

PETROLOGY AND CHRONOLOGY OF LATE CENOZOIC VOLCANICS

SOUTH AND EAST OF LASSEN PEAK, CALIFORNIA

A Thesis Proposal Submitted
To the Earth Sciences Board
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LASSEN VOLCANIC NATIONAL PARK
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INTRODUCTION

Volcanism along the western boundary of North America was nearly continuous during Cenozoic time, due to the presence of a continental margin-type trench and subduction zone along the Pacific edge of the continent (Christiansen and Lipman, 1972). Silver (1969) showed that the Gorda Plate has been underthrust beneath the continental margin off northeastern California for the last 6 m.y. resulting in subduction of young crustal material at a rate of 2-3 cm./yr. (Fig. 1). Evidence for subduction

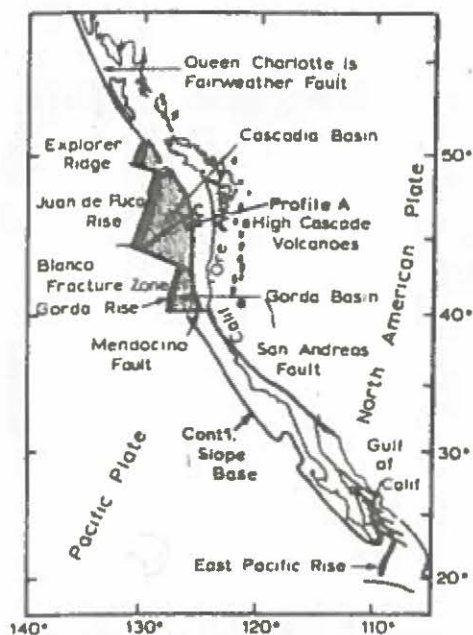


Figure 1. Location of tectonic features in the northeast Pacific and west coast of North America discussed in text. Shaded region represents the Gorda plate. Profile A is located. Silver, 1969, p. 101.

along this part of the Pacific margin of North America includes reflection records of deformed sediments and somewhat equivocal seismic and gravity observations. The young lithosphere of the Gorda Plate is relatively warm compared to the material being subducted under western Pacific island arcs. The less brittle Gorda plate apparently does not fracture so there is no clear seismic evidence for the

presence of a Benioff zone. Volcanism in northwestern United States provides some of the best evidence for the presence of converging plates and the nature of their interaction. Determination of the sequence and time of eruptions and of the relative volumes of material produced for a single volcanic area such as the Lassen region could yield valuable information bearing on the problem of relative motions of the Gorda and North American plates.

The locus of Cascade Range volcanism has shifted to the east with time, so that the Western Cascades of Eocene - Pliocene age and basaltic to andesitic composition are somewhat distinct from the late Pliocene to Recent andesitic stratovolcanoes of the High Cascades (Fig. 2). Lassen Peak, the southernmost volcano of the High Cascades, lies near the junction of three physiographic provinces: Klamath Mountains, Sierra Nevada, and the Cascades. The dome of Lassen Peak was formed relatively recently (11,000 B.P., Crandell, 1972) in an area dominated by volcanism since before Pliocene time. Rocks exposed in the southern part of Lassen Volcanic National Park (hereafter referred to as LVNP in this paper) are more diversified than lavas in other parts of the Cascade Range; they are predominantly two-pyroxene andesites but include basalts, dacites, and rhyodacites.

I propose to study the chemical and mineralogic evolution of the volcanic rocks in a 150 km.² area south and east of Lassen Peak (Fig. 3). Two summers of field work (supported by the U.S. Geological Survey) will enable me to prepare a geologic field map of the area at a scale of 1:62,500. The map will be used as a framework for my petrologic studies and for detailed geochemical studies of thermal areas in LVNP by Geological Survey personnel.

I am primarily interested in the problem of andesite petrogenesis. A combination of radiometric dating on at least a dozen rocks and detailed petrographic, chemical and mineralogic studies of the volcanic rocks in the Lassen area will help me determine the conditions of crystallization and the relative importance of different processes of formation of andesite magmas in continental margin areas.

VOLCANIC ROCKS, MOUNT JEFFERSON AREA, OREGON G3



FIGURE 2.—Location of Cascade Range (shaded), principal volcanoes, part of Western Cascades studied by Peck, Griggs, Schlicker, Wells, and Dole (1964), and area of this report (stippled). Boundary between Western Cascade Range and High Cascade Range in Oregon, from Peck, Griggs, Schlicker, Wells, and Dole (1964).

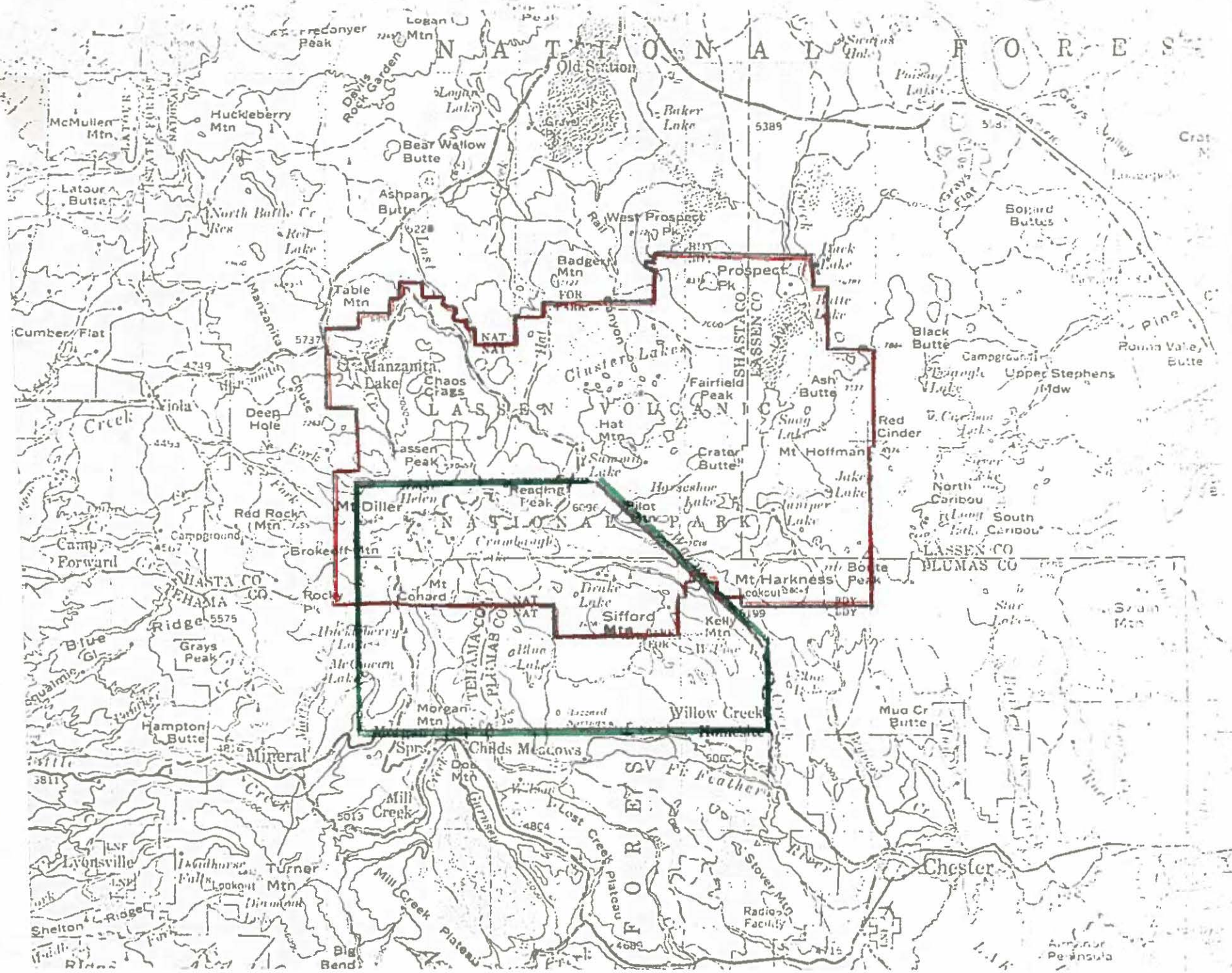


Figure 3. Location map of study area, from Susanville 1:250,000 sheet. Green: study area; Red: LVNP Boundary.

GEOLOGIC FRAMEWORK

A broad reconnaissance of the study area was completed during one summer of field work, and samples were collected for petrographic study and chemical analysis. LVNP has been studied by Williams (1929, 1931, 1932), and his names for different rock types are being used. The oldest rocks in the study area are probably Willow Lake basalts, exposed near Terminal Geyser (Fig. 4), 13 km. southeast of Lassen Peak. Perhaps the next oldest rocks are the Juniper and Flatiron andesites, indistinguishable in the field or by petrographic methods. These rocks cover at least 132 km.² and are well exposed along Flatiron Ridge, at Kelly Mt., and in a moderately well-preserved flow 2.5 km. west of Devil's Kitchen. Rhyodacites occur in fault contact with Willow Lake Basalts at Terminal Geyser. The pyroxene basalts of Red Mt. form a shield volcano in the central part of the study area and appear to be younger than Juniper-Flatiron andesites. The western part of the Park is dominated by pyroxene andesites of Brokeoff Mtn., Mt. Diller and Mt. Conard, remnants of Mt. Tehama (Brokeoff Volcano of Williams). These andesite flows and volcanic breccias are called Brokeoff andesites by Williams. According to Fountain, who has recently completed a detailed geochemical study of the Brokeoff andesites (unpub. Ph.D. thesis, U.C.S.B., 1975), the flows of Brokeoff Mtn. are predominantly pyroxene andesites with some olivine andesites in the central part of the pile topped by more pyroxene andesites and a few rhyodacitic flows. Pyroclastic activity increased during later stages of eruption. The final eruptions were on the northern flanks of the volcano and produced dacitic flows



and domes including Lassen Peak.

The rocks in my study area, then, include some early basalts and rhyolitic rocks, voluminous andesite flows and flow-breccias, dacite flows and perhaps six discrete dacite domes. A large part of the area has been affected by hydrothermal alteration. Two major fault trends appear to cut the area, one striking NNW from Morgan Springs to Pilot Pinnacle and the other WNW from Terminal Geyser to Bumpass Hell. The path of each fault is characterized today by active fumaroles, solfataras, hot springs, and severe alteration and erosion. Williams believed that the present hydrothermal activity in the Sulfur Works area marks the location of the main vent of Mt. Tehama and that extrusion of the dacite domes resulted in a collapse and formation of a caldera whose wall is partially preserved today as an abrupt ridge curving from Brokeoff Mtn. to Eagle Peak. There is no firm evidence for or against the formation of a collapse caldera in the Lassen region. Kane (1974) has suggested that much of the central part of Mt. Tehama could have been removed by glaciation and stream erosion, enhanced by the fumarolic alteration and resultant improved erodibility of the rocks in the headwaters of Mill Creek. One of my objectives in doing a field study is to determine whether or not a caldera actually formed there by looking for ring faults along the presumed caldera edges, and by establishing a stratigraphic succession of flows to check for continuity between the central and outer portions of the volcano.

PLAN OF STUDY

I intend to study this volcanic area in several ways. Field mapping will be completed during the summer of 1976. I will refine Williams' map and extend it beyond the southern boundary of the Park. Detailed petrographic studies will be done in the spring of 1976 in order to define the nature of the different rock types involved and to select rocks suitable for dating and further analysis.

I consider radiometric dating of the Lassen volcanics to be an essential part of this study. I need to know the relative order of eruption of rock types whose contacts are obscured by glacial and hydrothermal activity. Mineral separates and whole rock samples will be dated by K-Ar methods at the U.S.G.S. in Menlo Park. Fission track dates will be done by me at U.C.S.C. on apatites and zircons for rocks which contain these phases.

Williams used stratigraphic relationships and relative rock freshness to establish a possible eruptive sequence of major rock types in the Lassen area. He felt strongly enough about the field relationships to reject previous workers' generalized pictures of eruptions proceeding through time producing more differentiated magmas from an initial lava of intermediate composition. According to Williams, the lavas in the area I am studying may have erupted in the following order, oldest to youngest:

- Willow Lake pyroxene basalts
- Juniper pyroxene andesites
- Eastern pyroxene basalts
- hypersthene andesites of Brokeoff volcano
- pyroxene basalts of Red Mt.
- rhyolites and ryodacites of the Terminal Geyser and Grassy Swale

hornblende-mica and pyroxene dacite domes and flows of
Lassen Peak and vicinity

(from Williams, 1932, p. 376)

The earliest lavas are presumed to be upper Pliocene or older because of a resemblance of the eastern basalts to fragments in the Tuscan formation, exposed over a large area to the west. The Tuscan Formation has been dated at 3.4 ± 0.4 m.y. (Evernden et. al., 1964) on the basis of an interbedded ash layer, the Nomlaki Tuff. The age is not certain, however, because the ash bed that was dated does not lie within the Tuscan Formation, but was taken from a separate outcrop to the west.

Determination of absolute ages of the rocks in the Lassen area will permit me to estimate rates of magma production for correlation with proposed rates of subduction of the Gorda Plate under the continental margin to the west.

Twenty samples were analyzed for major element abundances by X-ray fluorescence at U.C.S.C. in Dec. 1975 and Jan. 1976. I will probably have at least 40 more samples to be analyzed after this summer's field work. Major element data shows that the rocks of the LVNP region follow typical calc-alkaline trends. They have high alumina contents and do not show iron enrichment. Twenty rocks were chosen as a representative suite after the first season of field work. The results of the major element determinations are presented in Figure 5, a composite silica variation diagram, and in Figure 6, an FMA diagram. Typical features of the calc-alkalic rock association are illustrated in these diagrams.

A detailed geochemical study focusing on the rocks of

FIGURE 5. LASSEN REPRESENTATIVE SUITE 1975
Analyses by XRF - UCSC 1975-76

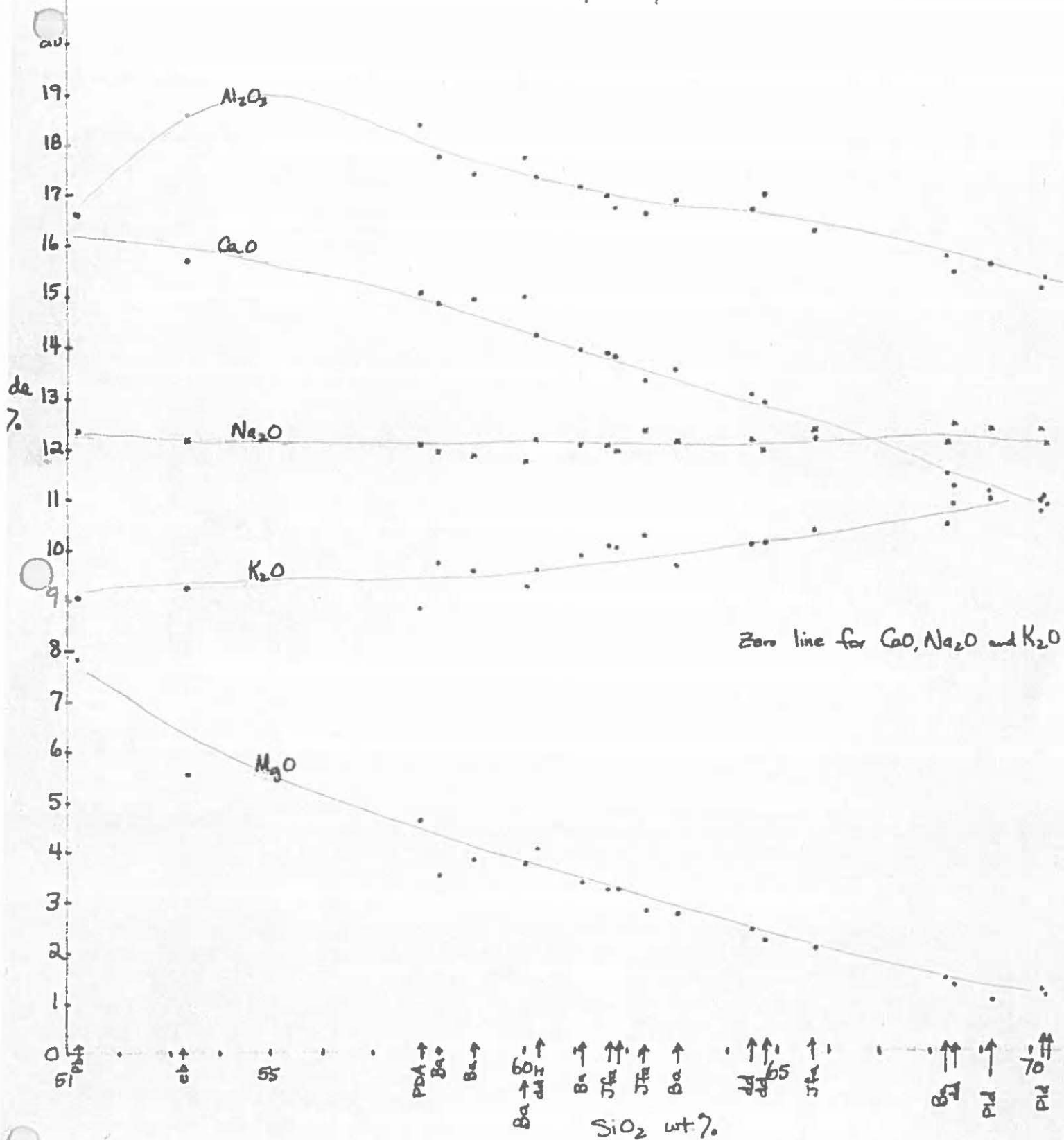


Figure 6,
Lassen Volcanics
1975 Representative
Suite

- x Brokeoff andesites
- dd dacite domes
- Pb Pyroxene basalt of Red Mtn.
- Eb Eastern basalt

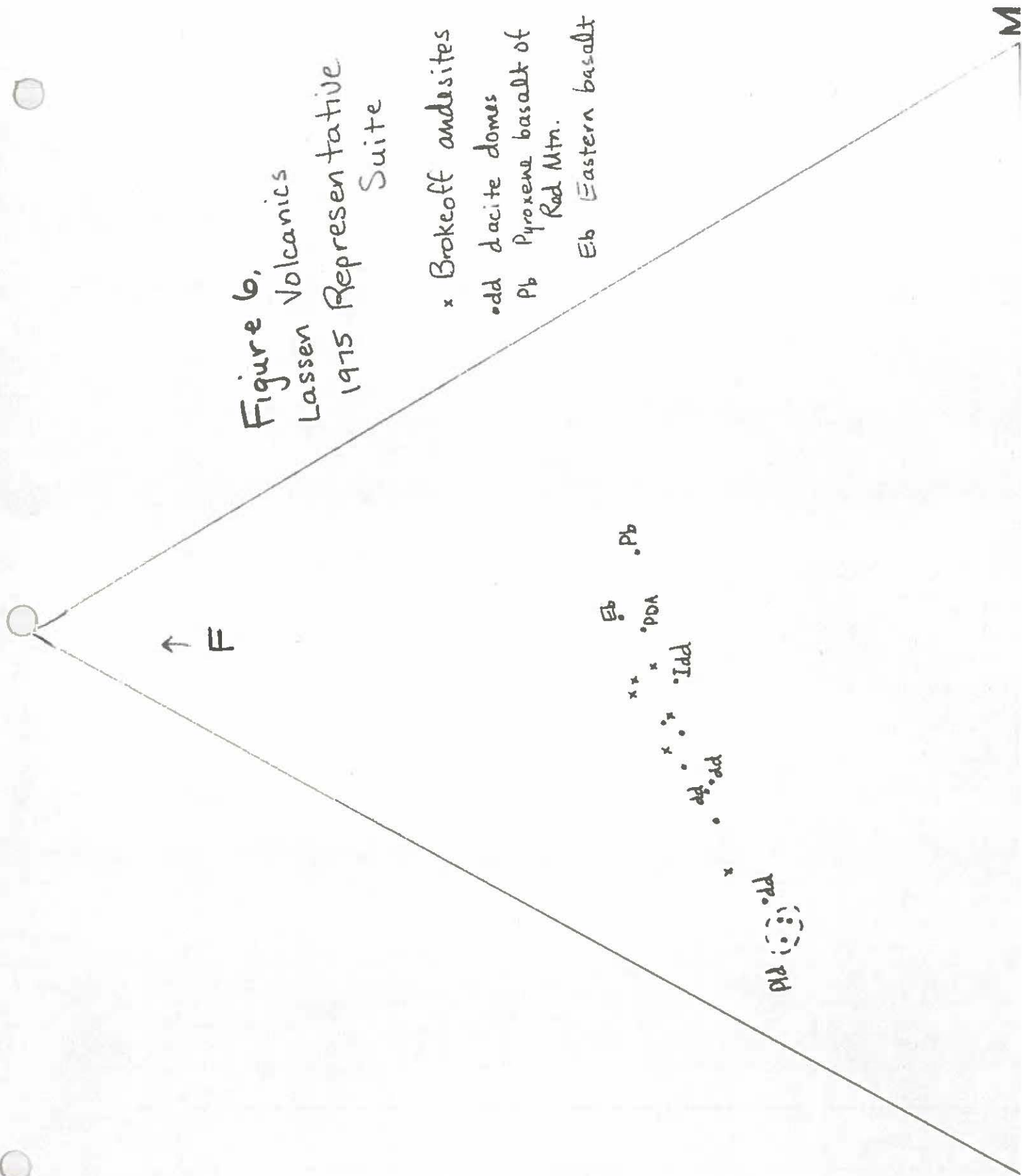
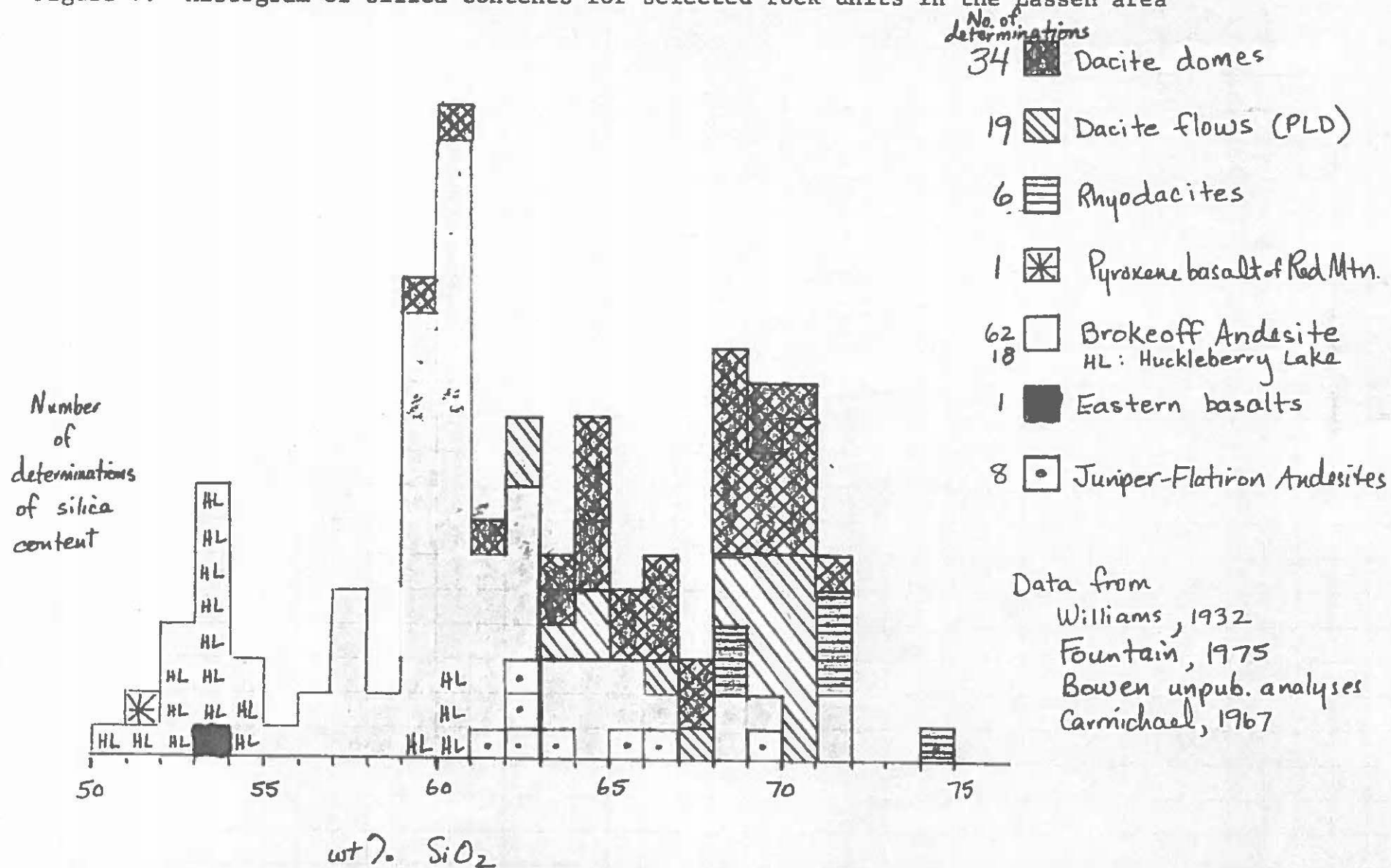


Figure 7. Histogram of silica contents for selected rock units in the Lassen area



Brokeoff Volcano has been completed by Fountain (1975, unpub. Ph. D. dissert., U.C.S.B., 167 p.). A histogram of silica contents for 80 samples of Brokeoff andesite and for other rocks in the Lassen area from his work and others' (Fig. 7) shows wide variation and no general trends. Huckleberry Lake andesites were identified petrographically by Williams and appear to be the most mafic of the Brokeoff lavas. A traverse south of Brokeoff summit revealed thin dacite flows 700 feet below the top of the mountain and a 350-foot thick series of olivine andesite flows cropping out between Huckleberry Lake and LVNP Boundary. Except for the 14 samples of olivine andesite, the other 66 analyses of Brokeoff lavas grade smoothly from andesites to dacites. The olivine andesite flows and possibly some dacitic flows may be recognizable marker beds within the thick pile of pyroxene andesite forming the bulk of Brokeoff lavas, allowing me to establish a stratigraphic succession in the field.

Electron microprobe studies of phenocryst phases and glassy groundmass will be started in the late spring of 1976 at the U.S.G.S. laboratory in Menlo Park and will continue throughout the following year. Figure 8 shows phenocryst and groundmass minerals observed in a reconnaissance petrographic study of the Lassen rocks. I hope to determine changes in the conditions of crystallization through time by examining specific mineral compositions in a series of rocks that are clearly related in space and time. As is common in andesites, the plagioclase phenocrysts are in clots and show complex oscillatory zoning. There are both clinopyroxenes and orthopyroxenes present in most rocks, and they are rimmed, resorbed, cracked, and clumped together. It is unlikely that equilibrium was attained, but detailed analysis of the chemical and mineralogic changes with time will help place some constraints on the conditions of crystallization and extrusion of this succession of volcanic rocks.

Figure 8. Mineralogy of Lassen Rocks

4/22/76

UNIT	PHENOCRYSTS								MATRIX				
	OL	PLAG	CPX	OPX	MT	HB	BIO		PLAG	CPX	OPX	MT	GL
Dacites (dd)		An ₄₀₋₅₀			X	X	X	apetite zircon	X	X		X + Hb	X
Pld I: inclusions		30-35% An ₃₀₋₃₅ I An ₆₀	X	(X)	X X	X X	X						55- 60%
Brokeoff andesites		An ₄₀	X	X	X	(X)			X			X	
~~//////////~~ Huckleberry Lake	X	An ₅₀	X	(X)	X				X			X	1%
Pyroxene basalt of Red Mtn.		52% An ₆₀ unzoned	3-40% X	2-15% X	5-10% X				X	X	X		X 0-40%
Eastern basalt	(X)	(X)	40% X rxn →	2% X	5% X				52% An ₆₅	X			
Juniper-Flatiron andesites		75% An ₃₀₋₆₅ fluorite incl	14% X	5% rxn ←	4% X	resorbed		Zircon	An ₃₀₋₄₀	X	X	X	<5%
Willow Lake basalts	X	X	(X)	X					X	X		X	X 50%

BIBLIOGRAPHY

- Carmichael, I.S.E., 1967, The Iron-Titanium Oxides of Salic Volcanic Rocks and their Associated Ferromagnesian Silicates. C.M.P., 14, 36.
- Christiansen, R.L. and Lipman, P.W., 1972, Cenozoic volcanism and plate-tectonic evolution of the Western U.S. II. Late Cenozoic. Phil. Trans. Roy. Soc. Lond. A., 271, 249.
- Church, S.E., and Tilton, G.R., 1973, Lead and Strontium Isotopic Studies in the Cascade Mountains: Bearing on Andesite Genesis. G.S.A. Bull. 84, 431.
- Crandell, D.R., 1972, Glaciation near Lassen Peak, N. Calif. U.S.G.S. Prof. Paper 800-C, C179.
- Day, A.L. and Allen, E.T., 1925, The Volcanic Activity and Hot springs of Lassen Peak. Carnegie Inst. of Wash. Publ. 360, 190 p.
- Diller, J.S., 1895, Lassen Peak, U.S. Geol. Survey Folio No. 15.
- Evernden, J.F., Savage, D.E., Curtis, G.H., and James, G.T., 1964, Potassium-Argon Dates and the Cenozoic Mammalian Chronology of North America. A.J.S. 262, 145.
- Fountain, J.C., 1976, The Geochemical Evolution of Brokeoff Volcano, LVNP, Calif. (Abs.). G.S.A. Abs. with Programs, 8, 374.
- Greene, R.C., 1968, Petrography and Petrology of volcanic rocks in the Mount Jefferson area, High Cascade Range, Oregon. U.S.G.S. Bull. 1251-G, 48 p.
- Kane, P.S., 1974, Pleistocene Glaciation and Volcanism in LVNP, Calif. (Abs.). G.S.A. Abs. with Prog. 6, 200.
- Nockolds, S.R. and Allen, R., 1953, The Geochemistry of Some Igneous Rock Series. G.C.A. 4, 105.
- Peterman, Z., Carmichael, I.S.E., and Smith, A., 1970, $\text{Sr}^{87}/\text{Sr}^{86}$ Ratios of Quaternary lavas of the Cascade Range, northern California. G.S.A. Bull. 81, 311.
- Silver, E.A., 1969, Late Cenozoic underthrusting of the continental margin off northernmost California. Science, 166, 1265.
- Silver, E.A., 1971, Small Plate Tectonics in the Northeastern Pacific. G.S.A. Bull. 82, 3491.
- Smith, A.L., and Carmichael, I.S.E., 1968, Quaternary Lavas from the Southern Cascades, Western U.S.A. C.M.P., 19, 212.

Williams, H., 1929, The Volcanic Domes of Lassen Peak and Vicinity, Calif. A.J.S., 18, 313.

Williams, H., 1931, The Dacites of Lassen Peak and Vicinity, Calif., and Their Basic Inclusions. A.J.S., 22, 385.

Williams, Howel, 1932, Geology of the Lassen Volcanic National Park, Calif. Univ. Cal. Bull. of Geol. Sci., 21, 195.

June 22, 1976

Dear Mr. Vance and Mr. Anderson:

This note is to inform you that I have begun my field work here at Lassen and where I can be reached. I am living in Kindig's house on Mineral Ave.

I thought you might be interested in reading my thesis proposal. You may keep the copy. Hopefully I will produce a document containing real information sometime within the next year rather than just a description of work to be done.

I would be most interested in meeting any other geologists who are working in the Park. I would appreciate it if you could tell any you encounter that I am here, representing the U.S. Geological Survey and the University of California at Santa Cruz. Pat Muffler will be here July 15, as he stated in his letter to Vance of May 7.

I am working alone this week and expect to be mapping along the Park Road from the Ski Hut northwards. After July 1 I will have a field assistant, Michael Clynne. At the moment I have my own car, but I will have a GSA vehicle after July 1.

Please let me know if I can be of any service to you.

Truly yours,

Penelope Bowen