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Eleven small Mesozoic plutons crop out within a 76-square-mile area of the southern Seven Devils Mountains in west-central Idaho. The plutons are divided into a mafic suite, an older granitic suite, and a younger granitic suite on the basis of age, lithology, and degree of metamorphism.

The six plutons of the mafic suite are Late Triassic-Middle Jurassic (?) in age. Maximum dimensions are slightly over 3 miles in length and about 4,000 feet in width. Rock types, which may vary within individual plutons, are quartz-bearing hornblende metagabbro, hornblende metanorite, metadiorite, and metamorphosed quartz diorite. Chemically, the rocks are dioritic. The elongation of plutons suggests that emplacement was guided by the northeast-trending zone of weakness exemplified by the mylonite of the Oxbow-Cuprum shear zone. Forceful emplacement is indicated by local deflection of mylonite around plutons. Amphibolitization of pyroxene implies an increase in water pressure during the late stages of

crystallization. The mafic plutons were subjected to greenschist facies regional metamorphism.

The three plutons of the older granitic suite are Late Jurassic (?) in age. Maximum dimensions are 2 1/2 miles long and 4,200 feet wide. Rock types include quartz diorite and granodiorite; the Crystal Lake pluton shows a faint compositional zonation. The elongation of plutons indicates that emplacement was guided by the northeast trend of the country rocks, including the Oxbow-Cuprum shear zone. Forceful emplacement is shown by the deformation of mylonite around the Crystal Lake pluton. The three intrusions show slight effects of greenschist facies regional metamorphism.

The two plutons of the younger granitic suite, Deep Creek and Echols Mountain stocks, are Late Jurassic-Early Cretaceous (?) in age. The Deep Creek stock, largest intrusive mass in the thesis area, covers 9 1/2 square miles and has a thermal aureole as much as 5,000 feet in width. Twelve tabular marble xenoliths, the largest about half a mile in length, were probably derived from the Martin Bridge limestone at depth. Platy flow structure, defined by the orientation of hornblende, biotite, and schliern, forms a concentric funnel-shaped closure in the main body of the stock and a glacier-like pattern in part of the eastern prong. The flow structure is thought to have originated, (1) by rotational alignment of platy minerals into parallelism with contacts early in the emplacement history of the stock, and (2) by orientation of platy minerals normal to the direction of greatest magmatic pressure during the later stages of intrusion. Marginal fissures, which form the only consistent joint pattern in the main body of the stock, indicate late stage adjustment of the consolidated shell to pressures from the interior. The main body of the quartz diorite pluton is compositionally zoned. Potassium feldspar and quartz increase inward; whereas color index decreases inward. Chemically, the stock exhibits a calc-alkaline trend of differentiation.

The Echols Mountain stock, about four square miles in area, is similar in petrography to the Deep Creek stock. Flow structure outlines a dome, however, rather than a funnel. Neither the Deep Creek nor the Echols Mountain stock is metamorphosed.

The eleven plutons of the map area represent three episodes of Mesozoic plutonism that in part straddle the time interval between emplacement of the Late Permian-Middle Triassic Canyon Mountain complex (Thayer and Brown, 1964) and the Middle Cretaceous-Early Tertiary Idaho batholith.

Plutonic Rocks of the Southern Seven Devils Mountains, Idaho

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PLUTONIC ROCKS OF THE SOUTHERN SEVEN DEVILS MOUNTAINS, IDAHO

INTRODUCTION

General Statement

Eleven discrete Mesozoic plutons, ranging in composition from gabbro to granodiorite, crop out in the southern Seven Devils Mountains of western Idaho. A reconnaissance study by Cannon (Hamilton, 1963, Plate 3) delineated the general outline of the plutons, but no detailed work was done.

The purposes of the present investigation are to present a detailed geologic map of the plutons, to determine their mineralogical and internal structural characteristics, to record their effects upon the surrounding country rocks, and to formulate this information into a concept of their evolution.

Location and Accessibility

The thesis area encompasses approximately 76 square miles of west-central Idaho between north parallels 45°7' and 45°16', and west meridians 116°28' and 116°42' (Figure 1). Access is provided by county and Forest Service roads from Oxbow, Oregon, 16 miles to the southwest, and Council, Idaho, 37 miles to the southeast.

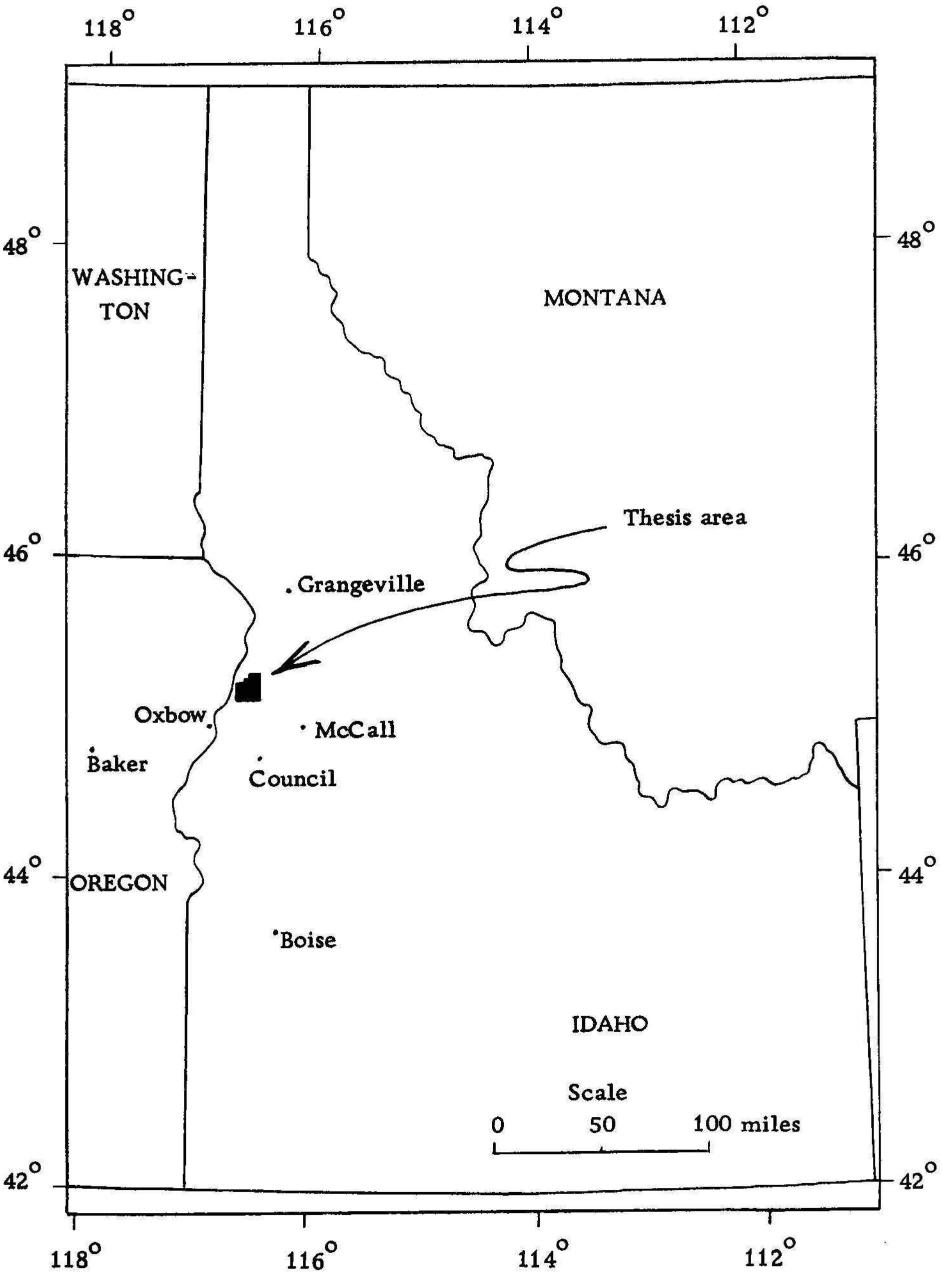


Figure 1. Index map showing the location of the thesis area.

There are no permanent human habitations in the southern Seven Devils area.

Topography and Drainage

The highest point in the thesis area, Monument Peak, is 8,957 feet, whereas the lowest elevation, in Deep Creek and Rapid River, is 4,800 feet. In the scenic northern part of the area, slopes plunge steeply from narrow ridges into deep U-shaped glacial valleys. South of Pepperbox Hill, a striking change in the topography occurs as precipitous cliffs give way to gentle grass- and tree-covered slopes.

The area is drained by west-flowing tributaries of the Snake River and east-flowing branches of the Little Salmon River. Major Snake River tributaries include Granite Creek on the north, Deep Creek in the central area, Kinney Creek on the west, and Indian and Bear Creeks on the south. The Little Salmon River drainage is represented by Rapid River and its Forks. Many smaller streams originate in the 30 cirque and moraine lakes of the region. The two largest lakes, neither more than 0.3 miles in length, are Black Lake in the central part of the map area, and Emerald Lake on Granite Creek.

Previous Investigations

Ore Deposits

Most previous investigations in the southern Seven Devils region dealt with the copper deposits of the Peacock and associated mines. Early studies by Packard (1895), Lingren (1899, p. 125; 1900, p. 88, p. 249-253; 1902), Beals (1900), and the various mine inspectors for the state of Idaho (Czizek, 1899, p. 34; Jacobs, 1902, p. 26-27; Bell, 1904a, p. 136-138; Bell, 1904b, p. 130; Bell, 1905, p. 131-134, 142; Bell, 1906, p. 166; Bell, 1907, p. 204, 205), described the geology, production, and history of these properties. Lindgren recognized that the ore deposits of the Peacock mine were of the contact metamorphic type, the first of this nature to be described in the United States.

Between 1905 and 1920, papers on the economic geology were mostly private mine-evaluation reports (Hancock, 1905; Dickman, 1907) and government bulletins (Weed, 1906, p. 108, 109; Hill, 1912, p. 507; Varley, 1919, p. 49, 50) that were surveys of copper in the United States and mentioned the Seven Devils in only a passing way. Reid (1907) made a brief description of the ore deposits and Umpleby (1916, p. 28-29, 36) recorded some notes regarding ore genesis. Livingston and Laney (1920) presented a comprehensive study of the mineral deposits, the most complete even to this day. Later articles included a four-part series by Bell (1929, 1930a, 1930b, 1930c) on northwestern porphyry copper prospects and a bulletin on the ore deposits by Cook (1954).

Distinctive Minerals

Of special note are three publications on the distinctive mineralogy of the contact deposits. Melville (1891) established the type locality for powellite, a calcium molybdate, at the Peacock mine. He named the mineral after John Wesley Powell, then director of the United States Geological Survey. Palache (1899) described the more common gangue and ore minerals from the Peacock and White Monument mines. Cannon and Gremaldi (1953) noted the presence of lindgrenite, a copper molybdate, and cuprotungstite, a copper tungsten mineral, at the Helena mine. Previously, lindgrenite, originally described in Chile, had not been recognized in the United States.

Plutonic Rocks

Early publications on the Seven Devils Mountains contain few details regarding the plutonic rocks. The first recognition of their variety and areal extent came with the field studies of Ralph S. Cannon Jr., who worked in the region between 1938 and 1940. His field and laboratory investigations were incorporated in reports by

Cook (1954, p. 4-5, Figure 4) and Hamilton (1963, p. 15, 16, Plate 3). Cannon delineated the approximate boundaries of most of the eleven plutons. Between 1940 and 1949, additional mapping by B. K. Thomas (Cook, 1954, Figure 4) added some detail to Cannon's work.

Methods of Investigation

Field work required 38 weeks during the summers of 1964, 1965, 1966, and 1967. Base maps include portions of the 15-minute Cuprum and He Devil quadrangles, and parts of the 7 1/2-minute Heaven's Gate, Pollock Mountain, and Railroad Saddle quadrangles (U. S. G. S. topographic map series). The Cuprum and He Devil sheets were enlarged to a scale of 1:24,000. Although no alluvium is shown on the geologic map (Plate 4), its presence is reflected in most dotted contacts.

Six hundred and twenty-five thin sections were examined. Between 2,000 and 2,200 points were counted in 250 thin sections from the Crystal Lake, Deep Creek, and Echols Mountain plutons and 1,000 to 1,100 points in representative sections from all other intrusive bodies. All thin sections exceed 900 square mm in area; methods of analysis were those described by Chayes (1949).

Five-axis universal stage techniques (Noble, 1965) were employed in measuring 2V's. Standard oil immersion methods (sodium light) were used to determine refractive indices; liquids were checked after each reading with an Abbe refractometer. The coarseness index of rocks in the Deep Creek stock was determined by tabulating the number of grain boundaries intercepted on three 40-mm-traverses and taking the average.

The three- and five-axis universal stage techniques of Slemmons (1962) and Noble (1965) were used for the optical determination of plagioclase composition. With the Slemmons method, used on 14 thin sections from the Deep Creek stock, only one or two crystals were measured per section. With the Noble method, used for all other determinations, a minimum of two crystals were measured per section. In dealing with zoned plagioclase, either special care was exercised to select areas within individual crystals that appeared representative of the average composition, or as many as four separate determinations were made in different parts of a crystal, and averaged. A total of 252 measurements were made on 165 crystals from the Deep Creek stock; about 148 measurements were made on 143 crystals from the other plutons. Both universal stage techniques are accurate within three percent An (Slemmons, 1962, p. 18; Noble, 1965, p. 380).

The following procedure was used for the X-ray examination of plagioclase, employed only on samples from the Deep Creek stock. Crystals were picked from a crushed aggregate, mixed with a small amount of silica gell as filler, and X-rayed using filtered CuKα

radiation in a Norelco diffractometer with Bristol recorder. Divergence and scatter slits were set at one degree; the receiving slit was set at .003 inches. A scanning speed of 0.25° 2θ per minute, chart scale of one degree per inch, and time constant of two seconds were used. The 2θ-values of the critical peaks were measured to the nearest hundredth of a degree using the 1/3-down-the-peak-method as the position for measurement. The factor, $\Gamma = [2\theta(131)+2\theta(220)-4\theta(1\bar{3}1)]$, was calculated, the figures plotted against weight per cent An/An+Ab on the low curve of Smith and Gay (1958, p. 749), and the An-values determined. At least two patterns were run on every sample and as many as eight were run on some. According to Hall (1965, p. 429) the accuracy of X-ray methods is better than three percent An.

Terminology

The granitic rock classification followed in this report (Figure 2) is similar to that by Travis (1955). The use of ten percent quartz as the division between diorite and quartz diorite is in accord with current usage (Moore, 1963; Bateman *et al.*, 1963). Gabbro is differentiated from diorite by the presence of labradorite.

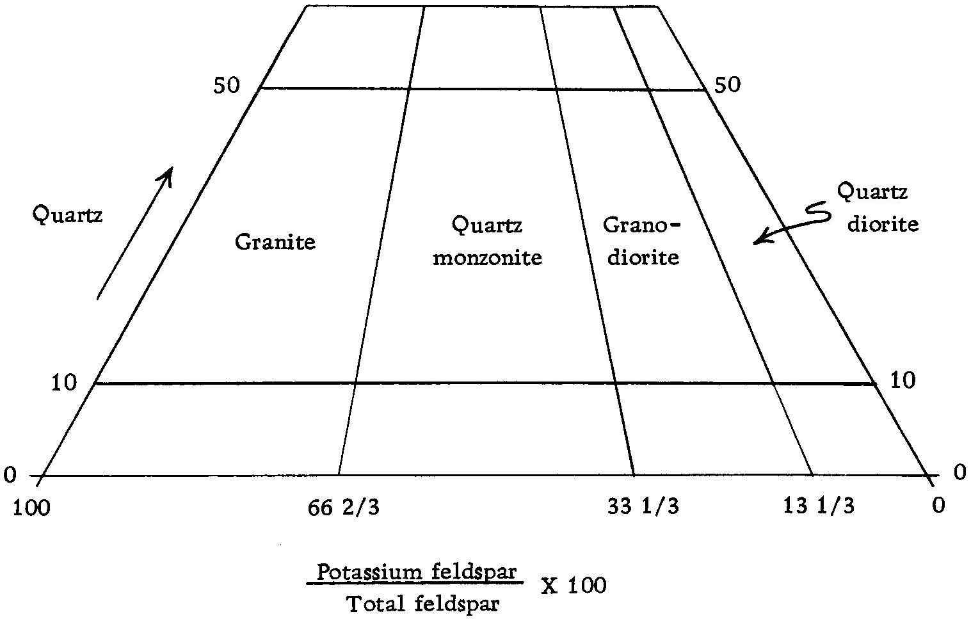


Figure 2. Classification of granitic rocks used in this report.

GENERAL GEOLOGY

General Statement

The Mesozoic plutons of the southern Seven Devils Mountains intrude the Seven Devils volcanics, the Oxbow-Cuprum shear zone, and the Martin Bridge Formation. A mafic dike system cuts the older plutons. Rocks of the Riggins Group were supposedly thrust westward over the plutonic rocks (Hamilton, 1963), but this relationship is not clear in the map area. Flows of Miocene Columbia River basalt persist in the southern part of the area; they formerly covered all intrusive bodies.

The plutons are subdivided into a mafic suite, an older granitic suite, and a younger granitic suite on the basis of differences in mineralogy, degree of metamorphism, and age.

Country Rocks

Seven Devils Volcanics

The Seven Devils volcanics, named by Anderson (1930, p. 13), crop out in about 50 square miles of the map area. They are a heterogeneous assemblage of purple and green spilite, keratophyre, metavolcanic breccia, and volcaniclastic metasedimentary rocks. Where present, bedding is best developed in metasedimentary rocks, but it is also defined by vesicular interflow zones in some extrusives. Northeast strikes are typical, fracture cleavage is common, and flow cleavage is characteristic of northeast-trending shear zones.

The mineralogy is indicative of greenschist facies regional metamorphism. Albite, actinolite, epidote, chlorite, magnetite-ilmenite, leucoxene, quartz, calcite, white mica, and rare biotite are present. Relict augite in volcanic rocks northwest of Kinney Point, and hornblende south of Smith Mountain, suggest that the original rocks were basalt and possibly hornblende andesite. Textures of flow rocks are felty, pilotaxitic, and intergranular. Many are porphyritic or glomeroporhyritic; phenocrysts reach lengths of 13 mm in a keratophyre near Horse Mountain. Poorly sorted wackes are the most common metasedimentary type.

An Early Permian and Middle-to-Late Triassic age for the Seven Devils volcanics is indicated by fossils in rocks of the adjacent Snake River canyon (Vallier, 1967a).

Oxbow-Cuprum Shear Zone--The Mylonite Zone

A zone of fluxion-layered mylonite (Reed, 1964), four miles long and a maximum of 2,500 feet wide, trends approximately N 42°E from Deep Creek to Paradise Creek (Plate 4). The south end of the mylonite zone, covered by alluvium in the canyon of Deep Creek, is probably terminated by the Deep Creek stock. The northern extremity of the zone, also concealed by alluvium, does not reappear in outcrops near the projected strike. Local folding and faulting of mylonite, caused by the emplacement of plutons, is particularly evident on the Paradise Creek-Pactolian Gulch divide.

Although exposures are good throughout the zone, they are best in Granite Creek canyon where the alternating light and dark gray layers give outcrops a striped appearance (Figure 3). The light-colored layers, which range in width from a few inches to as much as 15 feet, consist of hard, flinty rocks in which individual minerals are rarely discernible. Well-developed fluxion structure, marked by dark pods and platy flow layers, parallels contacts (Figure 4); augen of metadiorite locally persist between the Purgatory and Satan Lake plutons. Slickensides define a lineation that approximates the strike of the fluxion structure.

The darker layers, also as much as 15 feet wide, are either fine-grained rocks, which are only microscopically foliated, or schist. The dark layers commonly pinch out on strike; contacts are always sharp. Both the light and dark layers are cut by stringers of epidote and quartz.

Light gray mylonite consists of granoblastic quartz lenses and rounded, ragged-edged, sausseritized plagioclase porphyroclasts in a matrix of finer quartz and plagioclase. Fluxion structure is defined by the alignment of quartz lenses, the platy orientation of plagioclase,

Figure 3. Fluxion-layered mylonite, Granite Creek.

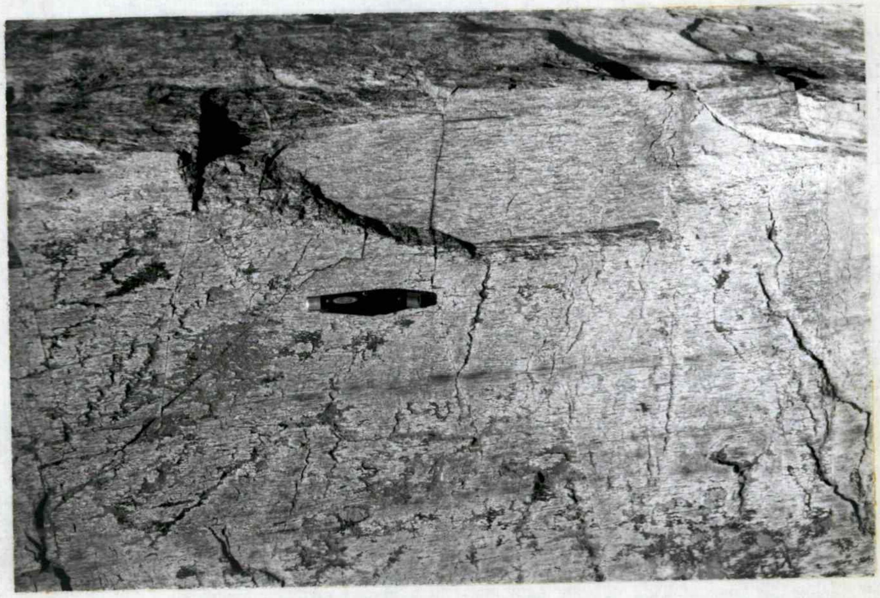


Figure 4. Fluxion structure in light gray mylonite, Granite Creek.

and the concentration in narrow strips of granular epidote and magnetite with rare chlorite and sphene. Apatite, zircon, hematite, and rarely potassium feldspar and biotite occur in some rocks. Less intensely sheared light gray mylonite contains more plagioclase porphyroclasts, little matrix, and less abundant, but more deformed, quartz. Fluxion structure is defined by strips of broken hornblende fragments.

Dark gray mylonite contains a jumble of anhedral and rarely subhedral sausseritized plagioclase surrounded by elongated patches and strips of hornblende that define the foliation. Quartz is not abundant; biotite occurs in some rocks.

The granoblastic nature of the quartz suggests that much is recrystallized. The difference between dark and light bands is in the concentration of hornblende, which may in part be a function of the intensity of shearing.

The Oxbow-Cuprum shear zone (Taubeneck, 1966, p. 2118) was mapped by Vallier (1967a) in lower Indian Creek, about 13 miles south of the map area, as a "foliated zone" characterized by a vertical northeast-trending foliation. Vallier (1967a, p. 186) defined the shear zone, however, as including not only the foliated and intensely sheared cataclastic rocks, but also unsheared, but faulted, metavolcanic, volcaniclastic, and plutonic rocks. He traced the foliated zone about six miles northeast of the Oxbow of the Snake River, but under the broader definition, traced the Oxbow-Cuprum shear zone northeast to within two miles of the Deep Creek stock (Vallier, 1967b). Vallier (1967a, p. 191) noted that localization of plutons, including gabbro and albite granite, was a distinctive feature of the zone.

The mylonite zone of this report is correlated with the Oxbow-Cuprum shear zone on the basis of trend similarity, character of fluxion rock, localization of plutons, and near coincident alignment across the intervening Deep Creek stock. Major movement on the shear zone, according to Vallier (1967a, p. 191), occurred during Late Permian-Middle Triassic.

Martin Bridge Formation

East-dipping gray limestone and light gray marble in the southeastern part of the map area (Plate 4) were described and tentatively correlated by Hamilton (1963, p. 9-11) with the Upper Triassic Martin Bridge Formation.

Dikes

Numerous mafic hornblende-plagioclase dikes crop out north of Deep Creek. Although a few trend northeast, most strike northwest and dip steeply. All dikes have sharp contacts, a few exhibit well-defined chilled borders, and some emit apophyses. Widths of several feet are typical; 15 feet is the maximum. Some dikes pinch, swell, and actually terminate by "tailing out" in the plutonic rocks, whereas others are continuous for more than 100 feet and discontinuous for almost half a mile. The mafic dikes are dark gray, greenish gray, and grayish purple. Most are porphyritic. Phenocrysts are plagioclase and (or) long acicular hornblende, which is, in general, entirely altered to chlorite, epidote, and calcite. Matrix plagioclase may be coarse and ragged, fine and granular, or lath shaped, forming felty and pilotaxitic textures. Additional minerals are quartz, white mica, an opaque mineral, hematite, leucoxene, and, within the aureole of the Deep Creek stock, flaky green biotite.

Light greenish gray dikes, one of which is near the head of Granite Creek and another south of Joe's Gap, generally trend north or east, and, as a group, are continuous for greater distances than the more mafic types. They have the same constituents as the mafic dikes, but there are fewer dark minerals; plagioclase is the most common phenocryst. Both varieties were subjected to regional metamorphism.

The dikes probably are Middle Jurassic in age. They transect the mafic suite plutons, which are Late Triassic-Middle Jurassic (?), but were affected by the regional metamorphism, which, according to Vallier (1967a, p. 174) and Hamilton (1963, p. 84), is Middle-to-Late Jurassic.

Riggins Group

Purple to gray biotite schist and phyllite occur as float in the southeastern part of the map area (Plate 4). Because no rocks in the Seven Devils volcanics are comparable, the schist and phyllite are referred to the Riggins Group (Hamilton, 1963). The thrust fault along Rapid River is extended southwest from the map by Hamilton (1963, Plate 1) on the basis of this float. Age of the Riggins Group, according to Hamilton (1963, p. 35), could be anywhere from Cambrian through Early Cretaceous.

Columbia River Basalt

Flows of Columbia River Basalt crop out in five places within the thesis area. Small exposures, not exceeding 1,000 feet in diameter, are about 1,500 feet northeast of Towsley Spring, on the saddle southeast of Lake Winifred, and on the west flank of Smith Mountain (Plate 4). Each outcrop consists of not more than three flows of coarsely crystalline Picture Gorge (Waters, 1961, p. 607) or lower basalt type (Bond, 1963, p. 6; Ptacek, 1965). A fourth patch, south of Smith Mountain, is about 3,300 feet long and composed of four flows, two of Picture Gorge type, and possibly two of overlying Yakima (Waters, 1961) or upper basalt type (Bond, 1963, p. 6; Ptacek, 1965). The largest outcrop, which covers six square miles in the southeastern part of the map (Plate 4), consists of as much as 1,100 feet of Picture Gorge and at least 340 feet of Yakima. The Picture Gorge section includes approximately 60 feet of palagonite breccia and pillow basalt in Rapid River canyon. The straight contact near Wesley Creek probably is a fault.

At Horse Heaven, approximately one mile north of the map area, six flows of Picture Gorge type basalt, totalling about 340 feet thick, mark the highest occurrence of Columbia River Basalt (base at about 7,800 feet) in the Seven Devils Mountains. Generalized attitude is N 40° W, 12° SW.

The Columbia River Basalt is Miocene-Pliocene in age (Waters, 1961).

PLUTONS OF THE MAFIC SUITE

General Statement

The six plutons of the mafic suite crop out on glaciated ridges and cirque-cliffs north of Deep Creek (Plate 4). They are closely spaced elongate intrusions ranging from about 1 mile to more than 3 miles in length and from less than 150 feet in width to as much as 4,000 feet. In each, the long dimension trends consistently N 30° - 40° E. Contacts are sharp; thermal metamorphic effects in the surrounding metavolcanics are minimal.

Hand specimens of the mafic rocks are medium bluish gray to greenish black. Generally equigranular textures are dominated by the near-tabular form of the two most abundant minerals, plagioclase and hornblende. Grain size is variable, but generally permits the distinction of a finer type, in which the minerals are barely discernible, from a coarser type, in which the larger hornblende crystals exceed 3 mm in length and in one sample reach 13 mm. All mafic rocks, both fine and coarse, are cut by ubiquitous epidote-healed microfractures.

In thin section, rocks of the mafic suite consist of quartz-bearing hornblende metagabbro, hornblende metanorite, metadiorite, and metamorphosed quartz diorite. Although individual plutons may contain several rock types, distributed in no obvious pattern, some show a tendency towards an average composition of one type or the other. Labradorite, andesine, albite, hornblende, and locally quartz, augite, hypersthene, potassium feldspar, and brown biotite are essential minerals; titaniferrous magnetite, pyrite, sphene, zircon, and apatite are accessories; and actinolite, colorless amphibole, green biotite, chlorite, epidote, clinozoisite, calcite, talc, white mica, hematite, and leucoxene are secondary products. Microscopic textures vary from hypidiomorphic to allotriomorphic granular. The former is the original texture of the igneous rock, whereas the latter is due to cataclastic and regional metamorphism.

The six mafic intrusions, named for geographic localities, are discussed separately. Microscopic characteristics are generally quite similar. To avoid repetition, the petrographic description of a given pluton is limited to the particular minerals and textures that are best displayed therein.

Black Lake Pluton

Field Description

Hook-shaped Black Lake pluton, approximately 1 mile long and 1,500 feet wide, is in the Black Lake cirque (Plate 4). Best exposures are on the northeast slopes of Pyramid Peak and at the western end of Black Lake.

Contacts with dark greenish gray metavolcanics are sharp and nearly vertical. Along the northwest contact an irregular 1- to 3-foot zone of shear disturbs the country rock, but does not appear to affect the adjacent metagabbro. The zone is characterized by epidote-veneered, slickensided fracture surfaces, and abundant red iron oxide stain.

Both fine- and coarse-grained rocks occur in the pluton, but the distribution has no obvious pattern. Though most contacts are marked by epidote slip surfaces, relationships in one outcrop suggest that the coarser rock intruded the finer.

Petrography

The predominant rock type of the Black Lake pluton is quartz-bearing hornblende metagabbro. Modal analyses (Table 1) reveal a uniformity of mineral percentages unusual for the mafic plutons. Albitized metagabbros (124, 143) show no areal pattern. Minerals include plagioclase, hornblende, quartz, augite, potassium feldspar, titaniferrous magnetite, apatite, actinolite, green biotite, chlorite, epidote, calcite, white mica, hematite, and leucoxene.

Euhedral labradorite ranges in composition from An_{52} to An_{59}. Alteration products, which include flaky white mica, epidote, and limited chlorite, obliterate plagioclase in some sections, but scarcely occur in others. In the few crystals where progressive zoning is

Table 1. Modes of metagabbro from the Black Lake pluton (volume percent).

Sample	Plagioclase	Hornblende	Quartz	Potassium feldspar	Accessories		Actinolite	Green Biotite	Chlorite	Epidote	Calcite	An-content of plagioclase
					Opaque	Non-opaque						
124	52.8	14.6	5.7	0.3	1.8	0.3	9.8	---	1.4	13.3	---	4,5,6,6
125	52.5	27.5	3.0	---	4.5	---	1.3	8.6	---	2.6	---	
135	50.6	35.7	8.2	---	1.9	0.3	---	3.3	---	---	---	56,58,58,59,59
140	54.3	25.5	6.5	---	1.2	0.1	1.3	8.6	1.1	8.4	---	52,55,55,56
141	54.0	34.6	8.0	---	1.4	---	0.7	0.3	0.2	0.9	---	
143	58.9	0.8	16.8	---	3.1	---	---	12.2	0.6	7.4	0.2	3,4

pronounced, alteration tends to be core-selective.

Subhedral albite (An_{3-6}) is always thoroughly impregnated with very fine white mica, stubby epidote crystals, and countless opaque leucoxene (?) particles. This sausseritic alteration gives the plagioclase a characteristic "speckled" appearance. In one unusual section angular wedges of quartz form a replacive mosaic with albite.

Ragged-edged, embayed, subhedral hornblende is pleochroic blue green to pale green to pale yellowish brown. Individual crystals, occurring in five-mm-wide synneusis aggregates, contain an abundance of minute drop-like inclusions. These core droplets, probably quartz, trend at high angles to the long directions of the hosts.

Interstitial quartz is anhedral, but a wedge-shaped form is commonly imparted by the straight-sided borders of adjoining minerals. Colorless augite, rare in this pluton, is generally rimmed by hornblende.

Blue-green actinolite occurs in pockets within hornblende and projects outward in feathery, fan-like sprays from the prismatic edges of hornblende crystals. In one section actinolite bundles have a rectangular form, suggesting probable replacement of pyroxene. Actinolite is also present independently in angular cavities between plagioclase crystals, and, locally, in association with epidote in quartz-epidote stringers.

Platy biotite is strongly pleochroic from dark green to very pale yellowish brown. The occurrence of flaky aggregates with tabular, prismatic outlines and inclusions of relict green amphibole, indicates that the biotite formed at least in part from hornblende. Common associated minerals are epidote, chlorite, and calcite. A second type of biotite, also flaky, is widely scattered within plagioclase, particularly along cleavage traces. The strong similarity between this biotite and that developed by contact metamorphism in metavolcanics near the Deep Creek stock suggests a like mode of origin.

Although the pleochroism of epidote is distinct, the intensity of the yellow color varies in different parts of individual crystals. The larger, euhedral crystals are best developed in veins and in green biotite aggregates, whereas the smaller ones are typical of plagioclase alteration. The wide distribution of epidote testifies to the mobility of its constituents.

Hypidiomorphic granular texture is typical of the metagabbro. As the northwest contact is approached, however, mild fracturing becomes important. Plagioclase twin lamellae are broken and displaced along stringers of epidote. Within a narrow six-mm-wide zone adjacent to the contact, angular mineral fragments and larger, somewhat rounded, metagabbro fragments, are contained in a fine granulated matrix of the same constituents. The presence of fragmented metagabbro indicates that the deformation took place after the gabbro had consolidated, but how long after cannot be determined. The fragments could represent segments of a congealed shell disrupted during intrusion, or, as suggested by outcrop data, they could be shear slivers developed during a much later tectonic episode. The contact with porphyritic albitized metavolcanic rock is extremely sharp; albite phenocrysts are cleanly severed. Banded concentrations of leucoxene in the country rock form alternating light and dark strips parallel to the contact.

Purgatory Pluton

Field Description

Purgatory pluton is best exposed on the northeast-trending ridge that includes Purgatory Saddle (Plate 4). Smallest of the mafic bodies, it is barely 1 mile long and a maximum of 1,100 feet wide.

The pluton is bounded by both shear and intrusive contacts. In Granite Creek metagabbro is coarse and unfoliated along a sharp contact with intensely foliated fluxion rock. Some straight contacts in this area are minor slip zones, as indicated by slickensided epidote surfaces, but others are irregular and definitely intrusive. Metagabbro sends a few short apophyses into the fluxion rock and includes a few fragments of it. At one place, mafic pods, which help define structure in the fluxion rock, are intersected at an angle of ten degrees by the metagabbro contact.

A crude banding, unique to this pluton, but limited to the ridge northeast of Purgatory Saddle, is defined by localized concentrations of coarse hornblende. Bands are well defined, but sporadic, ranging from a quarter of an inch to several feet in width. Closely spaced consistent banding such as reported by Thayer (1963a) and Weatherall (1960) in nearby Oregon gabbros is nonexistent. The north-northeast-striking bands parallel the long direction of the pluton and are either vertical or dip steeply east. Where developed, the bands are as common in the interior of the pluton as near contacts.

Petrography

The rock types of the Purgatory pluton include both quartz-bearing hornblende metagabbro and metadiorite. If, in the modal analyses (Table 2), the amount of hornblende is added to minerals from which and to which it has changed, the percentages are quite similar. Only sample 155 is distinctly different, and it, having been taken from a hornblende-rich band, is atypical. Minerals of the Purgatory pluton include plagioclase, hornblende, quartz, augite, brown biotite, titaniferrous magnetite, sphene, zircon, apatite, actinolite, colorless amphibole, green biotite, chlorite, epidote, calcite, white mica, hematite, and leucoxene.

Plagioclase includes both andesine-labradorite (An_{42-55}) and

Table 2. Modes of metagabbro and metadiorite from the Purgatory pluton (volume percent).

						Accessories									
Sample	Plagio-clase	Horn-blende	Quartz	Augite	Brown biotite	Opaque	Non-opaque	Actinolite	Green biotite	Chlorite	Epidote	Clino-zoisite	Calcite	Amphibole	An-content of plagioclase
130	61.9	5.8	5.3	13.8	0.7	1.5	---	---	---	2.3	1.1	---	---	7.6	54, 54, 56
155	37.0	52.4	---	2.5	0.4	---	---	2.5	---	2.5	0.1	2.6	---	---	
158	69.9	17.5	2.5	---	1.0	0.4	---	0.9	---	7.5	0.2	---	0.1	---	
159	56.2	20.6	8.1	0.4	4.4	2.0	0.2	4.1	0.5	1.3	2.2	---	---	---	43, 46

albite. The calcic feldspar, which has rare oscillatory, as well as progressive zoning, exhibits the usual epidote and white mica alteration. Albite includes small green hornblende crystals and, although in general heavily sausseritized, has narrow rims that are alteration free.

Colorless augite crystals, always anhedral, reach lengths of 5 mm in the coarser rocks, but on the average do not exceed 3 mm. Inclusions consist of subhedral plagioclase and clinopyroxene, both less than a quarter of a mm in length. Excellent malacolite parting (on (001)), easily the most distinctive characteristic of the augite, forms a series of straight, closely-spaced, parallel breaks that closely resemble cleavage. Twinning (100), commonly multiple, gives the V- or zig-zag-pattern known as herringbone structure. In some crystals, the parting is emphasized by narrow strips of opaque.

Rims of blue-green hornblende, well developed in this pluton, represent early stages in the replacement of augite. Replacement, rather than mere addition, is indicated by the presence of relict plagioclase laths that are included in hornblende in exactly the same manner as they are in augite. Contacts between the rim and host are sharp. Further transformation resulted in the migration inward of the hornblende rim against a shrinking augite core, and finally, complete replacement. The end product is euhedral hornblende.

Bundles of colorless amphibole fibers that occur in augite interiors, testify to a second augite transformation. In some rocks, augite is no longer present and green hornblende surrounds only fibrous amphibole. This critical relationship suggests first, that the two transformations of augite were separate and distinct, and second, that the green hornblende preceded the fibrous type. This shift from one kind of pyroxene amphibolitization to another may record the change from late magmatic to deuteric conditions. Miller (1938, p. 1220) noted a similar relationship in the San Marcos gabbro.

Biotite, occurring in small, irregular, ragged-edged crystals, is pleochroic dark to light brown. As one biotite crystal is included by a hornblende rim around augite, the biotite must be of an earlier, or at least equivalent period of crystallization. This relationship serves to differentiate this brown biotite from the flaky green varieties of the Black Lake pluton, which are much later. Alteration products include chlorite, epidote, sphene, and leucoxene.

One mass of titanomagnetite includes a pyrite crystal and is itself rimmed by hematite. Other opaque aggregates are rimmed by chlorite, sphene, or biotite, and coated by leucoxene.

One small myrmekitic intergrowth occurs in an interstitial position between plagioclase laths and quartz. No potassium feldspar was detected.

In the hornblende-rich rock, plagioclase is so completely masked by countless small euhedral crystals of clinozoisite and masses of flaky white mica that the composition is indeterminable.

There are two kinds of hornblende, a pleochroic dark red-brown to light brown variety and a very pale green to colorless type. The brown hornblende crystals reach six mm in length and ophitically enclose green hornblende and plagioclase. The subordinate green hornblende occurs in the brown variety and also in independent synneusis aggregates characteristic of the mineral elsewhere in the pluton.

Clinozoisite, in addition to its occurrence in plagioclase, is also a vein constituent. The large, colorless, zoned and twinned crystals invariably display the "Berlin blue" interference color. Epidote is notably absent. There is almost no titanomagnetite.

Hypidiomorphic granular and allotriomorphic granular textures typify all rocks except the hornblende-rich variety which displays an ophitic texture.

Satan Lake Pluton

Field Description

Satan Lake pluton, slightly over 3 miles long and 1,200 feet wide, is the longest of the mafic bodies. The younger Crystal Lake intrusion has divided the pluton into three discrete parts--the northern two, separated by only 200 feet, are located near Gum Saddle, whereas the southern segment crops out on the divide above Satan Lake (Plate 4). Exposures are best near Satan Lake.

Contacts of the southern end of the pluton conform in overall map pattern to the foliation and banding of the adjacent fluxion rock. They strike northeast and dip steeply northwest. At Satan Lake, however, a change occurs, and contacts swing obliquely northward, paralleling a narrow zone of contact foliation in the pluton. This deviation, together with a scattering of large fluxion rock inclusions within the pluton, confirms intrusive origin.

Mafic contacts against the younger Crystal Lake pluton generally are not well exposed and must be mapped on the basis of changes in color index and quartz content. Where revealed, however, the junctures are extremely sharp (Figure 5). Near Paradise Creek, the occurrence of transected country rock inclusions in the Satan Lake pluton suggests proximity to the original pre-Crystal Lake contact with metavolcanics.

Although wall rocks of the Satan Lake pluton are commonly as devoid of metamorphic effects as those of other mafic bodies, there is one notable exception. Near Paradise Creek, green volcanics locally record foliation up to 300 feet from the intrusion. At one place, the contact occurs in a ten-inch-wide zone of intense injection where the percent of igneous rock barely exceeds that of partly digested wall rock. Further from the contact, oriented pods of country rock

Figure 5. Contact between metadiorite of the Satan Lake pluton (left) and quartz diorite of the Crystal Lake pluton, north of Paradise Creek.

gain predominance over a matrix of narrow stringers until, beyond ten feet, only mildly foliated volcanics occur. Another contact is characterized by a pronounced country rock veination in which stringers commonly expand or merge into veins consisting essentially of quartz. Some stringers extend from the gabbro and do not appear to cut it.

Intense fracturing of the pluton is characteristic of the northern Gum Saddle-Middle Mountain area. Outcrops are stained a dark green, almost black, by the chlorite-epidote veneers that coat the myriad of slickensided fracture surfaces. Shattering in place, rather than great lateral movement is indicated by the lack of abundant pulverization and the occurrence of mafic dikes which, though fractured, maintain trends for distances up to several feet. Also included in the area are pods of volcanics, slices of granodiorite or quartz gabbro, and a few pockets of relatively unfractured metagabbro--which are the best indication that the shattered area is actually part of Satan Lake pluton. Immediately north of the shattered zone, the rock is no longer recognizable as being part of the pluton, but it does have a grainy aspect in outcrop that differentiates it from volcanics. Significantly, the style of this fracturing is that of shatter rather than mylonitization.

Petrography

Rock types of the Satan Lake pluton include quartz-bearing hornblende metagabbro, hornblende metanorite, metadiorite, and metamorphosed quartz diorite. Hypersthene (Table 3) is unique to the Satan Lake pluton. Minerals include plagioclase, hornblende, quartz, augite, hypersthene, potassium feldspar, brown biotite, titanomagnetite, sphene, zircon, apatite, actinolite, chlorite, epidote, clinozoisite, talc, white mica, hematite, and leucoxene.

Calcic plagioclase (An_{42-55}) forms local synneusis aggregates, which, in the coarser rocks reach four mm in greatest dimension. A disordered structure, indicated by five separate measurements in sample 184, establishes the aureole of the younger Crystal Lake pluton as at least 15 feet. Alteration, in the same rock, is characterized by either core, or entire plagioclase replacement by larger masses of clinozoisite with few intermingled strips and patches of white mica. The clinozoisite is impregnated with a fine, grainy brown pigment, possibly leucoxene, shows good cleavage, and consistently exhibits the anomalous blue interference color. Albite is rare.

Although brown and green hornblende generally grade into one another and commonly exhibit the same textural characteristics, there is, in some rocks, a tendency for the brown hornblende to form

Table 3. Modes of metagabbro, metanorite, metadiorite, and metamorphosed quartz diorite from the Satan Lake pluton (volume percent).

Sample	Plagio-clase	Horn-blende	Quartz	Augite	Hypersthene*	Brown biotite	Accessories		Actinolite	Chlorite	Epidote	Calcite	An-content of plagioclase
							Opaque	Non-opaque					
148	54.1	26.7	---	4.5	12.2	0.5	0.6	---	1.4	---	---	---	
173	54.8	20.5	15.2	1.1	---	1.1	3.2	0.2	---	0.8	3.1	---	
178	61.5	19.4	6.2	3.6	---	0.1	3.2	0.1	4.1	0.5	1.3	---	45, 47, 49
184	48.7	19.9	0.7	2.4	26.6	0.2	0.3	---	0.2	1.0	---	---	52, 53
186	57.1	22.6	13.4	0.3	---	---	5.2	0.2	---	0.1	1.1	---	
202	45.8	42.3	7.3	0.1	---	0.1	1.9	0.5	---	0.5	1.5	---	41, 42, 46
205	66.9	17.3	6.1	1.4	---	2.6	4.0	0.1	---	0.7	0.9	---	53, 54, 57

*Includes talc.

the larger crystals that ophitically enclose plagioclase. A distinctive, but local feature of the brown type is the abundance of opaque, which occurs either as a dense peppering, or as linear strips along cleavage.

Quartz crystals are atypically elongate and sutured in a narrow foliated zone that parallels the contact near Satan Lake. Metamorphic recrystallization in response to shear is suggested.

Colorless augite is invariably rimmed, in whole or in part, by hornblende. The augite is generally peppered with opaque crystals, but well-defined opaque-filled malacolite parting, common in other plutons, is rare. Boundaries between augite and surrounding hornblende are sharp, but exceedingly irregular. The occurrence of hornblende as patches within augite indicates that the augite-hornblende transformation proceeded outward from several centers within the pyroxene, as well as inward from the amphibole rim. This is further emphasized by hornblende crystals in which augite occurs in patchy, yet optically continuous, cores. The next-to-last stages in the hornblendization of augite are recorded by bleached amphibole interiors in which irregular vermicular intergrowths of quartz and (or) small opaque-flecked augite crystals occur.

Hypersthene is pleochroic pale red to colorless. Large anhedral to subhedral crystals, as much as eight mm long, poikilitically enclose plagioclase and rare clinopyroxene. Alteration to talc is well displayed. In the initial stages, the talc-transformation proceeded inward from the pyroxene grain boundaries, and outward from hypersthene cleavage planes and from the tiny, irregular fractures that cross-cut the prismatic hypersthene at near right angles. The intersection of fracture and cleavage tended to divide the hypersthene into sub-rectangular blocks and as alteration proceeded, the blocks became isolated from one another by ever-increasing areas of talc. The end result is a flaky mass of talc entirely devoid of pyroxene.

Although the talc is generally finely crystalline, a few larger flakes permit identification. Considerable iron ore, concentrated along former hypersthene cleavage traces and scattered in smaller crystals and groups of crystals, occurs throughout the talc. Iron probably was released in the hypersthene-talc transformation. A few talc pseudomorphs are partially rimmed by pale green hornblende.

Some biotite, occurring as scattered ragged-edged tablets and as kelyphitic outgrowths around opaque crystals, is strongly pleochroic deep foxy-red brown to pale brown. In sample 184 this distinctive color can be attributed to contact metamorphism by the Crystal Lake pluton. In sample 148, however, taken over 2,000 feet from the contact, the origin is uncertain.

The mobility and extraneous origin of some leucoxene and, in part, epidote and white mica, is indicated by the sharply delimited alteration zone that borders one epidote stringer. The plagioclase, on each side of the vein and within a distance of three mm from it, is intensely altered to a dense mass of epidote, white mica, and leucoxene. Beyond the three-mm-limit, the same alteration products occur, but in much less abundance.

Primary textures are hypidiomorphic granular.

White Mountain Pluton

Field Description

White Mountain pluton, about 3 miles long and 4,000 feet wide, extends from Emerald Lake to Deep Creek canyon (Plate 4). Best outcrops are on the steep west divide of Granite Creek and on the heights of White Mountain.

Parts of the north and east contacts, in Granite Creek canyon, are definitely intrusive. Epidote veins, minor slip surfaces, and breccia occur locally, but the intensity of these features is generally very small. Fragments of porphyritic volcanic rock as much as three feet long are included in the pluton.

The irregular northwest contact is marked by an abundance of country rock prongs--some are in part diagrammatic on Plate 4. Large inclusions of country rock, not all of which were mapped, are also common in the northern area. Most of the west contact is against the younger Big Lake pluton. The southeast contact, in

Horse Pasture Basin, is bounded by mylonite, some of which parallels the pluton contacts.

A distinctive feature of the pluton is the occurrence of large areas of lighter gray rock that contain mafics which have been bleached to a very pale green. One such area, on the peak just north of Joe's Gap, is 1,500 feet long and 400 feet wide.

Petrography

Metadiorite and metamorphosed quartz diorite are the principal rock types of the White Mountain pluton. Modal analyses are given in Table 4. Former hornblende in sample 208 is replaced by biotite. Minerals include plagioclase, hornblende, quartz, augite, brown biotite, titanomagnetite, pyrite, sphene, zircon, apatite, actinolite, green biotite, chlorite, epidote, calcite, white mica, hematite, and leucoxene.

Andesine crystals (An_{43-50}) exhibit synneusis. Individuals may be differentiated from the composite by the divergence of twin directions. Inclusions and alteration products are apatite, secondary biotite, subhedral epidote, white mica, and chlorite. Preferential concentration of these minerals in the cores or along internal zone-shells of plagioclase occurs, but random orientation is more prevalent. Albite (An_3) is typical of the bleached metadiorite.

Hornblende is altered to chlorite, chlorite-calcite, biotite,

Table 4. Modes of metadiorite and metamorphosed quartz diorite from the White Mountain pluton (volume percent).

Sample	Plagioclase	Hornblende	Quartz	Augite	Brown biotite	Accessories		Actinolite	Green biotite	Chlorite	Epidote	An-content of plagioclase
						Opaque	Non-opaque					
208	62.9	---	16.0	---	---	2.3	0.4	---	17.3	---	1.1	42, 42, 44, 45
213	60.1	6.7	21.3	---	---	2.0	0.2	0.3	---	4.5	4.9	3, 3, 3, 3
218	62.2	23.2	0.1	---	---	2.8	---	6.5	---	0.6	4.6	
220	64.9	10.6	9.5	0.2	4.1	3.3	0.3	4.1	---	0.6	2.4	48, 50, 52
221	61.4	15.4	13.0	---	1.2	1.9	0.1	---	6.7	0.3	---	43, 46

and minor epidote. Where epidote is common, calcite is either absent or minimal. In addition, hornblende has a definite reaction relationship with two types of green actinolite. In one, actinolite is flaky, having frayed, fibery terminations. In the other, actinolite is acicular, having euhedral, well-defined prisms. With both types, massive hornblende is intimately associated in such a way that transformation cannot be doubted. Actinolite also occurs independently in plummose interstitial aggregates.

Both the early tabular brown biotite of the Purgatory pluton and the late flaky olive biotite of the Black Lake pluton are present. The early brown type either transects or penetrates hornblende. The later green variety replaces it.

Titanomagnetite is so named because of the nature of associated minerals. Chlorite, biotite, pyrite, hematite, and the yellowing of proximal epidote indicate the presence of iron, whereas sphene and leucoxene suggest titanium. A further indication that the opaque is titanomagnetite is the peculiar character of chloritic alteration masses which, though typical of most mafic plutons, are strikingly developed in this one. Aggregates of unaltered massive opaque, together with an adjacent network of intersecting opaque rods, are set in a matrix of chlorite. The rods are generally coated with leucoxene and form a pattern of triangular, rhomb- or diamond-shaped interspaces. This unique geometric arrangement is best explained by the alteration of ilmenite-magnetite intergrowths. The chloritization of host magnetite left relict ilmenite rods in chlorite. The pattern resulted from the crystallographic orientation of exsolved ilmenite along the octahedral faces of original magnetite. The so-called rods observed in thin section may actually be plates when considered in three dimensions.

Horse Pasture Pluton

Field Description

Horse Pasture pluton stretches 2 1/2 miles from the cirque of Satan Lake to the canyon of Deep Creek (Plate 4). Exposures of the 3,500-foot-wide intrusion are best on the southeast cliffs of Horse Pasture Basin.

Intrusive contacts prevail except on the south where the pluton is cut by the Deep Creek stock. Contacts generally are sharp. Relationships along the northwest border are somewhat obscured by shearing.

Both coarse and fine rocks occur, the coarser probably intruded the finer. This relationship, also present in the Black Lake pluton, may suggest local autobrecciation.

Petrography

Horse Pasture pluton is composed of metadiorite and metamorphosed quartz diorite. Of special note is a significant increase in chlorite and decrease in hornblende towards the northern end of the intrusion. The reciprocity of this relationship, which records a reaction between the two minerals, is shown by samples 165 and 176 in Table 5. Sample 165, a normal metamorphosed quartz diorite from the southern end of the pluton, has 2.5 percent chlorite and 20.8 percent hornblende, whereas 176, a chloritized rock from the northern part, has 19.9 percent chlorite and no hornblende.

Minerals of the Horse Pasture pluton include plagioclase, hornblende, quartz, potassium feldspar, titanomagnetite, pyrite, sphene, zircon, apatite, actinolite, green biotite, chlorite, epidote, calcite, white mica, hematite, and leucoxene.

Both andesine (An_{35-46}) and albite (An_{2-5}) contain inclusions of hornblende and green actinolite. Albite, which generally includes the minerals in much greater abundance than andesine, also contains chlorite, calcite, and fine leucoxene. In chloritized rocks, some albite boundaries show a blotchy intergrowth with quartz, a relationship that suggests replacement.

Green hornblende, the only essential mafic in the pluton, is altered to chlorite, biotite, calcite, and epidote. Chloritization, the

Table 5. Modes of metadiorite and metamorphosed quartz diorite from the Horse Pasture pluton (percent).

Sample	Plagioclase	Hornblende	Quartz	Potassium feldspar	Accessories: Opaque	Accessories: Non-opaque	Actinolite	Green biotite	Chlorite	Epidote	Calcite	An-content of plagioclase
150	60.0	2.9	14.2	1.2	7.7	0.1	---	---	11.1	0.1	2.5	
153	57.7	17.1	10.9	---	4.8	0.3	---	---	1.0	8.2	---	3, 5
163	57.9	27.6	8.9	---	3.1	0.4	---	1.5	0.5	0.1	---	35, 35, 37, 37
164	67.1	13.2	12.5	---	2.6	0.7	---	2.4	1.3	0.2	---	
165	57.4	20.8	13.3	---	3.6	0.8	---	---	2.5	1.4	0.2	39, 43
167	51.6	22.5	9.0	---	5.4	---	4.1	6.9	0.5	---	---	43, 45, 45, 46
172	63.0	12.9	0.4	---	2.8	0.2	---	---	7.3	13.4	---	2, 3
176	64.3	---	6.6	---	4.3	0.3	---	---	19.9	0.3	4.3	

most dramatic transformation, is represented in all stages. Initially, chlorite formed along the borders and cleavage traces of hornblende crystals. Where host cleavage was not well developed, chlorite originated in small ragged-edged patches. In advanced stages of hornblende transformation, complete replacement by chlorite occurred. Chlorite cleavage and flake orientation in pseudomorphs may parallel the long direction of the hornblende outline or mimic the two-directional cleavage of the basal section. In extreme examples, such as sample 150, the chlorite pseudomorphs show no amphibole form, and are irregular, web-like masses. Relict inclusions of plagioclase, epidote, and titanomagnetite are common.

Anhedral potassium feldspar, present in only one section, occurs as few, but significant, interstitial crystals. Contacts with plagioclase are irregular, but no myrmekite was detected.

Flaky biotite, variably pleochroic in shades of brown or olive, is secondary. It occurs within, or adjacent to hornblende and forms coronas around titanomagnetite. Chlorite pseudomorphs of biotite are recognized by their tabular form and a relict cleavage marked by strips of epidote, leucoxene, and the orientation of chlorite fibers. Though many pseudomorphs, limited in size and localized on hornblende, are certainly after secondary biotite, others, which are larger and independent of hornblende, could possibly have formed from an earlier, primary type. In rocks where pseudomorphs of both biotite and hornblende occur, the green chlorite after biotite tends to be strongly pleochroic, is generally fibrous, and exhibits both anamolous brown and blue interference colors. Chlorite after hornblende is only slightly pleochroic, is somewhat scaley, and exhibits only the anamolous brown.

Textures are both hypidiomorphic and allotriomorphic granular. In one mildly fractured rock, broken minerals are engulfed in a matrix of chlorite and leucoxene. In another, an oval-shaped inclusion, 13 mm long by 9 mm wide, has a much finer grain size than the host, but differs mineralogically in only a slight increase of mafics and opaque.

Pactolian Pluton

Field Description

Pactolian pluton, about 2 miles long and 2,400 feet wide, displays a rude swan-shaped map pattern in stretching southwest from Paradise Creek almost to Black Lake (Plate 4). Exceptional outcrops are on the sharp divide between the Black Lake Fork of Rapid River and Pactolian Gulch.

Contacts are sharp; some are partly sheared. Internal fracturing is typical of the neck-shaped northern part of the pluton.

Petrography

Albitization of the plagioclase prevents determination of former compositions, but quartz diorite was probably the major rock type of the Pactolian pluton. Modal analyses (Table 6) reveal both a significant potassium feldspar percentage in all but sample 171 and an average quartz content slightly higher than that of any other mafic intrusion. Minerals include albite, hornblende, quartz, augite, potassium feldspar, biotite, titanomagnetite, pyrite, sphene, zircon, apatite, calcite, white mica, hematite, and leucoxene.

Albite (An_{2-5}) is intensively altered to white mica, chlorite, epidote, and calcite. Interstitial quartz exhibits Boehm lamellae and undulatory extinction.

Augite, except for a few scattered remnants, is thoroughly chloritized. The pseudomorphs, which are rimmed by green hornblende, exhibit a fiber orientation that faithfully mimics former malacolite structure. An opaque mineral, finely disseminated throughout the chlorite, is probably both a by-product of the alteration and a relict that originally defined the parting. Calcite and minor epidote are common. Considering the alteration sequence demonstrated in the Purgatory pluton, the rimming of augite by hornblende probably preceded chlorite replacement.

Potassium feldspar, most abundant in this pluton, is

Table 6. Modes of metamorphosed quartz diorite (?) from the Pactolian pluton (volume percent).

Sample	Plagioclase	Hornblende	Quartz	Augite	Potassium feldspar	Brown biotite	Accessories		Chlorite	Epidote	Calcite	An-content of plagioclase
							Opaque	Non-opaque				
171	52.7	8.6	19.8	---	---	0.1	5.0	0.4	9.5	2.4	1.5	2, 3
179	55.4	9.3	18.5	---	6.3	---	0.3	---	4.6	1.1	1.5	3, 4, 4, 5
180	51.9	14.1	19.1	---	2.7	2.6	3.2	0.2	2.6	2.1	1.5	
181	52.9	12.3	18.6	---	2.6	2.1	2.9	1.0	2.8	1.9	2.9	
195	59.4	18.6	13.3	0.3	1.6	---	4.1	0.1	1.5	0.5	0.6	

interstitial, and exhibits exsolution lamellae. Replacement of quartz is indicated by the isolation of optically continuous quartz "islands" in a matrix of potassium feldspar. A more distinct replacement, that of plagioclase, is shown by the continuous twinning and zoning of plagioclase segments detached by potassium feldspar, the relict shape of the pseudomorphed parts of plagioclase crystals, and the thin strips of chlorite that once followed plagioclase cleavage and now extend into adjoining potassium feldspar. Two stages of potassium feldspar are indicated by the local penetration of the pseudomorphed edge of a plagioclase crystal by a narrow stringer of potassium feldspar.

Biotite is pseudomorphed by chlorite, epidote, and leucoxene. The large size of the pseudomorphs, as much as 2 1/2 mm long, suggests that the original biotite was the early, rather than the late type.

The superb octahedral parting of the opaque confirms its identity as magnetite, rather than ilmenite. As in the White Mountain pluton, however, associated sphene and leucoxene indicate some titanium, and hence the term, titanomagnetite.

Apatite occurs in scattered euhedral crystals as much as three-fourths of a mm long; zircon causes discoloration in chlorite.

Calcite is in small, scattered patches and in separate stringers with epidote. In the very northern part of the pluton, massive leucoxene-permeated calcite stringers suggest the presence of hydrothermal alteration, possibly associated with the ore deposits at nearby Iron Springs.

Textures are predominantly hypidiomorphic and allotriomorphic granular, though a porphyritic texture, possibly due to recrystallization, occurs in one rock.

Chemistry

Chemical analyses of metagabbro and metadiorite from the Black Lake and Horse Pasture plutons (Table 7) show that the metagabbro is, as expected, higher in CaO, but lower in Na_2O and K_2O than the metadiorite. In comparison with average rocks (Table 7), however, both types are dioritic in character. A distinctive feature is the unusually high normative quartz.

Age of the Mafic Suite

The plutons of the mafic suite probably are Late Triassic-Middle Jurassic in age. The local occurrence of metadiorite augen in the mylonite of the Oxbow-Cuprum shear zone, a narrow belt of foliated metadiorite at Satan Lake, and the striking mineralogical similarity between mylonite and metadiorite, suggest that at least some mafic plutons were emplaced either during or before the episode of mylonitization. Sharp contacts, apophyses, and inclusions, on the other hand, indicate that the Purgatory pluton intruded the mylonite. Cross-cutting contacts and inclusions at Satan Lake suggest the same

Table 7. Chemical analyses and norms of metagabbro and metadiorite with averages for comparison (weight percent).

	1	135	2	165	3
SiO_2	48.36	54.30	51.86	54.66	54.66
TiO_2	1.32	1.12	1.50	1.34	1.09
Al_2O_3	16.84	15.95	16.40	15.39	16.98
Fe_2O_3	2.55	2.19	2.73	4.65	3.26
FeO	7.92	7.64	6.97	6.22	5.38
MnO	0.18	0.21	0.18	0.25	0.14
MgO	8.06	4.73	6.12	4.22	3.95
CaO	11.07	8.17	8.40	6.73	6.99
Na_2O	2.26	2.38	3.36	3.35	3.76
K_2O	0.56	0.84	1.33	1.05	2.76
H_2O^+	0.64	2.10	0.80	1.78	0.60
H_2O^-	---	0.10	---	0.04	---
P_2O_5	0.24	0.16	0.45	0.33	0.43
Total	100.00	99.89	100.10	100.01	100.00
Q	---	10.32	0.3	10.32	2.0
or	3.3	5.00	7.8	6.12	16.7
ab	18.9	19.91	28.3	28.30	31.9
an	34.2	30.30	25.8	23.91	21.1
di	8.0	7.79	5.6	6.09	4.5
hy	21.4	18.68	23.8	13.45	12.9
ol	6.8	---	---	---	---
il	2.4	2.13	2.9	2.58	2.4
mt	3.7	3.25	3.9	6.73	5.3
ap	0.6	0.31	0.8	0.68	0.8
H_2O	---	2.20	---	1.82	---
Total	99.3	99.89	99.2	100.00	97.6

1. Average gabbro (Nockolds, 1954, p. 1020).
135. Metagabbro from the Black Lake pluton. Analyst, K. Aoki.
2. Average diorite (op. cit., p. 1019).
165. Metadiorite from the Horse Pasture pluton. Analyst, K. Aoki.
3. Average mangerite (monzodiorite) (op. cit., p. 1018).

for the Satan Lake pluton. The mafic plutons are, then, at least in part younger than the Late Permian-Middle Triassic Oxbow-Cuprum shear zone. They are older than the regional metamorphism, which is Middle-to-Late Jurassic (Hamilton, 1963; Vallier, 1967a). The relative ages of the plutons are uncertain.

Conclusions

Controlled emplacement of the mafic intrusions is indicated by their pronounced elongation parallel to the northeast strike of both the metavolcanics and the mylonite of the Oxbow-Cuprum shear zone. The actual mode of emplacement, however, is conjectural. Regional metamorphism and subsequent faulting probably obliterated much pertinent evidence that was in the surrounding country rocks. Nonetheless, the overall deflection of fluxion rock trends parallel to contacts of the Satan Lake pluton near Satan Lake (Plate 4), between the Purgatory and Satan Lake plutons north of Purgatory Saddle, and at the southeast end of the White Mountain pluton in Deep Creek canyon, suggest emplacement of the plutons by forceful means. Also suggestive of this is the contact-paralleling foliation in metavolcanics adjacent to the Satan Lake pluton near Crystal Lake. Local autobrecciation is implied by sharply bounded fine- and coarsely crystalline rock types in some intrusions, but its exact nature was not determined.

A marked increase in water pressure during the late magmatic and deuteric stages of crystallization is shown by the nature of the mineral paragenesis. Early magmatic crystals were anhydrous minerals such as labradorite, andesine, augite, and hypersthene. Late magmatic crystallization, however, included the primary precipitation of hydrous brown biotite and green and brown hornblende, as well as nearly complete hornblendization of pre-existing augite. That this reaction was primarily magmatic, rather than deuteric, is indicated by the subhedral form of hornblende crystals (Best, 1963, p. 235), the massive, rather than fibrous habit of hornblende (Herz, 1951, p. 993), and by the sharp boundaries between hornblende and surrounded augite (Johannsen, 1937, v. 3, p. 213). Hornblendization of hypersthene was also initiated in one pluton, but there is no evidence that it was ever carried to completion. Interstitial quartz and potassium feldspar crystallized late.

The change from late magmatic to deuteric conditions may be recorded in the sharp boundaries between magmatic hornblende rims and deuterically altered pyroxene interiors. Colorless fibrous amphibole, and possibly some actinolite and hornblende, replaced augite, whereas talc replaced hypersthene. Deuteric biotite altered from hornblende. Sausseritization of plagioclase and chloritization-epidotization of biotite, hornblende, and remaining augite may be ascribed to either deuteric or regional metamorphic processes.

Regional metamorphism of the mafic suite is confirmed by the presence of albite and actinolite. The above minerals indicate that metamorphism was of the greenschist facies (Turner and Verhoogen, 1960, p. 553), a conclusion that is substantiated by a like metamorphic grade in the country rocks.

PLUTONS OF THE OLDER GRANITIC SUITE

General Statement

The three plutons of the older granitic suite are in the north and central parts of the map area (Plate 4). They are elongate, striking N 45°-55° E, and range from less than 2 miles in length to over 2 1/2 miles and from almost 1,900 feet in width to about 4,200 feet. Contacts with metavolcanics and fluxion rock are always sharp; those with mafic plutons are either sharp or gradational.

The granitic rocks are generally light gray, but vary in hues of green and pink depending upon the abundance of mafic constituents and potassium feldspar. Grain size is markedly fine, minerals rarely exceeding two mm in greatest dimension. The typical granular texture is interrupted locally both by platy foliation, defined by mafics, and by numerous fractures.

Quartz diorite and granodiorite are the principal rocks. Despite fracturing, which prohibits the definition of mineral variation in most plutons, the Crystal Lake body shows a possible zonation. Essential minerals include potassium feldspar, quartz, oligoclase, andesine, biotite, and hornblende; accessories are magnetite, pyrite, sphene, zircon, apatite, and allanite; and secondary products include actinolite, green biotite, chlorite, epidote, calcite, white mica, hematite, and leucoxene. Microscopic textures are hypidiomorphic granular, except where modifed by fracturing.

Big Lake, Ruth Lake, and Crystal Lake plutons, named for localities where they are best exposed, are discussed individually.

Big Lake Pluton

Field Description

Big Lake pluton is exposed along the east end of Six Lake Basin and on both the north and south slopes of Deep Creek canyon (Plate 4). Excellent exposures occur near Big Lake. Maximum size is about 2 1/2 miles long and 1,800 feet wide.

Contact with gray metavolcanics, along the northwest border of the pluton, is sharp and commonly marked by a narrow band of epidote. The pluton sends apophyses into the metavolcanic rock and includes digested fragments as much as 54 inches long. Neither pluton nor country rock is foliated.

Most of the east contact of the Big Lake intrusion is against the White Mountain pluton. In Six Lake Basin, a similarity of rock type in the two intrusions made precise location of the contact impossible. The contact could be gradational over a distance of several hundred feet.

Petrography

Big Lake pluton is composed of quartz diorite. Modes, given in Table 8, show a pronounced increase in secondary green biotite in samples 379 and 438, taken from near the middle and near the southern end of the pluton (Plate 4). Minerals are potassium feldspar, quartz, plagioclase, hornblende, magnetite, sphene, zircon, apatite, allanite, actinolite, green biotite, chlorite, epidote, calcite, white mica and leucoxene.

Oligoclase-andesine ranges in composition from An_{24} to An_{36}. Normal zoning is common and oscillatory zoning is either absent or poorly developed. White mica-epidote alteration perforates the larger part of most crystals, but commonly does not effect the narrow rims. Hornblende is the only primary mafic mineral.

At the northern end of the pluton, blue-green actinolite, present only in sample 367, has much the same habit as in the rocks of the mafic suite, --principally in fibrous aggregates directly adjacent to, and merging with, hornblende. At the southern end of the pluton, however, actinolite forms discrete acicular crystals, either localized in granulated fracture zones, or randomly scattered in conjunction with stubby blue-green hornblende. Biotite is also variable. Near the midsection of the pluton, biotite occurs with chlorite, epidote, and calcite in hornblende pseudomorphs, and as patches and strips

Table 8. Modes of quartz diorite from the Big Lake pluton (volume percent).

Sample	Potassium feldspar	Quartz	Plagioclase	Hornblende	Accessories Opaque	Accessories Non-opaque	Actinolite	Green biotite	An-content of plagioclase
222	3.8	30.9	53.4	3.1	2.9	1.2	---	4.7	25
367	6.8	24.0	56.7	6.8	1.6	0.7	3.2	0.2	27, 28
378	1.7	20.3	65.5	8.8	2.1	0.4	---	1.2	32, 32, 33, 35
379	2.0	19.6	54.5	0.5	1.2	0.6	---	21.6	28, 32, 32
438	2.4	27.3	33.1	6.4*	1.9	1.8	---	27.1	32, 34, 35, 36

*Contact metamorphic actinolite included.

along plagioclase cleavage traces. On the south, biotite occurs in aggregates that are locally concentrated around opaque, and as finely disseminated flakes, which are particularly abundant in plagioclase. There is no reaction relationship with hornblende. The southward change in character of both actinolite and biotite is from that typical of minerals which formed from regional metamorphic and igneous processes to that typical of contact metamorphic types. The change probably is due to contact metamorphism by the Deep Creek stock.

Recrystallization and granulation of felsic minerals is common along narrow slip zones. Epidote stringers are present.

Ruth Lake Pluton

Field Description

Ruth Lake pluton crops out on the divide between Granite Creek and West Fork of Rapid River (Plate 4). The pluton is the northernmost of all studied intrusions and is unique in its isolation. Although exposures are excellent in the Ruth Lake cirque, perhaps as much as one third of the pluton lies beneath alluvium in West Fork canyon. The maximum probable size is 1.7 miles long and 3,000 feet wide.

Contacts against porphyritic volcanic rock are generally sharp and in many places marked by narrow stringers of epidote. Numerous apophyses, some large and including fragments of country rocks, are lighter colored and more finely crystalline than the rock of the main body. Pink quartz monzonite dikes, rarely more than 5 or 10 feet long, occur near contacts. Their presence here, over a mile from any other granitic intrusion, suggests a genetic relationship to the Ruth Lake pluton.

Platy flow structure, observed in talus, but not in outcrop, appeared only in blocks that contained inclusions--an association which suggests that the blocks came from near contacts. The main body of the pluton contains no planar structure.

Petrography

Ruth Lake pluton is a quartz diorite intrusion. Quartz monzonite occurs in the foot-shaped prong near Granite Creek (sample 358), but replacement textures suggest that it is not a normal differentiated rock type. Modes are given in Table 9. Minerals include potassium feldspar, quartz, plagioclase, biotite pseudomorphs, hornblende, magnetite, sphene, zircon, apatite, allanite, green biotite, chlorite, epidote, calcite, white mica, and leucoxene.

In most sections, potassium feldspar occupies its characteristic interstitial position. In the quartz monzonite, however, it replaces plagioclase to the extent that in one pseudomorph, only a narrow plagioclase rim and skeletal framework remain. Assuming that the original rock was similar to the second most potassium feldspar-rich

Table 9. Modes of quartz diorite and quartz monzonite from the Ruth Lake pluton (volume percent).

Sample	Potassium feldspar	Quartz	Plagioclase	Hornblende	Chlorite and green biotite*	Accessories: Opaque	Accessories: Non-opaque	An-content of plagioclase
225	2.0	23.7	66.6	---	5.1	1.3	1.3	23, 26, 26
354	0.5	27.1	62.2	---	5.5	0.9	3.8	26
355	4.5	32.6	51.2	2.3	5.6	2.0	1.8	26
356	3.7	27.5	55.3	0.3	4.0	2.0	7.2	24, 25, 26, 28, 29
358	21.3	28.7	39.7	---	5.8	2.6	1.9	29, 30

*Alteration product of biotite and hornblende.

sample in the pluton (355), approximately 20 percent of the plagioclase was replaced.

The quartz of sample 355, from near the northern contact, is elongate, sutured, and strained. These features, together with an abundance of deformation bands (Carter, *et al.*, 1964), reflect mild shearing. Quartz, in the quartz monzonite, replaces plagioclase. Lobe-shaped quartz masses encroach upon plagioclase laths, and areas of quartz include small patches of disconnected, but optically continuous feldspar.

Oligoclase (An_{23-30}) shows normal, but very little oscillatory zoning. White mica alteration is typical. Local deformation is evidenced by bent twin lamellae and narrow zones of alteration-free feldspar that cut across individual plagioclase crystals. The zones are in optical continuity with host crystals and are probably areas of recrystallization along microfractures. One broken plagioclase is healed by quartz.

All primary biotite is chloritized. Most pseudomorphs exhibit characteristic strips of finely crystalline leucoxene, or sphene, which define relict cleavage, and some have chlorite fibers oriented parallel to former tablet elongation. On the whole, chloritization of hornblende is almost as complete as that for biotite. Additional alteration products of hornblende are epidote, calcite, and possibly green biotite.

Normal hypidiomorphic texture is modified by mild fracturing.

Narrow slip zones, as much as two mm wide, are marked by intensive recrystallization and rarely granulation of felsic minerals, and are in turn followed by stringers of epidote and calcite. The stringers may also contain minor amounts of chlorite and sphene. Some fractures are very narrow, appearing as lines of serration, but still displacing and slightly bending plagioclase twin lamellae. Displacement never exceeds a small fraction of a mm.

Deformation took the form of both minor shearing, as evidenced by quartz suturing and elongation in the northern parts of the intrusion, and a mild fracturing throughout.

Crystal Lake Pluton

Field Description

Crystal Lake pluton, 2.6 miles long and a maximum of 4,000 feet wide, is the largest and least fractured member of the older granitic suite. It extends southwestward from Gum Saddle to Granite Creek and transects the Satan Lake pluton (Plate 4). Best exposures are in the Paradise Creek cirques, particularly near Crystal Lake.

Contact with metavolcanics occurs along the northwest border of the pluton near the crest of the Granite Creek divide. The straight-line juncture that is apparent when the area is viewed from across Granite Creek (Figure 6) is an illusion created by the accumulation of

Figure 6. Approximate contact between the Crystal Lake pluton (center) and metavolcanics (left), on the divide between Granite Creek and the Rapid River drainage.

Figure 7. Contact between quartz diorite of the Crystal Lake pluton (right) and light gray mylonite of the Oxbow-Cuprum shear zone, Granite Creek.

light-colored granitic talus against a "joint-scarp" of the darker metavolcanics. Although the contact is abrupt and does occur in the same general vicinity as the "joint-scarp", for the most part, there is little precise coincidence.

Contacts with layered fluxion rock are best represented in Granite Creek canyon. Abutment of the pluton against dark fluxion layers is conspicuous because of the contrast in color between the two rock types. Contact against the lighter layers, however, is commonly difficult to determine because of similarity in color and resemblance along the concordant contact between foliation of the igneous rock with that of the adjacent fluxion structure. However, the granitoid nature of the plutonic rock, together with the few occurrences in which the contact transects fluxion structure, serve to differentiate the two rocks. The contact is as abrupt as any other (Figure 7).

Apophyses of the pluton, which range from less than 5 feet to as much as 30 feet in width, penetrate the adjacent fluxion rock. Pink quartz monzonite dikes, also noted in the Ruth Lake pluton, trend across the contacts at high angles. In addition, the pluton contains angular 1- to 20-foot-long blocks of fluxion rock and rounded 3-inch-long digested inclusions that are now merely concentrations of mafic minerals. The contrast in degree of assimilation between the two types of inclusions suggests that the digested ones were carried from deeper levels. All features indicate intrusion.

Where observed, contacts with the mafic Satan Lake pluton are sharp. Near Paradise Creek (Figure 5) mild contact-paralleling foliation in the Crystal Lake body confirms its younger age.

Intense biotite-defined foliation, best developed in Granite Creek canyon, parallels the contact and dips steeply. Although some foliation, such as that near Paradise Creek and Crystal Lake, is probably primary, the intensity of development and coincident occurrence of adjacent fluxion rock at Granite Creek suggests that shearing played a local role in its formation. There may have been minor movement along the trends defined by the fluxion rock during late stage crystallization of the pluton.

Fracturing is present near Gum Saddle.

Petrography

Granodiorite and quartz diorite compose the Crystal Lake pluton. Modes are recorded in Table 10. A compositional zonation is suggested by the slight increase in potassium feldspar, expressed as a percent of total feldspar, inward and towards the northern end of the pluton (Figure 8). Minerals include potassium feldspar, quartz, plagioclase, biotite, hornblende, magnetite, pyrite, zircon, apatite, allanite, green biotite, chlorite, epidote, calcite, white mica, hematite, and leucoxene.

Table 10. Modes of quartz diorite and granodiorite from the Crystal Lake pluton (volume percent).

Sample	Potassium feldspar	Quartz	Plagioclase	Biotite	Hornblende	Accessories: Opaque	Accessories: Non-opaque	An-content of plagioclase
187	11.4	32.7	44.9	4.1	5.6	1.1	0.2	30, 31
191	8.8	27.5	50.4	5.0	6.7	0.8	0.8	28
192	8.9	31.6	47.2	5.9	5.5	0.7	0.2	36, 38
193	6.4	29.9	52.5	4.4	5.7	0.9	0.2	35, 35
198	5.5	32.3	50.5	5.9	4.0	0.5	1.3	31
199	9.5	28.6	49.0	6.5	5.9	0.5	---	35
200	10.8	33.3	45.9	5.2	4.0	0.4	0.4	31, 32
201	6.7	32.5	48.8	6.2	3.8	0.5	1.5	29, 31
203	9.0	28.5	49.8	5.0	6.7	0.9	0.1	35, 39
204	11.7	30.4	45.6	5.6	5.9	0.6	0.2	24, 25
361	8.1	26.8	50.9	4.6	5.3	1.1	3.2	26, 27
362	9.6	32.0	46.0	4.5	7.1	0.6	0.2	26, 27, 28, 30
363	12.2	28.0	49.1	4.6	5.4	0.6	0.1	26, 27

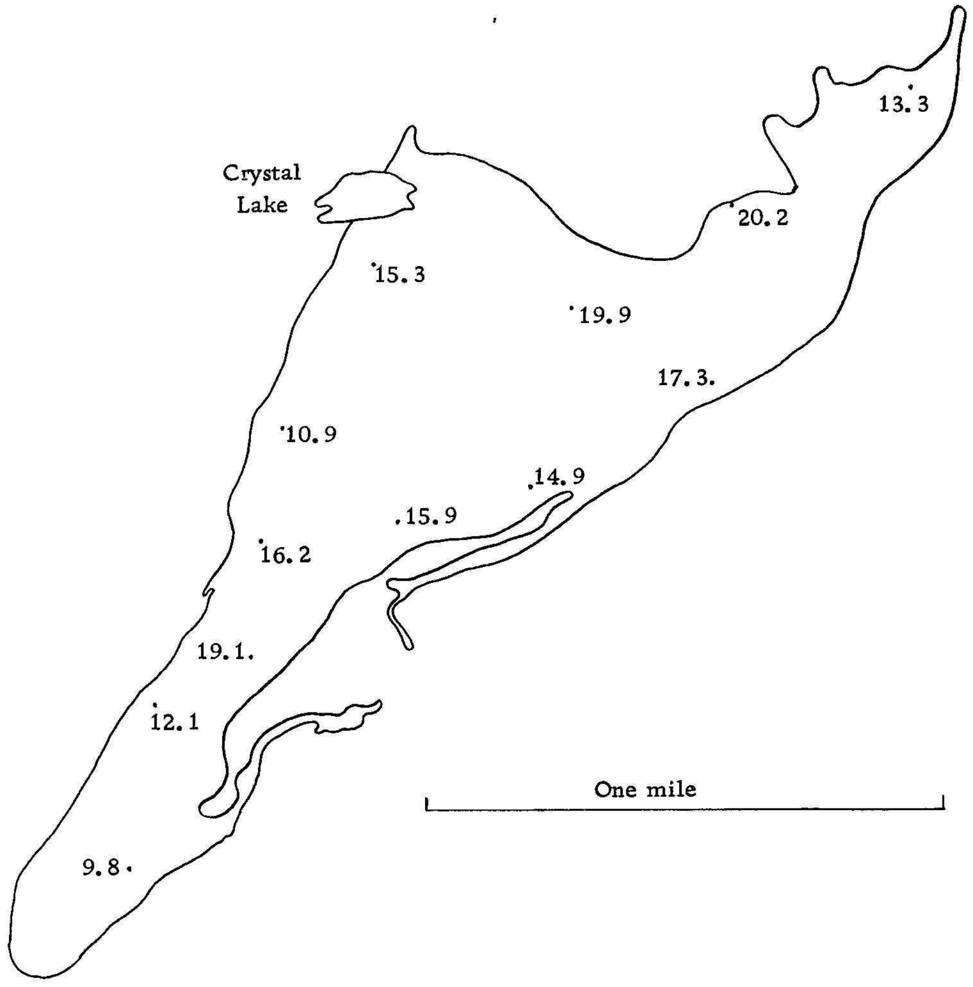


Figure 8. Map showing the distribution of potassium feldspar as a percent of total feldspar in the Crystal Lake pluton.

Interstitial potassium feldspar slightly embays plagioclase, quartz, and hornblende. Myrmekite is rare, and kaolin alteration is minor. Exsolved sodic feldspar generally occurs as small blebs and discontinuous strings. At the northern end of the pluton, however, blebs expand into large optically continuous patches forming what Alling (1938, p. 142) called replacement perthites. In one crystal, the albite-twinned patches (Seifert, 1964, p. 297) compose as much as 60 percent of the total perthite area. The coincidence of increasing patch size with degree of fracturing supports the theory (Gates, 1953, p. 69) that bleb enlargement is a function of the ease by which sodium could migrate. Although there are no fractures apparent in the particular perthites examined, sodium migration could have occurred along cracks located outside the plane of the thin section. Replacement perthites suggest that fracturing occurred while exsolution was in progress (Gates, 1953); that is, before final cooling of the Crystal Lake pluton.

Quartz crystals locally exhibit undulatory extinction and deformation lamellae. Grain boundaries are always irregular, but reach extreme development in the elongate sutured grains of the foliated rocks near Granite Creek. Direct correlation of the degree of suturing with foliation indicates that mild shearing probably was the cause.

Plagioclase compositions range from An_{24} to An_{39}. Both oscillatory zoning (An_{40-20}) and normal zoning are common. Inclusions consist of an opaque mineral, plagioclase, apatite, and some resorbed hornblende. In oscillatory zoned crystals, white mica alteration is concentrated in cores and along zone shells. In normally zoned crystals, white mica is either scattered randomly, or aligned along the two cleavage directions. Other alteration products are finely disseminated opaque (leucoxene ?), minor epidote, and calcite.

Biotite is pleochroic tan to dark brown. A triangular pattern, formed by hair-like closely spaced inclusions in basal sections, reflects the hexagonal arrangement of the crystal structure. Other inclusions are magnetite, apatite, zircon, plagioclase, and hornblende. Biotite is variously altered to strips and lense-shaped pods of chlorite and epidote that distort cleavage. Massive epidote replacement is local.

Hornblende, pleochroic green (not blue green) to pale yellow brown, exhibits synneusis and twinning. Inclusions are plagioclase and magnetite. Alteration products consist of chlorite, epidote, calcite, sphene, and possibly allanite. Epidote and calcite are not mutually exclusive, but one or the other generally predominates. Some unaltered hornblende is typical of all sections, except those from the fractured northern end of the pluton (361). There, masses of flaky green biotite, in addition to the above-mentioned alteration minerals, replace hornblende in either well-formed pseudomorphs, or irregular, wispy aggregates.

Allanite is pleochroic in shades of red brown. Its principal occurrence is with hornblende, either adjacent to it, causing radioactive discoloration of the amphibole, or in it, filling pockets and open cleavage traces. Although this association suggests a reaction relationship, the allanite also occurs in anhedral-to-subhedral crystals independent of hornblende or any other mafic from which it might have altered.

Hypidiomorphic granular texture is most common, but foliation, defined by quartz, plagioclase, hornblende, and biotite, modifies it in samples from Granite Creek. A xenoblastic texture is developed in the fractured rock from Gum Saddle. Fractures are commonly healed by recrystallized felsic minerals that are in turn cut by stringers of epidote.

Age of the Older Granitic Suite

The plutons of the older granitic suite are probably Late Jurassic in age. They are younger than the main phase of regional metamorphism, which is Middle-to-Late Jurassic (Vallier, 1967a; Hamilton, 1963), but older than the Deep Creek stock, which is Late Jurassic-Early Cretaceous (?).

The relative ages of the three plutons cannot be established with certainty because the bodies do not intersect. Local regional metamorphic effects and considerable fracturing imply that the Big Lake pluton may be the oldest, whereas the presence of unchloritized mafics and comparatively little fracturing suggests that the Crystal Lake mass may be the youngest.

Conclusions

The northeast elongation of the older granitic intrusions suggests controlled emplacement by the northeast striking metavolcanics and Oxbow-Cuprum shear zone. Active magma motion during emplacement is shown by inclusion-filled apophyses that extend from all three plutons, the occurrence of platy flow structure near some contacts of the Ruth Lake and Crystal Lake intrusions, and the presence of moved inclusions, as indicated by the juxtaposition of fresh and digested xenoliths in the Crystal Lake mass. That the emplacement was forceful, rather than permissive (Badgley, 1965, p. 352-353), however, is best shown by the shouldering aside of folded and faulted mylonite by the Crystal Lake pluton on the Paradise Creek-Pactolian Gulch divide.

Contact metamorphism of the Big Lake mass by the Deep Creek stock is reflected in the stubby blue-green actinolite and flaky green biotite in Deep Creek. Regional metamorphism of the older granitic suite is shown by the limited presence of actinolite in the Big Lake pluton and possibly by fracturing in all plutons. Lack of albitization, however, indicates that regional metamorphism was slight, and in the Crystal Lake pluton, negligible.

PLUTONS OF THE YOUNGER GRANITIC SUITE

General Statement

The two plutons of the younger granitic suite, east-trending Deep Creek and Echols Mountain stocks, are in the southern part of the map area (Plate 4). They are the largest intrusive bodies in the southern Seven Devils Mountains. The granitic rocks are light gray and have an average grain size of 3.5 mm. Equigranular textures are modified by the platy alignment of biotite and hornblende.

Quartz diorite is the principal rock type. Minerals include potassium feldspar, quartz, plagioclase, biotite, hornblende, apatite, zircon, sphene, allanite, magnetite, chlorite, epidote, calcite, white mica, and zeolite.

Deep Creek Stock

Location and Areal Extent

The Deep Creek stock is best considered as consisting of two portions, a main body, which occurs in the White Monument ridge area, and an eastern prong, which extends eastward across Pepperbox Hill and into the head of Deep Creek (Plate 4). Best exposures of the 9 1/2-square-mile pluton are along the southern flank of Deep Creek canyon.

Aureole

The thermal aureole of the Deep Creek stock is generally from 3,000 to 5,000 feet in width. A local widening to about 7,000 feet, north of the eastern prong, may record an overlap with effects of the Echols Mountain stock. The outer limit of the aureole, in both the metavolcanics and the older plutonic rocks, is marked by the appearance of flaky olive green to light tan biotite.

Other contact metamorphic minerals are blue-green actinolite, larger and more stubby than the needle-like regional metamorphic type, and hornblende, which is generally restricted to contact rocks. Near Hardrock Gulch, ten-foot-long lenses of garnet-epidote skarn are up to 1,200 feet from the contact, and garnet was observed 2,000 feet from the contact on Horse Mountain, 300 feet from the contact at Indian Creek, and 1,000 feet north of the eastern prong. Magnetite crystals as much as 1 1/4 inches in diameter occur in mixed rock in Ritchie Gulch, but were not observed elsewhere. No pyroxene was found in the aureole; plagioclase is ubiquitous.

Country rock foliation, in part defined by narrow granitic stringers, and in part by clots and streaks of biotite, occurs as much as 1,500 feet from the contact of the stock at Kinney Point. Foliation is much less prominent southeast of the pluton, but reaches 2,500 feet north of the eastern prong. Hornfelses are widely distributed.

Although most primary textures of the metavolcanics are obliterated near the pluton, relict plagioclase xenocrysts persist to within a few tens of feet of the contacts.

Contacts

Sharp contacts are typical of the upper west and east ends of Ritchie Gulch and of the Rose Creek divide. On Kinney Point ridge a five-foot-wide covered interval separates foliated granitic rock from foliated country rock. At Lockwood Saddle the contact lies in a broad 1,400-foot-wide zone of mixed granitic rock and metavolcanics.

Contacts rarely dip less than 70° and most range between 80° and 90°. They dip inward throughout most of the main body except at Hardrock Gulch where they are vertical and along the re-entrant at Ritchie Gulch where they locally dip outward. Dips project inward in the eastern prong on both the north and south borders, but swing outward along the re-entrant at Ritchie Gulch and at the eastern tip.

Inclusions

Dark gray mafic inclusions range in diameter from a few inches to over seven feet. Angular types occur at the Peacock mine, but the majority throughout the pluton are well rounded. Mafic inclusions, with the exception of a few biotite tablets and relict plagioclase phenocrysts, consist of finely crystalline xenoblastic mosaics of plagioclase, hornblende, and magnetite with some quartz and sphene. Contacts between inclusions and enclosing quartz diorite are sharp in general outline, but in detail there is a small amount of interlocking between adjoining minerals. The inclusions range in abundance from 2-3 per square yard throughout most of the interior of the pluton to as many as 40 per square yard within 40 feet of some contacts, as at Sucker Gulch. Inclusions are also abundant near the re-entrant in the contact of the eastern prong south of Deep Creek. Although a correlation between number of inclusions and proximity to contacts is suggested, the relationship is not everywhere consistent.

Most mafic inclusions probably are recrystallized metavolcanics. Those near Ritchie Gulch, however, maintain a semblance of plutonic igneous texture, suggesting derivation from the diorite of the re-entrant at Ritchie Gulch.

Inclusions of biotite schist, some exceeding ten feet in length, are abundant along the west wall of Ritchie Gulch (Figure 9). Green or brown finely crystalline inclusions of hornfelsed metavolcanics, such as the large mass in the Alaska mine area, are xenoblastic aggregates of pale green diopside and plagioclase with some sphene, magnetite, and quartz. Bedded inclusions consist of alternating layers of garnet and finely crystalline epidote. In one 30-foot-long inclusion at Ritchie Gulch, epidote layers are as much as 6 inches thick. A very large, poorly exposed bedded inclusion occurs along

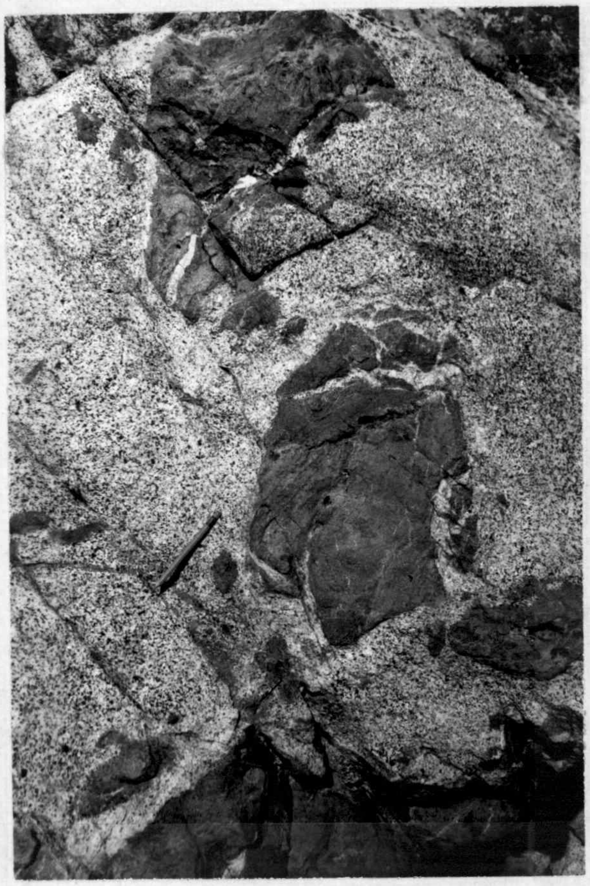


Figure 9. Biotite schist inclusions from near the contact of the Deep Creek stock in Ritchie Gulch.

the west flank of Pepperbox Hill. The bedded types are probably the recrystallized and silicated counterparts of intercalated meta-volcanics and limestone.

The most distinctive inclusions in the Deep Creek stock are composed of marble. There are about 14 mappable blocks, the largest of which, the Lockwood-Alaska inclusion, is 2,500 feet long and 500 feet wide. Massive gray cliffs typify some outcrops of marble--White Monument is a good example--but subdued exposures are also common.

Relict bedding, defined by narrow grooves, orange-stained calcite layers, and thin zones of garnet, generally parallels the exterior form of larger inclusions. A tight chevron fold outlined by alternating 1/2-to-5-foot-thick beds of garnet skarn and calcite occurs in the Humboldt block near Camp Creek, but this is unique.

Most calcite is coarsely crystalline. Although xenoblastic textures are typical of the larger blocks, cataclastic textures defined by bent deformation lamellae and sutured grain boundaries mark some of the smaller ones. Complete transformation to garnet-epidote skarn occurs in a few blocks, such as the South Peacock, but others are surrounded by only a rind of skarn, such as the White Monument, which is encircled by a 90-foot-wide rim. Other blocks have contact areas that contain no significant skarn.

Hornfelses are associated with some marble. The large hornfels inclusion near the Alaska mine may or may not be stratigraphically a part of the adjacent marble, but a 30-foot-thick section of alternating massive hornfels and flaky recrystallized material in Camp Creek, is definitely a part of the marble sequence. Rock of this nature is also evident in a tunnel near the Helena mine.

Most marble inclusions are tabular and (or) wedge shaped. The Arkansas mine inclusion is almost 1,000 feet long, but does not exceed 200 feet in width at the surface. The Lockwood-Alaska block tapers from a 500-foot width on the ridge northeast of Lockwood Saddle to less than 100 feet in an adjacent canyon, a vertical distance of about 650 feet. The South Peacock mine inclusion, best known because of accessible mine workings, is about 65 feet wide at the 40-foot level, but narrows slightly to about 60 feet and more generally 45 feet at the 200-foot level. The inclusion is 542 feet long.

In orientation, the inclusions conform remarkably to the flow structure in the stock. The South Peacock inclusion, for instance, strikes N 75°-80° E and dips 70°-80° SE, as confirmed from mine mapping. This trend almost coincides with surrounding flow measurements. The conformity is also noted with respect to pluton contacts. The form of the Lockwood-Alaska and Garnet Creek bodies faithfully mimics the stock boundary. The distribution of marble blocks is significant in that all large inclusions are located in the main part of the stock or along the re-entrant at Ritchie Gulch. With the exception of one small inclusion in Deep Creek, there is no marble in the east-trending portion of the eastern prong.

Origin of the Marble Inclusions

The marble inclusions probably were derived from the following two sources.

1. Limestone lenses intercalated with metavolcanics. One such lense, now marble, is in metavolcanics approximately 400 feet south of the quartz diorite contact in Deep Creek canyon (Plate 4). The lense trends northeast, is 600 feet long, and about 40 feet wide. Fault contacts are present, but intercalation of thin marble beds with metavolcanics indicates that the marble is close to its original stratigraphic position. Small northeast-trending marble inclusions such as the 300-foot-long Deep Creek body or the Indian Creek mass may have originated from the incorporation of such lenses.

2. Martin Bridge Formation. Limestone masses of the Martin Bridge Formation are scattered throughout northeastern Oregon and western Idaho. The outcrop closest to the Deep Creek stock is a 1,750-foot-thick sequence near Big Bar on the Snake River (Vallier, 1967a, p. 120), about 2 1/2 miles west. Other Martin Bridge limestone occurs in Rapid River canyon, about 3.4 miles east. Structural complications between these limestone outcrops and the stock make uncertain their direct projection beneath the intrusion. However, the

Martin Bridge Formation is the only known source of limestone masses as large as many inclusions within the stock.

The occurrence of marble lenses in the metavolcanics suggests that xenoliths derived from such a source could have been incorporated close to the level at which they are now exposed. Those from the Martin Bridge Formation, however, were more likely derived at depth. Evidence includes the marked absence of Martin Bridge limestone adjacent to the stock, the localization of large marble xenoliths in the western area where the stock reaches its greatest depths, and the cataclastic texture of some blocks. Original cataclastic features in the marble would have been eliminated by recrystallization. Moreover, because later shearing could not have taken place without disruption of the surrounding quartz diorite, deformation of the marble must have been by plastic flow during emplacement of the stock. Experiments with the Yule marble, as cited by Turner and Verhoogen (1960, p. 604), show that, although plastic flow at 3,000 bars is readily attained at magmatic temperatures, a necessary requirement is directed stress. Blocks of marble may have been torn from the walls of the chamber by rising magma.

Willow Lake-type Layering

One sample of Willow Lake-type layered rock (Poldervaart and Taubeneck, 1959) was found at a caved adit, called the Tussel prospect

(Cook, 1954, p. 13), at an elevation of about 6,400 feet on the south side of Tussel ridge (Plate 4). Although not in place, the sample clearly came from the contact between quartz diorite of the Deep Creek stock and an inclusion of silicated limestone. Massive green epidote, with some garnet, is separated from normal foliated border quartz diorite by a contact-paralleling, four-inch-wide zone of layering. Hornblende-rich layers that are as much as nine-sixteenths of an inch wide alternate with less mafic layers that are as much as one inch wide. Elongated and branching hornblende crystals, oriented at high angles to the layering, reach lengths of nearly five-eighths of an inch (see Taubeneck and Poldervaart, 1960, Fig. 10, D). Plagioclase compositions, as determined from 60 measurements on 21 crystals distributed throughout the layered zone, range from An_{35} to An_{45} and average An_{38}. The maximum core value is An_{45}.

Willow Lake-type crystallization is thought to result from undercooling of crystal-free magma along contacts with either wall rocks or inclusions (Taubeneck, 1967a, p. 43). The layering was found at no other contact of the Deep Creek stock.

Flow Structure

Flow structure is defined by the platy parallelism of individual minerals and schliern. The platy parallelism of minerals, chiefly biotite and horhblende, is by far the more common. It is always present at contacts and is generally prominent as much as 175 feet inward. Extreme development occurs at the south contact near Deep Creek, where gnessoid banding (Figure 10) is consistent inward for over 200 feet. Flow structure is generally well defined throughout the eastern prong of the stock, but in the interior of the main body, it becomes extremely faint and discontinuous.

Mafic schliern consist of lense-shaped concentrations of hornblende and some biotite. They occur locally throughout the pluton, particularly near contacts, but are best developed near the re-entrant in the southern contact northwest of Lake Winifred and along the east divide of Pepperbox Basin. Pods of as much as 3 feet in diameter and 3 to 5 feet in width are common. In general, both the external form of pods and the internal platy alignment of hornblende closely approximate the flow structure of the surrounding quartz diorite. At the pepperbox locality, however, schliern maintain dips that are for some unknown reason consistently opposite to those of the mineral-defined flow structure. On the ridge east of Pepperbox Basin a small area of schliern is drawn out into lenses that give the rock a layered appearance. In some places the lenses are also convoluted, yielding a "marble cake" effect.

Felsic schliern, composed of quartz, plagioclase, and very small amounts of biotite and hornblende, are comparable in size and shape to mafic schliern, but are much less abundant. In some places

Figure 10. Gneissoid banding near contact of the stock in Deep Creek canyon.

they form minor stringer-like segregations as much as 25 feet long. Contacts are gradational and generally conform in outline to the platy flow structure of the surrounding rock. Felsic schliern are best developed in the Deep Creek-Pepperbox Basin areas in conjunction with the mafic type.

Lineation is rare. Where present, generally near contacts, the elongation of either hornblende or schliern is always directed parallel to the dip of the platy flow structure.

The flow pattern of the Deep Creek stock, interpreted in Plate 1, was constructed by the form line method on over 350 attitudes. An individual symbol in Plate 1 may represent the average of several measurements. Important features include the consistent parallelism between flow structure and contacts, the concentric pattern and structural closure in the main body of the stock, and the glacier-like flow pattern of both the southern area and the eastern prong.

Joints

The Deep Creek stock is well jointed. In order to determine whether the joint pattern is systematically related to the platy flow structure, a series of 427 measurements were made at about 200 stations in the main body of the stock. The area was divided into four sectors and the measurements from each sector plotted on an equal area projection (Plate 2). There is (1) a system of

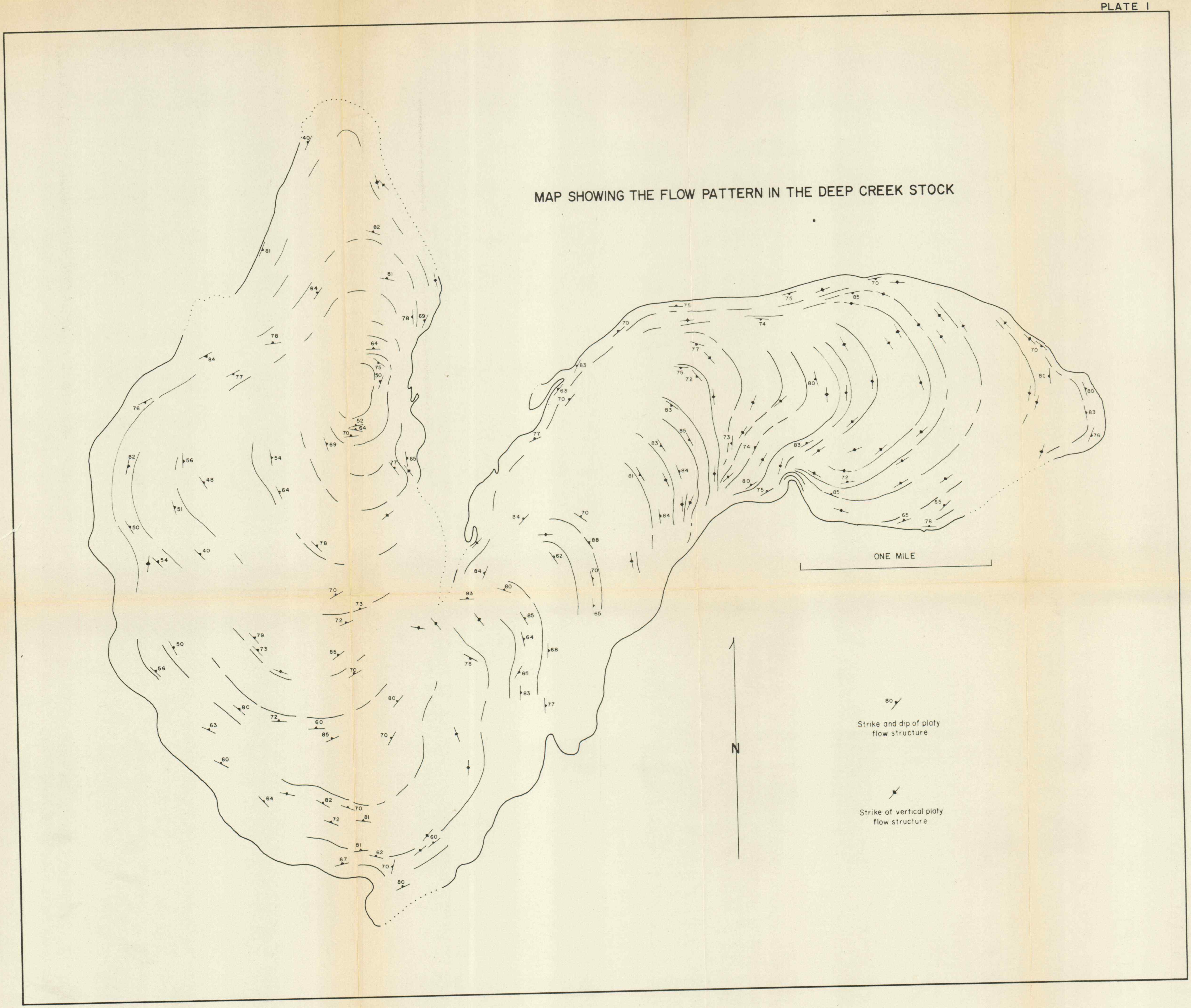
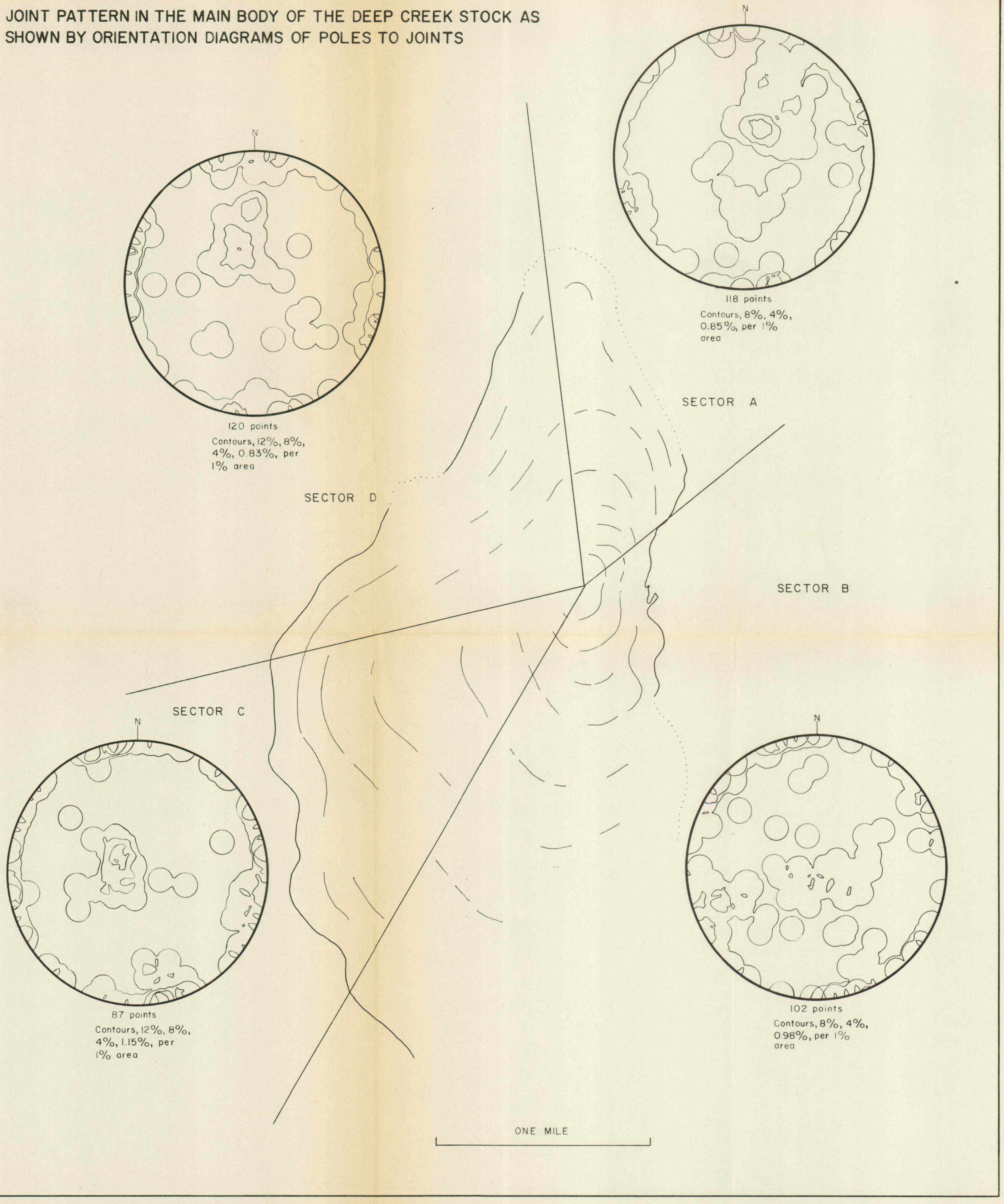

MAP SHOWING THE FLOW PATTERN IN THE DEEP CREEK STOCK
ONE MILE
N
Strike and dip of platy flow structure
Strike of vertical platy flow structure

PLATE 2

JOINT PATTERN IN THE MAIN BODY OF THE DEEP CREEK STOCK AS SHOWN BY ORIENTATION DIAGRAMS OF POLES TO JOINTS



inward-dipping joints that strikes approximately parallel to the platy flow structure, (2) a marked N 65°-85° E vertical joint set that is evident in all sectors, (3) a very poorly-defined system of vertical joints striking at angles of between 55° and 75° to the platy flow structure, (4) no consistent system of vertical joints striking either normal to, or parallel to the platy flow structure.

The inward-dipping joints are commonly followed by aplite dikes and quartz veins. The quartz locally contains sulfides, as at the Victoria mine in Devils Hollow, but the quartz diorite adjacent to the veins is not extensively altered. Slickensides are rare.

The vertical northeast joint set is locally followed by aplite and some quartz.

The vertical joints that strike at angles to the platy structure are a type of diagonal joint (Balk, 1937, p. 37). Two sets, intersecting at about 55°, are developed in each sector. In sectors A and D the northwest sets have aplite, whereas the northeast sets do not. In sector B, where the system is very poorly developed, both sets have aplite. No aplites were recorded in sector C.

Incipient joints stand out as narrow green- or orange-stained ridges on weathered surfaces of quartz diorite. Some have an epidote-filled central crack.

Origin of the Joints

Balk (1937) reviewed the interpretation of fracture systems within plutons. Primary joints are considered to be the manifestation in a consolidated shell of forces still active within the molten interior of a cooling pluton. They are marked by the presence of aplites. Secondary joints, which have no genetic relationship to the pluton, are barren.

Because inward-dipping joints, or marginal fissures (Balk, 1937, p. 101), contain aplite dikes, they must be primary. According to the mechanism proposed by Balk (1937, p. 102), marginal fissures are a tensional feature resulting from the upward motion of an intrusive body.

Because the northeast joint set maintains a well-defined and consistent strike without regard for the orientation of platy flow structure, it would ordinarily be considered as secondary. A few aplites, however, approximate the set in three sectors. This anomaly may be explained if a few primary joints, possibly related to the diagonal system, were filled with aplite, and a later, secondary set of coincident trend was superimposed. A northeast joint set is developed in the metavolcanics at Sheep Rock.

The poorly-defined diagonal joints are primary. Cross joints, tensional fractures that cut normal to the direction of elongation, and longitudinal joints, which cut parallel to it, were not detected in the Deep Creek stock. Since diagonal joints form angles of less than 45° with the elongation direction, they could be a shear system that accomodated the upward and outward pulsations of the interior. If so, cross joints and longitudinal systems might not develop. The poor definition of the diagonal joints, however, makes such an interpretation questionable.

Thrust Faults

Minor thrust faults, marked by zones of bleached biotite and iron oxide stain, range from 1 inch to 7 feet in width. Chlorite typically coats the many slickensided fracture surfaces within the zones; centrally located quartz stringers are common. The faults are best displayed in the cliffs of Devils Hollow where they generally dip less than 30° southward.

Mineral Distribution

Contours drawn on the percentage of potassium feldspar (Figure 11) define two highs and a surrounding intermediate zone in the main body of the stock and an intermediate zone in the southern part of the eastern prong. With the exception of minor fluctuations in the eastern prong, quartz and color index (Figures 12 and 13) follow the same general pattern. This coincidence, even though the contour

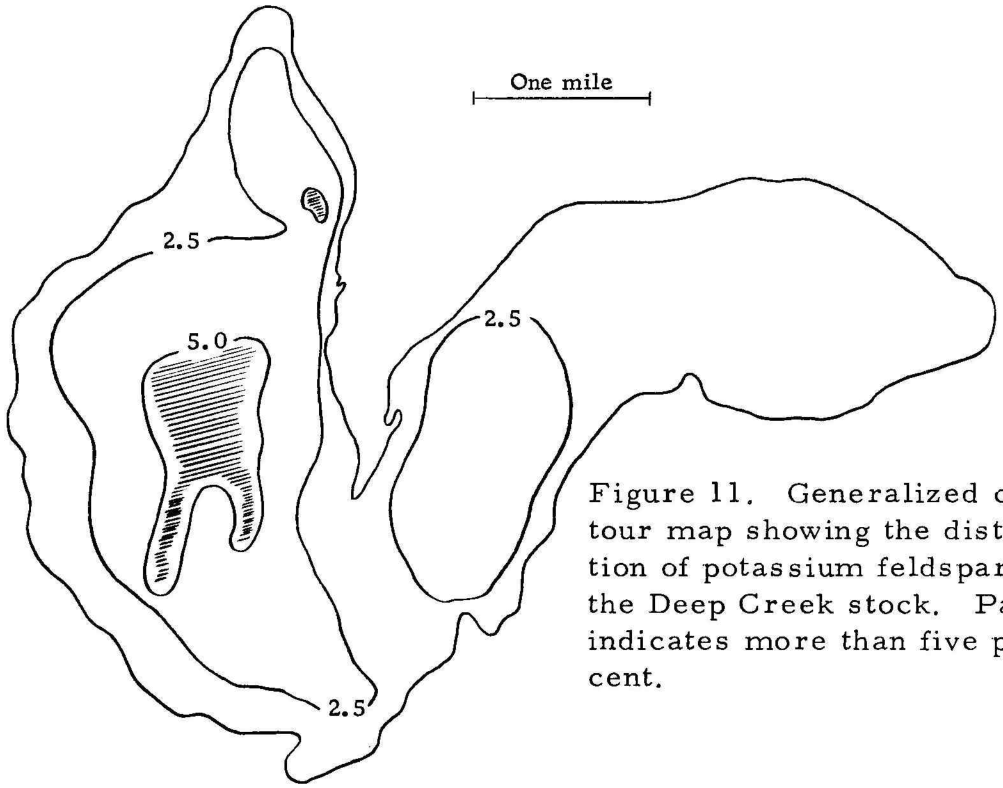


Figure 11. Generalized contour map showing the distribution of potassium feldspar in the Deep Creek stock. Pattern indicates more than five percent.

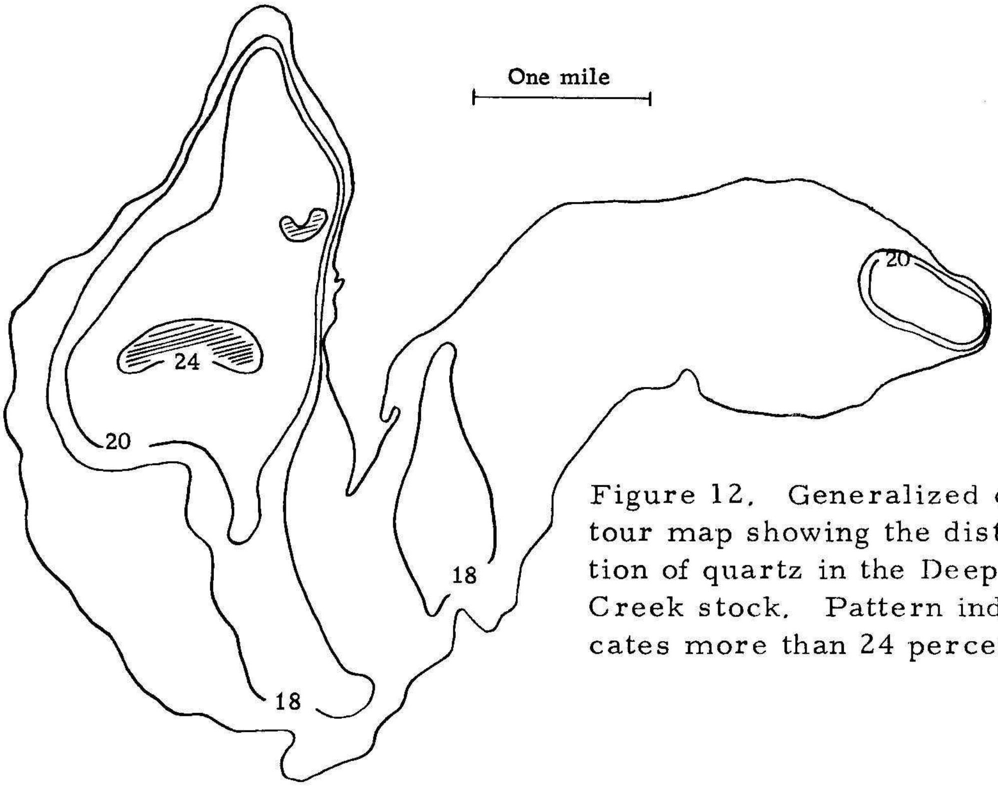


Figure 12. Generalized contour map showing the distribution of quartz in the Deep Creek stock. Pattern indicates more than 24 percent.

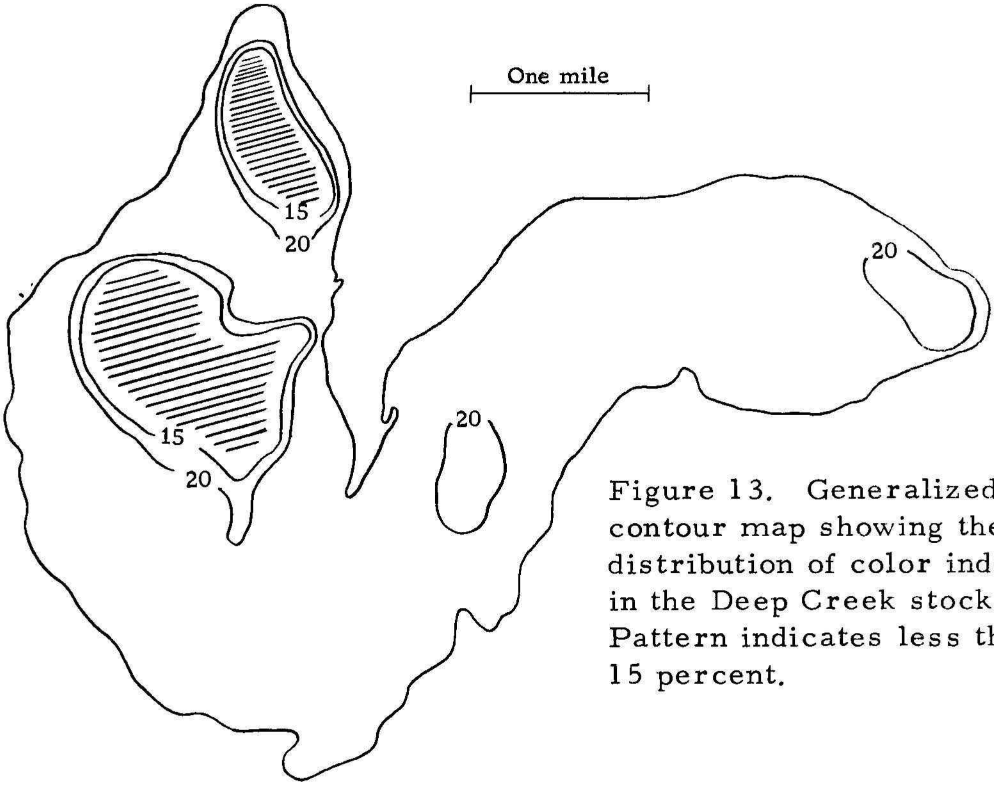


Figure 13. Generalized contour map showing the distribution of color index in the Deep Creek stock. Pattern indicates less than 15 percent.

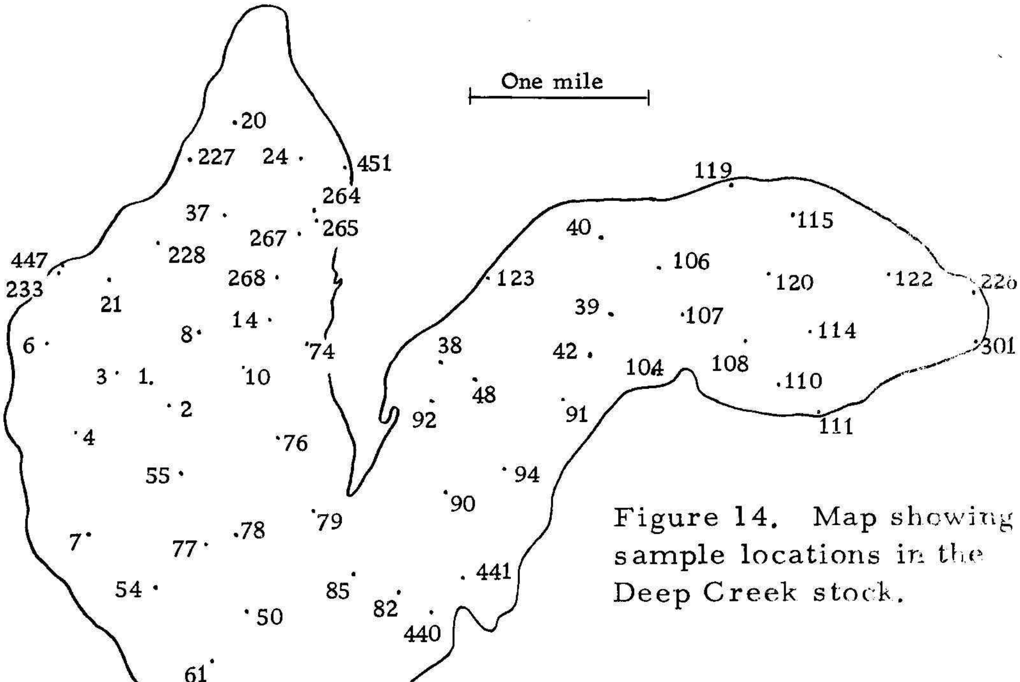


Figure 14. Map showing sample locations in the Deep Creek stock.

intervals are arbitrary and the contour lines generalized, suggests that the trends of the variations are valid.

The disposition of potassium feldspar is used as the basis for a partition of the stock into border, interior, and intermediate rocks. Border rocks, containing less than 2.6 percent potassium feldspar, occur near all contacts, in a narrow strip south of the re-entrant at Ritchie Gulch, and throughout the east two-thirds of the eastern prong. Interior rocks, containing more than 4.9 percent potassium feldspar, occur in two highs on White Monument ridge. Intermediate rocks encircle the two highs and, as stated, occur in an area in the southwest-trending arm of the eastern prong. Sample locations are shown in Figure 14.

Modes for border, interior, and intermediate rocks are given in Tables 11, 12, and 13. Means reflect the inward increase in potassium feldspar, quartz, and non-opaque accessories and decrease in biotite, hornblende, opaque accessories, and color index.

Variation in Degree of Coarseness

The degree of coarseness was measured by tabulating the number of grain boundaries intercepted during a thin section traverse of 40 mm. Because every major mineral grain boundary, rather than only those involving mineral identity changes, was counted, the index of coarseness as used in this study is slightly higher than the I. C.

Table 11. Modes of border rocks from the Deep Creek stock (volume percent).

Sample	Potassium feldspar	Quartz	Plagioclase	Biotite	Hornblende	Accessories Non-opaque	Accessories Opaque	Chlorite plus epidote	Color index
4	0.7	20.3	59.3	6.7	11.5	0.4	0.8	0.3	19.7
6	2.5	10.6	59.5	5.0	20.7	0.7	0.2	0.8	27.4
7	2.5	16.1	55.6	8.4	15.4	0.5	1.2	0.3	25.8
37	1.3	22.1	54.5	5.8	12.2	1.2	0.7	2.2	22.1
39	1.5	15.4	57.4	7.6	16.3	0.3	1.0	0.5	25.7
40	0.9	16.6	60.0	6.2	14.4	0.6	0.8	0.5	22.5
42	1.1	16.7	55.8	6.4	16.0	0.7	0.8	2.5	26.4
62	2.3	18.4	54.3	7.7	15.5	0.3	0.7	0.8	25.0
66	4.3	16.5	54.2	7.0	14.7	0.7	0.3	2.3	25.0
79	2.3	15.9	58.5	7.1	14.0	0.9	0.5	0.8	23.3
82	2.4	15.6	59.5	7.0	13.7	1.0	0.4	0.4	22.5
85	1.4	15.5	57.4	8.1	16.6	0.3	0.4	0.3	25.7
104	0.1	12.1	54.6	6.8	21.8	0.6	0.8	3.2	33.2
106	2.5	18.2	59.8	5.1	11.7	0.7	0.8	1.2	19.5
107	0.1	9.2	50.8	9.0	28.8	0.5	1.0	0.6	39.9
108	0.2	16.5	59.1	9.6	12.4	0.5	1.1	0.6	24.2
110	1.4	22.7	59.3	11.0	3.9	0.5	1.0	0.2	16.6
111	0.7	13.2	60.1	9.6	14.8	0.4	1.0	0.2	26.0
114	0.1	16.7	60.2	9.9	11.5	0.3	0.6	0.7	23.0
115	0.2	15.4	60.8	9.4	11.9	0.6	1.1	0.6	23.6
119	0.2	8.1	66.2	3.8	18.6	0.4	1.3	1.4	25.5
120	0.7	17.1	60.9	7.0	12.5	0.3	0.9	0.6	21.3
122	1.1	22.9	60.8	8.8	5.0	0.4	0.7	0.3	15.2
123	---	16.7	58.4	5.3	14.4	0.3	1.0	3.9	24.9
226	2.5	19.6	57.1	9.5	9.1	0.7	1.3	0.2	20.8
227	1.0	19.8	59.7	6.1	10.6	0.6	1.0	1.2	29.5
228	0.8	20.2	58.1	8.0	11.5	0.1	0.5	0.8	20.9
233	0.2	16.2	57.5	9.5	15.1	0.7	0.2	0.6	26.1
301	1.0	22.1	58.5	8.5	8.2	0.3	1.2	0.2	18.4
440	1.9	18.8	56.5	5.9	15.3	0.3	0.6	0.7	22.8
447	0.5	17.8	58.9	9.6	12.6	0.2	0.2	0.2	23.8
Mean	1.2	16.9	58.2	7.6	13.9	0.5	0.8	0.9	24.1
Standard deviation	1.02	3.67	2.81	1.74	4.70	0.24	0.32	0.93	4.65

Table 12. Modes of interior rocks from the Deep Creek stock (volume percent).

Sample	Potassium feldspar	Quartz	Plagioclase	Biotite	Hornblende	Accessories Non-opaque	Accessories Opaque	Chlorite plus epidote	Color index
1	5.5	22.2	56.9	6.8	6.8	0.7	0.5	0.6	15.4
2	4.0	23.2	59.1	5.0	5.8	0.9	0.7	1.3	13.7
10	5.3	26.2	55.7	6.2	3.7	0.6	0.6	1.7	12.8
54	6.3	17.5	56.2	5.8	12.3	0.9	0.3	0.7	20.0
55	5.0	15.8	59.2	5.1	12.7	0.8	0.3	1.1	20.0
77	6.2	21.8	54.1	6.8	8.7	1.1	0.3	1.0	17.9
264	5.3	21.4	57.4	6.1	7.1	0.9	0.9	0.9	15.9
265	5.3	25.4	57.6	7.5	2.1	0.6	0.6	0.9	11.7
Mean	5.4	21.7	57.0	6.2	7.4	0.8	0.5	1.0	15.9
Standard deviation	0.72	3.57	1.71	0.86	3.75	0.18	0.21	0.35	3.16

Table 13. Modes of intermediate rocks from the Deep Creek stock (volume percent).

Sample	Potassium feldspar	Quartz	Plagioclase	Biotite	Hornblende	Accessories Non-opaque	Accessories Opaque	Chlorite plus epidote	Color index
3	3.6	26.1	57.2	5.3	5.5	0.6	0.9	0.8	13.1
8	4.0	24.7	57.8	5.9	3.7	1.3	0.7	1.9	13.5
11	2.9	17.5	58.0	7.8	11.7	0.7	0.8	0.6	21.6
14	3.1	22.8	52.9	8.1	9.1	0.9	0.7	2.4	21.2
20	3.2	24.2	58.0	6.9	5.3	1.1	0.7	0.6	14.6
21	3.0	19.4	63.2	5.5	6.8	0.6	0.4	1.1	14.4
24	4.2	22.1	58.8	5.2	7.0	0.8	0.7	1.2	14.9
38	3.8	19.9	54.1	4.3	12.3	1.1	1.1	3.4	22.2
48	3.7	16.5	56.9	7.0	14.4	0.3	0.7	0.5	22.9
50	3.7	19.5	55.6	7.8	12.4	0.4	0.4	0.2	21.2
61	2.6	17.5	56.6	6.4	14.3	0.6	0.8	1.2	23.3
69	3.0	19.0	56.0	7.8	12.3	0.7	0.7	0.5	22.0
74	3.7	23.8	59.1	4.5	5.1	0.7	0.7	2.4	13.4
76	4.3	23.3	58.2	3.8	7.8	0.5	0.6	1.5	14.2
84	2.5	16.7	58.1	7.6	13.1	0.8	0.5	0.7	22.7
90	4.0	19.3	56.8	6.7	11.6	0.8	0.7	0.1	19.9
91	2.7	14.9	54.2	10.1	16.9	0.5	0.4	0.3	28.2
92	3.7	18.1	56.1	4.9	14.3	1.0	0.9	1.0	22.1
94	3.8	17.1	59.1	6.8	11.5	0.5	0.9	0.3	20.0
267	2.4	24.4	54.1	7.8	9.0	0.7	0.9	0.7	19.1
268	2.9	22.8	53.0	10.5	7.7	1.1	0.6	1.4	21.3
441	3.8	18.4	55.5	6.9	13.5	0.5	0.6	0.8	22.3
Mean	3.4	20.4	56.8	6.7	10.2	0.7	0.7	1.1	19.0
Standard deviation	0.57	3.22	2.30	1.72	3.69	0.26	0.22	0.83	4.21

number proposed by Chayes (1956, p. 72). Average figures for border, intermediate, and interior rocks are 86, 75, and 67, respectively. They show a definite inward increase in degree of coarseness.

Petrography

Potassium feldspar is interstitial and shows no crystal faces except against other potassium feldspar. It locally embays and corrodes adjoining plagioclase, hornblende, and rarely quartz. Oikocrysts as much as six mm long poikilitically enclose plagioclase and hornblende in the interior rocks. The development of narrow stringlet and string type perthite (Alling, 1938), though local in the interior, is notably lacking elsewhere in the pluton. Only one poorly defined replacement perthite was observed.

Myrmekite is typical of potassium feldspar-plagioclase contacts. If no potassium feldspar is present in the rock, there is no myrmekite. However, a correlation between the relative abundances of myrmekite and potassium feldspar is lacking.

Quartz is always interstitial. Undulatory extinction and dust trails are ubiquitous. Deformation lamellae (Carter, et al., 1964) are distributed throughout the pluton, but are unusually well developed in the southern part of the eastern prong and at the northern end of White Monument. At these locations quartz exhibits two sets of lamellae that intersect at angles of between 35° and 84°. Undulatory extinction and deformation lamellae suggest either that the pluton was subjected to an externally derived orogenic pressure, or that such features are a normal result of jostling during consolidation. The latter interpretation is preferred.

Minute needle-like inclusions, the largest of which is about half a mm long, also form intersecting networks in the quartz. Two sets cross at 145° and a third bisects this angle. Needles occur throughout the pluton, but they are more abundant and better arranged in border rocks. Other inclusions in quartz are apatite, zircon, magnetite, and hornblende.

Subhedral plagioclase crystals average 3.5 mm in length. The crystals are zoned with normally zoned rims surrounding a core of oscillatory shells and unzoned central portion. Twinning is extremely common; Carlsbad, Manebach-Ala, Albite, and Albite-Ala B laws were recognized with the U-stage. Synneusis is common; twin lamellae are bent in some border rocks.

Oscillatory zoning is represented by as many as 22 zone shells in a single crystal. Involutions in various zone shells, particularly the outermost ones, are common; normally zoned rims are ubiquitous. From an average of several samples, the core index, or modal volume of plagioclase cores (Vance, 1962, p. 758), is approximately 8. Zone shells, where not corroded, are generally euhedral, whereas the rims, though they mimic the overall rectangular form of the shells, are subhedral. Rim-core ratios (Vance, 1962, p. 754) of 14 in border rocks and 17 in the interior show that the plagioclase rims become wider in the interior of the stock.

Patchy zoning (Vance, 1965), generally superimposed on the oscillatory type, is characterized by the blotchy extinction of irregular patches in the cores and in certain zone shells. The patches are in optical continuity with either the rim or one of the outer shells. In some crystals the rim has actually breached the oscillations and penetrated the core area. Patchy zoning is present in all parts of the pluton.

The development of small near-rectangular inclusions (anti-perthite) of potassium feldspar is common within plagioclase of the western border, whereas corrosion of rims by potassium feldspar is typical of the interior.

Some plagioclase contains thin needle-like inclusions, very similar to those in quartz. The inclusions, which intersect at near 90°-angles, are present in rocks of the western border and the south-central part of the intrusion, but are absent elsewhere. Quartz inclusions are either round or ovoid, rarely exceed one third of a mm in diameter, and are generally localized in the outer part of zoned cores. They are abundant in rocks of the western border, where in one crystal there are 35, but over the pluton as a whole quartz inclusions are rare. Subhedral green hornblende and brown biotite inclusions are generally localized in plagioclase cores. A maximum of 36 hornblendes were counted in one core and 6 biotites (some partially chloritized) in another. Euhedral apatite is abundant; magnetite is common; zircon is rare.

Alteration of plagioclase occurs in almost every section but is minor, except in hydrothermally-affected rocks. White mica, the most common alteration product, occurs in local patches with finely disseminated opaque, in small scattered flakes, and in large, coarse aggregates near mineralized joints. Fine white mica selectively replaces individual zone shells, as does light brown flaky zeolite. These replaced rings commonly encircle concentrations of inclusions, particularly hornblende and biotite. Colorless epidote and rarely calcite and chlorite are also present.

Biotite (β:1.640 as determined in sample 264) is strongly pleochroic in shades of brown, a color that indicates a high titanium content relative to iron (Deer, et al., vol. 3, p. 71). Crystals, which range from less than 3 mm to as much as 5 mm in diameter, are tabular, but due to scalloped edges, their forms are rarely perfect. The interpenetration of large biotite with hornblende suggests simultaneous crystallization of the two minerals, whereas inclusions of hornblende indicate that biotite also crystallized later. Other inclusions are apatite, magnetite, zircon, plagioclase, and quartz.

Much alteration of biotite is localized along its excellent cleavage. Green chlorite, the most common alteration mineral, occurs in narrow cleavage-paralleling strips, as well as in broad replacement masses. Although large sphene crystals are not oriented, finely crystalline sphene (or leucoxene) always follows the cleavage both in unaltered biotite and in chlorite pseudomorphs. Yellow epidote forms elongate lensoid aggregates that shoulder aside the cleavage. Some magnetite is also aligned.

Expansion pods are another cleavage-paralleling, lense-shaped feature. The pods, always less than 0.1 mm wide, contain light brown to colorless inward-projecting or border-paralleling fibers which have parallel "birds-eye" extinction and the high birefringence typical of micas. They are thought to be either white mica, or biotite in the process of changing to white mica in response to a structural reorganization. There is no general correlation between pod development and location in pluton or pod development and other textural or mineralogical characteristics, but some of the best developed pods do occur in hydrothermally altered rocks in conjunction with sericitized plagioclase. Expansion pods may be in part due to normal weathering and in part to local hydrothermal alteration.

Biotite is commonly deformed. It exhibits numerous kink bands and cleavage is bent as much as 20°. Fractured biotite is healed by quartz and more commonly potassium feldspar. One chlorite pseudomorph is molded about the corner of a plagioclase crystal.

Chlorite typically fills the intercleavage voids created at the "elbows" of some bent crystals, whereas finely crystalline sphene is localized at the bend axes. Although biotite deformation is present throughout the stock, maximum deformation occurs near contacts.

Hornblende (2V:68°-73° as determined in five rocks, γ:1.668-1.670 as determined in sample 7) is strongly pleochroic (X = pale greenish brown; Y = green; Z = dark green) and commonly twinned. Except where embayed by potassium feldspar or, less commonly, quartz, hornblende is generally euhedral. The largest is 6 mm long, but most are less than 3 mm. Although broken hornblende is rare, if present, areas of separation are healed by either potassium feldspar or quartz. Aggregates of hornblende have varying characteristics and modes of origin. Very irregular and strongly resorbed varieties are thought to be the remnants of made over xenoliths. Aggregates in which crystals are small, of near uniform size, and enclose large areas of anhedral magnetite may in part have been transformed from augite. Other aggregates, in which crystals have shapes and sizes typical of independent hornblende, probably are the result of normal synneusis.

Inclusions are subhedral plagioclase, euhedral apatite, zircon, magnetite, and anhedral quartz. Plagioclase is by far the most abundant, as shown by one six-mm-long hornblende that contains at least 32 plagioclase, 5 apatite, and 2 quartz crystals. Plagioclase, apatite, and zircon are primary. Magnetite, however, is in part primary, and, together with quartz, is a possible by-product of the augite-hornblende transformation. Other quartz inclusions may have resulted from internal resorption of hornblende. Alteration products include sphene, minor chlorite, and calcite. The sphene forms cleavage-paralleling strips and large irregular masses that discolor the host.

Interpenetration of biotite and hornblende is very common. Biotite tablets (or chlorite pseudomorphs of biotite) either follow hornblende basal cleavage, or occur randomly throughout. The tabular, rather than flaky nature of the biotite, suggests that the hornblende-biotite transformation was a late magmatic, rather than deuteric, reaction. Where large biotite and hornblende crystals are adjacent, the biotite projects into hornblende and includes a few portions of it.

Many hornblende interiors are occupied by patches of colorless to very pale green augite. None of the relicts are very large, and many have extremely ragged edges. Bleaching of adjacent hornblende and concentrations of vermicular quartz, both in hornblende and augite, are common. In fact, the association is so consistent that areas of this type in hornblende crystals that do not contain augite are taken as evidence of its former presence (Taubeneck, 1964a, p. 295). Rings of magnetite commonly encircle the bleached areas.

The hornblendization of augite is thought to have taken place in several ways. The simplest and most common mechanism probably involved the replacement of a single augite by a single hornblende. Bleached hornblende, vermicular quartz, and magnetite were by-products.

Certain relationships, however, suggest several variations on this scheme. First, the lack of optical continuity of augite remnants at opposite ends of one hornblende crystal suggests that one hornblende may have formed from more than one augite. Second, incorporation of parts of three hornblende crystals in one magnetite rim suggests that more than one hornblende may have replaced one augite. Third, the occurrence of smaller hornblende crystals in the interiors of larger ones suggests that the smaller might have replaced augite relicts in the larger. The small hornblende is pale green and contains vermicular quartz. A sudden change in magmatic conditions might have forced rapid crystallization of a new hornblende crystal rather than continued replacement by the larger one. All reactions are thought to have been early magmatic.

Euhedral apatite averages 0.18 percent of the rocks and is as long as half a mm. Sub- to euhedral zircon averages 0.008 percent, but rarely exceeds one third of a mm. Both apatite and zircon are included in every essential mineral; apatite is also contained in magnetite.

Sphene, gray brown and slightly pleochroic, constitutes about 0.26 percent of the rocks. It is associated with biotite, hornblende, and magnetite. Where independent, sphene is always interstitial to plagioclase and generally, but not always, interstitial to hornblende and quartz. Euhedral faces are best displayed against potassium feldspar. The largest crystal is 1.2 mm long; parting is well developed in some. Rare leucoxene alteration marks the edges of larger crystals.

Allanite is present in only 12 thin sections. It is pleochroic deep orange brown to lighter orange brown, rarely shows normal and mild oscillatory zoning, and reaches a maximum length of 1.1 mm. Allanite occurs (1) as small anhedral masses on hornblende, bearing the same relationship to the amphibole as does epidote, (2) in subhedral crystals that merge with yellow epidote and are rarely in optical continuity with it, and (3) as anhedral or subhedral crystals completely independent of any contact with either hornblende or epidote. Where interstitial, faces are developed only against quartz and potassium feldspar.

Euhedral magnetite occurs in widely scattered grains, or sphene-rimmed clumps, whereas anhedral magnetite is best developed in hornblende aggregates.

Chlorite, variably pleochroic in shades of green, exhibits the anamolous "Berlin blue", violet, brown, and olive drab interference colors. Most chlorite is pseudomorphous after biotite. Some, however, occurs in fibrous, radiating bundles within plagioclase--particularly where the plagioclase has been partially altered to white mica--in pockets within hornblende, and as fibrous or flaky interstitial aggregates.

Yellow epidote, pleochroic and probably iron rich, occurs as anhedral crystals along biotite cleavage, on hornblende, and rarely in interstices between plagioclase and potassium feldspar. The occurrence with biotite is by far the most common. The intensity of the yellow color varies within individual crystals, being most pronounced where in contact with biotite, magnetite, or sphene. Colorless, iron-poor epidote occurs with white mica in plagioclase.

The deuteric transformation of biotite to chlorite and minor epidote is a very common phenomenon in granitic rocks (Deer, et al., v. 3, p. 156). The change may also take place, however, in response to low grade regional metamorphism. Hamilton (1963, p. 16) suggested that the Deep Creek stock might have been metamorphosed in the eastern part of the Cuprum quadrangle. In order to determine whether or not the chlorite and epidote were due to deuteric or regional metamorphic processes, the distribution of these minerals in the stock was plotted on an outline map (Figure 15). No increase eastward in percentages of these minerals occurs and, in fact, the highest percentages are more common in the western part of the

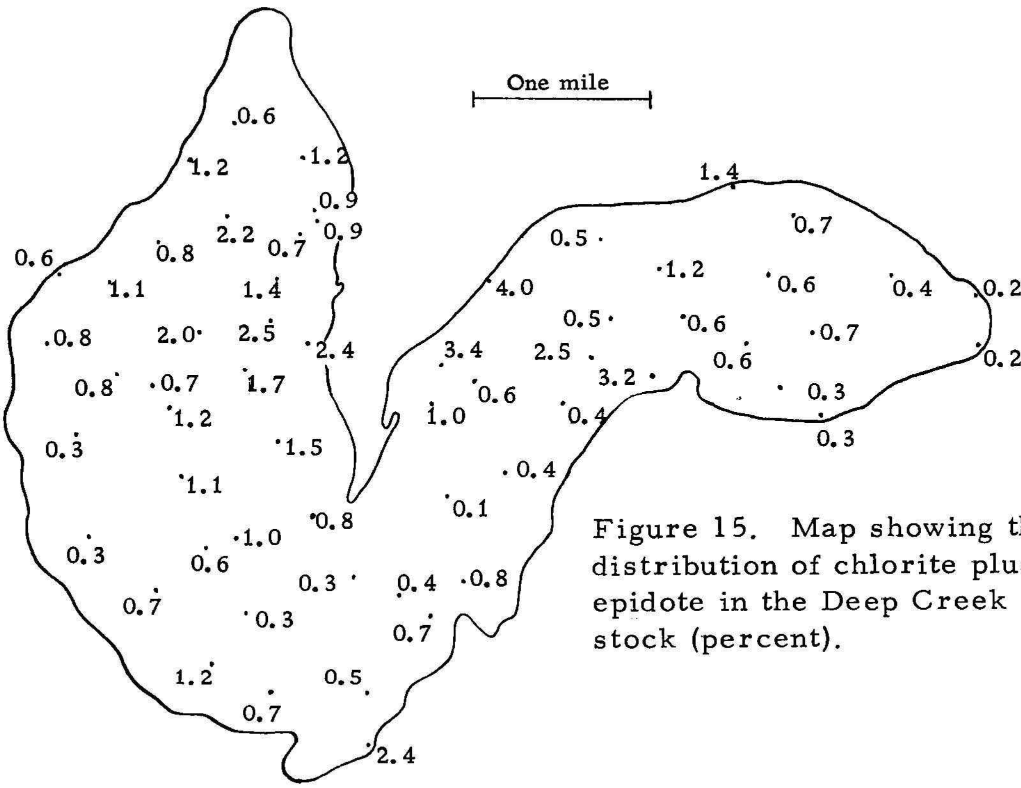


Figure 15. Map showing the distribution of chlorite plus epidote in the Deep Creek stock (percent).

pluton. Accordingly, the distribution of chlorite and epidote suggests that the transformation was deuteric, rather than metamorphic.

Most chlorite and epidote in hornblende probably altered from biotite that had previously replaced the hornblende. Chlorite and epidote on plagioclase and interstitial chlorite and epidote probably are also deuteric.

Calcite occurs in about one third of the rocks studied, but generally does not exceed 0.50 percent. As broad sparry crystals it is interstitial to almost every mineral, including sphene and chlorite. Calcite is also common in plagioclase, in pockets within hornblende, and as strips in potassium feldspar. The calcite is a late mineral, probably either deuteric or low temperature hydrothermal.

Zeolite (?) (Bire. = .004, R.I. < balsam) forms flaky brown or colorless aggregates in plagioclase cores and plagioclase zone shells. Zeolite (?) also fills interstitial cavities and narrow stringers, where it is commonly massive, as well as flaky. The mineral is in part an alteration product of plagioclase; occurrence in stringers and cavities indicates very late crystallization.

X-ray Study--Plagioclase

The X-ray determination of plagioclase composition is useful in that it averages the An-contents of zoned crystals and thereby gives a more precise bulk value for the plagioclase of a given rock than does the corresponding optical method (Hall, 1965, p. 427). X-ray technique, however, is not without its difficulties. The cell angle γ^*, upon which most curves of peak separation vs. composition are based, is a sensitive indicator of structural state as well as composition. One or the other must be controlled before X-ray compositions can be accepted with confidence.

A simple method of fixing the structure variable is to assume that the plagioclase of a pluton had a normal cooling history, and to determine X-ray values from the low structure curve. Such an assumption has been applied successfully to the plagioclase of certain intrusive bodies by Jackson (1961) and Moore (1963). A second and much more reliable method, however, is to check the composition determined using the low structure assumption against the composition determined by independent optical methods. If the two measurements differ widely, then the assumption as to low structural state is invalid. The optical value must then be used as the composition and the X-ray figure as an indicator of structural state.

The X-ray term, Γ (Smith and Gay, 1958), and the corresponding An-values of 30 plagioclase samples, together with 37 optical An-contents (as determined from 119 measurements on 107 crystals) are shown in Table 14. Structural state is also given. Details of the techniques are outlined on pages seven and eight.

Table 14. Average composition and structural state of the plagioclase in 41 samples from the Deep Creek stock (o = ordered; x = disordered).

	Average composition				Structural state	
	X-ray		Optical			
Sample	Γ	An	Range	An	Optical	X-ray - Optical
2	0.32	36	34-35	35	o-x	o
3	0.31	35	35-36	36	x	o
4	0.46	56	---	37	x	x
6	0.29	35	---	35*	o	o
7	0.40	53	35-37	36*	o-x	x
10	0.33	36	34-40	38*	o	o
20	0.39	53	32-33	33	o-x	x
24	0.37	51	36-37	37	o-x	x
37	0.34	37	34-40	37*	o-x	o
39	0.34	37	---	36*	o	o
40	0.41	54	36-38	37	x	x
48	0.34	37	---	37*	x	o
55	0.49	56	32-33	33	o-x	x
62	0.38	52	---	38*	o	x
77	0.34	37	---	38*	o	o
85	0.40	53	36-38	37	o	x
107	0.45	55	---	33*	o	x
108	0.36	48	---	34*	o	x
114	0.39	53	32-37	34*	o	x
119	0.42	54	---	34*	o	x
120	0.39	53	---	36*	x	x
122	0.40	53	---	38*	o	x
233	0.51	57	31-40	34	o-x	x
264	0.38	52	33-34	33	o-x	x
268	0.40	53	29-33	31	o-x	x
301	0.32	36	31-42	35	o-x	o
90	0.33	36				o
98	0.34	37				o
104	0.48	56				x
106	0.27	34				o
8			34-35	35	o	
50			35-36	36	o	
54			---	36	o	
74			32-33	33	o	
76			29-33	31	o	
91			32-33	33	o	
111			33-34	34	x	
226			34-35	35	x	
227			35-40	38	x	
440			28-33	30	o	
447			34-40	37	o-x	

*Determined by Slemmons method.

Results and conclusions are as follows:

1. X-ray values that exceed An_{48} do not agree with the corresponding optical determinations. The discrepancy is a function of structural state. X-ray Γ-factors should have been plotted in area B of Figure 16 rather than area A. The assumption of low structure is not valid for these samples.

2. For ordered samples the variation between optical An-contents and X-ray values is well within the limits of error of the methods used.

3. The range of optical An-values in any one sample does not exceed 9 percent An, and is generally less than 3 percent.

4. The plagioclase of the pluton exhibits a rather narrow compositional range. X-ray values of ordered plagioclase vary within 3 percent An (34-37), whereas average optical values, considering all structural states, vary within 7 percent An (31-38). Average bulk composition from ordered X-ray and all average optical values is An_{35}.

5. Some optical measurements of structural state vary within a single sample, whereas others disagree with those determined by X-ray. The unreliability of optical methods in this respect probably is due to optical scatter normal to the migration curves (Emmons, Crump, and Ketner, 1960; Vogel, 1965).

As determined from 16 optical measurements, the maximum

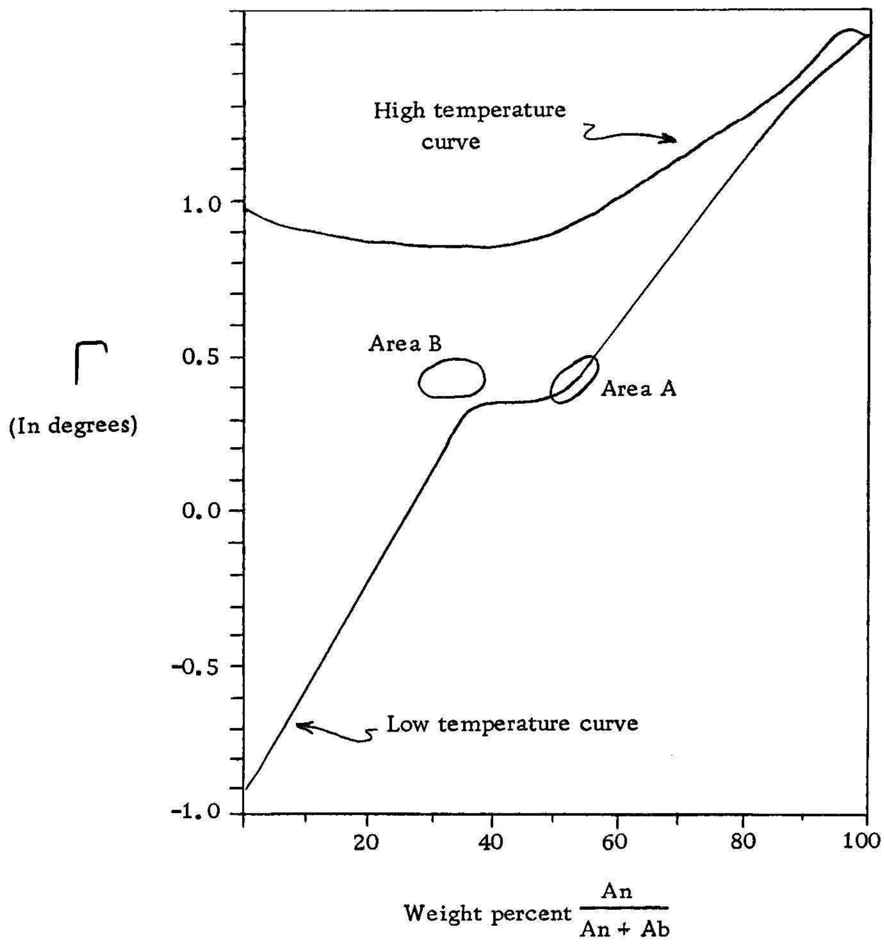


Figure 16. Plot of Γ against An-content of plagioclase (Smith and Gay, 1958).

An-content of plagioclase cores in border rocks of the Deep Creek stock is An_{46}, whereas that in interior rocks is An_{43}. Sodic normally zoned rims are narrower in rocks of the border than they are in rocks of the interior. Both factors suggest that average plagioclase An-contents should decrease towards the interior of the stock. Values given in Table 14, however, show no systematic variation, probably because the changes are more subtle than can be detected by the methods used. The distribution of structural state, however, does show a crude pattern (Figure 17). There is a tendency for the localization of disordered plagioclase along contacts in the main body of the stock, and both throughout the interior, as well as near contacts, in the east two-thirds of the eastern prong.

The structural state of plagioclase may be influenced by mineralization (which can cause ordering, as in ordered contact sample 98), by the pressure and volatile content of a magma (Smith and Gay, 1958, p. 753), and by the cooling rate. As rapid quenching of synthetic specimens yields plagioclase of high structural state (disorder) and slow cooling in plutons gives plagioclase of low structural state (order), cooling rate appears to be the most significant. In the Deep Creek stock, contact samples should have cooled faster than those in the interior. The apparent anomaly of disordered plagioclase in the interior of the eastern prong, well away from all known contacts, suggests the presence of an unseen, but proximal contact

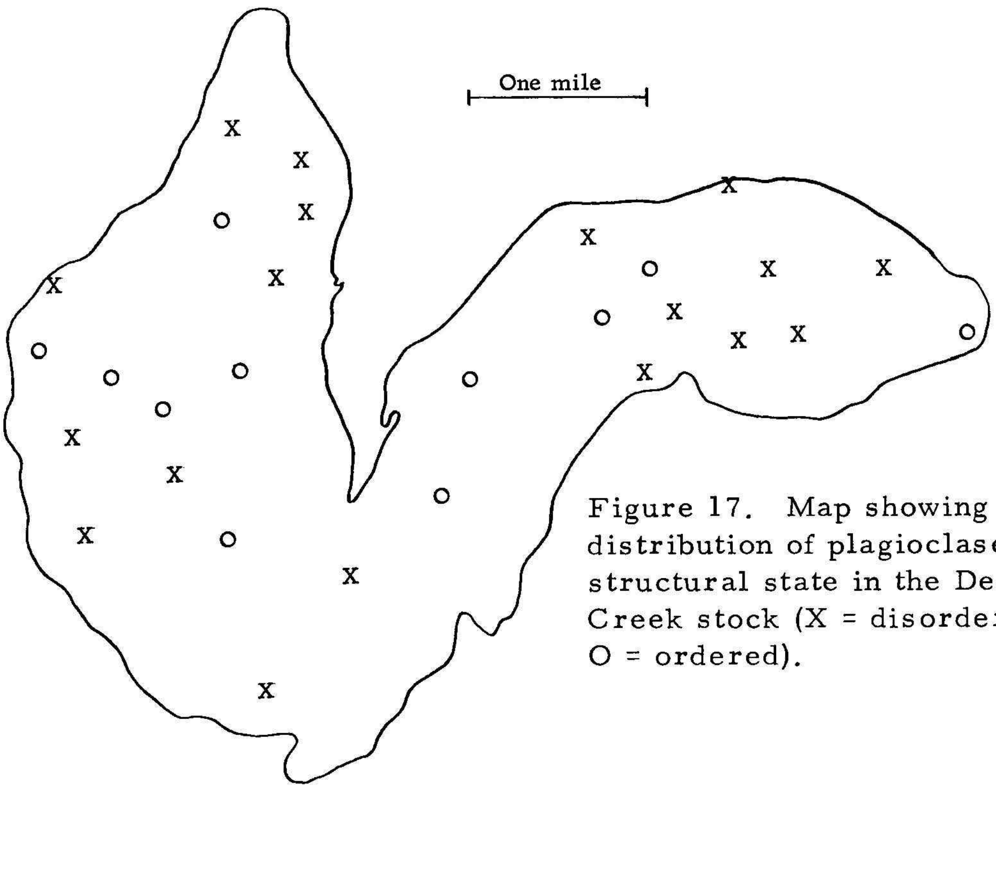


Figure 17. Map showing the distribution of plagioclase structural state in the Deep Creek stock (X = disordered; O = ordered).

beneath the land surface.

Contact Rock at Hardrock Gulch

A five-foot-wide zone of foliated, finely crystalline contact quartz diorite marks the juncture between biotite schist and the Deep Creek stock on the divide between Ritchie Gulch and Hardrock Gulch (Plate 4). Contact of the zone against schist lies within a two-foot-wide covered interval, but contact against border quartz diorite is sharp.

The contact rock is much more finely crystalline (I. C. = 183) than any other sample of quartz diorite from the Deep Creek stock. Maximum lengths of plagioclase and hornblende are 2.5 mm and 0.6 mm, respectively, as compared with lengths of 4.5 mm and 3.5 mm in normal border rocks. The contact rock is microporphyritic. Plagioclase phenocrysts compose approximately 30 percent.

The modal composition of the contact rock is very similar to that of the average border quartz diorite (Tables 11 and 15). Quartz commonly displays undulatory extinction, but deformation lamellae are rare, and deformation bands are absent. Larger plagioclase crystals exhibit oscillatory zoned cores within very narrow, or no, normally zoned rims. Average plagioclase composition, based on 16 measurements in 12 crystals, is An_{34}; the range is An_{29} to An_{38}. The maximum core value is An_{47}. Inclusions of hornblende are present, but not common; white mica alteration is slight. Green sub- to-euhedral hornblende contains no augite relicts, no vermicular quartz, and no bleached cores. Brown biotite tablets, some of which are slightly bent, generally form elongate groups that define the foliation.

Table 15. Mode of the quartz diorite contact rock at Hardrock Gulch, Deep Creek stock (volume percent)

Sample	Potassium feldspar	Quartz	Plagioclase	Biotite	Hornblende	Accessories Non-opaque	Accessories Opaque	Chlorite plus epidote	Color index
451	---	13.5	64.2	10.1	11.3	0.1	0.8	---	22.3

The fine grain size suggests that the contact rock at Hardrock Gulch was chilled. The zone of contact rock may be the remnant of a chilled "skin" that bounds other contacts of the stock. As marginal quartz diorite rarely is exposed within 20 feet of wall rocks, the possible extent of fine-grained contact rocks such as at Hardrock Gulch is unknown.

Aberrant Rock Types

Hornblende diorite forms a few small isolated outcrops, generally near, and inside contacts of the Deep Creek stock. Either schliern or country rock xenoliths are commonly associated. Good exposures are on the ridge northwest of Lake Winifred and northwest of Indian Creek, behind the smelter chimney at Landore (Plate 4).

The average hornblende diorite has a color index of 49.2, more than twice that of the average border rock. Both coarse and fine textures are common (I. C. = 58-104); hornblende crystals are as much as six mm long. Although modes (Table 16) show it to be essentially a hornblende-plagioclase rock, the diorite does contain all other minerals of the normal border quartz diorite. The average plagioclase composition is An_{37}, as determined from 17 measurements on 13 crystals from five rocks; the range is An_{33} to An_{40}. The maximum core value is An_{45}. Anhedral-to-subhedral green hornblende contains bleached areas, pockets of vermicular quartz, and rare augite. Zoning of hornblende, in one section, is defined by narrow green rims around brown-green interiors, or, under crossed nicols, by very slight differences in extinction. Boundaries between cores and rims are abrupt. Rarely, a hornblende crystal contains four zone shells, two in the core and two in the rim.

The occurrence near contacts and the association of schliern and inclusions suggest that the hornblende diorite is a product of local assimilation. According to Bowen (1928, p. 197-201), the assimilation of basic xenoliths by granitic magma is accomplished by the making-over of the xenolith constituents to minerals that are in equilibrium with the magma at the time of incorporation. The heat necessary for this process is created by the crystallization of

Table 16. Modes of hornblende diorite from the Deep Creek stock (volume percent).

Sample	Potassium feldspar	Quartz	Plagioclase	Biotite	Hornblende	Accessories: Non-opaque	Accessories: Opaque	Chlorite plus epidote	Color index	Average An-content of plagioclase
64	---	5.0	61.2	8.0	23.6	0.2	0.8	1.2	33.8	39
67	0.3	0.3	52.5	---	43.6	0.6	0.8	1.9	46.9	36
68	0.4	1.1	25.9	---	66.9	0.2	0.9	4.6	72.6	34
93	---	0.4	57.6	0.8	39.2	0.3	1.3	0.4	42.0	38
105	---	4.9	45.8	0.1	43.8	0.3	1.0	4.1	50.7	40
Mean	0.1	2.3	48.6	1.8	43.4	0.3	1.0	2.5	49.2	37

minerals from the magma that are, again, in equilibrium with it. The abundance of hornblende in the hornblende diorite may be due in part to enrichment by made-over xenolith minerals and in part to crystallization from the adjacent melt. That the magma received an influx of calcium from the decomposing xenoliths (Nockolds, 1935, p. 311) is also indicated by the abundant hornblende and by the slightly more calcic plagioclase. Zoning in hornblende may reflect a vascillating melt composition in the vicinity of reacting inclusions. If Bowen is correct, hornblende was the mafic phase in equilibrium with the magma at the time the xenoliths were incorporated.

In order to illustrate the types of igneous rock modification that resulted from reaction with marble, samples of modified diorite and quartz diorite were collected from the vicinity of two marble xenoliths. Five specimens from near the Lockwood-Alaska inclusion are described first; two samples from near the White Monument block are described second.

Quartz diorite and hornblende diorite occur in a 200-foot-wide zone of mildly structured dark-colored rock that parallels the southern edge of the Lockwood-Alaska marble xenolith near Lockwood Saddle (Plate 4). The quartz diorite (sample 453, Table 17), collected about 15 feet from the covered, but definitely skarn-free marble contact, is fine grained (I. C. = 95) and lacking in potassium feldspar. Quartz exhibits undulatory extinction, deformation bands, and

Table 17. Modes of limestone reaction rocks, Deep Creek stock (volume percent).

Sample	Potassium feldspar	Quartz	Plagioclase	Biotite	Hornblende	Clinopyroxene	Accessories		Chlorite plus epidote	Color index	Average An-content of plagioclase
							Non-opaque	Opaque			
51	---	3.0	45.6	4.3	44.8	---	1.0	0.3	1.0	51.4	38
53	0.1	0.8	68.1	---	10.0	19.7	1.2	---	0.1	31.0	36
83	0.1	0.1	70.4	---	0.2	27.7	1.4	---	0.1	29.4	--
453	---	12.0	66.2	---	14.5	---	0.3	0.6	6.4	21.8	36
454	1.6	0.7	68.2	---	---	28.9	0.5	---	0.1	29.5	32
455	0.6	0.1	58.6	---	38.2	1.7	0.4	0.3	0.1	40.7	33
456	6.8	4.3	55.3	---	32.5	---	1.0	0.1	---	33.6	34
Mean	1.3	3.0	61.9	0.6	20.0	11.2	0.8	0.1	1.1	33.9	35

deformation lamellae. Plagioclase twin lamellae and chlorite pseudomorphs after biotite are commonly bent, whereas hornblende is locally broken. The deformation, in a rock located between a large marble xenolith and the outer contact of the stock, is thought to reflect late stage outward movement of the xenolith in response to pressures from within the pluton. The hornblende diorite (sample 51, Table 17), taken approximately 150 feet from the marble contact, is characterized by fine grain size (I. C. = 113), lack of potassium feldspar, deficiency of quartz, and much hornblende. The plagioclase composition is An_{38}, slightly higher than average for the pluton. Subhedral green hornblende contains a few small areas of vermicular quartz, but no pyroxene.

Light-colored hornblende-pyroxene diorite (sample 53, Table 17) is developed within one foot of a ten-foot-wide garnet skarn zone on the north contact of the Lockwood-Alaska xenolith northeast of Lockwood Saddle. Pale green, slightly pleochroic clinopyroxene, which has a grainy texture, surrounds and corrodes large, ragged-edged green hornblende. The two minerals are commonly in crystallographic continuity such that pyroxene basal sections, for instance, surround basal sections of amphibole. Rarely, a second generation of small euhedral amphibole crystals projects from the outer borders of the pyroxene. Related pyroxene diorite (sample 83, Table 17) occurs at least 50 feet from a narrow skarn zone at the south contact of the xenolith near the Alaska mine. The abundance of pyroxene, surrounding only a few small relicts of hornblende, shows that the amphibole-pyroxene transformation proceeded farther than in the hornblende-pyroxene diorite. Sphene is a common accessory of both pyroxene rocks, in fact the average of 0. 68 percent is more than twice that for the normal quartz diorite of the pluton. The common localization of sphene on clinopyroxene suggests that it is a byproduct of the hornblende-pyroxene reaction.

Potassium feldspar-rich diorite (sample 456, Table 17) is a few inches from the northern contact of the Lockwood-Alaska xenolith along the ridge northeast of Lockwood Saddle. The diorite exhibits a hornblende-defined platy flow structure that strikes parallel to the contact, which in this area is marked by a 15-foot-wide zone of garnet skarn. Coarse grain size (I. C. = 57), high potassium feldspar, abundant hornblende, and absence of biotite are distinctive. The potassium feldspar is perthitic, displaying stringlet and string-type exsolution lamellae.

Pyroxene diorite (sample 454, Table 17) and pyroxene-bearing hornblende diorite (sample 455, Table 17) were collected 7 feet and 30 feet south, respectively, of the 90-foot-wide garnet skarn zone against the xenolith at White Monument (Plate 4). Because the diorites are from a mixed zone of granitic rock, schliern, hornfels, and garnet-epidote skarn (Plate 4), however, the relative distances from the marble may not be truly representative of the changes involved. The pyroxene diorite is typified by a lack of hornblende and biotite, and by a high percentage of pale green, well-formed, slightly pleochroic clinopyroxene. The pyroxene-bearing hornblende diorite contains pyroxene that is surrounded by green hornblende. The simultaneous extinction of disconnected pyroxene areas in hornblende leaves little doubt that the hornblende was actually making over the pyroxene at the time of consolidation.

According to Turner and Verhoogen (1960, p. 159-160), the modification of granitic magma by reaction with marble xenoliths commonly yields either of two end products--a mafic rock, which results from the incorporation of marble-derived calcium, or an alkali-enriched and (or) desilicated rock, which arises from the selective removal of certain constituents from the magma. In the latter case, the lost materials contribute to skarn formation in the adjacent marble.

Representative of the mafic type of modification are the quartz diorite and hornblende diorite south of the Lockwood-Alaska marble xenolith. They reflect addition of calcium in their abundance of hornblende and slightly more calcic plagioclase; no skarn developed in the adjoining marble. Of the second type, the pyroxene diorite near the White Monument inclusion is typical. The crystallization of pyroxene, rather than hornblende and biotite, is generally attributed to a loss of magmatic alumina (Tilley, 1949; Nockolds, 1950; Muir, 1953). The alumina deficiency is commonly accompanied by an increase in sodium (Tilley, 1949, p. 91), or potassium (Muir, 1953, p. 190), but, apparently, neither of these enrichments took place on a large scale in the Deep Creek stock. The pyroxene-bearing hornblende diorite at White Monument began crystallization of pyroxene, but must have been later exposed to free interchange with normal magma such that the usual hornblende precipitated. Significantly, the skarn at White Monument is about 90 feet wide.

Other reaction rocks appear to be the result of a combination of calcium enrichment and loss of constituents from the magma. The potassium feldspar-rich diorite north of the Lockwood-Alaska xenolith shows both addition of calcium, in that the hornblende content is high, and a possible late loss of iron and (or) water, in that biotite did not crystallize. The abundance of potassium feldspar may have resulted in part from the excess potassium remaining in the melt after biotite did not form. Likewise, the hornblende-pyroxene diorite above Lockwood Saddle commenced crystallization as a hornblende-rich rock, but was suddenly transformed by the precipitation of pyroxene in place of, and around, hornblende. The pyroxene diorite near the Alaska mine was subjected to a similar change, but it occurred much earlier in the crystallization history of the rock. Only narrow skarn zones developed in the adjoining marble.

The relationship between type of magma contamination and degree of skarn development is not unique to the Deep Creek stock. In the Boulder batholith, Knopf (1957, p. 97-98) described normal granodiorite adjacent to diopside-bearing marble, but augite granodiorite against skarn. At Crestmore, California, Burnham (1959) noted minor gabbroic and monzonitic variants of quartz diorite in contact with a skarn zone of less than one foot wide, but highly contaminated quartz monzonite porphyry adjacent to a skarn zone 50 feet wide.

The diffusion of materials from magma to marble requires that the magma remain in contact with the xenolith for a significant period of time. Calcium enrichment of the melt, however, could take place by incorporation of fragmented marble and not necessarily require prolonged diffusion. One possibility is that differences in the type of magma modification are due to the degree of magma agitation in the vicinity of the marble xenolith. Rocks in which initial calcium enrichment was followed by removal of constituents from the magma might reflect a change from active magma movement to relative quiet during crystallization.

White Monument Granodiorite

The White Monument granodiorite crops out at three localities within the Deep Creek stock. The largest and best exposed area, about 700 feet in diameter, is at the northern end of White Monument ridge (Plate 4). The next largest area, elongate northeast, is about 550 feet long and 250 feet wide and occurs in the canyon of Camp Creek, southwest of the Humboldt marble inclusion. The smallest mass, also elongate northeast, is about 135 feet long and 75 feet wide and crops out on the divide west of Sucker Gulch. The mass is too small, however, to be shown on the map. At the White Monument and Camp Creek areas, contacts are not exposed and must be drawn on the basis of field appearance and thin section mineralogy. At the smallest body, however, not only sharp contacts, but also apophyses are visible (Figure 18).

A pinkish hue and low color index serve to differentiate the White Monument rocks from the adjacent quartz diorite. The two types are similar, however, in texture and mineralogy. Modes for rocks of the three granodiorite areas (Table 18) are somewhat variable, particularly with regard to the extremely high hornblende and low quartz in the Camp Creek rock (sample 78, Table 18). The modes are consistent, however, in their high percentages of potassium feldspar. Minor string perthite and quartz deformation lamellae are locally developed, plagioclase has a disordered structure, biotite is mildly bent, and hornblende 2V's (as determined from three rocks) range from 69° to 74°. Allanite is a distinctive accessory.

White Monument granodiorite is thought to represent late stage

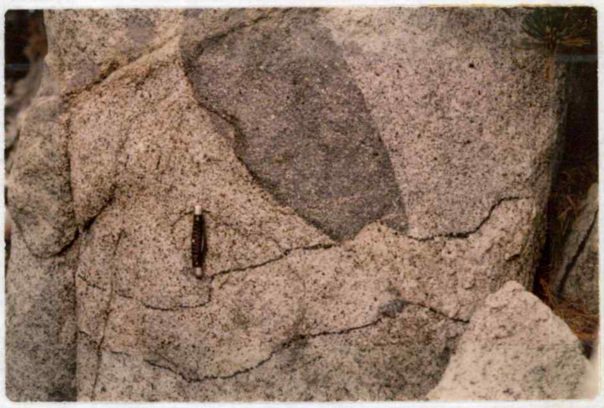


Figure 18. Apophysis of White Monument granodiorite in the Deep Creek stock at the divide west of Sucker Gulch. Contact was emphasized by black marking pencil. Note separation of inclusion (photo by W. C. Barnes).

intrusion from a core area more advanced in differentiation than the surrounding quartz diorite. Modal similarity suggests that the White Monument and Sucker Gulch masses are genetically related. The hornblende-rich Camp Creek body, however, may be of a slightly different period of emplacement.

Table 18. Modes of White Monument granodiorite, Deep Creek stock (volume percent).

Sample	Potassium feldspar	Quartz	Plagioclase	Biotite	Hornblende	Accessories Non-opaque	Accessories Opaque	Chlorite plus epidote	Color index
16	12.4	25.0	50.7	4.3	4.6	0.8	0.9	1.3	11.9
25	13.3	30.2	47.0	3.9	3.2	0.7	0.6	1.1	9.5
78	13.9	11.7	56.7	---	15.8	1.2	0.1	0.6	17.7
266	11.3	26.6	53.4	4.8	0.7	1.5	0.3	1.4	8.7
407	16.8	28.8	47.2	2.7	1.9	0.8	0.5	1.3	7.2
Mean	13.5	24.5	51.0	3.2	5.2	1.0	0.5	1.1	11.0

Felsic Dikes

Several gray quartz-rich quartz diorite dikes (sample 109, Table 19) north of Lake Winifred (Plate 4) transect the eastern prong of the Deep Creek stock. They vary in width up to 12 inches, and locally possess an internal biotite foliation that parallels sharp contacts. Quartz monzonite (sample 169, Table 19), as well as other quartz diorite dikes, which are not as rich in quartz as sample 109, are widespread in the country rocks. Some dikes are definitely apophyses of the Deep Creek stock; others cannot be confirmed as such.

Table 19. Modes of dikes in the Deep Creek stock (volume percent).

Sample	Potassium feldspar	Quartz	Plagioclase	Biotite	Hornblende	Accessories Non-opaque	Accessories Opaque	Chlorite plus epidote	Color index
15	19.5	32.2	46.3	0.7	---	0.2	0.2	0.9	2.0
22	33.0	33.7	32.3	0.2	---	---	0.1	0.7	1.0
56	1.2	9.1	52.2	12.1	24.2	1.1	---	0.1	37.5
109	1.5	54.7	39.3	3.4	---	0.1	0.5	0.5	4.5
112	37.7	37.1	24.4	0.2	---	---	0.1	0.5	0.8
169	26.5	37.9	32.2	2.9	---	---	0.4	0.1	3.4

Pink granodiorite dikes (sample 15, Table 19), 2 inches to as much as 14 inches wide, are typical of the western area, particularly near Camp Creek (Plate 4). The dikes, more resistant than the surrounding quartz diorite, stand up as narrow ridges that are pockmarked by the weathering of mafics. Mineralogical and textural similarity suggest that the dikes are closely related to the White Monument granodiorite.

Pink aplite and local pegmatite dikes (sample 22, Table 19), most common in the western core area of the stock, are generally small, about one quarter of an inch in width, but reach 9 1/2 inches locally. Individual dikes can be traced up to 30 feet on strike, some bifurcate, but most maintain fairly consistent trends. Grain size is variable, the largest being several centimeters in diameter. Perthitic potassium feldspar, plagioclase, and quartz are typical; graphic textures are local.

Light gray aplite dikes (sample 112, Table 19), as much as eight inches wide, cut the eastern prong near contacts north of Lake Winifred. Grain size rarely exceeds two mm; textures are equigranular.

The quartz-rich quartz diorite dikes parallel contacts, whereas the granodiorite, pegmatite, and aplite dikes appear to follow primary joints within the stock.

Mafic Dikes

About ten light gray hornblende diorite dikes (sample 56, Table 19) slice the Deep Creek stock on the north and south flanks of Pepperbox Hill (Plate 4). Two others cut country rocks east of the main body of the stock between Lost Basin and Lake Winifred. With only two minor exceptions, the dikes follow an east-trending joint set. Although the longest continuous outcrop is only 200 feet, individual dikes probably extend for at least one mile. Contacts are always sharp, and, in the larger dikes, marked by narrow chill zones. Quartz diorite inclusions up to one inch long are rare; local apophyses inject the walls. Texturally, the dikes vary from equigranular to porphyritic. Elongate green hornblende phenocrysts range from 2 mm to as much as 7.5 mm in length. Some biotite is primary, but most is an alteration product of hornblende. Plagioclase, the only other phenocryst mineral, is commonly zoned.

Two olive gray dikes of biotite-pyroxene lamprophyre, probably kersantite, crop out a quarter of a mile north of the intersection between Camp Creek and Sucker Gulch and about the same distance north of the confluence of Camp Creek and Indian Creek (Plate 4). Exposures are poor and very limited; the rocks are vesicular, vuggy, and easily weathered. Phenocrysts of brown biotite, pale green clinopyroxene, and rare brown hornblende are set in a matrix of elongate pyroxene, narrow biotite tablets, apatite, opaque, and many slender sub-radiating inclusion-filled laths, probably sodic plagioclase. Biotite phenocrysts are as much as 1.5 mm long, many pyroxene phenocrysts are altered to calcite.

The prominent east trend of the hornblende diorite dikes indicates lack of control by primary joints and, hence, probable emplacement later than the felsic dikes. The mineralogy and localization suggest a genetic relationship to the Deep Creek stock. Hornblende diorite and (or) lamprophyre dikes are typically associated with granitic plutons (Moore, 1963, p. 121-129; Taubeneck, 1957, p. 212).

Chemistry--Major Oxides

Inward increase in SiO_2, Na_2O, and K_2O characterizes rocks of the Deep Creek stock (Table 20). Other major oxides decrease inward. Compared to the average tonalite (Nockolds, 1954, p. 1015), the interior quartz diorite is slightly lower in CaO, but the White

Table 20. Chemical analyses and norms of rocks from the Deep Creek stock (weight percent).

	1	233	10	25	112
SiO_2	53.98	59.13	66.58	68.68	75.61
TiO_2	---	0.83	0.52	0.41	0.09
Al_2O_3	27.64	16.73	15.86	15.34	12.94
Fe_2O_3		2.24	1.59	1.20	0.46
FeO	---	3.90	2.27	2.02	1.00
MnO	---	0.10	0.06	0.06	0.02
MgO	4.63	3.88	1.99	1.44	0.05
CaO	7.03	6.18	3.60	3.09	0.90
Na_2O	4.51	3.73	4.17	3.87	3.04
K_2O	1.75	1.41	1.85	2.56	5.52
H_2O^+	---	1.29	1.02	0.89	0.14
H_2O^-	---	0.06	0.10	0.11	0.02
P_2O_5	---	0.20	0.09	0.08	0.01
Ignition	0.90				
Total	100.44	99.68	99.70	99.75	99.80
Q		12.66	24.00	26.94	34.14
or		8.34	11.12	15.01	32.80
ab		31.44	35.11	32.49	25.68
an		24.74	16.96	15.29	4.45
C		---	0.41	0.61	0.31
di		4.02	---	---	---
hy		11.83	7.11	5.71	1.42
il		1.52	0.91	0.76	0.15
mt		3.25	2.32	1.86	0.70
ap		0.31	0.31	---	---
H_2O		1.35	1.12	1.00	0.16
Total		99.46	99.37	99.67	99.81

1. Packard (1895, p. 299).

233. Border quartz diorite from Kinney Point ridge. Analyst, K. Aoki.

10. Interior quartz diorite from White Monument ridge. Analyst, K. Aoki.

25. White Monument granodiorite from White Monument ridge. Analyst, K. Aoki.

112. Quartz monzonite aplite from ridge north of Lake Winifred. Analyst, K. Aoki.

Monument granodiorite (Table 20) is readily comparable to the average biotite granodiorite (Nockolds, 1954, p. 1014).

A plot of border, interior, White Monument granodiorite, and aplite values on a calcium-sodium-potassium variation diagram (Figure 19) reveals a normal calc-alkaline trend of differentiation. The trend is similar to that of rocks from the southern California batholith and Lassen Peak areas (Nockolds and Allen, 1953, p. 107).

Chemistry--Trace Elements

The average copper, zinc, lead, and molybdenum contents of 15 stream sediment samples from the main body of the Deep Creek stock are shown in Table 21. These values, even though of sediments, may approximate true concentrations in the pluton. Samples were selected from drainage basins that lie entirely within the stock and that include no significant areas of mineralization.

A comparison of Deep Creek stock values with those of two quartz diorite intrusions and with some averages for all granitic rocks is made in Table 21. Copper is much higher than in Cornucopia tonalite, compares closely with Beaverdell quartz diorite, and is exactly the same as the average for all granitic rocks. Zinc, in spite of considerable variability, also approximates the average. The standard deviation of zinc in the 15 sediments from the Deep Creek stock is 14.6 as compared to 6.7 for copper, 3.1 for lead,

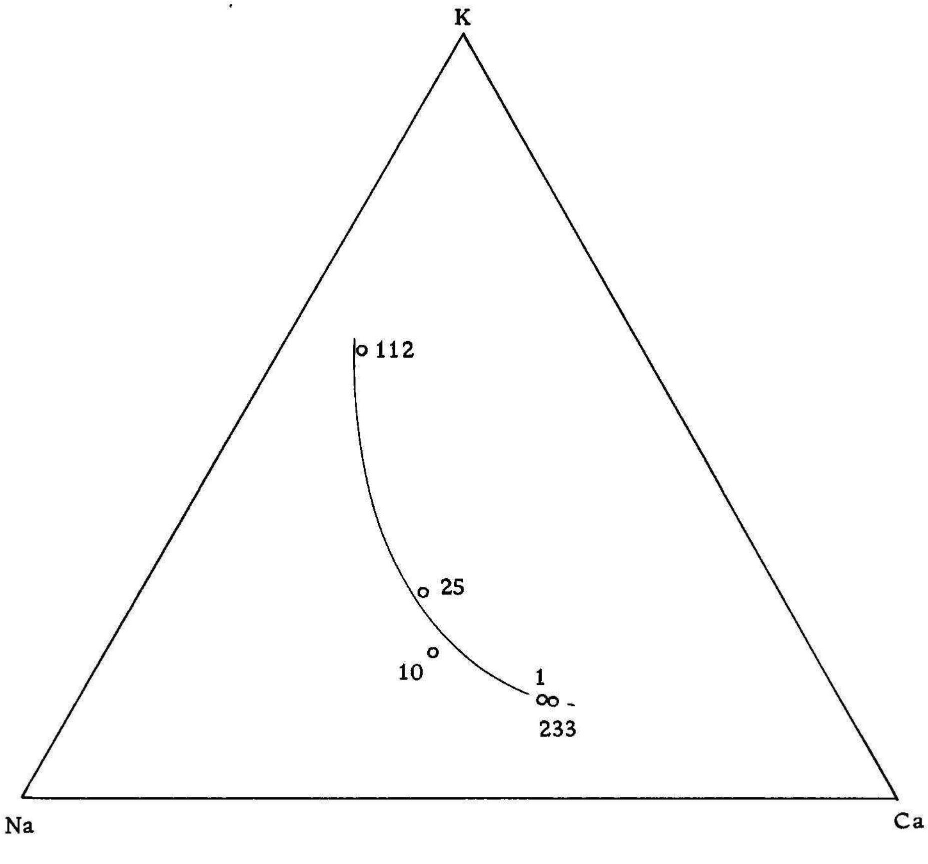


Figure 19. Variation diagram of rocks from the Deep Creek stock.

and 0.0 for molybdenum. Lead is much higher than in Cornucopia tonalite, but is similar to the average for granitic rocks. The lead value approximates 14 ppm, the average of 52 granitic rocks determined by Sandell and Goldich (1943, p. 170). Molybdenum, although higher than average, is close to 2.5 ppm, the average recorded by Sandell and Goldich (1943, p. 168) for 13 silicic rocks.

Table 21. Average copper, zinc, lead, and molybdenum in the Deep Creek stock, in two other quartz diorite intrusions, and in all granitic rocks (ppm).

	1	2	3	4
Cu	20	2.6	16	20
Zn	54	44	125	49.5
Pb	13	4.2	---	17
Mo	3	---	---	1.2

1. Deep Creek stock. Average of 15 sediment samples. Analyst, J. J. Johnson.
2. Cornucopia tonalite unit of the Cornucopia stock, eastern Oregon. Includes satellites. Average of 11 rocks (Taubeneck, 1967a, p. 25).
3. Beaverdell quartz diorite, British Columbia. Average of 5 rocks (Warren and Delavault, 1960, p. 60).
4. Average for all plutonic granitic rocks (Turekian and Wedepohl, 1961, Table 2).

The carbon in 52 samples from the Deep Creek stock varies between 120 ppm and 1,400 ppm (Table 22). In general, lowest carbon values are in the interior of the pluton, whereas highest values are along the borders (Figure 20). The one exception is the

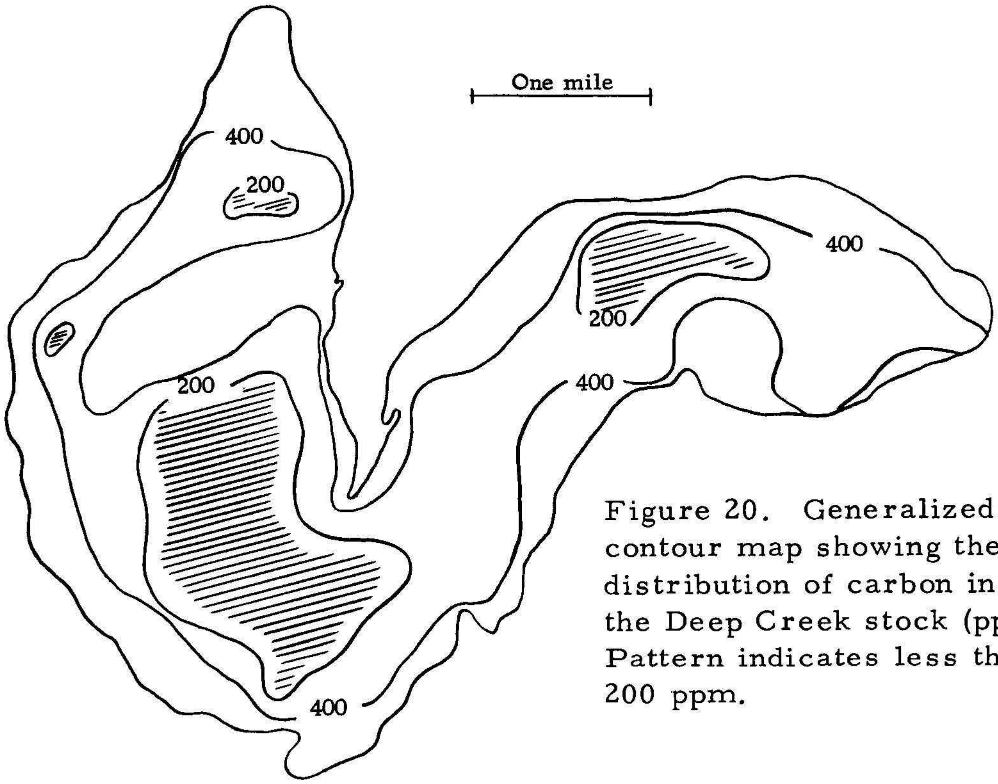


Figure 20. Generalized contour map showing the distribution of carbon in the Deep Creek stock (ppm). Pattern indicates less than 200 ppm.

area of high carbon that trends northeasterly across the main body of the stock. The average of 345 ppm for the Deep Creek stock is slightly higher than 300 ppm, the average for all igneous rocks (Rankama and Sahama, 1950, p. 532).

Table 22. Carbon analyses, Deep Creek stock (ppm). Analyst, C. B. Moore.

Sample	Carbon	Sample	Carbon	Sample	Carbon	Sample	Carbon
2	170	38	510	79	300	115	440
3	430	39	170	85	160	119	560
4	390	40	120	90	260	120	200
6	180	50	160	91	550	122	230
7	310	54	150	92	220	226	1400
8	930	55	180	94	360	227	290
10	210	61	380	104	220	228	240
11	150	62	200	106	170	233	790
16	160	69	350	107	400	264	210
20	490	74	220	108	640	268	1370
21	340	76	160	110	270	301	220
24	370	77	140	111	250	440	380
37	200	78	300	114	210	441	230

The only mineral in the stock that could contain significant carbon is calcite. Although, as expected, rocks with high carbon have high calcite, the correlation is not consistent. Either additional unrecognized sources of carbon occur, or, more probably, modal analysis of only two thin sections from a rock is not sufficient to record the small percentages of calcite present. A lack of any association between areas of high carbon and localization of marble xenoliths presupposes derivation from that source. The calcite is primary and most likely deuteric.

The areas of high carbon may represent places at which fugitive constituents were concentrated. The increase in carbon along borders suggests an outward localization of volatiles in areas of lower temperature and pressure (Kennedy, 1955; Taubeneck, 1967a, p. 35). The zone of high carbon that trends across the main body of the stock may reflect the configuration of a roof beneath which volatiles concentrated. A value of 1370 ppm, second highest in the stock, is at a position which, from the interpretation of flow structure, could underlie a dome apex. Areas of high carbon do not coincide with localities in which late magmatic minerals last consolidated.

Plutonic Rocks of the Re-entrant at Ritchie Gulch

The re-entrant at Ritchie Gulch separates part of the main body of the Deep Creek stock from the eastern prong (Plate 4). Although metavolcanics, as well as plutonic rocks, form the re-entrant, only the latter are discussed.

There are two groups of plutonic rocks, lighter colored quartz diorite, with an average color index of 26.8 (Table 23), and darker colored quartz diorite and hornblende diorite, with an average color index of 37.4 (Table 24). The lighter colored rocks are prevalent west of the southward-projecting finger of metavolcanics on the divide between Ritchie Gulch and Sucker Gulch, and on the west flank of the

Table 23. Modes of lighter colored quartz diorite from the re-entrant at Ritchie Gulch (volume percent).

Sample	Potassium feldspar	Quartz	Plagioclase	Biotite	Hornblende	Augite	Accessories Non-opaque	Accessories Opaque	Chlorite plus epidote	Color index	Average An-content of plagioclase
26	---	15.0	57.0	8.7	16.5	---	0.3	1.4	1.1	28.0	37
33	---	12.7	61.8	5.6	17.4	---	0.1	1.2	1.2	25.5	34
70	---	13.4	59.6	0.9	19.6	---	---	0.7	5.8	27.0	37
Mean	---	13.7	59.5	5.1	17.8	---	0.1	1.1	2.7	26.8	36

Table 24. Modes of darker colored quartz diorite and hornblende diorite from the re-entrant at Ritchie Gulch (volume percent).

Sample	Potassium feldspar	Quartz	Plagioclase	Biotite	Hornblende	Augite	Accessories Non-opaque	Accessories Opaque	Chlorite plus epidote	Color index	Average An-content of plagioclase
29	---	6.6	55.8	6.4	29.9	---	---	1.3	---	37.6	33
30	---	---	59.8	9.3	30.2	0.1	0.3	0.3	---	40.2	40
99	---	10.8	55.2	5.3	26.7	0.1	0.4	0.9	---	34.0	34
101	---	---	62.4	1.7	33.6	---	---	2.3	---	37.6	--
Mean	---	4.4	58.3	5.7	30.1	0.1	0.2	1.2	---	37.4	36

ridge between Ritchie Gulch and Pepperbox Basin (Plate 4). Contact exposures are rare, but those present suggest a gradation with border rocks of the Deep Creek stock. The darker colored rocks compose both the southeast wall of Ritchie Gulch and the isolated outcrop north of the small lake (Plate 4). The darker varieties are separated from the stock by areas of country rock and by zones of lighter colored quartz diorite. Contacts between dark and light-colored rocks are gradational; contacts of both types with metavolcanics and biotite schist are sharp.

Both groups of re-entrant rocks are more finely crystalline (light-colored rocks, I. C. = 100; dark rocks, I. C. = 113) and less strongly foliated than the average border quartz diorite. Both groups are cut by numerous dikes of quartz diorite and aplite, presumably from the Deep Creek stock (Figure 21). Chlorite and epidote-veneered joint and slip surfaces are common. Diorite apophyses, one almost three feet wide, inject the country rocks. Inclusions are common near sharp contacts, but except for an isolated five-foot-long pod of garnet-epidote skarn on the Ritchie Gulch-Sucker Gulch divide, they are not widespread.

The petrography of the lighter colored quartz diorite, except for the limited resorption of hornblende, is no different from that of the normal border quartz diorite of the Deep Creek stock. Average composition of the plagioclase, as determined from 11 measurements

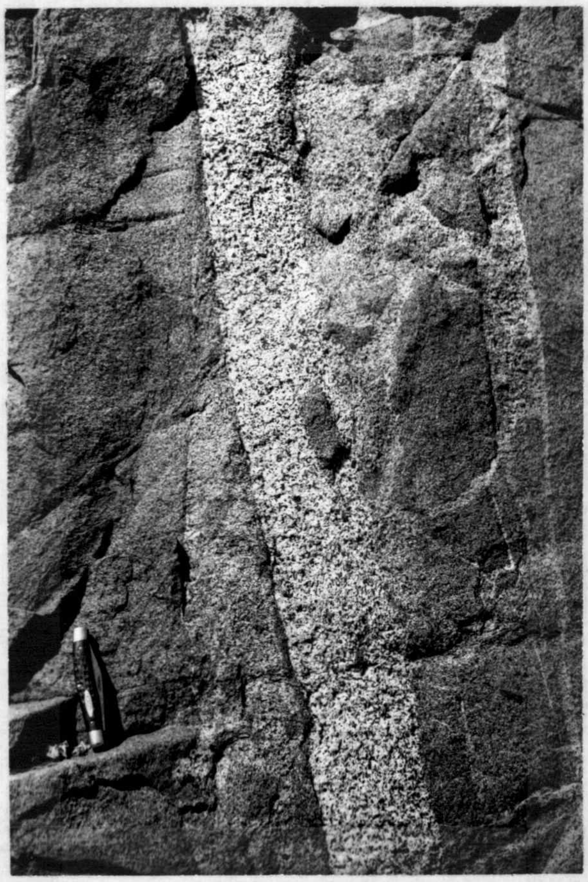


Figure 21. Quartz diorite dikes cutting darker hornblende diorite of the re-entrant at Ritchie Gulch. Note inclusions and the two generations of dike injection.

on six crystals from three rocks, is An_{36}. The range is An_{32} to An_{41}. Measurement of one plagioclase core gave An_{43}.

The darker rocks are characterized by plagioclase that includes numerous opaque crystals, brown or green biotite, hornblende, and possibly apatite. The average plagioclase composition is also An_{36}, as determined from nine measurements on six crystals from three rocks. The range is An_{32} to An_{41}. The maximum core value is An_{51}. Green hornblende, which is anhedral, corroded, and embayed, includes relicts of augite. Some textures are hypidiomorphic granular, whereas others, except for biotite, are allotriomorphic. The borders of small interstitial plagioclase and possibly quartz are sutured in a few of the darker rocks.

The lighter colored quartz diorite, although slightly darker, more finely crystalline, and much less intensely foliated than most border rocks of the Deep Creek stock, is, nonetheless, somewhat similar in mineralogy. The darker quartz diorite and hornblende diorite, however, are different from border rocks in high color index, fine grain size, and mineralogy. The lack of abundant inclusions and the presence of sharp contacts against metavolcanics suggests that the dark rocks are not a marginal assimilation facies of the Deep Creek stock. The absence of the diorite in any quantity at other contacts of the stock supports this conclusion. Both light and dark rocks are slightly older than the stock, as shown by quartz diorite dikes in the re-entrant and by xenoliths of re-entrant rocks in the stock, but gradational contacts suggest that the re-entrant rocks were not entirely crystalline at the time the Deep Creek stock was emplaced.

One possibility is that the darker rocks of the re-entrant constitute a basic forerunner of the Deep Creek stock that developed from a hybrid magma at depth and was emplaced shortly before injection of the main quartz diorite. The lighter colored rock may represent both normal border quartz diorite, and, in part, a product of the hybrid mixing of Deep Creek magma with that of the forerunner.

Echols Mountain Stock

Field Description

The Echols Mountain stock crops out in a four-square-mile area between the canyons of Granite Fork and Rapid River (Plate 4). The best exposures are on Echols Mountain. Contacts are either abrupt or, if transitional, limited to zones of less than five feet. They dip inward from 42°-70° in the western part of the stock, outward beneath the Martin Bridge limestone in the east, outward or vertical in the north, and steeply both in and out along the south. Foliation in adjacent metavolcanics is intense near contacts and discernible for at least 800 feet from them. On the ridge south of

Twin Lakes, country rock foliation arches above the pluton. Garnetization of adjacent limestone in the east is surprisingly rare. Apophyses are common.

There are only two mappable xenoliths of marble in the Echols Mountain stock. The largest, which lies precisely on the divide between Granite Fork and Twin Lakes basin (Plate 4), is about 500 feet long and 250 feet wide. This northwest-trending body is separated from adjacent contact schist by a 60-foot-wide zone of layered, recrystallized metavolcanics, intercalated marble, and large apophyses of quartz diorite. Selvages of garnet, which rarely exceed half an inch in width (Figure 22), generally mark the contacts between quartz diorite and marble. Together with a few thin garnet bands in the marble and small inclusions in quartz diorite, these narrow layers constitute the only significant silication. The smaller marble inclusion, between Rapid River and Sinking Creek, is 200 feet long and 75 feet wide. Some garnet occurs adjacent to cross-cutting quartz diorite stringers, but on the whole, silication is minimal.

The contact location and interlayering of the larger marble inclusion with recrystallized wall rock suggests that it was a lense in the metavolcanics. The smaller inclusion, situated in an area where the pluton intersects the Martin Bridge limestone, was probably derived from that formation.

Platy flow structure, defined by biotite and hornblende, varies

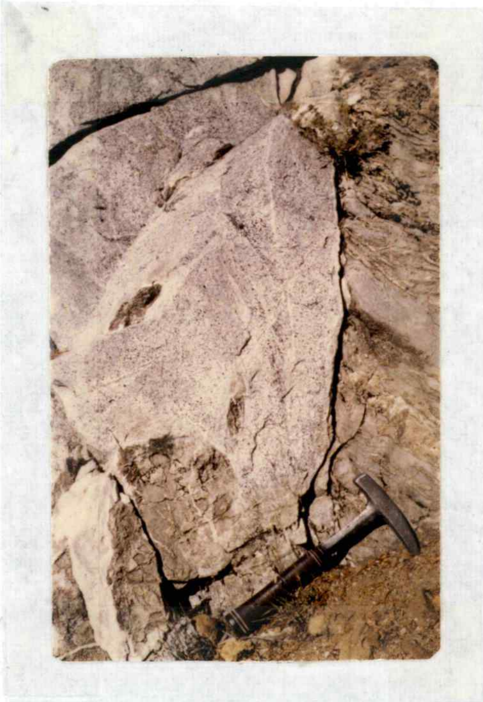


Figure 22. Contact between quartz diorite (left) and marble inclusion (right), Echols Mountain stock.

in intensity from extreme near contacts to moderate in the interior. Lineation is rare; where present, it plunges down the dip of the foliation. Approximately 158 measurements reveal a contact parallelism and a distinctive dome-shaped closure in the south-central part of the stock (Plate 3). Considering the dynamic interpretation of platy flow structure, the dome probably is the locus of upwelling from which magma moved upward and outward in feeding the rest of the pluton.

Mineral Distribution

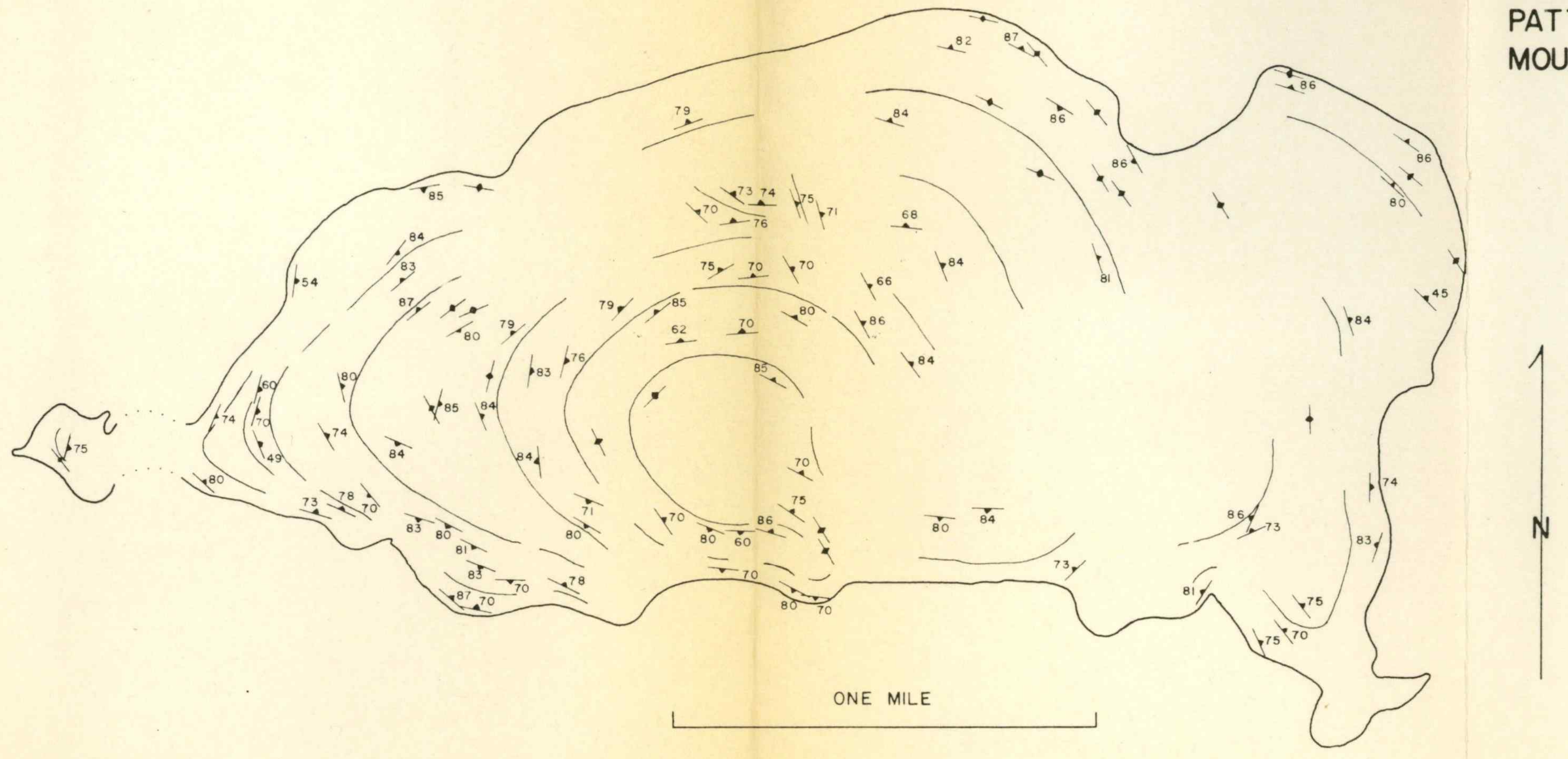
Mineral distribution maps show an inward increase in potassium feldspar and quartz, and decrease in color index (Figures 23, 24, and 25). Sample locations are shown in Figure 26. The variability of individual minerals, as shown by modes (Table 25), is small. By comparison, the standard deviations of essential minerals in the Echols Mountain stock are either the same as, or less than those for the same minerals in only the border rocks of the Deep Creek stock (Table 11).

Petrography

As the petrography of the Echols Mountain stock closely resembles that of the Deep Creek stock, only a few features are mentioned. Perthite in potassium feldspar and deformation lamellae in quartz are rare. Expansion pods in biotite are definitely white

PLATE 3

MAP SHOWING THE FLOW PATTERN IN THE ECHOLS MOUNTAIN STOCK



80 Srike and dip of platy flow structure

Strike of vertical platy flow structure

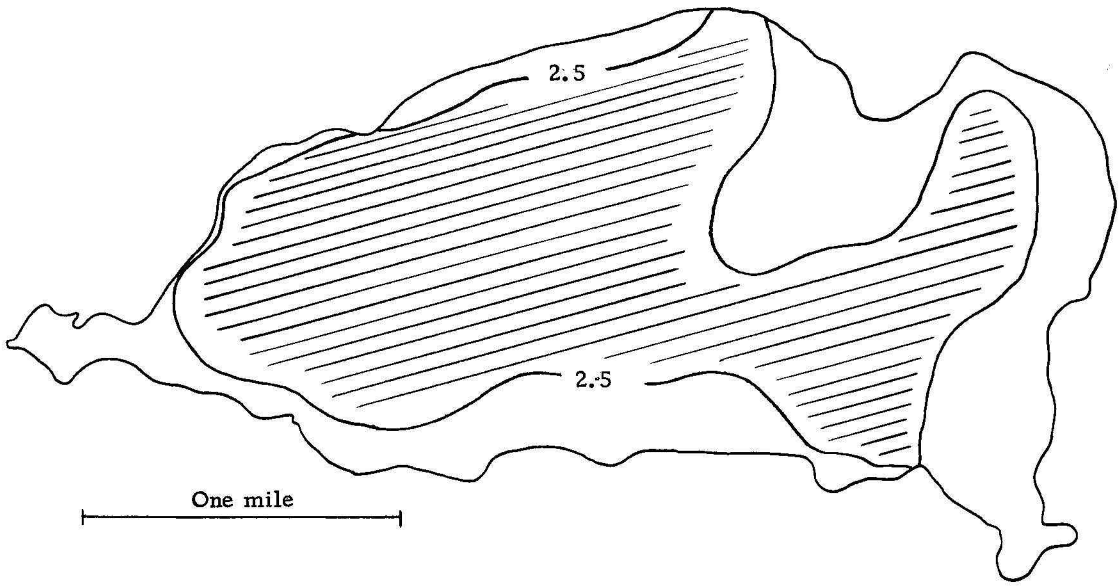


Figure 23. Generalized contour map showing the distribution of potassium feldspar in the Echols Mountain stock. Pattern indicates more than 2.5 percent.

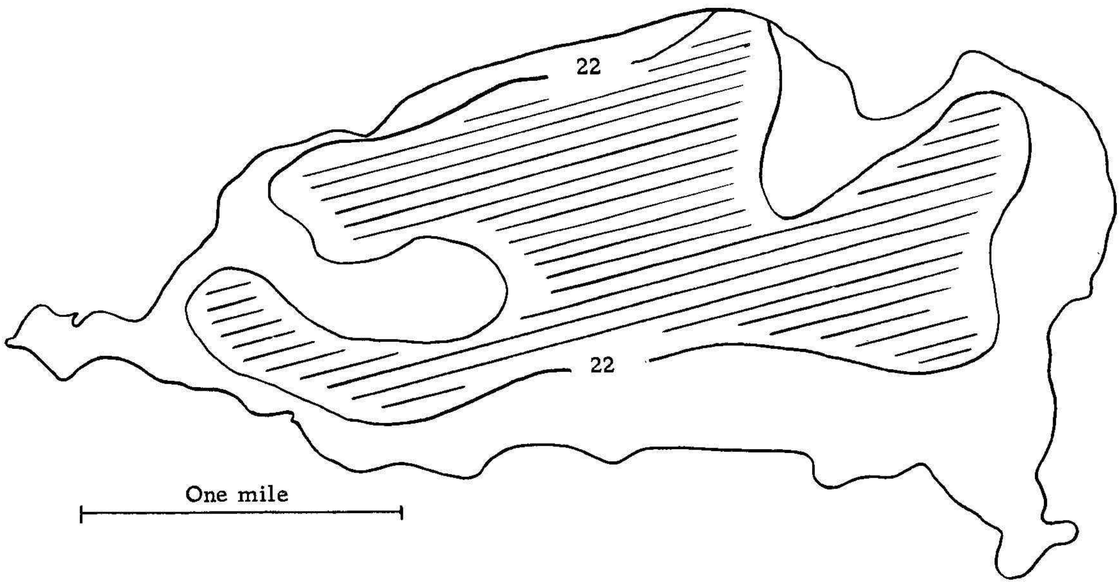


Figure 24. Generalized contour map showing the distribution of quartz in the Echols Mountain stock. Pattern indicates more than 22 percent.

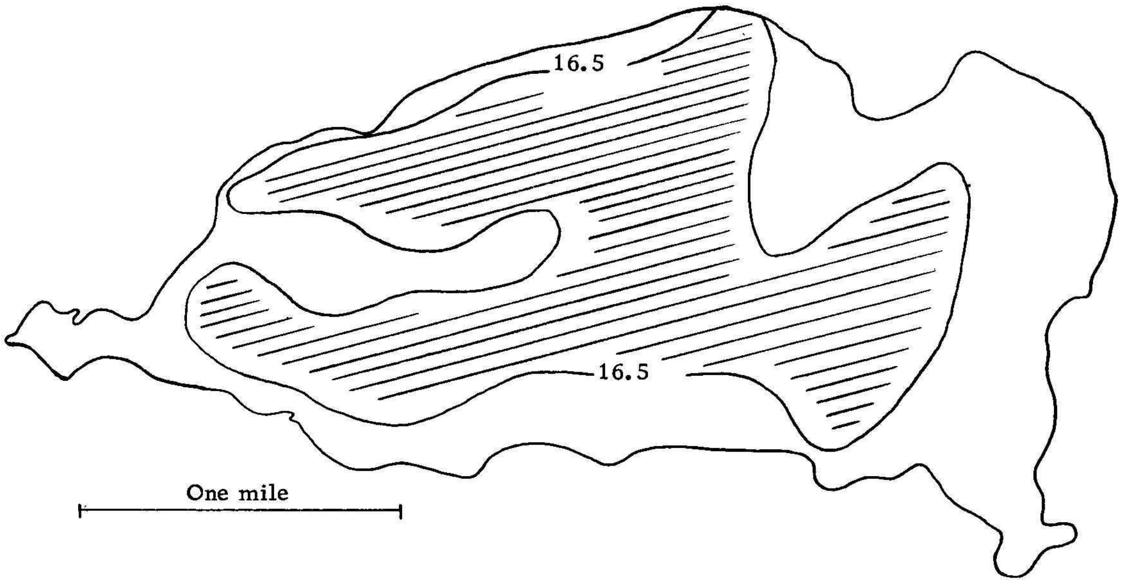


Figure 25. Generalized contour map showing the distribution of color index in the Echols Mountain stock. Pattern indicates less than 16.5 percent.

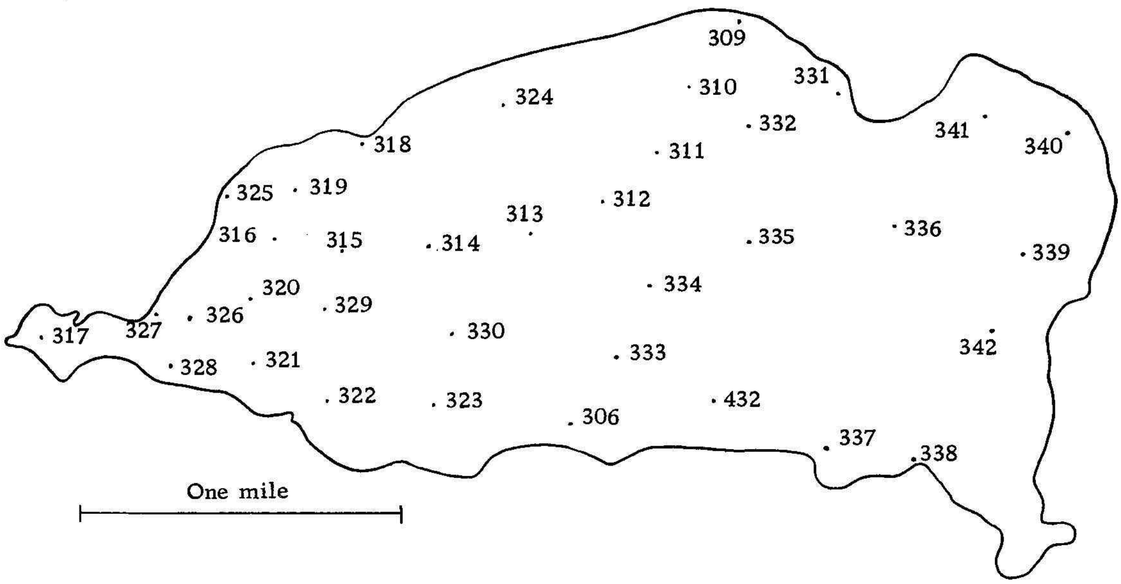


Figure 26. Map showing sample locations in the Echols Mountain stock.

Table 25. Modes of quartz diorite from the Echols Mountain stock (volume percent).

Sample	Potassium feldspar	Quartz	Plagioclase	Biotite	Hornblende	Accessories Non-opaque	Accessories Opaque	Chlorite plus epidote	Color index
306	0.8	21.6	58.7	5.0	9.2	0.6	1.0	3.1	18.9
309	3.7	22.7	60.7	6.9	4.4	0.4	0.7	0.5	12.9
310	2.6	23.3	59.3	7.0	5.9	0.4	0.7	0.8	14.8
311	3.3	23.5	58.4	7.4	4.9	0.7	0.8	1.0	14.8
312	2.9	21.6	60.6	5.4	7.0	0.6	0.9	1.0	14.9
313	1.6	23.5	56.9	9.6	5.3	1.0	1.0	1.1	18.0
314	3.1	19.9	60.9	7.7	6.0	0.5	0.9	1.0	16.1
315	3.2	23.9	55.1	9.4	7.0	0.5	0.5	0.4	17.8
316	3.3	18.0	61.2	8.9	6.7	0.8	0.7	0.4	17.5
317	0.1	15.3	65.6	7.2	8.7	0.4	1.3	1.4	19.0
318	2.5	24.9	57.8	7.8	5.7	0.3	0.5	0.5	14.8
319	2.8	24.8	60.5	6.7	3.6	0.5	0.6	0.5	11.9
320	3.6	22.3	59.4	6.8	5.9	0.2	1.1	0.7	14.7
321	2.7	23.1	59.2	8.9	4.7	0.3	0.8	0.3	15.0
322	3.0	24.2	61.1	4.1	4.0	0.7	1.2	1.7	11.7
323	2.9	23.2	59.6	8.0	4.7	0.6	0.5	0.5	14.3
324	3.8	22.4	57.4	8.8	5.7	0.5	1.0	0.4	16.4
325	2.8	20.3	63.1	5.2	6.6	0.5	0.9	0.6	13.8
326	3.3	22.1	59.5	1.8	6.8	1.0	1.0	4.5	15.1
327	---	21.2	60.1	2.9	8.4	0.2	1.1	6.1	18.7
328	0.9	19.9	60.5	7.6	8.9	0.4	1.2	0.6	18.7
329	3.0	21.2	55.3	6.0	9.2	0.4	1.2	3.7	20.5
330	3.6	20.9	59.7	7.0	5.6	0.6	0.9	1.7	15.8
331	1.4	21.8	58.5	6.3	9.7	0.6	0.8	0.9	18.3
332	3.5	22.0	59.0	6.5	6.9	0.6	0.6	0.9	15.5
333	3.1	23.9	59.7	4.7	6.1	0.5	0.9	1.1	13.3
334	2.6	23.6	59.3	7.9	4.7	0.5	0.6	0.8	14.5
335	1.9	23.2	58.9	6.7	7.1	0.6	0.7	0.9	16.0
336	2.3	26.6	55.9	7.2	6.4	0.5	0.7	0.4	15.2
337	2.4	21.9	59.9	6.2	8.0	0.4	0.8	0.4	15.8
338	3.9	21.2	57.0	8.6	7.0	1.2	0.9	0.2	17.9
339	3.4	20.9	58.9	7.2	7.5	0.5	1.0	0.6	16.8
340	1.7	19.9	58.4	5.6	9.1	0.9	1.1	3.3	20.0
341	2.9	23.1	56.2	8.4	7.7	0.8	0.7	0.2	17.8
342	1.9	23.3	58.1	7.3	7.0	0.7	0.8	0.9	16.7
432	1.8	20.3	59.5	8.5	8.7	0.2	1.0	---	18.4
Mean	2.5	22.1	59.2	6.9	6.7	0.5	0.9	1.2	16.2
Standard deviation	1.00	2.07	2.05	1.73	1.62	0.23	0.22	1.75	2.19

mica. They commonly occur in sections where seritization of plagioclase is best developed, but areal localization in the pluton is lacking. No augite relicts occur in hornblende. Only one bleached area was observed. As in the Deep Creek mass, the amounts of chlorite and epidote do not increase eastward in the stock. The minerals are more likely deuteric than metamorphic (see page 106).

Age of the Younger Granitic Suite

The Deep Creek and Echols Mountain stocks are probably Late Jurassic-Early Cretaceous in age. They are younger than the Late Triassic-Late Jurassic (?) plutons of the mafic and older granitic suites, which they metamorphose, but older than the Miocene Columbia River basalt, which they underlie. The limitation to Early Cretaceous is conjectural.

Conclusions

Condition of the Deep Creek Magma at the Time of Emplacement

The Deep Creek magma apparently was liquid when the marble inclusions were encountered at depth. This is indicated by the formation of Willow Lake-type layering around one marble xenolith (Poldervaart and Taubeneck, 1960) and the crystallization of early pyroxene around another (Muir, 1953, p. 189). As it reached the position now exposed, however, the magma probably contained crystals of plagioclase and small amounts of hornblende, in addition to the marble xenoliths. The presence of plagioclase is strongly suggested by phenocrysts in the microporphyritic contact rock near Hardrock Gulch. The presence of hornblende is indicated by inclusions in the plagioclase of the contact rock, but the rarity and small size of the inclusions suggests that hornblende was not abundant. The occurrence of hornblende adjacent to some marble xenoliths, in made-over inclusions, and in areas of assimilation indicates that hornblende was in equilibrium with the melt at the time at least some inclusions were incorporated.

The Deep Creek melt may have been relatively high in volatiles and, hence, a wet magma. The width of the thermal aureole, the width of the zone of contamination around marble xenoliths, and the amount of differentiation within the stock reflect the ease by which materials were allowed to migrate. This ease of migration is attributed to the presence of volatiles. The possible outward movement of volatiles, as suggested by the carbon distribution, and the presence of quartz veins, are also characteristic of wet magmas (Taubeneck, 1967, p. 47; Compton, 1960, p. 1408).

Origin of the Platy Flow Structure in the Deep Creek Stock

The platy flow structure in the Deep Creek stock is almost certainly primary. Evidence includes the preferred orientation of primary xenoliths and schliern within the plane of the structure, the absence of a relationship between foliation and cataclastic texture, and the unique structural pattern.

The classic explanation for the origin of plutonic platy flow structure, as outlined by Balk (1937), requires that minerals align themselves parallel to friction-exerting surfaces in attaining dynamic equilibrium within flowing magmas. This mode of origin is strongly supported by the common parallelism of plutonic flow structure with adjacent contacts, and by analogous structures in lava flows and dikes (Balk, 1937, p. 52). The concept suggests, and it is frequently either stated or implied (Billings, 1959, p. 325; Buddington, 1959, p. 734; Burnham, 1959, p. 888, 917; Taubeneck, 1967b, p. 220), that platy structure necessitates that crystals be present in a melt at the time of injection. Such an assumption is invalid for the Deep Creek stock, however, because, at emplacement, the minerals that defined the structure, biotite and hornblende, were either absent or only in the preliminary stages of crystallization.

The time of formation of the flow structure is of fundamental importance. That various primary structures form at different periods during consolidation was recognized by Cloos (1932, p. 294-295) in an outline of viscous, closing viscous, and solid stage elements, and by MacColl (1964) in a structural analysis of the Rattlesnake Mountain pluton. In the Deep Creek stock the contact rock at Hardrock Gulch reveals a sequence. The large number and small size of biotite crystals suggests that they crystallized rapidly from a liquid upon contact with cooler country rock. Yet, biotite tablets were concentrated and aligned end-to-end as if they had floated together and then oriented themselves parallel to the contact according to the principles of Balk (1937). In short, the biotite was not present at intrusion, but sufficient motion occurred after crystallization to orient the crystals. The well-developed flow structure along contacts in the main body of the Deep Creek stock is thought to have formed by continued movement of magma parallel to contacts.

This same mechanism also might be extended to explain flow structure in the interior of the pluton. The abundance of hornblende, an early crystallizer, in border areas of the Deep Creek stock, and potassium feldspar, a late crystallizer, in the interior, suggests that the pluton crystallized and differentiated from the borders inward. Such a process would require the inward progression of a consolidating shell, probably separated from a liquid interior by a zone of crystallization in which both crystals and liquid were present. In order for differentiation to occur, continued transfer of material from the zone of crystallization to the interior (Taubeneck, 1967a) is essential. Taubeneck (1967a, p. 41) pointed out the inadequacy of simple diffusion in this respect and suggested that movements in the interior melt, such as those produced by convection, could greatly facilitate transfer. The zone of crystals and melt between nearly solid shell and moving liquid interior would be an ideal place for minerals to orient. Compton (1955, p. 34) implied such a mechanism in the formation of platy flow structure in the Bald Rock batholith. If, in a given pluton, orientation of minerals originated in this manner, however, the resulting structural pattern should show closure around areas of last consolidation. In the Deep Creek stock there is no such relationship. The flow pattern is entirely independent of the compositional zonation. This suggests that the flowage of materials past a consolidating shell was not the mechanism of final orientation.

Although the orientation of minerals and schliern parallel to contacts is dominant in the classic concept, early workers did recognize that orientation in the interior of plutons could be related to expansion (Balk, 1937, p. 59). Martin (1952, p. 334) stated this idea more completely when he concluded from studies of the Flamanville intrusion that as the granite expanded "each . . . flow-plane in the granite was distended in all directions within these planes, like the skin of a growing balloon." Martin believed that the minerals became oriented in planes normal to the direction of distension. This concept was further applied to the origin of platy flow structure in the Ardara diapir (Akaad, 1956, p. 227) and the Caribou Mountain pluton (Davis, 1963, p. 341).

The expansion mode of origin requires that upward and outward pressures be active within the pluton. At emplacement of the Deep Creek stock, plagioclase crystals, some hornblende crystals, and xenoliths, principally those composed of marble, were the only solid constituents in the fluid magma. Plagioclase is not, in the present study, a useful structural element. To draw conclusions from the small number of hornblende crystals is not safe. Large tabular marble xenoliths, on the other hand, probably were sensitive to any pressures acting against them (Balk, 1937, p. 17). The lack of large marble outcrops in the immediate vicinity of the stock and the cataclastic texture of some marble xenoliths suggest that the blocks originated at depth and were forcefully carried upward. Assuming that the largest xenoliths moved up a conduit located near the north-central part of White Monument ridge, their present location, near Lockwood Saddle, implies a lateral transport of at least 5,000 feet. The upward and outward movement of marble xenoliths is thought to reflect the early upward and outward pressures within the pluton. Also indicative of early outward pressures are the rotational alignment of marble xenoliths parallel to the outer contacts of the pluton and the occurrence of contact-paralleling foliation in the adjacent country rocks (Compton, 1955, p. 43). That these forces continued during further crystallization of the pluton is shown by bent tablets of biotite and deformation features in quartz. That the forces did not cease, even after consolidation is confirmed by the mild cataclastic texture of quartz diorite immediately adjacent to the outer contact of a large marble xenolith and by the presence of marginal fissures.

In the western part of the Deep Creek stock, therefore, upward and outward pressures most likely persisted throughout emplacement and after consolidation. The orientation of the platy minerals in the interior of the stock is thought to reflect these pressures and the structural closure to mark the center from which the pressures radiated. This mode of origin best fits the dynamic pattern as outlined above and best explains the lack of structural control by compositional zonation. In summary, the origin of platy flow structure in the main body of the Deep Creek stock is two fold. Minor early orientation by frictional alignment parallel to contacts was followed by more pronounced orientation normal to greatest magmatic pressures from the interior. The contact rock at Hardrock Gulch exemplifies this two-fold origin. Biotite aggregates, presumably concentrated and aligned by flow, bend around large plagioclase phenocrysts, as if molded by later outward pressures.

The flow pattern in the eastern prong of the Deep Creek stock is quite different from that in the main body. There is no structural closure in the east, and no evidence of radial expansion. The pattern in the east is strikingly similar, however, to that of transverse ridges and dirt bands on valley glaciers (Hills, 1953, p. 139; Tyndall, 1911, p. 139), flow wrinkles and pressure ridges on lava flows (Hills, 1953, p. 139) and foam on streams (Balk, 1937, Plate 1). The similarity suggests a like mode of origin, that is, orientation of elements by friction near contacts and orientation normal to the direction of propagation in the interior (Hills, 1953, p. 139). The orientation mechanisms are the same in the west and east, only the directions of force application are different. Whereas in the west, last movement was upward and radially outward from a locus at White Monument, in the prong, last movement was directed eastward.

Furthermore, the structural patterns reflect basic differences in form between the two areas. The main body of the stock, as shown by the inward dip of most contacts and by the localization of large marble xenoliths, is funnel shaped and extends to great depths. Accordingly, the concentric flow pattern is funnel shaped and closes around the source of upward magmatic pressure, the locus of up-welling. The east two-thirds of the eastern prong, on the other hand, is lobe-shaped and shallow. The lobe form is revealed in horizontal section by the pattern of outcrop (Plate 4). In cross section it is shown by the proximity of a lower floor, as indicated by the mineral-ogy, which is the same as in border rocks of the main body, and by the disordered structural state of the plagioclase. The structural pattern is indicative of movement in a floored, constricted channel, as in valley glaciers and streams. Significantly, the eastern pattern is very similar to that defined by faint platy and well-developed linear structure in floored, plate-like granitic bodies near Barre, Vermont (Balk, 1937, p. 75).

Emplacement of the Deep Creek Stock

The Deep Creek stock was emplaced in the upper mesozone (Buddington, 1959). The well-developed platy flow structure and absence of related volcanics are incompatible with the epizone, whereas the low grade regional metamorphic terrane and absence of associated migmatites exclude emplacement in the catazone. Other mesozonal characteristics of the stock are marginal fissures, aplites, schistosity in adjacent country rocks and a well-developed contact aureole.

Emplacement of the stock probably was preceeded by injection of a dioritic basic forerunner at Ritchie Gulch. The forerunner was a rather small pluton, probably not exceeding 1 1/4 miles in diameter, and may have been elongate northeast, parallel to the regional trend.

The initial injection of quartz diorite magma near White Monument probably followed the same zone of weakness that localized the basic forerunner. The zone of weakness could have been the northeast-trending Oxbow-Cuprum shear zone, which is approximately on strike with the locus of upwelling, but the east trend of the eastern prong and the nearby Echols Mountain stock suggests an east-striking zone of weakness, as well. Perhaps the initial emplacement of the stock was guided by an intersection of these two elements. The nature of the east-trending element, however, is conjectural. The detailed structure of the surrounding country rocks is imperfectly known, but the overall strike of the beds, as confirmed by several attitudes away from the stock, is definitely northeast. A postulated east-trending discontinuity, therefore, would most likely be neither an unconformity nor a syncline (Cook, 1954, p. 4). An east-trending fault is most probable, although neither Vallier (1967a) nor Hamilton (1963) recorded one in adjacent areas. Pre-Tertiary east-trending faults are not a dominant structural feature of the region.

Regardless of the means of localization, the initial magma injection forced aside the country rock and was immediately followed by a prolonged surge or series of discrete pulses (Harry and Richey, 1963) that expanded the pluton northward, southward, and westward, in part guided by the bedding planes of surrounding metavolcanics. Magma also pushed southward around, and upward beneath the re-entrant at Ritchie Gulch in feeding the lobe-shaped eastern prong. Evidence for forceful emplacement includes the contact-paralleling foliation in adjacent country rocks, deflection of the Oxbow-Cuprum shear zone, and the cataclastic texture of some marble xenoliths. Digested inclusions and local concentrations of hornblende diorite suggest that incorporation of country rock may have occurred on a small scale. Generally sharp contacts show that metasomatism of wall rocks was limited. There is little evidence for stoping. Probable last directions of flow are recorded by the pattern of platy flow structure.

Comparison of the Deep Creek Stock with Other Granitic Plutons

The most distinctive characteristics of the Deep Creek stock are its structure and form. The funnel-shaped structure of the Loon Lake pluton (Cloos, 1934), the Flamanville intrusion (Martin, 1952), the Adara diapir (Akaad, 1956), and the Rattlesnake Mountain pluton (MacColl, 1964) compare favorably with the main body of the Deep Creek stock, but only the Rattlesnake Mountain pluton displays a connected, lobe-shaped prong. The Deep Creek and Rattlesnake Mountain plutons are also similar in the lack of coincidence between a core as defined by platy flow structure and a core as defined by mineralogy and (or) chemistry (Baird, McIntyre, and Welday, 1967). They are different, however, in that the Rattlesnake Mountain mass is lineated and contains large mafic screens.

Other examples of granitic plutons with inward dipping contacts include those reported by Sabine (1963), Nosyrev (1964), Wilkinson, *et al.* (1964), and Wilbanks (1966).

Emplacement of the Echols Mountain Stock

Characteristics similar to those of the Deep Creek stock indicate that the Echols Mountain stock was forcefully emplaced in the upper mesozone. The dome-shaped, near-concentric flow pattern suggests that magma moved upward and outward from a locus beneath the structural closure in the south-central part of the pluton.

Comparison of the Deep Creek and Echols Mountain Stocks

The Deep Creek magma probably was higher in volatiles than that of Echols Mountain. A greater degree of differentiation and silication of marble xenoliths in the Deep Creek mass suggests a greater volatile activity. A lesser viscosity, and, hence, higher volatile content (Shaw, 1965, p. 121) is also implied by the lesser intensity of country rock foliation near the Deep Creek stock.

Assuming a bulb-like form for the core areas, the present land surface of the main body of the Deep Creek stock may transect the lower mid-section of the pluton, whereas the land surface of the Echols Mountain stock may cut close to the roof. The funnel-shaped structure and inward dip of contacts in the Deep Creek body imply comparatively deep incision, whereas in the Echols Mountain mass, dome-shaped structure, local outward dip of contacts, paucity of marble xenoliths, and arching of country rock foliation indicate a more shallow erosion.

The two stocks may have been derived from the same source. This is suggested by the similarities of depth, manner, and time of emplacement, as well as like mineralogic and structural characteristics. As shown in Plate 4, however, the present level of erosion exposes two separate intrusions. Only 1, 300 feet separate the nearest outcrops of the two stocks, but the major loci of upwelling are over six miles apart.

REGIONAL CONSIDERATIONS

Thayer and Brown (1964) outlined two major episodes of plutonism in the eastern Oregon-western Idaho region. The first, called the Canyon Mountain magma series and typified by the Canyon Mountain complex, is Late Permian-Middle Triassic in age (Vallier, 1967a, p. 191), and the second, exemplified by the Idaho batholith, is supposedly Early-to-Middle Cretaceous (Thayer and Brown, 1964, p. 1260).

Plutons in the thesis area might appear at first consideration to fit within these two categories. The mafic suite might correlate with the Canyon Mountain magma series and the older and younger granitic suites might correspond to the Idaho batholith. Closer examination shows, however, that the suggested correlations have little basis in fact.

Plutons of the mafic suite differ from the Canyon Mountain complex in both character and age. The Canyon Mountain complex (Thayer, 1963b, p. C82) is about 56 percent peridotite, 40 percent gabbro and norite, and 4 percent albite granite and quartz diorite. The gabbro is both olivine rich and olivine free and has plagioclase ranging from An_{60} to An_{85}. The peridotite and gabbro exhibit well-defined flow layering (Thayer, 1963a). In contrast, the plutons of the mafic suite include neither peridotite nor albite granite.

Quartz-bearing hornblende metagabbro and metanorite occur in small amounts, but the predominant rock type is metadiorite. Chemically, all of the mafic rocks are dioritic. The metagabbro of the mafic suite contains no olivine and has no plagioclase more calcic than An_{60}. There is no well-defined flow layering. In addition, near the thesis area, Canyon Mountain type rocks are intensely deformed by the Oxbow-Cuprum shear zone (Vallier, 1967a), but the mafic suite rocks, though in part sheared, are also younger than the zone. The plutons of the mafic suite are of a different and younger episode of plutonism than the Canyon Mountain complex.

The plutons of the older granitic suite are Late Jurassic (?), and, hence, earlier than the Idaho batholith.

The younger granitic masses, though superficially similar to part of the Idaho batholith, are more probably related to the same episode of plutonism as the Bald Mountain and Wallowa batholiths of northeastern Oregon. Thayer and Brown (1964) included the Oregon intrusions, as well as the Idaho batholith, in the Early-to-Middle Cretaceous plutonic event. The Oregon masses are Late Jurassic, however, as shown by radiometric age determinations (Taubeneck, 1963), whereas the Idaho batholith apparently is Middle Cretaceous-Early Tertiary (Larsen, et al., 1958; Armstrong, 1968). Two episodes of granitic plutonism, rather than one, are thus implied.

An affinity of the Deep Creek and Echols Mountain stocks for the Oregon plutons is strongly suggested by lithologic similarity. Both groups of intrusions contain quartz diorite; both show inward increases in potassium feldspar (Taubeneck, 1957; 1964b). Whereas in the Oregon batholiths, the inward concentration of potassium feldspar is great enough so that rocks in the interior of the plutons are termed granodiorite, in the smaller Deep Creek and Echols Mountain stocks the inward increase yields only a potassium feldspar-rich quartz diorite.

The Idaho batholith is predominantly quartz monzonite and granodiorite (Ross, 1963). Quartz diorite, though present locally (Ross, 1963; Schmidt, 1964) in a gneissic border facies, is not widespread. The difference in lithology between the younger granitic suite and most of the Idaho batholith is emphasized by the quartz diorite line which, according to Moore (1959), passes through the western edge of the Idaho batholith, separating quartz diorite on the west from granodiorite-quartz monzonite on the east.

Early reconnaissance workers (Ross, 1928, p. 677-678; Ross and Forrester, 1947; Cook, 1954, p. 9) believed that the Deep Creek and Echols Mountain stocks were physically connected to the Idaho batholith. That this is not true is shown by the eastern termination of the Echols Mountain stock in the map area (Plate 4) and by the absence of an eastward continuation of the plutons on a map of the adjacent Riggins quadrangle (Hamilton, 1963, Plate 1).

In summary, the two-fold division of plutonism proposed by Thayer and Brown (1964) is not valid in, and immediately surrounding the area of this report. Three intrusive episodes occurred in the time interval between the Canyon Mountain magma series and emplacement of the Idaho batholith. The plutons of the mafic suite, together with igneous masses of comparable character and age in the western part of the adjacent Riggins quadrangle (Hamilton, 1963, p. 13-14), represent a Late Triassic-Early Jurassic (?) event. The older granitic suite, in conjunction with an intrusion of like age in the Snake River canyon (Brooks and Vallier, 1967, p. 255), typify a Late Jurassic (?) episode. The Deep Creek and Echols Mountain stocks are representative of a Late Jurassic-Early Cretaceous (?) period of intrusion.

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