BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES

Volume 21, Part 1 — March 1974

CONTENTS

Brigham Young University Geology Studies

Volume 21, Part 1 — March 1974

Contents

A publication of the
Department of Geology
Brigham Young University
Provo, Utah 84602

Editor

J. Keith Rigby

Brigham Young University Geology Studies is published semiannually by the department. *Geology Studies* consists of graduate-student and staff research in the department and occasional papers from other contributors. *Studies for Students* supplements the regular issues and is intended as a series of short papers of general interest which may serve as guides to the geology of Utah for beginning students and laymen.

Distributed May 6, 1974

Price $7.50

(Subject to change without notice)

Petrology of the Clayton Peak Stock, a Zoned Pluton Near Brighton, Utah*

Joel O. Palmer

Berge Exploration, 1315 South Clarkston, Denver, Colorado, 80219

ABSTRACT.—The Clayton Peak stock is one of several Tertiary intrusions occurring in a west-extending trend from the Uinta Arch in northeastern Utah. Textural and mineralogical variations of the Clayton Peak, Alta, and Little Cottonwood stocks form a coherent sequence. Older, more mafic plutons are on the east, while younger, more silicic, and larger plutons occur to the west.

The Clayton Peak stock ranges from a porphyritic, pyroxene-hornblende-biotite-quartz monzonite to a porphyritic, pyroxene-hornblende-biotite granodiorite. Four textural facies have been recognized within the pluton: (1) poikilitic K-feldspar facies and (2) phenocrystic biotite facies at the center, (3) nonpoikilitic K-feldspar facies on the margins, and (4) a microcrystalline facies. Trend-surface analyses show the Clayton Peak stock grading from a high K-feldspar and quartz, low plagioclase core to a low K-feldspar, high plagioclase and mafic margin. It is postulated that magmatic differentiation through crystal settling of mafic minerals downward from the center could produce a zoned pluton like the Clayton Peak stock. Mafic layering and mafic inclusions found in the pluton may also have genetic relationships to such magmatic processes.

Three mapped major joint patterns, showing parallel and normal trends to the northeast-southwest elongate axis of the pluton, may have some genetic relationship to the cooling and postintrusive adjustments of the Clayton Peak stock, the intrusion of the Alta stock, and/or the Tertiary faulting in the area.

Metallic mineralization related to the Clayton Peak stock appears to be rather scarce, but exploration to the east of the Clayton Peak stock may reveal noneroded deposits related to the Park City complex of granodiorite porphyries.

CONTENTS

*A thesis presented to the Department of Geology of Brigham Young University in partial fulfillment of the requirements for the degree Master of Science, December, 1973. Kenneth C. Bullock, thesis chairman.

Tables page

Plates page

INTRODUCTION

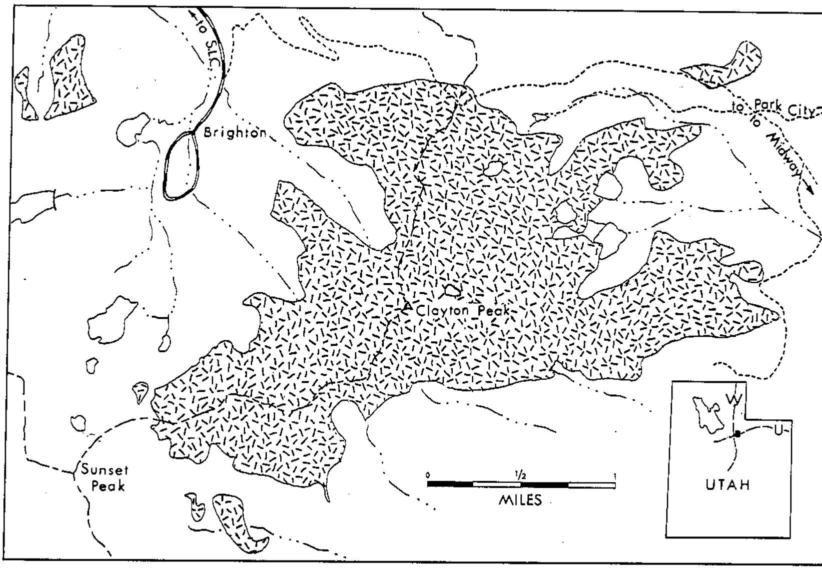
Nature of Investigation

The Clayton Peak stock is one of several Tertiary intrusions closely associated in space and time with ore deposits of the Park City-Cottonwood mining districts in the central Wasatch Mountains southeast of Salt Lake City, Utah. These mineralized areas have produced more than $500 million in lead, silver, zinc, gold, and copper ores since the first discovery in 1869 (Barnes, 1968). Interest in the Clayton Peak stock has developed because of small occurrences of metallic mineralization associated with the contact of the stock.

The principal objectives of this research are (1) to prepare a detailed geologic map of the Clayton Peak stock, related dike rocks and parts of adjacent igneous and sedimentary rocks, (2) to determine the nature and spatial relations of textures and mineralogy within the Clayton Peak stock, (3) to determine and interpret structures in the stock, and (4) to compare the compositional, spatial, and chronological relationships between the Clayton Peak stock and other plutons lying on an east-west alignment of granitic intrusions in north-central Utah.

Location and Accessibility

The Clayton Peak stock crops out in the highest part of the central Wasatch Mountains, 25 miles southeast of Salt Lake City, Utah (Text-fig. 1). Elevations in the area range from 8,600 feet, north of Brighton, to 10,795 on Mt. Wolverine, southwest of Brighton. Brighton Basin is accessible from Salt Lake Valley on the west via State Highway 152 to the head of Big Cottonwood Canyon. Brighton is a small village used for summer recreation and as a winter ski resort. The area south and east of Clayton Peak can be reached from Heber City via State Highway 113 as well as through Midway and westward up Snake Creek Canyon. Access to the area surrounding Cloud Rim Girl Scout Camp northeast of Clayton Peak may be reached via graded roads from Park City or from Midway.



TEXT-FIGURE 1.—Index map of study area. U = Uinta Arch, W = Wasatch Fault Zone.

Previous Geologic Work

A geologic study of the Park City District east of the Alta-Brighton area was done by Boutwell (1913). Butler (1915) described some of the copper mineralization of the Clayton Peak stock. Calkins and Butler (1943) mapped the region containing the Alta and the Clayton Peak stocks in a geologic study of the Cottonwood-American Fork area. They briefly discussed the metamorphism and the mineralogy of the igneous rocks. Sharp (1958) reported on many of the igneous rocks in the area, including numerous dikes common to the Clayton Peak stock. Baker, Calkins, Crittenden, and Broomfield (1966) published a geologic map of the Brighton Quadrangle on a scale of 1:24,000. A heavy mineral study was performed by Berge (1960), who concluded that the Park City complex, the Clayton Peak stock, the Alta stock, and the Little Cottonwood stock probably had common origins. Wilson (1960) mapped the textural changes of the Alta stock and described its geology in detail. Belt (1969) performed trace-element studies and discussed briefly the petrology and petrography of the Alta and Clayton Peak stocks. Radiometric dating of intrusive rocks in the Cottonwood area by Crittenden, Stuckless, Kistler, and Stern (1973) has determined more accurate dates for the Clayton Peak Stock (37 m.y.) and for the other intrusions of the Cottonwood area.

Method of Study

Actual field work commenced in July 1972 with general reconnaissance of the igneous and sedimentary rocks in the Albion Basin near Alta. Detailed geologic mapping and sampling of the Clayton Peak stock and related dikes were conducted through October 1972. Sample locations and geologic contacts were plotted on air photos of the area. Sampling was begun near the Sunset Peak area at intervals of every 500 feet; but, because the stock showed few facies changes within the smaller intervals, sampling was continued at intervals of 1,000 feet. Outcrops for sampling were found to be generally fresh except where vegetation has completely masked rock exposures. Sample locations and jointing patterns were recorded and later plotted on separate maps (Text-figs. 2, 14). Microscopic examination of more than 145 thin sections of the various rock types of the stock and dikes was performed to determine various textural zones (Text-fig. 4) and mineralogical trends. Mineral percentages were also obtained through modal analyses of 32 selected samples and were recorded on various trend-analyses maps using computer contouring. After hydrofluoric acid etching, more than 60 polished slabs and 60 thin sections were stained by sodium cobaltinitrite to facilitate distinguishing K-feldspar from quartz and plagioclase (Jackson and Ross, 1965).

Acknowledgments

The writer is grateful for the assistance provided by Dr. Kenneth C. Bullock, who served as chairman of the thesis committee. He was also helpful in the conception of the project, and he continually provided advice and encouragement during preparation of the manuscript. Dr. Myron Best also gave many helpful suggestions and advice with the petrology of the project, and Dr. Willis Brimhall assisted with the computer application of the trend-analyses maps.

GEOLOGIC SETTING

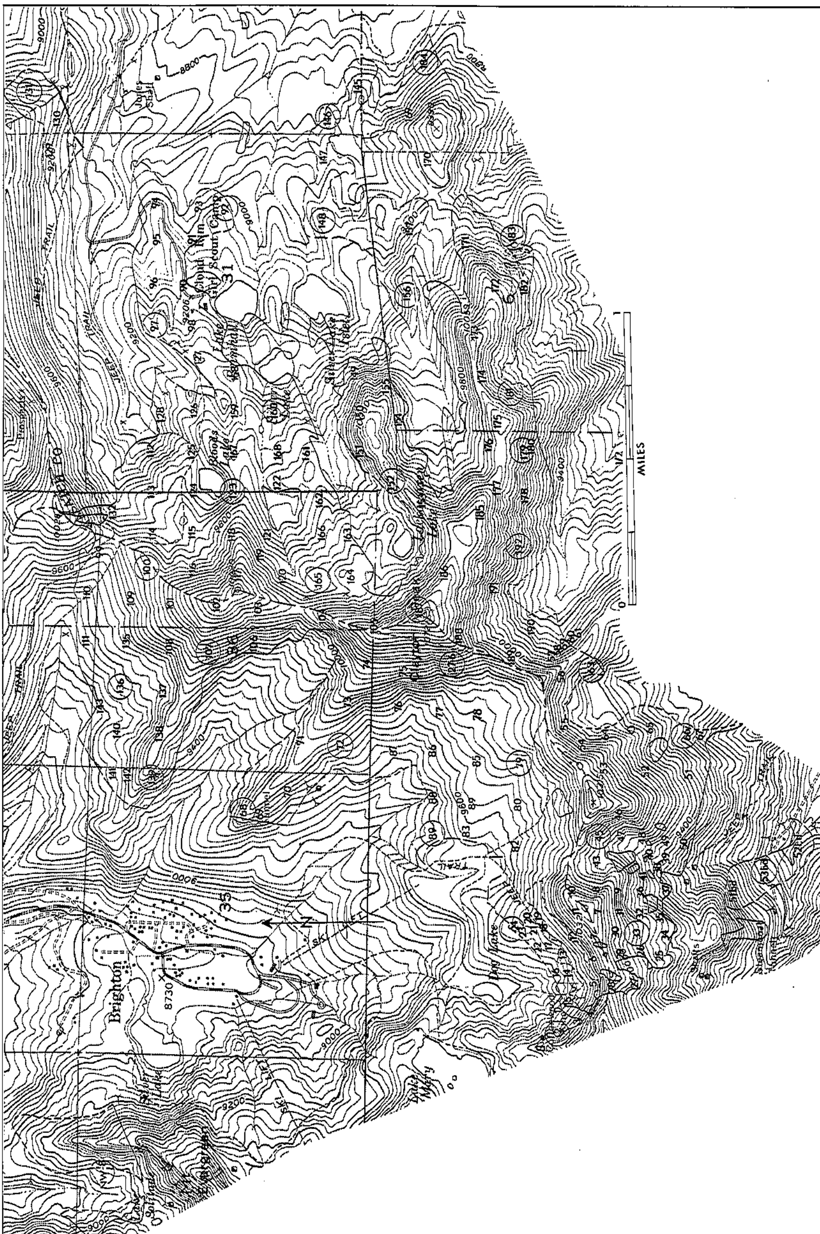
Phsyical Features

Clayton Peak, with an elevation of 10,721 feet, is one of the highest peaks in the area. The Clayton Peak stock, named after the peak, is at the head of the drainage basin of Big Cottonwood Creek and Bonanza Flat to the east of Clayton Peak (Text-fig. 3). The stock crops out over an area of approximately 9 square miles, and is slightly larger than the Alta stock to the west. The outcrop pattern is elongate in a northeast-southwest direction southeast of Brighton, with a separate exposure near Silver Lake, northwest of Brighton. Toward the southwest the stock narrows to smaller exposures, one-fourth mile wide in the thicker sediments near Sunset Peak.

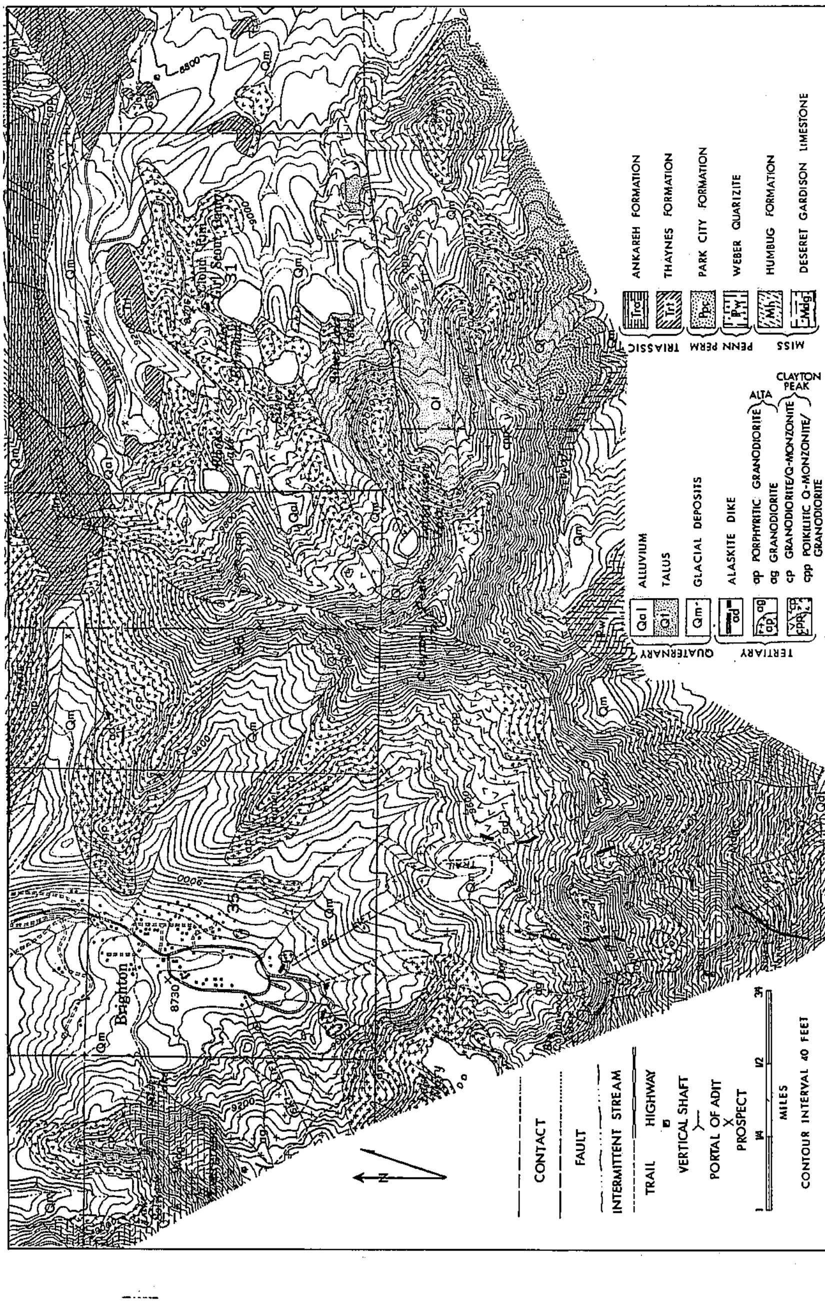
Alpine glaciation has produced majestic cirques forming steep-sided amphitheaters and U-shaped valleys around Clayton Peak (Pl. 1, figs. 1, 2). Outcrops of the stock are separated by narrow valleys filled with Quaternary glacial deposits, including "rock glaciers" of angular boulders up to 20 feet in diameter near the heads of the valleys, and radiating alluvial deposits along the valleys. Numerous clear mountain lakes (tarns) have been formed in the area (Pl. 1, fig. 2).

Sedimentary Rocks

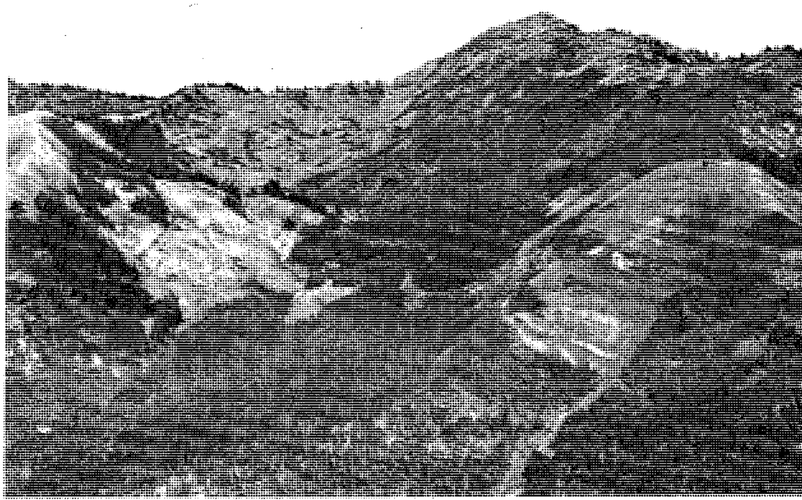
Sedimentary rocks in the study area range from Mississippian to Triassic according to Calkins and others (1943). Four hundred fifty feet of the Mississippian Gardison Limestone, a thin- to thick-bedded, fossiliferous limestone and dolomite with lenses and nodules of black chert in the upper part of the formation, is exposed near southwestern contacts of the intrusion.



TEXT-FIGURE 2.—Sample numbers and locations. Circled samples used in modal analyses.



TEXT-FIGURE 3.—Geologic map of the Clayton Peak stock and surrounding area. (Major portion after Baker et al., 1966.)



1

2

EXPLANATION OF PLATE 1
OBLIQUE AERIAL PHOTOGRAPHS OF CLAYTON PEAK

FIG. 1. Clayton Peak looking northwest.
FIG. 2. Lake Lackawaxen cirque.

According to Anderson (1974) the presence of chert is the main criterion for separating the Gardison Limestone from the overlying Deseret Limestone. Altered Gardison Limestone appears as a granoblastic, white dolomarble similar to that of the Fitchville Formation described by Anderson (1974). Numerous roof pendants of the Deseret and Gardison limestones are found in the Clayton Peak stock just east of Sunset Peak. The overlying Deseret Limestone is dark to light gray, fine to coarse-grained limestone and dolomite that contain lenses and thin beds of chert, and is up to 900 feet thick. Deseret beds also are bleached and show a granoblastic dolomarble similar to that of underlying Gardison and Fitchville formations.

The Humbug Formation overlies the Deseret-Gardison limestones and consists of approximately 200 feet (locally) of dark to light gray limestone with interbedded tan-weathering sandstone which have altered to fine-grained marble and calcareous, friable sandstone near the contact at the head of Snake Creek Canyon.

East of Clayton Peak the stock intrudes the Park City Formation, which consists of 600 feet of pale gray-weathering, fossiliferous, and cherty limestone. North and east of Clayton Peak, intrusive contact is made with other sedimentary formations, including 1,000 feet of the Thaynes Formation, which consists of a brown-stained, fine-grained lime-sandstone with interbedded olive green and red shale and fossiliferous limestone; and 1,500 feet of the Ankareh Formation, which consists of an upper Mahogany Member of reddish-brown and purple shales, a mudstone and sandstone member, and the Garta Grit Member of massive cross-bedded, white to purple, coarse-grained to pebbly quartzite (Baker and others, 1966).

Xenoliths of quartzite and limestone of the Weber Quartzite and Park City Formation were found near the instrusive contacts southeast of Clayton Peak.

Minor changes in the areas mapped by Baker and others (1966) were made by Anderson (1974) near Sunset Peak, where he detailed bleaching and metamorphism of limestones and dolomites, and also by the author near intrusive contacts with the Clayton Peak stock.

Structure

The Clayton Peak stock is one of nine Tertiary intrusions that lie just east of the intersection of two major structural elements in central Utah: the east-west-trending Uinta Arch and the north-south-trending Wasatch Mountains uplift which borders Salt Lake Valley (Wilson, 1961; Broomfield, 1968). Calkins and Butler (1943) recognized the extension of the Uinta Arch through superimposed complex Sevier, Laramide, and Basin and Range structures. Complex thrusting and folding of the area is discussed by Anderson (1974). Normal faults in sediments north of the intrusive contacts trend northeast-southwest, as do the Clayton Peak and Alta stocks; and the faults may have resulted from their injection. Anderson (1974) also recognized a broad homocline, probably caused by intrusion of the Alta and the Clayton Peak plutons, dipping 15° to 20° to the east from Albion Basin to Steamboat Tunnel at the head of Snake Creek Canyon. Locally, beds have been warped and lifted, owing to the emplacement of the igneous intrusions. Erosion undoubtedly has stripped much of the overlying altered sediments that once capped the Clayton Peak stock. The importance of this is fully realized only when one considers the vast amount of mineralized sediments that once may have covered the pluton but that now are removed by erosion.

DESCRIPTION OF THE CLAYTON PEAK STOCK

The Clayton Peak stock is highly variable in texture and mineralogy and is comprised throughout of porphyritic plagioclase, K-feldspar, pyroxene, amphibole, and biotite. The zoned pluton ranges from light-colored monzonites and quartz monzonites at the center to darker diorites and granodiorites generally towards the margins (Text-fig. 12). The stock has high concentrations of interstitial quartz and poikilitic K-feldspar and biotite at the core but becomes progressively higher in plagioclase and mafic-mineral percentages on the margins. Texture and mineral variations are gradational and thus are difficult to detect in the field.

Through extensive petrographic study of over 145 thin sections and 200 hand samples, four major textural facies have been recognized and mapped (Text-fig. 4):

1. Poikilitic K-feldspar facies, comprising the greatest and central portion of the stock and containing relatively high K-feldspar and quartz concentrations
2. Phenocrystic biotite facies, generally coextensive with the poikilitic facies and overlapping, in some locations, the outer nonpoikilitic K-feldspar facies
3. Nonpoikilitic K-feldspar facies containing higher mafic minerals and plagioclase and lower K-feldspar concentrations than the central facies and located at the margins
4. Microcrystalline facies, found locally within the other facies and with gradational contacts.

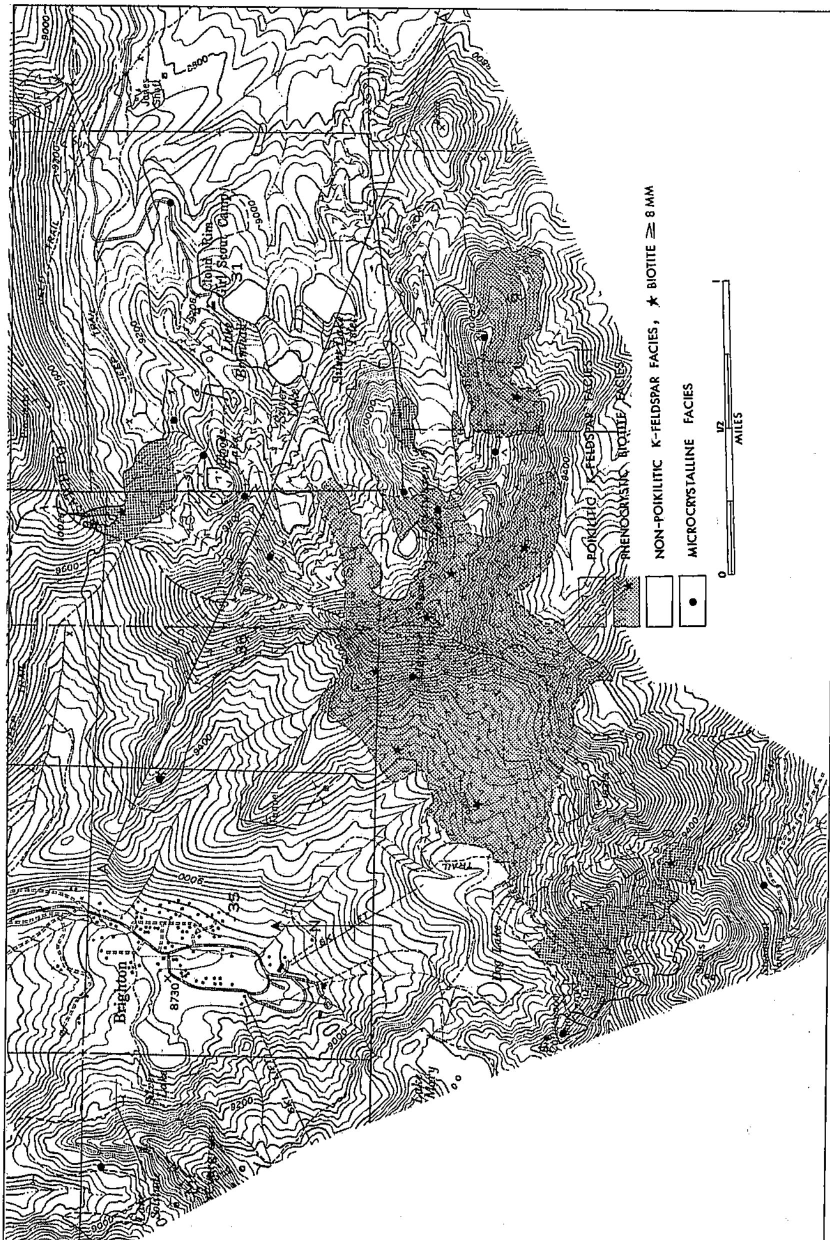
Systematic mineral gradations have been recognized ranging from high concentrations of K-feldspar and quartz at the center to high plagioclase and total mafic minerals towards the margin. Trend-surface analyses of the modal concentrations are plotted in Text-figures 5-11.

Details of the textural and mineral facies are discussed below.

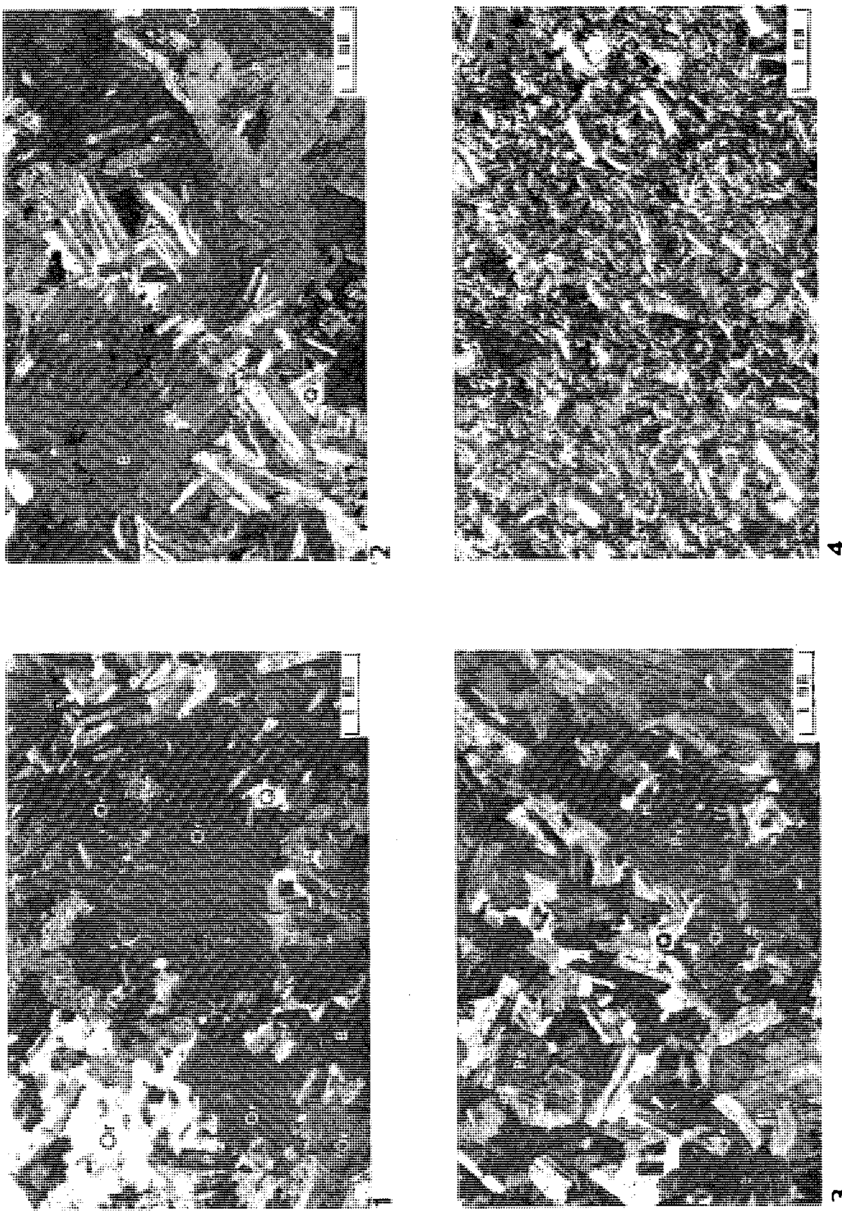
Petrography of the Major Textural Facies

Poikilitic K-feldspar facies.—A conspicuous poikilitic texture with feldspar oikocrysts between 2 and 20 mm in diameter is the main characteristic defining the central core of the Clayton Peak stock (Text-fig. 4; Pl. 2, fig. 1). The oikocrysts, enclosing numerous stubby laths of plagioclase and biotite, are found at many locations within the zone. The zone forms a somewhat rectangular body paralleling the outer boundaries of the elongate axis of the Clayton Peak stock. Outside the central zone the characteristic poikilitic texture is absent, and there is a gradual reduction in K-feldspar concentration as well (Text-fig. 4).

The poikilitic texture is difficult to distinguish in the field, and mapping of the textural boundaries was accomplished, for the most part, through microscopic examination. Staining by sodium cobaltinitrite after hydrofluoric acid etching revealed some of the larger poikilitic K-feldspar grains in hand



TEXT-FIGURE 4.—Textural zones of the Clayton Peak stock.



EXPLANATION OF PLATE 2
PHOTOMICROGRAPHS

FIG. 1. Poikilitic K-feldspar quartz monzonite, loc. 78 (crossed nicols).
FIG. 2. Phenocrystic biotite, loc. 181, (crossed nicols).
FIG. 3. Nonpoikilitic K-feldspar granodiorite, loc. 150, (crossed nicols).
FIG. 4. Microcrystalline quartz monzonite, loc. 75, (crossed nicols).

sample. The following mineral grain sizes and percentages represent an average for the poikilitic facies: (More detailed modal analyses are given in Table 1).

	Size (mm)	Volume Percentage
Plagioclase phenocrysts (An_{60-65})	3-10	13.0
Plagioclase (An_{40-45})	1- 2	29.5
K-feldspar oikocrysts	5-10	26.5
K-feldspar, interstitial	½- 1	incl. above
Quartz	1-1½	9.3
Biotite	2- 8	7.8
Pyroxene phenocrysts	4- 6	5.0
Pyroxene	½- 2	3.4
Hornblende	½- 3	3.1
Accessory minerals	½- 1	2.5
		100.1

The poikilitic texture increases in direct proportion to K-feldspar concentration. Some localities were observed to have even higher concentrations of K-feldspar than of plagioclase. Generally, K-feldspar and biotite appear to have crystallized enclosing euhedral to subhedral plagioclase and subhedral to anhedral pyroxene laths. Also enclosed within the K-feldspar grains are many small euhedral Fe oxide grains and slivers of biotite. The poikilitic zone was found to be variable in size of oikocrysts and size and abundance of inclusions. Plagioclase phenocrysts are found to be more abundant towards the outer borders of the zone. They are generally fresh and euhedral except where phyllosilicate alteration has occurred in the crystal cores and edges. Biotite is usually primary but does occur as intergrowths and reaction rims with hornblende. Clinopyroxene is approximately 20 times more abundant than orthopyroxene and is often rimmed with hornblende and biotite (Pl. 3, fig. 1).

Interstitial K-feldspar and quartz is randomly distributed for the most part, forming irregular and anhedral grains. Numerous stubby laths of plagioclase, about 1 mm across, also make up part of the interstitial material at many localities and possess good euhedral crystals unlike the earlier-formed and partially resorbed larger plagioclase crystals.

K-feldspar oikocrysts are randomly distributed but in some locations form definite irregular linear concentrations up to 1 cm thick, and spaced 1 to 2 cm apart. The irregular K-feldspar distribution obviously posed problems for thin-section modal analyses and necessitated point counts on rock slabs of areas up to 4 square inches to produce realistic K-feldspar/plagioclase ratios. Linear distributions of poikilitic K-feldspar are probably the result of a residual K-feldspar melt that was segregated and probably "squeezed" into a semirigid crystal "mush" of earlier-formed plagioclase and pyroxene. Mechanisms for such occurrences are discussed later.

Phenocrystic biotite facies.—The phenocrystic biotite facies is the part of the stock that contains biotite phenocrysts or oikocrysts at least 4 mm across (Text-fig. 4). The area defined is generally coextensive with the poikilitic K-feldspar facies, except in the northern part of the stock. Modal percentages and crystal sizes are essentially the same as in the poikilitic facies. Biotite phenocrysts are euhedral to subhedral and have no particular orientation. Large biotite phenocrysts, appearing slightly poikilitic and containing plagioclase and K-feldspar, are as large as 22 mm across at sample locations 181 and 84 (Text-fig. 2; Pl. 2, fig. 2). Areas in which biotite phenocrysts are $\geq$ 8 mm across are also identified on Text-figure 4. For the most part the biotite phenocrysts appear to have crystallized as primary oikocrysts around pyroxene and plagioclase. Textural relations suggest that biotite, as well as K-feldspar, crystallized after the formation of higher temperature plagioclase and pyroxene. Much of the texture of the phenocrystic biotite facies is described in the poikilitic K-feldspar facies.

Nonpoikilitic K-feldspar facies.—The nonpoikilitic K-feldspar facies generally surrounds the central poikilitic zone and characteristically lacks poikilitic K-feldspar but has large, medium-grained euhedral interlocking plagioclase laths instead (Text-fig. 4; Pl. 2, fig. 3). Some poikilitic K-feldspar was observed in the facies, but crystals were found to be less than 2½ mm across. The facies generally appears to be a granodiorite and to be slightly darker in hand sample than in the inner facies. Most previous descriptions of the Clayton Peak stock more closely resemble the outer, nonpoikilitic K-feldspar facies. The texture ranges from strongly porphyritic to seriate with variations in size and euhedralism of the phenocrysts and groundmass. The groundmass comprises approximately 90 percent of the rock and varies in texture from subequigranular to seriate. The following mineral grain sizes and percentages represent averages throughout the nonpoikilitic K-feldspar facies:

	Size (mm)	Volume Percentage
Plagioclase phenocrysts (An_{60-65})	2-3	4.8
Plagioclase	½-1	39.0
K-feldspar, interstitial	1	21.1
Quartz	1	8.8
Biotite	½-3+	8.2
Pyroxene phenocrysts	2-3	3.0
Pyroxene	1	1.7
Hornblende	3	9.8
Accessory minerals	1	3.3
		99.7

Total phenocryst percentage averages 10 and is comprised of euhedral to subhedral interlocking plagioclase, subhedral biotite and anhedral clinopyroxene. Plagioclase in many locations contains phyllosilicate alteration minerals but shows no definite trend throughout the facies. K-feldspar, as well as quartz, is generally restricted to interstitial materials between the early formed crystals. Biotite crystals are generally subhedral and less than 4 mm across except where the phenocrystic biotite facies overlaps the outer facies. Locally, reaction rims of biotite and hornblende surround "spongy" clinopyroxene phenocrysts. The outer texture facies probably represents the earlier stage of crystallization of plagioclase and clinopyroxene.

Microcrystalline facies.—Conspicuous euhedral phenocrysts of plagioclase and some anhedral pyroxene and biotite 1½ mm across encased in a subequigranular groundmass of plagioclase, K-feldspar, pyroxene, biotite, and quartz characterize the texture of the microcrystalline facies identified by black dots on Text-figure 4. Modal average percentages for some of the microcrystalline zones are listed in Table 1.

The finest-grained sample observed in the Clayton Peak stock, from locality 75, is characterized by plagioclase phenocrysts in a groundmass of extremely small interlocking crystals 0.16-0.25 mm across (Pl. 2, fig. 4). Mafic minerals, especially clinopyroxene, occur as disseminated anhedral crystals from 0.25-0.6 mm. Some samples contained large percentages of chlorite and other phyllosilicate alteration products near contacts. Variations in the phenocrysts were observed in most of the designated sample locations. Generally the phenocrysts are about the same size as the crystals comprising the groundmass of the coarser textures described above. The fine-grained textures were most likely the result of a sudden extrusion of the magma into colder country rocks or a sudden loss or uneven distribution of volatiles in the residual liquid. These textures reflect only local variations and do not pertain to the crystallizing conditions of the entire stock.

Modal Analyses and Mineral Facies Trends

To determine textural and mineralogical variations in the Clayton Peak stock, hierarchial sampling schemes for a large pluton by Baird and others (1967a), by Moore (1963), and by Whitten (1961) were reviewed. Whitten (1961) and Compton (1955) both concluded that one sample per quarter square mile gave meaningful mineral trends for intrusions of composition and variability trends similar to those of the Clayton Peak stock. The small areal extent of the Clayton Peak stock enabled extensive hand sampling at intervals of approximately 1,000 feet. The outcrop variability and the lack of extensive schlieren features in the Clayton Peak stock suggest that the sample-data density of 5 samples per quarter square mile is adequate for modal trend-surface study.

Of the 200 samples taken from the Clayton Peak stock, 145 thin sections were used to define the textural facies, and detailed modal analyses were performed on 32 samples selected for the trend maps (Text-fig. 2).

Modal analyses were performed under 80X magnification using an average of 1,446 points and various point spacings. The mean spacing, a, was regulated by varying the distance between horizontal traverses of an average 80 stops at $\frac{1}{3}$ mm spacings. For each thin section, the average grain radius, R, was determined using Chaye's (1956) IC method, thus enabling the proper selection of grid spacing, a, area to be counted, A, and number of points counted, N.

Average grain sizes range from 0.37 to 0.7 mm in the coarser rocks with even larger phenocrysts. Stained rock slabs covered with a zip-a-tone of 0.64 and 1.7 mm spacings were used to determine the K-feldspar/plagioclase ratios and to support modal analyses performed on thin sections of rocks having large and irregularly spaced K-feldspar distributions.

Using the chart by Solomon and Green (1965), the necessary mean grid spacing and number of counts were determined using a maximum variance, O^2, of 3. After obtaining modal percentages, the theoretical variance, O^2, was calculated according to Solomon (1963) using an average grain radius of 0.135 mm, an average grid spacing of 0.539 mm, and an average count number of 1,446. The variance ranges from 5.6 for plagioclase to 0.28 for the Fe-Ti oxides. Standard deviations, δ, are recorded on Table 1; and, according to Solomon (1963), they range from 0.20 to 2.37 percent. Using the point count reliability (standard deviation) chart by Van Der Plas and Tobi (1965), standard deviations were found to be comparable to those obtained by Solomon's method: they ranged from less than 1 to 2.7 percent with a 95 percent confidence level, the greater mineral percentages having the higher standard deviations.

Modal analyses are reported in volume percent of the constituent minerals and are listed in Table 1. Trend surfaces of the modal data were computed

TABLE 1
SAMPLE MODAL ANALYSES OF THE CLAYTON PEAK STOCK

Sample	2	24	33	45	63	66	68	72	79	89	92	97
Plagioclase*	47.5	43.7	33.3	41.4	41.2	46.0	38.8	45.0	39.7	34.9	39.8	43.2
K feldspar	8.5	18.5	34.2	18.3	17.7	19.2	27.4	26.0	24.9	15.5	30.3	24.8
Quartz	16.8	10.8	6.2	9.8	5.2	2.9	10.0	4.9	13.7	8.7	11.1	10.8
Biotite	11.2	7.8	0.0	8.4	13.0	0.5	7.1	9.5	10.5	16.3	7.2	10.2
Hornblende	13.2	17.1	22.9	9.6	6.2	24.4	8.8	0.7	6.6	17.4	7.7	7.3
Pyroxene^x	0.0	0.6	0.0	5.6	14.5	0.5	4.9	11.0	2.0	3.7	2.0	1.3
Chlorite	0.7	--	1.3	2.2	--	2.8	0.5	t	--	1.7	--	0.1
Sphene	1.0	0.6	0.5	--	--	1.1	--	--	--	0.1	0.3	0.1
Fe-Ti oxides	1.0	0.9	1.6	1.6	2.2	2.6	2.5	2.0	2.6	1.6	1.6	2.2
Total	99.9	100.0	100.0	99.9	100.0	100.0	100.0	99.6	100.0	99.9	100.0	100.0
Color Index#	27.1	27.0	26.3	30.4	35.9	31.9	23.8	23.2	21.7	40.8	18.8	21.2
Ave. gn. size	.3	.17	.45	.23	.7	.35	.25	.2	.3	.16	.25	.2

Sample	100	107	123	131	136	139	146	148	152	156	160	165
Plagioclase*	40.4	49.8	43.2	35.8	48.4	39.5	41.2	38.7	41.4	41.9	44.6	44.2
K feldspar	26.0	19.1	24.8	35.0	24.5	24.6	27.0	32.4	25.4	23.8	24.0	22.8
Quartz	7.3	8.6	10.0	9.4	9.0	17.9	9.6	9.8	12.6	11.7	7.2	7.2
Biotite	9.8	7.2	7.6	3.0	6.0	15.5	9.8	8.1	10.6	9.8	10.4	7.2
Hornblende	10.2	7.6	6.7	5.9	9.9	0.5	2.6	--	2.9	5.4	9.8	1.4
Pyroxene^x	2.5	4.5	4.5	6.8	0.0	--	8.5	8.4	4.8	5.4	1.9	15.6
Chlorite	0.9	--	t	t	--	1.2	--	--	t	t	--	--
Sphene	--	0.2	t	0.1	0.4	0.7	--	--	0.6	0.4	--	--
Fe-Ti oxides	2.8	3.0	2.0	3.9	1.7	0.1	1.3	2.5	1.8	1.6	--	1.5
Total	99.9	100.0	98.8	99.8	99.9	100.0	100.0	99.9	100.1	100.0	100.1	99.9
Color Index#	26.2	22.5	20.8	19.7	18.0	18.0	22.2	19.0	20.7	27.0	24.3	25.7
Ave. gn. size	.18	.31	.25	.18	.37	.25	.26	.3	.15	.17	.2	.33

Sample	181	183	184	187	192	27-6	B53	NW8	179X	Ave	σ
Plagioclase*	43.6	46.5	44.2	43.0	47.4	35.6	42.8	47.4	33.7	42.3	2.37
K feldspar	17.5	24.3	22.1	27.4	16.9	31.2	17.3	15.2	15.2	23.3	1.75
Quartz	8.0	7.3	14.8	15.0	11.1	9.8	16.7	9.8	3.4	10.1	1.15
Biotite	11.0	9.1	4.5	7.5	7.0	5.2	10.4	9.8	7.5	8.5	1.06
Hornblende	6.2	2.8	0.7	1.1	4.7	8.6	7.5	13.9	16.7	7.8	1.01
Pyroxene^x	10.6	7.0	10.0	3.8	11.3	6.8	0.9	--	23.1	5.0	0.81
Chlorite	--	--	t	--	--	--	0.5	--	--	t	--
Sphene	--	0.8	t	--	--	--	1.1	--	--	0.3	.20
Fe-Ti oxides	3.1	2.1	2.8	2.1	1.7	2.8	2.8	4.2	0.2	2.1	.53
Total	100.0	99.9	99.1	99.8	100.1	100.0	100.0	100.3	100.0	99.4	
Color Index#	30.9	21.8	18.0	14.5	24.7	23.4	23.2	37.7	47.5	24.4	
Ave. gn. size	.43	.3	.2	.2	.25	.3	.15	.25	.50	.27	

t = trace
* = Feldspar alteration minerals included
x = Major pyroxene-clinopyroxene, some orthopyroxene
# = Total dark minerals (biotite, hornblende, pyroxene, chlorite, sphene and oxides)
Ø = Standard deviation

by a least squares method (Esler, Smith, and Davis, 1968) to provide trend-surface maps at 2 percent contour intervals for plagioclase, K-feldspar, quartz, pyroxene, hornblende, biotite, and color index (total dark minerals).

The mineral mapping of any rock body can be accomplished only when the regional variation can be detected above the local variability or compositional "noise" (Baird et al. 1967b). Three thin sections cut at right angles to each other from the same hand sample have standard deviations of less than 2 percent for most minerals and as high as 3.5 percent for quartz (Table 3). Modal analyses of samples taken 5 feet apart at different localities throughout the stock were also performed to determine outcrop variability. For most major minerals the standard deviation is less than 2 percent (Table 4). Plagioclase, however, is slightly over 2 percent. Crystal foliations and small schlieran structures might explain some of the variation in the modal analyses. Some samples exhibit foliations brought out by parallelism of plagioclase crystals. Other foliations caused by differing distributions of K-feldspar are also apparent after staining. High standard deviations that were recorded for hornblende and biotite in samples near the contact probably were caused by the rock's having been subjected to variable degrees of alteration and subsequent mineralization.

Statistical data generated with each accompanying trend-surface map indicate that the coefficients in the trend-surface equations are significant at

TABLE 2
MODAL COMPARISONS OF THE CLAYTON PEAK STOCK AND RELATED INTRUSIONS

	1	2	3	4	5	6	7
Plagioclase	48.1	35.2	42.3	45.8	42.2	5.0	34.0
K feldspar	17.4	20.5	23.3	19.1	18.2	62.0	23.0
Quartz	17.6	20.5	10.1	19.6	28.5	25.0	9.0
Biotite	6.2	4.3	8.5	5.6	9.7	7.0	6.0
Hornblende	7.0	13.0	7.8	6.0	0.3	--	15.0
Pyroxene	--	--	5.0	--	--	--	12.0
Chlorite	0.2	3.9	0.1	1.0	--	--	--
Accessory	1.2	0.4	0.3	1.3	1.0	1.0	1.0
Oxides	2.4	2.0	2.1	1.6	0.1	--	--
Totals	100.1	99.8	99.5	100.0	100.0	100.0	100.0
Color Index	17.0	23.2	23.8	15.5	11.1	8.0	34.0

1. Ontario granodiorite, Wilson, 1961.
2. Park City (Valeo Porphyry), Wilson, 1961.
3. Clayton Peak granodiorite/quartz monzonite, Palmer, 1973; avg. of 32 modes.
4. Alta granodiorite, Wilson, 1961; avg. of 10 modes.
5. Little Cottonwood quartz monzonite, Sharp, 1958; avg. of 2 modes.
6. Bingham "granite" no. 1, Stringham, 1953.
7. Last Chance "quartz monzonite" no. 11, Stringham, 1953.

TABLE 3
THIN-SECTION MODES FROM SINGLE HAND SAMPLE

	Plag.	K-feld.	Cpx	Hornb.	Bioti.	Quartz	Oxides
187wa	45.1	23.3	6.6	7.7	8.2	6.2	2.9
187wax	43.7	22.2	4.2	6.7	10.9	10.4	2.0
187way	43.2	20.2	6.6	8.5	9.4	10.5	1.9
σ*	1.39	2.22	1.96	1.36	1.91	3.5	.77

Ø = Standard deviation

TABLE 4
THIN-SECTION MODES FROM SAMPLES SPACED 5 FEET APART

	Plag.	K-feld.	Cpx	Hornb.	Bioti.	Quartz	Oxides
187w	49.2	22.2	7.5	5.6	9.4	4.0	2.1
187wa	45.1	23.3	6.6	7.7	8.2	6.2	2.9
σ	2.90	.77	.63	1.50	.85	1.55	.57
100X	47.2	19.4	7.3	9.7	9.5	4.2	2.8
100Y	51.0	19.5	4.8	11.6	7.3	3.6	2.9
σ	2.68	.07	1.76	1.34	1.55	.42	.07
172	50.1	20.7	0.2	23.3	0.2	3.5	1.9
172a	52.1	13.4	2.3	20.0	3.7	5.7	2.7
σ	1.47	5.16	1.48	2.33	2.47	1.55	.57

Ø = standard deviation

the 95 percent confidence level or higher. Thus, there exists only a 5 percent probability or less that the trend-surface equations do not account for modal data employed in the computations (Harbaugh and Merriam, 1968).

Considering the hand sample and outcrop variability, the analytical error associated with modal analyses, and uncertainties in calculation of the trend surfaces, it is believed that trend-surface maps generated are fair to good representations of the real mineral compositional trends in the rock. To obtain more reliable data at various sampling levels would require double or triple the work, but such effort may invoke diminishing returns, probably with small changes in the mineral trends.

The Clayton Peak stock is a zoned pluton mineralogically as well as texturally (Text-figs. 5-11). K-feldspar and quartz are generally high in the center portion of the stock with higher plagioclase and color index on the margins with the same west-northwest trend. The high K-feldspar central portion is essentially coextensive with the poikilitic textural zone (Text-fig. 4). Generally high potassium-bearing oikocrysts are much larger within the 25 percent contour lines at the center. Areas of 25 percent K-feldspar corresponding to those high in quartz are classified as quartz monzonites, while granodiorites and diorites are generally restricted to the margins (Text-fig. 12). The origin of a high K-feldspar residual liquid that may have produced the high concentration of K-feldspar in the central zone is discussed later.

The nonpoikilitic texture zone is characterized by high plagioclase concentrations, less K-feldspar, generally less quartz, and more mafic minerals. Towards the margins K-feldspar is usually restricted to anhedral material interstitial between phenocrysts of plagioclase, pyroxene, and biotite.

Pyroxene and hornblende also have an inverse relationship; pyroxene dominating the central portion of the stock while hornblende forms higher concentrations near the margins (Text-figs. 8 and 9). Samples near the southern and northern contacts are generally dark green, where samples towards the center of the stock are usually light medium gray. Hornblende occurs as both a primary and a secondary mineral and is nearly 25 percent of the rock in samples 33 and 66 in Snake Creek Canyon. A conspicuous lack of pyroxene, an abundance of euhedral hornblende, and some chlorite and secondary sphene characterize samples near the southern contacts. Samples of the northern margin of high hornblende concentrations contain hornblende

EXPLANATIONS OF TEXT-FIGURES 5-10

TEXT-FIGURE 5.—Trend analysis of Plagioclase distribution, degree 5. Total variation—479.737419; mean—45.151613; variation not explained by surface—167.662747; variation explained by surface—312.074672; coefficient of determination—0.650511, standard deviation—2.325613; F-Ratio—0.797710 with 21 and 9 degrees of freedom.

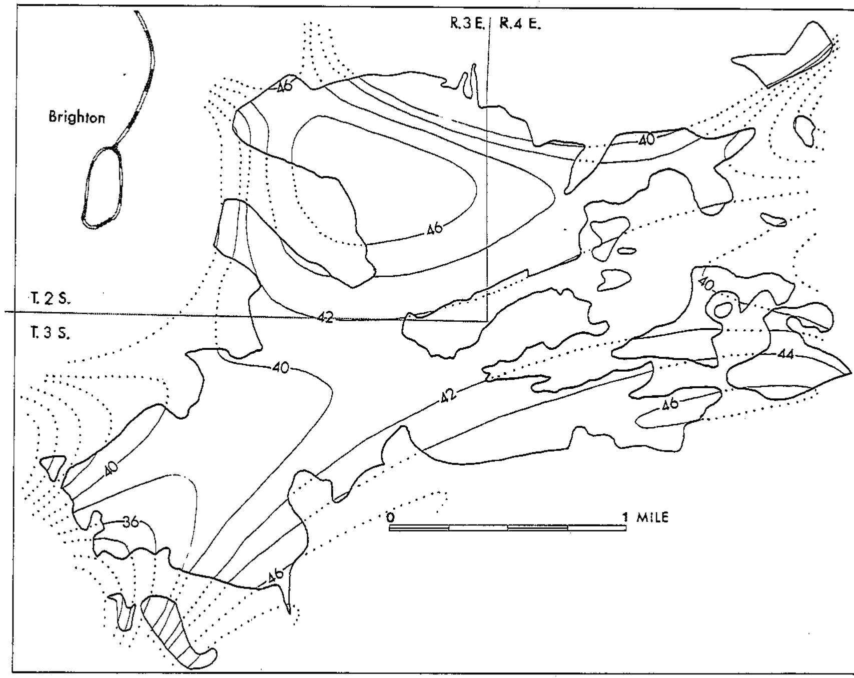
TEXT-FIGURE 6.—Trend analysis of K-feldspar distribution, degree 5. Total variation—1031.498710; mean—23.593548; variation not explained by surface—144.949519; variation explained by surface—886.549191; coeffecient of determination—0.859477; standard deviation—2.162358; F-Ratio—2.621255 with 21 and 9 degrees of freedom.

TEXT-FIGURE 7.—Trend analysis of quartz distribution, degree 6. Total variation—381.579355; mean—10.125806; variation not explained by surface—17.797651; variation explained by surface— 363.781704; coefficient of determination—0.953358; standard deviation—0.757706; F-Ratio—1.459991 with 28 and 2 degrees of freedom.

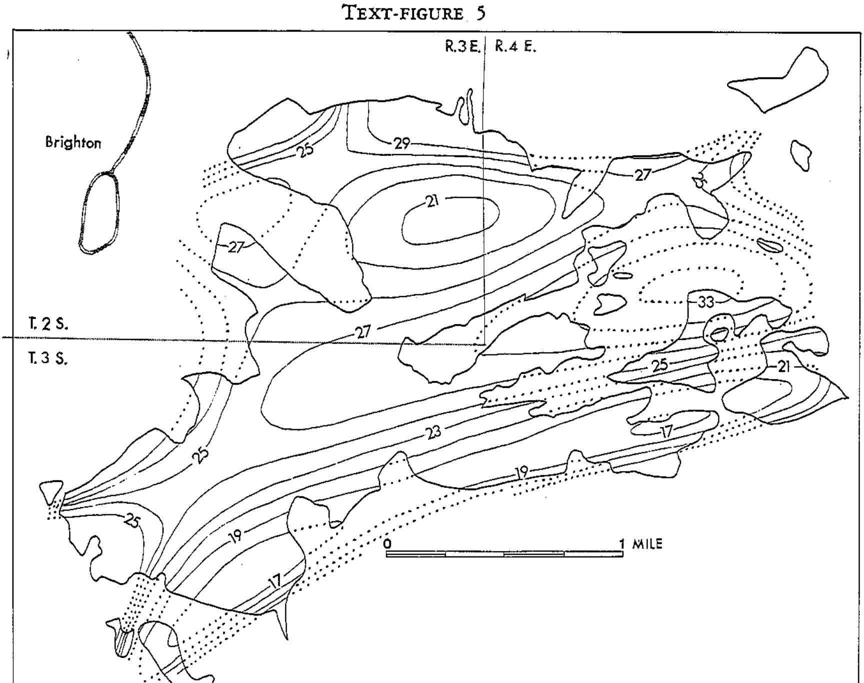
TEXT-FIGURE 8.—Trend analysis of pyroxene distribution, degree 5. Total variation—576.495484; mean—5.141935; variation not explained by surface—114.120504; variation explained by surface—462.374980; coefficient of determination—0.802044; standard deviation—1.918673; F-Ratio—1.736416 with 21 and 9 degrees of freedom.

TEXT-FIGURE 9.—Trend analysis of hornblende distribution, degree 5. Total variation—1133.479355; mean—7.625806; variation not explained by surface—187.673865; variation explained by surface—945.805489; coefficient of determination—0.834427; standard deviation—2.460487; F-Ratio—2.159838 with 21 and 9 degrees of freedom.

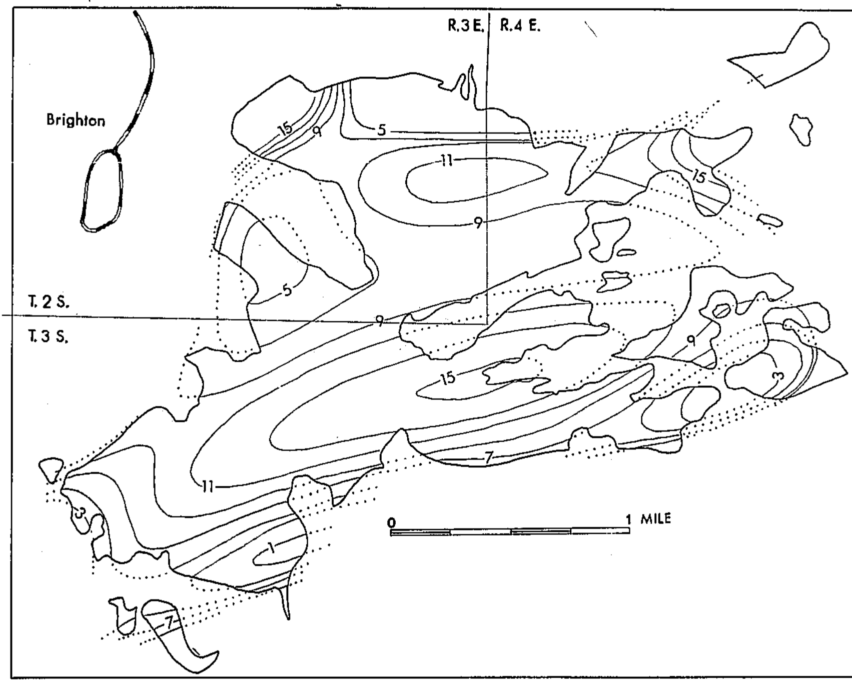
TEXT-FIGURE 10.—Trend analysis of biotite distribution, degree 6. Total variation—379.827742; mean—8.432258; variation not explained by surface—18.467845; variation explained by surface—361.359897; coefficient of determination—0.951378; standard deviation—0.771840; F-Ratio—1.397641 with 28 and 2 degrees of freedom.



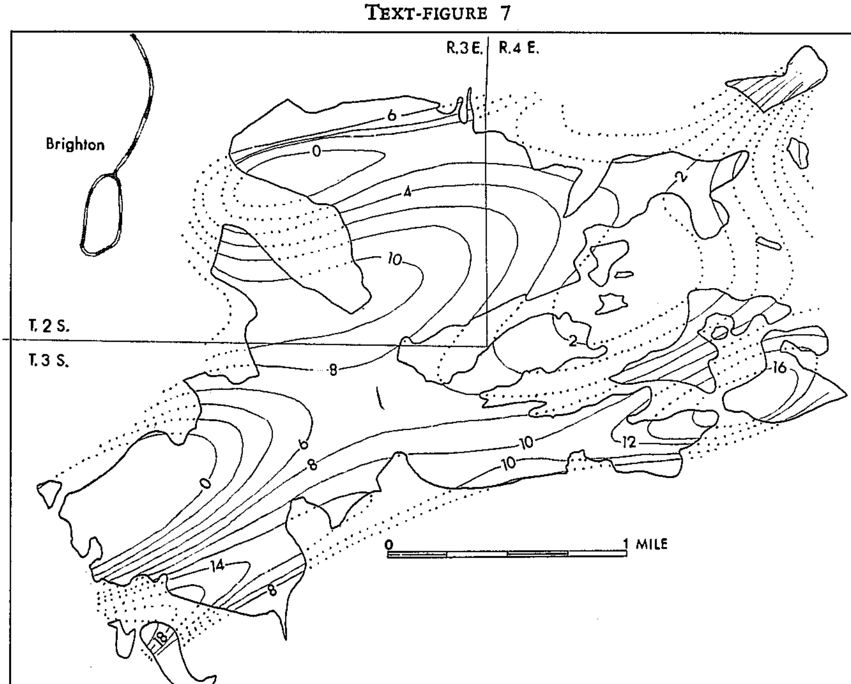
TEXT-FIGURE 5



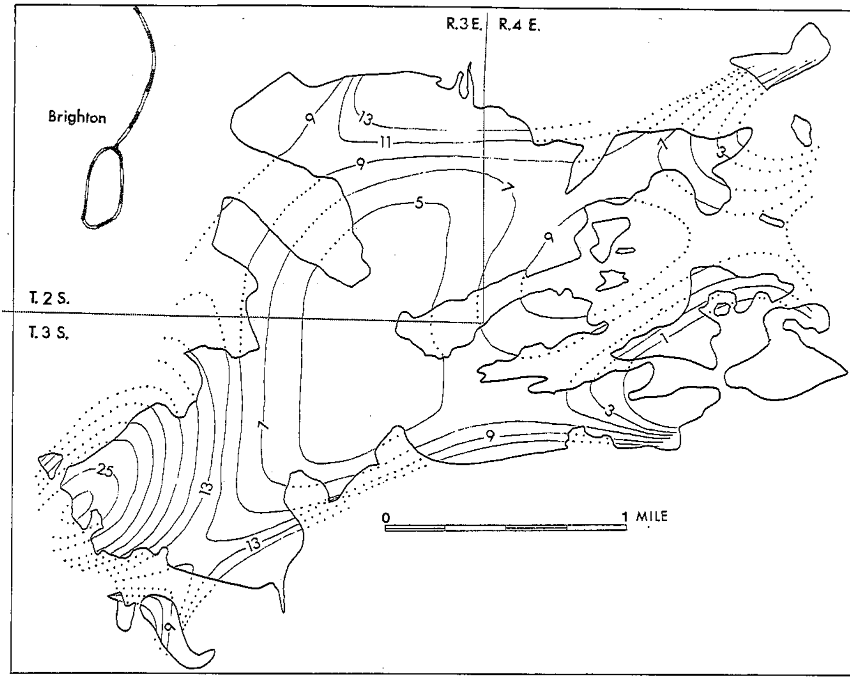
TEXT-FIGURE 6



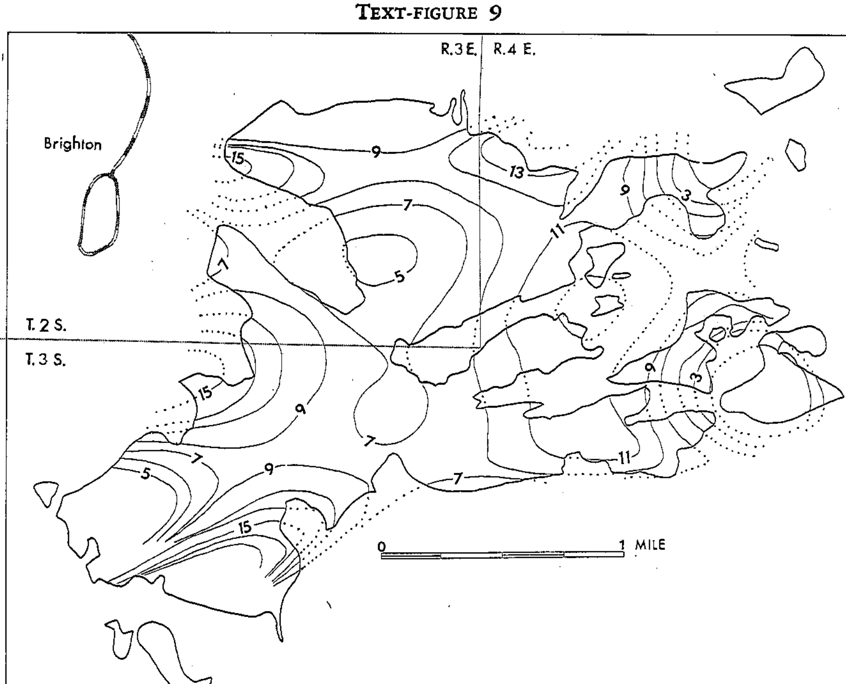
TEXT-FIGURE 7



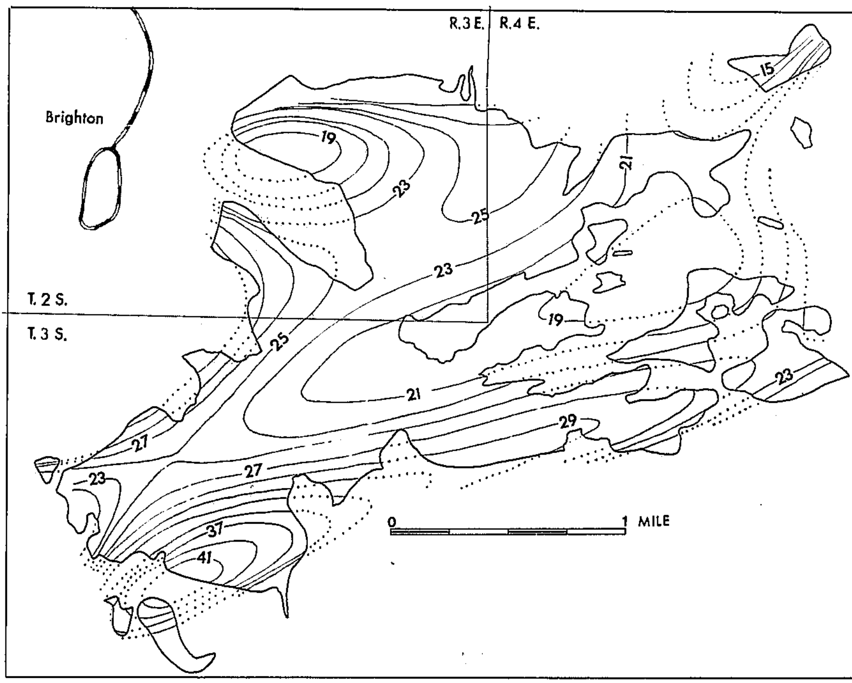
TEXT-FIGURE 8



TEXT-FIGURE 9

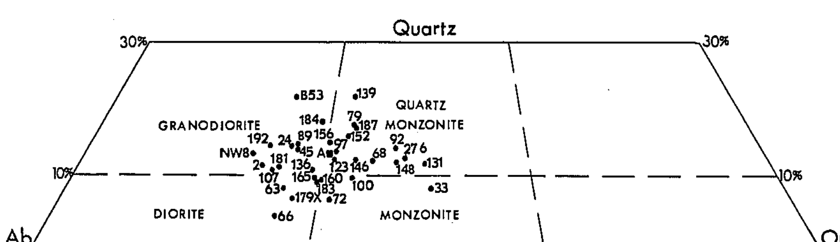


TEXT-FIGURE 10

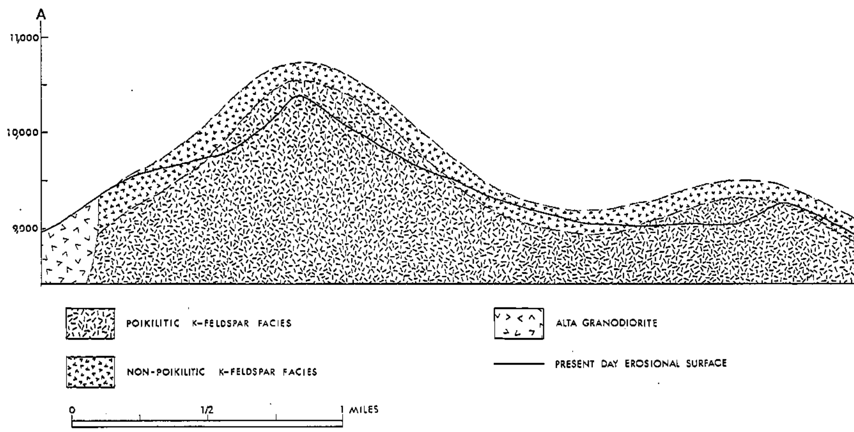


TEXT-FIGURE 11.—Trend analysis of color-index distribution, degree 5. Total variation—924.047097; mean—24.009677; variation not explained by surface—244.794400; variation explained by surface—679.252697; coefficient of determination—0.735084; standard deviation—2.810088; F-Ratio—1.189195 with 21 and 9 degrees of freedom.

as intergrowths and reaction rims with pyroxene and biotite. Phenocrysts and groundmass crystals of the high hornblende-percentage facies generally have higher sphene concentrations. Resorption of pyroxene, producing hornblende, plagioclase and Fe-Ti oxides, is evident throughout the zone. Alteration of pyroxene to hornblende (uralitization) may have resulted from a reduction in silica through metasomatic conditions near the contacts and would explain the proximity of the high hornblende percentages to the sedimentary contacts. Metasomatic zones near the Clayton Peak and Alta intrusive contacts were investigated by Cranor (1974).



TEXT-FIGURE 12.—Ternary diagram, quartz, orthoclase, albite.



TEXT-FIGURE 13.—Schematic cross section of textural zones in the Clayton Peak stock along A-A'.

Biotite distribution does not seem to coexist with any of the other mineral trends or with the phenocrystic biotite texture facies described previously. High biotite percentages found outside the biotite texture facies are possibly the result of high percentages of biotite alteration products with hornblende that did not form as primary crystal growths. A north-south trough, low in biotite, is apparent through the center of the stock, suggesting a low concentration of biotite constituents related to the residual melt responsible for the poikilitic texture at the center.

Color-index (total dark minerals) concentrations are generally lower in the center and higher on the margins with the same obvious west-northwest trend of the plagioclase, K-feldspar, and quartz. High percentages are generally restricted to the margins, especially near the southern border where hornblende is abundant. Trend patterns for K-feldspar and color index were found to be remarkably similar (Text-figs. 6 and 11). Moore (1963) has shown the same relationship for the K-feldspar and color-index distribution trends and suggests reintrusion of a primary intrusion by a more silicic central portion as a possible mechanism for the zonation in the pluton.

STRUCTURES IN THE CLAYTON PEAK STOCK

Layered Igneous Rock

Layered quartz monzonite is found in only a few local areas of the rock. Mafic-layered rocks with light and dark gray bands 1-3 mm thick were observed on the cirque (location 105, Text-fig. 3; Pl. 1, fig. 2) northwest of Lake Lackawaxen, striking north-south and dipping 30° to the west.

Light layers are characterized by a coarse-grained texture with only about 4 percent mafic minerals. A thin section of sample 105 revealed the lighter bands to have a quartz monzonite composition with approximately 25 percent quartz. Large phenocrysts (3-7 mm) of biotite, pyroxene, zoned plagioclase (An_{25-40}), and subhedral K-feldspar contain inclusions of quartz, biotite, and pyroxene. Equigranular groundmass consists of anhedral quartz grains, stubby plagioclase laths, and euhedral crystals of biotite (1 mm). Biotite has replaced some pyroxene and formed intergrowths. Numerous growths of sericite have replaced the cores of most plagioclase crystals. Fe-Ti oxides outline many of the pyroxene phenocrysts and make up about 3 percent of the total rock.

Darker bands are characterized by an equigranular groundmass of stubby interlocking euhedral zoned plagioclase laths surrounding irregular phenocrysts of subhedral biotite and pyroxene. Plagioclase is the dominant mineral and is followed by K-feldspar, biotite, and pyroxene. Quartz is much less (5 percent), and Fe-Ti oxides are more abundant than in the light bands. Biotite has produced interstitial crystals between the feldspar grains.

A much finer layered rock was found at locality 148 approximately 1,000 feet due east of the Silver Lake Islet. Laboratory studies have shown the conspicuous bands to be composed mostly of high potassium bearing feldspars. The bands measure 4-5 mm thick and strike north 45° east and dip 32° west. The strike orientation is similar to the layering near location 105 but does not appear genetically related. The lighter bands have fewer and smaller mafic minerals. Conspicuous poikilitic K-feldspar crystals enclosing smaller laths of plagioclase, augite, and biotite were observed in thin section. No quartz was found in the rock. The darker bands are characterized by larger and more abundant mafic minerals, mainly pyroxene and biotite and Fe-Ti oxides. Slender spindles of rutile were observed within the K-feldspar crystals. The lighter bands of K-feldspar also may owe their origin to a residual magma, high in vapor pressure and K-feldspar, that subsequently was introduced into weaker zones of the stock during crystallization of the intrusion. The K-feldspar bands dip toward the center of the stock and further suggest the origin of a potassium-rich melt from within the stock.

Mafic Inclusions

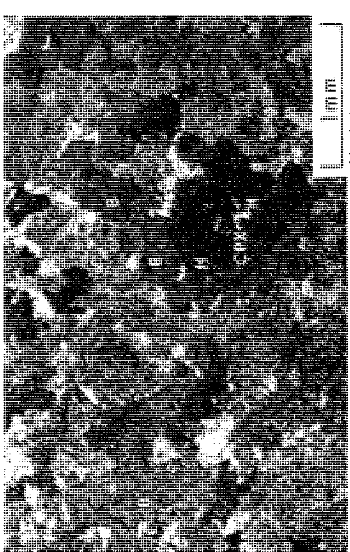
Rounded mafic inclusions from 1 to 5 cm in diameter were observed as resistant "knobs" on weathered surfaces at sample location 179 (Text-fig. 2). The mafic inclusions in hand sample show conspicuous euhedral stubby laths of pyroxene protruding from a weathered chalky mass of plagioclase and K-feldspar. Staining revealed about 15 percent K-feldspar in the inclusions.

Petrographic examination of the mafic knobs revealed a very coarse-grained, porphyritic, poikilitic texture (Pl. 3, fig. 4). Large euhedral phenocrysts of biotite, clinopyroxene, plagioclase (An_{55-60}), and K-feldspar ($\approx$10 mm) are the dominating constituents. Subhedral clinopyroxene appears as inclusions and as interstitial material between the large phenocrysts. Hornblende is present and surrounds some of the pyroxene crystals (Pl. 3, fig.

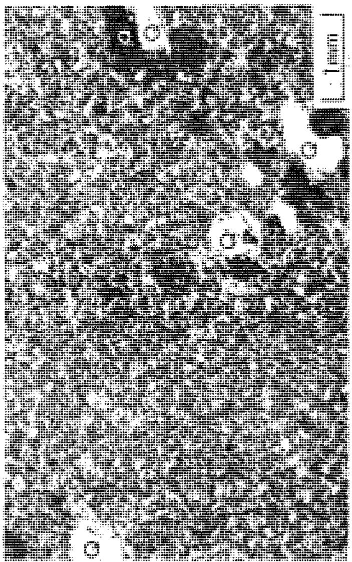
EXPLANATION OF PLATE 3
PHOTOMICROGRAPHS

FIG. 1. Poikilitic quartz monzonite, loc. 79, showing reaction rims of biotite and hornblende on pyroxene (crossed nicols).
FIG. 2. Alaskite, loc. 83d (crossed nicols).
FIG. 3. Aplite, loc. 108, (crossed nicols).
FIG. 4. Mafic inclusion, loc. 179X, biotite, pyroxene granodiorite (crossed nicols).

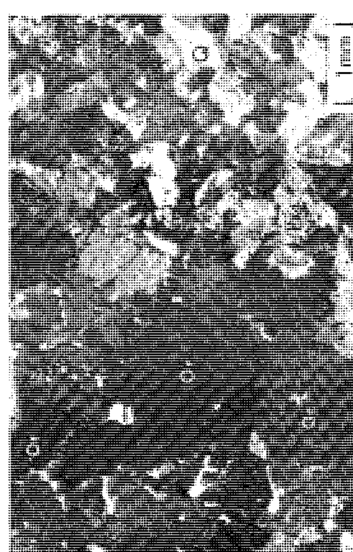
PLATE 3



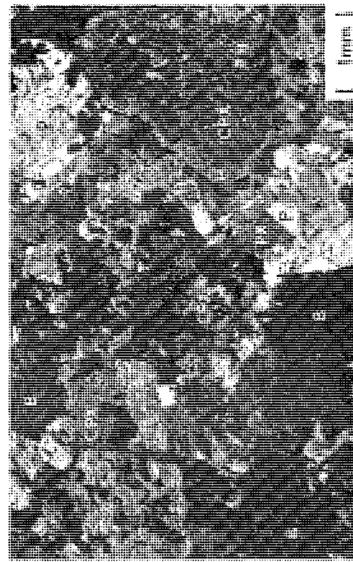
1



2



3



4

4). Only about 3 percent quartz was observed in the inclusions mostly surrounded by poikilitic K-feldspar. Biotite and hornblende crystals with clinopyroxene cores show quite euhedral growths in contrast to the subhedral-anhedral feldspar. Modal analyses of sample 179X are listed in Table 1 and are plotted in Text-figure 12. The mafic inclusions would be classified as hornblende, pyroxene, biotite diorite.

Interpretations for the origin of mafic inclusions are varied. Balk (1937) made the following statement regarding inclusions found in the Sierra Nevada and Coast Ranges and the Idaho Boulder batholiths:

> Their origin is controversial; some may represent foreign inclusions, altered to such an extent that their minerals are identical with those of the enclosing igneous rocks, according to Bowen's reaction principle; others may represent accidental accumulations of the normal ferromagnesian minerals in the magma, and they are referred to as segregations or autoliths.

Moore (1963) has shown that some mafic inclusions of the Sierra Nevada batholith are undoubtedly assimilated wall rocks. Hyndman (1972), however, suggests a direct relationship of the inclusions to concentric zoning in plutons. The fact that xenoliths of quartzite and limestone from the nearby sediments near locations 182 and 183 in the Clayton Peak stock (Text-figs. 2 and 3) show no conspicuous alteration indicates that the dark inclusions at 179X were probably not derived from the host sediments. Sharp (1958) recognized similar inclusions in the Little Cottonwood stock and suggests that they represent material which crystallized earlier against the walls of the stock and was then broken up and scattered throughout the magma.

Piwinskii (1967) indicates that the mafic inclusions of the Sierra Nevada batholith probably are not clots of early-formed minerals of basic facies. The composition of plagioclase (An_{30-40}) of the Sierra Nevada rocks thus may indicate a higher sodic plagioclase than would be expected to crystallize with the early high-temperature minerals. Piwinskii (1967), therefore, suggests that the Sierra Nevada mafic inclusions represent refractory residue left over from the partial melting of the earth's crustal material during the formation of the magma. This would explain the ubiquitous occurrence of mafic inclusions throughout the Sierra Nevada batholith. However, the fact that the mafic inclusions of the Clayton Peak stock are found in only one locality and that their high Ca plagioclase compositions and basic mineral assemblages so closely resemble that of the outer, earlier formed facies of granodiorite/diorite suggests that the mafic inclusions are, more likely, early crystallized mafic material (formed at the margin of the pluton). The mafic material probably was incorporated subsequently as autoliths through flowage or movement into the still liquid portion of the melt and was assimilated and rounded to present shapes, being exposed later as resistant "knobs" on weathered surfaces.

Jointing

At most sample locations in which samples were fresh, measurements were made on joint attitudes and relative intensity and were plotted on Text-figure 14. Measurements plotted by the author combined with some joint measurements by Belt (1969) have revealed at least three prominent joint sets in the Clayton Peak stock. The major trends have been schematically drawn and do not represent actual joints. The major strike trend is northeast-southwest, paralleling the longer axis of the stock. Normal joints cut the major axis of the stock, and still others were found to encircle the stock. Joint spacing ranges from inches to several feet apart throughout the stock. Smaller and less abundant joint patterns cut the major northeast-southwest trend and probably represent local adjustments within the stock. Most of the joints dip more than 50°. Vertical or high-angle dips of 80° or more are abundant throughout the stock and seem to be more abundant in the high cliffs near sample localities 46 and 47 (Text-figs. 2 and 14). Some of these joints, particularly those in which two or more intense joint patterns intersect (sample locations 139, 138, 168, and 167), contain coatings of malachite and limonite. Smaller and more irregular fractures are filled with malachite near a test pit near locality 139.

The individual points plotted on a stereo net projection represent the intersection on the lower hemisphere of poles normal to joint planes. A concentration of points reveals an average attitude. Contouring, using the point method by Billings (1954), has made areas of point concentrations more apparent (Text-fig. 14). High concentrations of points on the circumference indicate vertical or steeply dipping joints. The greater concentration of points in the northwest and southeast quadrants indicates that the majority of the joints strike in a northeasterly direction parallel to the longer axis of the pluton, which is also apparent from the trends of the pattern lines (Text-fig. 14). Joints striking approximately north 5° west and north 80° west are also apparent from the stereo projection. The concentration of points in the northwestern quadrant indicates that a separate joint set, also striking northeast-southwest, dips between 50° and 70° to the southeast.

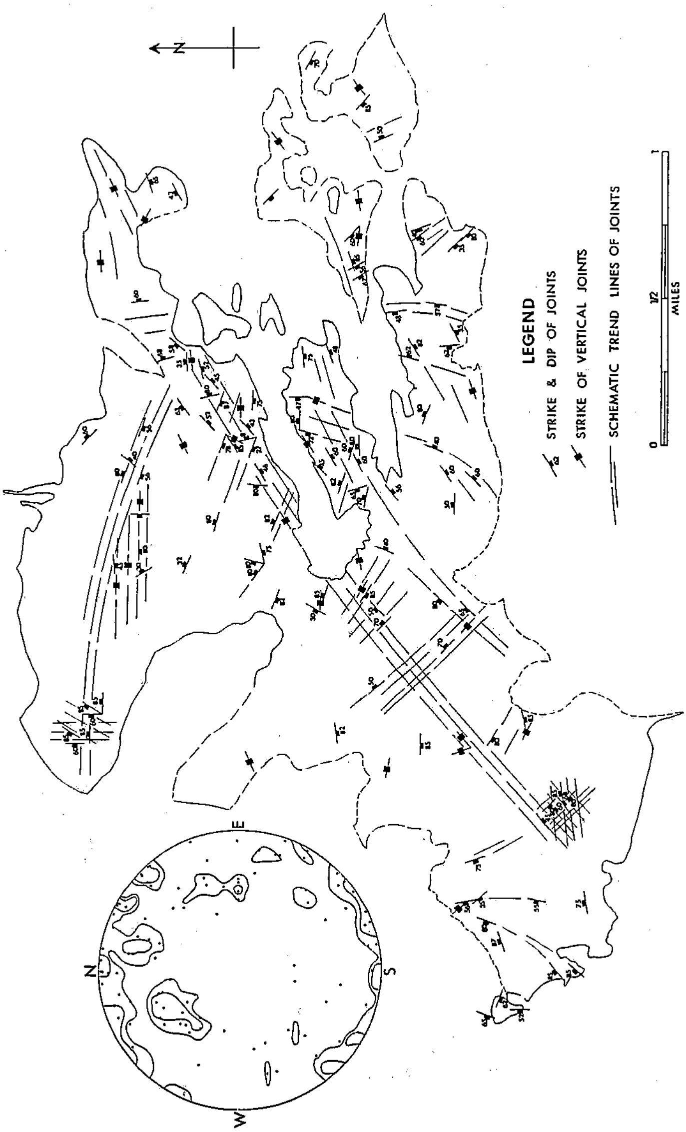
Wilson (1961) recorded numerous joint measurements on the Alta stock and also schematically illustrated the joint trends. He noted that many joints parallel the elongate axis of the Alta stock and the axis of the Clayton Peak stock. Many of the silicic dikes and lineations also strike in a northeast-southwest direction and suggest that some of the northeast-striking joints are closely related to emplacement of the stock (Hyndman, 1972). Unloading probably produced many of the joints paralleling topographic surfaces that occur on the relatively steep exposures of the stock. Other local joint sets are most likely related to postintrusive adjustments. Because the major set of steeply dipping northeast-southwest joints is parallel to the long axis of the pluton, it is probably related to the emplacement of the Clayton Peak stock, the intrusion of the similarly trending Alta stock, and/or the regional forces responsible for some of the Tertiary faults adjacent to the northeastern edge of the stock (Text-fig. 3). No definite conclusions can be reached at present concerning the direction of emplacement of the Clayton Peak stock.

DIKE ROCKS

Two major types of dikes that intrude the Clayton Peak stock are wide north-south-striking alaskite dikes up to 10 feet thick southwest of Clayton Peak and small irregular dikelets of aplite 1 cm thick found in many locations of the stock.

Alaskite

Calkins and Butler (1943) mapped some large chalky-white "alaskite porphyries" in the southwestern part of the stock in Snake Creek Canyon,



TEXT-FIGURE 14.—Joint measurements, patterns, and stereo-net projection on lower hemisphere.

north of the tunnel of the Steamboat mine (sample localities 30, 23, Text-figs. 2 and 3). Alaskite dikes intruding the Alta stock and the Little Cottonwood stock were described by Wilson (1961) and Sharp (1958), respectively. Similarly trending dikes have been recognized and mapped by the author at locality 44, approximately 2,000 feet east of those mapped on the Brighton quadrangle (Baker, Calkins, Crittenden, and Broomfield, 1966). An apparent extension of the dike found at locality 44 was found near localities 82 and 83. East-west outcrops of alaskite were also observed near localities 140 and 143.

Characteristic wavy folding, platy parting, and conchoidal fractures are obvious in outcrops. Weathered samples show oxidation of mafic minerals.

Petrographic examination reveals conspicuous phenocrysts of partially resorbed quartz and equal amounts of altered feldspar (1 to 2 mm across) enclosed in a fine-grained groundmass of quartz and feldspar and a high percentage of phyllosilicates (Pl. 3, fig. 2). Some feldspar crystals are completely altered to phyllosilicates and have weathered out, leaving rusty cavities in many of the specimens.

Sharp (1958) suggested the alaskite originated from a late magma, rich in potassium and silica, which may have incorporated and assimilated earlier material that crystallized near the walls of the magma chamber. Similar alaskite dikes intrude the Clayton Peak, Alta, and Little Cottonwood stocks, possibly indicating that the alaskite intrusions are genetically related, and if so, that they are at least younger than 22 my, the radiometric date of the Little Cottonwood stock, the youngest stock.

Aplite

Aplite dikelets, approximately 1 to 1½ cm wide, were found paralleling the local joint system at localities 15, 57, and 108 and elsewhere. All their observed contacts are sharp and usually straight. No inclusions of country rock were observed within the dikelets. Na-cobaltinitrite staining revealed a high K-feldspar percentage (80-95 percent) in the dikelets.

Petrographic examination of samples from locality 108 revealed approximately 90 percent large anhedral-subhedral K-feldspar crystals, 2½ mm in diameter, and about 3 percent subhedral plagioclase of the same size (Pl. 3, fig. 3). Between the larger crystals lie minor amounts of anhedral quartz, pyroxene, biotite, and chlorite and traces of sphene and magnetite. The formation of chlorite from biotite probably resulted in residual titanium producing sphene and Fe-Ti oxides.

A dikelet at locality 15 has a texture similar to that at locality 108 but with greater plagioclase and quartz percentages. Some graphic intergrowths of K-feldspar and quartz occur in some grains. A dikelet at locality 57 has about equal amounts of quartz, orthoclase, and plagioclase, with a greater percentage of mafic minerals—biotite, pyroxene, and hornblende—than in those described above.

Small "stringy" veinlets (1-2 mm thick) occur in a small outcrop near locality 37. They probably resulted from local fracturing and subsequent introduction of residual accumulation of quartz between K-feldspar, pyroxene, and plagioclase crystals. Experiments by Johns and Burnham (1969) suggest that pegmatites are directly related to a separate vapor phase produced within the melt after the crystallization of aplite. No pegmatites, however, were found in the pluton. The production of a residual, high vapor pressure, high K-feldspar melt might account for the high percentage of large K-feldspar oikocrysts found in the central texture zone and possibly also for the high concentration of K-feldspar in the aplite dikelets.

ORIGIN OF TEXTURE AND MINERAL FACIES

Total plagioclase, K-feldspar, and quartz percentages were recalculated to 100 percent and plotted on the ternary diagram, Q-Or-Ab (Text-fig. 12). The pluton varies in composition from a monzonite and quartz monzonite to a diorite or granodiorite. The average mode was calculated and determined to be a quartz monzonite after most modern classifications. O. F. Tuttle and N. L. Bowen (1958) have shown that granitic rocks are gradational and that boundaries established between various rock types are arbitrary. They found that the frequency distribution of granite rocks showed 75 percent to be distributed at the center of the albite-orthoclase-quartz ternary diagram. They proposed to call those rocks found at the center "granites" and those outside the center by other descriptive names. They also proposed that the granitic rocks may further be divided into two classes: (1) hypersolvus (one feldspar) granites, syenites, and nepheline syenites, characterized by the absence of plagioclase except as a component of perphite, and (2) subsolvus (two feldspar) granites, syenites, and nephenline syenites characterized by discrete grains of potassium feldspar and plagioclase. The hypersolvus texture, formed by separation during cooling, indicates that the rock crystallized at a temperature above that of the solvus, possibly because of low PH_2O. The subsolvus texture suggests that the higher PH_2O produced crystallization on the solvus.

Plagioclase phenocrysts and crystals have An values as high as 65 to 70. Referring to the three-component system $CaAl_2Si_2O_8$-$NaAlSi_3O_8$-$KAlSi_3O_8$, Stewart and Roseboom (1962) have shown that on the An-Or face of the An-Ab-Or diagram the solidus always intersects the solvus. Thus, the precipitation of two feldspars would occur relatively early. The high-Ca system would be prone to precipitate plagioclase at even higher temperatures or lower water pressure than those characterizing the Ab-Or system described by Tuttle and Bowen (1958). The lack of perthite in the Clayton Peak stock again substantiates such a system. Changes in temperature or PH_2O serve only to raise or lower the intersection of the solidus and the solvus. As the formation of plagioclase and pyroxene progressed, the residual liquid phase became more alkalic and hydrous, migrating towards the eutectic valley in which alkali feldspar begins to precipitate. The fact that pyroxene shows evidence of being resorbed and of reacting to hornblende in the Clayton Peak stock suggests instability in the system, a tendency to become more hydrous (Piwinskii and Wyllie, 1968). As the residual PH_2O increases, the temperature of intersection of the solidus and solvus is lowered, which would terminate the critical solution curve at a more Or-rich composition (Stewart and Roseboom, 1962).

High-Ca plagioclase crystals, such as those of the Clayton Peak stock, may owe their origin to earlier magmatic processes. Experimental studies by Piwinskii and Wyllie (1958) have shown the persistence of plagioclase at temperatures of 900°C in granodiorite and tonalite and suggest that such rocks were never completely molten or that plagioclase phenocrysts began forming at depths at which temperatures are much higher than 900°C. Piwinskii (1958) further suggests that if such rocks were formed by anatexis, then either high temperatures were required at the base of the crust or the magmas consisted of a eutecticlike granite liquid with suspended crystals of plagioclase and hornblende (pyroxene with low PH_2O). Piwinskii and Wyllie (1968) favor the suspended crystal magma and describe various methods for the formation of batholithic rocks. Their preferred working model involves hybridization of gabbroic magma (probably partly crystallized and differentiated) with anatectic granitic magma in the lower crust. Such a system could explain the mineralogy and texture of the Clayton Peak stock. The occurrence of high-Ca plagioclase in the central as well as the outer portions of the stock also suggests that these crystals may have originated deep within the magma before the development of textural and mineralogical zoning during the final crystallization period after emplacement.

Detailed field, petrographic, and trend-analyses studies have shown the Clayton Peak stock to be a heterogeneous intrusion. Variations in texture and mineralogy obviously indicate variations in temperature, pressure, and/or composition of the magma during crystallization. The ubiquitous occurrence of phenocrysts throughout the Clayton Peak stock suggests early stages of crystallization followed by stages of more rapid cooling that created the relatively finer groundmass. Sudden losses of PH_2O locally might also explain the areas of microcrystalline textures.

The fact does exist, however, that an inner zone of coarse oikocrystic quartz monzonite contains more K-feldspar and biotite phenocrysts and less plagioclase than does an outer zone of greater plagioclase bearing granodiorite or diorite.

Allingham (1954), in his description of the Cable stock, Montana, recognized a similar poikilitic texture with K-feldspar and quartz oikocrysts enclosing smaller plagioclase laths. He noticed that the texture is fairly constant throughout the stock except near the contacts with the sedimentary rocks. Moore (1963) recognized large porphyritic K-feldspar in the central part of the Carthridge Pass and other plutons. They were also found to grade mineralogically from high K-feldspar, quartz, and biotite at the center to lower percentages near the margins.

The core of the Clayton Peak pluton is poikilitic, whereas the margin is not, suggesting that the K-feldspar oikocrysts formed after emplacement of the pluton during the period of final zonation and crystallization.

There are a number of suggested mechanisms for the production of zoned plutons (Moore, 1963; Turner and Verhoogen, 1960; and others). The magma could have become differentiated either before or after the period of intrusion and crystallization. A compositional gradient might be the product of ion migration caused by the buildup of H_2O and alkalic constituents wherever temperature or pressure gradients develop in the melt. It is difficult, however, to visualize ionic diffusion on a large enough scale to produce zones like those of the Clayton Peak stock.

The possibility that such intrusions might have been produced by the "flotation" of early-formed crystals that attached themselves to bubbles formed during early gas phases lacks evidence (Turner and Verhoogen, 1960). The lack of xenoliths and the composition and heterogeneity of the country rocks surrounding the stock provide no evidence that the contamination or migration of ions produced a mafic margin. The lack of schlieren structures in the Clayton Peak stock does not support the hypothesis that early-formed crystals moved from the center outward to the edge by convection currents.

The diffusion of mafic constituents towards the cooler margin of the pluton, where they may have been removed from the melt by crystallization and diffusion of sialic constituents towards the warm core, is feasible but only speculative (Moore, 1963).

A compatible mechanism for the production of the textural and mineral facies in the stock most likely involved the downward gravitational settling of early-formed mafic minerals and, possibly, of plagioclase in the center, while those at the cooler margins were frozen in place (Moore, 1963).

To establish which mechanism or combination of mechanisms produced the textural and mineralogical variations would require more evidence. The author's preferred model involves a combination of crystal settling, possible diffusion of mafic minerals downward at the hotter core of the pluton, and intensified crystallization on the margins. It is postulated that as crystallization of higher-temperature minerals occurred and diffused near the colder sedimentary host rocks, the melt at the margins became more viscous, producing a crystal "mush." Crystals within the viscous melt probably became suspended and relatively immobile, producing an outer, nonpoikilitic K-feldspar facies, higher in plagioclase and mafic minerals, much like the outer zone of the Carthridge Pass pluton described by Moore (1963). The formation of the viscous outer zone and the crystal settling of mafic minerals at the center probably produced a residual liquid high in K-feldspar and water pressure restricted towards the hotter central portion of the stock (Turner and Verhoogen, 1960). A residual melt high in water pressure resulting from the early crystallization of anhydrous minerals might also account for the large biotite phenocrysts as well as the large oikocrysts of K-feldspar. Local losses in volatiles during crystallization might explain the lack of large biotite crystals in some areas throughout the phenocrystic biotite facies. The formation of hornblende from pyroxene in various locations further attests to the presence of a hydrous melt.

As crystallization progressed, two major textural facies formed: the outer zone, composed mainly of high temperature minerals, plagioclase, and pyroxene; and the central zone, containing large poikilitic K-feldspar grains and generally large biotite phenocrysts. Moore (1963) suggests that the production of large K-feldspar phenocrysts (and possibly oikocrysts) is more likely to occur in larger plutons (at least 1.5 miles in width) and in plutons of intermediate composition (silicic granodiorite).

The schematic cross section through A-A' (Text-fig. 13) of the texture facies illustrates the postulated model for the origin of the major crystallization facies within the Clayton Peak stock the nonpoikilitic-low K-feldspar facies of granodiorite and diorite generally on the margins and the poikilitic K-feldspar facies of quartz monzonite and monzonite at the center.

Alternating light bands of poikilitic K-feldspar and dark bands of plagioclase and pyroxene are found dipping towards the center of the stock (locality 148). Because of local fracturing within the more rigid outer zone, the residual melt may have been able to penetrate some areas filling the fractures with high-potassium feldspars. The dark bands probably represent part of the earlier high-temperature crystalline facies.

Aplite dikes composed almost entirely of K-feldspar, some having poikilitic texture, formed either from this residual K-feldspar-rich vapor phase or from smaller vapor systems of similar origin.

REGIONAL RELATIONSHIPS OF THE CLAYTON PEAK STOCK

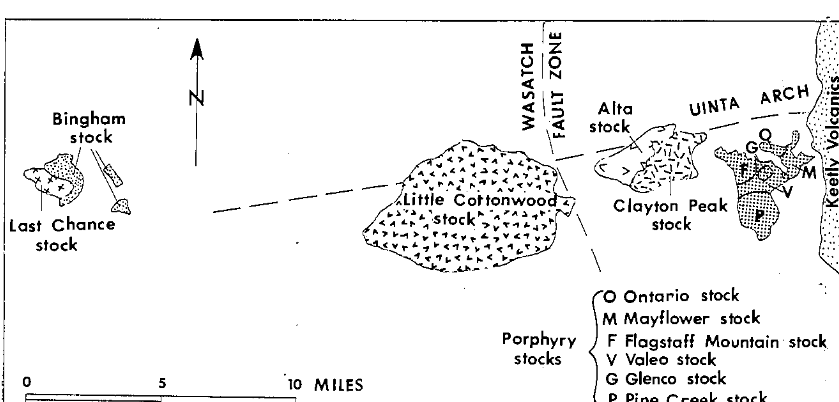
Two major structural trends intersect near the Park City-Cottonwood district: the north-south Wasatch fault zone and the Uinta arch, which extends from the east (Text-fig. 15). A large volcanic mass and nine major plutons are located along the Uinta Extension in the area mentioned above, and two other plutons are further to the west in the Oquirrh Mountains.

Description of the Igneous Masses along the Uinta Arch

Far to the east of Clayton Peak lies a mass of volcanic breccias, tuffs, and flows of rhyodacite and andesite commonly known as the Keetley Volcanics (Broomfield et al., 1970). Just west of the extrusive rocks occur 6 separate intrusions, within a large porphyry complex, recognized and described by Broomfield and others (1970): the Ontario stock, a medium-grained granodiorite; the Mayflower stock; the Flagstaff Mountain stock; the Valeo stock; the Glencoe stock; and the Pine Creek stock. They are light to dark green granodiorites and granodiorite porphyries and are distinguished by slight differences in texture, although their compositions are rather uniform. Generally phenocrysts of plagioclase and hornblende are dominant; quartz and biotite phenocrysts are common; and the groundmass of the stocks is microgranular, consisting of orthoclase, plagioclase, and quartz. Exposed contacts between the various stocks are usually sharp with some brecciation near chilled selvages.

West of the porphyry stock complex lies the Clayton Peak stock, a light to dark gray, fine- to coarse-grained granodiorite/quartz-monzonite. The Alta stock, just west of the Clayton Peak stock, was studied in detail by Wilson (1961), who recognized a porphyritic granodiorite facies intruding a nonporphyritic granodiorite facies. Complete gradation between the two textures is apparent. The Alta stock intrudes the Clayton Peak stock to the east. Contacts are not sharp generally, except near the Big Cottonwood Mine.

West of the Alta stock the Little Cottonwood stock, the largest and most quartz-rich igneous intrusion in the central Wasatch Mountains, covers more than 25 square miles. The stock is elliptical and elongated in an east-west direction. The dominant rock type is a quartz monzonite, and it is coarsely



TEXT-FIGURE 15.—Tertiary intrusions along the Uinta Arch alignment.

porphyritic with 2 to 6 cm phenocrysts of K-feldspar in a granular groundmass. Fresh quartz monzonite is light gray with visible plagioclase, biotite, quartz, and orthoclase phenocrysts. The pluton also contains conspicuous dark rounded mafic inclusions, uniformly distributed, containing biotite, sphene, hornblende, plagioclase and some orthoclase phenocrysts. Sharp (1958) discusses in greater detail the petrology of the Little Cottonwood stock concerning possible relations to tungsten mineralization.

Exposed along the same Uinta extension, but farther to the west in the Oquirrh Mountains, are the Last Chance and Bingham stocks. The Last Chance stock consists of a fine-grained equigranular, augite-quartz monzonite intruded by the Bingham stock. The Bingham intrusion has been separated into 5 different facies: fine-grained equigranular quartz-monzonite, biotite-granite, granite porphyry, rhyolite porphyry, and quartz-latite porphyry. Mineralization is related to the granite porphyry phase of the Bingham stock.

The variations in texture and composition of the Clayton Peak, Alta, and Cottonwood stocks form a coherent sequence, increasing in coarseness of grain and percentage of silica, and decreasing in mafic minerals from east to west (Table 2). The least silicic mass was intruded first (Table 5) and was followed by more silicic masses containing mainly quartz (Calkins and Butler, 1943), suggesting that the Little Cottonwood quartz monzonite is the youngest and most silicic. The plutons in the Cottonwood district generally increase in size toward the west. The Last Chance and Bingham intrusions are comparable to the Little Cottonwood stock in composition. Average plagioclase An values also increase from the Little Cottonwood stock through the Alta stock to the Clayton Peak stock.

General trends in the relative ages of the various intrusions may also be significant. Ages on various plutons in the area have been determined by

TABLE 5
RADIOMETRIC AGE DATE COMPARISONS OF MAJOR INTRUSIONS ALONG THE UINTA ALIGNMENT

NAME	ROCK TYPE	AGE	SOURCE
Keetley Volcanics	(Rhyodacite andesitic tuffs and flows)	32-35 my	Crittenden, Stuckless Kistler and Stern (1973)
Pine Creek Stock	(Granodiorite porphyry)	37 my	Crittenden (1973)
Clayton Peak Stock	(Monzonite-monzodiorite	37-41 my	Crittenden (1973)
Alta Stock	(Granodiorite)	32-33 my 39-45 my	Crittenden (1973) Armstrong (1963)
Little Cottonwood Stock	(Quartz monzonite)	24-31 my	Crittenden (1973)
Last Chance Stock	(Quartz monzonite)	38-39 my	Moore and Lanphere (1971)
Bingham Stock	(Granite-quartz monzonite)	36 my	Moore and Lanphere (1971)

Armstrong (1966), Crittenden, Sharp, and Calkins (1952), and more recently by Crittenden, Stuckless, Kistler, and Stern (1973), who used new, improved K-Ar techniques. They also summarized much of the age dating for the Park City–Cottonwood and Bingham districts. Some of the major intrusions, their rock types, and relative radiometric dates are listed in Table 3. The Clayton Peak stock was intruded 37-41 m.y. ago, the Alta stock about 32-33 m.y. ago and the Little Cottonwood stock between 24 and 31 m.y. ago.

That the three intrusive masses are so closely related spatially (the Clayton Peak and Alta stocks having actual contact with one another, the plutons generally becoming larger to the west), compositionally (varying with increasing SiO_2 and decreasing mafic minerals) and in time (having average calculated radiometric dates approximately within 10 m.y.) suggests a common origin for the magmas. Magmatic differentiation of a large granitic magma could possibly explain the textural and mineralogical variations of the stocks.

Berge (1960) observed that the stocks appear to have crystallized at shallower depths towards the east. He suggests that the Park City porphyry complex may represent the outer portion of a large igneous mass that has moved up the Wasatch Fault. He also postulates that the Little Cottonwood stock could be the innermost and deeper portion of the igneous mass, having been uplifted further and, consequently, eroded more deeply. Further to the west a similar model of magmatic differentiation might also have produced the variations in the Last Chance and Bingham stocks, which also show similar radiometric dates of intrusion. Regional studies on differentiation indices on the various igneous bodies along the Uinta alignment would undoubtedly provide a better understanding of the regional relationships of the stocks.

ORE DEPOSITS NEAR THE CLAYTON PEAK STOCK

The Cottonwood District has produced some $40 million in lead, silver, gold, copper, and zinc ore between the years of 1867 and 1954. There are two types of ore deposits associated with the Clayton Peak and Alta stocks: contact deposits and bedded replacement deposits. Most major deposits of economic value are related to the Alta stock. Small amounts of chalcopyrite and bornite were found on the mine dumps and near the contacts by the Big Cottonwood mine. The Mid-Park Mining Company of Provo, Utah, reportedly encountered a copper deposit related to the Clayton Peak stock (Cranor, 1974). Other adits and test pits are located above the Mid-Park Mine in Snake Creek Canyon and near localities 110 and 111 west of Guardsman Pass.

Test pits near the Alta-Clayton Peak contacts at the Big Cottonwood Mine, locality 1 and near locality 68, show fracture fillings of malachite and some limonite staining. Since most sedimentary contacts of the Clayton Peak stock show only contact metamorphism with little or no metallic mineralization, the writer believes that the mineralizing fluids that produced the deposits of malachite near the Alta contacts were probably related to the Alta intrusion or episode, not the Clayton Peak intrusion.

The Clayton Peak stock, however, must have had some secondary ore-forming solutions to produce the small areas of malachite and magnetite fracture-fillings near localities 138, 139, and 167 (Text-fig. 2). One might speculate that these small mineralized deposits probably represent the lower portions of much greater mineralized zones within the sediments that once covered the intrusion but that have been removed by erosion.

Geochemical studies by Belt (1969) and some minor studies by the author have determined the relative amounts of Cu, Zn, and Pb in the stock to be insignificant. Detailed studies on metallic mineral percentages of the Alta and Clayton Peak skarn zones were conducted and reported by Cranor (1974). A heavy-mineral study by Berge (1960) revealed a trend of mineralization and suggests the possibility of a mineralized area east of the Park City intrusions.

SUMMARY AND CONCLUSIONS

The Clayton Peak stock is one of several Tertiary intrusive bodies occurring in a westward-extending trend from the Uinta Arch in north-central Utah. The Clayton Peak stock undoubtedly was subjected to variable magmatic changes, as is suggested by the textural and mineralogical zoning recognized through petrographic and field studies of the stock. Four textural zones recognized include a central poikilitic K-feldspar facies; a phenocrystic biotite facies, also located towards the center; an outer, nonpoikilitic K-feldspar facies; and a microcrystalline facies.

Trend analyses of various samples throughout the stock have shown the Clayton Peak stock to grade from a high K-feldspar and quartz, low plagioclase core to a low K-feldspar and quartz, high plagioclase and mafic margin. Hornblende is especially abundant near the contacts associated with an apparent lack of pyroxene. Petrographic modal analyses suggest that the Clayton Peak stock is a pyroxene, hornblende, biotite granodiorite or quartz monzonite rather than a diorite, as described by former writers.

It has been postulated that magmatic differentiation of a magma during crystallization resulted in two major textural facies: the nonpoikilitic K-feldspar high-plagioclase diorites or granodiorites near the margin of the pluton and the poikilitic K-feldspar facies at the center. Crystallization of anhydrous minerals resulted in a hydrous melt that most likely facilitated the growth of large biotite phenocrysts and the poikilitic K-feldspar grains.

Alaskite dikes of similar texture and composition have intruded the Clayton Peak stock as well as the Alta and the Little Cottonwood stocks and are possibly more closely related to the Little Cottonwood intrusive period.

Aplite dikelets and alternating silicic and mafic bands may also be genetically related to a residual melt high in K-feldspar responsible for the poikilitic K-feldspar facies of the pluton.

Mafic inclusions found near locality 179 are postulated to have originated from early crystallized material near the walls of the magma chamber that were later assimilated and rounded to their present shapes.

Three major joint trends have been mapped and may have some genetic relationship to either the cooling and postintrusive adjustments of the Clayton Peak stock, the intrusion of the Alta stock, and/or Tertiary faulting in the area.

Textural and mineralogical variations of the Clayton Peak, Alta, and Little Cottonwood stocks form a coherent sequence, the older more mafic pluton on the east becoming younger, more silicic, and larger to the west. Radiometric age dating by Crittenden and others (1973) and field observations by the author show that the Alta stock intrudes the Clayton Peak stock. It is proposed that magmatic differentiation of a parent magma would account for the three closely related stocks. A large zoned igneous mass eroded to deeper levels on the west would explain the variations in texture, mineralogy, and radiometric age dates of the intrusions from east to west.

Metamorphic skarn zones within the sedimentary contacts of the Clayton Peak stock show very little metallic mineralization. Secondary malachite has filled fractures in some locations and may represent lower portions of much greater mineralized zones within the overlying sediments that have been removed by erosion.

There has been some mining of sulfide minerals at the Big Cottonwood mine and Snake Creek Canyon area. Metallic mineralization related to the Clayton Peak stock appears to be rather scarce and of low grade. Exploration to the east of the Clayton Peak stock may reveal noneroded metallic deposits related to the Park City complex of granodiorite porphyries.

Additional geochemical trend analyses of the Clayton Peak stock may supply further information on the mineral zonation, provided that careful sampling schemes are employed.

REFERENCES CITED

Allingham, J. W., 1954, Metamorphism at the contact of the Cable stock, Montana; Unpublished thesis, California Inst. Tech., 236 p.

Anderson, S. R., 1974, Stratigraphy and structure of the Sunrise Peak area, south of Brighton, Utah; Brigham Young Univ. Geol. Studies, v. 21, pt. 1, 131-50.

Armstrong, R. L., 1966, K-Ar dating using neutron activation for Ar analysis, granitic plutons of the eastern Great Basin, Nevada and Utah: Geochim. Cosmochim. Acta, v. 30, p. 565-600.

———, 1968, Sevier orogenic belt in Nevada and Utah: Geol. Soc. Amer. Bull., v. 79, p. 429-58.

Baird, A. K., McIntyre, D. B., and Welday, E. E., 1967a, Geochemical and structural studies in batholithic rocks of southern California; Part 2, Sampling of the Rattlesnake Mountain pluton for chemical composition, variability, and trend analysis: Geol. Soc. Amer. Bull., v. 78, p. 191-222.

———, McIntyre, D. B., Welday, E. E., and Morton, D. M., 1967b, A test of chemical variability and field sample methods, Lakeview Mountain tonalite, Lakeview Mountains, Southern California Batholith; *in* Short Contributions to California Geology: Calif. Div. Mines Special Report 92, p. 11-19.

Baker, A. A., Calkins, F. C., Crittenden, M. D., Jr., and Broomfield, C. S., 1966, Geologic map of the Brighton quadrangle, Utah: U.S. Geol. Surv. Geologic Quadrangle Map GQ-534.

Balk, R., 1937, Structural behavior of igneous rocks: Geol. Soc. Amer. Mem. 5, 177 p.

Barnes, M. P., and Simost, J. G., 1968, Ore deposits of the Park City district with a contribution on the Mayflower Lode: *in* Ore deposits in the United States, 1933-1967: v. 2, Amer. Inst. Mining, Metal., Petrol. Engineers, Inc., 888 p.

Belt, C. B., Jr., 1969, Preliminary geochemical study of the Alta and Clayton Peak intrusives: *in* Guidebook of northern Utah: Utah Geol. Mineral. Surv. Bull. 82, p. 111-23.

Berge, C. W., 1960, Heavy-minerals study of the intrusive bodies of the central Wasatch Range, Utah: Brigham Young Univ. Research Studies, Geol. Series, v. 7, no. 6, 31 p.

Billings, M. P., 1954, Structural geology: Prentice-Hall, Inc., 514 p.

Boutwell, J. M., 1913, Geology and ore deposits of the Park City District, Utah: U.S. Geol. Surv. Prof. Paper 77, 231 p.

Broomfield, C. A., 1968, General geology of the Park City region, Utah: *in* Guidebook to the Geology of Utah: Utah Geol. Soc., no. 22, p. 10-29.

———, Baker, A. A., and Crittenden, M. D., Jr., 1970, Geologic map of the Heber quadrangle, Utah: U.S. Geol. Surv. Geologic Quadrangle Map GQ-864.

Butler, B. S., and Loughlin, B. F., 1915, A reconnaissance of the Cottonwood-American Fork area, Utah: U.S. Geol. Surv. Prof. Paper 201, 152 p.

Chayes, F., 1956, Petrographic modal analysis: John Wiley and Sons, Inc., N. Y., 113 p.

Compton, R. R., 1955, Trondhjemite batholith near Bidwell Bar, Calif.: Geol. Soc. Amer. Bull., v. 66, p. 9-44.
Cranor, J. I., 1974, Petrology and geochemistry of the calc-silicate zone adjacent to the Alta and Clayton Peak stocks near Brighton, Utah: Brigham Young Univ. Geol. Studies, v. 21, pt. 1, p. 151-76.
Crittenden, M. D., Jr., Sharp, B. J., and Calkins, F. C., 1952, Geology of the Wasatch Mountains east of Salt Lake City, Parleys Canyon to Traverse Ridge: Guidebook to the geology of Utah, no. 8: Utah Geol. Soc., p. 1-37.
———, Stuckless, J. S., Kistler, R. W., and Stern, T. W., 1973, Radiometric dating of intrusive rocks in the Cottonwood area, Utah: U.S. Geol. Surv. Jour. Research, v. 1, no. 2, p. 173-78.
Emerson, D. O., 1964, Modal Variations within granitic outcrops, Amer. Min., v. 49, p. 1224-33.
Esler, J. E., Smith, P. F., and Davis, J. C., 1968, KWIKR8, a Fortran IV program for multiple regression and geologic trend analysis: Kansas Geol. Surv. Computer Contrib. 28, 31 p.
Harbaugh, J. W., and Merriam, D. F., 1968, Computer applications in stratigraphic analysis: John Wiley and Sons, Inc., 282 p.
Hyndman, D. W., 1972, Petrology of igneous and metamorphic rocks: McGraw-Hill Co., 533 p.
Jackson, E. D., and Ross, D. C., 1956, A technique for modal analyses of medium- and coarse-grained (3-10 mm) rocks: Amer. Min., v. 41, p. 648-51.
Jahns, R. H., and Burnham, C. W., 1969, Experimental studies of pegmatite genesis: 1. A model for the derivation and crystallization of granitic pegmatites: Econ. Geol., v. 64, p. 843-64.
Jaffe, H. W., et al., 1959, Lead-alpha age determination of accessory minerals of igneous rocks (1953-1957): U.S. Geol. Surv. Bull. 1097-B., p. 65-148.
Johannsen, A., 1939, A descriptive petrography of igneous rocks: Univ. Chicago Press, v. 1, 318 p.
Moore, W. J., and Lanphere, M. S., 1971, The age of porphyry-type copper mineralization in the Bingham district, Utah—a refined estimate: Econ. Geol., v. 66, p. 331-34.
Nockolds, S. R., 1954, Average chemical compositions of some igneous rocks, Geol. Soc. Amer. Bull., v. 65, p. 1007-1032.
Piwinskii, A. J., 1968, Experimental studies of igneous rock series, Central Sierra Nevada batholith, California: Jour. Geol., v. 76, p. 548-70.
———, 1968, Studies of batholithic feldspars: Sierra Nevada, California: Contr. Min. Petrol., v. 17, p. 204-223.
———, and Wyllie, P. J., 1968, Experimental studies of igneous rock series: a zoned pluton in the Wallowa batholith, Oregon: Jour. Petrol., v. 76, p. 205-234.
Sharp, B. J., 1958, Mineralization in the intrusive rocks in Little Cottonwood Canyon, Utah: Geol. Soc. Amer. Bull., v. 69, p. 1415-30.
Solomon, M., 1963, Counting and sampling errors in modal analysis by point counter: Jour. Petrol., v. 4, p. 367-82.
———, and Green, R., 1965, A chart for designing modal analysis by point counting: Geol. Rundschau, v. 55, p. 844-48.
Stewart, D. B., and Roseboom, E. H., Jr., 1962, Lower-temperature terminations of the three-phase region plagioclase-alkali feldspar-liquid: Jour. Petrol., v. 3, pt. 2, p. 280-315.
Stringham, B., 1953, Granitization and hydrothermal alteration at Bingham, Utah: Geol. Soc. Amer. Bull., v. 64, p. 945-91.
Turner F. J., and Verhoogen, J., 1960, Igneous and metamorphic petrology: McGraw-Hill Co., 2nd ed., 694 p.
Tuttle, O. F., and Bowen, N. L., 1958, Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2–H_2O; Geol. Soc. Amer. Mem. 74, 153 p.
Van Der Plas, L., and Tobi, A. C., 1965, A chart for judging the reliability of point-counting results: Amer. Jour. Sci., v. 263, p. 87-90.
Whitten, E. H. T., 1961, Quantitative areal modal analyses of granitic complexes: Geol. Soc. Amer. Bull., v. 72, p. 1331-60.
Wilson, J. W., 1961, Geology of the Alta stock: Unpublished Ph.D. dissertation, Calif. Inst. Tech., 236 p.