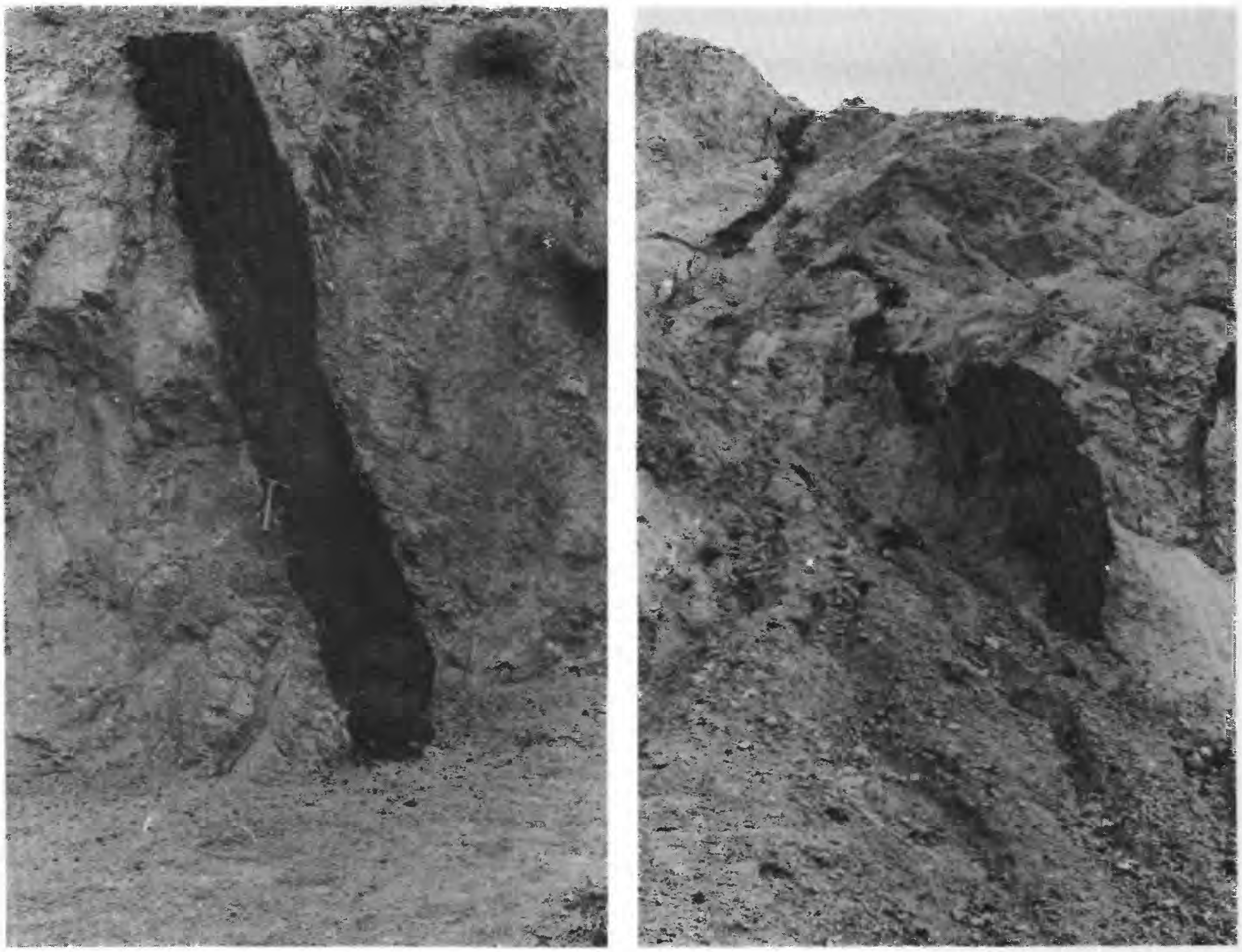
Only one sample of this group of rocks has been chemically analyzed (specimen 11, pl. 1), and it is from a pluglike mass that is dark gray, dense, has numerous small iron-stained spots marking altered olivine crystals, and weathers to a distinctive olive-drab color and blocky surface. It has an intersertal texture with labradorite, clinopyroxene, and olivine crystals set in a brown glass matrix. The glass contains crystallites; some of the forms referred to as cumulites and margarites are present. Alteration of the olivine in this rock is very unusual. Rather than the red iddingsite (?) alteration so common in this area, the olivine is veined and rimmed by dark-greenish-yellow, weakly pleochroic material that is also found as interstitial masses in the rock. Chemically, (table 1) this rock is trachyandesite after the classification of Rittmann, and despite its somewhat different microscopic appearance, it seems to be chemically compatible with the caprocks, of which it is probably an intrusive equivalent.

TRACHYANDESITE CAPROCKS OF THE SALINE RANGE

FIELD DESCRIPTION AND RELATIONS

About 125 square miles of the Saline Range in the Waucoba Wash and adjoining Waucoba Spring, Last Chance, and Dry Mountain quadrangles is covered by a veritable flood of trachyandesitic flows and associated agglomeratic and flow breccia layers. Similar rocks, isolated by erosion from the main field, lap up onto the east face of the Inyo Mountains. Other probably correlative rocks are common in the south part of Dry Mountain (fig. 9) and in the Last Chance Range (Ross, 1967B). Numerous small cinder cones appear to be superimposed on the trachyandesite, but there are no major volcanic centers associated with it. A prominent set of northeast-trending faults, which have displacements of as much as several hundred feet, cut the volcanic field. The apparent association of large tongues of volcanic rock with this fault system suggests these are fissure flows that were extruded along a set of weak planes that have continued to be active and have now chopped up the surface of the flows by their continued movement. Numerous 1- to 10-foot-thick dikes have been seen in the Paleozoic and Mesozoic basement rock; some can be traced up into the capping flows, but no major feeders have been found. The window of cindery layers and the plugs of partly pegmatitic intrusive trachyandesite athwart one of these northeast-trending faults in the north-central part of the Waucoba Wash quadrangle may represent a partly uncovered volcanic center for part of the caprock. Mainly, however, it appears that the flood of trachyandesite has buried its feeder sources.

The maximum thickness of the sequence may be more than a thousand feet, as sections over 600 feet thick are exposed in fault scarps in the Saline Range. These sections are composed of numerous flows, a few feet to a few tens of feet thick, intercalated with agglomeratic and flow breccia layers. In addition, bedded tuffaceous material and gravelly alluvium containing volcanic fragments are interbedded in some volcanic sections. Unfortunately, the best exposed and thickest sections of flows in the Waucoba Wash quadrangle are in areas where access is particularly difficult (south of the area of specimen 8 and west of specimen 13, pl.1). The main sequence of flows is underlain by mixtures of



A *B*

FIGURE 8.—Two-foot-thick, vesicular and amygdaloidal trachyandesite dike chilled against quartz monzonite walls about one mile SSE. of locality of specimen 14. *A*, Straight-walled segment at wash level in small canyon. Pick used for scale. *B*, Irregular discontinuously exposed segment higher on canyon wall.

tuffaceous and alluvial material at many places. A repeating sequence of volcanism and alluviation is represented in these sections. Where the trachyandesites lap up on the Inyo Mountains, an initial outpouring of flows and a showering down of tuffs covered alluvial material similar to the present fanglomerates of the area. This volcanism was followed by deposition of more fanglomerate rich in granitic debris and fault displacement of the flows (fig. 10). Then a second period of volcanism provided the capping trachyandesites, which presumably are correlative with the main caprocks of the Saline Range.

The trachyandesite presents a dark, somber, monotonous terrane broken into numerous block faults (fig. 11). The rocks are typically medium to dark gray, dense to vesicular, and have scattered olivine phenocrysts. Much less commonly, the flow rocks are dark shades of brown to red. They are particularly susceptible to desert varnish, which develops to an iridescent metallic sheen on some exposed surfaces. Cinder cones are present and seem to be in part superimposed on top of the flow sequence as though they represent a dying phase of the volcanic period. The largest concentration of cinder layers, however, is beneath the caprocks near the north margin of the Waucoba Wash quadrangle (fig. 2). The intercalation of ash, lapilli, and cinder layers in the flow sequences indicates that pyroclastic activity was important throughout the volcanic sequence.

Megascopically these rocks do not offer any clues to their potassium-rich nature. They have the physical appearance of typical olivine basalt; in fact, they are

Figure 9. Aerial view east across south end of trachyandesite field of the Saline Range to faulted and warped volcanic rocks of the Dry Mountain area. These rocks may originally have been continuous with the Saline Range volcanic field. Photograph by Roland von Huene.

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FIGURE 10. View north to area of locality of specimen 14. Flow of trachyandesite (Tt) beneath intravolcanic alluvium (Tal) is more highly faulted than trachyandesite caprock. Intravolcanic alluvium is rich in granitic debris of same composition as weathered granitic rock (Mzgr) in foreground. In background, across Waucoba Wash, is volcanic field of the Saline Range.

FIGURE 11. Aerial view looking north along the east side of the trachyandesite field of the Saline Range, here broken by a series of north-trending normal faults, downthrown to the west. Striped rocks in the middle distance are Cambrian sedimentary rocks. White patches along east edge of volcanic field are deposits of active and dormant hot springs.

called basalt on the geologic map of the Waucoba Wash quadrangle (Ross, 1967a).

MICROSCOPIC DESCRIPTION

Only 18 thin sections of the trachyandesite were examined—a very small sample of a volcanic field of this size (see Ross, 1967a, fig. 1 for index to specimen coverage). These rocks are pilotaxitic with fresh plagioclase laths mixed with interstitial grains and small phenocrysts of dark minerals; most commonly clinopyroxene is interstitial and olivine is in small phenocrysts. The rock is liberally sprinkled with metallic opaque grains that appear to be dominantly magnetite, although the titanium content of the chemical analyses indicates ilmenite is also present. In some specimens the plagioclase crystals are alined to give a trachytic texture. Most specimens are somewhat porphyritic. Phenocrysts are most commonly olivine in crystals as large as 2 mm in maximum dimension; less common are phenocrysts of clinopyroxene and plagioclase of about the same size. Nearly all specimens are vesicular; most vesicles are clean, but some have fillings of calcite and other secondary material. Some specimens have a texture that suggests three generations of crystals: they contain phenocrysts from 1 to 3 mm, a distinctly finer grained generation of plagioclase microlites, and an equally distinctive, much finer grained groundmass rich in magnetite, very fine grained plagioclase needles, and clinopyroxene and olivine.

Five thin-section modes of samples selected to give a good geographic range are listed in table 2. These samples show that in mineral composition the rocks are about ½ to ⅔ plagioclase, that pyroxene exceeds olivine, and that metallic opaques are abundant. In addition to these major constituents, apatite is widespread and secondary calcite is found as vesicle lining, as thin veins, and scattered through the rocks. Most hand specimens will effervesce slightly with dilute HCl, showing that secondary calcite in small amounts is widespread in these rocks.

The plagioclase in these rocks is dominantly intermediate andesine to calcic labradorite. Sodic andesine is present in one red anomalous-looking specimen that has had all its ferromagnesian minerals replaced by iron oxide(?). In other specimens the plagioclase is largely clean and unaltered. Locally some plagioclase "phenocrysts" are embayed and spotted and streaked with microcrystalline alteration(?) material that suggests they are exotic crystals that have reacted with the trachyandesitic lava. In another specimen, fractured grains of quartz are certainly exotic; one is insulated from the rest of the rock by a reaction rim of clinopyroxene.

The clinopyroxene is pale greenish gray and is generally unaltered in thin section. On the basis of extinction angle, birefringence, and $2V$, it is augite. Olivine, where fresh, is colorless or somewhat yellow. It has a $2V$ of close to 90° and therefore is considered to be magnesian chrysolite olivine. The olivine is rarely fresh, however, but is veined and replaced along the typically curving fracture of olivine by

TABLE 2.—*Thin-section modes, in percent, of Saline Range volcanic rocks*

Trachyandesite caprocks

Sample No.	Plagioclase	Clinopyroxene	Olivine and alteration products	Metallic opaques
2	65	15	13	7
13	51	27	15	7
14	59	19	18	4
A	55	28	11	6
B	67	17	12	4
Average	59	21	14	6

Intrusive trachyandesite

Sample No.	Total feldspar (Plagioclase+K-feldspar)	Clinopyroxene	Olivine and alteration products	Metallic opaques	Biotite	Amphibole
5	65	17	14	3	1	----------
6	76	11	4	8		1
C	63	17	11	8	1	----------
D	[1] 61	17	13	8	1	----------
E	66	17	12	4	1	----------
F	64	18	11	6	1	----------
G	70	17	6	6	----------	1
Average	67	16	10	6	1	----------

[1] Plagioclase=47, K-feldspar=14 (stained thin section, but inconclusive).

reddish-brown alteration material generally referred to as iddingsite. Some olivine is completely pseudomorphosed by this alteration material.

CHEMICAL DATA

Six specimens of the trachyandesite were chemically analyzed, and five of them were flow rocks; one (specimen 11) from the Saline Range is from an intrusive plug, but it is presumed to be related to the trachyandesite caprock sequence also. One of the most interesting features of this admittedly sparse sample is the range of 9 percent in SiO_2 content in a suite of rocks that were presumed to be rather homogeneous, judging by their field appearance. Even this small chemical sample, however, points out the alkalic nature of these rocks; they are anomalously high in K_2O compared with many volcanic rocks of comparable SiO_2. The generally K_2O-rich nature of this suite seems to have exceptions though, for specimen 13 has a K_2O content closer to that of "normal" calc-alkaline basalt.

In order to supplement the chemical data, 26 additional samples were selected for fused-glass-bead index determinations. The results of this work, plotted in figure 12, confirm a suspicion from the fieldwork that the specimens with higher SiO_2 may be less important quantitatively than the varieties with lower SiO_2. The glass-bead clustering suggests that the bulk of the trachyandesite rocks have an SiO_2 content in the range of 47–49 percent.

The present study has revealed that there are significant variations in composition over the surface of this volcanic field. Thus, detailed sampling in some of the massive, several-hundred-foot-thick sections of those flow rocks exposed in the fault scarps might be worthwhile in determining the range of chemical variations with time in this trachyandesitic suite.

AGE OF THE TRACHYANDESITE

The trachyandesite caprock and plugs of the Saline Range are late Cenozoic. The caprock flows are underlain and overlain by and interlayered with alluvial material, but there have been no data to establish their age precisely.

The nearest volcanic rocks to be dated radiometrically are from the Deep Spring Valley area, about 30 miles to the northwest. Dalrymple (1963, p. 387) reported an age of 10.8 m.y. (million years) from a basalt capping a tuff from which sanidine yielded an age of 10.9 m.y. Other radiometric ages that were reported by Dalrymple in the same publication and that were made on latitic and basaltic rocks from the Sierra Nevada range from 2.6 to 9.6 m.y. and point out a widespread province of Pliocene volcanic rocks northwest of the Saline Range volcanic field.

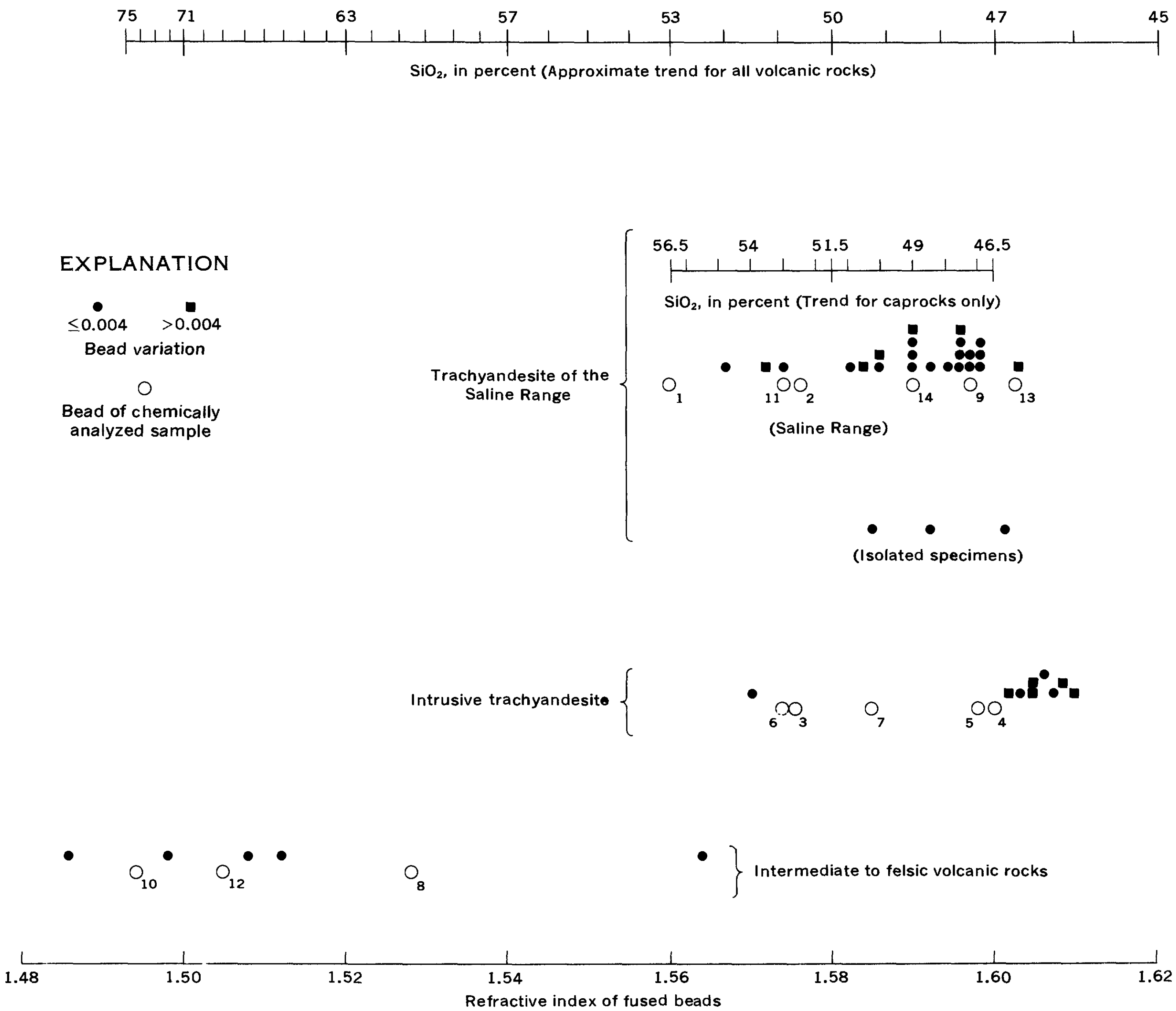

FIGURE 12—Comparison of refractive index of fused samples of volcanic rocks of the Saline Range–Inyo Mountain region. Silica estimates from curves in figure 15.

To help determine how the trachyandesites of the Saline Range fit into this picture, three whole-rock samples from the caprock flows and clinopyroxene and K-feldspar mineral separates from the south trachyandesitic plug were submitted for potassium-argon age determination. The data and results of these determinations are shown in table 3, the location of the samples, on plate 1.

Two of the three caprock samples, specimens 14 and F–158, gave essentially the same age. The third sample, W–352, may also be about the same age, considering its larger analytical error. Specimen W–352 also contains small amounts of what looks like devitri-

TABLE 3.—*Potassium-argon ages of trachyandesites*

[Ages were calculated using the following constants: K^{40} decay constants: $\lambda_e = 0.585 \times 10^{-10}$ year^{-1}, $\lambda\beta = 4.72 \times 10^{-10}$ year^{-1}; Abundance ratio: $K^{40}/K = 1.19 \times 10^{-4}$ atom per atom. Potassium analyses on a Baird flame photometer using a lithium internal standard by Lois Schlocker. Argon analyses made by using standard techniques of isotope dilution and age calculations by Jarel Von Essen]

Specimen	Material	Percent K_2O	Ar^{40}_{rad} (moles per gm)	$Ar^{40}_{rad}/Ar^{40}_{total}$	Apparent age (m. y.)
14	Whole rock	1.54	6.865×10^{-12}	0.05	3.0±1.2
F–158	Whole rock	1.28	5.367×10^{-12}	.11	2.8± .5
W–352	Whole rock	.629	5.996×10^{-12}	.04	6.4±3.2
7	K-feldspar	6.50	3.368×10^{-11}	.40	3.5± .1
7	Clinopyroxene	.126	1.274×10^{-12}	.05	6.8±3.9

Specimen locations, given in California Grid System coordinates, Zone 4:
14: 2,314,000 E., 559,300 N.
F–158: 2,336,900 E., 594,600 N.
W–352: 2,328,500 E., 574,600 N.
7: 2,336,800 E., 596,300 N.

fied glass, in contrast to the other samples, which are clean and completely crystalline. Thus there are both petrographic and analytical reasons for placing less confidence in the age determination for specimen W–352. Probably an age of 2.5–3.5 m.y is the best estimate of the age of the caprock we can make with the present data.

The radiometric age determination on the K-feldspar from the south plug is analytically very good with 40 percent radiogenic argon. The determination of the clinopyroxene is much less certain, and analytically we can say it is not distinguishable from the age determination of the K-feldspar. Thus, we can assign, very tentatively, an age of about 3.5 m.y. to the south plug. This means the trachyandesite plugs are probably slightly older than the flow rocks, which fits the most plausible field interpretation, that the plugs were somewhat eroded before the flows were emplaced.

These radiometric ages place both the plugs and the flows in the later part of the Pliocene, although some current estimates of the length of the Pleistocene might include these rocks in the Pleistocene.

FELSIC TO INTERMEDIATE VOLCANIC ROCKS

The felsic to intermediate volcanic rocks which underlie the caprocks in a few places are quantitatively unimportant in present-day exposures but would probably be of considerable areal extent if the capping trachyandesitic rocks were stripped away. These exposures give hints of a more complex volcanic history for this area than might be supposed from first encounters with the overwhelming flood of rather monotonous caprock extrusives. Exposures of these older, more felsic volcanic rocks are limited to the eastern part of the Waucoba Wash quadrangle. Outcrops of rhyolitic rocks are found to the north at about the same longitude in the Waucoba Springs quadrangle (C. A. Nelson, written commun., 1965). To the east in the Dry Mountain quadrangle, rather extensive areas of more felsic rocks are exposed beneath the caprock (B. C. Burchfiel, written commun., 1964). The two small felsic rock exposures in the Paleozoic rocks of the Saline Range are definitely intrusive. The other exposures could be either intrusive or extrusive.

The northernmost exposure of older volcanic rocks, on the north border of the Waucoba Wash quadrangle, is the tip end of a more extensive exposure in the Waucoba Springs quadrangle. According to C. A. Nelson (written commun., 1966), these rocks are a series of rhyolitic and obsidian flow rocks with associated tuff beds.

The exposures in the area of specimen 8 (pl. 1) are the largest exposures of felsic to intermediate volcanic rocks in the area, but they cover an area of only about one-twentieth of a square mile. The rocks are pale reddish brown, generally massive, but with some faint flow banding. They are overlain by tuff and alluvium, which in turn is covered by the trachyandesite caprock. According to the Rittmann classification (1952), this rock is a latite. It has an aphanitic, pilotaxitic groundmass liberally sprinkled with phenocrysts of andesine. Much less common are small phenocrysts of biotite and amphibole nearly masked by iron oxides and relatively clean pale-green clinopyroxene. One specimen has a few small patches that may be pseudomorphs of olivine. This rather distinctly colored latite is older than the caprock by an interval of erosion of unknown length. To my knowledge it is a unique rock type in this region.

Two dikes of rhyolitic rocks are intrusive along faults into the Paleozoic rocks of the Saline Range. The northernmost occurrence, which intrudes the Rest Spring Shale of Mississippian age, is made up of white to light-gray rocks that look felsic but appear to be altered; their original composition is somewhat uncertain. In part, this is a breccia mass that looks as though it might have been a feeder for pyroclastic material. The southern exposure (specimen 10, pl. 1) is a dike of light- to dark-gray flow-banded obsidian and rhyolite which was intruded along a fault in Lower Cambrian clastic rocks. The dike rock is dominantly glass studded with small phenocrysts of quartz, sodic plagioclase, and biotite (hyalopilitic). Embayed quartz phenocrysts with square outlines indicate crystallization as high-temperature (beta) quartz. Some rounded quartz grains may be xenocrysts, as the quartzitic wallrocks would be an easily available source of quartz grains. Devitrification of the groundmass glass is taking place by the development of what looks like sericitic material along curved cooling cracks. Also, microcrystalline patches indicate devitrification elsewhere of the groundmass glass. Chemically, specimen 10 (table 1) is a soda rhyolite according to Rittmann (1952). Rhyolitic pumice and ash in tuffaceous beds that are present elsewhere beneath the capping trachyandesite flows are also part of what may have been a rather widespread period of rhyolitic volcanism and pyroclastic activity, now largely buried by the trachyandesite.

The southernmost exposure of felsic to intermediate volcanic rocks is in the area of specimen 12 near the south end of the Saline Range. A window along a fault scarp exposes some 400 feet of nearly horizontally layered volcanic rocks below the capping trachyandesite. The lower part of the section consists of layers of ash and lapilli and dense olive-gray flow rocks that contain olivine, completely pseudomorphed by red iddingsite(?), and clinopyroxene in a pilotaxitic to trachytic matrix of plagioclase laths. The upper part of the section consists of dusky-yellow, light-olive-brown, and moderate-brown dense glassy volcanic rocks overlain by red cinder layers which are in turn capped by the trachyandesite flows. These glassy (hyalopilitic) rocks have a very faint felty texture. Rounded to embayed plagioclase crystals are the most common visible crystals, but thin plates of biotite rimmed with iron-rich material are also scattered through the rock. Specimen 12 is one of these glassy rocks; it is a soda rhyolite by the Rittmann (1952) classification. Neither in the field nor from thin-section examination was it suspected that these glassy rocks were so felsic, as no quartz was visible.

The upper rhyolitic part of this section as well as the rhyolitic dikes just discussed and the rhyolitic pyroclastic layers in some older alluvium probably are part of a sequence of rhyolitic volcanism that preceded the caprock trachyandesitic volcanism. This rhyolitic interval was itself preceded by earlier andesitic or basaltic volcanism with accompanying pyroclastic activity. The position of the latitic rocks of the area of specimen 8 in this volcanic history is unknown except that it preceded the caprock trachyandesite volcanism.

OWENS VALLEY VOLCANIC ROCKS

In the course of mapping the Independence quadrangle, only cursory observations were made of the volcanic rocks in and adjacent to Owens Valley. After chemical data had been accumulated on the Saline Range volcanic field, it seemed worthwhile to have some comparative chemical data. Consequently one fresh, and hopefully representative, sample was selected from each of the two flows (Specimens 15, 16, pl. 1) and chemically analyzed. To supplement the descriptions of Moore (1963, p. 135–138) of the westward extension of these flows, which he refers to as the olivine basalt west of Aberdeen, a few samples were examined in thin section and the index of refraction of several glass beads, prepared from powders of these volcanic rocks, was determined.

The volcanic rocks in Owens Valley (pl. 1) in the northwestern part of the Independence quadrangle are the ends of basaltic flows that originate along faults (marked by alined cinder cones) along the east front of the Sierra Nevada (Moore, 1963). The older olivine basalt of Oak Creek (pl. 1), exposed farther south, also originates from the lower eastern slope of the Sierra Nevada. In addition, there are several patches of black volcanic ash and fine-grained lapilli (Qba on pl. 1) plastered along the west side of the Inyo Mountains near the north boundary of the Independence quadrangle. Mixtures of ashy material with granitic debris in some of the alluvial deposits suggests that originally the ash deposits were much more extensive but have largely been washed off the granitic exposures. Some of these ash patches are virtually continuous with a volcano and associated flows to the north in the Waucoba Mountain quadrangle (Nelson, 1966).

The only volcanic rocks that originated within the Independence quadrangle form an areally insignificant, but nevertheless interesting, occurrence in the SE¼ sec. 30, T. 11 S., R. 35 E. (Ross, 1965, pl. 1). Here, a small ringlike outcrop, only a few hundred feet across, is made up of basalt ash, lapilli, bombs, and cinder chunks as long as 5 feet. Presumably this outcrop, which straddles a shear zone in the underlying granitic rocks, represents a single pulse of volcanic activity.

Felsic volcanic rocks are not exposed in the Independence quadrangle, but there are two occurrences of rhyolitic material in tuffaceous sedimentary rocks. One, first noted by Knopf (1918, p. 52), consists of several feet of bedded pumice and crystal fragments resting on granitic rock and is exposed in the north-central part of sec. 6, T. 13 S., R. 36 E. Probably these beds are similar to the lower layer of the older alluvium in the SE¼ sec. 5, T. 13 S., R. 36 E., which is rich in rhyolitic pumice and ash (Ross, 1965, p. O51). The nearest exposed source of rhyolitic material is an extrusive dome of pumiceous rhyolite about 18 miles to the northwest (Mayo, 1944). The rhyolitic volcanic rocks beneath the capping flows of the Saline Range are about the same distance to the northeast (Ross, 1967a; C. A. Nelson, oral commun., 1966), but they are presumably somewhat older. It seems most probable that these pumiceous and ashy layers in the Independence quadrangle represent fallout from airborne material associated with the outpouring of the voluminous Bishop Tuff of Pleistocene age (Bateman, 1965, p. 151).

In the field the Owens Valley basaltic volcanic rocks are dark gray to black, dense to vesicular, and some specimens have visible olivine phenocrysts. The surfaces of both flows are locally ropy; in part, they are extremely vesicular, and even scoriaceous. Vesicles are commonly elongate and show conspicuous but varied foliation in the flows. Cindery, blocky breccia is common along the surface and is particularly abundent near the exposed margin of the north flow. Some bombs have been found on the surface and embedded in the breccia. From field examination the north and south flows look like similar typical olivine basalt.

Microscopically there is some difference between the flows. The north flow is mainly equigranular, and the largest crystals of olivine are about 1 mm in maximum dimension. It is holocrystalline pilotaxitic, and almost all grains are coarse enough to be optically identifiable. The south flow, on the other hand, is more porphyritic, although the largest crystals are not much larger than those of the north flow. The grain-size variation is much greater, as the south flow has a very fine grained groundmass, though it seems to be holocrystalline. Olivine is notably fresh in the north flow, but is in part altered to iddingsite(?) in the south flow. Another difference is reflected in the refractive index of glass beads from these flows. Those from the north flow average 1.594, those from the south flow, 1.600. Even though the number of samples is small and there is a slight overlapping of indices between the two flows, there does appear to be a real, if small, difference in their glass-bead index of refraction. This is all the more unusual because they have almost identical SiO_2 and total iron contents (table 1). It would seem the difference in glass-bead indices must be accounted for by the differences in Al_2O_3, MgO, and CaO content in these two flows.

Although there are striking textural differences between these two flows, they have the same general mineralogy. Both have microlites of calcic labradorite. Both have clear olivine that has a $2V$ near 90°, and both have pale-yellowish-green clinopyroxene (probably augite). Judging by the chemical variations of the two flows with regard to Al_2O_3, CaO, and MgO, however, the percentages of these minerals are different, although no modal counts were made on these rocks. The major difference between the two flows in normative minerals (table 4) is that olivine exceeds diopside in the north flow, whereas these two normative constituents are almost equal in the south flow. The total of these two ferromagnesian minerals also is higher in the norm for the south flow.

TABLE 4.—*Normative mineral comparison, in percent, of Owens Valley flows*

Normative minerals	North flow (sample 15)		South flow (sample 16)	
Orthoclase	11.3		8.3	
Plagioclase	48.6		46.7	
Nepheline	2.4		.9	
Diopside	13.0	29.6	18.5	36.3
Olivine	16.6		17.8	
Magnetite-ilmenite-apatite	8.2		8.0	
Total	100.1		100.2	

The chemical analysis of these two flows (table 1) bear out the conclusions from microscopic examination that these two flows are different. Moore (1963, p. 135), who had the opportunity to study a much larger area of exposure of these rocks and their source area, noted "the similarity and apparent contemporaneity of these volcanic rocks." He did not, however, have the benefit of chemical analyses. Petrographic and chemical differences in the selected samples from the two flows suggest the need of further study of the Big Pine volcanic field to see if these variations are significant, or if they represent fortuitous differences due to the small size of the sample of the present study.

Both of the analyzed samples have trachybasalt affinities according to the chemical classification of Rittmann (1952). The sample from the north flow is an olivine-andesine trachybasalt, whereas the sample from the south flow is an andesine basalt, but is almost on the border of Rittmann's trachybasalt field. The Owens Valley basaltic volcanic rocks are alkali basalts (fig. 13) that furnish one more set of chemical data on a volcanic province that seems to be characterized by high K_2O.

There can be little doubt that the Owens Valley flows are much younger than the Saline Range flows. Those in the Owens Valley still preserve some original form and original surface features. Moore (1963, p. 135) has noted, however, that these rocks are not as young as casual inspection of their forms might suggest, for as much as 30 feet of valley fill has accumulated since

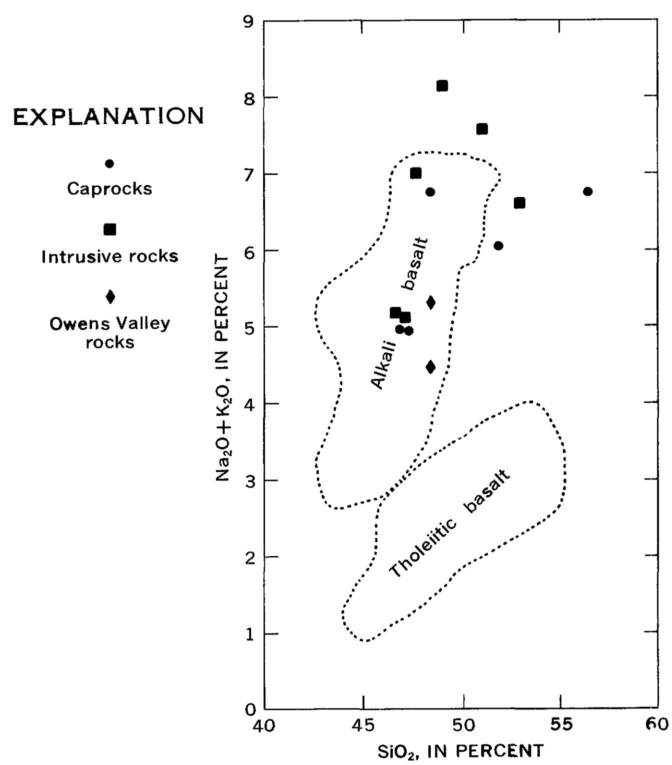

FIGURE 13.—Plot of total alkalis and silica for volcanic rocks of Saline Range area. Dotted lines show fields of Hawaiian lavas after MacDonald and Katsura (1961, p. 367).

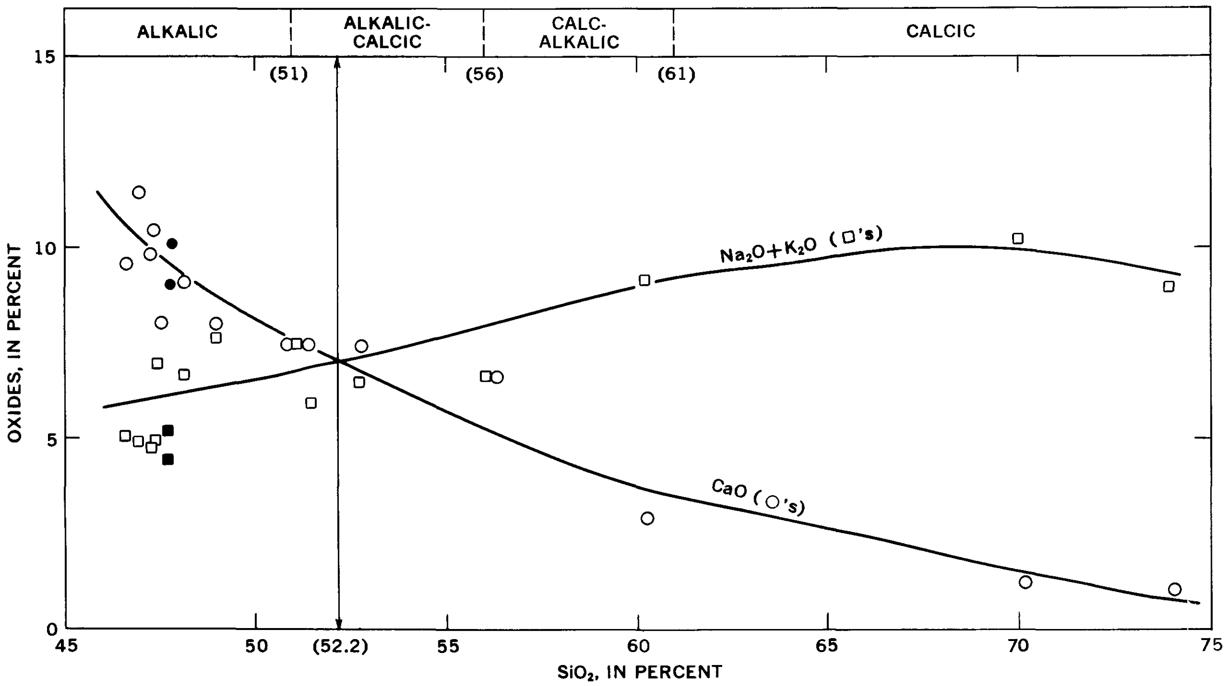

FIGURE 14.—Variation diagram showing classification of Saline Range–Inyo Mountains suite according to alkali-lime index of Peacock (1931). Solid points are Owens Valley volcanic rocks.

their eruption. Nevertheless, these flows are definitely Quaternary and may be Holocene. The Saline Range flows, by contrast, are strongly dissected by canyons and are disrupted by faults of several hundreds of feet of vertical displacement.

Chemical comparison shows the Owens Valley flows are considerably higher in MgO and somewhat lower in Na_2O than the Saline Range flows. Other oxide percentages seem to overlap for the two areas.

CHEMICAL CHARACTERISTICS OF THE SALINE RANGE SUITE

Rocks of the Saline Range suite, as stated in the "Introduction," are markedly alkalic. In the plot of K^2O+Na^2O against SiO_2 of MacDonald and Katsura (1961, p. 367), the Saline Range rocks plot well up into the alkalic basalt field (fig. 13). High total alkalis are probably the outstanding chemical characteristic of these rocks. By using Rittmann's classification (1953), *p* value, [1] all the chemical samples are alkaline. Peacock (1931) has subdivided the calc-alkaline and alkaline fields and has established two intermediate classes, alkali-calcic and calc-alkalic, on the basis of the SiO_2 content where total alkalis equal CaO. Using this classification, the suite is alkali-calcic, but near the alkalic boundary (fig. 14).

[1] *p* is derived as follows: $p=(SiO_2)\ (An+0.7)$, where $An=(Al-Alk)/(Al+Alk)$; $Al=0.9Al_2O_3$ and $Alk=K_2O+1.5Na_2O$ in weight percentage. *p* values higher than 55 are calc-alkaline, 55 or lower are alkaline.

Fused-glass beads were prepared from powders from each chemically analyzed specimen according to the method described by Rinehart and Ross (1964, p. 60) and modified somewhat by Huber and Rinehart (1966, p 103). The plot of the indices of these beads against SiO_2 of the chemical analysis, shown in figure 15, is not as linear as one would hope. There is a suggestion that the capping trachyandesites plot on one roughly linear trend (dashed line in fig. 15), and the intrusive trachyandesites and the intermediate to felsic volcanic rocks plot on a somewhat different curved trend. When an average curve is fitted for all the points, there are some rather anomalous points. Specimens 6 and 7 can probably be discounted, as they are probably too coarse grained for a powder of a small sample to represent any average composition. Specimen 1 plots as the most anomalous point and has an anomalous composition, being high in SiO_2. Yet it appears to be fresh and definitely is part of the caprock sequence. The reason for its anomalous position is unknown. Specimen 11, the fine-grained intrusive of the Saline Range, also appears to be anomalously high in silica and off the general trend. In view of these irregularities, it is probably best to use the average curve as the best approximation for the whole suite—we just do not have enough data to evaluate the possibility of two trends.

Although generally only SiO_2 is plotted against the refractive index of fused-glass beads, and this plot is

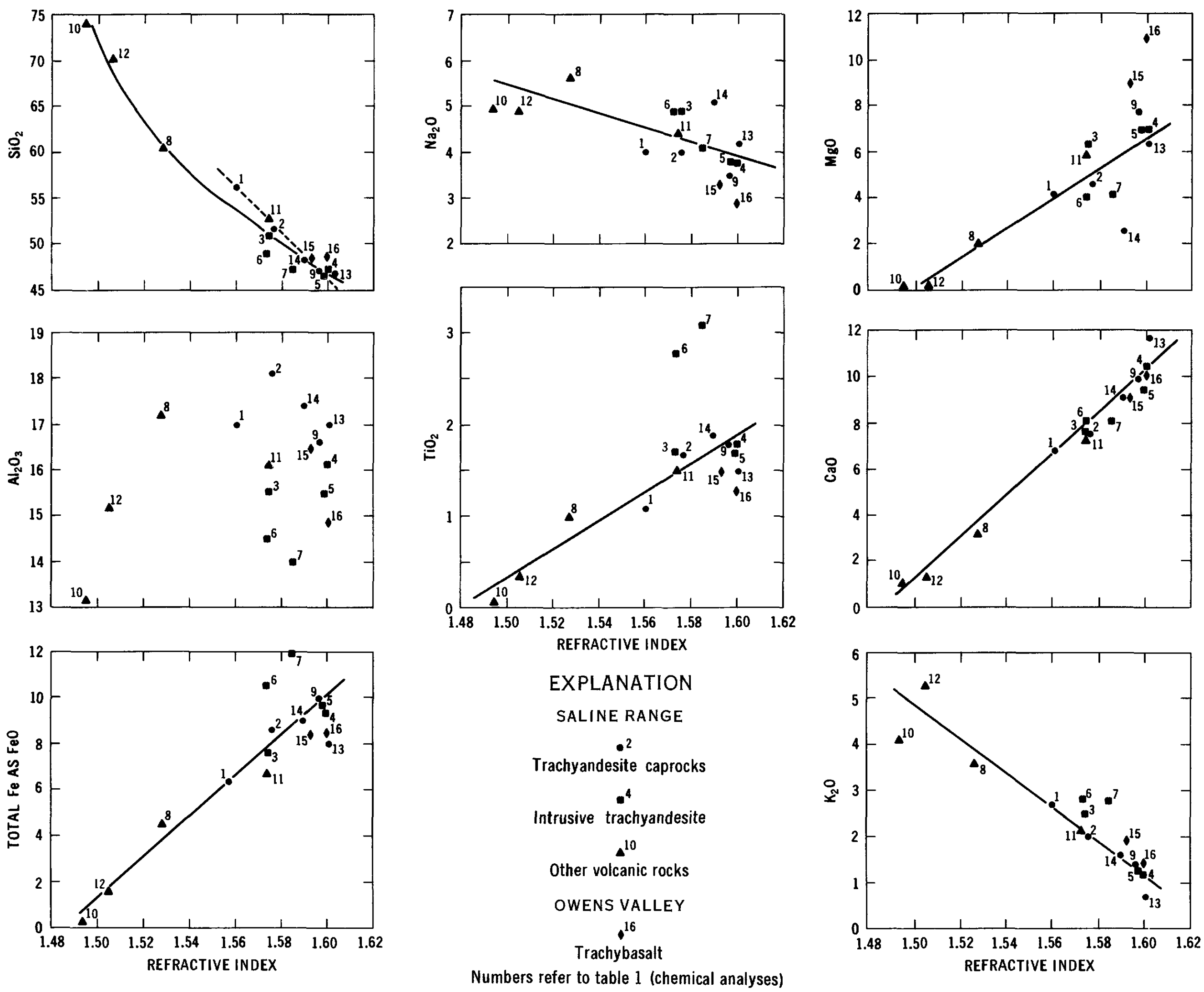

FIGURE 15.—Refractive index of fused-glass beads plotted against oxides, in weight percent, for chemically analyzed volcanic rocks, Saline Range–Inyo Mountains area.

used to estimate SiO_2 percentage of fused-glass-bead specimens for which there are no chemical analyses, some authors (for example, Callaghan and Sun, 1956; Shilov and others, 1958) have used this refractive index of fused-glass beads to determine other oxides. To see how valid this was for the Saline Valley suite, all the oxides were plotted against this refractive index (fig. 15). From these plots it seems that the index of a fused-glass bead of this suite is a good clue to the amount of CaO and the amount of total FeO (with the exception of the two coarse-grained intrusives, specimens 6 and 7), a fair help in estimating K_2O, MgO, and TiO_2, but rather hopeless for estimating Al_2O_3 or Na_2O. The CaO plot against refractive index is extraordinarily linear; even the coarse-grained specimens 6 and 7 and the much younger and chemically dissimilar specimens 15 and 16 fall on the trend. Only specimen 13, which is unusually rich in CaO, is off the trend.

In current petrochemical discussion, the interrelations of total Fe as FeO, MgO, CaO, and TiO_2 are considered significant. Various pairs of these oxides have been plotted in figure 16. The plots are generally self explanatory, and show good correlations but with some marked divergences. By far the best correlation is obtained from the plot of total Fe as FeO against TiO_2.

Standard variation diagrams (fig. 17) show that these volcanic rocks follow good normal trends and that the suite appears to be a chemically related one. The best linear trends are shown for total Fe as FeO, K_2O, and CaO. Somewhat comparable trends were plotted by using the differentiation index of Thornton and Tuttle (1960). These plots (fig. 18) show even more concen-

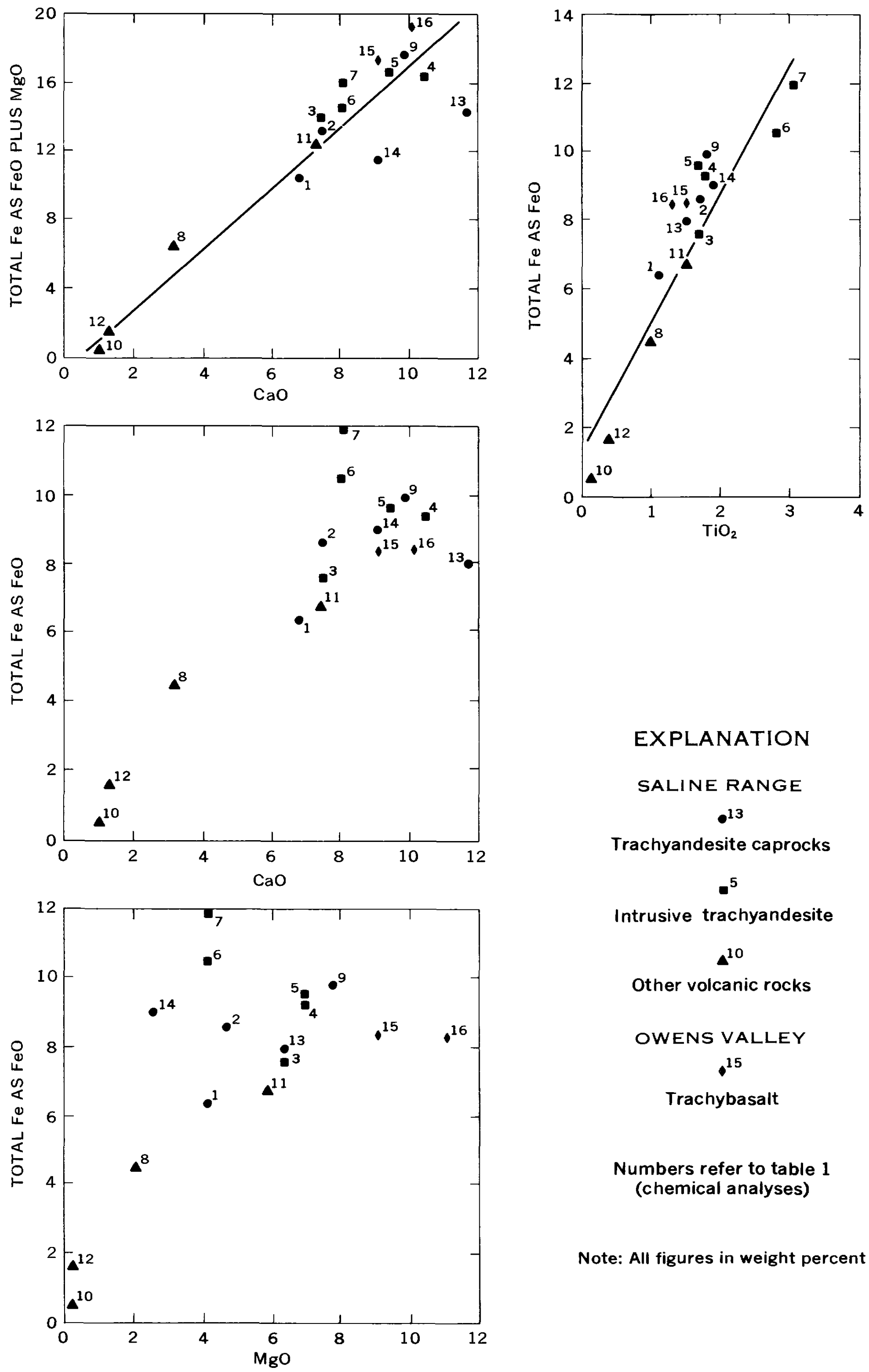

FIGURE 16.—Selected oxide ratios of volcanic rocks, Saline Range–Inyo Mountains area.

trated linear trends than the standard variation diagrams. CaO, Na_2O, and K_2O have particularly good linear trends.

A ternary diagram was prepared to show the plot of the normative feldspar molecules (fig. 19*A*). All the specimens, including the two younger rocks from Owens Valley, make a relatively compact field. Normative An is the most variant constituent and its range in the suite is the major control of the elongate field. It can also be stated that the relation between normative An

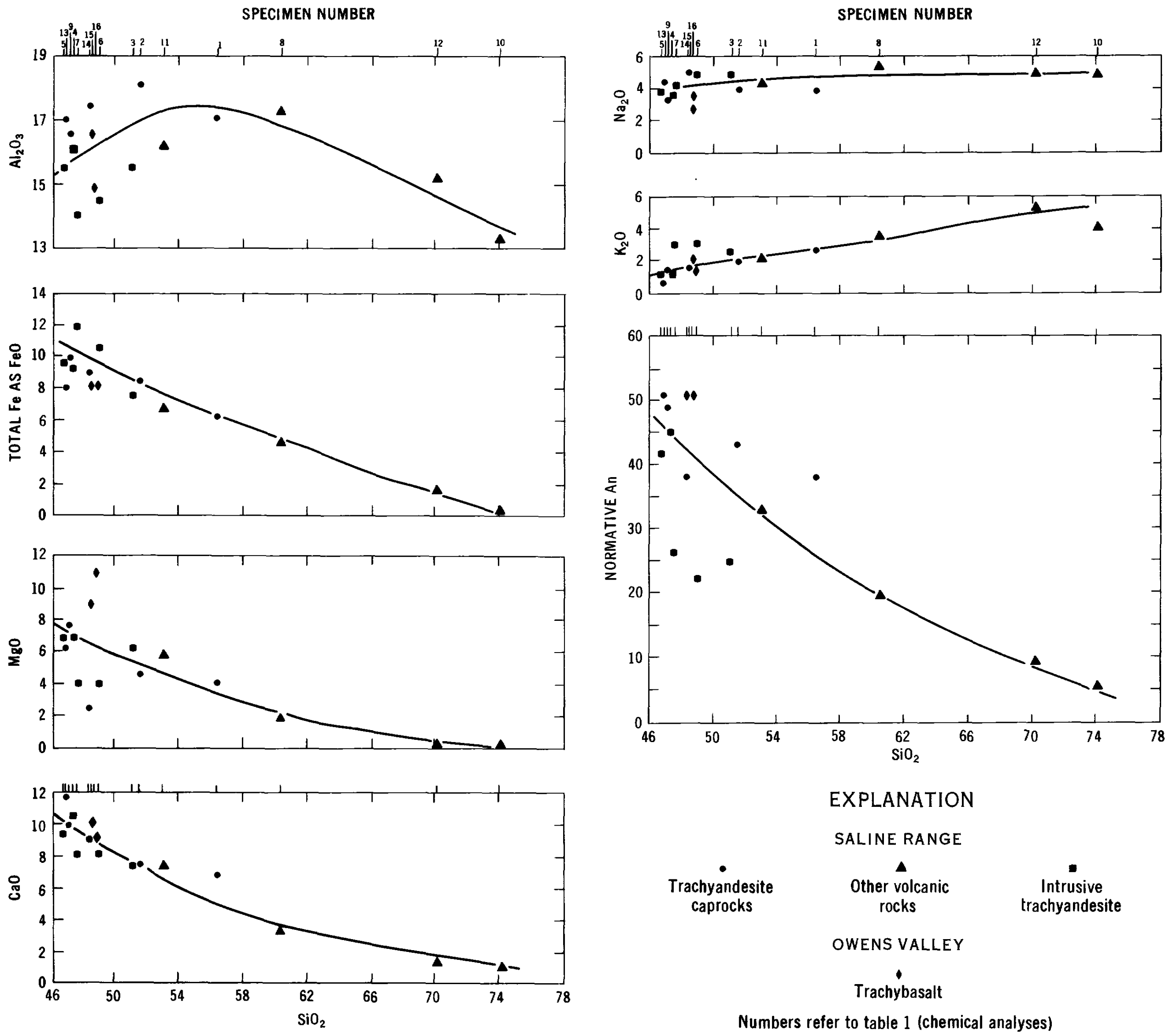

FIGURE 17.—Variation diagram of common oxides, in weight percent, in volcanic rocks of Saline Range–Inyo Mountains area plotted against SiO_2.

and Or is the most significant, normative Ab being much less variable.

The ternary A–C–F diagram (fig. 19*B*) shows a good clustering of points except for specimen 10. This diagram tends to show unaltered igneous rocks clustering along the F–An join. The displacement of the field of the Saline Range region suite below this join reflects the related richness in alkalis, which gives a somewhat lower than normal A value for comparable C and F values. The markedly aberrant specimen 10 has an unusually low content of iron oxide, even for so felsic a rock. Total Fe as FeO is only 0.5 percent, in contrast to about 2 percent total Fe as FeO for the average rhyolites of Nockolds (1954, p. 1012, table 1). This glassy dike rock is incipiently devitrified and iron has possibly been leached out. From thin-section study, however, this rock did not look extensively altered. It is not a normal rhyolite chemically, but the single small dikelike occurrence does not permit any definitive statement as to whether this was originally an unusual rock or was made unusual by subsequent alteration—of course it is possible that the low iron value is an analytical error.

The Alk–F–M diagram (fig. 19*C*) is shown for comparison with other chemical plots. This rather standard ternary diagram does not show a good linear-differentiation trend, but if specimens 15 and 16 from Owens Valley and specimens 6 and 7 of coarse-grained

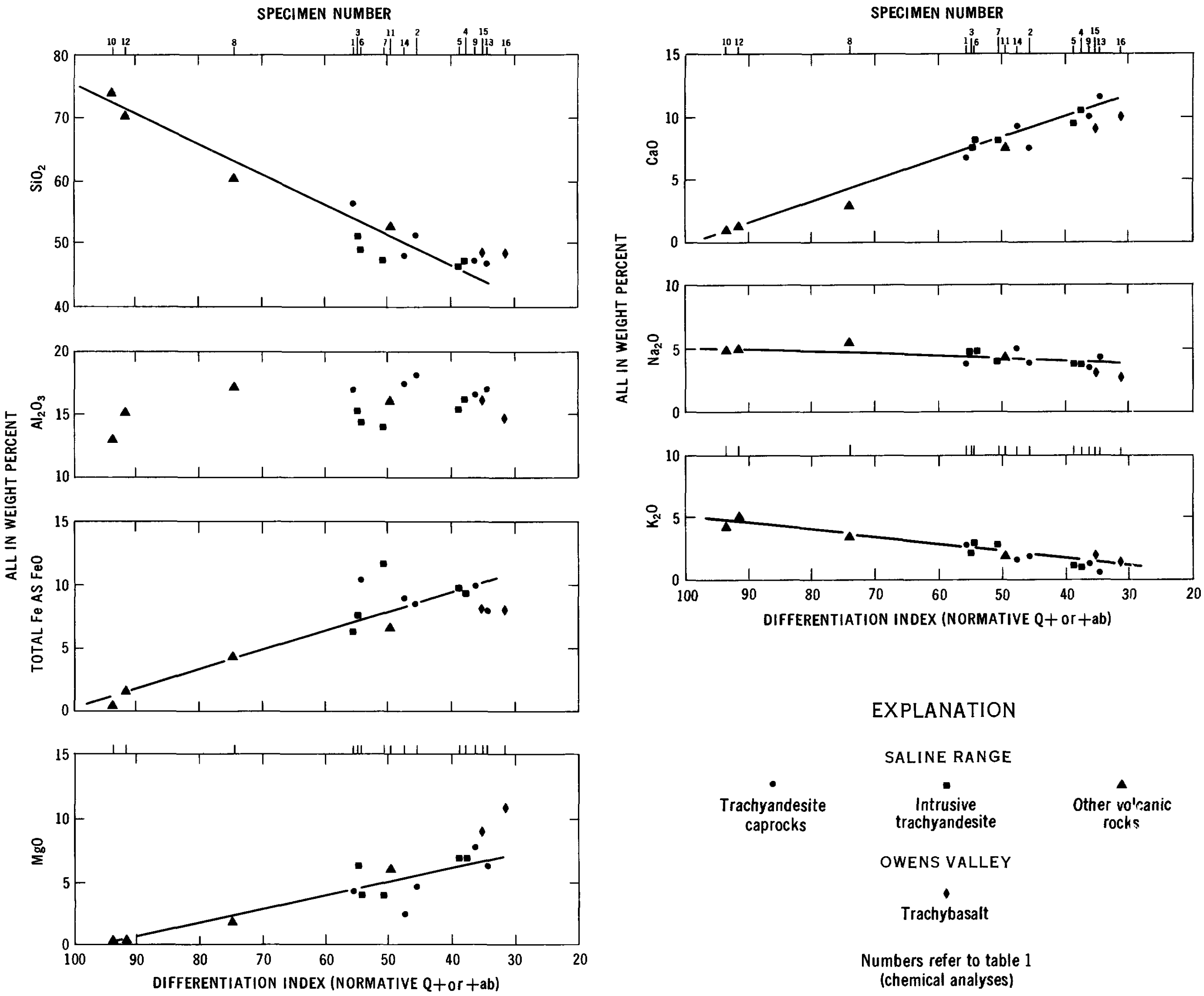

FIGURE 18.—Oxide percentage plotted against differentiation index of volcanic rocks, Saline Range–Inyo Mountains area.

intrusive are ignored, there is a fairly good clustering of the mafic rocks that ties reasonably well with the more felsic rocks along the plotted trend line.

Semiquantitative spectrographic analyses of the 16 volcanic rock specimens are shown in table 1. Some 22 minor elements were detected and 29 others that are listed were looked for but not found. Because there is almost no comparable published data on other volcanic rocks of this region, these data constitute a first tie point of the minor-element concentrations in volcanic rocks of this region. Comparisons have been made with igneous-rock averages of Vinogradov (1956) as compiled by Green (1959, table 2). Vinogradov's averages for mafic and felsic rocks are generally similar to chemically comparable volcanic rock types in the Saline Range area. Notable exceptions are lanthanum (La), strontium (Sr), and neodymium (Nd). Both lanthanum and strontium are some two to four times more abundant in the Saline Range rocks, and neodymium in the trachyandesite rocks is some 15–30 times more abundant than Vinogradov's average for mafic and intermediate igneous rocks. Until more trace-element data are available in the western Great Basin and Sierra Nevada region, it will be difficult to evaluate the significance of these figures.

Comparison of trace-element concentration in the Saline Range and Owens Valley specimens (table 1) shows comparable values except for nickel and chromium, which show about 300–500 ppm (parts per million) and 500–700 ppm, respectively, in Owens Valley rocks as compared with only about 20–100 ppm and 20–300 ppm in the Saline Range rocks. The considerably higher MgO and CaO in the Owens Valley analyses may indicate a higher concentration of ferromagnesian minerals that could carry the nickel and chromium, although Saline Range rocks with nearly

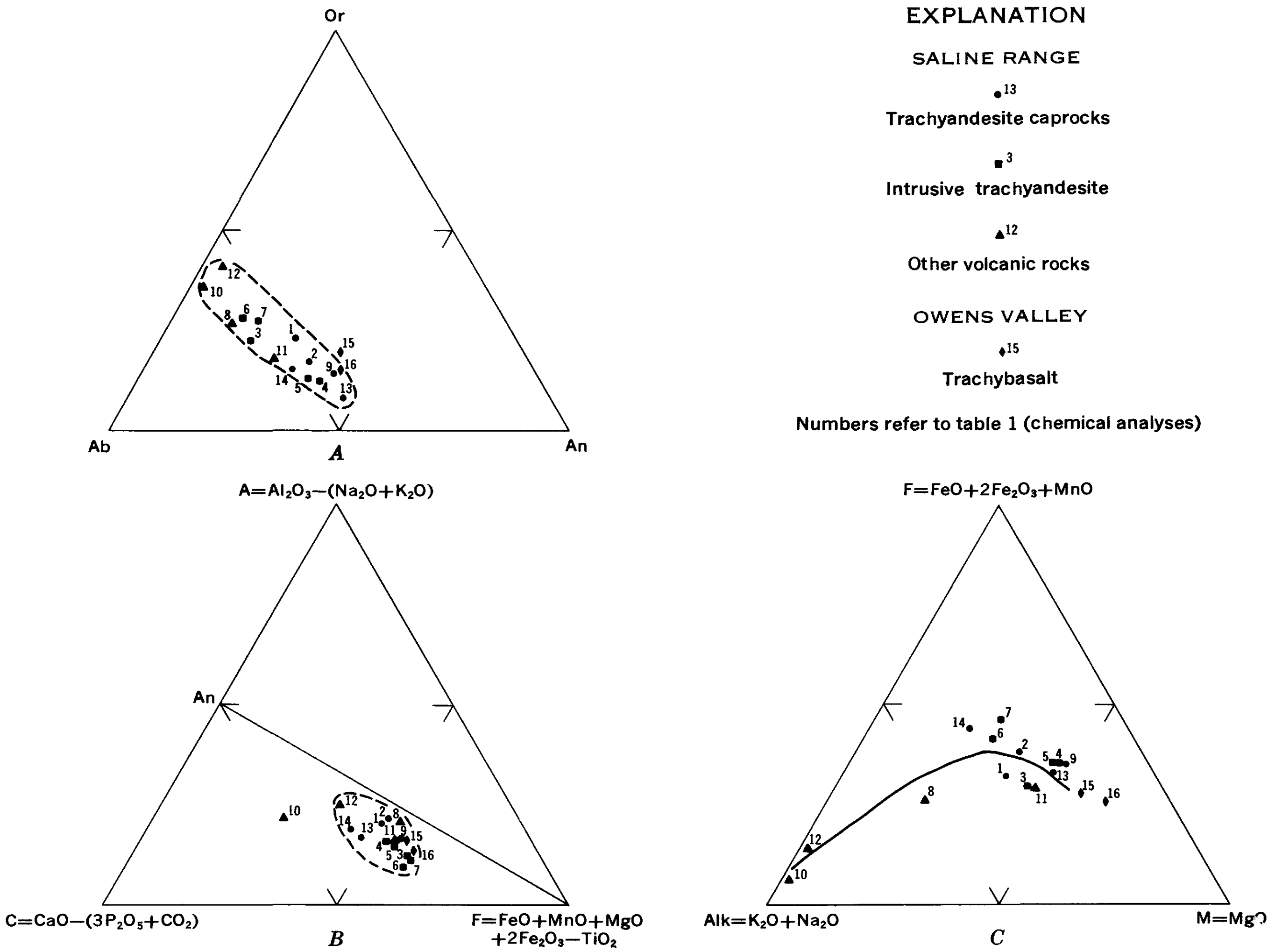

FIGURE 19.—Ternary plots of selected oxides and normative minerals, volcanic rocks, Saline Range–Inyo Mountains area.

comparable MgO and CaO (specimens samples 9 and 13, table 1) do not have comparatively high nickel and chromium concentrations. Possibly, the higher concentration of nickel and chromium could be a clue to a deeper source for the Owens Valley lavas. Moore (1963, p. 138) has suggested, from other evidence, that these lavas did originate at great depth, perhaps near the Mohorovicic discontinuity.

Semiquantitative spectrographic analyses have been published from the latite series of the Bridgeport-Sonora Pass area of the eastern Sierra Nevada (Nockolds and Allen, 1954, p. 280). Most of the 17 trace elements determined from this latite series are present in concentrations comparable to concentrations in rocks of similar composition from the Saline Range region. Differences are: Gallium (Ga) is two to three times more abundant in the Bridgeport-Sonora Pass area; lanthanum (La) was not detected in the Bridgeport-Sonora Pass andesitic and basaltic rocks, whereas it is present in concentrations of 50–200 ppm in the Saline Range rocks; scandium (Sc) was generally not detected in the Sierra rocks, but is present in concentrations of 10–50 ppm in the Saline Range rocks; nickel (Ni) is found in comparable concentrations in the two areas except for the Owens Valley rocks, in which it is more abundant (see p. D24).

Spectrographic data from the late Cenozoic trachyvolcanic rocks from the Death Valley area (Drewes, 1963, p. 21) show the following comparison with the Saline Range volcanics: Cesium (Ce), lanthanum (La), niobium (Nb), scandium (Sc), strontium (Sr), ytterbium (Yb), and zirconium (Zr) are more abundant in the Saline Range rocks, and lead (Pb) is less abundant. All the other trace elements have comparable values.

In all the comparisons, lanthanum appears to be more highly concentrated in the Saline Range rocks, both in specific volcanic suites and for general crustal averages of similar rocks.

In order to give some idea of the trends of the minor elements for the Saline Range suite, graphs using the

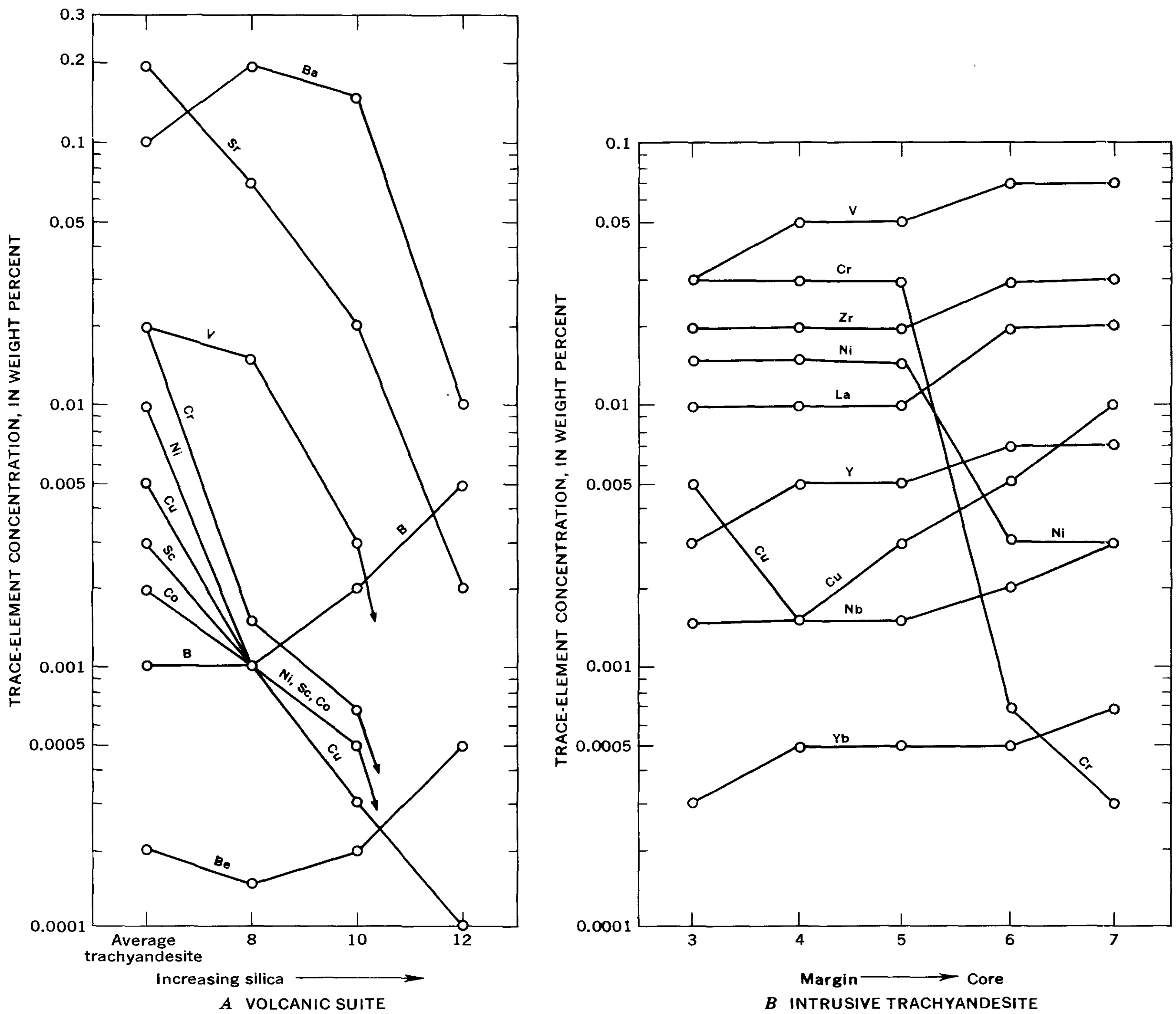

Figure 20. —Trace-element trends in volcanic rocks, Saline Range.

semiquantitative center points as plotting points were constructed for the intrusive trachyandesite analyses and for the entire suite (fig. 20*A*, *B*). It must be remembered that these percentage figures are not absolute values; but even so, the slopes show relative increases and decreases in the minor elements.

Minor-element trends within the trachyandesite caprock (specimens 1, 2, 9, 13, 14) were noticeable for only a few elements and thus were not plotted. Beryllium increases about threefold with increasing silica. Chromium decreases threefold to fourfold with increasing silica. Other minor elements have inconclusive trends or are relatively constant for the caprock range of 9 percent in SiO_2 content.

Trends within the intrusive trachyandesite (specimens 3–7) are rather pronounced for several elements from the dense marginal rocks to the pegmatitic core rocks. Increases of two or more times from margin to core are noted for vanadium (V), ytterbium (Yb), copper (Cu), niobium (Nb), and yttrium (Y). Cesium (Cs), lanthanum (La), zirconium (Zr), and neodymium (Nd) are also somewhat concentrated in the pegmatitic core rocks. The most evident trends, however, are the decreases coreward, by five to ten times, in nickel (Ni) and chromium (Cr). It should be noted that these trends are based solely on physical position relative to the margin of the intrusive plugs. The trend of

SiO_2, which has a range of 3.5 percent, does not seem to be consistent, at least from the samples analyzed.

By using an approximate average for minor-element content for the trachyandesite caprocks and by using the more felsic rocks as plot points, plots of figure 20*A* show general trends for the entire Saline Range volcanic suite. Rather strong decreases are noted for barium (Ba), strontium (Sr), vanadium (V), chromium (Cr), nickel (Ni), copper (Cu), scandium (Sc), and cobalt (Co), with the increase in silica from the trachyandesite to the rhyolite specimens. The only minor elements that showed concentration with increasing silica were boron (B) and beryllium (Be). Other minor elements show no noticeable trend over this silica range of about 25 percent.

REGIONAL INDICATIONS OF AN ALKALINE SUITE

One of the first indications of the presence of alkalic volcanic rocks in this region was an analysis reported by Gilbert (1941, p. 792) showing 2.11 percent K_2O for a rock described by him as unusual from the center of a thick flow in an olivine basalt sequence in the Benton Range. Unfortunately, we cannot determine from this one high value the range in K_2O content of average volcanic rocks of that sequence. Two additional chemical analyses of mafic volcanic rocks mapped as basalt are reported by Ross (1961, p. 40) from southern Mineral County, Nev. One of these rocks, which consists of abundant small olivine phenocrysts set in a pilotaxitic groundmass of plagioclase and clinopyroxene, contains 3.4 percent K_2O. Another, a dense grayish-black vesicular rock composed of plagioclase, hypersthene, and clinopyroxene phenocrysts set in a hyalopilitic groundmass, contains 3.8 percent K_2O. These three samples of strongly K_2O-rich volcanic rocks suggest that the widespread "basalt" fields of this area, about 80 miles north of the Saline Range area, are part of a K_2O-rich suite.

Trachybasalt has been described by Bateman (1965, p. 151) from the Tungsten Hills area of the eastern Sierra foothills, about 45 miles to the northwest. These scattered flow remnants are holocrystalline and are composed of tabular to elongate plagioclase, rounded grains of augite and olivine, magnetite, and minor hypersthene; groundmass K-feldspar constitutes about 15 percent of the rock.

Somewhat detailed work on the volcanic rocks of the Mammoth Lakes area, about 75 miles to the northwest, has been done by Rinehart and Ross (1964) and Huber and Rinehart (1967). These workers have recorded several chemical analyses of rocks mapped as basalt and andesite which contain about 2 percent K_2O. It is interesting to note, however, that one sample of basalt from this area has only 1 percent K_2O in a rock that contains 48.8 percent SiO_2 and normative sodic labradorite. Although this too exceeds the amount of K_2O in most basalts, it is not far out of line, and dictates caution in assuming that all these mafic volcanic rocks have extremely high K_2O. Trachyandesite affinities are also shown by dark-colored hypersthene and olivine-bearing volcanic rocks from the Merced Peak quadrangle, west of the Mammoth Lakes area, that contain from 2.6 to 3.0 percent K_2O (D. L. Peck, written commun., 1968), and by trachybasalts present in the Shuteye Peak quadrangle, just south of the Merced Peak quadrangle, that contain from 2.1 to 3.6 percent K_2O (N. K. Huber, written commun., 1968).

Some 75 miles to the west-northwest, in the Huntington Lake area of the Sierra Nevada, are scattered remnants of intrusive plugs and flows of trachybasalts that average 54 percent SiO_2 and 3 percent K_2O and that contain modal olivine and K-feldspar (Hamilton and Neuerburg, 1956). These rocks, which are also described as vuggy, seem to be very similar to the intrusive trachyandesites of the Saline Range, except that the Huntington Lake occurrence does not attain coarse pegmatitic texture.

About 125 miles northwest of the Saline Range region is a volcanic area in the Sierra Nevada that is characterized by an episode of latitic volcanism. These rocks, named the Stanislaus Formation by Slemmons (1966, p. 203–205), are the source for 10 chemical analyses listed by Nockolds and Allen (1954, p. 280). Five of the analyses are identified as basalt, and they range in composition from 48.0 to 53.8 percent SiO_2 and from 0.7 to 2.4 percent K_2O; grossly, the lower the SiO_2, the lower the K_2O. Other rocks in this suite contain as much as 63.7 percent SiO_2 and 5.4 percent K_2O, with intermediate rocks of about 57 percent SiO_2 and 3–4 percent K_2O. These rocks of the Bridgeport-Sonora Pass area are thus typified by abundant K_2O, but, like the Saline Range volcanic rocks, for rocks called basalt in the field, there is a wide range in K_2O, from less than 1 percent to 3 percent.

For the area about 50 miles to the east near Beatty, Nev., Cornwall and Kleinhampl (1964, table 2) have published analyses of basaltic rocks that contain from 1.30 to 1.67 percent K_2O. Somewhat farther to the southeast in the Funeral Peak quadrangle in the Death Valley area, Drewes (1963, p. 19–22) has tabulated a number of chemical analyses and spectrographic analyses for late Cenozoic olivine-bearing andesitic and basaltic rocks. These rocks range in SiO_2 content from 47 to 57 percent and have about 1.5 to 2 percent K_2O. By the Rittmann (1952) classification, they are trachybasalt, trachyandesite, or andesine basalt.

Considering the rather great distances separating the Sierra Nevada, the Mineral County-Benton Range area, and Death Valley from the Saline Range, there is no intention here of suggesting that these areas are part of the same eruptive suite. It is suggested, however, that regionally the Saline Range volcanic rocks are part of a rather extensive late Cenozoic alkaline volcanic province. More chemical data are needed, particularly of "basaltic" rocks of late Cenozoic age to the south and east of the Saline Range, to help determine the extent and limits of this province.

Moore (1962, p. 101) has synthesized a large amount of data on K_2O and Na_2O in Cenozoic volcanic rocks of the western states, and to compare these data he has used Niggli's k value (the molecular ratio of K_2O:K_2O plus Na_2O). Moore has then plotted k against SiO_2 for the various areas and obtained k value trend lines. The k values where these trend lines crossed 50 and 60 percent SiO_2 were used as control points to contour these data. Moore stated: "These maps show that potassium is least abundant relative to total alkalis (when rocks of the same SiO_2 content are compared) in a zone along the Pacific Coast, becomes more abundant eastward, and is highest in the Colorado Plateau and Northern Rocky Mountains." The values of k for the Saline Range volcanic suite, 0.23 for 50 percent SiO_2 and 0.32 for 60 percent SiO_2, fit into an area of intermediate k values between a local high in the Sierra Nevada and a much larger high to the east in Nevada and Utah (Moore, 1962, p. 128, 129).

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