CIRCULAR 141

Petrography and Petrogenesis of Tertiary Camptonites and Diorites Sacramento Mountains, New Mexico

by
*George **B.** Asquith*

1974

New Mexico Bureau of Mines & Mineral Resources
A DIVISION OF
NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

Circular 141

New Mexico Bureau of Mines & Mineral Resources

A DIVISION OF
NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

Petrography and Petrogenesis of Tertiary Camptonites and Diorites, Sacramento Mountains, New Mexico

by
George B. Asquith
West Texas State University

SOCORRO 1974

First printing, 1974

Published by Authority of State of New Mexico, NMSA 1953 Sec. 63-1-4
Printed by University of New Mexico Printing Plant, April, 1974

Available from New Mexico Bureau of Mines & Mineral Resources, Socorro, NM 87801

Price $1.00

CONTENTS

Figures

Tables

ABSTRACT

Thin dikes and sills (3 ft to 40 ft thick) of diorite and minor camptonite of Tertiary age (44.2 ± 2.2 m.y.), intruded into Paleozoic sediments, are the dominant igneous rocks of the Sacramento Mountains. The diorite and camptonite are similar mineralogically, but differ texturally. The camptonites have large (up to 30 mm) phenocrysts of euhedral hornblende and altered diopsidic augite with minor phenocrysts (5 mm) of plagioclase (An$_{a\ 0-45)}$. The dominant phenocrysts of the diorite are plagioclase (An$_{4\ 0-4\ 5}$) up to 5 mm long accompanied by minor euhedral hornblende and altered diopsidic augite (12 mm maximum). Both rocks have a ground-mass of plagioclase laths, interstitial chlorite, magnetite, minor orthoclase, and apatite.

These rocks are comagmatic. The paragenetic sequence (olivine?-pyroxene-hornblende-reaction of olivine and pyroxene-plagioclase) is similar to that described by Yoder and Tilley (1962) for alkaline basaltic magmas with H_2O pressure between 2 to 5 kb (kilobars). After total olivine resorption, but before total pyroxene resorption, the pressure dropped due to intrusion. Differences in mineralogy and texture are the result of flow differentiation (Asquith, 1973b). With a high rate of discharge from the magma chamber, strong magma currents picked up the large hornblende and augite crystals concentrated at the base of the magma chamber, and intruded them along with smaller crystals of hornblende, augite, and minor plagioclase — forming a camptonite.

ACKNOWLEDGMENTS

F. W. Daugherty, Coordinator, Earth Science Research at Killgore Research Center, and J. R. Renault, New Mexico Bureau of Mines and Mineral Resources, critically read the manuscript. Their suggestions were most helpful in the final draft of the paper.

This paper was financed by Organized Research Grant 1062-3628 at West Texas State University.

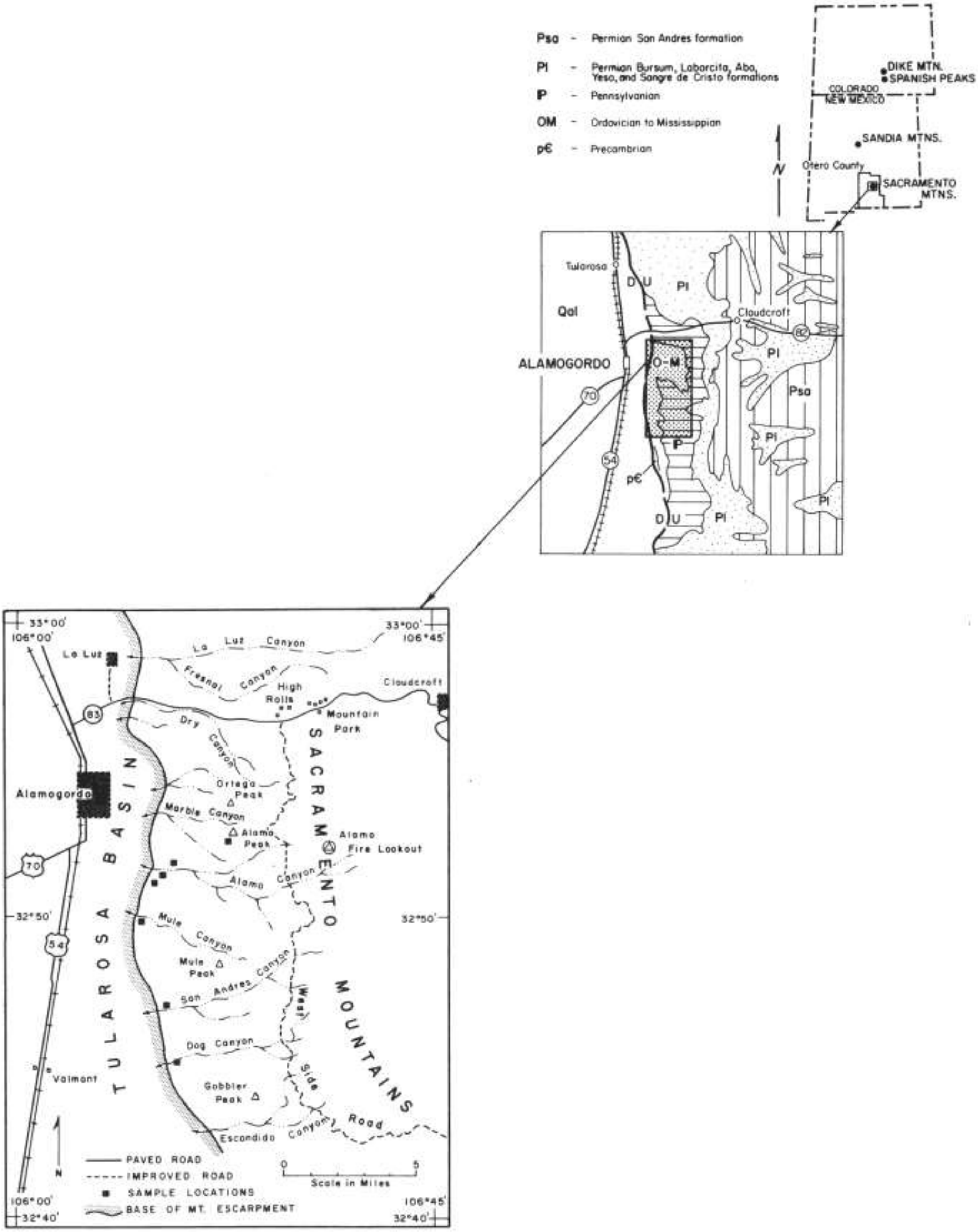

FIGURE 1 — *Index and location maps of study area.*

INTRODUCTION

The Sacramento Mountains are located in south-central New Mexico a few miles east of Alamogordo (fig. 1). A steep fault scarp marks the western boundary of the mountains with the Tularosa basin. The range is composed mostly of gently dipping limestones and dolomites, with subordinate sandstones and shales, of Early Ordovician to Permian age. The sedimentary rocks are intruded by numerous thin sills and dikes. The geology of the Sacramento Mountains has been described by Pray (1961).

The Tertiary igneous rocks (dated 44.2 ± 2.2 m.y. on basis of K/Ar date on hornblende by Asquith, 1973a) are predominately fine grained diorite porphyries with a few closely associated camptonites (fig. 2). These rocks occur as numerous thin dikes and sills (3 ft to 40 ft thick) along the northern and central parts of the escarpment. The steeply dipping dikes trend northeast; the sills are concentrated in the shaly, sandy strata of the Devonian, lower Mississippian, and basal Pennsylvanian (Pray, 1961, p. 4).

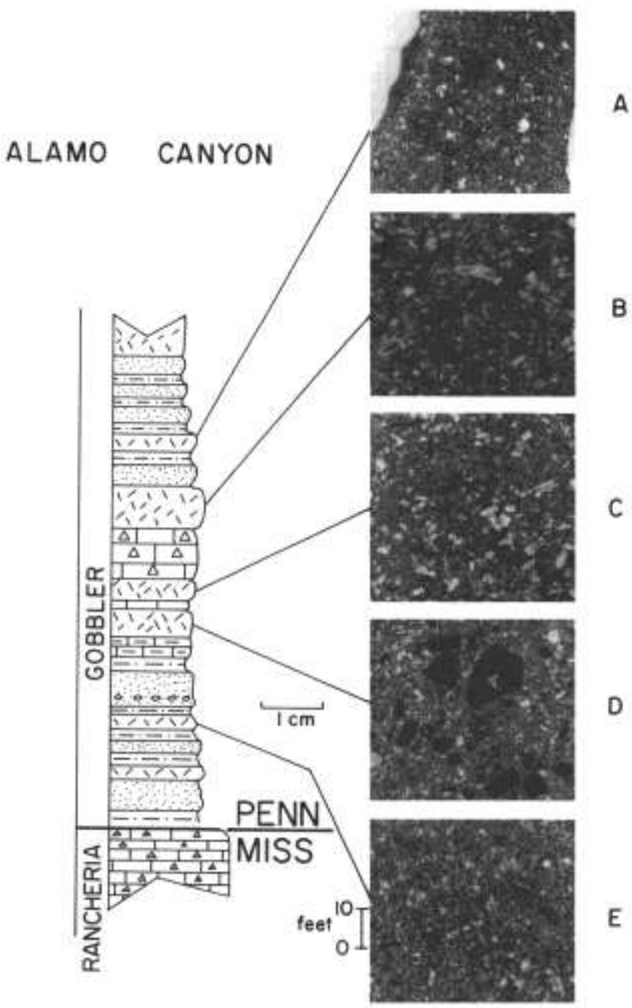

FIGURE 2 — Partial section located on the south wall of Alamo Canyon in Gobbler Formation (lower Pennsylvanian), illustrating close association of camptonites (D) and diorite porphyries (A, B, C, E).

This study is concerned with the petrography and petrogenesis of the diorites and associated camptonites in the central Sacramento Mountains (fig. 1). Mineralogically both rocks consist of phenocrysts of diopsidic augite, euhedral green hornblende, and plagioclase (Ana 0_4 5) in a groundmass of plagioclase laths (An3 5 _40), interstitial chlorite, minor orthoclase, magnetite, and apatite. The rocks differ by the proportions of the various phenocrysts and by the size of the phenocrysts. The camptonites have larger phenocrysts (30 mm maximum); the mafic minerals predominate with only minor plagioclase. In the diorites the phenocrysts are smaller (12 mm maximum) and plagioclase phenocrysts predominate with only minor pyroxene and hornblende (fig. 2).

PETROGRAPHY

Introduction

The term *camptonite* as used in this paper refers only to a hornblende-augite-bearing lamprophyre (Turner and Verhoogen, 1960, p. 250). The term *diorite* is used to denote an intermediate plutonic rock consisting of andesine and hornblende with or without augite (Turner and Verhoogen, 1960, p. 73). The presence of transitional rock types, however, hinders classification.

Mineral identification was based on optical constants using data of Deer and others (1963) and Heinrich (1965). Refractive indexes as well as optic angles and extinction angles were determined for the hornblende and pyroxene. Refractive indexes were measured relative to monochromatic light (D = 589 *m*m), and corrected to 25°C when necessary. The optic and extinction angles were measured by universal stage and corrected for differences in refractive indexes. The exact chemistry of the hornblende was determined by wet chemical analysis after which the cation percentages based on 24 (0, OH) were calculated. Chemical analyses were necessary because many of the ionic substitutions in hornblende cannot be determined by optical properties. The plagioclase compositions were determined by the 5-axis method (Emmons, 1943).

Diorite

The diorites (samples 113 and 116; table 1) are medium gray green with a weakly porphyritic texture (fig. 2). They contain 23 to 27 percent phenocrysts mainly plagioclase (Ana ₒ -4 5) and minor amounts of hornblende and pyroxene (table 1). The plagioclase phenocrysts are white, lath shaped, and vary from 0.5 mm to 5.0 mm. The hornblende is green, and occurs as euhedral crystals (up to 12 mm long but with average length of 1 to 2 mm) having oscillatory zoning. The pyroxene phenocrysts are very pale green, with a maximum size of 6 mm and a mean of 0.5 to 1.0 mm. The pyroxene is diopsidic augite with oscillatory zoning, and exhibits extensive alteration along

TABLE 1 – Modal Analyses of igneous rocks, Sacramento Mountains

(Percentages based on 600 counts; 300 for each of two thin sections/rock sample)

	Sample No. →	Diorite 116	Diorite 113	Dioritic Camptonite 21	Camptonite 17	Camptonite 27
PHENOCRYSTS	Pyroxene	2	3	3	10	7
	Hornblende	3	8	17	17	16
	Plagioclase	18	16	8	4	3
GROUNDMASS	Plagioclase	50	46	45	43	47
	Orthoclase	3	2	2	2	1
	Chlorite	14	17	19	17	19
	Epidote	2	2	1	1	1
	Magnetite	4	3	5	3	4
	Apatite	3	1	1	2	1
	Calcite	1	2	1	1	1

edges, cleavages, and fractures. Alteration products include calcite, chlorite, and iron oxides. The optical properties and chemical compositions of the hornblende and pyroxene phenocrysts are given in tables 2 and 3. A chemical analysis and cation percentages of a hornblende phenocryst from a camptonite (sample 17) are given in table 3. Inasmuch as the hornblende in the diorites have similar optical properties, they should have similar chemistry (table 2). The groundmass consists of laths (0.25 to 0.5 mm long) of plagioclase (An_{35-40}), interstital chlorite, minor orthoclase, magnetite, and euhedral apatite.

TABLE 2 – Optical and chemical data

PYROXENE PHENOCRYSTS

	Diorite (113)	Camptonite (17)
Refractive Index	α = 1.6835	α = 1.6840
	β = 1.6907	β = 1.6920
	γ = 1.7124	γ = 1.7134
2V	60° (calc); 57° (meas.)	62° (calc); 59° (meas.)
$\gamma \wedge C$	46°	44°

$Ca_{.48}(Mg_{.36}, Fe_{.16})SiO_3$*

Color: very pale green

HORNBLENDE PHENOCRYSTS

	Diorite (113)	Camptonite (17)
Refractive Index	α = 1.6705	α = 1.6710
	β = 1.6862	β = 1.6850
	γ = 1.6950	γ = 1.6941
2V	74° (calc); 75° (meas.)	77° (calc); 79° (meas.)
$\gamma \wedge C$	24°	22°

Color: α = pale yellow green β = brownish green γ = green

$$\frac{(100)\ Mg}{Mg + Fe^{2+} + Fe^{3+} + Mn} = 55^{*} \qquad \frac{(100)\ Mg}{Mg + Fe^{2+} + Fe^{3+} + Mn} = 57^{*}$$

$$\frac{(100)\ Mg}{Mg + Fe^{2+} + Fe^{3+} + Mn} = 63^{**}$$

* Based on optical data
** Based on wet chemical analysis

These fine-grained plagioclase-rich rocks are classified, in this paper, as diorites in accord with Johnson's (1968) terminology applied to the Spanish Peaks area of Colorado. However, because of the high percentages of CO_2 and $\mathbf{P_2 0_5}$**,** and the presence of normative nepheline, these rocks might also be classified as fine-grained camptonites (Asquith, 1973b).

Camptonites

The camptonites (samples 17 and 27, table 1) and a transitional dioritic camptonite (sample 21, table 1) are medium gray green with a strongly porphyritic texture (fig. 2). They contain 26 to 31 percent phenocrysts, with the mafics (hornblende and diopsidic augite) predominating over the plagioclase (An_{40}-$_{45}$) (table 1). The minor plagioclase phenocrysts are white, lath shaped, and vary from 0.5 mm to 5.0 mm. The hornblende in the camptonite occurs as euhedral green crystals (with oscillatory zoning) up to 30 mm long but with an average length of 2 to 4 mm. The diopsidic augite phenocrysts with oscillatory zoning are very pale green and up to 10 mm long, but most are only about 2 mm. They exhibit the same extensive alteration as the pyroxene phenocrysts in the diorites. The optical and chemical data for the hornblende and pyroxene phenocrysts from the camptonites is given in tables 2 and 3.

The groundmass of the camptonites is similar to that of the diorites. It consists of plagioclase (An_{35-40}) laths (0.25 to 0.5 mm long), interstitial chlorite, minor orthoclase, magnetite, and euhedral apatite.

Phenocrysts in the camptonites are both coarser grained and contain a much higher percentage of mafics relative to plagioclase than do the diorites. Figure 3 indicates that the plagioclase phenocrysts are concentrated in the smaller grain sizes.

TABLE 3 – Hornblende analysis

Analyst: T. Asari

Analysis		Metal atoms to 24 (O, OH)		
SiO_2	41.05	Si	6.15	Z = 8.00
Al_2O_3	14.09	Al	1.85	
TiO_2	1.94	Al	0.70	Y = 5.19
Fe_2O_3	5.36	Ti	0.21	
FeO	7.85	Fe^{+3}	0.59	
MnO	0.18	Fe^{+2}	0.98	
MgO	11.93	Mn	0.01	
CaO	11.70	Mg	2.70	
Na_2O	2.07			
K_2O	1.70	Ca	1.90	X = 2.85
H_2O	2.07	Na	0.62	
	99.94	K	0.33	
		OH	2.08	24.00
		0 (diff)	21.92	

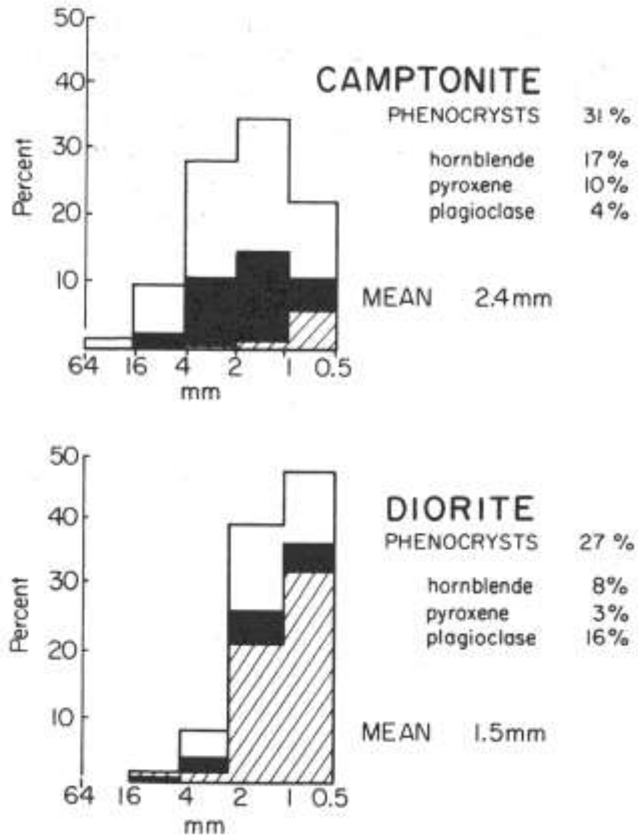

FIGURE 3 — *Phenocryst grain-size distribution and mineralogy (based on 300 counts/sample), Tertiary igneous rocks, Sacramento Mountains.*

TABLE 4 — Chemical analyses and normative calculations (molecular norm), igneous rocks of Sacramento Mountains

*Analyst: T. Asari **Analyst: S. Imai

Sample No. →	Diorite 116	Diorite 113	Dioritic Camptonite 21	Camptonite 17	Camptonite 27
SiO_2	51.19	46.70	50.55	49.54	48.79
TiO_2	0.66	0.76	0.64	1.05	0.97
Al_2O_3	18.96	19.01	16.84	15.74	15.72
Fe_2O_3	5.61	4.58	4.95	6.47	5.19
FeO	2.28	3.29	2.14	3.25	3.80
MnO	0.15	0.13	0.12	0.15	0.15
MgO	2.72	4.20	2.88	4.75	4.11
CaO	5.62	9.46	6.53	7.91	7.46
Na_2O	5.18	3.89	6.07	4.00	3.67
K_2O	2.49	2.17	2.13	3.12	3.83
H_2O^+	2.31	2.69	2.43	1.89	2.31
H_2O^-	1.23	1.04	0.90	0.71	0.95
P_2O_5	0.46	0.44	0.34	0.49	0.46
CO_2	1.67	2.12	3.03	1.50	2.47
TOTAL	100.53*	100.48*	99.55**	100.57*	99.84**
Or	15.5	13.5	13.0	19.5	24.0
Ab	45.5	25.0	42.2	29.5	23.0
Ne	1.5	6.9	8.9	4.5	7.2
An	21.0	29.0	13.0	16.0	16.0
Di	4.4	14.4	14.8	17.6	18.8
Ol	4.2	4.8	1.4	3.6	3.0
Mt	6.1	4.9	5.4	6.9	5.5
Ap	0.8	0.8	0.5	1.1	1.1
Il	1.0	1.0	0.8	1.4	1.4

CHEMISTRY

Normative calculations (table 4; molecular norm) indicate that all these rocks are undersaturated, with both olivine and nepheline appearing in the norm. The AMF diagram (fig. 4) shows the variation of the diorite-camptonite association of the Sacramento Mountains, the variation of the lamprophyre-diorite association of the Spanish Peaks in Colorado (Johnson, 1968), and the variation in a differentiated lamprophyre dike from the Sandia Mountains in New Mexico (Woodward, 1970). The continuous increase in total alkalis with very little iron enrichment is similar to the trend shown by alkaline basaltic magma during differentiation. The differentiated alkaline basalt shown in fig. 4 is from a teschenite sill from the Tertiary of Scotland (Walker, 1930).

The positions of the camptonites and diorites from the Sacramento Mountains indicate that the parent magma was alkaline basalt. A similar conclusion was reached for a camptonite-dolerite association in Greenland (Vincent, 1952). The positions of the Sacramento Mountain rocks on fig. 4 also suggest that some differentiation had taken place before intrusion.

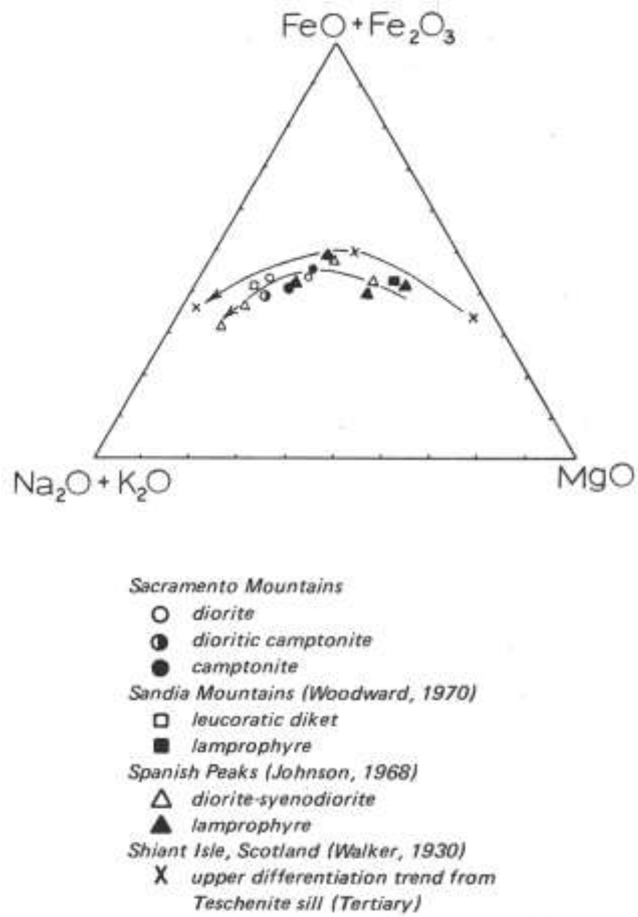

FIGURE 4 — *AMF diagram of Tertiary igneous rocks.*

PETROGENESIS

The order of crystallization for these rocks is similar to that described by Yoder and Tilley (1962) for alkaline basalts at **H2 0** pressures between 2 to 5 kb (fig. 5). The heavy line on fig. 5 illustrates a probable course of crystallization for the Sacramento Mountain igneous rocks.

The presence of normative olivine suggests that olivine was the first phase to crystallize and was followed by pyroxene. Much of the olivine and pyroxene separated from the melt thus shifting the composition of the magma towards the acid end of the differentiation trend (fig. 4). Hornblende was the next phase to crystallize; the pyroxene and any remaining olivine started to react with the melt. The presence of oscillatory zoning in both the pyroxene and hornblende phenocrysts indicates cycling of the phenocrysts through hot and cold zones of the magma chamber by convection prior to intrusion. At some point (fig. 5) after total olivine resorption (no modal olivine), but before total pyroxene resorption, the pressure dropped due to intrusion. A short interval of plagioclase crystallization, before the pressure drop (fig. 5), probably accounts for plagioclase phenocrysts being restricted to the finer grain sizes (fig. 3). The curve for pressure decline shown in fig. 5 is only a probable course of crystallization. However, the complete lack of reaction rims on the hornblende indicates that the stability line for hornblende was
not crossed

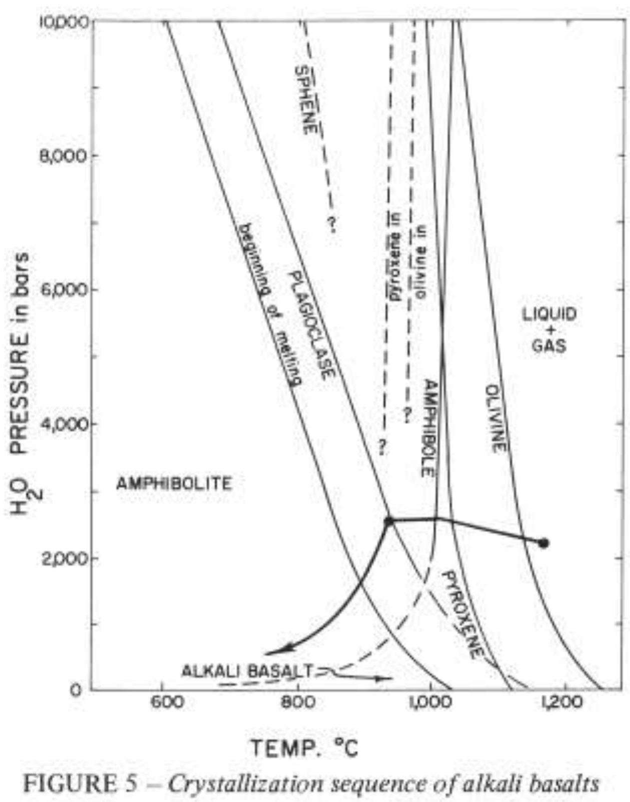

FIGURE 5 – Crystallization sequence of alkali basalts at elevated water pressures (Yoder and Tilley, 1962). The heavy line represents probable course of crystallization for igneous rocks of Sacramento Mountains.

The mineralogical and textural differences are the result of flow differentiation. The process of flow differentiation was first described by Bhattacharji and Smith (1964). If the discharge rate from the magma chamber during intrusion was high, strong magma currents would pick up both the large and small pyroxene and hornblende crystals concentrated near the base of the magma chamber, and intrude them (along with a minor amount of plagioclase) forming a camptonite. With a lower rate of discharge, only smaller crystals of pyroxene and hornblende (along with a higher percentage of less dense plagioclase) would be expelled, forming a diorite (Asquith, 1973b). This process of flow differentiation has also been utilized by Murata and Richter (1966) to explain the eruption of picrites and olivine-poor basalts from the 1959 Kilauean eruption (fig. 6).

Asquith (1973b) has demonstrated that flow differentiation results in a linear log-log relationship between mineralogy and composition and the mean size of phenocrysts. This relationship is illustrated in fig. 6 along with photographs showing the corresponding textural variations for the diorite-dioritic camptonite-camptonite transition.

SUMMARY

The camptonites and associated diorites of the Sacramento Mountains are comagmatic. The magma was of alkaline basaltic parentage modified by elevated water pressure and early fractionation of olivine and pyroxene. These conclusions are supported by the presence of hydrous phases (hornblende phenocrysts and interstitial chlorite) and the positions of these rocks on the AMF diagram (fig. 4). The sequence of crystallization (olivine?-pyroxene-hornblende-reaction of olivine and pyroxeneplagioclase) is similar to that described by Yoder and Tilley (1962) for alkaline basalt at **H20** pressure between 2 to 5 kb. After total olivine resorption, but before total pyroxene resorption and after the start of plagioclase crystallization, the pressure dropped due to intrusion of sills and dikes.

The textures and mineral composition of the camptonites and diorites vary as a result of flow differentiation. With a high rate of discharge from the magma chamber, strong magma currents picked up both the large and small pyroxene and hornblende crystals concentrated near the base of the magma chamber and intruded them, along with a minor amount of plagioclase crystals, forming a camptonite. With a lower rate of discharge, only smaller pyroxene and hornblende crystals together with a larger percent of less dense plagioclase crystals, were expelled — forming a diorite. With an increasing rate of discharge, therefore, the abundance and coarseness of the mafic phenocrysts increased (Asquith, 1973b).

This process is not restricted to the camptonitediorite association of the Sacramento Mountains. A similar association between Tertiary lamprophyres and diorites has been noted at Dike Mountain in Colorado.

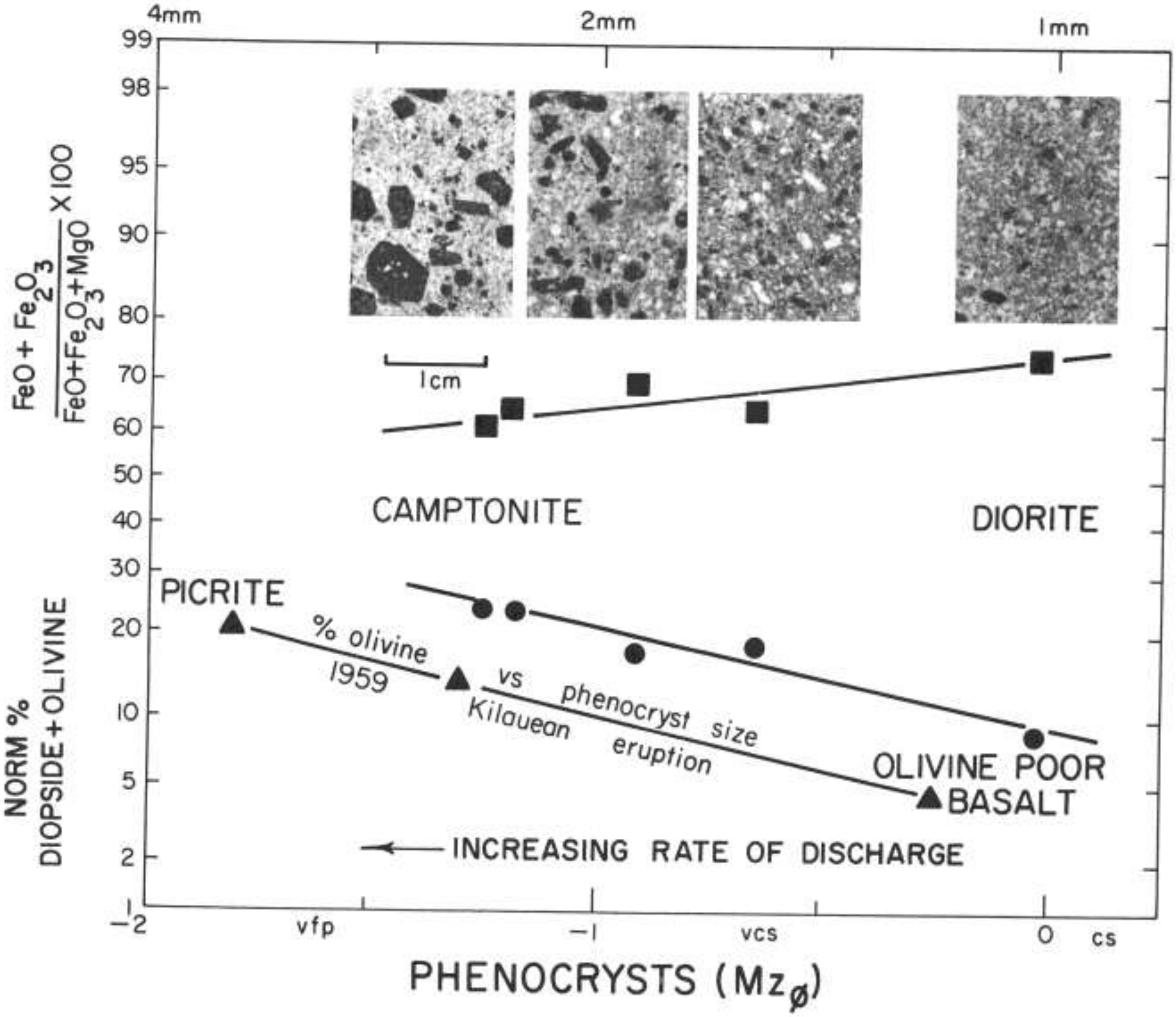

FIGURE 6 – *Plot of phenocrysts mean grain size $M_{z\phi}$ vs percent normative diopside + olivine and ratio ($FeO+Fe_2O_3/FeO+Fe_2O_3+MgO$) x 100 Tertiary igneous rocks, Sacramento Mountains. Concomitant textural variations are illustrated by photographs. Percent olivine vs phenocryst mean grain size, 1959 Kilauean lavas (Murata and Richter, 1966).*

($\phi = -\log_2$ of grain size in mm)

References follow

REFERENCES CITED

Asquith, G. B., 1973a (in press), Late magmatic adularia from cavities in camptonite sills, Sacramento Mountains, Otero County, New Mexico: Texas Jour. Sci.

_____, 1973b (in press), Flow differentiation in Tertiary lamprophyres (camptonites), Sacramento Mountains, Otero County, New Mexico: Jour. Geology.

Bhattacharji, S. and Smith, C. H., 1964, Flowage differentiation: Science, v. 145, p. 150-153.

Deer, W. A., Howie, R. A. and Zussman, J., 1963, Rock forming minerals, Vol. II, Chain Silicates: Longmans, Green and Co. Ltd., London, 379 p.

Emmons, R. C., 1943, The universal stage: Geol. Soc. America, Mem. 8, p. 135-150.

Heinrich, E. W., 1965, Microscopic identification of minerals: McGraw-Hill, New York, 414 p.

Johnson, R. B., 1968, Geology of the igneous rocks of the Spanish Peaks region, Colorado: U. S. Geol. Survey Prof. Paper 594-C, 47 p.

Murata, K. J. and Richter, D. H., 1966, The settling of olivine in Kilauean magma as shown by lavas of the 1959 eruption: Am. Jour. Science, v. 264, p. 194-203.

Pray, L. C. 1961, Geology of the Sacramento Mountains escarpment, Otero County, New Mexico: New Mexico Bureau Mines Mineral Resources, Bull. 35, 144 p.

Turner, F. J. and Verhoogen, John, 1960, Igneous and metamorphic petrology: McGraw-Hill, New York, 694 p.

Vincent, E. A., 1952, Hornblende lamprophyres dykes of basaltic parentage from the Skaergaard area: Geol. Soc. London Quart. Jour., v. 109, p. 21-47.

Walker, F., 1930, The geology of the Shiant Isles (Hebrides): Geol. Soc. London Quart. Jour., v. 86, p. 355-398.

Woodward, L. A., 1970, Differentiation trends of spessartite dikes, Sandia Mountains, New Mexico: Jour. Geology, v. 78, no. 6, p. 741-745.

Yoder, H. S. and Tilley, C. E., 1962, Origin of basaltic magmas: An experimental study of natural and synthetic rock systems: Jour. of Petrology, v. 3, p. 342-532.

Type Faces: Camera-ready copy composed at N.M. Bureau Mines on IBM MT
Text in 10 pt. Press Roman leaded two points
Subheads in 11 pt. Press Roman

Presswork: Text printed on 29" Single-color Harris
Cover printed on 20" Single-color Harris

Paper: Cover on 65# antique white
Body on 60# white offset

George B. Asquith CAMPTONITES OF SACRAMENTO MOUNTAINS New Mexico Bureau Mines *Circular 141*