Geology of the French Gulch Quadrangle Shasta and Trinity Counties California

By JOHN P. ALBERS

CONTRIBUTIONS TO GENERAL GEOLOGY

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CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

CONTRIBUTIONS TO GENERAL GEOLOGY

GEOLOGY OF THE FRENCH GULCH QUADRANGLE, SHASTA AND TRINITY COUNTIES, CALIFORNIA

By JOHN P. ALBERS

ABSTRACT

The French Gulch quadrangle, in Shasta and Trinity Counties, northern California, contains rocks ranging in age from pre-Silurian (and possibly Precambrian) to Recent. The oldest rocks are coarsely crystalline actinolite- and quartz-mica schists exposed in the southwestern part of the quadrangle; these rocks are correlated with the Abrams mica schist and possibly in part with the Salmon hornblende schist of Hershey.

Two formations that are probably much younger overlie these schists. These formations are the Copley greenstone and Balaklala rhyolite. The Copley greenstone of Devonian(?) age consists mostly of intermediate and mafic volcanic rocks and crops out over a large area in the east-central and southeastern parts of the quadrangle. It is at least 3,700 feet thick in the central part of the quadrangle, but the base of the formation has nowhere been recognized. The Devonian Balaklala rhyolite, which is composed of siliceous felsic volcanic rocks, overlies and intertongues with the Copley greenstone in an intricate manner. It is mainly extrusive but includes minor intrusive bodies. The main area of Balaklala exposure is in the eastern and northeastern part of the quadrangle.

Overlying the Balaklala in places in the east-central and northeastern parts of the quadrangle are beds of dark siliceous cherty shale of the Kennett(?) formation. This shale is lithologically similar to shale of the lower part of the Kennett formation at the type locality in Backbone Creek, east of the French Gulch quadrangle, and on this basis they are correlated. However, no fossils have been found, and because of its peculiar distribution, highly contorted character and position along a probable thrust fault, and similarity to cherty shale within the overlying Bragdon formation of the Backbone Creek area, it is possible that the cherty shale is highly deformed and altered Bragdon. The Kennett formation east of the French Gulch quadrangle is well dated by fossils as late Middle Devonian, and because the Kennett grades downward into tuffaceous rocks of the Balaklala rhyolite, the Balaklala is probably also Middle Devonian. Intertonguing of Balaklala rhyolite with Copley greenstone indicates further that if the Balaklala is of Middle Devonian age the Copley must also be nearly the same age.

The Bragdon formation, composed mainly of shale and siltstone in the lower part and of coarse grit and conglomerate along with shale and siltstone in the upper part, locally rests with marked structural discordance on Copley green-

stone, Balaklala rhyolite, and Kennett(?) formation. The Bragdon is here divided into a lower unit and an upper unit for cartographic purposes. The formation has been dated as Mississippian by Diller from exposures outside the quadrangle, but no fossils were found within the area of this report.

Tabular bodies of peridotite, partly altered to serpentine, intrude the schists and gneiss in the extreme southwestern part of the quadrangle, and two large plutons, the Mule Mountain stock and the Shasta Bally batholith, and subsidiary intrusives, occupy about 100 square miles of the map area. The Mule Mountain stock consists of trondhjemite and albite granite. It contains large pendants and many inclusions in various stages of reconstitution, all oriented in structural harmony with the wallrocks if projected along the strike. Metamorphic effects on surrounding rocks are restricted to within a few feet or tens of feet from the stock border, and chilled contacts are almost absent. The stock itself is highly altered. It seems to have most of the features of an epizone pluton, although granitization appears to have been the most important mechanism in its emplacement.

The Shasta Bally batholith consists mostly of quartz diorite but locally grades to granodiorite. The northeastern part of the batholith is rich in biotite and has conspicuous flow layering that dips northeastward parallel to the contact. In the southwestern part, hornblende predominates over biotite; weak flow banding and an inconspicuous steep lineation are present. The batholith is elongated northwest and southeast, and the flow banding suggests that it has the form of a crude arch, both limbs of which dip steeply toward the northeast. The northeast contact of the batholith is largely concordant and is in contact with fine-grained gneiss as much as 3,500 feet thick, which was derived by contact metamorphism largely from the Copley, Balaklala, and Bragdon formations. The southwest contact is discordant and is marked by a zone of injected rock and breccia as much as 1,000 feet wide and by gneiss as much as 5,000 feet wide derived from schist. The batholith seems to have emplaced itself forcibly; it has the features of a mesozone pluton. Stratigraphic cover at the time of intrusion may have been as much as 35,000 feet thick, but was probably less if allowance is made for erosion. Dikes of diorite porphyry, dacite porphyry, andesite porphyry, metagabbro, hornblendite, lamprophyre, and aplite cut the Mule Mountain stock and rocks older than the stock. Aplite dikes cut the Shasta Bally batholith.

With the exception of the Shasta Bally batholith and some of the dike rocks, pre-Cretaceous rocks throughout the quadrangle are altered. Mafic and intermediate rocks are albitized and chloritized; felsic rocks are albitized, are silicified in many places, and contain fine-grained white mica, epidote, and other secondary minerals as alteration products. In the Bragdon formation, fine-grained white mica is the principal alteration, but it is not a conspicuous feature.

In the auréole of the Shasta Bally batholith and locally near the Mule Mountain stock, mafic rocks are converted to amphibolite and epidote amphibolite, and more felsic rocks are characterized by quartzose gneiss containing some biotite.

The quadrangle lies in a large structural bend where the strike of the basement volcanic rocks changes from northwest to northeast. The Mule Mountain stock is in this bend. The northwest-trending Shasta Bally batholith, and its gneissic aureole, dominates the structure of the western part of the quadrangle. A thrust fault is inferred to separate the Bragdon from underlying formations because beds in the Bragdon strike nearly at right angles to its lower contact at many places and indicate that part of the section has been cut out. This fault is named the Spring Creek thrust.

Folds are not conspicuous; most are hard to follow and do not seem to continue for great distances. Folds of three trends—northwest, north, and northeast—are recognized.

Faults are abundant and seem to be primarily of the normal type. These faults are common in all rocks except the Shasta Bally batholith and the schist southwest of the batholith. The largest are the Hoadley, Shirttail, and French Gulch faults. The French Gulch fault is one of a system of east- and northeast-trending faults that seem to control the distribution of massive sulfide deposits in the northeastern part of the quadrangle and gold quartz veins in the French Gulch mining district.

INTRODUCTION

LOCATION AND ACCESS

The French Gulch 15-minute quadrangle is in northern California in Shasta and Trinity Counties (fig. 1). It lies in the Klamath Mountains at the northwest end of the Sacramento Valley and is bounded by the 40°30′ and 40°45′ parallels and by the 122°30′ and 122°45′ meridians. The principal town of the region is Redding, about 6 miles east of the quadrangle boundary. Small settlements within the quadrangle include French Gulch, Whiskeytown, and Igo. U.S. Highway 299W, from Redding to Eureka, extends across the quadrangle and is the principal means of access. This highway, supplemented by a network of secondary roads, which include numerous logging roads built mostly during the years 1950–57, makes most of the quadrangle readily accessible with four-wheel-drive vehicles.

PHYSICAL FEATURES

Relief is rugged throughout the French Gulch quadrangle (pl. 1). Altitudes range from about 600 feet in the canyon of Clear Creek at the southeast corner of the quadrangle to 6,359 feet on Paradise Peak near the west edge. The dominant peak is Shasta Bally, altitude 6,209 feet, in the central part of the quadrangle. Iron and Sugarloaf Mountains and Shirttail Peak are prominent landmarks in the northeastern part of the quadrangle. Clear Creek, which flows diagonally across the quadrangle from the north-central edge to the southeast corner, is the principal stream. The drainage divide between Clear Creek and the Trinity River to the west extends approximately north-south through the western part of the quadrangle. The overall drainage pattern is dendritic. Virtually all the streams are characterized by steep V-shaped canyons that generally pass into more gentle slopes within a few hundred feet above the canyon bottoms. A striking topographic feature is the deeply incised canyon of Clear Creek in the southeastern part of the quadrangle.

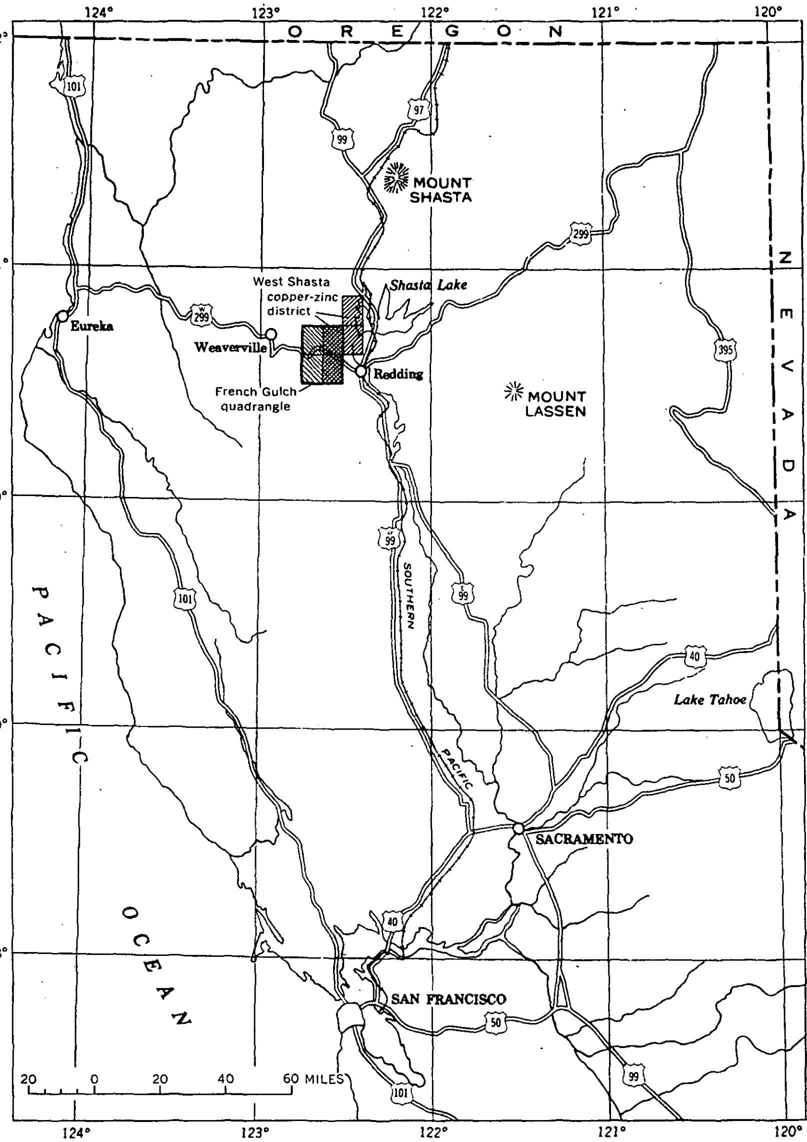

FIGURE 1.—Index map showing location of the French Gulch quadrangle, California, and its relation to the area previously reported on as the "West Shasta copper-zinc district."

CLIMATE AND VEGETATION

The climate of the quadrangle is characterized by a cool wet season from November to April and a hot dry season from May to October. The average annual precipitation ranges from 35 inches in the lowlands to 60 inches at the higher altitudes. However, the Iron Mountain mine, at an altitude of about 2,600 feet in the eastern part of the quadrangle, has received as much as 110 inches of precipitation during a single calendar year. Snow is common in the winter at altitudes above 1,500 feet, but, except on the highest mountains, it rarely stays for more than a few days.

Temperatures at the lower altitudes are generally above freezing during the winter months but decrease with increasing altitude. During the period of June to September, daytime temperatures of 100° F in the shade are not uncommon in the valleys and at lower altitudes. However, the nights are generally cool.

Most of the lower parts of the quadrangle and some of the highest ridges are covered by a dense growth of brush, including manzanita (*Arctostaphylos* sp.) and several varieties of scrub oak. Larger trees include digger pine (*Pinus sabiniana*), which is common at low altitudes, and ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*), Douglas-fir (*Pseudotsuga taxifolia*), California black oak (*Quercus kelloggii*), canyon live oak (*Quercus chrysolepis*), and interior live oak (*Quercus wislizenii*), which grow mainly on the higher slopes. Extensive logging, mostly since the World War II period, has greatly depleted the once-abundant timber in the quadrangle.

PREVIOUS WORK

The east half of the French Gulch quadrangle was mapped during the period 1946–51 by the U.S. Geological Survey in cooperation with the State of California, Department of Natural Resources, Division of Mines, as part of a study of the West Shasta copper-zinc district. The report of this work, including a geologic map at a scale of 1:24,000, was written by Kinkel and others (1956). A detailed report on the Iron Mountain mine was published earlier (Kinkel and Albers, 1951). The only geologic map published prior to this work by the Survey is included in Hinds' study (1933) of the Redding-Weaverville districts. Hinds' map includes a much larger area and is on a reconnaissance scale of 1:250,000. Reports by Ferguson (1914) and Averill (1933) contain descriptions of the more important gold mines of the quadrangle and information on the geology of local mine areas.

FIELDWORK AND ACKNOWLEDGMENTS

Field mapping of the west half of the quadrangle on a scale of 1:48,000 was conducted by the author and Avery A. Drake, Jr., from August to November 1, 1956. All except the extreme northwest corner was mapped during this period. The author, assisted by William P. Irwin and Donald B. Tatlock, completed mapping of the west of the quadrangle and mapped important faults exposed in new roadcuts in the east half during June and July 1957. The geology of the east

half of the quadrangle, which was originally mapped on a scale of 1:24,000 in 1945–47 (Kinkel and others, 1956), is here generalized to a scale commensurate with 1:62,500 and is included on the quadrangle map to give continuity to the geologic pattern.

The study has benefited from field conferences with Thomas E. Gay, Gordon B. Oakeshott, and J. C. O'Brien of the California Division of Mines, Ira E. Klein of the U.S. Bureau of Reclamation, and E. H. Bailey, R. J. Roberts, and P. B. King of the U.S. Geological Survey. We are indebted to Redding Pine Mills, Inc., and to Shasta Minerals and Chemical Co. for allowing access on private roads in various parts of the quadrangle.

The work was done in cooperation with the State of California, Department of Natural Resources, Division of Mines.

SUMMARY OF GEOLOGIC UNITS

The rocks in the French Gulch quadrangle include those of pre-Silurian (and possibly Precambrian), Devonian(?), Devonian, Mississippian, Jurassic or Cretaceous, Cretaceous, Pleistocene, and Recent ages (pl. 1). The oldest rocks are probably the coarsely crystalline schists in the extreme southwestern part of the quadrangle. Some of these rocks were included in the Abrams mica schist and some were included in the Salmon hornblende schist by Hinds, who considered both formations to be of pre-Silurian and possibly Precambrian age (1933, p. 84). The area underlain by schist in the French Gulch quadrangle is too small and too poorly exposed to permit a reliable correlation of the various rock types with the Abrams and Salmon formations.

The Copley greenstone, probably of Devonian age, consists mostly of intermediate and mafic volcanic rocks. It crops out over a large area in the east-central and southeastern parts of the quadrangle. The Copley is at least 3,700 feet thick at its best exposed section in the Modesty Gulch-Grizzly Gulch area, but the base of the formation has nowhere been recognized. Moreover, because it is of volcanic origin, the thickness of the formation no doubt differs markedly from place to place.

The stratigraphic positions of rocks assigned to the Balaklala rhyolite vary. The thickest accumulations, which probably represent the major episode of rhyolitic activity, overlie the Copley greenstone; these crop out mostly in the northeastern part and locally in the northern and northwestern parts of the quadrangle. Elsewhere, silicic volcanic rocks indistinguishable from the Balaklala are intertongued and interlayered with the Copley in an intricate manner (pl. 1.). South and west of Tower House, rocks correlated with Balaklala on the basis of lithology seem to underlie a large thickness of Copley. A similar inverse relationship exists on O'Brien Mountain a few miles northeast of the French Gulch quadrangle (Albers and Robertson, 1961). These relations indicate that silicic and mafic volcanic rocks were probably being erupted from several volcanic centers more or less contemporaneously, although the culmination of activity that gave rise to the main mass of silicic rocks occurred after the eruption of intermediate and basic material had died down. The distinction between the Copley and Balklala formations shown on the geologic map is thus a lithologic distinction and, except in the northern and northeastern part of the quadrangle, has no definite stratigraphic significance. The Balaklala is considered to be of Middle Devonian age because of its relation to the overlying Kennett formation east of the French Gulch quadrangle, where the two formations are gradational (Kinkel and others, 1956, p. 19).

A discontinuous belt of gray to black siliceous cherty shale, tentatively assigned to the Kennett formation, lies between the volcanic rocks of the Balaklala rhyolite and the Bragdon formation between Mad Mule Mountain and the northeast corner of the quadrangle. Lithologically this shale is similar to the cherty shale that makes up the lower part of the Kennett formation at its type locality in Backbone Creek in the West Shasta map area; it is tentatively correlated with the Kennett on the basis of this similarity. Peculiar features of this cherty shale are that virtually everywhere it is extremely contorted and faulted and also that it seems to be separated everywhere from the overlying Bragdon formation, which is much less deformed, by a marked structural discordance. This discordance, along with the failure of folds in the Bragdon to extend into the underlying rocks, and the fact that bedding in the Bragdon dips more steeply and is at an angle to the Bragdon contact with underlying volcanic rocks, suggest the possibility that the contorted cherty shale, which occupies a position of natural structural weakness between competent and incompetent units, marks a thrust zone beneath the Bragdon formation. If it does, the cherty shale may actually be part of the Bragdon formation, its siliceous character having resulted from the same hydrothermal alteration that also greatly affected the underlying Balaklala rhyolite.

The Bragdon formation, which consists mostly of fine- to coarse-grained clastic sedimentary rocks, locally rests on the Copley greenstone, the Balaklala rhyolite, and the Kennett(?) formation. Near the junction of Willow Creek and Trail Gulch, quartz keratophyre, tentatively correlated with the Balaklala rhyolite, is interlayed with phyllite of the Bragdon formation. Diller (1906, p. 3) dated the Bragdon as Mississippian, but no additional fossils were found in it during our recent studies. In this report, the Bragdon formation is differentiated into a lower unit consisting mainly of mudstone, siltstone, and minor sandstone and conglomerate, and an upper unit in which sandstone and conglomerate are about as abundant as the fine-grained clastics.

The layered bedrock sequence was intruded, probably during Late Jurassic time, by two large plutonic masses of granitic rock and by dikes and sills of peridotite and hypabyssal rocks. The older intrusive mass is the Mule Mountain stock, a pluton about 50 square miles in area and consisting mostly of trondhjemite and albite granite. The stock is elongate in a north-south direction, and approximately the west half is in the French Gulch quadrangle. Its shape is highly irregular in detail and its boundaries markedly crosscutting. It is in general much faulted, crushed, and altered. It has most of the features characteristic of plutons of the mesozone, as defined by Buddington (1959).

Somewhat younger than the Mule Mountain stock is the Shasta Bally batholith, a concordant pluton of quartz diorite and granodiorite that underlies approximately the southwest one-third of the quadrangle. As mapped by Hinds (1933), this batholith has a total areal extent of about 125 square miles. In the French Gulch quadrangle it intrudes schist and gneiss of the Abrams and Salmon formations, and the Copley, Balaklala, and Bragdon formations; apophyses from the batholith cut the Mule Mountain stock. The batholith contains small inclusions of peridotite near its southwest margin; the inclusions suggest that the batholith is younger than the belt of ultramafic rock in the southwestern part of the quadrangle (pl. 1). The batholith seems to have features typical of mesozone plutons.

The intruded rocks along the margins of the Shasta Bally batholith, and locally along margins of the Clear Creek plug, which is believed to be an apophysis of the batholith, have been converted by contact metamorphism into fine-grained gneissic rocks. The rocks in the contact aureole include amphibolite, hornblende gneiss, siliceous light-colored gneiss, quartz-biotite gneiss, and phyllite. The type of gneiss at any given locality is determined largely by the composition of its parent rock.

Hypabyssal intrusive rocks include tabular bodies of hornblendite, lamprophyre, andesite porphyry, diorite porphyry, dacite porphyry, quartz porphyry, and aplite. With the possible exception of the hornblendite and some of the quartz porphyry, all postdate deformation, for they are largely controlled by fractures and partially controlled by bedding planes and formation contacts. Some tabular bodies of quartz porphyry in the Copley greenstone probably were feeder dikes for the Balaklala rhyolite and are much older than the bulk of the hypabyssal rocks. However, only a few of these Balaklala feeder dikes were recognized.

Conglomerate of Late Cretaceous age and well-cemented gravel belonging to the Red Bluff formation of Pleistocene age overlie the basement rocks unconformably in the southeastern part of the quadrangle. Recent stream gravels, older gravels possibly correlative with the Red Bluff formation, slope wash, and landslide debris obscure the bedrock geology in many places. The relationship of rock units in the French Gulch quadrangle is shown diagrammatically in figure 2.

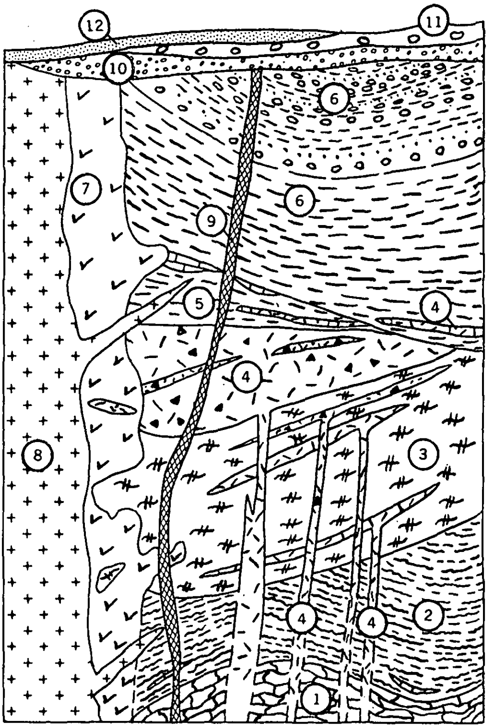

FIGURE 2.—Generalized diagrammatic section of rock formations in the French Gulch quadrangle.

Formation	*Age*	*No.*	*Formation*	*Age*	*No.*
Unconsolidated deposits.	Recent	12	Kennett(?) formation	Devonian	5
Red Bluff formation	Pleistocene	11	Balaklala rhyolite	----do	4
Cretaceous rocks	Cretaceous	10	Copley greenstone	Devonian(?)	3
Dike rocks	Jurassic or Cretaceous	9	Abrams mica schist	Pre-Silurian	2
Shasta Bally batholith	----do	8	Salmon hornblende schist.	----do	1
Mule Mountain stock	----do	7			
Bragdon formation (upper and lower units).	Mississippian	6			

ROCK UNITS

ABRAMS MICA SCHIST AND SALMON(?) HORNBLENDE SCHIST

GENERAL DESCRIPTION

Schist that ranges in color from light gray and light green to greenish and grayish black underlies an area of about 1 square mile in the extreme southwestern corner of the quadrangle. It also crops out over large areas in adjoining quadrangles to the west and south.

Most of this schist is coarsely crystalline, but some is fine grained. The schist is not homogeneous but consists mainly of four different rock types interlayered in beds a few feet to a few hundred feet thick. The main types are albite-actinolite-biotite schist, plagioclase-biotite-actinolite schist, quartz-muscovite schist, and albite-quartz-muscovite-chlorite-epidote schist. Because individual beds could not be mapped separately, owing to poor exposure, the schist is shown on the geologic map (pl. 1) as a single unit. It appears that albite-actinolite schist and plagioclase-biotite-actinolite schist are present in about equal amounts and together constitute a slightly higher proportion of the formation than quartz-muscovite schist and albite-quartz-muscovite-chlorite-epidote schist.

Much of the schist shows a thin banding caused by the segregation of light- and dark-mineral constituents into more or less discrete layers. This banding parallels contacts between different rock types as well as schistosity and is thought to represent original bedding. In places, lenticles and knots of quartz and pegmatitic material occur in the schist, and both replacement and dilation dikes of fine-grained hornblende-quartz diorite cut it locally. Crinkles, drag folds, and terrace folds in the schistosity are common; in places the schistosity is cut at a high angle by a conspicuous slip-cleavage.

Hinds (1933, p. 81–84, geologic map) mapped the schist in the southwestern part of the French Gulch quadrangle partly as Abrams mica schist and partly as Salmon hornblende schist. These formations were named by Hershey (1901) from exposures in the Trinity Alps northwest of the French Gulch quadrangle, and Hinds (1932) grouped them together as the Siskiyou terrane.

As described by Hershey (1901), the Abrams mica schist is overlain by the Salmon hornblende schist, and at the boundary between them is a gradational zone of graphitic and actinolite schist 5 to 15 feet thick. Whether Hershey recognized more than one layer of actinolite schist in the Abrams is not known, but there are several layers of albite-actinolite schist in the southwestern part of the French Gulch quadrangle. These may mark a thicker transition zone between the dominantly sedimentary Abrams and the dominantly volcanic Salmon than is present farther northwest where the formations were named by Hershey.

Irwin (1960a, p. B315), from detailed mapping in the Weaverville quadrangle west of the French Gulch, has found the Abrams mica schist to overlie rather than underlie the Salmon hornblende schist. He regards the albite-actinolite schist layers in the southwestern part of the quadrangle as part of the transitional zone between the Salmon and Abrams formations (oral communication, 1960).

Hornblende gneiss and amphibolite, interlayered in places with quartz-plagioclase gneiss and quartz-plagioclase-garnet gneiss, crop out along the southwest side of the belt of ultramafic rock in the southwestern part of the quadrangle and also in places along the northeast side of this belt. This sequence represents a higher metamorphic grade than the schists and, inasmuch as it has a close spatial relationship to the Shasta Bally batholith, it is interpreted as being in the contact aureole of the batholith. Whether the hornblendic rocks of this sequence represent part of the Salmon hornblende schist or simply part of a thick transitional zone between the Abrams and Salmon formations could not be determined in the French Gulch quadrangle, and therefore the two units are not differentiated on the geologic map (pl. 1).

PETROGRAPHY

Study of thin sections reveals that the undifferentiated schist formations include a variety of petrographic types, but that four general types predominate. These dominant types are albite-actinolite-biotite schist, plagioclase-biotite-actinolite schist, quartz-muscovite schist, and albite-quartz-muscovite-chlorite-epidote schist. The two actinolite-bearing types are the most common. In the albite-actinolite-biotite schist, actinolite is the principal mafic mineral; in the plagioclase-biotite-actinolite schist, biotite predominates over actinolite. Most specimens of these two rock types show a mixture of the two mafic minerals the actinolite being partly altered to biotite. Actinolite is present in all specimens, whereas biotite is not. Other common minerals, include garnet, chlorite, sphene, leucoxene, black opaque minerals, pyrite, quartz, calcite, apatite, and zircon. The plagioclase is generally albite in the actinolite-rich rocks, but it ranges to oligoclase and sodic andesine in the biotite-rich rocks. Twinning is absent in albite and rare in the more calcic plagioclase. Sieve texture is common, as also is helicitic structure, which shown by the alinement of included ferromagnesian minerals, sphene, and more rarely, quartz, in plagioclase porphyroblasts. The actinolite forms elongate needles that in most specimens are markedly alined, but in a few specimens form radiating clusters. It commonly is slightly pleochroic and shows a distinct bluish tint when oriented parallel to the Z vibration direction. The biotite is generally pale brown to reddish brown.

In the quartz-muscovite schist and the albite-quartz-muscovite-chlorite-epidote schist the proportion of the main minerals differs greatly among specimens. Albite forms irregular porphyroblasts and has alined inclusions of quartz and epidote that give a helicitic structure. Quartz forms mosaics of irregular grains mostly in and between albite porphyroblasts. Muscovite occurs as elongate tabular crystals in discrete layers. The crystals are strongly crumpled and bent. Epidote replaces muscovite and chlorite and occurs as inclusions in albite porphyroblasts.

Petrographic data are summarized in table 1.

TABLE 1.—*Summary for typical volcanic, sedimentary, and metamorphic rocks of the French Gulch quadrangle*

[Because descriptions are of average rock types rather than of specific specimens, a given mineral may appear in more than one percentage column. Grain size: F=<0.1 mm; M=0.1–2 mm; C= >2 mm]

Rock		Minerals			Grain size	Texture	Remarks
Formation or unit	Name	Dominant (>20 percent)	Subordinate (5–10 percent)	Minor (<5 percent)			
Abrams mica schist and Salmon(?) hornblende schist, undifferentiated.	Albite-actinolite-biotite schist.	Actinolite, albite.	Biotite, black opaques, garnet, quartz, chlorite.	Sphene, leucoxene, chlorite, quartz, biotite, zircon, apatite, pyrite, black opaques, epidote, garnet.	Mostly M	Crystalloblastic, markedly schistose, locally gneissic and porphyroblastic.	Crinkles, drag folds, terrace folds, and slip cleavage common. Quartz appears to be mostly secondary.
Do	Plagioclase-biotite-actinolite schist.	Biotite, oligoclase or andesine.	Actinolite, black opaques, quartz, chlorite.	Sphene leuocoxene, chlorite, quartz, actinolite, zircon, apatite, pyrite, black opaques, epidote, garnet.	F and M	Crystalloblastic, schistose, locally gneissic.	Do.
Do	Albite-quartz-muscovite-chlorite-epidote schist.	Albite, quartz	Muscovite, chlorite, epidote.	Opaques	Mostly M	Crystalloblastic, schistose.	Helicitic structure, conspicuous puckering of muscovite and chlorite.
Copley greenstone	Keratophyre	Albite or sodic oligoclase, chlorite, secondary quartz, augite, actinolite.	Secondary quartz, actinolite, chlorite, calcite.	Clinozoisite, zoisite, epidote, calcite, montmorillonite, sphene, leucoxene, apatite, green biotite, pumpellyite, opaque minerals.	F	Porphyritic and nonporphyritic, pilotaxitic or felty groundmass.	Commonly amygdaloidal. Phenocrysts, if present, are albite, augite, hornblende, or uralite or chlorite pseudomorphous after augite and hornblende.
Do	Metaandesite	Plagioclase (mostly albite but may range to andesine in a single specimen), hornblende, augite, epidote.	Chlorite, epidote, clinozoisite, actinolite, augite.	Chlorite, epidote, clinozoisite, secondary quartz, montmorillonite, black opaques.	do	do	Commonly amygdaloidal. Phenocrysts, if present, same as in keratophyres except plagioclase may be andesine.
Balaklala rhyolite	Porphyritic quartz keratophyre containing phenocrysts larger than 4 mm.	Quartz, albite (ranges from An_8 to nearly pure albite).		Biotite, epidote, zoisite, chlorite, fine-grained white mica, clay minerals, magnetite.	do	Porphyritic, quartz and feldspar phenocrysts as much as 10 mm in diameter in a micrograniitoid groundmass.	Quartz phenocrysts are in places dark-colored owing to inclusions. Myrmekitic and micrographic quartz-albite intergrowths are common.

Do	Porphyritic quartz keratophyre containing phenocrysts 1–4 mm in diameter.	do	Fine-grained white mica (in highly sheared facies), pyrite.	Fine-grained white mica, pyrite epidote, chlorite, clay minerals, orthoclase(?) zoisite, biotite, calcite, magnetite, sphene.	do	Porphyritic, quartz and albite phenocrysts as much as mm in pilotaxitic, microgranitoid, or granophyric groundmass.	Some myrmekitic intergrowths. Phenocrysts locally occur in clusters giving a glomeroporphyritic texture. Locally flow banded.
Do	Nonporphyritic quartz keratophyre (may contain microphenocrysts to 1 mm).	do	Fine-grained white mica, chlorite (in highly sheared facies).	Fine-grained white mica, chlorite, clay minerals, epidote, green biotite, magnetite, apatite.	do	Pilotaxitic, trachytic, microspherulitic, microgranitoid; microphenocrysts of quartz and albite 1 mm diameter may be present.	Flow banding and coarse breccia common. (Groundmass in all types of Balaklala rhyolite may be highly silicified).
Do	Tuff	Quartz and albite clasts and lithic fragments composed chiefly of quartz and albite.	Fine-grained white mica, chlorite.	Fine-grained white mica, chlorite, rutile, magnetite, biotite, zeolites, kaolinite, montmorillonite.	F and M	Clastic	Grain size variable, commonly bedded in outcrop.
Kennett(?) formation.	Black siliceous shale.	Quartz, carbonaceous material.	Fine-grained white mica.	Clay minerals, sphene, rutile, limonite.	F	do	Commonly highly contorted and fractured; quartz veinlets fill fractures.
Bragdon formation	Mudstone (mostly very dark gray).	Fine-grained white mica, carbonaceous material, clay minerals.	Quartz, clay minerals (some quartz looks like clasts of quartz phenocrysts).	Clay minerals, chlorite, leucoxene, graphite.	do	do	Some shows compositional banding defined by difference in grain size or by concentrations of different minerals in discrete layers.
Do	Siltstone (mostly gray to very dark gray).	Quartz, chert fragments.	Carbonaceous material, fine-grained white mica, feldspar, chert fragments.	Carbonaceous material, fine-grained white mica, feldspar, clay minerals, black opaques.	do	do	Mostly finely banded owing to concentration of certain minerals in discrete layers.
Do	Tuff and tuffaceous sandstone.	Feldspar clasts (albite), clasts of optically continuous quartz phenocrysts, fragments of volcanic rocks.	Albite clasts, quartz clasts, fragments of volcanic rocks, actinolitic amphibole.	Chlorite, clay minerals, sphene, leucoxene, black opaques.	F, M, and C.	Clastic. Generally consists of closely packed clasts and lithic fragments in subordinate matrix.	Specimens having virtually all angular grains are classed as tuff. Specimens having rounded grains are classed as tuffaceous sedimentary rocks.
Do	Graywacke	Chert, shale, clasts of optically continuous quartz, albite, fragments of volcanic rocks.	Chert, shale, clasts of optically continuous quartz, albite, actinolite, black opaques, chlorite, fragments of volcanic rocks.	Chlorite, fine-grained white mica, black opaques, clay minerals, sphene, leucoxene, actinolite, biotite, plagioclase.	F and M	Clastic (commonly consists of slightly rounded clasts and (or) lithic fragments in matrix of chlorite, white mica, quartz, and amphibole).	Virtually all gradations to tuffaceous sedimentary rocks. Basis of distinction is presence of lithic fragments of sedimentary material in amounts exceeding 10 percent.

TABLE 1.—*Summary for typical volcanic, sedimentary, and metamorphic rocks for the French Gulch quadrangle*—Continued

[Because descriptions are of average rock types rather than of specific specimens, a given mineral may appear in more than one percentage column. Grain size: F=<0.1 mm; M=0.1–2 mm; C=> 2 mm]

Rock		Minerals			Grain size	Texture	Remarks
Formation or unit	Name	Dominant (>20 percent)	Subordinate (5–10 percent)	Minor (<5 percent)			
Bragdon formation	Conglomerate	Fragments of chert, limestone, sandstone, shale, and vein quartz in various proportions.		Fine-grained white mica (in matrix having quartz).	C	Clastic with angular to well-rounded pebbles, cobbles, and boulders as much as 1 foot diameter.	Chert predominates in all but the coarsest conglomerate.
Do	Phyllite (derived mostly from shale and mudstone).	Fine-grained white mica, quartz, carbonaceous material.	Quartz, carbonaceous material (commonly forms spherical bodies with quartz and chiastolite(?)).	Chlorite, black opaques, chiastolite (?).	F and M	Mostly crystalloblastic, foliate structure.	Has silky sheen and knotty appearance owing to small clots consisting mostly of carbonaceous material.
Mule Mountain stock.	Trondhjemite	Plagioclase (mostly An_{10}–An_{14}, quartz plagioclase generally not zoned).	Epidote, green biotite.	Epidote, green biotite, chlorite, fine-grained white mica, apatite, sphene, magnetite.	M and C	Hypidiomorphic granular; in places is poikilitic, having irregular oikocrysts of quartz that enclose plagioclase chadacrysts.	Gradational contacts to albite granite; mafic minerals are almost entirely secondary; some saussuritic alteration in cores of plagioclase.
Do	Albite granite	Albite, quartz (commonly make up more than 90 percent of the rock).	Epidote, fine-grained white mica.	Epidote, chlorite, zoisite, biotite, fine-grained white mica, apatite, opaque minerals.	do	Hypidiomorphic granular, commonly poikilitic with oikocrysts of optically continuous quartz to 10 mm enclosing plagioclase chadacrysts. Myrmekitic and other intergrowths of quartz and plagioclase common.	Gradational contacts to trondhjemite; saussuritic alteration rare; epidote in veinlets and large clusters; albite formed by replacement of originally more calcic plagioclase.

Peridotite	Peridotite	Olivine, serpentine minerals (mostly antigorite).	Augite, serpentine minerals, actinolite, black opaques.	Pyrite, black opaques, talc.	do	Xenomorphic granular.	Weakly to moderately serpentinized in most places.
Shasta Bally batholith.	Coarse biotite quartz diorite and granodiorite.	Plagioclase (An_{31-52}), quartz, biotite.	Biotite, orthoclase.	Orthoclase, hornblende, black opaques, sphene, clay minerals, apatite, zircon, fine-grained white mica.	do	Hypidiomorphic granular.	Plagioclase crystals commonly show oscillatory zoning, having rims about 1 to 5 percent more sodic than cores. Commonly has well-defined planar structure.
Do	Coarse biotite-hornblende quartz diorite and granodiorite.	Plagioclase (An_{35-48}), quartz.	Hornblende, biotite, orthoclase.	Orthoclase, biotite, hornblende, black opaques, sphene, apatite, zircon, clay minerals, fine-grained white mica.	do	Hypidiomorphic granular.	Plagioclase crystals commonly show oscillatory zoning, having rims about 1 to 5 percent more sodic than cores. Planar structure poorly defined or absent.
Do	Fine-grained biotite quartz diorite and granodiorite.	Plagioclase (An_{30-45}), quartz.	Biotite, orthoclase.	Black opaques, fine-grained white mica, zircon.	M	Xenomorphic granular.	Generally very light-colored with shreddy biotite. No planar or linear structure.
Do	Hornblende diorite.	Plagioclase (An_{42-52}), hornblende.	Hornblende, biotite.	Quartz, orthoclase, biotite, augite, sphene, apatite, zircon, black opaques.	M and C	Hypidiomorphic granular, locally poikilitic.	Occurs mostly in border facies of the batholith and in satellitic bodies.
Clear Creek plug (satellite of the Shasta Bally batholith).	Gabbro	Plagioclase (more calcic than An_{50}), hornblende.		Quartz, augite, sphene, apatite, zircon, black opaques.	do	Hypidiomorphic granular.	Forms dikes and small irregular bodies near the margin and in roof rock of the Clear Creek plug.
Shasta Bally batholith.	Hornblende-rich mafic inclusion.	Plagioclase (An_{45-58}), hornblende.	Biotite, quartz, orthoclase.	Biotite, orthoclase, black opaques, sphene, apatite, chlorite, fine-grained white mica.	do	Hypidiomorphic granular, locally poikilitic; in part crystalloblastic.	Quartz and hornblende commonly form large optically continuous crystals that enclose other minerals giving a poikilitic texture. Hornblende locally bleached colorless but ranges to blue green and green. Plagioclase strongly zoned.
Gneiss in aureole of the Shasta Bally batholith.	Amphibolite	Green acicular hornblende ($2V=70°$; $n\beta=1.664\pm0.003$), plagioclase (An_{32-50}).	Biotite	Biotite, secondary calcite, quartz, chlorite, orthoclase, epidote, magnetite.	M	Crystalloblastic; locally contains porphyroblasts of plagioclase and (or) hornblende in aureole of the Clear Creek plug.	In innermost part of the contact aureole; derived from Copley greenstone and probably in part from the Salmon schist of Hershey (1901). Marked segregation of different minerals in discrete layers.

TABLE 1.—*Summary for typical volcanic, sedimentary, and metamorphic rocks for the French Gulch quadrangle*—Continued

[Because descriptions are of average rock types rather than of specific specimens, a given mineral may appear in more than one percentage column. Grain size: F=<0.1 mm; M=0.1–2 mm; C= >2 mm]

Rock		Minerals			Grain size	Texture	Remarks
Formation or unit	Name	Dominant (>20 percent)	Subordinate (5–10 percent)	Minor (<5 percent)			
Gneiss in aureole of the Shasta Bally batholith.	Hornblende gneiss.	Hornblende, plagioclase (An_{50}), quartz.	Quartz, chlorite, biotite, epidote.	Chlorite, biotite, epidote, orthoclase, magnetite, apatite, sphene.	do	Crystalloblastic; mortar structure and augen common in some places; cataclastic.	Acicular hornblende penetrates and also bends around plagioclase and quartz augen. Probably derived in part from somewhat silicified Copley greenstone and (or) Salmon schist of Hershey (1901).
Do	Siliceous leucocratic gneiss.	Quartz, albite-oligoclase.		Biotite, fine-grained white mica.	F and M	Crystalloblastic and cataclastic.	Some quartz augen that may be relict phenocrysts from parent quartz porphyry (Balaklala rhyolite).
Do	Quartz-muscovite-biotite gneiss.	Quartz, muscovite, biotite.	Muscovite, biotite, plagioclase.	Chlorite, magnetite, limonite.	do	Crystalloblastic, weakly to strongly schistose.	A little retrograde metamorphism of biotite to chlorite. Probably derived from shaly and silty rocks of the Bragdon formation.
Intrusive into Copley greenstone and Balaklala rhyolite.	Metagabbro	Albite, uralitic hornblende, chlorite.	Uralitic hornblende, epidote, chlorite, augite.	Augite, epidote, calcite, olivine, magnetite.	M	Hypidiomorphic granular.	Much saussuritic alteration; uralite pseudomorphous after augite.
Intrusive into Copley greenstone, Balaklala rhyolite, and Mule Mountain stock.	Lamprophyre	Plagioclase (An_{0}–$_{41}$), biotite, chlorite.	Biotite, chlorite, epidote.	Secondary quartz, actinolite, carbonate, zoisite, hornblende.	F and M	Hypidiomorphic granular, locally microporphyritic, locally pilotaxitic.	Exhibit various degrees of alteration.
Dikes in Shasta Bally batholith and locally in adjacent country rocks.	Aplite	Plagioclase (An_{28}–$_{42}$), quartz, orthoclase.	Orthoclase	Biotite, black opaques.	M	Xenomorphic granular.	Some plagioclase crystals show reverse oscillatory zoning having cores=An_{28} and rims An_{42}. Locally veinlets of albite cut plagioclase crystals.
Hornblendite	Hornblendite	Hornblende	Augite, serpentine minerals.	Augite, serpentine minerals, black opaques, talc, epidote.	M and C	Hypidiomorphic granular; commonly porphyritic having phenocrysts to 1 cm.	Occur as dike rocks and are commonly somewhat altered.

Intrusive mainly into the Bragdon formation but also into other rock units.	Biotite-hornblende diorite ("birdseye") porphyry.	Plagioclase (An_{33-52}) (commonly shows normal oscillatory zoning), albite.	Hornblende, biotite.	Biotite, quartz, epidote, fine-grained white mica, chlorite, sphene, orthoclase, calcite, magnetite, limonite, leucoxene.	F and M	Hypidiomorphic granular to granophyric; commonly porphyritic having plagioclase, hornblende, and biotite phenocrysts.	Zoned plagioclase crystals show various stages of albitization in same specimen; hornblende and biotite generally have a pale washed-out appearance and are accompanied by various alteration minerals.
Do	Dacite porphyry and quartz diorite porphyry ("birdseye" porphyry).	Plagioclase (An_{40-50}), albite.	Hornblende, quartz, biotite.	Hornblende, biotite, fine-grained white mica, clinozoisite, sphene, leucoxene, black opaques, orthoclase(?).	do	Hypidiomorphic microgranular, porphyritic having phenocrysts of plagioclase, quartz, and ferromagnesian minerals.	Plagioclase shows various stages of albitization; ferromagnesian minerals have pale washed-out appearance and clouded by alteration products; quartz phenocrysts much rounded.
Intrusive into Shasta Bally batholith and locally into other rock units.	Hornblende diorite porphyry.	Plagioclase (An_{35-45}), hornblende.		Quartz, biotite, sphene, chlorite, black opaques.	do	Idiomorphic granular, porphyritic having euhedral hornblende phenocrysts and plagioclase microphenocrysts.	Contains rare highly corroded quartz and biotite crystals that may be xenocrysts.
Dikes intrusive mainly into the Copley greenstone and Mule Mountain stock.	Andesite porphyry.	Hornblende, plagioclase (An_{43-48}).		Biotite, epidote, apatite, magnetite, zoisite, calcite, clay minerals, chlorite.	F	Microgranular, porphyritic with phenocrysts of hornblende to 6 mm and of plagioclase to 2 mm.	Mostly dark greenish gray in color.
Dikes and sills in all formations except the Shasta Bally batholith.	Quartz porphyry (soda granite porphyry of Ferguson, 1914, p. 30-31).	Quartz, albite		Fine-grained white mica, biotite, chlorite, calcite, pyrite, sphene, leucoxene.	do	Holocrystalline microgranular, porphyritic having phenocrysts of quartz and albite.	Feldspar nearly pure albite; biotite phenocrysts replaced pseudomorphously by fine-grained white mica, calcite, chlorite, sphene and leucoxene; this prophyry indistinguishable from porphyritic quartz keratophyre of the Balaklala rhyolite except by presence of altered biotite.

COPLEY GREENSTONE

GENERAL CHARACTER AND DISTRIBUTION

The overall distribution of volcanic rocks within and beyond the limits of the French Gulch quadrangle indicates that during probable Early Devonian time, much mafic material and a considerable volume of felsic material was erupted more or less contemporaneously, though probably from different volcanic centers. The eruption of these materials was followed by the eruption of a large volume of predominantly intermediate and mafic lavas and pyroclastic material that are mapped as Copley greenstone containing minor felsic material of the type mapped as Balaklala rhyolite; later, a great outpouring of felsic material formed the main mass of the Balaklala in the northeastern part of the quadrangle and adjacent areas. This overlapping age relationship between mafic and felsic volcanic rocks, characteristic of the Copley greenstone and the Balaklala rhyolite respectively, makes it necessary to distinguish between the two formations entirely on the basis of lithology. The mafic volcanic material is designated as Copley greenstone on the geologic map (pl. 1), and the felsic volcanic material is shown as Balaklala rhyolite, regardless of its position in the volcanic sequence. Consequently, except in the northeastern part of the quadrangle and in the adjacent central part of the West Shasta mineral belt, the contact between Copley greenstone and Balaklala rhyolite has no time-stratigraphic significance.

The Copley greenstone crops out in a belt 1 to 2 miles wide that extends from near the southeast corner of the quadrangle northwestward to Whiskeytown. This belt lies between the Shasta Bally batholith on the west and the Mule Mountain stock on the east (pl. 1). Near Whiskeytown, the dips are northeast at moderately low angles; farther south, the dips seem to be steeper to the northeast but reliable data on bedding are scarce. North and northwest of Whiskeytown, the outcrop area of the Copley broadens to a width of several miles, and near the latitude of Merry Mountain the formation passes beneath younger rocks. It reappears as inliers at several places in the extreme northern part of the quadrangle. From the map pattern (pl. 1), it seems likely that the Copley extends beneath the entire north third of the quadrangle.

The Copley consists of intermediate to mafic pillow lava, massive flows, flow breccia, coarse- and fine-grained pyroclastic material, minor tuffaceous shale, and shale. Approximately the upper 1,000 feet of the formation is amygdaloidal pillow lava that contains subordinate lenses of fragmental material. Most of the lithologic units seem to be lenticular.

Within the aureole of the Shasta Bally batholith, the Copley has a conspicuous gneissic foliation and is strongly metamorphosed. Farther away from the batholith, the greenstone consists mostly of weakly schistose to nonschistose keratophyre, spilite, and meta-andesite. These petrographic types are not distinguishable from each other in the field and can be distinguished only with difficulty in thin section. A highly important fact bearing on origin and metamorphism is that although the keratophyre, spilite, and some meta-andesite are almost completely reconstituted mineralogically, they retain their original igneous textures and structures. Only in localized shear zones, where these textures and structures are obliterated by shearing, is there doubt as to the rock's original character.

STRATIGRAPHIC RELATIONS AND THICKNESS

In the northeastern part of the quadrangle and in adjacent areas to the northeast (Kinkel and others, 1956, pl. 1), the Copley greenstone is overlain by the Balaklala rhyolite of Devonian age; elsewhere in the northern part of the quadrangle, the Copley is either overlain by, or is in fault contact with, the Bragdon formation of Mississippian age; in the central and southern parts of the quadrangle it is intruded by the Shasta Bally batholith and by the Mule Mountain stock of Jurassic or Cretaceous age.

In the southeastern part of the quadrangle, however, sheets of felsic rock similar to the Balaklala rhyolite are interlayered and apparently contemporaneous with the Copley greenstone. The best examples of this relationship are south of Mule Mountain and for several miles northwest of Monarch Mountain. Except in the vicinity of the upper part of Dry Creek, where the strike is anomalously northeast and the Balaklala is infolded in the Copley (pl. 1), these layers of felsic rock strike northwest and dip northeast in what seems to be a homoclinal sequence. Available structural and stratigraphic evidence indicates that many of these sheets of silicic rock are overlain by several thousand feet of Copley greenstone. Other layers of felsic material in the vicinity of Grizzly Gulch and on Merry Mountain are stratigraphically somewhat higher in the Copley section, but not at the top. The main mass of felsic rock south of Tower House (pl. 1) is overlain by the Copley greenstone, a relationship similar to that seen on the south side of O'Brien Mountain in the East Shasta copper-zinc district a few miles northeast of the French Gulch quadrangle (Albers and Robertson, 1961, pl. 1).

Some sheets of felsic rock interlayered with greenstone northwest of Monarch Mountain are pyroclastic material and probably are of extrusive origin, but other sheets of quartz keratophyre in this same area are demonstrably intrusive. Nevertheless, the scarcity of intrusive crosscutting relationships and the local presence of pyroclastic material suggest that much of the felsic rock interlayered with Copley greenstone in this area is extrusive. The same origin may apply to some sheets of the felsic rock interlayed with greenstone south of Mule Mountain, although here no pyroclastic material was seen and the possibility exists that these sheets may be sills.

In places in the northeastern part of the quadrangle, as well as in adjacent parts of the West Shasta copper-zinc district, the contact between the Copley greenstone and the overlying Balaklala rhyolite is transitional, marked by a layer of pyroclastic material ranging from a few feet to 150 feet thick. This pyroclastic layer contains abundant fragments of felsic quartz porphyry as well as fragments of amygdaloidal greenstone in a tuffaceous greenstone matrix. The proportion of greenstone to quartz porphyry fragments decreases upward and the pyroclastic bed is overlain conformably by quartz keratophyre of the Balaklala rhyolite.

Inasmuch as the base of the Copley greenstone has nowhere been recognized, only partial sections of the formation have been measured. Hinds (1933, p. 87) measured a partial section of 1,500 feet on Shirttail Peak, and Kinkel and others (1956, p. 10) measured a partial section of 3,700 feet in the Modesty Gulch area. Actually the thickness may be much greater than 3,700 feet, if the wide area of greenstone southwest from Modesty Gulch is included. However, original layering in the greenstone south of Modesty Gulch is largely destroyed by shearing and metamorphism, and any estimate of thickness in that area would have to rest on the assumption that schistosity parallels original layering. Although this relation might safely be assumed to exist in some localities, it is know to be absent in others.

LITHOLOGY AND PETROGRAPHY

All the rocks of volcanic origin assigned to the Copley greenstone are of intermediate or mafic composition. The greenstone consists of a wide variety of lithic types, including amygdaloidal pillow lava, massive flows, volcanic breccia, agglomerate, flow breccia, tuffaceous shale, and shale. Virtually all these lithic types are mineralogically and, to some extent, chemically reconstituted owing to regional hydrothermal alteration and local contact metamorphism, but, except where schistosity is strong, primary structures and textures are preserved and the original lithic character of the rock can be determined.

Even though the various lithic types that make up the Copley could be distinguished with confidence in many places in the field, it was not possible to subdivide the volcanic components of the formation on the geologic map (pl. 1). Only the tuffaceous shale and shale lenses are shown separately.

The lower part of the Copley is mainly fine-grained lava and tuff. Some flows are porphyritic and contain small phenocrysts of ferromagnesian minerals in an aphanitic greenish-gray groundmass. Much of the fine-grained greenstone, especially in the belt between the Mule Mountain stock and the Shasta Bally batholith, is hard and massive in fresh outcrop. However, weathering, as in roadcut exposures, commonly reveals a platy structure ranging in intensity from close-spaced jointing to strong schistosity. Generally, tuffaceous beds are more strongly schistose than lava flows, but in places the intensity of schistosity appears unrelated to the lithic character of the rock.

At least the upper part of the Copley consists predominantly of pillow lava that contains subordinate lenses of pyroclastic material. Several varieties of pillow lava have been described by Kinkel and others (1956, p. 11). Most of the pillow lava is amygdaloidal. The amygdules range from about 1 mm to as much as 25 mm in diameter. Minerals that commonly form amygdules include quartz, calcite, chlorite, epidote, clinozoisite, albite, and zeolite. The best exposures of the pillow lava sequence is in Modesty Gulch in the north-central part of the quadrangle. Practically all the greenstone exposed in the northwestern part of the quadrangle (pl. 1) consists of pillow lava and is believed to be in the upper part of the Copley section.

The upper part of the Copley greenstone also includes numerous lenses of coarse volcanic breccia consisting largely of blocks, bombs, lapilli, and ropy material in a greenish-gray matrix that has the same general appearance in outcrop as the fragments. The various kinds of fragments are rarely more than 6 inches in diameter and average about 4 inches. In places all gradations seem to occur between ropy lava, lava containing sparce fragments, and pyroclastic material composed almost entirely of bombs and blocks. The bombs in the pyroclastic facies are commonly well rounded and of a slightly lighter color than the matrix (Kinkel and others, 1956, fig. 4). Accidental fragments of schistose and gneissic rock, possibly derived from the Salmon or Abrams formations, were seen in Copley fragmental rocks on Monarch Mountain.

A distinctive volcanic breccia as much as 150 feet thick that contains fragments of quartz keratophyre in a chloritic matrix is present in some places at the top of the Copley. Near the head of Modesty Gulch on Mad Mule Mountain, this breccia forms a transition zone between the Copley greenstone and the Balaklala rhyolite.

A few thin beds of shaly tuff and shale occur in what seems to be the lower part of the Copley from Brandy Creek northwest to Crystal Creek (pl. 1). Some of these beds on the west side of Monarch

713–195—64——4

Mountain consist in part of felsic material and overlie sheets of quartz keratophyre correlated with Balaklala rhyolite. Others, too small to show at the map scale, are shaly greenstone tuff. A 25-foot thick bed of dark shale having a good slaty cleavage crops out in the roadcut west of Crystal Creek and appears to continue for about a mile southeastward along strike. This slaty shale is lithologically similar to shale in the nearby Bragdon formation, but it seems to be definitely interlayered with sheets and lenses of coarse and fine felsic pyro-

The petrography of the Copley greenstone is described in detail by Kinkel and others (1956, p. 13–16) and is briefly summarized in table 1.

AGE

No fossils have been found in the Copley greenstone, and its precise age has not been determined with certainty. However, it intertongues with and is overlain conformably by the Balaklala rhyolite, the uppermost part of which is probably of Middle Devonian age. Therefore, the Copley is presumably at least in part of Middle Devonian age, but the lower part may be older than Middle Devonian.

BALAKLALA RHYOLITE

GENERAL CHARACTER AND DISTRIBUTION

The Balaklala rhyolite consists of light-colored siliceous lava flows interlayered with sheets and lenses of coarse and fine felsic pyroclastic material. These flows and pyroclastic rocks, together with a few layers of greenstone mapped as Copley, form a volcanic pile overlying the main mass of the Copley greenstone in the northeastern part of the quadrangle (pl. 1) and in the adjacent area to the northeast (Kinkel and others, 1956, pl. 1). In addition, a large tongue-like pendant of Balaklala rhyolite which is separated from the main body of Balaklala by the granitic rock of the Mule Mountain stock, extends from near White Rock Gulch (northeast of Whiskeytown) southeastward to the vicinity of Orofino Gulch. Numerous smaller intrusive and extrusive sheets of felsic aphanitic rock, also mapped as Balaklala, are interlayered and locally infolded with Copley greenstone south of Mule Mountain and for several miles northwest from Monarch Mountain. A body of similar rock as much as 2,000 feet thick underlies Copley greenstone from Boulder Creek northwestward to Trail Gulch.

STRATIGRAPHIC RELATIONS AND THICKNESS

The Balaklala rhyolite both overlies and intertongues with the Copley greenstone, as described on pages J19–J20. It is overlain by the Kennett (?) formation of Devonian age in some places in the quadrangle and by the Bragdon formation of probable Mississippian age in other places.

In the Backbone Creek area of the West Shasta copper-zinc district, which is the type locality of the Kennett formation, the Kennett conformably overlies the Balaklala rhyolite; the contact is gradational (Kinkel and others, 1956, p. 21 and pl. 1). Beds of fine-grained felsic pyroclastic material that form the uppermost part of the Balaklala rhyolite in Backbone Creek grade upward into tuffaceous shale and shale of the Kennett formation. The contact is placed where shale predominates over tuff.

In the northeastern part of the French Gulch quadrangle, a belt of rock consisting mostly of gray and black siliceous shale lithologically similar to that of the Kennett overlies the Balaklala rhyolite in most places. However, no fossils of Kennett age have been found in this shale, and for reasons given in the section on the Kennett(?) formation, there is some doubt that it is actually Kennett.

Felsic quartz porphyry tuff, which is identical to that forming the upper part of the Balaklala rhyolite in the Backbone Creek locality, also forms lenses between the Copley greenstone and the Bragdon formation on the west side of hill 3670 south of Shirttail Peak and in the vicinity of the Franklin and Washington mines in French Gulch. Here the tuff grades upward into the Bragdon formation. If the Bragdon formation in the French Gulch quadrangle is of Mississipian age, as found by Diller (1906, p. 3) in the Redding quadrangle, and if the Kennett and Bragdon formations are separated by an unconformity, there then exists an anomalous and seemingly irreconcilable situation whereby tuff of the Balaklala rhyolite grades upward into the Kennett formation of Middle Devonian age in the Backbone Creek area, but grades into the Bragdon formation of Mississippian age only a few miles away in the western part of the French Gulch quadrangle. The solution to this problem may become apparent when the Bragdon formation has been mapped in detail and its age and relations to underlying rocks have been studied over its entire area of outcrop.

Owing to its volcanic origin and the probable derivation of constituent lithic units from a number of vents, the thickness of the Balaklala rhyolite differs greatly from place to place. The maximum thickness is about 3,500 feet on Mammoth Butte 2 miles northeast of the quadrangle (Kinkel and others, 1956, p. 22). Within the quadrangle, the thickness may be nearly this great in the ridge south of Squaw Creek and in the large pendant east of Whiskeytown. However, bedding is rare in the Balaklala in both of these areas. Therefore, any estimate of thickness is necessarily based on few stratigraphic and structural data and is applicable only to the specific locality where it is made.

In the northwestern part of the French Gulch quadrangle, the Balaklala is absent in some places and in others consists of tuffaceous rock only a few feet thick.

LITHOLOGY AND PETROGRAPHY

The bulk of the Balaklala rhyolite consists of felsic siliceous lava flows, flow breccias, and pyroclastic rocks, most of which have the composition of quartz keratophyre. A subordinate percentage of the formation is represented by dikes and sills in the Copley greenstone, and a very minor percentage is shaly tuff. The dikes and sills that cut the greenstone are lithologically and petrographically identical to the extrusive flows.

Much of the felsic material constituting the Balaklala is light-gray or light greenish-gray quartz keratophyre consisting of sparse to abundant megascopically visible quartz and feldspar phenocrysts in an aphanitic groundmass. A somewhat subordinate percentage of the formation is nonporphyritic, although it has nearly the same composition and color as the porphyry. The presence of the quartz phenocrysts, along with the commonly lighter color, are the main characteristics that permit ready distinction of the porphyritic facies of the Balaklala from the Copley greenstone. However, both porphyritic and nonporphyritic facies of the Balaklala are in places more or less chloritized, and locally chloritization is intense. Conversely, the Copley greenstone is silicified and its color made lighter in a few places. Where either or both of these types of alteration have affected the rocks, color is not a reliable criterion for distinguishing Balaklala from Copley. On the other hand, quartz phenocrysts in quartz keratophre and amygdules in greenstone survive alteration and remain as reliable criteria to distinguish their respective units. However, where phenocrysts and amygdules are lacking in altered rocks, the problem of distinguishing the rocks of the Balaklala from those of the Copley becomes acute and leads to considerable uncertainty; much of the rock between Boulder Creek (southeast of Tower House) and Bear Gulch (about 3 miles northwest of Tower House) is of this type. Some of the material mapped as Balaklala in this area (pl. 1) is, therefore, probably silicified greenstone, and conversely, some rock mapped as Copley may be chloritized Balaklala rhyolite.

Kinkel and others (1956, p. 19–22) subdivided the Balaklala into three main map units, a lower unit, middle unit, and upper unit, on the basis of quartz phenocryst size. The lower unit is characterized by nonporphyritic rhyolite that may contain microphenocrysts as much as 1 m in diameter (quartz keratophyre) and rhyolitic pyroclastic material; the middle unit consists mostly of quartz porphyry (quartz keratophyre) that contains phenocrysts 1 to 4 mm in diameter and abundant pyroclastic material in the upper part of the unit; and the upper unit consists chiefly of quartz porphyry (quartz keratophyre) that contains phenocrysts more than 4 mm in diameter. Generally this lithologic sequence was found to hold throughout the district, although in places, especially away from the center of the volcanic pile, one or two of the units may be missing. Also, rocks typical of a particular unit commonly contain sheets and lenses of material characteristic of a different unit, and in places the contacts are gradational. The interlayering and gradation of facies is especially typical of the lower nonporphyritic and middle, medium-phenocryst units of the Balaklala. Largely because of the complexities resulting from this relationship, it was impractical, for cartographic reasons, to distinguish between the lower and the middle units of Kinkel and others at the scale of the French Gulch quadrangle map. However, the coarse-phenocryst upper unit and the beds of fine-grained tuff in the Balaklala are mapped separately.

Included in the two nontuffaceous Balaklala rhyolite units shown on the geologic map (pl. 1) are numerous lenses, sheets, and irregular bodies of flow breccia and pyroclastic material. Most of the beds are only a few feet thick and extend for only a few hundred feet laterally, but a few are several hundred feet thick and continue for more than a mile. Fragments in most of the pyroclastic material are angular to subrounded and locally range up to 18 inches in diameter. However, the rounded fragments present in some pyroclastic layers suggest a volcanic conglomerate. The size of fragments in pyroclastic layers is rarely uniform. Many layers consist of coarse unstratified breccia interlayered with finer pyroclastic material and well-bedded tuff. Coarse pyroclastic material commonly shows an upward gradation into finer material and then into tuff. The finer grained material generally shows bedding and is of considerable importance in delineating the structure of local areas.

Virtually all the felsic rock of the Balaklala type that underlies and intertongues with the Copley greenstone in the western part of the quadrangle, south and west of Tower House, is either nonporphyritic quartz keratophyre or porphyritic quartz keratophyre containing 1 to 4 mm phenocrysts, and thus it is characteristic of the lower and middle units as defined in the West Shasta map area. A large proportion of the gneissic rock contiguous to this body of Balaklala in the contact aureole of the Shasta Bally batholith between Boulder Creek and Trail Gulch is very siliceous and was evidently derived from quartz keratophyre of the Balaklala rhyolite. The Balaklala is represented locally in the north-central and northwestern part of the quadrangle chiefly by lenses of quartz porphyry tuff that lie between the Copley greenstone and the Bragdon formation.

Near the junction of Trail Gulch and Willow Creek in the western part of the quadrangle, lenses of quartz keratophyre are interlayered with phyllite derived from shaly rocks of the Bragdon formation by contact metamorphism. The largest of these lenses, and the only one of mappable scale, is about 100 feet thick and was traced for about a mile (pl. 1). The lens lies 150 to 200 feet above the base of the Bragdon, parallel to schistosity and probably parallel to bedding. In the ridge above the Greenhorn mine, it contains sparse medium-sized quartz phenocrysts, but in Bear Gulch to the east and also along U.S. Highway 299W to the west, phenocrysts are extremely rare. The quartz keratophyre has a weak platy structure that parallels the schistosity of the enclosing phyllite; this fact shows that the quartz keratophyre has undergone deformation and is therefore probably not a sill genetically related to the posttectonic quartz porphyry dikes of Late Jurassic or Cretaceous age. The absence of crosscutting relations and the proximity to a large mass of quartz keratophyre of probable though not demonstrable extrusive origin suggest that it may be a flow rather than a sill in the Bragdon.

The petrography of typical varieties of Balaklala rhyolite is summarized in table 1. For a more detailed description of the lithology and petrography of the Balaklala, the reader is referred to Kinkel and others (1956, p. 19–31).

ORIGIN AND AGE

The origin of the Balaklala rhyolite, that is, whether it is intrusive or extrusive, has been a matter of controversy for many years. Diller, who first described and named the formation (1906, p. 6), considered it to be a series of siliceous lava and tuff beds underlying the Kennett formation of Devonian age. On the other hand, Graton (1910, p. 81) concluded after studying part of the West Shasta mining district that the Balaklala is a complex mass of alaskite and alaskite porphyry intrusive into the surrounding rocks.

The intrusive origin proposed by Graton was accepted by several geologists who later published information on the geology of the area (Averill, 1939, p. 122; Ferguson, 1914, p. 30; Hinds, 1933, p. 107; Seager, 1939, p. 1958). However, detailed mapping of the West Shasta district by Kinkel and others (1956, p. 31–32), has shown that Diller's interpretation of the Balaklala, as a pile of extrusive lavas and pyroclastic rocks containing subordinate feeder dikes and sills indistinguishable from extrusive facies, is correct.

The age of most of the Balaklala rhyolite is probably Middle Devonian or late Middle Devonian. The upward gradation in several localities outside the French Gulch quadrangle of tuff beds at the top of the Balaklala into shaly tuff and siliceous shale of the Kennett formation of late Middle Devonian age is interpreted to mean that deposition of the two formations was almost continuous and that the formations are of nearly the same age. The apparent interbedding of quartz keratophyre with Bragdon formation in the Trail Gulch area suggests, however, that the eruption of Balaklala-type rocks continued into Bragdon time.

KENNETT(?) FORMATION

DISTRIBUTION, LITHOLOGY, AND THICKNESS

A discontinuous belt of gray to black cherty shale lies between the Balaklala rhyolite and shaly rocks of the Bragdon formation between Mad Mule Mountain and the northeast corner of the quadrangle (pl. 1). This shale is tentatively correlated with the Kennett formation; it is commonly made up of beds 1 to 2 inches thick, which are separated by parting planes or by thinly fissile shale. The cherty shale is commonly black on a fresh surface but weathers gray. A conspicuous feature of the cherty shale virtually everywhere in the French Gulch quadrangle is its highly contorted character.

The basis for correlating this contorted cherty shale with the Kennett formation is its stratigraphic position and its lithologic similarity to black siliceous shale that forms the lower part of the Kennett at its type locality in Backbone Creek (Kinkel and others, 1956, p. 35–38). At the type locality, however, the shale is not contorted, and it is overlain conformably by limestone containing fossils of Middle Devonian age. No fossils have been found in the black shale either in the Backbone Creek locality or in the French Gulch quadrangle.

The cherty shale consists mostly of quartz, carbonaceous material, and fine-grained white mica; minor constituents include clay minerals, sphene, rutile, and limonite. Most specimens contain angular quartz clasts averaging 0.1 mm in diameter in a matrix made up of grains averaging about 0.01 mm in diameter. Locally, the cherty shale contains poorly preserved structures that are probably Radiolaria. The shale is very commonly highly fractured as well as highly contorted and the fractures are filled with quartz. Although there is no obvious hydrothermal silicification of the cherty shale, the intense and widespread silicification of the underlying Balaklala rhyolite indicates that the shale has not entirely escaped this alteration.

A close estimate of the thickness of the cherty shale is extremely difficult because of its highly deformed character. The maximum thickness, based on the outcrop width of the belt, is about 400 feet. However, if allowance is made for repetition of beds by folding and faulting, the true thickness is probably much less.

STRATIGRAPHIC RELATIONS AND AGE

The dark cherty shale of the Kennett(?) formation overlies the Balaklala rhyolite everywhere except on the east side of Whiskey Creek where it apparently overlies Copley greenstone. The exact contact between the shale and the underlying rock is exposed in only a few places, and in all such places the underlying rock is felsic tuff. The contact between the tuff and the shale is gradational and is conformable in detail. A thin layer of tuff may be present everywhere beneath this shale, but the few exposures of the underlying rock suggest that the tuff is discontinuous.

The possibility that the black siliceous shale belongs to the Bragdon formation rather than to the Kennett is suggested by the following features:

1. North of Backbone Creek in the West Shasta map area (Kinkel and others, 1956, p. 41), two layers of black cherty shale lithologically identical to that between the Balaklala and Bragdon formations are interbedded with conglomerate and shale of the Bragdon; this shows that the black cherty shale lithology is not restricted to the Kennett formation.
2. The apparently uniform thickness of the black cherty shale where present, coupled with the absence of any other kind of known Kennett lithology in the French Gulch quadrangle, demands an unlikely coincidence: If the black cherty shale facies was originally discontinuous, perhaps being deposited only in basins between volcanic islands, it would seem that some recognizable variation in thickness should reflect this original lenticularity. On the other hand, if the shale was originally continuous and if erosion of the Kennett took place prior to deposition of the Bragdon, it seems too much a coincidence that a fairly uniform thickness of shale was preserved while all other rocks of the Kennett were stripped away.

The age of the Kennett formation has been established as Middle Devonian on the basis of fossils found in the limestone at the Backbone Creek type locality of the Kennett formation in the West Shasta copper-zinc district (Kinkel and others, 1956, p. 38).

BRAGDON FORMATION

GENERAL CHARACTER AND DISTRIBUTION

Much of the northern part of the French Gulch quadrangle, as well as a large area north of the quadrangle, is underlain by the Bragdon formation presumably of Mississippian age. The formation was named by Hershey (1904, p. 347–360) from exposures at the community of Bragdon on the Trinity River about 10 miles north of the French Gulch quadrangle.

The lower part of the Bragdon consists mostly of shale, mudstone, and siltstone and subordinate sandstone, conglomerate, and mafic tuff. In the upper part, coarse clastic material, including sandstone, grit, and conglomerate, is interbedded with and about equal in abundance to the fine clastics. In Kinkel and others (1956, 1:24,000-scale geologic map) individual beds of coarse clastic material in the Bragdon formation are delineated, but these could not be shown on the smaller scale map (pl. 1) accompanying the present report. In the French Gulch quadrangle, however, it is convenient to delineate at least a lower and an upper unit in the Bragdon on the basis of the difference in lithology just described. The lower unit includes all rocks up to the base of the lowest prominent and continuous conglomerate beds. A few local conglomerate beds that have little continuity are considered part of the lower unit (pl. 1, cross section).

STRATIGRAPHIC RELATIONS AND THICKNESS

The Bragdon formation in some places rests directly on the Copley greenstone or is separated from it only by intrusive sills or a few quartz veins. Elsewhere, it overlies the Balaklala rhyolite or contored cherty shale of the Kennett(?) formation. In a few places, flows of rhyolite tentatively mapped as Balaklala are included in the Bragdon. In the Hoadley Peaks area the Bragdon is intruded by the Shasta Bally batholith.

Where the Bragdon rests on Copley greenstone, mainly in the northwestern part of the quadrangle, the contact was seen in a few prospect pits, mine workings, and roadcuts. In virtually all these exposures, a few feet to a few tens of feet of the Bragdon are sheared and faulted, generally almost parallel to the contact. More commonly the two formations are separated by intrusive rock or by quartz veins. No exposures of sedimentary rock of the Bragdon formation were seen resting undisturbed in depositional contact with the greenstone. It appears that the contact between the greenstone and the relatively incompetent shaly rocks of the Bragdon formation was a plane of structural weakness along which movement readily took place during deformation, and it is inferred that a thrust fault separates the two units. The presence of sill-like sheets of intrusive rock or quartz veins of Late Jurassic or Cretaceous age in many places along this contact shows that the contact was not only a favorable locale for intrusion and mineralization, but also a plane of structural weakness.

On the west flank of peak 3670 south of Shirttail Peak, in places around the inlier of Copley greenstone in French Gulch, and south of Tower House, the Bragdon formation rests on a layer of felsic tuff a few feet thick; the contact is gradational. This tuff is correlated with the Balaklala ryholite and is markedly similar to the tuff layer assigned to the Balaklala that underlies the Kennett formation at its type locality in Backbone Creek. The gradational contact between the tuff and the overlying shaly sedimentary rocks is likewise similar to that in Backbone Creek.

Sheets of weakly sheared quartz keratophyre lithologically similar to the Balaklala rhyolite are interlayered parallel to schistosity and probably parallel to bedding in phyllitic rock of the Bragdon formation near the Greenhorn mine, between Bear Gulch and U.S. Highway 299W. Although the extrusive origin of these quartz keratophyre sheets cannot be proved, the lack of intrusive features, and the demonstrable extrusive origin of the bulk of the Balaklala rhyolite, suggests that they are flows in the Bragdon. Similar sheets of weakly sheared quartz keratophyre which are interpreted as flows, are also interbedded with cherty shale in the Kennett formation east of the Mammoth mine in the West Shasta district (Kinkel and others, 1956, p. 36).

Diller (1906, p. 3) placed an unconformity between the Bragdon and Kennett formations because of the presence of cobbles of fossil-bearing limestone derived from the Kennett in conglomerates of the Bragdon. His conclusions were based mainly on relations in the Redding quadrangle east of the present map area. In the French Gulch quadrangle, (1) the presence of beds of quartz keratophyre tuff interbedded with mudstones (table 1), (2) the gradation of tuffaceous mudstone downward into tuff of the Balaklala rhyolite in some localities, and (3) the presence locally of sheets of quartz keratophyre lava interbedded in the lower unit of the Bragdon, indicate either (1) that the eruption of Balaklala rhyolite continued throughout Kennett and into Bragdon time uninterrupted by any significant erosional break, or (2) that some of the rocks we now consider as Bragdon in the French Gulch quadrangle are Kennett, the difference in Kennett lithology being due to a marked change in facies between the Backbone Creek type locality and the western part of the French Gulch quadrangle. Interpretation (1) is here preferred because the lithology of the sedimentary rocks is in general more like the Bragdon than the Kennett and the lithology of the rhyolite is very similar to the Balaklala.

Available data are inadequate for a solution of the problem of the Kennett and Bradgon relationship, but careful mapping of the large area underlain mostly by Bragdon north and northwest of the French Gulch quadrangle may reveal the answer.

Diller (1906, p. 3) states that the maximum thickness of the Bragdon formation in the Redding quadrangle, where the top of the formation is exposed, is 6,000 feet. Recent geologic work in the Shasta Copper-zinc district and in the French Gulch quadrangle has yielded little additional information on the thickness, partly because the top of the formation is not present in the area. Moreover, accurate estimates of the thickness are very difficult to make because of the abundance of large and small faults within and at the base of the formation, because of the lenticular character and lack of distinctive features of component beds, and because of poor outcrops in critical areas. Cross section *A–A′* (pl. 1) indicates a thickness of about 4,500 feet for the lower unit of the Bragdon and at least 1,500 feet for the upper unit. This section, however, does not reflect the myriad of minor faults that cut the formation, some at very low angles and others at high angles to bedding. Therefore, the thickness, particularly the thickness of the lower unit, is at best only a rough approximation.

LITHOLOGY AND PETROGRAPHY

LOWER UNIT

The lower unit of the Bragdon formation is about 90 percent shale, mudstone, and siltstone and 10 percent sandstone, graywacke, conglomerate, tuff, and tuffaceous sedimentary rocks. On the ridge between Centennial Gulch and Boswell Gulch south of Highland Ridge (pl. 1), where there seems to be only minor faulting along the contact between Bragdon and underlying tuff, the lowest part of the Bragdon is dark-gray tuffaceous mudstone that grades downward into quartz porphyry tuff. The contact between this tuff and the underlying greenstone is not exposed. Above the tuff is a sequence of mudstone, siltstone, graywacke, tuff, and fine conglomerate beds ranging from a few inches to about 4 feet thick. About 150 feet above the tuff is a 5-foot-thick bed of chert conglomerate that contains chert pebbles as much as half an inch in maximum dimension. Overlying this conglomerate is a monotonous sequence of shale, mudstone, and siltstone in beds a few inches to a few feet thick, interbedded with a few lenses of coarser clastic material. This sequence has an apparent maximum thickness of about 3,500 feet and extends to the top of the ridge, but the amount of duplication and omission of beds by many small faults not mappable at the quadrangle scale is unknown. The top of this unit is above the present erosion surface.

The petrography of various rocks in the lower unit of the Bragdon formation is summarized in table 1.

UPPER UNIT

The upper unit of the Bragdon formation is characterized by an abundance of coarse conglomerate, grit, and sandstone interbedded with about an equal amount of mudstone and siltstone. The conglomerate beds, which are commonly in shades of gray, are most distinctive. Some beds were traced for several miles. Other beds were traced for only a few hundred feet, until they either lens out or are cut off by faults. The beds generally range from 10 to 20 feet thick, but the overall range is from a few inches to possibly 100 feet. Chert in various colors is the principal component of most beds; other constituents, most common in the coarsest beds, include limestone, sandstone, shale, and vein quartz. The matrix is generally subordinate to the fragments and consists mostly of fine-grained quartz and white mica. Some beds show graded bedding, from conglomerate containing fragments 1 to 2 inches in diameter at the base, upward through grit to sandstone or siltstone at the top. Other beds show no graded bedding and no sorting whatever. The coarsest beds, which include fragments as much as a foot in diameter, are characterized by abundant fragments of limestone, sandstone, and other noncherty material. The limestone fragments commonly weather out, and leave solution cavities that give the rock a pitted aspect. According to Diller (1906, p. 3), the limestone fragments, which commonly contain corals and other fossils, were derived from the Kennett formation.

Beds of dark-gray mudstone and siltstone, a few feet to 100 feet thick, are commonly interbedded with the coarse clastics in the upper unit of the Bragdon. The upper unit appears to be at least in part structurally discordant on the lower unit, but no thrust fault could be mapped with certainty.

AGE

No fossils were found in the Bragdon formation either in the French Gulch quadrangle or the adjoining Shasta copper-zinc district. About 12 miles to the northeast, where fossils were found by Diller (1906, p. 3), the age was determined as Mississippian. But, as was stated earlier, the age and correlation of rocks presently included in the lower part of the Bragdon at least, is by no means well established.

MULE MOUNTAIN STOCK

LOCATION AND GENERAL CHARACTER

A stock consisting mostly of coarse-grained light-colored trondhjemite (quartz-rich oligoclase-quartz diorite) and albite granite crops out in the eastern part of the French Gulch quadrangle and in the adjacent Redding quadrangle to the east. The stock is roughly elliptical, being about 10 miles long and 5 miles wide, elongate in a northerly direction. Approximately the west half of the stock is in the French Gulch quadrangle (pl. 1). Diller (1906, p. 8) mapped this stock as quartz-hornblende diorite. Hinds (1933, p. 105) named it the Mule Mountain stock from its prominent exposure on Mule Mountain.

Most of the stock is coarse-grained holocrystalline rock with a granitoid texture. In a few places, particularly near the borders, the rock is weakly foliated, but for the most part it has no planar structure or mineral alinement. The principal minerals are quartz, plagioclase, and epidote. Average grain size is about 2 mm, but some facies of both the trondhjemite and the albite granite have a poikilitic or pseudoporphyritic texture owing to the presence of irregular masses of glassy quartz as much as 10 mm in diameter. Except in Clear Creek and other deep stream canyons, the stock is deeply weathered and tends to be crumbly in outcrop. Most of the stock is light-colored owing to its low content of ferromagnesian minerals, and the siliceous albite-granite facies is generally a brilliant white that contains sparse splotches of green epidote as much as 6 mm in diameter. This facies is prominently exposed in roadcuts along U.S. Highway 299W near the west edge of the quadrangle.

A large pendant of Balaklala rhyolite about 4 miles long projects into the stock, and many inclusions of Copley greenstone and Balaklala ryholite measuring a few hundred to a few thousand feet in maximum dimension are contained in the stock. The inclusions of greenstone show various stages of assimilation or replacement by the granitic rock. No chilled contacts were seen. Relict layering, present in most of the large inclusions, shows that they are in structural harmony with each other as well as with country rock surrounding the stock and that they were not detached from the roof during emplacement of the pluton.

Breccia, consisting of blocks or fragments of dark-colored hybrid dioritic rock in a matrix of light-colored granitoid rock, crops out along U.S. Highway 299W at the east edge of the quadrangle. This breccia is in a narrow belt about a mile long (pl. 1). Fragments range from a few inches to several feet in diameter. In places, irregular replacement dikes of coarse trondhjemite a few inches thick and having unmatched walls cut through the darker colored fragments. Similar breccia was mapped in the Democrat Mountain area of the West Shasta district (Kinkel and others, 1956, pl. 1 and fig. 23). In the area north of Democrat Mountain, some fragments only slightly metamorphosed show relict layering and are clearly derived from Copley greenstone. These fragments are structurally undisturbed in relation to each other; this fact coupled with the undisturbed large inclusions of country rock in the stock leads to the inference that breccia fragments in which no relict layering is preserved are also undisturbed. The distribution of the breccia bodies and their relation to the topography suggest a tabular shape; the breccia is interpreted as remnants of tabular bodies of greenstone that occupied a position close to the roof of the stock. The brecciation of the greenstone was probably caused partly by the passive injection of magmatic fluids into a myriad of crosscutting fractures and cleavage planes and partly by the subsequent partial replacement of the greenstone in the walls of these injected fractures.

About 50 percent of the part of the Mule Mountain stock that lies in the French Gulch quadrangle is trondhjemite consisting of quartz, oligoclase, and mafic minerals. Virtually all the remaining part of the stock within the quadrangle is albite granite that forms irregular, mostly elongate, masses and has gradational contacts with the trondhjemite (Kinkel and others, 1956, pl. 1).

Petrographic, chemical, and field data indicate that the albite granite was probably derived largely from trondhjemite and perhaps in part from quartz diorite by either deuteric or hydrothermal alteration. However, the distribution of albite granite also bears a broad relationship to pendants and inclusions of the Balaklala rhyolite. Albite granite is most abundant in the area east of Whiskeytown, where the largest inclusions of Balaklala are present, and also southward from the vicinity of the Mount Shasta mine along the projected trend of the large pendant of Balaklala. This spatial relationship between the two rock types, and their chemical and mineralogical similarity, suggests that some bodies of albite granite may be derived from Balaklala rhyolite by isochemical recrystallization.

The petrography of typical facies of the Mule Mountain stock is summarized in table 1.

Aplite dikes are common in a few places near the borders of the Mule Mountain stock and on Mule Mountain, but are rare elsewhere. They are commonly only a few inches thick. Some aplite contains euhedral quartz phenocrysts as much as 2 mm in diameter in a fine-grained sugary groundmass of quartz, albite, epidote, sphene, leucoxene, and minor amounts of chlorite. The groundmass texture is micrograniioid. Myrmekitic and micrographic intergrowths of quartz and albite are common.

Metamorphism resulting from the emplacement of the Mule Mountain stock is limited to the recrystallization, in a few areas, of Copley greenstone to granular amphibolite and epidote amphibolite for a few feet to a few tens of feet from the contact. In many places along the contact, little or no recrystallization has occurred.

STRUCTURAL SETTING AND MODE OF EMPLACEMENT

The Mule Mountain stock is situated where the regional trend of enclosing rocks changes gradually from about N. 45° W. to north-

northeast; it thus defines a broad irregular bend whose maximum inflection is where the stock occurs (fig. 5). South and southeast of the stock, the strike of rock units and schistosity is northwest and dips are northeast; along the west side, strikes are mostly a little west of north and dips are steeply east; north of Whiskeytown, and at the north end of the stock, strikes are northeast and dips are either northwest or southeast. Along the east side of the stock, lithic units in the Copley, Balaklala, and Kennett formations, as mapped by Kinkel and others (1956), and by V. F. Hollister [1], define a nearly straight north-south pattern very slightly convex towards the east (fig. 5; Kinkel and others, 1956, pls. 1, 3). It is inferred that the eastern and western contacts of the stock dip steeply eastward nearly parallel to schistosity. Although the contact of the stock is highly irregular and crosscutting in detail and is characterized by many angular bends that suggest controls by fractures in the country rocks, it is from a broad viewpoint roughly concordant along its east and west borders and more markedly transgressive at the north and south ends. The position of the stock suggests that this large structural bend played an important part in its localization. Possibly the rocks in the inflection were more crumpled and fractured than elsewhere and therefore in a relatively dilated condition and structurally receptive to intrusion and replacement.

That metasomatic replacement was one important mechanism by which the Mule Mountain stock was emplaced is suggested by both structural and compositional evidence. The structural harmony between inclusions and pendants and the country rock surrounding the stock indicates that the emplacement was passive. Randomly oriented foundered blocks, which might be expected if stoping had been an active process, seem to be absent. Although the very slight and none too definite eastward convexity of rock units and schistosity on the east side of the stock (Kinkel and others, 1956, pls. 1, 3) could have resulted from a shouldering action by the intrusive, it is interpreted as a structural feature that predated the emplacement of the stock.

Further suggestion of a metasomatic origin is furnished by the compositional heterogeneity of the stock (which seems to be especially conspicuous in the vicinity of inclusions and pendants), the lack of chilled contacts, the common occurrence of replacement dikes, particularly along the northeast border of the stock, and the presence of undisturbed inclusions of Copley greenstone in various stages of reconstitution. Without doubt, magma was also involved in the process, but a significant proportion of the stock is interpreted to be of replacement origin.

[1] Hollister, V. F., 1949, Geology of the Shasta gold-silver district, Shasta County, California: California Univ., Berkeley, Master's thesis, 45 p.

The depth at which the emplacement took place cannot be ascertained by direct evidence, for the rocks surrounding the stock are steeply dipping. The maximum thickness of strata that could have overlain the stock is estimated to be 25,000 to 30,000 feet. This thickness includes all layered rocks of the region (through the Potem formation of Early and Middle Jurassic age) that predate the stock's emplacement. The depth of emplacement was almost certainly less than 6 miles and probably much less.

The stock seems to have most of the features of a pluton of the epizone, as defined by Buddington (1959, p. 677–680), notably the contacts, which are highly discordant in detail, the absence of internal foliation or lineation except very locally, the abundance of large inclusions and roof pendants, the small amount of metamorphism clearly associated with the stock, the absence of pegmatites, and the scarcity of aplite dikes. On the other hand, the absence of chilled borders and the probability that granitization was an important mechanism of the emplacement are more characteristic of zones deeper than the epizone.

AGE

The Mule Mountain stock cuts the Copley and Balaklala formations and is in turn cut by satellites of the Shasta Bally batholith of Late Jurassic or possibly Early Cretaceous age. On the basis of direct evidence, the age of the stock cannot be closely determined. However, granitic rocks correlated with the stock on the basis of similar lithology intrude the Baird formation of Mississippian age in the East Shasta copper-zinc district (Albers and Robertson, 1961) and, according to Diller (1906, geologic map), similar rocks also intrude the Bully Hill rhyolite of Triassic age in the eastern part of the Redding 30-minute quadrangle. If the lithologic correlation is valid, the Mule Mountain stock is at least as young as Triassic. Moreover, the markedly crosscutting relationship of the stock to folded schistose Copley greenstone and Balaklala rhyolite in many places shows that the stock was probably emplaced after the main folding had occurred, and the Potem formation of Middle Jurassic (Bajocian) age according to A. F. Sanborn [2], is the youngest formation in this area affected by the folding. It is inferred that the stock was emplaced after Middle Jurassic time.

The age of the Shasta Bally batholith, apopheses of which cut the Mule Mountain stock, is probably very Late Jurassic. The Mule Mountain stock is apparently only slightly older.

[2] Sanborn, Albert, 1952, The geology of the Big Bend area, Shasta County, California: Stanford Univ. Ph. D. thesis; microfilm available at Michigan Univ., Ann Arbor, Mich.

PERIDOTITE

In the southwestern part of the quadrangle are two elongate tabular masses of greenish-black slightly serpentinized periodotite that strike northwest parallel to the enclosing schist and gneiss. The larger, on the north side of Jerusalem Creek, has an outcrop width of about a third of a mile within the quadrangle and widens to nearly a mile in Bully Choop Mountain west of the quadrangle boundary. It encloses a body of gneiss about 100 feet wide and a mile long. The smaller peridotite mass southwest of Jerusalem Creek is only about 100 feet wide.

Both peridotite masses dip steeply and appear to lie in the foliation of the schists and gneisses. The larger mass dips steeply northeast; the smaller mass dips southwest near the crest of a schistosity anticline in Jerusalem Creek. Much of the peridotite is crudely banded, and locally, near the contact, the banding parallels the foliation of enclosing rocks. A petrographic description of typical peridotite is given in table 1.

SHASTA BALLY BATHOLITH

LOCATION AND GENERAL CHARACTER

Most of the southwestern part of the French Gulch quadrangle is underlain by a batholith composed of light-colored quartz diorite and granodiorite. The batholith underlies Shasta Bally, the most prominent mountain in the French Gulch quadrangle, and was named the Shasta Bally batholith by Hinds (1933, p. 105). The batholith is markedly elongate, trends about N. 45° W., and extends in both directions beyond the quadrangle boundaries (fig. 5). According to Hinds (1933, p. 105), its exposed length is 30 miles. Its maximum width within the quadrangle is about 9 miles. A short distance south of the quadrangle, the batholith is overlain nonconformably by rocks of Early Cretaceous age; hence its maximum southward extent is unknown.

At least six satellites, ranging from a few acres to a little more than a square mile in area of exposure and correlated with the batholith on the basis of lithology, crop out in the southeastern part of the quadrangle. The largest of these is the Clear Creek plug.

The batholith is concordant with foliation in the gneissic wallrocks along its northeast side, but along the southwest side it is slightly discordant and is bounded by a zone of injected rock and breccia. The satellites are mostly discordant. The grain size of the plutonic rock in the borders of some satellites is locally slightly finer than in the interior parts, but chilled contacts are in general rare; none were seen along the borders of the main batholith.

The rocks that border that Clear Creek plug and the northeast side of the batholith are mostly fine-grained amphibolite and banded gneiss derived by contact metamorphism from Copley greenstone, Balaklala rhyolite, and Bragdon formation. Contacts between the batholith and gneiss are everywhere very sharp. Foliation banding in the wallrocks dips northeast at angles ranging from 40° to 75°. Broadly, it is concordant with the contact and also parallel to flow banding within the batholith; however, over widths of a few inches, the intrusive contact cuts across the foliation in at least one place in a roadcut in Crystal Creek.

Along its southwest side, the batholith is bounded by a belt of dikes, sills, and coarse breccia a few hundred feet wide. This breccia consists mostly of blocks of gneiss, schist, and peridotite. The matrix is equigranular coarse-grained diorite. The batholith for a few hundred feet inward from its southwest margin has a weakly defined flow banding that dips northeast at angles of 70° to 80°. The overall topographic expression of the batholith and its local contact relations indicate that its western contact also dips very steeply northeast or vertically. Foliation in the gneissic rocks that lie just west of the belt of dikes and breccia dips northeastward toward the batholith at angles of only 50° to 80°; the batholith is evidently locally discordant with the wallrocks along its southwest side. From observation on the dip of the contacts and the attitudes of flow banding, it is inferred that the batholith (1) has the form of a northwest-trending east-dipping arch whose southwest limb is steep and discordant and whose northeast limb is less steep and concordant, and (2) widens gradually with depth (pl. 1, cross section; fig. 4).

The batholith, like the Mule Mountain stock, is commonly deeply weathered, except in the bottom of canyons and on the main ridges. On most secondary ridges and hillslopes the rock weathers to grus.

LITHOLOGY AND PETROGRAPHY

Although the Shasta Bally batholith is in general a fairly homogeneous mass, three facies were distinguished in the field—a coarse biotite facies, a fine biotite facies, and a biotite-hornblende facies. The coarse biotite facies, which has an average grain size of 2 mm and typically shows planar structure, forms a belt ranging from ½ mile to 4 miles wide in the northeastern part of the batholith (pl. 1); the fine biotite facies has an average grain size of slightly less than 1 mm and forms small masses as much as three-fourths of a mile wide and 3 miles long in the central part; and the biotite-hornblende facies, which also has a grain size of about 2 mm, makes up approximately the western two-thirds of the intrusive mass. The contact between the coarse biotite facies and the biotite-hornblende facies is gradational over a wide area, but the limits of the fine biotite facies are rather sharply defined.

The most biotite-rich and darkest-colored facies is along the northeast border of the batholith, and the percentage of biotite decreases from 20 to 5 percent within a few thousand feet inward from the border. Thin sections show that hornblende is present in very minor amounts in the biotite facies, although it is rarely noticeable in hand specimen. Planar structure, defined by preferred orientation of biotite plates parallel to the contact of the intrusive mass, is present throughout the coarse biotite facies but is most conspicuous near the border. In addition to the preferred orientation of minerals, thin sections reveal the following local relict cataclastic structures: Plagioclase crystals and twin lamellae are bent; biotite books are locally bent and some have ragged ends as though they had been pulled apart; quartz is more or less segregated in discrete layers, and it consists of mosaics of small sutured crystals in contrast to the large, optically continuous crystals that are typical of rock elsewhere in the batholith, where little or no planar structure is present.

The coarse-biotite facies, by an increase in the amount of hornblende, grades over a distance of a few hundred feet into the biotite-hornblende facies, which forms the bulk of the western part of the batholith. This facies contains 10 to 15 percent mafic minerals. Hornblende is generally more abundant than biotite, and locally it is the only mafic mineral. Planar structure, shown by preferred orientation of the mafic minerals, is absent or only weakly defined in the biotite-hornblende facies, and its attitude could be determined only in blocky outcrops of fresh rock.

The fine-grained biotite facies is lighter-colored than the two coarse-grained facies. It forms rather small discrete masses (pl. 1) enclosed in one or the other of the coarse-grained types. The precise contact between the fine-grained facies and surrounding coarse-grained rock was seen at only one place, on the south slope of Little Bally at an altitude of 4,300 feet. Here the contact is sharp; the fine-grained facies either cuts or replaces the coarse biotite-hornblende facies, and schlieren of the coarse facies are enclosed in the fine-grained facies. Elsewhere, although no exposed contacts were seen, it appears from the distribution of float that the contacts are either sharp or gradational over only a small distance.

The composition of the batholith ranges from quartz diorite to granodiorite. As shown in table 1, plagioclase, quartz, and orthoclase, along with biotite and hornblende are the chief minerals. The orthoclase, which is everywhere in irregular, optically continuous crystals as much as 5 mm in diameter, is interstitial to other minerals; it ranges from less than 1 to about 10 percent and averages about 5 percent. The rocks are near the dividing line between quartz diorite and granodiorite. Figure 3 is a diagram of 17 specimens from the Shasta Bally batholith showing the modal variation of essential minerals. Table 2 gives analyses and norms of four samples from the Shasta Bally batholith.

Unlike the Mule Mountain stock, which is extensively albitized and silicified, the Shasta Bally batholith is little affected by hydrothermal alternation. The only exceptions are in border facies where a few miscroscopic veinlets of albite have formed in plagioclase and where fine-grained white mica is a minor alteration product on some plagioclase crystals.

Hornblende diorite containing as much as 40 percent hornblende and less than 5 percent quartz is common near the borders of the batholith and in satellite bodies in the southeastern part of the quadrangle. Coarse-grained hornblende gabbro forms small dikes and irregular bodies in the roof and near the margin of the Clear Creek plug. Much of the hornblende diorite and gabbro was evidently derived from the Copley greenstone by metamorphic processes, which are explained in detail by Kinkel and others (1956, p. 71).

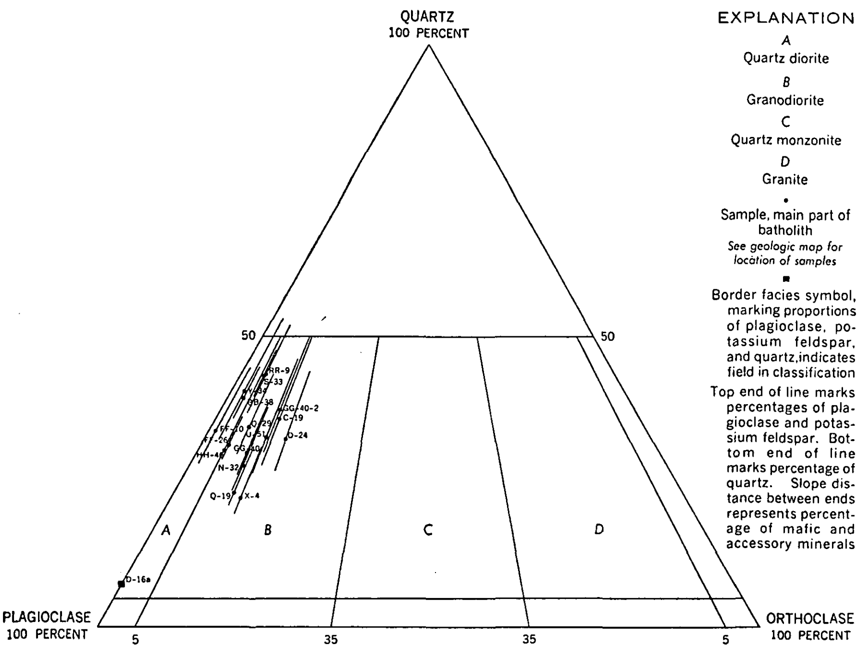

FIGURE 3.—Diagram showing intrusive rocks of the Shasta Bally batholith according to proportions of essential minerals. Diagram modified after Johannsen (1939, p. 152).

TABLE 2.—*Analyses, in percent, of samples from the Shasta Bally batholith*

[Samples L-5, D-24, BB-38, by U.S. Geological Survey rapid-analysis method (see Shapiro and Brannock, 1956) analysts, Paul L. D. Elmore and Katrine E. White. Sample A analyzed by T. M. Chatard (Clark and Hillebrand, 1897). See plate 1 for sample locations]

Laboratory No.	150014	150014	150017	
Field No.	L-5	D-24	BB-38	A
Chemical constituents				
SiO_2	64.5	68.0	70.4	68.10
Al_2O_3	16.3	16.0	15.9	15.18
Fe_2O_3	1.6	1.5	.9	1.34
FeO	2.5	1.5	1.4	1.70
MgO	2.9	2.0	1.3	2.06
CaO	4.1	4.1	3.2	4.66
Na_2O	4.0	3.8	4.0	3.71
K_2O	2.0	2.2	2.5	1.48
TiO_2	.48	.33	.28	.35
P_2O_5	.10	.09	.07	.18
MnO	.06	.04	.04	.20
BaO	----------	----------	----------	.06
H_2O	1.6	.56	.56	.55
CO_2	$<.05$	$<.05$	$<.05$	.0
Total	100	100	101	99.57
Norms [Computed by the CIPW system]				
Quartz	19.6	25.9	31.2	27.54
Orthoclase	11.0	12.8	15.0	8.90
Albite	34.1	32.0	29.9	31.44
Anorthite	19.5	18.9	15.0	20.29
Corundum	.4	.3	1.0	.0
Ilmenite	.9	.6	.6	.91
Magnetite	2.3	2.1	1.4	1.86
Apatite	.3	.3	.3	.34
Hypersthene	9.8	6.1	4.4	6.18
Diopside	.0	.0	.0	1.84
Total	97.9	99.0	98.8	99.30

L-5. Biotite hornblende quartz diorite from Moon Fork, Cottonwood Creek.
D-24. Biotite hornblende quartz diorite from Paradise Peak.
BB-38. Hornblende quartz diorite from top of Shasta Bally.
A. Analysis of Shasta Bally batholith from near Ono.

SEGREGATIONS AND INCLUSIONS

Small bodies of hornblende-rich and biotite-rich mafic material measuring a few inches to 1 to 2 feet in maximum dimension are scattered throughout the coarse-grained biotite facies and biotite-hornblende facies of the Shasta Bally batholith. None of these bodies of mafic material were seen in the fine-grained biotite facies.

Most of these small bodies are spheroidal or ellipsoidal in shape. Those in the coarse biotite facies of the batholith are commonly rich in biotite, whereas those in the biotite-hornblende facies are typically rich in hornblende, though they also contain some biotite. Thin sections show that the bodies of the mafic material have a texture similar to that of the enclosing host rock and differ only in having a higher mafic mineral content. Most of the bodies probably represent segregations formed during consolidation of the magma, but some may be reworked inclusions of rocks intruded by the batholith.

A few of the bodies of mafic material are spindle shaped, pancake shaped, tabular, or angular and are as much as 3 feet in maximum dimension. These inequidimensional types are commonly oriented parallel to planar or linear elements in the host rock and are gradational into the host. Some tabular bodies show a layering defined by alternating bands of dark- and light-colored minerals. As with the spheroidal and ellipsoidal bodies, the inequidimensional bodies in the coarse biotite facies of the batholith are rich in biotite, and those in the biotite-hornblende facies are rich in hornblende. The texture of some, but not all, of the bodies is similar to the texture of the enclosing rock. The bulk of the hornblende-rich inequidimensional bodies are mineralogically similar to the hornblende-diorite and hornblende-gabbro facies of the batholith that Kinkel and others (1956, p. 71) have shown to be derived probably from Copley greenstone.

In addition to the hornblende- and biotite-rich inclusions, one inclusion of gneissic amphibolite and a few inclusions of peridotite were seen on Paradise Peak near the west margin of the batholith. The peridotite inclusions indicate that at least some peridotite is older than the batholith, and in view of the proximity of the inclusions to the belt of peridotite in the southwestern part of he quadrangle, it seems reasonable to assume that they were derived from it. The peridotite is, therefore, believed to be older than the batholith.

GNEISS IN THE AUREOLE OF THE BATHOLITH

A nearly continuous belt of slightly injected gneissic rock as much as a mile wide lies adjacent to the Shasta Bally batholith on its northeast side for a distance of almost 20 miles in the French Gulch quadrangle (pl. 1). A belt of similar gneiss, a mile or more wide and separated from the batholith by a zone of dikes and breccia, crops out parallel to the batholith in the southwestern part of the quadrangle. The Clear Creek plug is also partly surrounded by gneiss. Its spatial relationship to the intrusive masses, as well as its fairly systematic variation in composition, shows that most of the gneiss was derived by contact metamorphism of the intruded rocks. A small percentage, probably less than 5 percent, is injected material.

In outcrop, the gneiss is characterized chiefly by its fineness of grain (mostly 0.2 to 1.0 mm) and by its uncrumpled foliation banding.

These two features, coupled with distribution, distinguish the gneiss in the contact aureole of the batholith from the generally much coarser grained, folded, and plicated schist of the Abrams and Salmon (?) formations in the extreme southwestern part of the quadrangle.

That the composition of the gneiss differs considerably from place to place, reflects mainly its derivation from different rock units and also, in part, minor changes during metamorphism. Along the northeast side of the batholith, about as far north as Brandy Creek, the gneiss consists mostly of amphibolite and hornblende gneiss formed from the Copley greenstone. These rocks are in sharp contact with the intrusive, and they grade outward into epidote amphibolite, which in turn grades into green chloritic and actionolitic schist, and finally into greenstone. The epidote amphibolite, green schist, and greenstone do not have a well-defined metamorphic banding and are not included with the gneissic rocks on the geologic map (pl. 1). A detailed description of the mineralogical and textural changes involved in the metamorphism of Copley greenstone to amphibolite and hornblende gneiss in the aureole of the batholith is given by Kinkel and others (1956, p. 68–74).

From the vicinity of Brandy Creek northwestward to the quadrangle boundary, gneissic rocks derived from units other than Copley greenstone are included in the contact aureole. Just west of Brandy Creek, the southern part of a satellite of the Mule Mountain stock is changed to a well-foliated light-colored hornblende gneiss having an average grain size of 1 to 2 mm. Farther northwest, between Boulder Creek and Trail Gulch west of U.S. Highway 299W, much, though by no means all, of the gneiss is very siliceous and light-colored, and contains only very minor amounts of dark minerals. In places, it grades into and was apparently derived from Balaklala rhyolite. Other gneissic rocks in this segment of the belt are rich in hornblende and doubtlessly represent metamorphosed facies of the greenstone interlayered with the Balaklala.

In the extreme western part of the map, near Hoadley Peaks, the aureole consists of mainly dark fine-grained muscovite-biotite gneiss. The map pattern (pl. 1) indicates that this mica gneiss was probably derived mostly from shaly rocks of the Bragdon formation and represents a higher grade of metamorphism than the phyllite described in the succeeding section.

On the southwest side of the batholith, most of the rock in the gneiss zone is amphibolite, hornblende gneiss, and quartz-plagioclase gneiss. The proximity and gradational contact of these gneissic rocks to the coarse-grained Abrams and Salmon (?) schists in the southwest corner of the quadrangle suggest that the gneisses were derived at least in part by contact metamorphism of the coarse schist. However, they may also have been derived in part from the Copley greenstone and Balaklala rhyolite.

The petrography of the principal varieties of gneiss in the contact aureole is summarized in table 1. A characteristic feature of the gneiss that was mentioned previously, but which deserves further comment, is its uncrumpled foliation banding. In small- or medium-sized outcrops a few feet long, this banding appears as a very uniform alternation of different colored layers ranging from a few millimeters to a few inches thick and gives the impression that each discrete layer probably maintains a uniform thickness indefinitely along strike. However, a few critical exposures in canyons in the Branch Creek area and also in Dry Fork show that many layers lens out within 20 to 40 feet along strike. Thus, in gross aspect, the gneiss has a streaked appearance, characteristic of mylonitic foliation. This, together with the local presence of augen and the ubiquitous crystalloblastic and locally relict cataclastic textures, suggests that the gneiss is in part a recrystallized mylonite; that is, a mylonite gneiss as defined by Quensel (*in* Waters and Campbell, 1935, p. 478).

PHYLLITE IN THE AUREOLE OF THE BATHOLITH

A belt of phyllite having a maximum outcrop width of nearly a mile extends from Crystal Creek northwestward almost to the edge of the quadrangle. This phyllite is in the aureole of the Shasta Bally batholith and its composition, relict structures, distribution, and gradational relationship to the Bragdon formation show that it was derived from the Bragdon. It has a silky sheen caused by abundant fine-grained white mica parallel to cleavage. It also has a knotty appearance resulting from irregularly distributed small spherical or elliptical bodies about 1 mm in diameter. Thin sections reveal that these small bodies or knots consist mostly of carbonaceous material and quartz and that they probably represent discrete fragments of unsheared parent rock in a sheared recrystallized matrix consisting mostly of fine-grained white mica having a conspicuous crystallographic orientation. A few fragments are almost connected to neighboring ones by small trains of carbonaceous material in a way that suggests that they may have been rotated during shearing. Schistosity bends around the knots, and the mica in pressure shadows along the schistosity plane adjacent to the knots is more coarsely crystalline than elsewhere.

The phyllite was derived mainly from the lower unit of the Bragdon, but a small segment of conglomerate, correlated with the upper unit in the upper part of Trail Gulch, also occurs in this zone of metamorphism. Fragments in the sheared conglomerate have a common orientation and are roughly ellipsoidal, their elongation ratio ranges from 4 or 5 to 1.

Generally, bedding is not discernible in the phyllite. However, in a few places, relict bedding in the phyllitic rock parallels the schistosity or cleavage, and in other places the schistosity cuts the bedding at a high angle.

ZONE OF INJECTED ROCK AND BRECCIA ALONG SOUTHWEST SIDE OF BATHOLITH

Bounding the Shasta Bally batholith on its southwest side is a belt of gneissic rock that is cut by innumerable intersecting dikes and sills of hornblende diorite and quartz diorite ranging from a few inches to a few feet thick. Although many of the dikes have unmatched walls and are at least in part of replacement origin, they clearly followed a complex set of fractures in the gneiss. Likewise, the sills followed foliation planes. In places the dikes and sills are so numerous that the country rock remains only as isolated fragments ranging from a few inches to a few feet across, and in outcrop they resemble fragments of a breccia.

The zone of injected rock ranges from about 100 to 1,000 feet wide. The lithologies comprising it differ from place to place, depending on the character of the country rock. West of Rainbow Lake, near the south edge of the map area, the rocks have the character of a breccia and consist of coarse-grained rocks rich in hornblende crystals that range from a few millimeters to several inches in maximum dimension. On the south side of Paradise Peak, a breccialike rock that includes disoriented blocks of Abrams(?) mica schist as well as gneiss is cut by replacement dikes of coarse-grained hornblende diorite that is much less hornblendic than that near Rainbow Lake. Specimen 16a, plotted on figure 3, gives the composition of a typical specimen of this hornblende diorite. North of Paradise Peak, on the road to Bully Choop Mountain, quartz porphyry tuff(?), and recrystallized greenstone(?) are cut by dikes of fairly light colored hornblende-quartz diorite.

The injected zone along the southwest edge of the batholith is also exposed west of the quadrangle boundary in roadcuts on Highway 299W and on the main road to Lewiston in the Weaverville quadrangle. The zone seems to be a feature that continues for many miles and possibly along the entire southwest edge of the batholith.

MODE OF EMPLACEMENT OF THE BATHOLITH

The Shasta Bally batholith is inferred to have been emplaced mainly by forcible injection and to some extent by piecemeal stoping. Granitization seems to have played only a minor role.

The batholith is in the main a concordant intrusive along its entire northeast margin where the contact dips parallel to the adjoining gneissic rocks, some of which are mylonitic. Along the southwest margin, marked by the zone of dikes and breccia, the batholith is discordant; its boundary dips northeastward at an angle of 80° to 90°, and the gneiss dips in the same direction but at a lower angle (fig. 4). This difference in the character of the northeast and southwest borders of the batholith suggests that stresses and modes of emplacement were slightly different. The banding in the gneiss along the northeast side of the batholith was probably formed by stresses created in the wallrocks at the time of intrusion.

These stresses are attributed to the upward push of magma, rather than to orogenic forces, because of the marked general concordance of the igneous contact to flow banding in the batholith and to gneissic banding in the wallrocks, and because of the restriction of the gneissic zone to the margins of the intrusive mass.

Some corroboration of this mechanism is furnished by the areal variation in the intensity of flow banding; it should be, and is, most conspicuous in marginal parts, where shearing was most intense, and progressively less conspicuous toward the interior.

Balk 1937, p. 122) states that:

Dome and arch structures of primary flowage elements are due to an upward current of magma, dragging and lengthening all suspensions in a viscous mush. The motion was strongest in the central apical section and was retarded along the relatively stationary walls.

In the Shasta Bally batholith, particularly in the northeastern part, flow banding is markedly parallel to and most pronounced near the walls. To the writer, this fact suggests that the magma moved upward by lamellar flow, and that aided by heat and pressure, it partially mobilized the wallrocks along the northeast edge of the batholith and imparted to them a gneissic foliation parallel to the direction of laminar flow and to the intrusive contact.

The gneiss on the southwest side of the batholith generally does not have such prominent gneissic banding, contains no mylonite, and is of somewhat different character than that on the northeast side. It also dips discordantly into the batholith at a lower angle than the contact of the batholith itself and is highly injected by dikes and sills and locally brecciated. Flow banding and lineation within the intrusive mass is less strongly formed than that in the opposite or northeastern part. These features suggest that the southwest side of the batholith may have moved upward somewhat more passively than the northeast side, and that the gneissic rock on the southwest side may have formed more by simple static recrystallization of schistose coun-

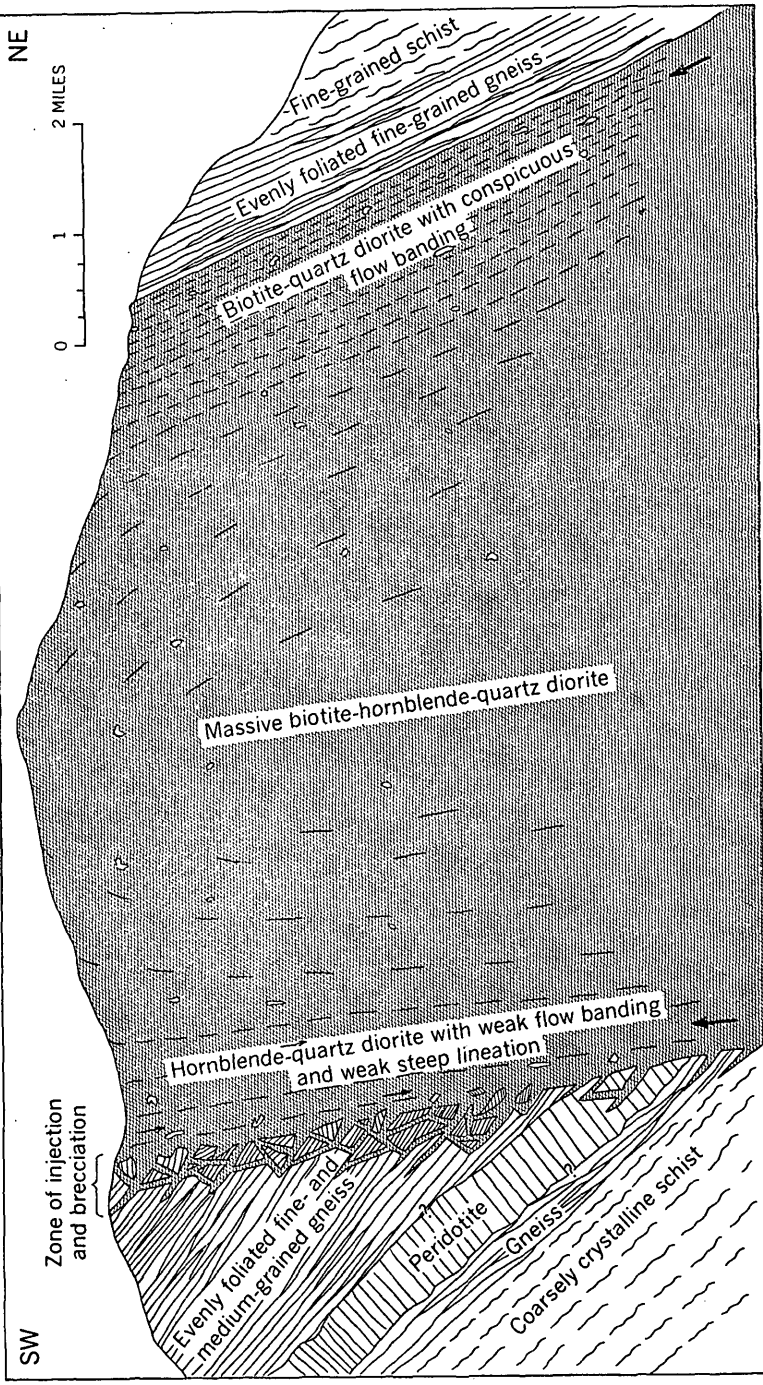

FIGURE 4.—Diagrammatic section across Shasta Bally batholith showing internal structure and structural relation to wallrocks. Light arrow shows plunge of lineation indicated by hornblende crystals. Heavy arrows indicate assumed direction of magma movement. Inclusions and segregations are present throughout the batholith but are somewhat more abundant in the border zones.

try rocks than by recrystallization accompanied by shearing and mylonitization. The dikes, sills, and breccia formed mostly at a later stage than the gneissic banding and probably as a result of an upward surge or surges of the magma body. This surge apparently dilated the gneiss by opening it up along foliation planes and fracturing it across foliation; the fracturing in turn allows penetration of the magma to form the sills, dikes, and breccia (fig. 4).

This mechanism implies that stoping may have been an active process along the southwest side of the batholith, but, except for the zone of dikes, sills, and breccia at the very edge of the intrusive mass, neither inclusions nor segregations of country rock seem to be any more abundant in the southwestern part than in the northeastern part. By the time the stoped blocks had been incorporated in the batholith and transported away from the walls, they may have been completely assimilated, and only sparse small remnants of the blocks may now remain. Of interest in this connection are the few small inclusions of peridotite seen near the southwest border; these show that some stoping definitely did occur. That these inclusions, unlike most others, are virtually unaltered shows their mineralogical stability in the magma.

Evidence of granitization is almost entirely lacking, except in the injected zone along the southwest border where replacement dikes occur. The importance of granitization, like that of piecemeal stoping, is difficult to evaluate, but it is inferred to have been minor.

Although the batholith is represented by three slightly different facies, it probably was emplaced as two intrusions. The contact between the two main facies is everywhere highly gradational; a separate intrusion for each facies should have produced more sharply defined contacts. The relatively small differences in composition and in texture of the two facies may actually be due to differences in the amount of material assimilated rather than to differences in composition of the primary magma. The fine-grained biotite-quartz diorite and granodiorite facies have fairly sharp contacts with the other facies and may be a separate and slightly later phase of the plutonic activity.

The strata overlying the Shasta Bally batholith is estimated to have been not more than 30,000 to 35,000 feet thick at the time of intrusion and may have been much less, depending on how much erosion of the section had taken place. This thickness is only about 5,000 feet more than the estimated maximum cover over the Mule Mountain stock and is the same as the thickness of the belt of eastward-dipping Copley greenstone, for it occurs between the stock and the batholith in the southeastern part of the quadrangle.

The batholith has virtually all the features characteristic of plutons of the mesozone as defined by Buddington (1959, p. 695–697). It is of a composite character, the youngest phase being the most alkalic and siliceous; has complex relationships to the intruded country rock; has locally well developed planar structure in the outer parts, but is massive in the interior; has a probable archlike shape, as suggested by flow banding; has a contact metamorphic aureole of gneissic wall-rock with foliation parallel to the contact; has abundant aplite dikes; and lacks chilled borders. The batholith differs from Buddington's mesozone plutons in that the grade of metamorphism reached in the contact aureole is the amphibolite rather than the lower-grade epidote-amphibolite facies.

It therefore seems likely that within about a mile of each other in the French Gulch quadrangle are two plutons of approximately the same age but of different origins: the Mule Mountain stock, which in many respects is typical of the epizone group of Buddington (1959), and the Shasta Bally batholith, which is typical of the mesozone. Whether the marked contrast between the two results merely from the possible mile or so of difference in depth of intrusion, or whether the structural environment or some other factor was responsible for the contrast cannot be ascertained from data presently available.

AGE

Apophyses of the Shasta Bally batholith cut the Mule Mountain stock, and a small stock lithologically correlative with the Mule Mountain is in the aureole of the batholith between Brandy and Boulder Creeks (pl. 1) and has undergone contact metamorphism. For reasons stated on page J36, the Mule Mountain stock is inferred to be younger than the Potem formation, which is of Middle Jurassic (Bajocian) age (A. F. Sanborn, 1952[8]). The batholith is in turn overlain nonconformably by Cretaceous sedimentary rocks that are of late Early Cretaceous (Hauterivian) age (Murphy, 1956, p. 2098). The batholith is thus probably post-Bajocian and certainly pre-Hauterivian age; if allowance is made for time required by erosion to unroof the batholith, a Late Jurassic rather than Early Cretaceous age for both plutons seems likely.

Curtis and others (1958, p. 5) made a potassium-argon age determination on the Shasta Bally batholith of 134 million years; this age puts the intrusion at the end of the Jurassic and in good agreement with geologic data. An age determination of 97 million years by the lead-alpha method is reported in Kinkel and others (1956, p. 50), and ages of 81 and 101 million years by the same method are reported by

[8] Sanborn, Albert, 1952, The geology of the Big Bend area, Shasta County, California: Stanford Univ. Ph. D. thesis; microfilm available at Michigan Univ., Ann Arbor, Mich.

Jaffe and others (1959). These three dates are all incompatible with geologic evidence.

MINOR INTRUSIVE BODIES

The plutonic and older rocks of the quadrangle are cut by dikes and sills consisting of metagabbro, lamprophyre, aplite, diorite porphyry, dacite porphyry, andesite porphyry, and quartz porphyry. In table 1, the occurrence and petrography of these rocks is summarized.

METAGABBRO

A few small generally tabular bodies of highly altered mafic rock that intrude the Copley greenstone, Balaklala rhyolite, and Kennett(?) formation in the central and northeastern part of the quadrangle are classified as metagabbro. Kinkel and others (1956, p. 15), considered this rock to be preorogenic and probably an intrusive facies of the Copley greenstone. However, roadcuts made on Sugarloaf Mountain after the field work of Kinkel and others was completed have revealed the presence of rocks of similar character along faults in the Balaklala rhyolite; this relation indicates that the metagabbro is postorogenic or at least very late orogenic, that is, Late Jurassic.

HORNBLENDE DIORITE PORPHYRY

A few hornblende diorite porphyry dikes, as much as 75 feet thick, intrude the Shasta Bally batholith near its west boundary in the vicinity of Paradise Peak. Practically all these dikes are along cross joints. The rock is characterized by markedly euhedral hornblende phenocrysts and abundant tiny plagioclase phenocrysts in a holocrystalline sugary groundmass. Some specimens have extremely corroded quartz phenocrysts or possibly xenocrysts.

ANDESITE PORPHYRY

Dikes of andesite porphyry as much as 50 feet thick and 1,000 feet long intrude the Copley greenstone and Balaklala rhyolite in the vicinity of Bull Gulch and Grizzly Gulch. Only two of these intrusions are large enough to show on the quadrangle map. They are dark greenish-gray rocks that contain hornblende phenocrysts as much as 6 mm long and plagioclase phenocrysts as much as 2 mm long in an aphanitic groundmass.

LAMPROPHYRE

A few very fine grained hard dark-gray to black lamprophyre dikes as much as 50 feet thick intrude the Copley greenstone, Balaklala rhyolite, and Mule Mountain stock. Thin sections show that they are much altered, although they appear fresh in hand specimen. Principal minerals are plagioclase (andesine and albite), biotite, chlorite, epidote, and a carbonate mineral. These dikes are most common in the Mule Mountain stock on Mule Mountain, but only a few are large enough to show on the geologic map (pl. 1). The lamprophyre dikes cut dikes of diorite and dacite porphyry in the Copley greenstone.

APLITE

Aplite dikes, a few inches to a few feet thick, are common in the Shasta Bally batholith and locally in adjoining country rocks. All the aplite dikes seen are tabular bodies along joints. In the inner part of the batholith, isolated individual dikes are common, but along the margins of the batholith they locally occur in swarms in cross joints at a high angle to the intrusive contact. One such swarm is well exposed west of the Greenhorn mine along U.S. Highway 299W.

QUARTZ PORPHYRY

Dikes and sills of light-gray to white quartz porphyry, commonly containing what appear in hand specimen to be biotite crystals, intrude the Bragdon and Copley formations in the northwestern part of the quadrangle. Dikes of similar rock intrude the Mule Mountain stock and the Copley greenstone south of Mule Mountain. The largest masses of this porphyry are sill-like bodies a few tens of feet thick and as much as a mile long, intruded mainly along the contact between the Bragdon and Copley formations in the Franklin and Milkmaid mines area in French Gulch. Ferguson (1914, p. 31) called this rock "soda granite porphyry" in his description of the gold lodes of the Weaverville quadrangle. I believe that quartz porphyry is a more descriptive name and one that bears no genetic connotation.

In its texture and mineralogy, this quartz porphyry is very similar to the quartz porphyry of the Balaklala rhyolite. Quartz and albite are the dominant minerals; they form phenocrysts and are the principal constituents of the microcrystalline groundmass. The main difference between this porphyry and the Balaklala rhyolite is the common, though not ubiquitous, presence of what seem to be biotite phenocrysts in the quartz porphyry dikes. Thin sections show that those "biotite" phenocrysts are virtually everywhere pseudomorphously altered to secondary minerals, including fine-grained white mica, calcite, epidote, sphene, leucoxene, and magnetite.

"BIRDSEYE" PORPHYRY

The most common dike rocks in the French Gulch quadrangle are light-gray porphyries containing abundant plagioclase, hornblende, and biotite phenocrysts and, locally, quartz phenocrysts, in a sugary to aphanitic groundmass. These porphyries are most abundant as dikes and sills in the Bragdon formation, particularly in the lower part of the Bragdon near the gold deposits (pl. 1). In detail, many of the intrusive bodies are very irregular in shape, although in gross aspect they are tabular. Local gold miners have applied the name "birdseye" porphyry to these dike rocks (Ferguson, 1914, p. 31), probably because the centers of the zoned feldspar phenocrysts commonly weather out and leave a depression that somewhat resembles the pupil of an eye.

From the standpoint of composition, virtually every gradation was seen from nonquartzose diorite porphyry, through porphyry containing sparse rounded to lobate phenocrysts of quartz, to dacite porphyry or quartz diorite porphyry that contains abundant quartz phenocrysts. The proportion of other mineral components remains about the same regardless of the quartz content. Phenocrysts as much as 1 cm in maximum dimension are in a groundmass that ranges from sugary to aphanitic. The feldspar phenocrysts are intermediate plagioclase and commonly show normal oscillatory zoning. In places they are cut by a network of albite veinlets, and locally they are completely albitized.

In Mill Gulch, in the northwestern part of the quadrangle, a dike of coarse-grained biotite-hornblende-quartz diorite having a hypidiomorphic granular texture intrudes the Bragdon formation. This dike is virtually identical in texture and composition to the biotite-horneblende facies of the Shasta Bally batholith, and it is very probably an offshoot of the batholith. The mineralogic similarity between other dikes of diorite porphyry, dacite porphyry, and quartz diorite porphyry to this coarse-grained dike and to the batholith suggests a genetic relationship despite textural differences.

The "birdseye" porphyries occur along faults, joints, and bedding planes. They are cut by younger faults and by lamprophyre dikes and quartz veins. In places in the French Gulch mining district, they are intruded along the same structure as the quartz porphyry dikes described in the previous section. The relative age of the "birdseye" porphyries and quartz porphyry could not be established on the basis of crosscutting relationships, but the quartz porphyry seems to be more extensively altered and therefore older; calcic plagioclase crystals in the "birdseye" porphyries are in various stages of albitization, but in the quartz porphyry their alteration to albite is apparently complete.

HORNBLENDITE

A few coarse-grained hornblendite dikes cut the gneissic rock along the northeast side of the Shasta Bally batholith between Brandy and Boulder Creeks. These dikes are as much as 200 feet thick and parallel the foliation of the enclosing rocks. The principal minerals are horneblende and plagioclase, the proportion of hornblende ranging from 50 to 90 percent (see table 1).

CRETACEOUS ROCKS

The oldest postorogenic sedimentary rocks in the French Gulch quadrangle are the well-cemented sandstone and conglomerate of Cretaceous age that crop out in a small area about a mile north of the southeast corner (pl. 1). Kinkel and others (1956, p. 41) mapped these rocks as Chico formation of Late Cretaceous age, following Diller (1906, geologic map), who mapped rocks of similar lithology as Chico in a contiguous area. However, more recent work (Peter Rodda, University of California at Los Angeles, written communication, 1957) indicates that this conglomerate and sandstone belongs to Murphy's (1956) Ono formation of Early Cretaceous age. Rodda states that:

> While the basal conglomerates of this section [in the French Gulch quadrangle] have as yet yielded no fossils, graywackes about 300 feet stratigraphically above these conglomerates [half a mile south of the French Gulch map] have yielded good Lower Cretaceous fossils. These fossils are representatives of Murphy's [1956] *Beaudanticeras hulense* zone in the upper part of his Ono formation on Huling Creek in the Ono quadrangle.

RED BLUFF FORMATION

Coarse, poorly to well-cemented gravel lithologically similar to the Red Bluff formation (Diller, 1906, p. 6) of Pleistocene age crop out in the extreme southeastern part of the quadrangle and at two localities along Clear Creek between Tower House and French Gulch (pl. 1). The gravel consists chiefly of well-rounded boulders and cobbles of various rock types, in an iron-stained matrix of sand and clay. It is very poorly sorted.

This gravel is correlated with the Red Bluff formation on the basis of its lithology. It is distinguished from younger stream gravel mainly by its reddish color and by its position on benches well above the present stream levels.

No fossils have been found in the Red Bluff formation but, according to Anderson and Russell (1939, p. 238–239), the Red Bluff is usually assigned to the Pleistocene.

UNCONSOLIDATED DEPOSITS

Unconsolidated deposits of Recent age include slope wash or colluvium, landslide debris, and stream gravel.

Large parts of almost every mountain slope and hillslope in the area are covered by slope wash, but in most places careful examination of the float and its spatial relation to sparse outcrops permits reasonably consident identification of the bedrock. Therefore, only where slope wash effectively obscures the bedrock and prevents its identification is it shown on the geologic map (pl. 1). The largest areas of slope wash are in the north-central part of the quadrangle on Shirttail Peak, Merry Mountain, and Mad Mule Mountain, and south of Tower House in the Boulder Creek area.

In some places landslides are difficult to distinguish from slope wash, and in fact locally they are contiguous with areas of wash. However, practically all the areas mapped as landslide are on steep hillsides and are topped by a topographic bench that is either flat or slopes inward toward the hill at a very gentle angle.

Unconsolidated alluvial gravel occupies most of the larger stream beds and some smaller ones. The largest area of such gravel is in the upper part of Clear Creek; it extends from near Tower House approximately to the north edge of the quadrangle. This gravel has been dredged for gold, and in Whiskey Creek and other places smaller areas have been sluiced for gold.

ROCK ALTERATION

Nearly all the rocks in the quadrangle have undergone some form of alteration since their consolidation. The Copley, Balaklala, Kennett(?), and Bragdon formations, the Mule Mountain stock and most of the minor intrusive rocks have undergone some metamorphism as well as weathering. The Shasta Bally batholith is deeply weathered in most places but is otherwise virtually unaltered. Rocks of Cretaceous and Quaternary age in the southeastern part of the quadrangle are weathered but otherwise not altered.

The alteration of rocks in places along the borders of the Mule Mountain stock and in the aureole of the Shasta Bally batholith is attributed to igneous metamorphism and has been discussed in previous sections describing the plutons. The alteration of the Mule Mountain stock to albite granite in many places, also described previously, is attributed to late magmatic deuteric and hydrothermal processes.

In most places outside the aureoles of the plutons, the Copley greenstone is composed mainly of albite and chlorite and lesser amounts of epidote, sphene, leucoxene, and calcite. Locally, actinolite rather than chlorite is the chief mafic mineral. Most of the Balaklala rhyolite consists of quartz, albite, and minor amounts of fine-grained white mica and chlorite. There is abundant evidence indicating that the Copley, which is now largely keratophyre, was originally andesitic, and that the Balaklala, now chiefly quartz keratophyre, was originally dacitic and probably rhyolitic (Albers and Robertson, 1961, 45–50; Kinkel and others, 1956, p. 9–32). The alteration of calcic plagioclase to nearly pure albite and a mineral of the epidote group normally involves a reduction in volume, recrystallization of the minerals, and development of metamorphic textures and structures. But in many places throughout the area where Copley and Balaklala rocks are massive or only slightly schistose, their original igneous structures and textures are almost perfectly preserved in spite of the nearly complete mineralogical reconstitution of the rocks. This fact and the absence of cataclastic and crystalloblastic structures show that no change in volume has occurred, that the alteration must therefore have been on a volume for volume basis, and that there must have been an introduction of sodium and perhaps silicon into the rocks, accompanied by the simultaneous removal of calcium and probably aluminum. The mechanism inferred is pervasive hydrothermal alteration affecting principally the feldspars and ferromagnesian minerals in the volcanic rocks. This alteration probably took place, at least in part, after the emplacement of the Mule Mountain stock, for the stock is extensively albitized. Moreover, it is a regional feature affecting rocks over hundreds of square miles and seems to have no spatial relation either to the Mule Mountain stock or to the Shasta Bally batholith. Possibly it is related to a subjacent igneous mass as discussed by Albers and Robertson (1961).

Although most of the alteration of the Copley and Balaklala, as well as minor intrusive bodies, is ascribed to metasomatism, the alteration of rocks that are schistose was certainly effected in part by dynamothermal processes. In schistose rocks extensive recrystallization has taken place, and it was doubtless accompanied by some reduction in volume; in such places, the alteration may have been more nearly isochemical without much addition or removal of substances. Probably dynamothermal metamorphism and metasomatism were simultaneously active, but the importance of each in effecting the alteration of the rocks is difficult to evaluate.

In addition to being extensively albitized, the Balaklala rhyolite is strongly silicified in many places, and is sericitized or altered to fine-grained white mica and other clay minerals locally near massive sulfide deposits. The cherty siliceous character of the Kennett(?) formation may in part result from secondary silicification.

Except in the aureole of the Shasta Bally batholith, where it is converted to phyllite and biotite schist, the Bragdon formation is but slightly altered. Fine-grained white mica along cleavage and bedding and some secondary quartz are the main alteration products.

STRUCTURE

GENERAL FEATURES

The dominant structural feature in the French Gulch quadrangle is the northwest-trending Shasta Bally batholith and its aureole of strongly foliated gneiss. East of the batholithic mass is a wide belt of metavolcanic rocks, including the Copley greenstone and Balaklala rhyolite, that dip generally eastward and define a broad irregular bend around the Mule Mountain stock. This bend, which predates the stock, is also reflected by the orientation of a pendant of Balaklala rhyolite and by the orientation of detached inclusions of the Balaklala and Copley formations within the stock (pl. 1). Overlying the metavolcanic rocks with marked structural discordance is the large mass of Bragdon formation that occupies most of the northern part of the quadrangle; this mass is probably a thrust plate.

Viewed on a broad scale, the quadrangle occupies a critical position where the regional structural trend changes from northwest to north-northeast (fig. 5). The northwest trend, shown by the batholith and nearby rock units, dominates in the southern and western parts of the quadrangle and probably represents the prevailing trend of basement rocks beneath younger rocks in the Central Valley southeastward to the northern Sierra Nevada. A north-northeast trend dominates in the northeastern part of the quadrangle and an extensive area to the north and northeast. It is well shown by the strike of various rock units and by the strike of schistosity northeast of Whiskeytown (see also Kinkel and others, 1956, pl. 1).

As shown by the maps (pl. 1 and fig. 5), the juncture of the two regional trends is not sharply angular, but instead has an arcuate shape concave toward the east-northeast. The axis of this arc has been traced for about 25 miles east-northeast across strike though the East Shasta copper-zinc district (Albers and Robertson, 1961, pl. 1). A map of northwestern California by Irwin and Tatlock (Irwin, 1960b) shows that this arcuate bend becomes broader but still persists southwestward beyond the limits of the French Gulch quadrangle for about 35 miles to South Fork Mountain in central Trinity County. Irwin (1960b, p. 59) has applied the name Klamath arc to this structure. At least four plutonic bodies—the Mule Mountain stock and the Shasta Bally batholith in the French Gulch quadrangle, the Pit River stock northeast of the quadrangle in the East Shasta copper-zinc district, and an unnamed pluton southwest of the Shasta Bally batholith (Irwin, 1960b, geologic map)—are spaced irregularly across the arc. Virtually all the important known base- and precious-metal deposits in the region are also in this segment of the arc (fig. 5).

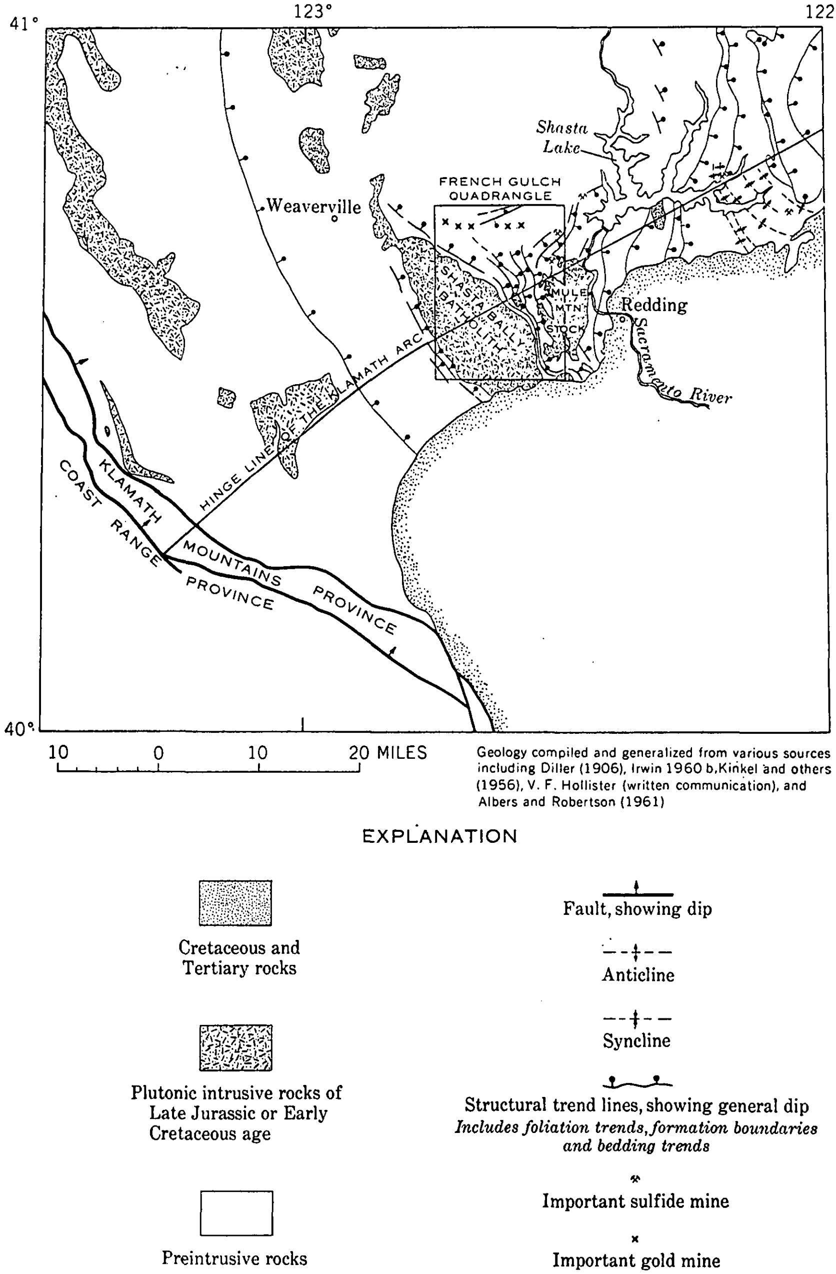

FIGURE 5.—Sketch map showing location of the French Gulch quadrangle, plutonic intrusives, and principal ore deposits in relation to regional structural trends.

Although the Klamath arc is fairly simple when viewed on a regional scale, the structure within the inflection is complex on the scale of a 15-minute quadrangle. Folds of three trends have been recognized, and numerous shear zones of diverse trends are marked by a conspicuous secondary schistosity, which itself has locally been drag folded. In addition, the rocks are disrupted by a thrust fault near the base of the Bragdon formation and by abundant high-angle normal faults.

The rock deformation affects rocks as young as Middle Jurassic (Bajocian) age and is believed to have taken place during an orogeny in Late Jurassic time. Culminating the orogeny was the intrusion of the undeformed Shasta Bally batholith.

CLEAVAGE AND SCHISTOSITY

A weak cleavage that is hardly more than close-spaced jointing and involves only scant development of platy minerals along parting surfaces is present at many places in the Copley and Balaklala formations. This weak cleavage commonly grades either into massive or into schistose rock.

The schistose rock in the Copley and Balaklala formations is characterized by parting planes spaced mostly 1 mm or less apart. Thin sections show that each parting plane is marked by an abundance of fine-grained platy minerals oriented approximately parallel to the parting plane. Between parting planes, platy minerals are sparse, and in places the original igneous texture of the rock is retained. Field mapping shows that some of these schistose rocks are in discrete zones separated from each other by massive rock or rock having only a weak cleavage. Some of these zones of schistose rock seem to have had much distributed movement concentrated along them, but the limits of most zones are too indefinite to be shown on the geologic map. In places, schistose rocks are crumpled and drag folded and possess a slip cleavage at a high angle to schistosity.

Weak cleavage at an angle to bedding cleavage is present locally in shaly rocks of the Bragdon formation in the north-central and northwest part of the quadrangle, and a weak schistosity is present in the fine-grained phyllitic facies of the Bragdon near the Shasta Bally batholith. Much of the phyllite also has a knotty surface in hand specimen. Thin sections show that schistosity in the phyllite results from abundant fine-grained white mica along parting planes spaced about 0.1 mm apart. The knotty surface is due to clots of carbonaceous material rotated normal to the plane of schistosity. Virtually all the cleavage and schistosity in the Bragdon strikes northwest and dips northeast at moderate to moderately steep angles.

The coarse-grained schist in the extreme southwestern part of the quadrangle has a pervasive schistosity that reflects the complete recrystallization of the rock. Rather coarsely crystalline platy minerals are concentrated along parting planes spaced about a tenth of a millimeter apart, and the nonplaty minerals between parting planes show typically crystalloblastic forms. In many places, this schistosity is crinkled, contorted, and drag folded.

FOLIATION

In most of the gneissic rocks in the aureole of the Shasta Bally batholith there is a marked segregation of light- and dark-colored minerals in discrete layers a few millimeters to several inches thick. This segregation results in a conspicuous banding or foliation that parallels the batholith contacts and is straight and quite persistent along strike. Only in a few places, mostly near faults, is the foliation in the gneiss at all contorted. The lack of contortion, and the finer grain size and more banded character, distinguishes the gneiss of the aureole from the schists in the extreme southwestern part of the quadrangle.

FOLDS

Folds of three different trends have been recognized in the quadrangle. These trends are N. 40° to 60° E., north, and N. 50° to 80° W., as shown on plate 2. All the larger folds in the quadrangle are open folds. The only tight folds are small drag folds near the two large plutons and locally near faults.

FOLDS OF NORTHEAST TREND

The only northeast-trending folds recognized are between Whiskeytown and Sugarloaf Mountain and in the upper part of Dry Creek west of Whiskeytown. These folds are revealed mainly by the pattern of the Copley greenstone and Balaklala rhyolite and also by a few bedding attitudes in tuff layers. The most clearly defined fold is a broad anticline whose core, marked by Copley greenstone, lies just north of Iron and Sugarloaf Mountains (pl. 1). This fold is part of the broad northeast trending anticline, described by Kinkel and others (1956, p. 53), which extends along the West Shasta mineral belt. In the vicinity of Spring Creek, the anticline is cut by a large transverse fault striking N. 70° E., and the location of the fold crest north of that locality is not precisely known.

The elongate mass of Balaklala rhyolite extending northeastward through Iron and Sugarloaf Mountains is on the southeast flank of the anticline described above. Inasmuch as the rhyolite is also bounded along its southeast side by greenstone, it may be in a syncline or a combination syncline and graben; it is partly bounded by faults. Most of this mass of Balaklala, which is host to the largest known massive sulfide deposit of the area, is highly sheared and in places drag folded; this, and the extreme scarcity of bedding, prevents the satisfactory unravelling of its internal structure.

Three northeast-trending bodies of extrusive Balaklala rhyolite, a few hundred feet wide and about a mile long in the upper part of Dry Creek west of Whiskeytown, probably mark a complex synclinal structure lying anomalously at nearly right angles to the dominating northwest structural trend along the Shasta Bally batholith. Schistosity in these rhyolite bodies and in the intervening Copley greenstone also strikes northeast (pl. 1). The relation of this northeast-trending structure to the surrounding rocks of northwest trend is not known; it is almost on strike with the northeast-trending folds through the Iron Mountain-Sugarloaf area, but it is separated from these features by about 2 miles of Copley and Balaklala rocks that strike northwest. Possibly the structure represents an unconformity in the volcanic sequence, but if so, it seems unlikely that schistosity superimposed at a subsequent date would also strike northeast. Alternatively, it may have been thrust onto the northwest-trending rocks, but field evidence in support of such an interpretation is scanty.

FOLDS OF NORTHERLY TREND

The only fold of northerly trend is a syncline in the Bragdon formation. The syncline trough was traced from about three-quarters of a mile north of Merry Mountain to the west side of peak 3195, south of Shirttail Peak. It is revealed by opposed bedding attitudes and by the outcrop pattern of conglomerate beds in the Bragdon. The syncline is cut off on the north by a large fault that brings the Copley greenstone into juxtaposition with the Bragdon. The fold could not be recognized in the Copley north of the fault. Toward the south, the syncline dies out north of Merry Mountain.

FOLDS OF NORTHWEST TREND

Folds that trend northwest or west-northwest are most common in the Bragdon formation in the northwestern part of the quadrangle; few are present east of Shirttail Peak in the north-central part. These folds are defined only by opposed bedding attitudes. Most of the folds do not seem to persist for more than a few thousand feet along strike and none can be traced into rocks underlying the Bragdon. One fold, east of Hoadley Peaks, is shown on the map as extending for about 3 miles, but it is extrapolated at either end on the basis of scanty data. The amplitudes of these folds could not be precisely determined owing to the lack of marker beds, but most are probably on the order of a few hundred feet.

In addition to the northwest folds in the Bragdon formation, a northwest-trending schistosity anticline is indicated by opposed schistosity attitudes in the coarse-grained schist in the extreme southwestern part of the quadrangle. The axis of this anticline is about in Jerusalem Creek, and the fold apparently continues in both directions beyond the limits of the quadrangle. This fold, like others in the quadrangle, is an open fold.

DRAG FOLDS

Small drag folds, ranging from a few inches to a few feet in wavelength, are fairly common in four localities: (1) the faulted and probably synclinal northeast-trending body of Balaklala rhyolite that extends through Iron Mountain and Sugarloaf; (2) the Balaklala rhyolite roof pendant in the Mule Mountain stock southeast of Whiskeytown; (3) the Copley greenstone and Balaklala rhyolite outside the contact aureole of gneiss and extending approximately from Boulder Creek southeastward to Monarch Mountain; (4) the coarsely crystalline actinolite-biotite schist in the extreme southwestern part of the quadrangle. Only a few of these small drag folds are plotted on the map (pl. 1).

The drag folds are almost all in schistose rocks, or at least in rocks having conspicuous cleavage, and in virtually all places it is the schistosity rather than bedding that is folded. The plunge of most drag folds is fairly gentle, mostly 10° to 20°, but it ranges as high as 55° near the south end of the large pendant of Balaklala rhyolite in the Mule Mountain stock. The orientation of drag folds differs in the four individual areas just mentioned. In the belt of schistose Balaklala rhyolite extending through Iron and Sugarloaf Mountains, the drag folds plunge mostly east or northeast; in the Balaklala rhyolite roof pendant and in the Copley and Balaklala southeast of Boulder Creek, drag folds plunge southeast. The schists exposed in the extreme southwest corner of the quadrangle contain minor folds that plunge either to the east or to the west. Too small an area is covered by the French Gulch quadrangle to permit evaluation of the relation of the drag folds to larger scale structures.

Abundant small folds are also present in the Kennett(?) formation, but with few exceptions they seem to be chaotic even within an individual outcrop. They may have formed contemporaneously with the thrust fault beneath the Bragdon formation.

OTHER FOLD STRUCTURES

In addition to the folds just described, S-shaped and arcuate bends are defined by schistosity in a number of places. Most of these features are in the probably synclinal body of Balaklala rhyolite that extends through South Fork, Iron and Sugarloaf Mountains. Except on Sugarloaf Mountain, the schitosity in this elongate body of rhyolite strikes generally northeast and dips southeast (pl. 1), but at irregular intervals it bends north for a few tens or hundreds of feet and then resumes its northeast trend. The overall pattern suggests a series of sinistral bends. An example of this type of bend or fold occurs on Iron Mountain, where the largest massive sulfide deposit of the West Shasta copper-zinc district lies in the concave part of the fold. In view of their apparent role in the localization of this deposit, these folds or bends in schistosity deserve close scrutiny in prospecting for hidden sulfide deposits.

FAULTS

GENERAL STATEMENT

Faults are abundant in the rocks north and east of the Shasta Bally batholith but are rare within and southwest of the batholith. The faults are of two main types: the irregular low-angle fault, here called the Spring Creek thrust, that lies mainly beneath the Bragdon formation, and high-angle normal faults.

SPRING CREEK THRUST

One of the most puzzling structural relationships in the quadrangle is that of the Bragdon formation to the underlying rock units, particularly the Kennett (?) formation. From Mad Mule Mountain to Spring Creek, the lower limit of the Bragdon trends generally northeast and is very irregular in plan (pl. 1). The lower contact swings broadly southward on the ridges and northward in the valleys and suggests a gentle northerly dip. However, inspection of the map reveals that in several places the reverse relationship exists; this reversal indicates that the lower contact of the Bragdon is by no means a smooth plane but must be quite irregular. This irregularity does not result from folds, and it is concluded that a low-angle fault of unknown displacement separates the Bragdon formation from underlying rocks. Features indicating this fault, in addition to the configuration of the contact just noted, are: (1) the apparent lack of continuity of folds and faults affecting the Bragdon into underlying rocks, (2) the marked divergence in many places between the attitude of bedding in the Bragdon and the attitude of the underlying contact, (3) the highly contorted shale of the Kennett(?) formation along the contact in the eastern part of the quadrangle, and (4) the common presence of dike rocks and quartz veins along the contact in the western part of the quadrangle. This low-angle fault is here named the Spring Creek thrust, because most of the features that serve to identify it may be seen in the general area where Spring Creek crosses the Bragdon contact (pl. 1).

The exact contact between sedimentary rocks of the Bragdon and underlying rock units is exposed in only a few places. The contact between Bragdon and Kennett(?) was nowhere seen, but locally, where shaly rocks of the Bragdon overlie Balaklala rhyolite, bedding in the shale seems to parallel the contact. The Kennett(?) formation, which is discontinuous between Mad Mule Mountain and Spring Creek, is in most places highly contorted; in a few places it is uncontorted, and where it is, as southwest of peak 3054 east of Whiskey Creek, the strike of bedding is northeast, parallel to the local strike of the Bragdon contact (pl. 1). However, just to the north, bedding in the Bragdon strikes nearly at right angles for thousands of feet, which clearly indicates marked structural discordance.

From Spring Creek northward to the map boundary, the Kennett(?) formation is almost continuous as a narrow belt of highly contorted siliceous shale. Over a distance of 3 miles, the strikes of the Kennett(?) outcrop and lower boundary of the Bragdon are approximately north, and are offset at Squaw Creek; in contrast, the strike of bedding in the Bragdon formation only a short distance west of the contact is consistently N. 30° to 45° W., and the dip is southwest over the 3-mile span. Within this area, each bed in the Bragdon, if projected southeast along strike, would intersect the contact at a high angle. This relationship demands a fault beneath the Bragdon to explain the disappearance of several thousand feet of stratigraphic section. The highly contorted character of the Kennett(?) formation is probably in large part a result of the movement on this fault, although the principal surface of discordance, and therefore the main plain of movement in this area, must be between the Kennett(?) formation and the Bragdon.

In the north-central and northwestern parts of the quadrangle, the Bragdon in some places overlies the Copley greenstone, and in other places it is separated from the Copley by a few feet to a few tens of feet of felsic tuff that is correlated with the Balaklala rhyolite. Many contacts between the Bragdon and Copley are high-angle normal faults. Other contacts show distinct slickensiding and other evidence of minor faulting, but little indication of intense faulting. Commonly the minor faults show normal movement. The Bragdon formation that caps the ridge between Crystal Creek and Bear Gulch contains well-defined folds that are not reflected in the configuration of the contact with the underlying greenstone and that are not traceable in the greenstone. The single small exposure of this contact, in a prospect adit on the ridge west of Crystal Creek, appears to be a mineralized fault striking parallel to bedding in the overlying shale. In a few places where shale overlies tuff of the Balaklala rhyolite, the contacts are not faulted, but the shale itself commonly contains abundant low-angle bedding plane faults for several tens of feet above the tuff. Most of these faults show normal movement.

The amount and direction of movement on the Spring Creek thrust cannot be ascertained from evidence presently available. In some areas, as between Whiskey and Spring Creeks, the conspicuous discordance between bedding and the trend of the Bragdon contact indicates that thousands of feet of Bragdon are cut out. In other places, as locally south of Tower House, the Bragdon seems to rest conformably on the underlying tuff of the Balaklala rhyolite and, apparently, very little of the section is missing. In these places the main thrust is thought to lie beneath the thin tuff bed rather than beneath the Bragdon, but exposures are so poor that this cannot be stated with assurance. The lithology and structure of the entire outcrop area of the Bragdon formation need to be mapped in considerable detail before the problem of its relation to the underlying rock units and the magnitude of offset on the Spring Creek thrust can be satisfactorily resolved.

HIGH-ANGLE NORMAL FAULTS

The rocks of the French Gulch quadrangle, particularly those north and east of the Shasta Bally batholith, are cut by a great many high-angle normal faults. Faults within and southwest of the batholith are comparatively rare. Most of the normal faults dip at angles greater than 45°, although, as mentioned on page J62, low-angle normal faults are locally abundant in the lower part of Bragdon formation.

The largest normal faults, which for convenient reference are given a name (pls. 1 and 2), are: (1) the Hoadley fault, which strikes northwest, dips northeast, and has been traced across the quadrangle for a distance of about 18 miles; (2) the Shirttail fault, which strikes northeast and dips southeast at about 65°; and (3) the French Gulch fault (the probable westward extension of the Shirttail fault), which strikes east-west and dips southward at an angle of about 80° (pl. 1). Between the Hoadley fault on the south and the Shirttail and French Gulch faults on the north is a downdropped block cut by numerous other faults. North of the Shirttail and French Gulch faults is a much-faulted structural high that is marked by windows and inliers of the Copley greenstone. This high is interrupted by another small east-northeast-trending graben of the Bragdon formation north of

Shirttail Peak. Normal faults are also abundant on the southwest side of the Hoadley fault in the southeastern part of the quadrangle. A few normal faults occur even within the Shasta Bally batholith north of Andrews Creek.

HOADLEY FAULT

The most conspicuous and continuous fault in the quadrangle has been traced diagonally across the French Gulch quadrangle from the vicinity of Mule Mountain northwestward to a prominent saddle east of Hoadley Peaks. The name "Hoadley fault" is applied for convenience in reference; it is not meant to imply that the fault is particularly well exposed in the Hoadley Peaks area. The average strike of the fault across the quadrangle is N. 50° to 55° W., and the dip is 60° to 65° NE., although the overall range in strike is from N. 40° W. to S. 85° W., and the dip ranges from 50° to 80° NE. The most marked bend in the fault is near the junction of Clear Creek and Paige Boulder Creek where the strike changes from N. 40° W. to S. 85° W. and then back to N. 45° W. within a distance of about 2 miles.

The Hoadley fault is marked topographically by a series of sharp saddles and draws all the way across the quadrangle (pl. 1). The topographic slot formed by these saddles may be seen clearly if one looks southeastward along its strike from where it crosses U.S. Highway 299W west of the Greenhorn mine. The fault ranges from a poorly defined zone of cataclasite, where it cuts a promontory of the Shasta Bally batholith south of Trail Gulch, to a strong zone of gouge and breccia several hundred feet wide, where the bend in strike occurs at Paige Boulder Creek.

The Hoadley fault is also marked by small impotable saline springs at several places, chiefly in Salt Creek near its junction with Clear Creek, and where it crosses U.S. Highway 299W.

In spite of its prominence, the Hoadley fault is believed to have at most only a few hundred feet of displacement. The precise displacement is impossible to determine because the fault nearly parallels the strike and dip of foliation throughout most of its length. Only where it cuts the Mule Mountain stock and the Shasta Bally batholith does it offset contacts that can be recognized on both the hanging wall and footwall sides, and these steeply dipping igneous contacts provide little information with which to determine the amount of displacement. However, they do give some clue on the direction of offset, and they identify the fault as a normal fault having possibly some left-lateral strike-slip component. The west contact of the Mule Mountain stock has been observed to dip steeply east in at least two places, and its intersection with topography also indicates a very steep dip.

Therefore, where the north-dipping Hoadley fault cuts the contact, it should be offset toward the west in hanging wall if the fault is normal. This relation does exist near the junction of Clear Creek and Paige Boulder Creek.

The small promontory of Shasta Bally batholith cut by the Hoadley fault gives little evidence of the direction of movement because the batholith contact is so nearly parallel to the fault. However, the fact that the part of the promontory in the hanging wall seems somewhat smaller than it should be suggests that the hanging wall has been displaced downward.

Further indication that the Hoadley fault is normal is given by the Bragdon formation. Near Hoadley Peaks, conglomerate of the upper unit of the Bragdon is in the hanging wall and intersects the fault at an acute angle, but does not appear in the footwall. The gneissic rock of the footwall appears to have been derived from fine-grained mudstone and siltstone characteristic of the lower unit of the Bragdon. Normal movement on the fault is indicated here.

The Hoadley fault is thought to be one of the youngest faults in the quadrangle because it cuts all the rocks it crosses as well as faults of various other trends. It is unmineralized except for local lacy networks of calcite veinlets in the gouge. It does not cut Cretaceous and Tertiary rocks southeast of the French Gulch quadrangle.

SHIRTTAIL FAULT

Probably the second most conspicuous normal fault in the quadrangle, and possibly the fault having the largest offset, is the one that separates the Bragdon and Copley formations east of Shirttail Peak. This fault, here called the Shirttail fault, strikes about N. 45° E. near Shirttail Peak, but the strike changes to approximately east at Clear Creek. The dip is about 65° SE. West of Clear Creek the Shirttail fault seems to split into several strands that die out in the Bragdon formation. However, a strong zone of faulting, that probably represents the same system, continues westward through the French Gulch mining district to the edge of the quadrangle.

The Shirttail fault is poorly exposed, except in Clear Creek where it forms a zone of highly contorted and slickensided shale about 200 feet wide, and on the south side of Shirttail Peak where a similar but narrower zone of sheared shale is adjacent to a prominent straight cliff of Copley greenstone.

Displacement on the fault cannot be closely determined because the thickness of the Bragdon formation is not accurately known. However, beds of conglomerate that belong to the upper unit of the Bragdon and are in juxtaposition against the Copley greenstone along the fault south of Shirttail Peak show that the hanging wall is down-dropped an amount at least equal to the thickness of the lower unit. The displacement is at least 2,000 feet and it may be as much as 4,000 feet, depending on the thickness of the lower unit.

FRENCH GULCH FAULT

The French Gulch fault strikes approximately east over most of its length and dips 80° S. Where it crosses the creek known as French Gulch, it forms the south boundary of a window of Copley greenstone. Because of its character, attitude, and location, the fault is thought to be a westward continuation of the Shirttail fault. The vertical displacement on this fault must be at least 200 feet where it crosses French Gulch, because the contact between the Bragdon formation and Copley greenstone is offset by at least this amount. How much more than 200 feet the contact is displaced depends on the thickness of the Bragdon on the hanging wall side of the fault. The French Gulch fault seems to die out a short distance west of the Niagara mine, but exposures are insufficient in that area to establish definitely the limit of the fault.

OTHER FAULTS

In addition to the three faults just described, many others are shown on the maps (pls. 1 and 2). Some of these faults may be even larger than the three described, and some certainly are greater in economic importance. Inspection of plates 1 and 2 reveals about four main trends. Most conspicuous is a N. 60° to 90° E. trend that dominates throughout the eastern part of the quadrangle and also in the extreme northern part of the quadrangle. Faults of this trend dip steeply either to the north or to the south but mainly to the north, and they may be the oldest normal faults in the quadrangle. They are largely premineral in age and marked by quartz veins, pyritized rock, or gossan. A few faults in this group are occupied by dikes of "birdseye" porphyry and quartz porphyry and hence were formed prior to the intrusion of these Late Jurassic rocks. Displacement on these faults ranges from a few feet to a few hundred feet; on most, however, the displacement is a few tens of feet.

A second conspicuous group of normal faults strikes in the range N. 10° to 25° W. and dips at high angles either east or west. These faults are most common in the Bragdon formation, but a few cut the Copley and Balaklala and the Mule Mountain stock. Few of these faults can be traced with assurance from the Bragdon into the underlying formations, and they are inferred to be cut off by the Spring Creek thrust.

The best exposed faults of this group displace the Bragdon contact in the vicinity of Tower House. Those faults shown cutting the Bragdon in the general vicinity of Whiskey Creek were not actually traced in the field, but they are necessary in order to explain the apparent repetition of the upper unit of the Bragdon formation three times between the upper part of Grizzly Gulch and Spring Creek. The displacement on each of these faults is probably more than 1,000 feet. An alternative explanation that would nullify the necessity of the large northwest-trending faults in the general vicinity of Whiskey Creek is that the upper unit of the Bragdon is not actually repeated three times but is instead a great deal thicker than supposed. A section drawn across strike from Clear Creek to the eastern Bragdon contact in the upper part of Squaw Creek would portray about 15,000 feet of Bragdon formation, if there were no repetition of beds by faulting. This stratigraphic thickness would necessitate a large displacement on the Spring Creek thrust. Though this interpretation is highly attractive, its validity cannot be adequately appraised until the internal stratigraphy of the Bragdon has been studied over a larger area and more is known about variations in its thickness in this quadrangle. The N. 10° to 25° W. faults are rarely mineralized.

A third main group of normal faults strike N. 45° to 60° W., about parallel to the Hoadley fault, and dip either northeast or southwest. Faults of this group that cut the Bragdon formation are commonly occupied by quartz veins or by porphyry dikes. Displacement is probably small.

A fourth general group of faults strikes north to about N. 20° E. These faults are not abundant but are locally occupied by veins and are, therefore, of economic importance. These faults cut those that strike N. 60° to 90° E., and locally they also cut those that strike northwest. The displacement on most is small.

In addition to the normal faults shown on the map (pl. 1), a great multitude of faults, too small to be mapped, are present in the Bragdon formation and to a lesser extent in other formations. These faults include both high-angle and low-angle faults. The vast majority have normal movement.

MINERAL DEPOSITS

Within the French Gulch quadrangle are several large massive sulfide deposits, one of which, at Iron Mountain, was being worked in 1960. Five other deposits, the Balaklala, Early Bird, Keystone, Stowell, and Greenhorn, were worked in earlier years. With the exception of the Greenhorn, these deposits are described by Kinkel and others (1956). The Greenhorn deposit will be described in a report on the economic geology of the French Gulch quadrangle which is in preparation.

Numerous gold deposits, which have had a production of around $30 million, are also located in the quadrangle. None of these deposits was being worked in 1960. Most of the gold deposits are quartz veins containing free gold that cut the Bragdon formation or lie along the contact between the Bragdon formation and the Copley greenstone. A few deposits are veins in other rock units. These deposits also will be described in the forthcoming report on the economic geology of the quadrangle.

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