Geology of the Frenchie Creek Quadrangle North-Central Nevada

GEOLOGICAL SURVEY BULLETIN 1179

Geology of the Frenchie Creek Quadrangle North-Central Nevada

By L. J. PATRICK MUFFLER

GEOLOGICAL SURVEY BULLETIN 1179

General geology, with emphasis on stratigraphy, intrusion structures, hydrothermal iron mineralization, and hydrothermal alteration

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1964

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

The U.S. Geological Survey Library has cataloged this publication as follows:

Muffler, Leroy J Patrick, 1937-

Geology of the Frenchie Creek quadrangle, north-central Nevada. Washington, U.S. Govt. Print. Off., 1964.

vi, 99 p. illus., maps (1 fold. col. in pocket) diagrs., tables. 24 cm. (U.S. Geological Survey. Bulletin 1179)

Bibliography: p. 94-96.

1. Gelogy—Nevada—Eureka Co. 2. Rocks, Igneous. 3. Rocks—Analysis. I. Title: Frenchie Creek quadrangle, north-central Nevada. (Series)

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402

CONTENTS

ILLUSTRATIONS

TABLES

GEOLOGY OF THE FRENCHIE CREEK QUADRANGLE, NORTH-CENTRAL NEVADA

By L. J. Patrick Muffler

ABSTRACT

The Frenchie Creek quadrangle is in north-central Nevada in the Basin and Range physiographic province. Two major bedrock blocks, each titled southeastward and bounded on the northwest by a Cenozoic normal fault, are separated by a bolson underlain by several thousand feet of alluvium. Bedrock consists primarily of Paleozoic and Mesozoic sedimentary and volcanic rocks, widespread Mesozoic plutonic rocks, and local Cenozoic volcanic rocks.

The Upper Pennsylvanian or Permian Brock Canyon Formation consists of approximately 5,000 feet of near-shore marine and nonmarine sedimentary rocks, which was deposited unconformably on deformed eugeosynclinical rocks of the Orodovician Valmy Formation, part of the allochthonous upper plate of the Roberts thrust (Late Devonian to Early Pennsylvanian). The Brock Canyon Formation comprises four informal members: in ascending order, (1) conglomerate member, (2) dolomite member, (3) claystone member, and (4) arkose member. The upper two members are unfossiliferous and may be of early Mesozoic age.

Permian(?) dellenite flows and hypabyssal plutons, partly sericitized and locally albitized, are exposed near the north boundary of the quadrangle. Erosion of the volcanic rocks soon after eruption may have supplied feldspathic detritus to the Permian(?) arkose member of the Brock Canyon Formation.

A sequence of Mesozoic volcanic and sedimentary rocks is herein named the Pony Trail Group and is divided into three new formations. The Big Pole Formation consists of volcanic wackes and subordinate altered flows. The overlying Sod House Tuff is a felsic ash-flow tuff. The Frenchie Creek Rhyolite (Jurassic?) is made up predominantly of rhyolite and rhyodacite flows. A few rhyolite plugs that intrude the group probably are comagmatic with the Frenchie Creek Rhyolite.

Lower Cretaceous(?) plutonic rock consists of dominant granodiorite and adamellite, and subordinate diorite, monzodiorite, rhyodacite porphyry, tonalite, alaskite, and quartz albitite. A general trend of magmatic differentiation was modified by deuteric alteration, involving introduction of soda and loss of iron, potash, and magnesia. Forcible emplacement of the plutons caused intrusion brecciation, shearing and thrusting along the contact of the Brock Canyon and Valmy Formations and along bedding planes within the Brock Canyon Formation, and rotation of gently dipping beds of arkose and quartzite into remarkably continuous subvertical septa and screens.

Cenozoic rhyodacite flows and dellenite ash-flow tuffs are found in the northwestern part of the quadrangle, and a regional northwest-trending Pliocene(?) diabase dike swarm extends into the southwestern part. Tertiary continental sedimentary rocks at the east margin of the quadrangle are almost wholly masked by Quaternary pediment alluvium.

Three periods of deformation are recorded in rocks of the Frenchie Creek quadrangle: (1) the Late Devonian to Early Pennsylvanian Antler orogeny, (2) Early Cretaceous(?) deformation associated with and largely caused by forcible emplacement of plutons, and (3) Cenozoic basin and range faulting, which has continued to the present.

Cretaceous(?) hematite and magnetite ore deposits are found in the Jurassic(?) Frenchie Creek Rhyolite. The iron concentrated in these deposits probably represents material removed from Lower Cretaceous(?) plutonic rocks during deuteric alteration and transported to the site of deposition by hydrothermal fluids. Kaolinization, sericitization, and potash metasomatism accompanied iron mineralization and locally affected all three formations of the Pony Trail Group, as well as some Lower Cretaceous(?) plutonic rock and parts of the arkose member of the Brock Canyon Formation.

INTRODUCTION

PHYSICAL SETTING

The Frenchie Creek 15-minute quadrangle is in the northern part of Eureka County, north-central Nevada. The nearest towns are Beowawe (6 miles northwest), Palisade (7 miles northeast), and Carlin (15 miles northeast); all three are located on the Humboldt River.

The quadrangle is split by the northeast-trending Cortez Mountains, which rise up to 4,000 feet above Crescent Valley and 3,000 feet above Pine Valley (fig. 1). Access to the west side of the mountains is by graded roads leading south from Beowawe. The east side of the mountains is reached by traveling south from Carlin on Nevada Highway 20 for 20 to 30 miles, and thence west on any of a number of graded roads and unimproved jeep trails. Although several jeep trails extend into the rugged Cortez Mountains, the only through trail from Crescent Valley to Pine Valley is in the Frenchie Creek-Modarelli mine area.

The Dewey Dann Ranch is the only permanently inhabited place in the quadrangle. The Duff and Frenchie Ranches are used occasionally during cattle roundups.

The Frenchie Creek quadrangle is in an area of semidesert climate (Brown, 1960). Vegetation is primarily sagebrush, but greasewood grows in the valleys at localities where the water table is relatively near surface. Cottonwood trees are abundant along intermittent streams in the mountains, and a few groves of aspen are found at high altitudes. Hay is grown in irrigated fields in Crescent Valley. There are many small springs, but because of pollution by cattle, potable water is obtainable only at a few larger springs improved by the ranchers.

PREVIOUS WORK

Published geologic data on the Frenchie Creek quadrangle are scant. The quadrangle was studied as part of the U.S. Geological Exploration

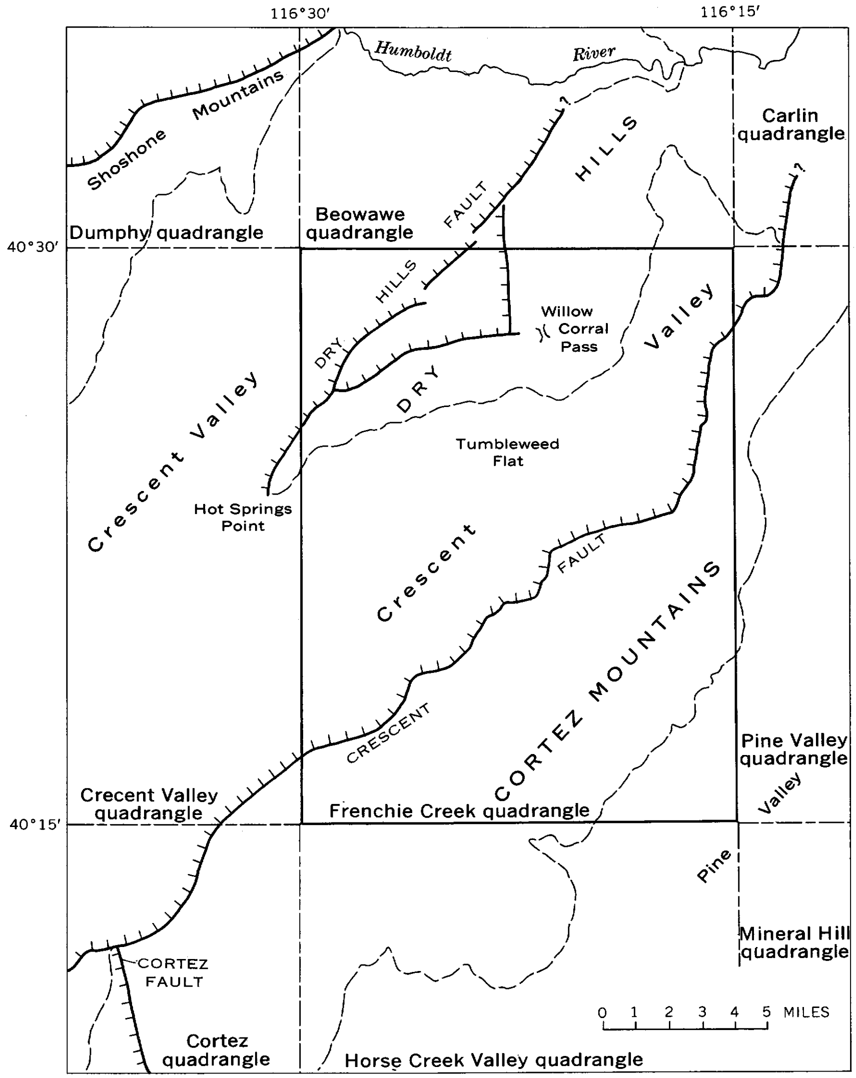

FIGURE 1.—Index map of the Frenchie Creek quadrangle and surrounding areas showing major basin-and-range faults. Hachures on downthrown blocks.

of the 40th Parallel (King, 1878; Emmons, 1877); reconnaissance geologic relations are shown on part of Map IV of King (1876). Rocks collected from the quadrangle by the 40th Parallel Survey were described by Zirkel (1876). Regnier (1960) discussed the Cenozoic geology of Pine Valley. Shawe and others (1962) investigated the Modarelli mine and the surrounding area as part of a study of iron ore deposits of Nevada. The preliminary reconnaissance geologic map of Eureka County (Lehner and others, 1961) includes the Frenchie Creek quadrangle.

Intensive exploration for iron in the Modarelli mine area has been conducted by J. R. Simplot Co. and by Columbia Iron Mining Co., and prospecting in the northern Cortez Mountains has been carried out by Utah Construction Co. The information gained from these studies has not been published.

The U.S. Geological Survey is currently engaged in an extensive geologic mapping program in the region. The following adjacent quadrangles have been studied or are currently being studied: Crescent Valley, Cortez, Horse Creek Valley, Pine Valley, and Carlin.

PRESENT INVESTIGATION

This report is based on 10 months of geologic fieldwork in the Frenchie Creek quadrangle during the summers of 1959–61, supplemented by petrographic, ore microscopic, and X-ray diffraction studies conducted in 1960–62. Geology was mapped at 1:48,000 on a topographic base mounted on a light-weight planetable and tripod. Location was accomplished by leveling and orienting the board, and then resecting on three known topographic points with an open-sight alidade.

Although aerial photographs at 1:24,000 and 1:37,400 were used extensively during fieldwork, the geologic map was made directly on the topographic base.

Localities mentioned in this report are specified to the nearest 50 feet in terms of Nevada coordinate system, east zone.

The chemically analyzed rock specimens are referred to serial numbers of the Denver Rock Analysis Laboratory of the U.S. Geological Survey.

The modal classification of igneous rocks used in this report is similar to that of Peterson (1961), differing only in the inclusion of modal nonperthitic albite in "plagioclase" rather than in "alkalic feldspar." This modification was made necessary by the replacement of intermediate plagioclase by albite found in several rock types.

ACKNOWLEDGMENTS

This investigation was carried out under the auspices of the U.S. Geological Survey, which supported all the fieldwork as well as laboratory work and report preparation during the winter of 1962. Laboratory work in 1960 and 1961 was conducted at Princeton University during the writer's tenure of National Science Foundation predoctoral fellowships and with the assistance of a Grant-in-Aid of Research from Princeton University.

The writer is grateful to A. F. Buddington and H. H. Hess for guidance and for review of the manuscript. Thanks also are due F. B. Van Houten, who visited the Frenchie Creek quadrangle and reviewed much of the manuscript.

The writer also wishes to acknowledge his indebtedness to the many geologists of the U.S. Geological Survey who supplied encouragement and material aid. Harold Masursky, in particular, was instrumental in guiding the writer during the first stages of mapping, and gave unstintingly of his time and ideas throughout the course of the project.

Assistance in the fieldwork was provided by T. H. Brown, B. T. C. Davis, and D. G. Griggs.

PALEOZOIC SEDIMENTARY ROCKS

VALMY FORMATION

The Valmy Formation (Ordovician) crops out in the Frenchie Creek quadrangle only in two small areas at the mouths of Brock and Cottonwood Canyons (pl. 1). It makes up part of the highly deformed complex upper plate of the Roberts thrust (the thrust itself is exposed 7 miles to the southwest in the Cortez quadrangle). In addition to being involved in the middle Paleozoic Antler orogeny, the Valmy Formation in the Frenchie Creek quadrangle was deformed during emplacement of the Lower Cretaceous(?) Brock Canyon pluton, and is cut by the Cenozoic Crescent fault. Owing to this structural complexity, the thickness and internal stratigraphy of the formation are unknown.

The Valmy Formation is unconformably overlain by the Brock Canyon Formation of upper Pennsylvanian or Permian age. Most of the contact, however, was greatly modified by shearing during the Early Cretaceous(?) episode of pluton intrusion.

The Valmy Formation is characterized by highly contorted thin-bedded dark chert and by mottled dark-gray medium- to coarse-grained poorly sorted quartzite. The quartzite differs from that found in the lower members of the Brock Canyon Formation principally in its unsorted character. Detrital chert grains are abundant. Subordinate rock types include light-gray fine-grained quartzite, gray and black siltstone, lithic (chert) wacke, and rare chert-pebble conglomerate. Greenstone, although present in varying amounts in the Valmy Formation of adjacent areas (Roberts and others, 1958), is lacking in the Frenchie Creek quadrangle.

Graptolites collected from light-gray siltstone at E. 245,450, N. 2,015,400 were identified by R. J. Ross (written commun., 1960) as *Didymograptus*(?) (Lower or Middle Ordovician) and as either

Dicellograptus or *Dicranograptus* (both Middle or Upper Ordovician). This dates the collection as probable Middle Ordovician.

The Valmy Formation of the Frenchie Creek quadrangle is correlated on both paleontologic and lithologic grounds with the Valmy Formation in the Shoshone Range (Roberts and others, 1958) and in the Antler Peak quadrangle (Roberts, 1951).

BROCK CANYON FORMATION

The Brock Canyon Formation was named by James Gilluly in the Crescent Valley quadrangle (Gilluly and Gates, 1964). Inasmuch as only the lower few hundred feet of the formation (which totals just under 5,000 ft in thickness) is exposed in the Crescent Valley quadrangle, the writer and Gilluly agree that the section in the upper part of Cottonwood Canyon in the Frenchie Creek and Horse Creek Valley quadrangles should be designated as the type section. This section was measured by the writer and is presented at the end of this report (p. 83–88).

Two supplementary stratigraphic sections are also given (p. 88–93). Section 1 typifies the dolomite member better than does the type section, and both supplementary aections include a basal dolomite that is absent in the type section. In addition, the supplementary section details tectonic features imposed on the lowermost Brock Canyon Formation in Early Cretaceous(?) time.

The writer has divided the Brock Canyon Formation into four informal members: in ascending order, (1) conglomerate member, (2) dolomite member, (3) claystone member, and (4) arkose member. These members are not designated as formations inasmuch as they can be discriminated only in part of the Frenchie Creek quadrangle and in none of the surrounding quadrangles.

The Brock Canyon Formation is found primarily in the Frenchie Creek and Horse Creek Valley quadrangles; small areas of outcrop extend into the Crescent Valley and Cortez quadrangles. The best exposures are in Cottonwood and Brock Canyons (pl. 1). Unfossiliferous sedimentary rocks that crop out in the Dry Hills are correlated by lithologic similarity with the Brock Canyon Formation.

The Brock Canyon Formation in the type section totals about 4,900 feet, but the thickness of the arkose member (1,600 ft) can only be guessed at, owing to uncertainty of bedding attitudes and to recrystallization. The sections in lower Cottonwood and Brock Canyons are truncated by Lower Cretaceous(?) plutons and are only 1,000 to 1,500 feet thick; the arkose member is absent, and only the lower few hundred feet of the claystone member is preserved.

Fossils are scarce in the Brock Canyon Formation. Abundant plant material collected at the base of the dolomite member near supplementary measured section 1 consisted almost exclusively of fragments of *Taeniopteris* sp., with a few other poorly preserved fragments which were not generically identifiable (S. H. Mamay, written communs., 1959 and 1960). Mamay considered that if this assemblage "is Pennsylvanian, it is very young Pennsylvanian, and * * * there is a possibility that it is Permian or even early Mesozoic."

A small silicified mollusk faunule was etched out of the basal dolomite of the conglomerate member. The locality is in the NW¼ sec. 30, T. 28 N., R. 49 E., on top of the ridge west of Brock Canyon at an altitude of about 6,000 feet (late Paleozoic locality 15715–PC). The collection contain *Astartella*? sp., *Naticopsis* sp. indet. (juvenile), *Paleostylus* (*Pseudozygopleura*) sp., *Donaldina* sp., and ?*Stegocoelia* sp. indet. None of the specimens is preserved well enough to be identified specifically, but the assemblage is suggestive of Pennsylvanian or Permian age (E. L. Yochelson and M. Gordon, written communs., 1955).

Attempts to obtain other identifiable fossils proved futile. In particular, a careful search was made for fusulinids, ostracods, and conodonts. A number of siltstone and sandstone samples were processed for ostracods, with negative results (I. G. Sohn, written commun., 1960). Dissolution of several dolomite samples from the dolomite member also produced no identifiable fossils (P. E. Cloud, Jr., written commun., 1961). Samples of black siltstone from the same beds that yielded the *Taeniopteris* flora were devoid of pollen or spores (G. O. W. Kremp, written commun., 1960).

Therefore, according to the available paleontologic data, the Brock Canyon Formation in this report is considered to be of Late Pennsylvanian or Permian age. However, inasmuch as there is no paleontologic control in the upper 4,500 feet of the Brock Canyon Formation, it is quite possible that the formation spans the Permian and extends into the Mesozoic.

CONGLOMERATE MEMBER

The conglomerate member contains three characteristic rock types: (1) black or gray fine- to medium-grained moderately well sorted stylolitic quartizite, (2) black chert pebble and cobble conglomerate, and (3) black lithic arenite. Subangular to subrounded chert clasts are found in all three rock types. There is a prominent dolomite near the base of the member in Brock Canyon (see supplementary stratigraphic sections 1 and 2, p. 88–93). Fine-grained gray quartzite is locally interbedded with the basal dolomite.

The member rests unconformably on Ordovician Vinini Formation in the Horse Creek Valley quadrangle near the type section (Harold Masursky, oral commun., 1961), and appears to be unconformable on Ordovician Valmy Formation along the Crescent fault northeast of Cottonwood Canyon. The contact of the conglomerate member and the Valmy Formation in lower Cottonwood and Brock Canyons may have been originally an unconformity, but it now a thrust plane. The writer considers this thrust, as well as the bedding plane thrust, shear zones, and breccias within the conglomerate member, to have been produced by forcible intrusion of the overlying Lower Cretaceous (?) Brock Canyon pluton (p. 44); therefore, he considers the Brock Canyon Formation in lower Cottonwood and Brock Canyons to be parautochthonous.

Owing to deformation and to similarity of rock types, the contact of the Brock Canyon and Valmy Formations could not be located everywhere. During the mapping in Brock Canyon, the lowest dolomite was considered to be the basal bed of the conglomerate member. Light-gray quartzites of the upper part of the Valmy Formation are readily confused with the sporadic light-gray quartzites interbedded with this basal dolomite, and may be incorrectly mapped in some places.

The upper contact of the conglomerate member is at the base of the lowest thin cherty dolomite of the dolomite member. The top of the highest cliff-forming black quartzite was used in mapping when this thin dolomite was missing or covered.

The conglomerate member is about 750 feet thick in upper Cottonwood Canyon, but only about 300 feet thick in Brock Canyon. This thinning may in part be due to thrusting in Brock Canyon. The presence of the basal dolomite in Brock Canyon, however, suggests that the original thickness may well have been less than in upper Cottonwood Canyon.

DOLOMITE MEMBER

The dolomite member, 750 to 1,000 feet thick, is very heterogeneous and shows much lateral variation. Dark-gray thinly laminated cherty dolomite occurring in beds 2 to 4 feet thick is a characteristic although subordinate rock type. White to gray fine- to coarse-grained quartzites and sandstones are dominant, and commonly grade into quartzites rich in chert pebbles and granules. Thick-bedded lenticular chert pebble conglomerates have a sporadic distribution. Other rock types include yellowish-gray dolomitic siltstone, black, gray, and olive-green siliceous siltstone, rare black quartzite, and sporadic light-green arkosic wacke.

The percentage of outcrop of the dolomite member is lower than that of the conglomerate member. The contact of the two members is commonly marked by a conspicuous swale (formed on dolomite, siltstone, and fine-grained quartzite) just above the highest cliff-forming black clastic rocks of the conglomerate member.

The upper contact of the dolomite member is placed at the lowest outcrop of reddish-gray claystone or conspicuous yellowish-gray siltstone. Yellowish-gray siltstone of the dolomite member is less abundant than that of the claystone member, has a dolomitic character, and is associated with gray dolomite.

The arkosic wacke of the dolomite member differs from that of the arkose member in its green cast, dominance of quartz grains, abundance of microcline, presence of chert grains, and absence of volcanic fragments.

CLAYSTONE MEMBER

The full thickness (1,881 ft) of the claystone member is exposed only in the type section. On the north side of upper Cottonwood Canyon and in the Brock Canyon area, the upper parts of the member are cut out by Lower Cretaceous (?) plutons.

Interbedded reddish-gray claystone and yellowish-gray siltstone are dominant in the claystone member. Reddish-gray claystone is restricted to this member, but yellowish-gray siltstone also occurs as a subordinate rock type in the dolomite member.

Other prominent rock types found in the claystone member include black fine- to medium-grained poorly sorted quartzite, white medium-grained sandstone and quartzite, and fine-grained reddish and yellowish-gray silty sandstone. All these sandstones and quartzites have a calcite or quartz cement and little or no matrix. Detrital feldspar grains are abundant only locally (in Brock Canyon), but almost all the sandstones and quartzites contain detrital chert grains, which, in some specimens, make up 10 to 20 percent of the detrital material.

The contact of the claystone member and the dolomite member is gradational; a few beds of conglomerate and dolomite are found in the lower 100 feet of the claystone member. In mapping, the contact was placed at the base of the lowest reddish-gray claystone. The upper contact is at the top of the highest yellowish-gray siltstone.

ARKOSE MEMBER

The arkose member was mapped only near the crest of the Cortez Mountains near the south margin of the Frenchie Creek quadrangle. Exposures are poor, and structural control is almost nonexistent owing to the massive nature of the rocks and to common metamorphic recrystallization related to nearby Lower Cretaceous (?) intrusive rocks. The measured thickness (1,600 ft) given in the type section is therefore only approximate.

The arkose member is made up of gray and light-brownish-gray arkosic sandstones—both wackes and arenites [1]—with subordinate arkosic siltstones and quartz arenites. Many rocks made up of fine-grained sand- or silt-size particles and designated by the writer in the field as ordinary quartz-bearing sandstones or siltstones proved upon petrographic examination to contain abundant detrital sodic plagioclase (in some samples as much as 60 or 70 percent) with subordinate quartz, minor potash feldspar, and a few volcanic fragments (fig. 2). The matrix material of the arkosic wackes is primarily quartz and plagioclase; chlorite and clay minerals occur only sporadically. The arenites are cemented by quartz and subordinate calcite.

Contact metamorphism due to intrusion of Lower Cretaceous(?) plutons commonly consisted solely of recrystallization and partial obliteration of detrital texture, although acicular tremolite, poikiloblastic potash feldspar, and secondary kaolinite are found adjacent to some plutons. The albite-epidote-hornfels facies of contact metamorphism is the only metamorphic facies reognized. Thin screens of meta-arkose on the east side of the Cortez Mountains are locally intensely kaolinized (fig. 13).

The arkose member of the Brock Canyon Formation may be part of the same depositional sequence as the Big Pole Formation of Mesozoic age (p. 22–26; compare figs. 2 and 3). Plagioclase-bearing wacke is dominant in both units. The arkose member contains only a small percentage of volcanic fragments, whereas the Big Pole Formation contains abundant volcanic detritus. Detrital potash feldspar occurs sporadically in both units but is more abundant in the arkose member of the Brock Canyon Formation. No fossils were found in either unit. Any physical stratigraphic relations between the arkose member and the Big Pole Formation were obliterated by intrusion of the Lower Cretaceous(?) plutons. Therefore, depositional continuity of the Upper Pennsylvanian or Permian Brock Canyon Formation with the Mesozoic Big Pole Formation cannot be substantiated without paleontological evidence.

BROCK CANYON FORMATION IN THE DRY HILLS

Poorly exposed sedimentary rocks of the Dry Hills are correlated by gross lithologic similarity with the Brock Canyon Formation of the Cortez Mountains. These rocks, dominantly, very fine grained sandstones, form talus slopes with few outcrops. Bedding is faint

---

[1] The classification of Gilbert (Williams, Turner, and Gilbert, 1954, p. 289–296) is used in this report. Arkose and arkosic indicate merely a high (greater than 25 percent) feldspar content and imply by themselves neither feldspar composition nor a granitic nor basement source terrane. Wackes are defined as unsorted or immature sandstones with greater than 10 percent clay- or silt-sized matrix (usually argillaceous); arenites are well-sorted sandstones with less than 10 percent matrix. The arkosic wacke and arkosic arenite of Gilbert's system correspond approximately to the feldspathic graywacke and arkose of Pettijohn (1957, table 48, p. 291).

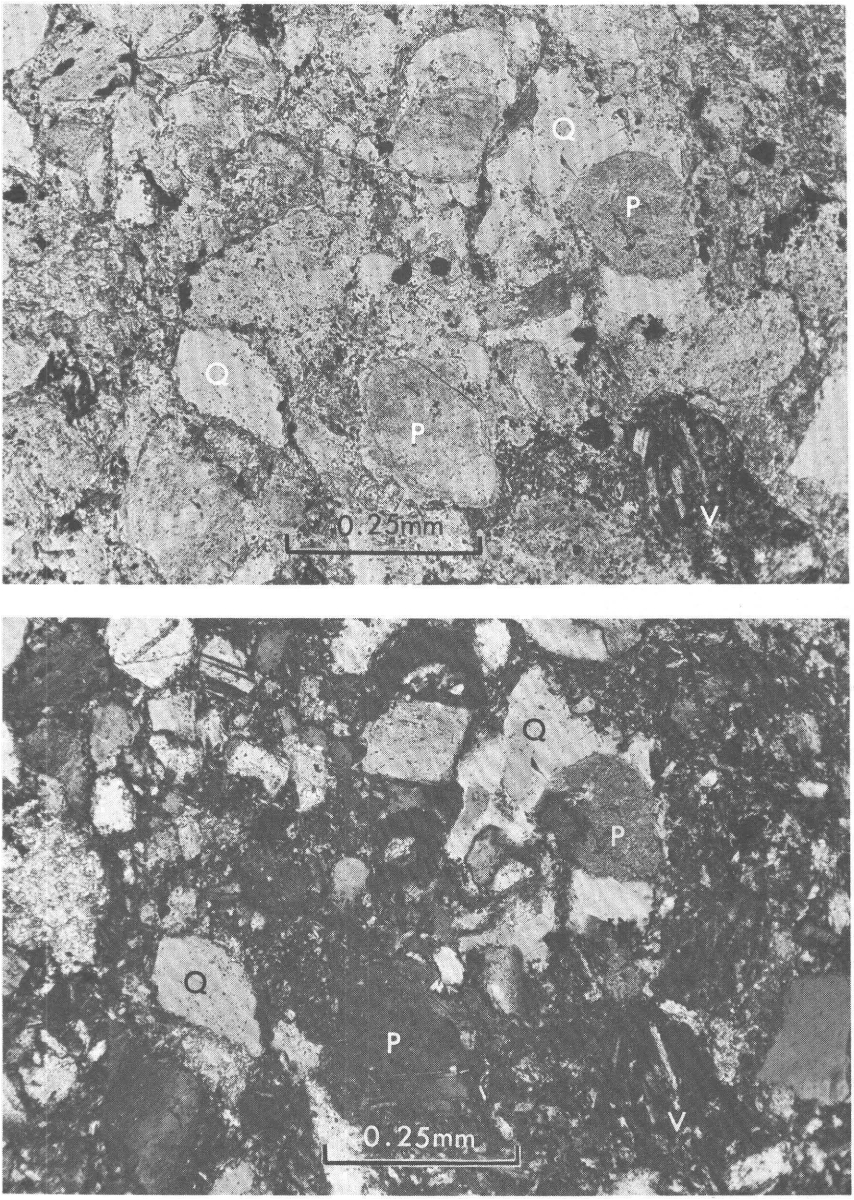

FIGURE 2.—Photomicrographs (upper—plane light; lower—crossed polars) of arkosic wacke of the Brock Canyon Formation. × 100. Note subparallel plagioclase laths in the volcanic fragment (V) at the lower right. Q, quartz; P, plagioclase. Compare with figure 3 of volcanic wacke from the Big Pole Formation. Photomicrographs taken by R. B. Taylor.

735-726 O-64-2

at best, and commonly has been completely obscured by the recrystallization that accompanied emplacement of Permian(?) and Lower Cretaceous(?) intrusive rocks. Stratigraphic and structral relations are speculative throughout most of the outcrop area, and thicknesses are unknown.

Gray and light brownish-gray fine-grained quartz (-chert) arenites and wackes are dominant near the west margin of the outcrop area. These rocks grade eastward into very fine grained arkosic wackes and sandy arkosic siltstones, probably equivalent to the arkose member in upper Cottonwood Canyon. The dolomite and claystone members are represented by conglomerate, dolomite, and reddish-gray siltstone found only in the fault block in the vicinity of E. 251,000, N. 2,071,500.

DEPOSITIONAL ENVIRONMENT AND PROVENANCE

The lower two members of the Brock Canyon Formation probably were deposited in an environment that alternated between continental and littoral or lagoonal conditions. The coarse clastic rocks suggest continental deposition, while the dolomites and plant-bearing siltstones are more compatible with lagoonal conditions. According to S. H. Mamay (written commun., 1959) *Taeniopteris* fragments collected from black siltstone at the base of the dolomite member seem "to represent the remains of a fairly lush vegetation preserved some distance from its site of growth, judging from the small size of most fragments." Common crossbedding in sandstones indicates shallow-water deposition.

The upper two members may well have been deposited in a continental environment. Carbonate rocks are absent, and poorly sorted clastic rocks are dominant.

The clastic rocks of the lower two members probably were derived from lower Paleozoic western facies cherts and quartzites. The absence of the basal dolomite in upper Cottonwood Canyon, and the increase of clastic material to the southeast (see unit 3, dolomite member, type section, p. 86) may indicate a local source area to the southeast. The feldspathic detritus of the light-green arkosic wacke which occurs sporadically in the dolomite member could have been derived from the Upper Cambrian Harmony Formation.

The flood of feldspathic detritus that characterizes the arkose member, however, finds no such ready source. The dominance of plagioclase grains over quartz suggests a nearby source, whereas the closest outcrop of Harmony Formation is in the Antler Peak quadrangle 40 miles to the northwest (Roberts, 1951). Also, the Harmony Formation is only one of many lower Paleozoic formations; feldspathic detritus from this arkose probably would have been greatly diluted with chert, quartzite, and other rock types.

Permian(?) volcanic rocks in the northeastern Dry Hills may be the source of the plagioclase, potash feldspar, and volcanic fragments in the arkose member of the Brock Canyon Formation.[2] This is pure conjecture, for the age of these dellenitic volcanic rocks is even more uncertain than that of the arkose member. Commencement of volcanic activity and degradation of the volcanic pile during Permian time could, however, account for the rather abrupt appearance of dominant feldspathic detritus in the Brock Canyon Formation.

REGIONAL STRATIGRAPHIC RELATIONS

The Brock Canyon Formation is part of the "overlap assemblage" (Roberts and others, 1958, p. 2821), which comprises coarse clastic rocks derived from highlands elevated during the Late Devonian to Early Pennsylvanian Antler orogeny. The overlap assemblage west of the orogenic belt is known as the Antler sequence, and east of the orogenic belt, as the Eureka-Carlin sequence.

The Frenchie Creek quadrangle was on or near the axis of the Antler orogenic belt (Roberts and others, 1958, fig. 6, p. 2825) and did not become a site of deposition until Late Pennsylvanian or Early Permian time. The rocks deposited at this time more closely resemble the Eureka-Carlin sequence than the Antler sequence. In particular, the conglomerate and the dolomite members may correspond to the unfossiliferous conglomeratic middle members of the Garden Valley Formation (Nolan and others, 1956), and the claystone member to the upper "red beds" member of the Garden Valley Formation, considered as latest Permian or earliest Triassic by Steele (1960). This correlation would require that the arkose member of the Brock Canyon Formation be of Triassic age.

Fossiliferous limestone forms the lower (Wolfcamp) member of the Garden Valley Formation (Nolan and others, 1956), and calcarenite, calcilutite, and coquinite are abundant in the Pennsylvanian and Permian sedimentary rocks near Carlin (Dott, 1955; Fails, 1960). Coarse clastic rocks are dominant in the Brock Canyon Formation of the Frenchie Creek quadrangle, however, and limestones are totally lacking.[3] These differences possibly indicate that the Frenchie Creek quadrangle was nearer the source area. The abundance of clastic detritus suggests muddy waters, and perhaps abnormally low salinity. Both conditions would be inimical to the deposition of fossiliferous limestone. The exclusively molluscan fauna of the basal dolomite of

[2] Arkoses need not be derived from a granitic terrane. Indeed, intermediate volcanic rocks could be an important source of detritus for arkosic wackes. The glassy or cryptocrystalline groundmass and the mafic minerals would be readily comminuted and altered to clay, chlorite, quartz, and other minerals and deposited as the matrix of arkosic wackes.

[3] The dolomites of the Brock Canyon Formation possibly were deposited as limestones and later dolomitized. Even if this were so, however, the carbonate rocks make up only a small part of the total sedimentary section.

the conglomerate member (p. 7) also suggests a depositional environment differing from that of the Eureka and Carlin areas, where fusulinids, brachiopods, and corals are abundant in the Pennsylvanian and Permian rocks.

PERMIAN(?) IGNEOUS ROCKS

The Permian(?) igneous rocks of the northeastern Dry Hills consist of three map units: (1) dellenitic volcanic rocks, (2) pyroxene dellenite porphyry,[4] and (3) alaskitic dellenite porphyry. A holocrystalline aphanitic groundmass is characteristic of these Permian(?) rocks, and all three map units are affected by alteration to a greater or lesser degree. The extreme difficulty experienced in identifying mineral phases of the groundmass in thin section—even with the use of staining techniques—led the writer to study these rocks by X-ray diffraction analysis of whole-rock powders and to attempt X-ray modal analysis. The insufficient number of samples, the modal variability of the map units, the lack of applicable determinative curves for minerals other than quartz (Tatlock, 1961, p. 337), and the inherent complexities of X-ray modal analysis, however, combined to preclude the presentation of the results in other than a qualitative form.

The pyroxene dellenite porphyry and the alaskitic dellenite porphyry appear to form hypabyssal plutons that intrude both the Upper Pennsylvanian or Permian Brock Canyon Formation and the Permian(?) dellenitic volcanic rocks, and are probably comagmatic with the volcanic rocks. It is possible that some of the alaskitic dellenite porphyry near the northeast border of its outcrop area is extrusive and should have been mapped with the dellenitic volcanic rocks (p. 17).

VOLCANIC ROCKS

The volcanic rocks of the northeastern Dry Hills are the southern extension of a volcanic sequence exposed over much of the Beowawe quadrangle. The writer made no attempt to trace exposures of these rocks more than about three-quarters of a mile into the Beowawe quadrangle. Recrystallized and (or) altered dellenite of several obscure textural varieties was the only volcanic rock type seen by the writer. This uniformity is in striking contrast to the heterogeneous aspect of the volcanic and sedimentary rocks of the Pony Trail Group (Jurassic, probably in part Triassic). The two volcanic sequences are nowhere in contact in the Frenchie Creek quadrangle, but it is possible that their stratigraphic relation is exposed in unmapped parts of the Beowawe quadrangle.

[4] Porphyry is used in accordance with the first definition given by Peterson (1961, p. 32): "A hypabyssal rock containing phenocrysts. 'Granite porphyry,' etc., imply that phenocrysts are set in a fine-grained phaneritic matrix; 'rhyolite porphyry,' etc., imply that phenocrysts are set in an aphanitic matrix."

Light-gray or tan holocrystalline dellenite is the most common rock type in the volcanic sequence of the northeastern Dry Hills. Parallel biotite flakes and color banding mark a faint megascopic foliation. Autobrecciated flows are common. Phenocrysts of oligoclase and biotite make up about 10 percent of the rock. The groundmass consists of plagioclase microlites enclosed in a complex micrographic intergrowth of orthoclase and quartz. The orthoclase crystals average 0.35 mm in size, whereas the enclosed anhedral quartz crystals are about 0.02 mm. This peculiar texture probably was formed by recrystallization of an original felted aphanitic groundmass during intrusion and alteration of the hypabyssal dellenite porphyries (p. 15–17).

One dellenitic(?) flow rock is extremely spherulitic. The spherulites are almost completely recrystallized to a granular aggregate of quartz and orthoclase, but the palimpsest radial and concentric structures of the spherulites are outlined by cryptocrystalline opaque material. This rock is abnormally rich in quartz (approximately 60 percent by X-ray modal analysis), probably owing to secondary silicification.

Subordinate varieties of dellenite include olive-green and dark-green rocks, some of which may have been of pyroclastic origin. These rocks contain phenocrysts of andesine and of clinopyroxene or amphibole. X-ray diffraction study indicates quartz in excess of 20 percent and an excess of plagioclase over orthoclase.

PYROXENE DELLENITE PORPHYRY

Pyroxene dellenite porphyry is found only in the northeastern Dry Hills, where it forms prominent dark-gray jointed outcrops. The contacts of pyroxene dellenite porphyry and other rock types are nowhere exposed.

The pyroxene dellenite porphyry contains phenocrysts of plagioclase, clinopyroxene, and biotite. Plagioclase is zoned from calcic andesine to oligoclase [5] and shows fleck sericite alteration. Clinopyroxene is commonly glomeroporphyritic and is wholly or partly replaced by biotite, by chlorite, and opaque material, or rarely by amphibole. The microgranitic groundmass consists of euhedral

[5] Determination of the composition of the plagioclase was hindered in both petrographic and X-ray diffraction study by the zoning, and in X-ray diffraction study also by the interference of the $1\bar{3}1$ peak of orthoclase with that of plagioclase. The plagioclase probably averages about An_{20}.

The $2\theta(131)$–$2\theta(1\bar{3}1)$ curve for pegmatites and granites (Smith and Yoder, 1956, fig. 3, p. 641) is used in X-ray determination of plagioclase throughout this report. Although rigorous application of the curve is prohibited by considerations of thermal state, the curve can be used for intrusive rocks as an approximate guide. X-ray determinations of composition of plagioclase from pre-Tertiary intrusive rocks of the Frenchie Creek quadrangle are consistent with optical determinations using low-temperature curves (Tröger, 1956 p. 111). In addition, the presence of orthoclase rather than sanidine in these intrusive rocks suggests that the plagioclase approximates a low-temperature state. Even if the plagioclase is of an intermediate thermal state, the low-temperature X-ray spacing curve gives a maximum percentage of anorthite.

plagioclase laths with interstitial quartz, orthoclase, and opaque material.

The pyroxene dellenite porphyry has undergone sporadic albitization along joints and in local breccias. Joints commonly are emphasized by adjacent bleached zones several inches in width. At one locality (E. 295,050, N. 2,082,950) massive rock with bleached zones along joints grades into a breccia of dark-gray porphyry fragments in a white matrix, the matrix corresponding to the bleached zones. Petrographic and whole-rock X-ray diffraction study showed this matrix to consist of fine-grained anhedral albite (An_{09} by X-ray spacing) with minor monoclinic potash feldspar and little or no quartz. Over 5 percent of this rock is sphene, and associated rutile and opaque material (ilmenite?) each constitute 1 percent.

ALASKITIC DELLENITE PORPHYRY

Alaskitic dellenite porphyry forms rounded, talus-mantled hills with poor outcrops. The rock is homophanous [6], white, streaked with limonite, and uniformly monotonous. A few outcrops show oval cavities about one-quarter inch long, some of which are filled with barite. A pink color of the rock near the west border of the outcrop area is the only systematic variant observed in the alaskitic dellenite porphyry.

The alaskitic dellenite porphyry is as uniform and monotonous in thin section as it is in the field. Phenocrysts consist of euhedral sericitized albite (An_{04-07} by $131-1\bar{3}1$ X-ray spacing) and subhedral orthoclase. Megascopic biotite flakes make up less than 1 percent of the rock, and commonly are either absent or replaced by muscovite and granular opaque material. The biotite flakes cut across albite phenocrysts and may be secondary. The groundmass is an aphanitic granular aggregate of anhedral albite, quartz, orthoclase, sericite, and sporadic calcite.

Owing to the absence of exposed contact relations, conclusive proof of the intrusive nature of the alaskitic dellenite porphyry is lacking. Quartzite screens, however, occur between the alaskitic dellenite porphyry and the granodiorite to the south and are analogous to those found between adjacent intrusive bodies in the Cortez Mountains and in other areas (for example, Bateman, 1961). Moreover, quartzite masses several hundred feet across occur within the alaskitic dellenite porphyry. These are more readily interpreted as xenoliths in a plutonic body than as xenoliths in volcanic rocks or as sandstones interbedded with volcanic flows.

---

[6] Homophanous is used following Buddington (1959, p. 678) to describe the absence of foliation or lineation in an intrusive igneous rock.

The contact of alaskitic dellenite porphyry and pyroxene dellenite porphyry is nowhere exposed, although its approximate trace is readily followed in float. In several areas, notably in the vicinity of E. 295,000, N. 2,082,000, there appears to be a complex intertonguing of the two porphyry types. Masses of pyroxene dellenite porphyry ranging in size from several feet to two-thirds of a mile occur sporadically in the alaskitic dellenite porphyry, and can be interpreted either as inclusions or as remnants of rock unaffected by hydrothermal alteration (p. 19).

Remnants of a light-gray alaskitic dellenite porphyry are distributed throughout the white alaskitic dellenite porphyry, and the white porphyry is probably the product of hydrothermal alteration of the light-gray porphyry. The light-gray pophyry forms only a fraction of a percent of the outcrop area of the alaskitic dellenite porphyry and is not discriminated on the geologic map (pl. 1). A large outcrop at E. 293,000, N. 2,079,800 shows irregular masses of gray slightly altered porphyry (H3589) as much as 20 feet across enclosed in white porphyry (H3590) and veined by it. The contact of the two types is gradational in detail. Chemical and normative data for these two varities of alaskitic dellenite porphyry are given in table 1. Despite the petrographic, field, and normative differences between the two varieties (table 2), the chemical change involved in the alteration of light-gray alaskitic dellenite porphyry to white alaskitic dellenite porphyry was very slight (table 3).

The alteration that converted light-gray alaskitic dellenite porphyry to white alaskitic dellenite porphyry probably also affected adjacent parts of the Permian(?) dellenitic volcanic rocks. The contact of the alaskitic porphyry and the volcanic rocks could not be located even approximately and is shown on the geologic map (pl. 1) as a gradational contact. The zone of gradation ranges in width from several hundred yards to three-quarters of a mile.

The possibility that the light-gray alaskitic dellenite porphyry represents an intermediate stage in the alteration of pyroxene dellenite porphyry to white alaskitic dellenite porphyry is considered in the next section (p. 19).

INFERRED PETROGENESIS

Approximate X-ray modal data indicate that, with the exception of the spherulitic volcanic rock (probably augmented in secondary silica), the compositional field of the volcanic rocks on a quartz-orthoclase-plagioclase diagram overlaps that of the alaskitic dellenite porphyry, suggesting that the two rock types are merely differing expressions of the same magma. Under this interpretation, the vol-

TABLE 1.—*Chemical analyses and norms of alaskitic dellenite porphyries*

[Standard rock analyses by C. L. Parker]

Chemical analyses

[Weight percents]

	Light-gray alaskitic dellenite porphyry (H3589) (E. 293,600, N. 2,079,800)	White alaskitic dellenite porphyry (H3590) (E. 293,600, N. 2,079,800)		Light-gray alaskitic dellenite porphyry (H3589) (E. 293,600, N. 2,079,800)	White alaskitic dellenite porphyry (H3590) (E. 293,600, N. 2,079,800)
SiO_2	72.74	74.55	H_2O^+	0.68	0.72
Al_2O_3	14.54	14.41	H_2O^-	.25	.32
Fe_2O_3	.29	.32	TiO_2	.17	.16
FeO	1.08	.07	P_2O_5	.03	.02
MgO	.24	.15	MnO	.17	.01
CaO	.66	.18	CO_2	.05	.01
Na_2O	3.64	3.05			
K_2O	5.19	5.65	Total	99.73	99.62

CIPW norms

[Weight percents]

	Light-gray (H3589)	White (H3590)		Light-gray (H3589)	White (H3590)
Q	29.29	34.58	ht	0	0.32
or	30.64	33.36	il	.32	.17
ab	30.76	25.78	rt	0	.07
an	2.78	.75	ap	.07	.03
C	1.92	3.00	cc	.11	.02
en	.60	.37			
fs	1.78	0	Total	98.69	98.45
mt	.42	0			

TABLE 2.—*Comparison of light-gray and white alaskitic dellenite porphyries*

Light-gray alaskitic dellenite porphyry (H3589)	White alaskitic dellenite porphyry (H3590)
Prominent outcrops of resistant gray rock.	Inconspicuous outcrops of punky white rock.
Sodic oligoclase.	Albite.
Euhedral lath-shaped plagioclase in groundmass.	Subhedral granular plagioclase in groundmass.
Fleck sericitization of plagioclase.	Pervasive sericitization of plagioclase.
0.5 percent biotite.	Biotite altered to muscovite and opaque granules.
Normative magnetite and ilmenite.	Normative ilmenite, hematite, and rutile.

canic sequence is discriminated from the alaskitic dellenite porphyry solely on the basis of fabric, and is considered to be a slightly older extrusive equivalent of the alaskitic dellenite porphyry.

The pyroxene dellenite porphyry is slightly more mafic than the alaskitic dellenite porphyry (the plagioclase is more calcic and the color index is higher) and therefore may represent an earlier liquid on a path of magmatic differentiation. The product of this inferred differentiation would have been an alaskitic magma that crystallized

TABLE 3.—*Chemical change involved in the alteration of light-gray alaskitic dellenite porphyry to white alaskitic dellenite porphyry*

[Method of presentation after Eskola (1954)]

	Loss (−) or gain (+) expressed in one-cation molecular percentages		*Loss (−) or gain(+) expressed in one-cation molecular percentages*
Si	+2.05	K	+0.61
Al	−.02	Ti	−.03
Fe^{+3}	+.02	P	−.02
Fe^{+2}+Mn	−.95	C	−.05
Mg	−.13	(OH)	+.60
Ca	−.45	Anions per 100 cations	+3.07
Na	−1.03		

to light-gray alaskitic dellenite porphyry and after emplacement was almost completely altered to white alaskitic dellenite porphyry.

Alternatively, the light-gray alaskitic dellenite porphyry (and consequently the white alaskitic dellenite porphyry) could have been produced by hydrothermal (possibly deuteric) alteration of the pyroxene dellenite porphyry. This interpretation is suggested by the probability (p. 17) that the light gray alaskitic dellenite porphyry altered to white alaskitic porphyry, and is consistent with the complex intertonguing of the pyroxene dellenite porphyry and the white alaskitic dellenite porphyry (p. 17). The absence of critical outcrops, the lack of chemical data for the pyroxene dellenite porphyry, and the insufficient number of specimens available for study do not permit confirmation of this suggestion. A possible argument against an alteration origin is the presence of pyroxene aggregates in the pyroxene dellenite porphyry and the complete absence of these as well as any pseudomorphs in the light-gray or white alaskitic dellenite porphyries.

AGE RELATIONS

The dellenitic volcanic rocks of the northeastern Dry Hills are probably pre-Cretaceous and post-Pennsylvanian. Known Tertiary volcanic rocks from north-central Nevada are only slightly altered or devitrified; Cretaceous volcanism, though not excluded, is unknown. Pre-Permian felsic volcanic rocks have not been found in northern Nevada. The Permian(?) age here assigned to the dellenitic volcanic rocks is based on tenuous indirect relations to the Pony Trail Group of Mesozoic, probably Jurassic, age and the Brock Canyon Formation of upper Pennsylvanian or Permian age.

Dissimilarities between the dellenitic volcanic rocks and the volcanic rocks of the Pony Trail Group suggest that the two sequences are not the same age. The sequences differ in mineralogic details, heterogeneity of chemical and mineralogic composition, heterogeneity of rock type (the Pony Trail Group commonly has interlayered flows of varying character, tuffs, and sedimentary rocks), character of alteration (strong potash enrichment in the Pony Trail Group), and physiographic expression. This argument of dissimilarity is strengthened by the fact that rocks of the Pony Trail Group in widely separated outcrop areas (Frenchie Creek, Pony Trail Canyon, and the Dry Hills southeast of Willow Corral Pass) can be recognized and readily correlated with specific formations of the group. Thus, while recognizing the lack of rigor in this argument, the writer considers it suggestive that the dellenitic volcanic rocks do not correlate with the Pony Trail Group.

In addition, unaltered Frenchie Creek Rhyolite (a formation of the Pony Trail Group) is in contact with altered alaskitic dellenite porphyry of Permian(?) age in the vicinity of E. 290,300, N. 2,074,600, southeast of Willow Corral Pass (the alaskitic dellenite porphyry is probably comagmatic with the Permian(?) dellenitic volcanic rocks; see p. 17). Poor outcrops make it impossible to determine the nature of the contact. If this contact is either an unconformity or a fault of small displacement, however, it may be significant that the Frenchie Creek Rhyolite (a black rhyodacite at this locality) shows none of the features of alternation that are characteristic of the alaskitic dellenite porphyry (p. 17 to 18). This would suggest that the intrusion and alteration of the alaskitic dellenite porphyry took place before eruption of the Mesozoic (probably Jurassic) Frenchie Creek Rhyolite.

The abrupt appearance of feldspathic detritus in the arkose member of the Brock Canyon Formation may reflect the beginning of volcanism in the northeastern Dry Hills, with degradation of the volcanic pile during and soon after eruption. Even if this tenuous correlation is accepted, however, the age of the volcanic rocks is only suggested, for the arkose member of the Brock Canyon Formation is unfossiliferous and only questionably assigned to the Permian.

If the tentative age assignment of the dellenitic volcanic rocks of the northeastern Dry Hills is correct, the apparently comagmatic dellenite porphyries are also Permian(?). The alaskitic dellenite prophyry, however, contains large inclusions of feldspathic quartzite (Brock Canyon Formation) probably derived from degradation of the Permian(?) volcanic pile. Therefore, the dellenite porphyries must have been emplaced somewhat after the eruption of the volcanic rocks, but still could well be Permian(?).

MESOZOIC VOLCANIC AND SEDIMENTARY ROCKS

PONY TRAIL GROUP

Mesozoic volcanic and sedimentary rocks found in the northeastern part of the Cortez Mountains in the Frenchie Creek, Pine Valley, Carlin, and Beowawe quadrangles are here named the Pony Trail Group. This group is divided into three new formations: in ascending order, the Big Pole Formation, the Sod House Tuff, and the Frenchie Creek Rhyolite. All three formations are internally heterogeneous and of varying thickness. An unconformity probably separates the Big Pole Formation and the Sod House Tuff.

The type section for the group is here designated as Pony Trail Canyon in the Frenchie Creek and Pine Valley quadrangles (from the mouth of the canyon at E. 310,500, N. 2,068,300 eastward along the main canyon into the Pine Valley quadrangle). The beds in this section strike north and dip gently to the east. There is much local variability in bedding attitude, and a few small comagmatic rhyolite plugs intrude the sequence.

The Big Pole Formation in the type section is truncated to the west by the Crescent fault. Stratigraphically lower beds corresponding to those cut out by this fault are found in the Big Pole Creek area, but the base of the formation is nowhere exposed. The upper part of the Frenchie Creek Rhyolite in the type section lies outside the Frenchie Creek quadrangle and has not been mapped by the writer. J. F. Smith (written commun., 1962), however, has found the formation to be overlain unconformably by Lower or lower Upper Cretaceous sedimentary rocks.

The thickness of the group is uncertain, owing to alteration and deformation in the Frenchie Creek area, to the variable thicknesses of individual flows and tuffs, and to the near absence of reliable bedding in the upper two formations. The type section in Pony Trail Canyon is probably about 3,500 feet thick, but much of the Big Pole Formation is cut out by the Crescent fault. The thickness in the Frenchie Creek and Big Pole Creek areas may be as much as 10,000 feet. Owing to the structural uncertainty and the variations in thicknesses and lithology, no sections were measured.

These volcanic and sedimentary rocks are Mesozoic, not Tertiary as suggested by previous workers (Shaw and others, 1961; Lehner and others, 1961). No fossils were found in these rocks in the Frenchie Creek quadrangle. J. F. Smith and K. B. Ketner collected dinosaurian tooth fragments from the mudstones in the uppermost Frenchie Creek Rhyolite in the adjoining Pine Valley quadrangle to the east. Barnum Brown and Edward Lewis (written commun., 1961) identified these fossils as a Theropod and ?Ankylosaurid, probably of Cretaceous age. In view of the overlying Lower or lower Upper Cretaceous sandstones and conglomerates of Pine Valley,[7] the group can be no younger than Early Cretaceous, and probably is Jurassic. A Triassic

[7] Plant fragments and pollen were collected from these continental sedimentary rocks in the Pine Valley quadrangle by J. F. Smith, K. B. Ketner, and J. A. Wolfe. The plants were identified by J. A. Wolfe (written commun., 1959) as Cretaceous. The pollen were designated by E. B. Leopold (written commun., 1959) as of Early Cretaceous or early Late Cretaceous age.

age for lower parts of the group, particularly for the Big Pole Formation, is not ruled out by the meager paleontologic evidence.

Samples for potassium-argon geochronology were collected by R. L. Armstrong from the Frenchie Creek Rhyolite and the Sod House Tuff, but the analytical ages are not yet available.

In general, the Frenchie Creek Rhyolite corresponds to the "older volcanic rocks" of the Eureka County map (Lehner and others, 1961). The Sod House Tuff and the Big Pole Formation were included in the "younger volcanic rocks" of that map, but were found by the present writer to lie stratigraphically beneath the Frenchie Creek Rhyolite. All three formations are cut by Lower Cretaceous(?) plutons.

Iron mineralization and several types of associated hydrothermal alteration affected the Pony Trail Group. Iron ore deposits are restricted to the Frenchie Creek Rhyolite, but the other two formations were subjected to minor enrichment in iron. Kaolinization affected all three formations, as well as the arkose member of the Brock Canyon Formation and a large part of the Duff Creek chonolith. Intensive sericitization produced the subordinate green tuffs in the Sod House Tuff. Silicification affected the Frenchie Creek Rhyolite locally in the Frenchie Creek area. All these phenomena are interpreted as having taken place in a single period of alteration, probably during the Cretaceous.

A comprehensive study of this alteration is beyond the scope of the Frenchie Creek project, but presents an attractive problem for future research.[8] In this report, altered rocks are described and discussed along with the primary geologic units in which they occur.

BIG POLE FORMATION

The Big Pole Formation is here named after Big Pole Creek, which drains the area of most extensive outcrop of the formation. This area, however, consists of talus-covered hills with little material in place. The type locality is therefore designated as Pony Trail Canyon, even though only the upper 700 feet of the formation are exposed there. The Big Pole Formation in the Big Pole Creek area may be as much as 6,000 feet thick, but this estimate is of low reliability owing to the possibility of much repetition by unidentified faults.

The most common rocks in the formation are volcanic wackes.[9]

[8] Of particular interest would be an analysis of the chemical and physical properties of the volcanic rocks in an attempt to isolate those factors that determined the type of alteration expressed in a given primary rock type (that is sericitization, kaolinization, silicification, or iron mineralization).

[9] The descriptive term "volcanic wacke" is used in preference to the term "graywacke." As defined by Gilbert (Williams, Turner, and Gilbert, 1955, p. 293), graywackes are "hard, dark-colored rocks having a low porosity. They are consolidated by a dark-colored, firmly indurated matrix, which has the general composition of slate or argillite and contains an abundance of very fine-grained micaceous and chloritic minerals." Neither a dark color nor a dark chloritic matrix is characteristic of the sedimentary rocks of the Big Pole Formation. In addition, "graywacke" has come to imply a marine eugeosynclinal environment. The writer does not intend such an implication for the Big Pole Formation.

These rocks are uniform, fine- to medium-grained, and usually light brown or light brownish gray (local intense red color is due to secondary hematite; white and green volcanic wackes occur near intrusive contacts). Bedding averages 1 to 3 inches, and both current bedding and graded bedding were found.

A typical volcanic wacke (fig. 3) contains subequal amounts of volcanic fragments (showing trachytic texture), plagioclase (An_{30-35}) and quartz, with a matrix of microcrystalline quartz, comminuted volcanic detritus, argillaceous material, and chlorite(?). Quartz cement occurs sporadically, and secondary calcite is common. The rock is typically poorly sorted. Plagioclase and quartz are subangular; volcanic fragments, subrounded.

The volcanic wackes grade with decrease in matrix into volcanic arenites, and with addition of glass shards (now devitrified) into tuffaceous volcanic wackes. The latter are found in Pony Trail Canyon near the top of the formation; they are dark green, and contain a higher percentage of chlorite than do the volcanic wackes of the Big Pole Creek area.

The volcanic wackes are highly recrystallized near intrusive contracts with Lower Cretaceous(?) plutons. The trachytic texture of lithic fragments is obliterated, kaolinite replaces feldspar and lithic fragments, and the quartz grains develop extensive lacy overgrowths. In hand specimen this recrystallization is expressed by bleaching, irregular limonite staining, and destruction of clastic texture. These effects may extend up to 325 feet from the intrusive contact.

Flows of intermediate composition are interlayered with volcanic wacke in the upper 500 to 1,000 feet of the formation. These flows are not distinguished from the rest of the formation on the geologic map (pl. 1), but probably could be mapped as a member.

The least altered flows crop out in Pony Trail Canyon. These rocks consist of andesine phenocrysts and chlorite-calcite pseudomorphs after biotite, in a trachytic plagioclase-rich groundmass. Quartz amygdules are common. Flow breccias occur sporadically. Chemical analysis of a typical specimen from near Pony Trail Canyon indicates a rhyodacite composition (table 4).

Recrystallized and altered flows occur immediately beneath the Sod House Tuff to the north of Big Pole Creek and in Sheep Creek Canyon. The less altered rhyodacites(?) are gray to black amygdaloidal flows in which phenocrysts of shattered clinopyroxene and chlorite pseudomorphs (after orthopyroxene?) are in a recrystallized felted plagioclase-rich groundmass. Distinctive tan rhyolites(?) show complete replacement of phenocrysts by sericite, along with recrystallization, sericitization, and silicification of a felted groundmass. Highly altered gray amygdaloidal flows (rhyolite?) are common, and contain

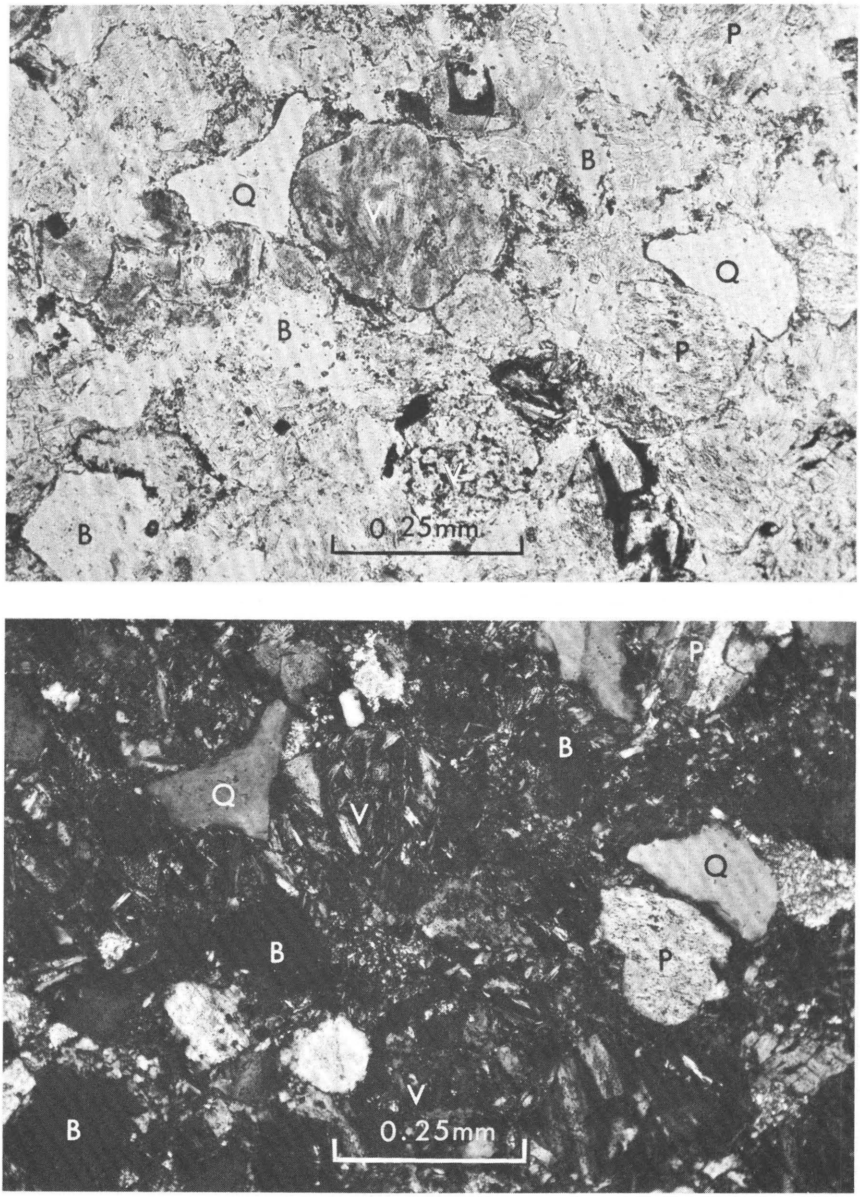

FIGURE 3.—Photomicrographs (upper—plane-polarized light; lower—crossed polars) of a typical volcanic wacke from the Big Pole Formation. × 100. Q, quartz; P, plagioclase; B, plucked areas. Note the trachytic orientation of plagioclase laths in the volcanic fragment (V) at the lower center. Compare with figure 2 of arkosic wacke from the Brock Canyon Formation. Photomicrographs taken by R. B. Taylor.

TABLE 4.—*Chemical analysis, norm, and mode of a rhyodacitic greenstone from the Big Pole Formation*

[Specimen H3595; location E. 309,450, N. 2,064,600. Standard rock analysis by C. L. Parker]

Chemical analysis (weight percents)		CIPW norm (weight percents)		Mode (volume percents)	
SiO_2	60.63	Q	17.79	Plagioclase	4.6
Al_2O_3	15.29	or	16.35	Chlorite	7.8
Fe_2O_3	2.93	ab	30.60	Opaque material	x
FeO	2.88	an	12.51	Quartz amygdules	4.5
MgO	3.36	C	1.75	Groundmass [1]	83.1
CaO	3.69	en	8.33		
Na_2O	3.62	fs	1.64	Total	100.0
K_2O	2.77	mt	4.25		
H_2O^+	2.02	il	1.69		
H_2O^-	.69	ap	.52		
TiO_2	.89	cc	1.55		
P_2O_5	.23				
MnO	.12	Total	96.98		
CO_2	.68				
Total	99.80				

[1] Recognized minerals in groundmass include plagioclase, chlorite, and an opaque mineral. Staining of a cut slab with sodium cobaltinitrite suggests the presence of potash feldspar.

potash feldspar phenocrysts almost completely replaced by sericite. In several specimens, volcanic textures were almost completely obscured by introduction of iron oxides, producing vuggy rocks composed of quartz, hematite, and limonite.

Poorly exposed rocks to the east of the conspicuous north-trending fault in the Modarelli mine area are assigned to the Big Pole Formation. The most common rock types in this area are maroon and black flows (rhyodacite?). Subordinate rock types include tan flows similar to those near the top of the member in Little Pole Creek, and volcanic wackes. Both flows and sedimentary rocks have undergone intense kaolinization, sporadic hematite mineralization, and local brecciation.

The Big Pole Formation apparently was deposited in a rapidly subsiding basin in a tectonically active volcanic area. Features that would characterize the depositional environment were not observed. If the rocks were laid down in a marine environment, it probably was shallow, at least in part, for local crossbedding suggests deposition above wave base.

A nearby source area is indicated by the poorly sorted detritus and by the abundant unstable constituents. The primary source terrane was volcanic, possibly the Permian(?) volcanic rocks of the northeastern Dry Hills. A secondary source terrane, probably Paleozoic clastic rocks, is required to supply locally abundant subrounded quartz grains.

The depositional environment of the volcanic wacke member differs from a typical flysch environment (Pettijohn, 1957, p. 615) in the complete absence of interbedded shale and chert. Turbidity currents, however, may in part have been the agents of deposition, as suggested by the graded bedding.

SOD HOUSE TUFF

The Sod House Tuff is here named after Sod House Creek, which drains part of an extensive area of poor outcrops of the formation. The type section, however, is in Pony Trail Canyon.

Altered white silicic ash-flow tuff is the predominant rock type in the formation.[10] Subordinate green ash-flow tuff was probably identical to the white tuff at the time of deposition, but later underwent sericitization. A few individual tuffs were reworked by water soon after deposition, resulting in interlayered current-bedded sandstones. Silicic flows occur sporadically throughout the formation.

The Sod House Tuff ranges in thickness from zero to possibly 1,000 feet. The formation is about 300 feet thick at the type locality in Pony Trail Canyon, and appears to pinch out to the southeast. If it is assumed that bedding dips gently, the thickness of the formation in the Sod House Creek and Big Pole Creek areas can be estimated to be approximately 1,000 feet. Such an assumption is supported by distant views of the area and by the generally low dipping, but variable, compaction foliation. Reliable bedding orientation could be determined only locally, owing to poor outcrops and to scarcity of interbedded sandstone. The formation appears to thin abruptly northeastward from Big Pole Creek, but may be affected by unidentified faults. The thickness and stratigraphy of the Sod House Tuff in the Cave Canyon area are unknown, as the rocks are highly recrystallized and virtually impossible to distinguish in the field from altered porphyritic alaskite of Early Cretaceous(?) age.

The Sod House Tuff is at least locally unconformable on the Big Pole Formation. In Pony Trail Canyon the contact is irregular; the lower beds of the Sod House Tuff are sandstones, which appear to have been deposited in depressions on an eroded surface cut in volcanic wacke. Slumping and minor faulting (maximum of 6 inches slip) affected beds both above and below the contact, and probably occurred at or shortly after the time of deposition. In Sheep Creek Canyon and in Big Pole Creek the Big Pole Formation dips steeply under gently dipping ash-flow tuffs, suggesting an angular unconformity. The apparent variation in thickness of the Sod House Tuff may indicate deposition on an irregular topographic surface. The existence of an unconformity is compatible with the active tectonic environment inferred from the poorly sorted and immature detritus of the Big Pole Formation.

---

[10] See Ross and Smith (1961) for an exhaustive discussion of the nomenclature and characteristics of ash-flow tuffs, variously called welded tuffs or ignimbrites by many writers.

The Sod House Tuff lies below the Frenchie Creek Rhyolite, contrary to the conclusions of Lehner and others (1961) and Shawe and others (1962). This relation is unequivocal in Pony Trail Canyon, but is less clearly indicated in other areas owing to poor outcrops. The actual contact is exposed only in the highly kaolinized zone east of the Modarelli mine. This interpretation of the Sod House Tuff as older than the Frenchie Creek Rhyolite is stregthened by the almost complete absence of flow rock xenoliths in the ash-flow tuffs.

The ash-flow tuffs commonly weather to rounded featureless hills; the Sod House Tuff forms cliffs only in the Pony Trail Canyon area and near the mouth of Frenchie Creek. Individual tuffs cannot be traced laterally, for recrystallization and (or) alteration obliterated any primary megascopic distinctions. Most outcrops are massive; foliation, where present, is expressed by eutaxitic alinement of relic pumice fragments. This foliation only approximates bedding (as determined by sandstone interbeds), and cannot be used as a stratigraphic or structural datum in the absence of the sandstones.

Inclusions are common in the ash-flow tuffs. Autoliths of buff-colored ash-flow tuff, averaging one-half inch in diameter, locally make up 10 percent of the rock. Xenoliths are much less abundant than autoliths and are of smaller size. These foreign rock fragments include fine-grained gray and pink quartzite, gray chert, and gray and green siltstone.

All the ash-flow tuffs have undergone granophyric recrystallization. The groundmass material now consists of an aphanitic intergrowth of quartz, feldspar, sericite, clouds of submicroscopic opaque material, and sporadic kaolinite. These recrystallization (and alteration) products are not primary (in the sense of Smith, 1960, p. 156), but probably formed during the Early Cretaceous(?) episode of pluton intrusion. Many specimens show intense replacement of the groundmass by rosettes of microcrystalline kaolinite.

Ghosts of shards and of pumice fragments occur as areas relatively free of disseminated submicroscopic opaque material. A few shards show axiolitic structure, and the characteristic banded internal structure of collapsed pumice fragments (Ross and Smith, 1961, p. 63–64) is preserved in some specimens (fig. 4). The pumice fragments are relatively free of megascopic quartz and sanidine crystals, and commonly are alined in a crude eutaxitic foliation. In many white tuffs, the pumice fragments were replaced preferentially by kaolinite; the resulting irregular clay masses weather to limonite-stained pits. Pumice fragments in green tuffs have been replaced by dense sericite, and appear as dark-green streaks in a light-green groundmass containing a lesser quantity of sericite.

735–726 O–64–3

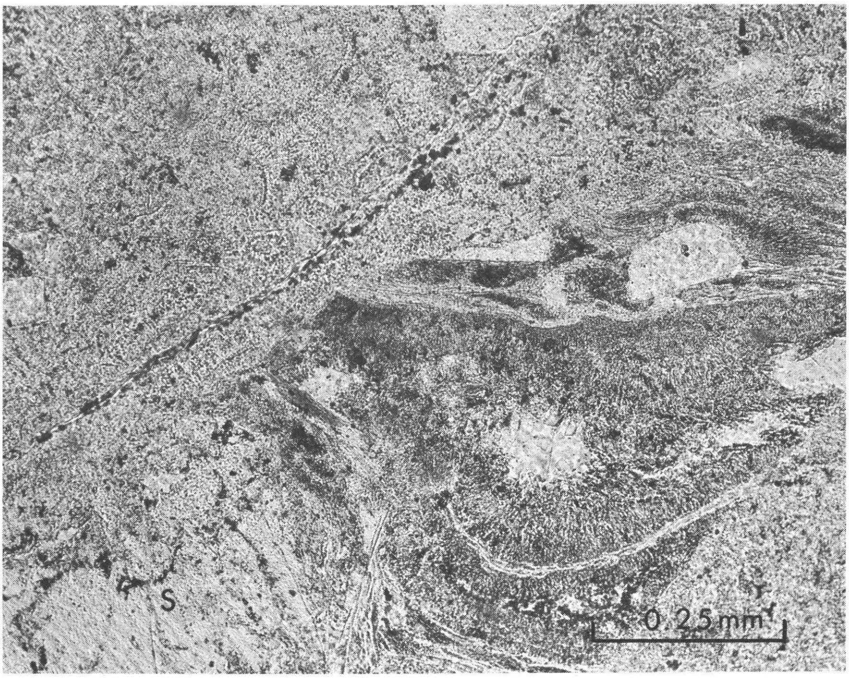

FIGURE 4.—Photomicrograph of a kaolinized ash-flow tuff from the Sod House Tuff, showing relic primary pumice fragments and shards. × 100. Plane light. Note the banded structure (subhorizontal in the photograph) in the pumice fragment at right. At top left are a number of ill-defined shards. S, sanidine. Photomicrograph taken by R. B. Taylor.

The extent and intensity of welding are uncertain owing to the common obliteration of primary textures by recrystallization, kaolinization, or sericitization. Pumice fragments showed compaction wherever they were recognized, but welded shards were seen only in a specimen from one of the ash-flow tuff hills east of the main range. Shards in the Sod House Tuff are usually undistorted (fig. 4; compare Ross and Smith, 1961, figs. 16–23, p. 56–57).

The white (locally light-gray) ash-flow tuffs commonly contain phenocrysts of quartz (about 20 percent), sanidine (about 10 percent), and minor biotite in a granophyric groundmass, which in many specimens is kaolinitic. A few samples contain abundant phenocrysts of sodic plagioclase. Quartz crystals range in size from <0.1 mm to >2.5 mm. The larger crystals (>0.5 mm) are rounded and embayed; the smaller ones (<0.5 mm) are angular, with crescent- or wedge-shaped outlines. These smaller crystals are the products of shattering of phenocrysts along conchoidal fracture surfaces, with dispersal of the resulting fragments in the groundmass. Arrested stages of this process show fractured phenocrysts, with the fragments slightly separated and rotated. The presence of groundmass material between these fragments indicates that the fracturing took place before final solidification of the magma. Sanidine crystals are also broken, but form rectangular fragments bounded by cleavage surfaces.

Specimen H3594, from the Pony Trail Canyon area, was selected in the field as typical of the white tuffs of the formation. Chemical analysis (table 5) shows that the specimen is high in potash relative to an average calc-alkali rhyolite, and low in soda, lime, and total iron. These aberrant chemical characteristics are particularly striking when the analysis is recalculated to normative minerals. Figure 5 shows that this white ash-flow tuff plots nowhere near the central low-temperature sink of the system SiO_2–$NaAlSi_3O_8$–$KAlSi_3O_8$, and is therefore unlikely to be the product of typical magmatic differentiation (Thornton and Tuttle, 1960).

A potash-rich magma could possibly be produced by a high degree of reaction of primary plagioclase crystals with a melt, followed by separation of crystals and the potash-rich melt (Bowen, 1956, p. 227–233; Noble, 1948, p. 934–938). Such a course of fractional crystallization and differentiation appears unlikely but cannot be

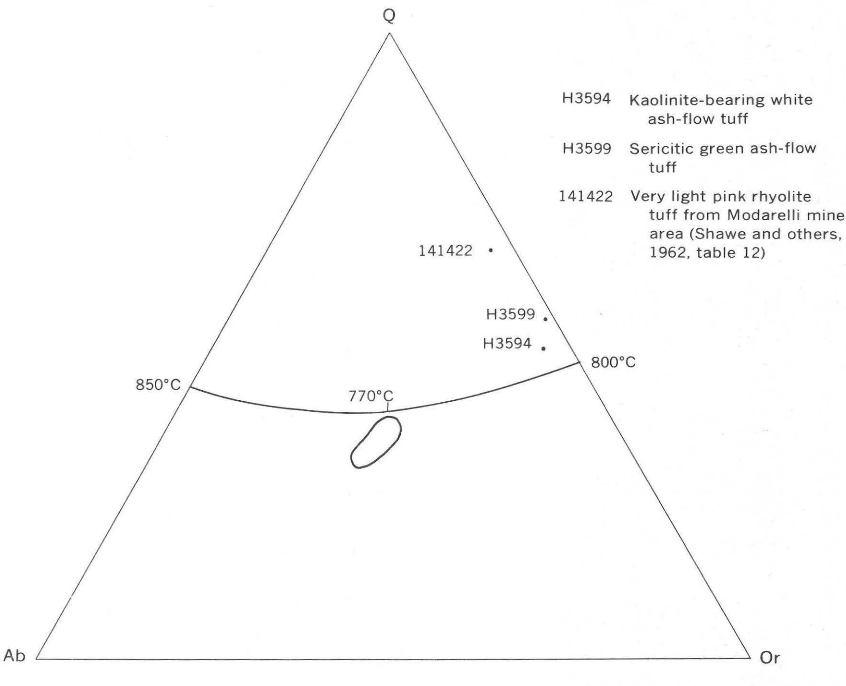

FIGURE 5.—Diagram showing the relation of three samples of the Sod House Tuff to the quartz-feldspar cotectic in the experimental system SiO_2–$KAlSi_3O_8$–$NaAlSi_3O_8$–H_2O at 500 kg per cm^2 water pressure. CIPW normative percentages are plotted. Experimental diagram taken from Tuttle and Bowen (1958, figs. 22, 38, and 41). Outlined area is the 5 percent maximum of normative quartz, orthoclase, and albite of the 362 extrusive rocks listed by Washington (1917) that carry 80 percent or more Q+Or+Ab.

TABLE 5.—*Chemical analyses, norms, and modes of ash-flow tuffs from the Sod House Tuff*

[Standard rock analyses (H3594 and H3599) by C. L. Parker; rapid rock analysis (141422) by K. E. White and P. L. D. Elmore. Nd.=not determined]

	White ash-flow tuff (H3594) (E. 310,650, N. 2,063,750)	Very light pink tuff (141422)[1]	Green ash-flow tuff (H3599) (E. 295,650, N. 2,049,800)	Average calc-alkali rhyolite [2]
Chemical analyses [Weight percents]				
SiO_2	76.87	77.4	73.73	73.66
Al_2O_3	12.00	11.8	12.66	13.45
Fe_2O_3	.86	1.2	3.21	1.25
FeO	.05	.08	.38	.75
MgO	.20	.62	.45	.32
CaO	.22	.32	.23	1.13
Na_2O	.46	.38	.08	2.99
K_2O	7.33	4.6	6.57	5.35
H_2O^+	1.16	3.7	1.77	.78
H_2O^-	.19	Nd.	.25	Nd.
TiO_2	.24	.16	.14	.22
P_2O_5	.05	.07	.02	.07
MnO	.02	.01	.02	.03
CO_2	.01	.05	.15	Nd.
Total	99.66	100.39	99.66	100.00
CIPW norms [Weight percents]				
Q	45.49	56.3	47.34	33.2
or	43.26	27.1	38.75	31.7
ab	3.88	3.2	.68	25.1
an	.67	.8	.11	5.0
C	3.07	5.9	5.44	.9
en	.50	1.5	1.12	.8
mt	-----	-----	.88	1.9
ht	.86	1.2	2.61	-----
il	.15	.2	.27	.5
rt	.16	.1	-----	-----
ap	.13	.2	.03	Nd.
cc	.02	.1	.34	Nd.
Total	98.19	96.6	97.57	99.1
Modes [Volume percents]				
Quartz	18.4	Unknown	13.4	-----
Sanidine	3.4	do	9.2	-----
Plagioclase	.1	do	-----	-----
Biotite	.4	do	-----	-----
Opaque mineral	.1	do	1.4	-----
(holes)	7.8	do	-----	-----
Groundmass	[3] 69.8	do	[4] 76.0	-----
Total	100.0	do	100.0	-----

[1] Shawe and others (1962, table 12).
[2] Nockolds (1954, p. 1012).
[3] Holocrystalline. Includes kaolinite and sericite.
[4] Holocrystalline. Includes sericite.

ruled out, particularly in view of the potash-rich glasses found by Swineford and others (1955) in the late Tertiary ash-fall tuffs of Kansas and Nebraska.[11]

It appears equally possible to the writer, however, that these kaolinite-bearing tuffs of the Sod House Tuff were somewhat enriched in K_2O by hydrothermal fluids related to the period of iron mineralization. This hypothesis is supported by the alteration of near-normal calc-alkali rhyolites of the Frenchie Creek Rhyolite to potash-rich rocks in the vicinity of the Modarelli mine (table 7).

Specimen 141422 (table 5; Shawe and others, 1962, table 12) is a very light pink tuff from the Sod House Tuff near the Modarelli mine. The chemical characteristics of this specimen are also anomalous and are brought out by the high normative quartz, orthoclase, and corundum. The mineralogy of this sample is unknown.

The green ash-flow tuffs were intensely sericitized. Microscopic characteristics include (1) abundant disseminated sericite in the groundmass, (2) replacement of pumice fragments by dense mats of sericite, and (3) replacement of sanidine phenocrysts by goethite and sericite (fig. 6). Although chemical data are not available for the more intensely sericitized tuffs, a partially sericitized light-green tuff from near the mouth of Frenchie Creek was analyzed (specimen H3599, table 5). In addition to being extremely low in Na_2O and CaO and high in K_2O, this rock contains an anomalously high amount of iron, particularly ferric iron. This high ferric iron is emphasized by the high percentage of hematite in the norm. The aberrant chemical composition of this light-green tuff is shown in figure 5. All three analyzed specimens from the Sod House Tuff appear to be arrested stages of hydrothermal alteration, the ultimate product being highly sericitized dark-green ash-flow tuff.

The ash-flow tuffs in areas of granodiorite or alaskite intrusion are intensely recrystallized. Extensive lacy overgrowths occur on quartz phenocrysts, and sanidine phenocrysts are replaced by microcrystalline quartz, kaolinite, sericite, and calcite. Untwinned poikiloblastic albite is common, and some of it may represent altered plagioclase phenocrysts. The groundmass material is coarser than in the less highly recrystallized tuffs and contains quartz, plagioclase, potash feldspar, an opaque mineral, epidote(?), and sporadic andalusite. Megascopic characteristics of this recrystallization include a brilliant white color and almost complete obliteration of volcanic fabric.

Several small altered felsic flows are interlayered with the ash-flow tuffs. These varicolored rocks contain phenocrysts of plagioclase

---

[11] Truesdell (1962) briefly reports that natural glasses undergoing low-temperature chemical alteration may gain K_2O and H_2O and lose Na_2O while remaining glassy.

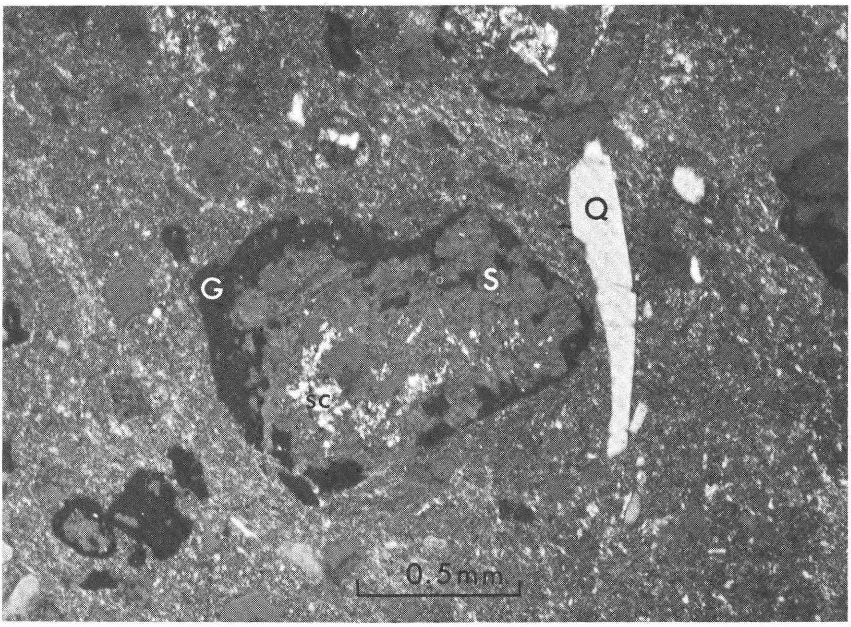

FIGURE 6.—Photomicrograph of sericitized green ash-flow tuff from the Sod House Tuff. × 44. Obliquely crossed polars. Phenocrysts of sanidine (S) are rimmed and penetrated by goethite (G), and their cores are altered to sericite (sc). In other specimens the replacement of sanidine by goethite is complete. Q, quartz.

(intensely argillized) and biotite in a recrystallized groundmass showing a ghost felted texture.

FRENCHIE CREEK RHYOLITE

The Frenchie Creek Rhyolite is best exposed in the type section in Pony Trail Canyon, where it is about 2,500 feet thick. Reconnaissance indicates other good stratigraphic sections to the northeast in the Pine Valley quadrangle. In the canyon of Frenchie Creek (after which the formation is here named) the Frenchie Creek Rhyolite is highly brecciated, altered, and mineralized, and only a few individual flows can be mapped. Correspondingly, the stratigraphy of the formation in this area is imperfectly understood, and the thickness is unknown. A small patch of rhyodacite(?) in the Dry Hills probably belongs to the Frenchie Creek Rhyolite.

The formation consists predominantly of maroon or black rhyolite and rhyodacite flows. Subordinate rock types include altered green and white flow breccias and scarce volcanic wackes. No ash-flow tuffs were recognized in the member.

Flow layering in these rocks is expressed by (a) orientation of biotite and plagioclase phenocrysts, (b) streaks and wisps of deuteric quartz (fig. 7; compare Woods and Eckelmann, 1962), (c) trachytic texture, and (d) variation in content and grain size of opaque granules in the groundmass. Attempts to utilize flow layering in structural interpretation proved futile. Layering in single outcrops commonly is convoluted, and attitudes in adjacent outcrops may differ widely. Only in the Pony Trail Canyon area is there any suggestion of parallelism of flow layering and attitude of flow units, and even in this area extreme divergence is the rule.

The rocks of the Frenchie Creek Rhyolite were originally vitrophyric, but the glass is now devitrified and commonly altered. Relic pilotaxitic or felted textures of plagioclase microlites can be seen in some specimens. In many rocks, however, alteration or contact metamorphism has completely recrystallized the groundmass material to a micrograinitic aggregate.

Phenocrysts make up 2 to 30 percent of these flow rocks, and groundmass material, much of which could not be identified with the petrographic microscope, the other 70 to 98 percent. Petrographic names were necessarily based on phenocryst composition, and were proven by chemical analyses to be in error. Therefore, where possible, the

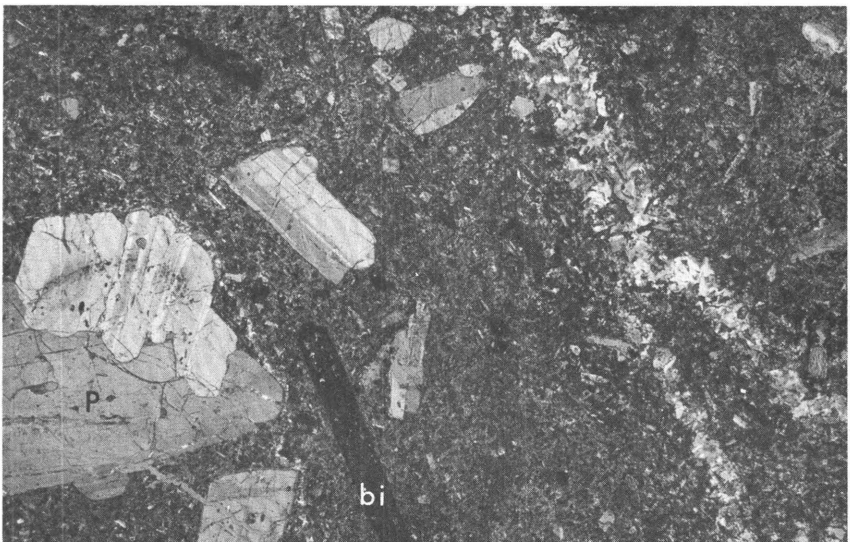

FIGURE 7.—Photomicrograph of a rhyolite from the Frenchie Creek Rhyolite, showing flow layering. × 21. Obliquely crossed polars. On the right the foliation is followed in part by an irregular branching streak of deuteric quartz. A similar zone passes between the largest plagioclase (P) crystal and a conspicuous biotite (bi) crystal (now almost completely replaced by opaque material). The phenocrysts show an approximate alinement in the foliation.

rock names given below are based directly on chemical analyses or determined indirectly by the establishment of petrographic identity with a chemically analyzed specimen. Names for those varieties for which there are no available chemical analyses were based on thin-section petrography, and are followed in the text by a query.[12]

Rhyolite is the most common rock type in the formation. The less intensely altered examples are maroon or black, with conspicuous flow layering (fig. 7). Phenocrysts of plagioclase (zoned from labradorite to andesine), biotite (partly replaced by granular opaque material), and quartz make up 5 to 30 percent of the rock. The groundmass is trachytic or felted, and is rich in plagioclase and chlorite. Sanidine phenocrysts occur sporadically. Apatite and sphene are characteristic accessory minerals. Phenocryst quartz may be absent. Although the phenocryst mineralogy suggests a dacitic composition, chemical analyses of two specimens show that this rock type is a calc-alkali rhyolite (table 6).

Featureless flows of light-gray rhyolite(?) form prominent cliffs at the base of the formation in Pony Trail Canyon. Microphenocrysts (about 0.3 mm in size) consist of plagioclase and biotite, and make up only 2 to 6 percent of the rock. The remaining 94 to 98 percent is a recrystallized color-banded trachytic groundmass containing feldspar, quartz, sericite, an opaque mineral, and very sparse biotite. In several specimens the plagioclase microphenocrysts have been replaced by microcrystalline quartz.

A distinctive highly altered flow breccia, probably of rhyolitic(?) composition, crops out on the west side of Frenchie Creek. This rock consists of fragments as much as 3 inches across of varicolored flow rock (some showing relic trachytic texture; others containing quartz phenocrysts) in a green or white matrix, sporadically replaced by hematite. These punky light-green to white breccias contrast strikingly with the interlayered tough maroon flows.

Several minor silicic rock types of the Frenchie Creek Rhyolite differ from the chemically analyzed rhyolites in phenocryst mineralogy but probably are of similar overall composition. A distinctive bright-red rhyolite(?) contains abundant euhedral sanidine phenocrysts, along with lesser quantities of sericitized plagioclase, quartz, and biotite. Several partly altered flows contain phenocrysts of sodic andesine, but no quartz; one of these also contains clinopyroxene crystals partly altered to amphibole, which in turn has been replaced peripherally by chlorite and an opaque mineral. Hornblende-bearing rhyolite(?) occurs locally near the Crescent fault west of Frenchie

[12] In view of the holocrystalline nature of all these flows, whole-rock *X*-ray diffraction studies using the techniques described by Tatlock (1961) should prove useful.

TABLE 6.—*Chemical analyses, norms, and modes of unaltered flow rocks from the Frenchie Creek Rhyolite*

[Standard rock analyses by C. L. Parker]

	Rhyolite (H3587) (E. 312,300 N. 2,063,250)	Rhyolite (H3588) (E. 313,500 N. 2,064,050)	Rhyodacite (H3600) (E. 298,150 N. 2,049,600)		Rhyolite (H3587) (E. 312,300 N. 2,063,250)	Rhyolite (H3588) (E. 313,500 N. 2,064,050)	Rhyodacite (H3600) (E. 298,150 N. 2,049,600)
Chemical analyses [Weight percents]							
SiO_2	69.70	70.18	64.24	H_2O^+	0.75	0.97	1.50
Al_2O_3	15.19	14.95	14.88	H_2O^-	.58	.77	.29
Fe_2O_3	2.04	2.04	1.69	TiO_2	.36	.34	.88
FeO	.23	.26	2.23	P_2O_5	.06	.11	.23
MgO	.32	.46	2.38	MnO	.02	.04	.27
CaO	1.28	1.53	3.19	CO_2	.24	.09	.64
Na_2O	3.46	2.80	3.72				
K_2O	5.57	5.17	3.46	Total	99.80	99.71	99.60
CIPW norms [Weight percents]							
Q	25.84	30.63	20.55	ht	2.05	2.05	----------
or	32.86	30.52	20.41	rt	.08	.01	----------
ab	29.24	23.68	31.44	il	.53	.64	1.67
an	4.45	6.31	10.31	ap	.13	.26	.52
C	1.85	2.43	1.23	cc	.55	.20	1.45
en	.79	1.14	5.90				
fs	----------	----------	1.74	Total	98.37	97.87	97.68
mt	----------	----------	2.46				
Modes [Volume percents]							
Plagioclase	[1] 2.7	[1] 22.4	[2] 17.0	Groundmass	96.5	73.9	75.8
Biotite	.5	2.0	----------				
Clinopyroxene [3]	----------	----------	6.6	Total	100.0	100.0	100.0
Opaque mineral	.3	1.7	.6				

[1] Sericitized; composition uncertain.
[2] Andesine.
[3] Includes chloritic alteration.

Creek, and rhyolitic flow breccias are sporadically distributed in the Frenchie Creek area.

Black or maroon rhyodacite is common in the Frenchie Creek Rhyolite. Phenocrysts of zoned plagioclase (labradorite to andesine) and of partly altered augite ($Mg_{41.5}$, $Fe_{16.5}$, $Ca_{42.0}$; $2V_z=51.4°$, $\beta=1.691$) make up about 25 percent of the rock. The augite shows alteration to an acicular light-green amphibole and (or) to penninite and hematite. This alteration is commonly either complete or wholly absent; intermediate stages are rare. A perfectly fresh euhedral augite crystal may touch or enclose one that has been completely replaced (fig. 8). Some of these pseudomorphs may be after hypersthene, but no relic orthopyroxene was seen. The groundmass is commonly pilotaxitic, and in several specimens has recrystallized to very irregularly bounded

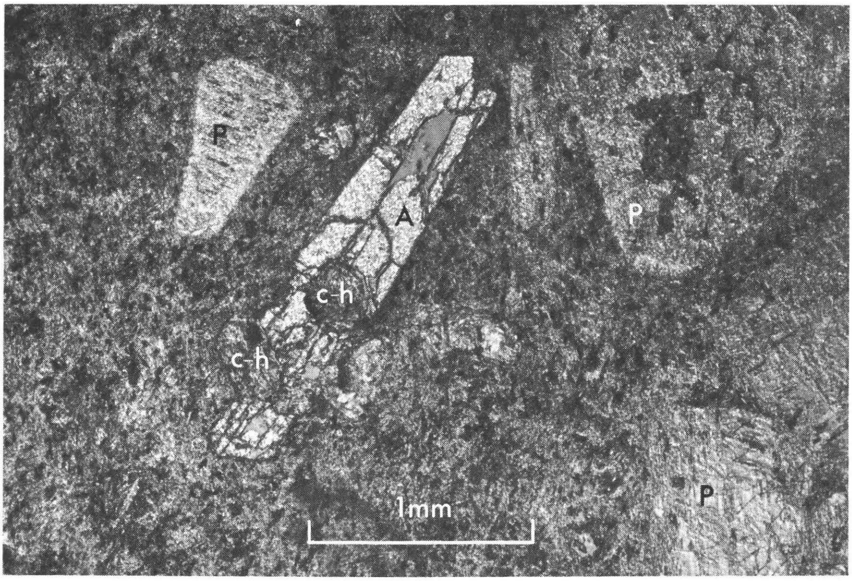

FIGURE 8.—Photomicrograph of a rhyodacite from the Frenchie Creek Rhyolite. × 30. Obliquely crossed polars. A fresh euhedral crystal of augite (A) encloses two chlorite-hematite pseudomorphs (c-h), which originally may have been either augite (rare augite crystals in this thin section show partial alteration) or hypersthene. Euhedral phenocrysts of partially sericitized intermediate plagioclase (P) contain vermiform inclusions of groundmass material.

plagioclase crystals, 0.3 to 0.4 mm in diameter, in optical continuity with some plagioclase microlites but including others of differing optical orientation, along with much opaque material and epidote(?). This rock type, called andesite on the basis of phenocryst mineralogy is in actuality a rhyodacite, as shown by the chemical analysis (table 6).

Dark-green amygdaloidal greenstones are found in the complexly faulted area near the mouth of Sod House Creek and as inclusions in alaskite. Phenocrysts of cloudy plagioclase (An_{30-35}) are partly replaced by clear albite. Aggregates of penninite, quartz, calcite, and an opaque mineral appear to be pseudomorphous after an original mafic mineral. The groundmass is an obscure recrystallized aggregate of penninite, feldspar, quartz, and opaque material.

Shawe and others (1962) presented six chemical analyses of altered volcanic rocks around the Modarelli mine. Five of these are of rocks from their "older series volcanic rocks" (the Frenchie Creek Rhyolite of the present report) and are reproduced in table 7 along with norms calculated by the present writer (the sixth analysis is of a rock probably belonging to the Sod House Tuff and is given in table 5). The mineralogy and petrography of the rocks corresponding to these analyses are unknown to the present writer. The silica percentages in conjunction with an AKN diagram (fig. 9), however, suggest that

TABLE 7.—*Chemical analyses and norms of altered flow rocks of the Frenchie Creek Rhyolite in the vicinity of the Modarelli mine*

[From Shawe and others (1962, table 12). Rapid rock analyses by K. E. White and P. L. D. Elmore. Numbers are USGS laboratory numbers]

	141421	141418	141425	141423	141424		141421	141418	141425	141423	141424
Chemical analyses [Weight percents]											
SiO_2	67.0	70.0	68.6	69.8	61.0	H_2O	3.2	4.0	3.6	2.4	3.1
Al_2O_3	14.8	16.0	14.2	16.2	13.8	TiO_2	1.0	.87	.89	.75	.63
Fe_2O_3	3.5	2.6	5.2	1.3	11.6	P_2O_5	.20	.26	.25	.12	.30
FeO	.19	.09	.16	.14	.30	MnO	.03	.02	.02	.00	.02
MgO	.40	.22	.26	.34	.20	CO_2	1.2	.06	.05	.05	.06
CaO	2.0	.55	.38	.36	.33						
Na_2O	2.4	.40	.82	1.2	.36	Total	100.2	100.3	100.0	100.2	100.4
K_2O	4.3	5.2	5.6	7.5	8.7						
CIPW norms [Weight percents]											
Q	35.5	46.9	42.0	33.2	25.0	il	0.5	0.2	0.4	0.3	0.7
or	25.4	30.7	33.0	44.3	51.4	rt	.8	.7	.7	.6	.3
ab	20.3	3.4	6.9	10.2	3.0	ap	.5	.6	.6	.3	.4
an	1.1	1.0	0	.8	0	cc	2.7	.1	.1	.1	.1
C	5.8	9.4	6.8	5.8	3.8						
en	1.0	.6	.6	.8	.5	Total	97.0	96.2	96.3	97.7	96.8
ht	3.4	2.6	5.2	1.3	11.6						

these altered rocks were originally rhyolites and have been depleted in soda by the hydrothermal alteration. Inspection of the analyses and norms suggests further that this alteration involved introduction of iron, oxidation (as indicated by the high normative hematite and rutile and the absence of normative magnetite), and production of sericite or kaolinite (to account for the high normative corundum). The probable development of sericite is also indicated by the AKN diagram.

RHYOLITE(?) PLUGS

A rhyolite(?) plug which may have been a feeder for the rocks of the Frenchie Creek Rhyolite intrudes the Sod House Tuff near the mouth of Frenchie Creek (fig. 10). This intrusive rock contains phenocrysts of plagioclase (partly replaced by sericite and chlorite) and of a prismatic mafic mineral (now completely altered to chlorite, calcite, and opaque material) in a recrystallized trachytic groundmass consisting of plagioclase laths, chlorite, and an interstitial micrographic intergrowth of quartz and feldspar. Quartz stringers about 0.1 mm wide parallel the trachytic flow layering. All these petrographic features are consistent with the interpretation of this plug as comagmatic with the Frenchie Creek Rhyolite.

Small hypabyssal plugs intrude all three formations of the Pony Trail Group in Pony Trail Canyon. These plugs differ texturally both from the rhyolite flows and from the plug in Frenchie Creek, but may nevertheless be related to the Frenchie Creek Rhyolite.

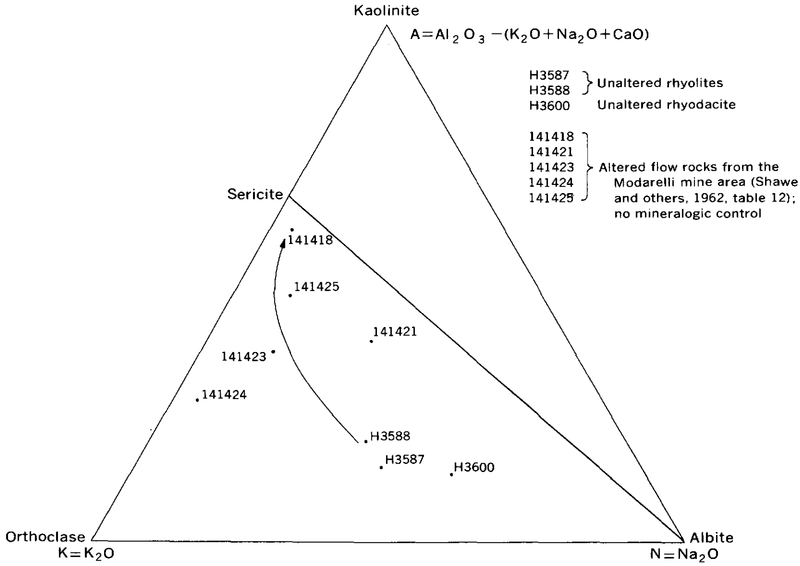

FIGURE 9.—Diagram showing probable course of hydrothermal alteration followed by silicic flow rocks of the Frenchie Creek Rhyolite.

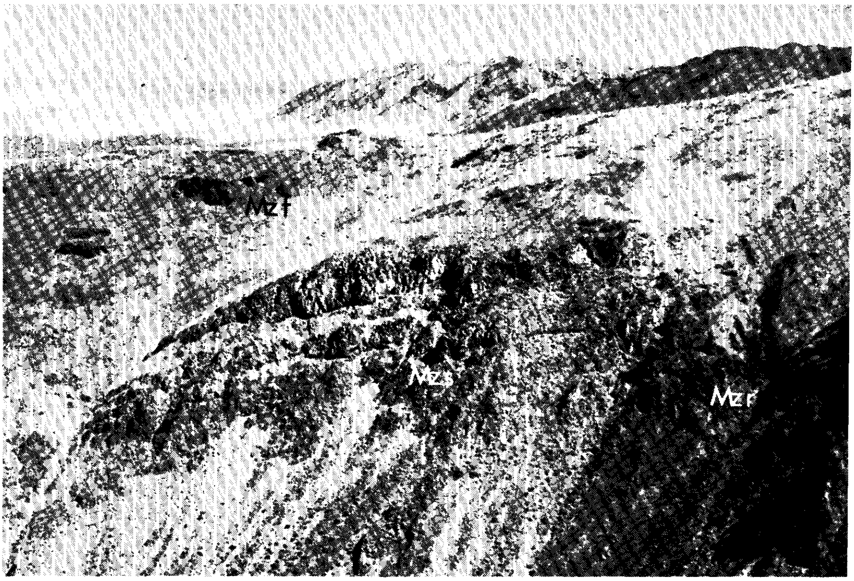

FIGURE 10.—Photograph showing the intrusive relations of a rhyolite plug to the Sod House Tuff near the mouth of Frenchie Creek. Light-gray ash-flow tuffs (Mzs) dip away from the observer and are overlain by maroon and black flows of the Frenchie Creek Rhyolite (Mzf). The rhyolite plug (Mzr) truncates bedding of the ash-flow tuffs and interlayered volcanic sandstones. Photograph taken looking northeast across Frenchie Creek. Pony Trail Canyon is at top right-center. Crescent Valley is at left, and the canyon of the Humboldt River is in the left distance.

The rhyolite(?) of these plugs contains phenocrysts of plagioclase, biotite, and quartz, as well as chlorite pseudomorphs. The groundmass is trachytic, but contains no quartz stringers. The plagioclase is altered to a cryptocrystalline brown material, and is partly replaced by secondary albite.

LOWER CRETACEOUS(?) PLUTONIC ROCKS

Epizonal plutonic rocks of probable Early Cretaceous age are widespread in the Frenchie Creek quadrangle. Granodiorite and adamellite are the dominant rock types; subordinate varieties include diorite, tonalite, fine-grained monzodiorite, rhyodacite porphyry, alaskite, and quartz albitite. Almost every type has undergone deuteric alteration.[13]

These plutonic rocks were emplaced in the Upper Pennsylvanian or Permian Brock Canyon Formation and in the Pony Trail Group (Mesozoic, most probably Jurassic). An unequivocal upper age limit cannot be given, but it is highly unlikely that the plutonic rocks are as young as the Lower or lower Upper Cretaceous basin sediments of Pine Valley, which are neither intruded by plutonic rock nor affected by hydrothermal alteration and mineralization. Therefore, the plutons probably were emplaced during the Early Cretaceous, although a Jurassic age is not excluded. Potassium-argon geochronology is being done by R. L. Armstrong on specimens of granodiorite, red porphyritic granodiorite, and alaskite.[14]

For ease of discussion, the main plutonic bodies are referred to by the names used on the geologic map (pl. 1). The often ridiculed term "chonolith" seems appropriate for the largest mass of plutonic rock (the Duff Creek chonolith). This intrusive form was defined by Daly (1933, p. 106) as "a discordant igneous body (a) injected into dislocated rock of any kind, stratified or not; (b) of shape and relations irregular in the sense that they are not those of a dike, sheet, laccolith, bysmalith, ethmolith, sole injection, or neck; and (c) composed of magma passively squeezed into a subterranean orogenic chamber or

---

[13] Deuteric is defined in the AGI Glossary (Howell, 1960, p. 79) as "a term applied to alterations in an igneous rock produced during the later stages of, and as a direct consequence of, the consolidation of the magma or lava. The term discriminates such alterations from the more strictly secondary changes due to a later period of alteration." Hydrothermal is a more general term embodying both deuteric alteration and "the more strictly secondary changes" referred to in the above definition.

[14] Analytical ages of the granodiorite and alaskite were reported by R. L. Armstrong (1963, p. 165–166) after the completion of this report. The granodiorite (specimen YAG 130 of Armstrong; collected from the same locality as specimen H3597, table 9) had a potassium-argon hornblende age of 150_{-8}^{+23} m.y. Replicate argon analyses on the alaskite (specimen YAG 132 of Armstrong; collected from the same locality as specimen H3586, table 10) gave 2 ages: 125_{-6}^{+19} m.y. and 145_{-7}^{+22} m.y. Armstrong (written commun., 1963) considers that 140 ± m.y. is a reasonable estimate of the true age of the alaskite.

Comparison of these figures with recent compilations of the geological time scale (Kulp, 1961; Holmes, 1960) indicates a Late Jurassic age for the plutonic rocks designated in this report as Early Cretaceous(?). These analytical ages also preclude a Cretaceous age for the Pony Trail Group.

actively forcing apart the country rocks." (Italicization by present writer.)

Owing to the strong deuteric and hydrothermal overprints and to the fine-grained groundmass of many of the porphyritic varieties, petrographic rock types often could not be distinguished in the field, and are therefore not everywhere delimited on the geologic map (pl. 1). This is particularly true for the Duff Creek chonolith.

FORCIBLE MODE OF EMPLACEMENT

The writer interprets the masses of Lower Cretaceous(?) plutonic rock as magmatic plutons, forcibly emplaced in Upper Pennsylvanian or Permian and Mesozoic rocks. The magma at the time of emplacement probably had a high viscosity and contained a relatively low percentage of disseminated volatiles, although the water pressure may have exceeded the saturation pressure during the later stages of crystallization.

These Lower Cretaceous(?) plutons show almost all the characteristics considered by Buddington (1959, p. 677–680) to be diagnostic of epizonal plutons. A partial list of significant features includes the following: (1) homophanous fabric, (2) local miarolitic alaskitic facies, (3) uncommon pegmatite nests and aplite dikes, (4) late-stage porphyritic dikes, (5) chill zones in satellitic plutons and dikes, (6) sharp contacts, (7) emplacement in regionally unmetamorphosed country rock, (8) possible genetic relation to the Jurassic(?) volcanic rocks, (9) peripheral intrusion breccias, and (10) peripheral deformation of country rock. The last two features are particularly significant as indicators of forcible emplacement, and are described in detail below.

INTRUSION BRECCIAS

Breccias formed during intrusion occur peripherally to red porphyritic adamellite in the upper parts of Cottonwood Canyon and Hand-me-down Creek and are best displayed at E. 275,300, N. 2,006,100 (fig. 11). Tremolitic arkose at this locality dips 40° to 50° beneath brecciated red porphyritic adamellite. Bedding of the arkose is truncated by a dark-green rock composed of silt-sized particles of quartz, plagioclase, and orthoclase, with secondary acicular tremolite and poikiloblastic orthoclase. About 9 inches of arkose is truncated by this green rock, which is interpreted as gouge material produced by comminution of arkosic sedimentary rock. Subrounded fragments of red adamellite enclosed within this green gouge become progressively more abundant upward, and the gouge of granulated sedimentary rock passes into a chloritic matrix made up of comminuted adamellite. Arkose fragments are found within this breccia as much as 6 feet above the lowest adamellite fragment. Only the lower 20 feet of the

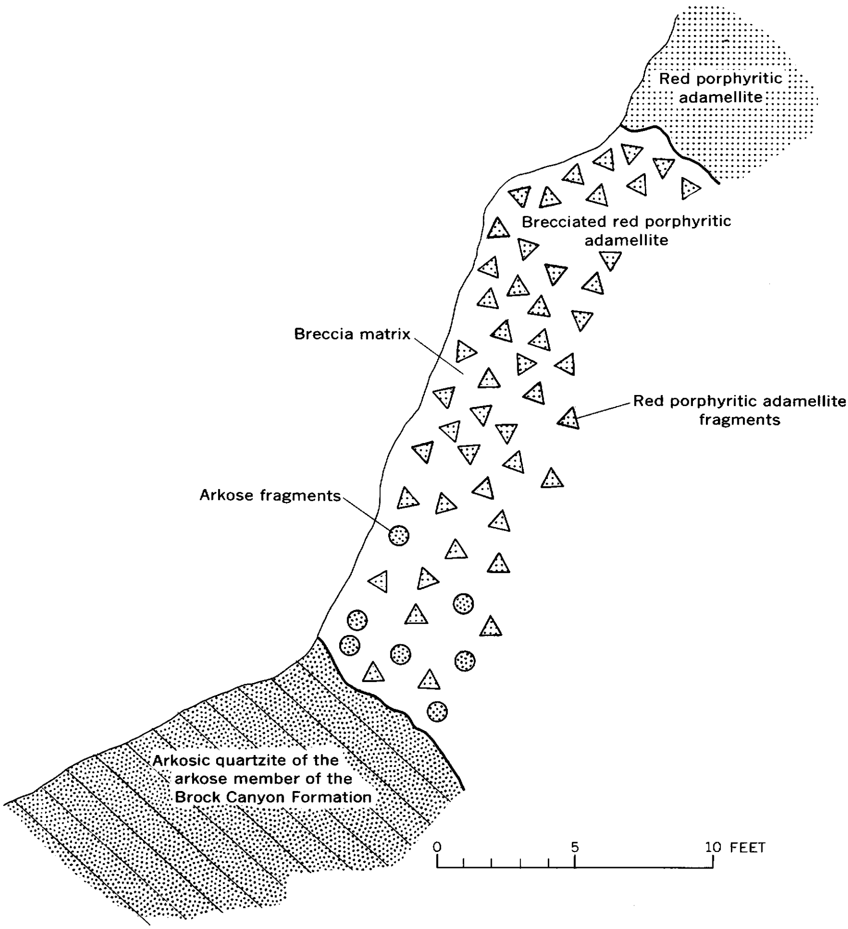

FIGURE 11.—Diagramatic section of intrusion breccia at E. 275,300, N. 2,006,100.

red adamellite is brecciated; above this border zone the adamellite is normal massive plutonic rock.

Breccias of this type are restricted to the contacts of red porphyritic adamellite and the arkose member of the Brock Canyon Formation and were probably formed at the time of intrusion. They are not related to any system of later faulting but apparently were produced by movement of consolidated red adamellite aganist arkose, this movement being caused by pressure of fluid magma at lower levels. The breccias therefore mark "faults" in a general sense, but these faults were related to and caused by magmatic pressure and movement. The plutons of red porphyritic adamellite seem to be excellent examples of the "dead" plutons of Read (1957, p. 365), but with the central parts still liquid and mobile at the time of emplacement.

Protoclastic textures occur sporadically throughout all the Lower Cretaceous(?) plutons.

DEFORMATION OF COUNTRY ROCK

Individual Lower Cretaceous(?) plutons commonly are separated by subvertical septa [15] of metaquartzite or recrystallized arkose in which sedimentary features are preserved despite metamorphic recrystallization. Several septa can be traced into the main areas of gently dipping rocks of the Brock Canyon Formation. Unfortunately, however, the critical areas where the septa join the gently dipping strata are areas of poor outcrop; individual marker beds cannot be followed into the septa. Nevertheless, the geometric relations suggest strongly that the septa are competent quartzite beds bent into a vertical position by forcible lateral intrusion of magma along bedding planes (sections *A–A′* and *B–B′*, pl. 1).

The process of intrusion is visualized as follows: (1) injection of magma laterally along gently dipping bedding planes, (2) arching of the roof over a body of magma having the form of a laccolith, (3) rupture of the roof near the distal end of the laccolith, and (4) bending of the roof into a subvertical attitude.

This mode of emplacement is best illustrated by the Brock Canyon pluton (section *A–A′*, pl. 1). The planar floor of the body dips gently southeast and is controlled by bedding planes of the Brock Canyon Formation (fig. 12; also fig. 21). The contact is exposed in several places, either as a smooth intrusive contact controlled by quartzite bedding or as a zone of shearing parallel to the bedding. The uppermost beds of quartzite commonly are stained with hydrous iron oxides, and locally are brecciated. Fine-grained tonalite found adjacent to the quartzite appears to be a chill zone, and locally is itself brecciated and veined with calcite.

The roof of the pluton is represented by the poorly exposed nearly vertical quartzite septum that separates the Brock Canyon and Cottonwood Canyon plutons and that can be traced into the Brock Canyon Formation in Brock and Cottonwood Canyons. This septum was originally a gently dipping quartzite bed lying immediately above the bed that forms the floor of the Brock Canyon pluton, and was rotated into its present position by forcible intrusion of magma laterally from the southeast.

This forcible lateral intrusion also caused shearing and local brecciation along bedding planes throughout the 1,300 feet of sedimentary rocks of the Brock Canyon Formation beneath the Brock Canyon

---

15 The term "septum" is used in this report to designate any thin band of sedimentary rock that occurs within a pluton or between two plutons and that is attached by one or both ends to an extensive area of country rock. A "screen" on the other hand refers to a band of sedimentary rock that is isolated and cannot be traced into an extensive area of country rock.

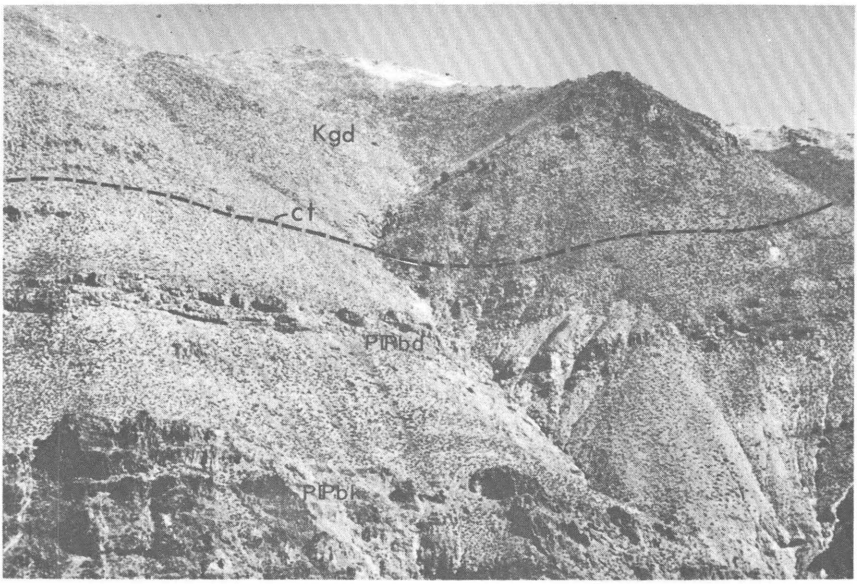

FIGURE 12.—Contact of the Brock Canyon Formation and the Brock Canyon pluton. Photograph taken looking east across Brock Canyon. Both the intrusive contact (ct) and the bedding within the dolomite (PPbd) and conglomerate (PPbk) members dip 15°–35° away from the observer. Kgd, granodiorite.

pluton. Several bedding-plane thrusts were mapped (pl. 1). These thrusts are marked by shear planes, zones of gouge, limonite staining, and truncation of beds both above and below the thrust planes. One thrust has been thrown into overturned folds of 50-foot amplitude at two localities (E. 246,700, N. 2,007,050, and E. 247,150, N. 2,006,-800) on the west side of Brock Canyon.

Thrusting due to intrusion is particularly intense along the contact of the Brock Canyon Formation and the Valmy Formation in Brock Canyon. Details of this contact are described in the supplementary measured sections of the Brock Canyon Formation (p. 88–93).

Thrusting within and beneath the Brock Canyon Formation is restricted to those parts of Brock and Cottonwood Canyons peripheral to the Brock Canyon pluton. Low-angle thrusts or shear zones were observed neither in the numerous well-exposed sections in upper Cottonwood Canyon nor in the excellent section in the southwestern-most corner of the Frenchie Creek quadrangle. R. J. Roberts (oral commun., 1960) found that the Brock Canyon Formation unconformably overlies Ordovician clastic rocks (Vinini Formation) in the northern part of the Horse Creek Valley quadrangle, and Harold Masursky (oral commun., 1961) collected undistorted graptolites from the Ordovician shales within 6 inches of this unconformity at the same locality.

735-726 O-64-4

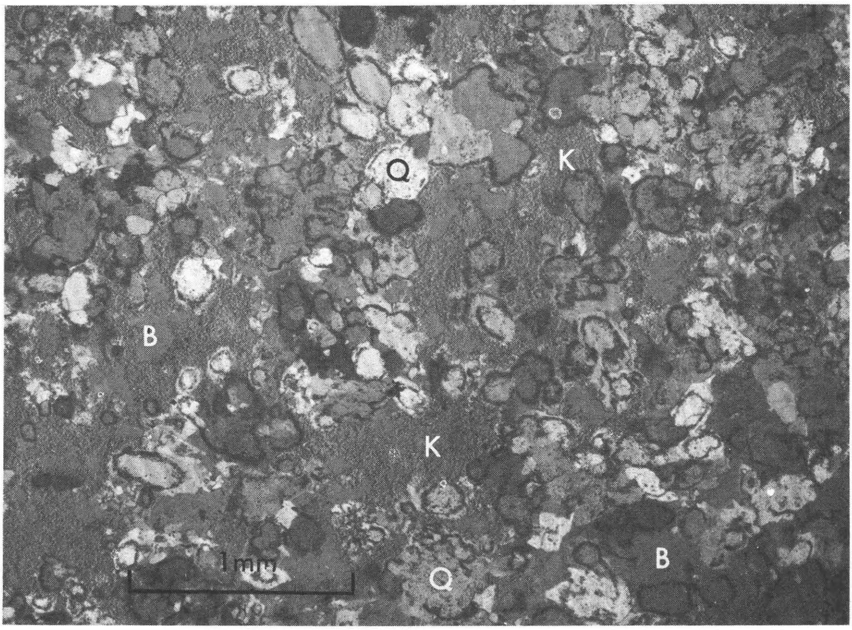

FIGURE 13.—Photomicrograph of recrystallized and kaolinized arkose(?) of the Brock Canyon Formation from a screen in Doc Creek. × 30. Obliquely crossed polars. Bands of submicroscopic opaque material in quartz crystals (Q) outline relic detrital forms. K, kaolinite; B, plucked areas.

The restriction of low-angle deformation to the area peripheral to the Brock Canyon pluton is strong evidence that the thrusts and shear zones were caused by intrusion of the pluton. The magma apparently was injected from the southeast and moved generally northwest, dragging the strata of the floor along with it. Owing to the pronounced mechanical anisotropy of the underlying sedimentary rocks, this drag produced thrusts, shear zones, and breccias within and beneath the Brock Canyon Formation.

Thin screens of recrystallized arkose are found within the Duff Creek chonolith in Deer, Doc, and Lamb Creeks and probably were also formed by mechanical disruption of originally gently dipping strata with rotation of arkose beds into subvertical attitudes. These screens, commonly only 20 to 200 feet thick, are similar in most respects to the septa in Brock and Cottonwood Canyons, but are thinner and cannot be traced into gently dipping strata of the Brock Canyon Formation. Sedimentary features, including detrital grains (fig. 13), sporadic crossbedding, and a few chert pebbles, have persisted through recrystallization and kaolinization (p. 63–64). The screens commonly separate plutonic rocks of differing texture or intensity of alteration. Each screen shown on the geologic map (pl. 1) has been walked out by the writer in outcrop or float for its entire length and is continuous, not merely an imaginary stratum extrapolated from a few inclusions.

The septa and screens are not "resisters" (Read, 1957, p. 346–347) in a granitized sedimentary sequence owing to the epizonal regional setting of the plutons. Read pointed out (1957, p. 349) that "large-scale granitization, applicable throughout a granite mass, must be accompanied by the appropriate apparatus of migmatites and metamorphites." Migmatites are features of the catazone and are completely absent from the Frenchie Creek quadrangle, as are metamorphic rocks of facies other than the albite-epidote-hornfels facies of contact metamorphism.

Strong evidence for the emplacement of granodiorite magma between sedimentary strata is provided by the sharp contacts of arkose and granodiorite. These sharp contacts persist even in intensely kaolinized rocks.

Were the quartzite screens on the east side of the Cortez Mountains relics of a sedimentary sequence granitized in place, this hypothetical sequence would have to have been over 15,000 feet thick and be over 90 percent granitized. Inasmuch as advocates of granitization commonly invoke a pelitic or semipelitic composition for granitized rock (that is, a composition that does not differ widely from that of granite), this implies some 13,500 feet of pelitic rock. Such a sequence would have no counterpart in northern Nevada, not even in the Ordovician Vinini Formation, which, in addition to much shale, contains abundant chert, and minor quartzite and greenstone.

Had granitization been an important phenomenon in the Frenchie Creek quadrangle, the claystone and dolomite members of the Brock Canyon Formation should have been affected before the arkose member. On the contrary, however, the contacts of plutonic rock and the claystone and dolomite members are discordant and crosscutting on a large scale, suggesting stoping, cauldron subsidence, or possibly assimilation, rather than granitization. Quartzite and conglomerate strata interbedded with the claystones are truncated by adamellite at the south margin of the Deer Camp pluton and by the Duff Creek chonolith west of Linka Creek, and do not extend into these plutons as septa.

Septa of the Big Pole Formation and of the Sod House Tuff occur near the northeast border of the Duff Creek chonolith. These septa are in general poorly exposed, but locally show subvertical bedding in recrystallized volcanic wacke or tuffaceous sandstone.

The interpretation of the septa and screens of the Frenchie Creek quadrangle as strata rotated into a subvertical attitude is significant in regard to metamorphic septa commonly found between adjacent mesozonal plutons (Bateman, 1961; Hamilton, 1956). The origin of these mesozonal septa is uncertain; their metamorphic mineral assemblages and textures preclude the recognition of relic sedimentary features. Undoubtedly such septa would be interpreted as "resisters" by some geologists, but the common occurrence of chemically and mineralogically distinct plutons on opposite sides of a septum is difficult to explain by granitization. These mesozonal septa, however, may be mechanically analogous to the epizonal septa of the Frenchie Creek quadrangle, and reflect injection of magma along preexisting planes of mechanical anisotropy (be they bedding or schistosity planes), with rotation of these planes into orientations approximately parallel to the general direction of magmatic flow.

ROCK TYPES

RHYODACITE PORPHYRY

A heterogeneous map unit in the western Dry Hills is made up of porphyries varying in composition from dellenite through rhyodacite to andesite. The average rock type probably approximates a rhyodacite. Rocks from this unit are typically dark gray and contain up to 10 percent phenocrysts of sericitized plagioclase. Rare euhedral greenish-brown amphibole phenocrysts have a sporadic distribution. The groundmass material consists primarily of very dusty plagioclase laths, commonly oriented in a trachytic foliation.[16] Material interstitial to these laths includes orthoclase, quartz, muscovite, biotite, chlorite, epidote(?), allanite, and calcite. Quartz content ranges from 5 to 25 percent. Dense cryptocrystalline brown alteration material pervades the feldspars.

When present, the amphibole phenocrysts are partly replaced by chlorite and peripherally altered to coronas of cryptocrystalline opaque material and epidote(?). These coronas have a conspicuous radial texture. Many specimens show complete alteration of amphibole to opaque material and epidote(?).

Plagioclase has a highly variable composition, apparently owing to partial albitization. The least altered specimen shows relatively fresh groundmass plagioclase laths, which are zoned from An_{45} to An_{15} (determined by extinction angles and relief). Plagioclase of other specimens (including the chemically analyzed specimen H3592) is highly sericitized and is about An_{10} in composition (determined by X-ray spacings). Completely albitized rhyodacite porphyry is described below as a separate map unit.

Chemical, normative, and modal data of a sample (H3592) from the rhyodacite porphyry unit are given in table 8. This specimen contains slightly more potash feldspar than the assumed average rock

[16] Foliation was not observed in the strip of rhyodacite porphyry adjacent to the fine-grained monzodiorite (pl. 1).

TABLE 8.—*Chemical analyses, norms, and modes of a dellenite porphyry* [1] *from the rhyodacite porphyry unit and of fine-gained monzodiorite* [2]

[Standard rock analyses by C. L. Parker. Tr.=trace]

	Dellenite porphyry (rhyodacite porphyry unit) H3592	Fine-grained monzodiorite H3593		Dellenite porphyry (rhyodacite porphyry unit) H3592	Fine-grained monzodiorite H3593		Dellenite porphyry (rhyodacite porphyry unit) H3592	Fine-grained monzodiorite H3593
Chemical analyses [Weight percents]			**Norms** [Weight percents]			**Modes** [Volume percents]		
SiO_2	62.38	59.31	Q	10.07	1.10	Quartz	11.4	5.5
Al_2O_3	16.76	17.24	or	23.35	16.68	Potash feldspar	31.4	25.5
Fe_2O_3	2.39	1.22	ab	43.70	54.08	Sodic plagioclase	44.5	53.6
FeO	2.11	1.62	an	10.12	9.98	Amphibole	Tr.	11.6
MgO	1.68	2.37	C	.27		Epidote(?)	9.1	Tr.
CaO	2.55	5.31	wo		4.51	Chlorite		.6
Na_2O	5.17	6.40	en	4.17	5.88	Opaque material	3.6	1.3
K_2O	3.96	2.83	fs	.57		Calcite	Tr.	.5
H_2O^+	1.28	.86	mt	3.48	1.72	Sphene		1.4
H_2O^-	.16	.36	il	1.64	2.42			
TiO_2	.86	1.27	ht		.03	Total	100.0	100.0
P_2O_5	.31	.45	ap	.72	1.05			
MnO	.05	.06	cc	.18	.93			
CO_2	.08	.41						
Total	99.74	99.71	Total	98.27	98.38			

[1] E. 263,000, N. 2,077,150.
[2] E. 254,750, N. 2,067,500.

type of the rhyodacite porphyry map unit and is technically a dellenite (Peterson, 1961, p. 31), although its proportion of plagioclase to total feldspar is almost high enough for it to be classified as a rhyodacite. A plot of normative quartz, orthoclase, and plagioclase is presented in figure 14 in order to facilitate comparison among the chemically analyzed specimens from the Lower Cretaceous(?) plutons.

The rhyodacite porphyry is intrusive into quartzites of the Brock Canyon Formation. Near the porphyry body the quartzites are highly recrystallized and contain much secondary muscovite and chlorite. The contact of the porphyry and the quartzite exposed at E. 258,400, N. 2,072,800 is of mixed character. It is marked in places by a breccia of porphyry fragments in a matrix of recrystallized quartzite and comminuted porphyry material. Nearby, however, it is very sharp and gently undulating, with no brecciation or shearing. Small fragments of quartzite are included in the porphyry.

Rhyodacite porphyry was at least in part emplaced before the comagmatic granodiorite. Although the contact is nowhere exposed, the grandiorite is usually finer grained near the rhyodacite porphyry, and near granodiorite the porphyry becomes light gray or white (possibly owing to albitization). A few float contacts of rhyodacite porphyry are marked by quartzite fragments, probably derived from screens of metasedimentary rock between the two intrusive bodies.

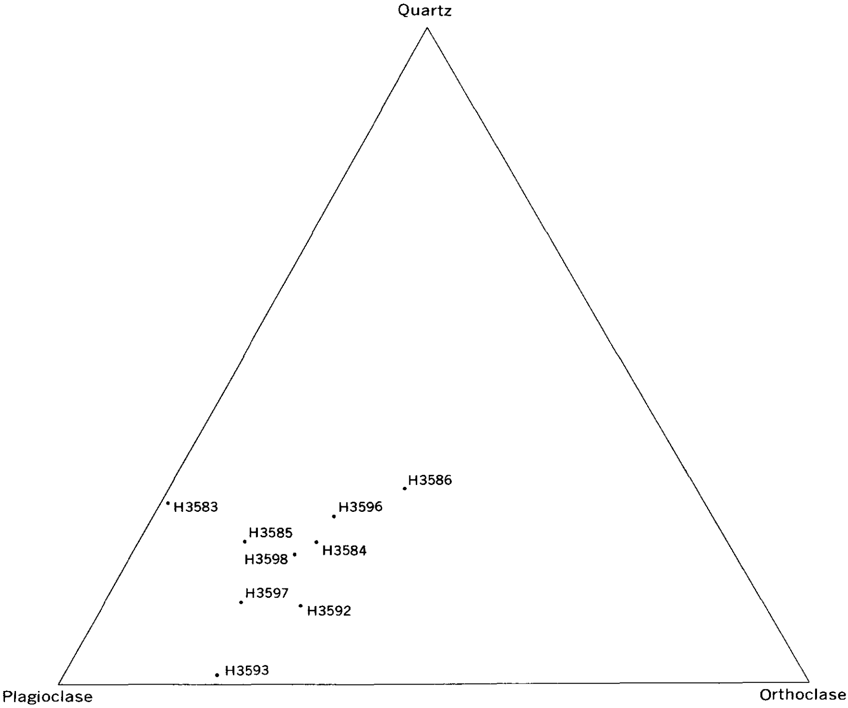

FIGURE 14.—Plot of normative quartz, orthoclase, and plagioclase in the Lower Cretaceous(?) plutonic rocks of the Frenchie Creek quadrangle.

The rhyodacite porphyry unit differs from most of the lower Cretaceous(?) plutonic rocks in its aphanitic groundmass and in the presence of a trachytic texture. The unit is referred to the Early Cretaceous(?) plutonic episode on the basis of chemical and mineralogical similarities, deuteric albitization similar to that observed in many of the Lower Cretaceous(?) plutonic rocks, and the gradational contact with the fine-grained mozodiorite.

ALBITIZED PORPHYRY

Rhyodacite porphyry has been completely albitized at scattered localities peripheral to the three largest bodies as well as throughout the low hills in the vicinity of E. 262,500, N. 2,083,000. Only the larger areas of albitized porphyry are shown on the geologic map (pl. 1).

Albitization has produced a pink or light-gray uniform aphanitic rock. Phenocrysts of plagioclase (now albitic) make up less than 10 percent of the rock; megascopic biotite is uncommon and is usually replaced by calcite and hydrous iron oxides. The groundmass consists of microcrystalline anhedral albite (An_{04-10}), subordinate quartz, scarce orthoclase, and accessory sericite, calcite, and opaque material. Trachytic orientation of groundmass plagioclase laths has been only partly destroyed by albitization. This rock contains no sphene or rutile, in contrast with the albitized rock adjacent to joints in the Permian(?) pyroxene dellenite porphyry (p. 16).

X-ray modal analysis shows a pronounced enrichment in albite with complementary depletion of orthoclase and quartz. Orthoclase was completely absent in one sample. The K_2O lost in this alteration may have been deposited in part as the potash feldspar that partly replaces detrital plagioclase in nearby arkosic wacke of the Brock Canyon Formation.

FINE-GRAINED MONZODIORITE

Fine-grained monzodiorite crops out in a belt on the south flank of the Dry Hills. This rock appears to grade southward into medium-grained granodiorite, and northward into rhyodacite porphyry. It is not known whether the three map units represent separate intrusions or are facies of a single complex pluton.

The monzodiorite is a fine-grained (avg 0.35 mm) pink rock with a seriate texture. Grains and patches of green amphibole are conspicuous in hand specimen. Two varieties of plagioclase are present: (1) cloudy laths of sodic andesine, and (2) intergranular crystals of clear albite.[17] Light-green hornblende crystals contain remnants of clinopyroxene and are altered to chlorite and a submicroscopic gray material. Minor potash feldspar (orthoclase) replaces plagioclase and, along with quartz, is intergranular to plagioclase.

Chemical, normative, and modal data for a typical fine-grained monzodiorite (H3593) are given in table 8.

GRANODIORITE

Granodiorite is the most abundant rock type of the Lower Cretaceous(?) intrusions. It makes up almost all of the Brock Canyon and Cottonwood Canyon plutons, is common in the Duff Creek chonolith, and is the dominant granitic rock of the Dry Hills.

The granodiorite is a gray to greenish-gray medium-grained rock with an equigranular or seriate texture. Porphyritic varieties occur on the east side of the Cortez Mountains and in the vicinity of Willow Corral Pass in the Dry Hills.

Plagioclase crystals, 0.2 to 0.8 mm are euhedral. The cores of the larger crystals are labradorite (as calcic as An_{74}) with ocsillatory zoning. Peripheral parts show normal zoning to rims of calcic oligoclase. The smaller plagioclase crystals show little zoning and are of oligoclase composition. Plagioclase commonly is lightly

---

[17] X-ray diffraction showed definite splits of the 131, $1\bar{3}1$, and 220 plagioclase peaks in specimen H3593 (table 8). Othei specimens of fine-grained monzodiorite contain only albite.

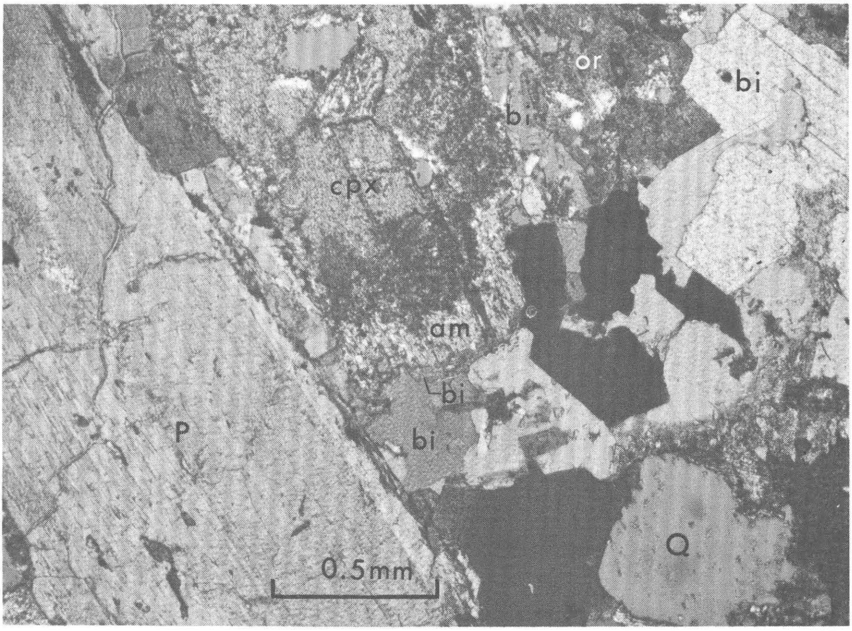

FIGURE 15.—Photomicrograph of Lower Cretaceous(?) granodiorite from the Cottonwood Canyon pluton (specimen H3598, table 9). × 44. Obliquely crossed polars. Clinopyroxene (cpx) is altered to amphibole (am), which in turn is altered to a thin rim of biotite (bi). Biotite also occurs as discrete crystals. P, plagioclase; or, orthoclase; Q, quartz.

sericitized, and in deuterically altered specimens is replaced along cleavages by secondary albite and sporadic penninite.

The mafic mineral was originally clinopyroxene, but it has been partly or totally altered to hornblende (fig. 15). This hornblende is pleochroic from light green to colorless. Optical properties are $\alpha=1.624$, $\gamma=1.649$, $2V_x=79.4°$, and $Z\wedge c=20.5°$. These properties and the light-green color are consistent with an iron-poor tremolitic composition (Winchell and Winchell, 1951, p. 434). Dark-blue hornblende (hastingsite?; compare Gilluly, 1933, p. 69) occurs as sporadic patches in (and optically continuous with) light-green hornblende. Hornblende has undergone all degrees of alteration, commonly to peripheral biotite or to pervasive penninite. Complete alteration produces an aggregate of biotite, chlorite, calcite, ilmenite, and rutile.

Biotite both replaces hornblende and is present as a discrete mineral.

Quartz and perthitic potash feldspar are interstitial and are graphically intergrown in part. Quartz commonly is poikilitic with respect to the smaller plagioclase laths. Potash feldspar replaces groundmass plagioclase in some specimens.

Accessory minerals include apatite, zircon, ilmenite (in some specimens partly altered to sphene and rutile), magnetite (with secondary hematite), pyrite, pyrrhotite, and chalcopyrite.

Chemical analyses, norms, and modes of five granodiorites are listed in table 9. Specimen H3598 is typical of the Cottonwood Canyon pluton, and shows relatively little deuteric alteration. Specimen H3597, although exhibiting no megascopic indications of alteration, has been subjected to deuteric introduction of sodic plagioclase and to replacement of groundmass plagioclase by potash feldspar. This rock probably was emplaced as a tonalite and deuterically altered to its present granodioritic composition. Specimen H3584 is an unaltered black porphyritic granodiorite from the eastern part of the Duff Creek chonolith. Specimen H3596 is a relatively unaltered light-gray porphyritic granodiorite also from the Duff Creek chonolith.

DIORITE

Medium-grained equigranular diorite is the dominant rock type in the part of the Duff Creek chonolith along Crescent Valley from Dewey Dann Creek to Sod House Creek. Porphyritic varieties occur sporadically. Outcrops are quite good and show conspicuous regular joints.

The diorite is a medium-gray or pink rock containing plagioclase, hornblende, and minor potash feldspar. Plagioclase is andesine and shows little or no zoning; secondary albite occurs along the cleavage, and the cores are replaced in part by chlorite, biotite, or both. Hornblende is the light-green iron-poor variety and shows alteration to chlorite and peripheral biotite. Potash feldspar occurs both as a sporadic replacement of plagioclase and as small (0.005 mm) crystals intergranular to plagioclase. Sphene is abundant (up to 3 percent) as anhedral crystals replacing plagioclase, hornblende, and ilmenite.

Highly altered dark-green diorite occurs in the area of complex intrusion and faulting in the lower part of Sod House Creek. This rock is an allotriomorphic granular aggregate of plagioclase, chlorite, calcite, and an opaque mineral. Calcite forms up to 20 percent of the rock.

TONALITE

Tonalite occurs as a border phase of the Brock Canyon pluton and as several small bodies in the Frenchie Creek area. The rock is gray or dark green, fine grained, and has a seriate texture. Quartz is interstitial to zoned andesine (in one specimen, labradorite), hornblende, and biotite, and makes up about 20 percent of the rock. Potash feldspar is almost completely absent.

Tonalite may have been a more common rock type at the time of emplacement of the Early Cretaceous(?) plutons and have been

TABLE 9.—*Chemical analyses, norms, and modes of Lower Cretaceous(?) granodiorites*

[Standard rock analyses by C. L. Parker. Tr.=trace]

	H3598 (E. 255,600 N. 2,004,550)	H3597 (E. 266,800 N. 2,026,100)	H3584 (E. 290,750 N. 2,013,450)	H3596 [1] (E. 283,250 N. 2,015,050)	H3585 [1] (E. 278,950 N. 2,023,400)
Chemical analyses [Weight percents]					
SiO_2	61.37	63.67	64.50	66.55	67.41
Al_2O_3	14.88	15.60	15.68	15.27	15.29
Fe_2O_3	1.03	.53	.57	.53	1.18
FeO	4.23	2.18	3.74	3.26	1.08
MgO	4.38	2.65	2.07	1.44	1.37
CaO	5.49	4.64	4.08	3.15	1.85
Na_2O	2.93	5.61	3.41	3.50	6.25
K_2O	2.79	2.51	3.44	3.56	2.11
H_2O^+	.93	.47	.64	1.07	1.05
H_2O^-	.15	.18	.20	.15	.38
TiO_2	.92	1.09	.98	.95	.83
P_2O_5	.26	.30	.28	.20	.17
MnO	.11	.05	.08	.04	.02
CO_2	.01	.12	.09	.02	.78
Total	99.48	99.60	99.76	99.69	99.77
CIPW norms [Weight percents]					
Q	14.87	10.09	18.56	22.38	19.56
or	16.46	14.79	20.29	21.02	12.45
ab	24.79	47.42	28.82	29.61	52.82
an	19.18	9.98	17.32	14.21	3.14
C	------	------	------	.45	1.58
wo	2.64	4.32	.22	------	------
en	10.86	6.57	5.13	3.57	3.40
fs	5.62	1.86	4.92	4.07	------
mt	1.48	.77	.84	.77	1.14
il	1.75	2.07	1.87	1.81	1.58
ht	------	------	------	------	.40
ap	.59	.69	.65	.46	.39
cc	.02	.27	.20	.05	1.77
Total	98.26	98.83	98.82	98.40	98.23
Modes [Volume percents]					
Quartz	16.5	9.7	15.2	21.3	15.4
K-feldspar	13.5	18.3	19.5	31.9	27.1
Plagioclase	45.5	50.6	46.1	35.3	46.3
Clinopyroxene and amphibole (+ chlorite)	14.5	17.5	9.6	4.6	9.0
Biotite	9.2	------	6.8	5.7	------
Opaque	.8	2.2	2.4	1.2	1.9
Accessories	Tr.	1.7	.4	Tr.	.3
Total	100.0	100.0	100.0	100.0	100.0

[1] Modes of H3596 and H3585 of very low accuracy owing to sericitization of feldspars and the very fine granularity and irregular distribution of the deuteric potash feldspar.

altered to granodiorite by replacement of plagioclase by potash feldspar.

PORPHYRITIC ADAMELLITE

Porphyritic adamellite is a light-gray rock which forms prominent resistant outcrops. It is dominant in the Deer Camp pluton and forms a part of the Duff Creek chonolith in upper Duff Creek and on the east side of the Cortez Mountains, where it grades into porphyritic granodiorite (specimen H3596, table 9). This rock type differs from the granodiorite and porphyritic granodiorite in the lower percentage of mafic minerals, the higher percentage of potash feldspar, and the absence of clinopyroxene.

Phenocrysts consist of plagioclase (zoned from labradorite to oligoclase) and light-green hornblende (with biotite and chlorite alteration products). The zones within plagioclase phenocrysts are euhedral, but the margins are complexly intergrown with potash feldspar and quartz. The fine-grained groundmass is made up of oligoclase laths with interstitial quartz and potash feldspar. The potash feldspar makes up a variable percentage of the rock, and replaces plagioclase in part. Ilmenite shows little or no alteration.

RED PORPHYRITIC ADAMELLITE AND GRANODIORITE

Hematite staining and associated deuteric alteration have affected several discrete plutons of porphyritic adamellite and granodiorite, thus producing a distinctive map unit. These discrete sharply bounded plutons are shown on the geologic map (pl. 1). In addition, much of the porphyritic granodiorite on the ridge between Duff Creek and Sod House Creek has also been stained red. In this area, however, the red porphyritic rock is irregularly distributed, grades into gray porphyritic granodiorite, and could not be mapped as a separate unit.

The red porphyritic adamellite is a resistant unit, underlying some of the highest peaks of the Frenchie Creek quadrangle. Outcrops are abundant, but commonly are shattered along closely spaced randomly oriented fractures. This is in contrast to the conspicuous regular jointing of the less altered lower Cretaceous(?) intrusive rocks. Red porphyritic adamellite weathers to uniformly sized subspherical fragments, which produce characteristic "popcorn" slopes.

Phenocrysts of altered plagioclase and hornblende make up about 15 percent of the rock, and are set in a fine-grained felsic groundmass. Plagioclase phenocrysts as much as 10 mm in size have large homogeneous labradorite cores with abrupt peripheral zoning to oligoclase. Hornblende is the light-green iron-poor variety typical of the Lower Cretaceous(?) intrusive rocks. Biotite occurs only as a secondary mineral.

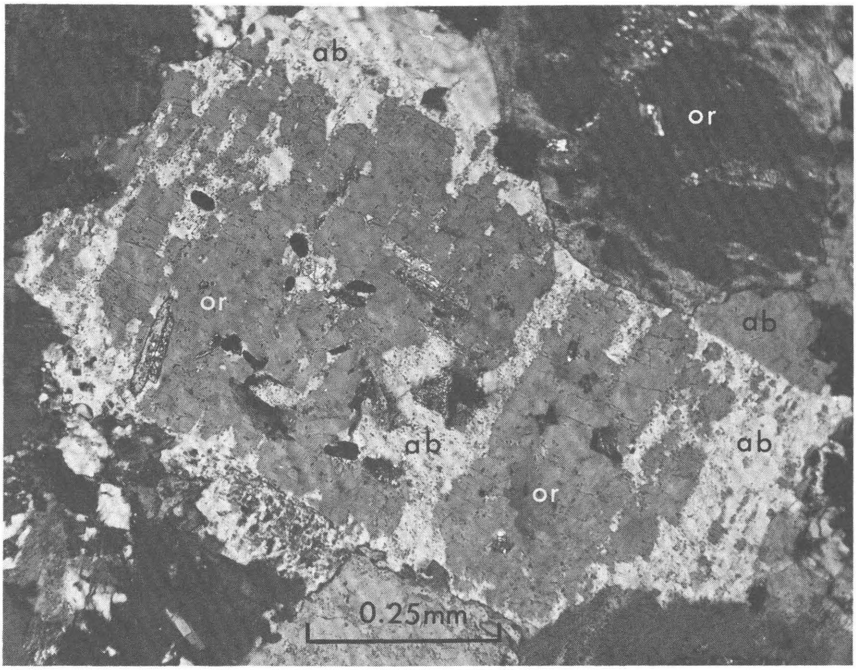

FIGURE 16.—Photomicrograph of replacement perthite in deuterically altered Lower Cretaceous(?) red porphyritic adamellite. × 100. Crossed polars. Orthoclase (or) is rimmed and veined by albite (ab). Rare crystals (not shown in this photograph) exhibit faint polysynthetic twinning in the ablite phase. Photomicrograph taken by R. B. Taylor.

The fine-grained groundmass consists of oligoclase laths poikilitically enclosed in quartz and in a graphic intergrowth of quartz and perthite. Perthite also occurs as discrete crystals intergranular to plagioclase. Accessory minerals (apatite, zircon, ilmenite, sphene, rutile) make up several percent of the rock.

Deuteric alteration has affected almost all the constituent minerals. Cores of plagioclase phenocrysts are partly replaced by calcite and sericite and are veined by secondary sodic plagioclase. Cores of hornblende are altered to penninite, commonly leaving a peripheral shell of relatively fresh amphibole discontinuously altered to biotite. The albitic phase of the perthite probably was produced by replacement; it occurs as continuous rims and as veinlets and wedges pinching out towards the center of the potash feldspar grain (fig. 16). Ilmenite is replaced by rutile and sphene.

Several anomalous features of the chemical analysis of a red porphyritic granodiorite from the Hand-me-down pluton (H3585, table 9) probably are due to this deuteric alteration. The high CO_2 and H_2O^+ are related respectively to the calcite and penninite. The high Na_2O (in this particular specimen probably higher than the average of the map unit) reflects the sodic plagioclase, which replaces both labradorite and potash feldspar. The site of the high Fe_2O_3 is not apparent in the microscopic mineralogy; both the hornblende and the chlorite are iron-poor varieties, and neither hematite nor magnetite was seen in polished sections. The intense red color of the rock, however, suggests that some ferric iron may be disseminated through the rock as submicroscopic hematite.

The discrete plutons of red porphyritic adamellite and granodiorite are probably slightly younger than the diorite, granodiorite, and gray porphyritic adamellite, although direct evidence is lacking. Red porphyritic adamellite is localized along several quartzite septa in a structural setting similar to that of quartz albitite (demonstrably post-diorite, see p. 57). This similarity suggests that the red porphyritic adamellite also was emplaced after the diorite. Inasmuch as red staining, interpreted as a deuteric phenomenon, is found both in discrete plutons of red porphyritic adamellite and granodiorite and irregularly in gray porphyritic granodiorite, the emplacement of the discrete plutons could not have been much later than that of the other Early Cretaceous(?) intrusives. This conclusion is supported by the similarity of primary mineral phases.

ALASKITE

Epizonal alaskite plutons were emplaced discordantly in the Mesozoic Pony Trail Group and in the Duff Creek chonolith along the west side of the Cortez Mountains north of Duff Creek. The alaskite probably is a salic differentiate related to the more mafic plutonic rocks described above (figs. 14 and 19).

The alaskite is a fine- to medium-grained light-gray or pink rock with a granitic or porphyritic texture. Distinguishing features include rounded quartz grains, albitic plagioclase, and conspicuous (although minor) biotite.[18] Clots of amphibole and chlorite as much as 12 mm in size probably are due to contamination of the alsakitic magma by older plutonic rock.

Granitic alaskite makes up most of the two plutons southwest of Frenchie Creek, and occurs sporadically in the plutons of the Cave Canyon and Pony Trail Canyon areas.

Chemical composition, CIPW norm, and petrographic mode of a typical granitic alaskite (specimen H3586) are given in table 10. Essential minerals are zoned albite, perthitic orthoclase, and quartz. Varietal minerals consist of biotite and amphibole, the latter almost completely replaced by chlorite, biotite, quartz, and ilmenite. Acces-

[18] Plagioclase of albite rather than oligoclase composition, and the presence of only a few percent of mafic minerals are the features that distinguish alaskite from adamellite (Bateman, 1961, p. 1523, 1535).

TABLE 10.—*Chemical analyses, norms, and modes of Lower Cretaceous(?) alaskite and quartz albitite*

[Standard rock analyses of alaskite and quartz albitite by C. L. Parker and of quartz keratophyre by H. M. Hyman. Tr=trace]

	Alaskite H3586 (E. 288,350, N. 2,046,550)	Quartz albitite H3583 (E. 256,650, N. 2,016,600)	Quartz keratophyre [1]		Alaskite H3586 (E. 288,350, N. 2,046,550)	Quartz albitite H3583 (E. 256,650, N. 2,016,600)	Quartz keratophyre [1]
Chemical analyses [Weight percents]							
SiO_2	72.00	75.50	70.45	H_2O^+	0.52	0.25	1.13
Al_2O_3	14.42	14.95	14.47	H_2O^-	.09	.12	.06
Fe_2O_3	.84	.01	1.25	TiO_2	.21	.01	.36
FeO	.91	.12	2.07	P_2O_5	.07	.07	.10
MgO	.55	.11	1.38	MnO	.01	.01	.05
CaO	1.24	.34	.85	CO_2	.21	.08	.22
Na_2O	3.77	8.14	5.99				
K_2O	4.98	.19	1.70	Total	99.82	99.90	100.08
CIPW norms [Weight percents]							
Q	27.98	26.83	25.06	fs	0.65	0.21	2.27
or	29.41	1.11	10.01	mt	1.23	.02	1.81
ab	31.86	68.80	50.62	il	.40	.02	.68
an	4.34	.72	2.20	ap	.17	.16	.23
C	1.23	1.09	1.98	cc	.48	.18	.50
en	1.36	.27	3.42	Total	99.11	99.41	98.78
Modes [Volume percents]							
Quartz	27.8	22.4	------	Amphibole	Tr.	------	------
Orthoclase	[2] 30.0	------	------	Chlorite	.2	Tr.	------
Plagioclase	[3] 38.7	[4] 77.4	------	Accessories	1.1	.2	------
Biotite	2.2	------	------	Total	100.0	100.0	------

[1] Albers and Robertson (1961, table 2, No. 4).
[2] Perthitic. $2V_z=47.6°$.
[3] Albitic.
[4] An_{01-04}. $2V_z=80.0°$.

sory minerals include magnetite (with secondary martite), ilmenite (partly altered to rutile and sphene), zircon, and allanite.

The small pluton of granitic alaskite found between Sod House and Duff Creeks is mineralogically similar to specimen H3586, but shows many features suggestive of deuteric alteration. Rims of dusty albite crystals are intergrown with smaller felsic crystals and are veined by clear albite. Amphibole is partly altered to biotite and calcite. Sphene replaces plagioclase along cleavage traces and makes up almost 2 percent of the rock. Opaque minerals are absent, apparently having been completely altered to sphene. Miarolites of quartz, orthoclase, and calcite are common.

Porphyritic alaskite is a subordinate rock type in the pluton southwest of Frenchie Creek, but it makes up the greater part of the plutons of the Cave Canyon and Pony Trail Canyon areas.[9] This rock type contains phenocrysts of albite, orthoclase, and quartz in a fine-grained groundmass. Plagioclase crystals are highly altered to sericite, kaolinite, and calcite. Calcite and kaolinite vein and replace orthoclase. Primary biotite is usually altered to chlorite, calcite, and ilmenite; mafic minerals are wholly absent in a few samples.

QUARTZ ALBITITE

A number of dikes and irregular masses of quartz albitite crop out on the west side of the Cortez Mountains between Brock Canyon and Sod House Creek. The dikes range in thickness from 2 inches to about 150 feet and intrude diorite. The irregular masses, as much as 3,800 by 1,500 feet in size, were emplaced in quartzite of the Pennsylvanian or Permian Brock Canyon Formation or along the contact of quartzite and granodiorite.

The quartz albitite is a brilliantly white porphyritic rock, commonly with a saccharoidal groundmass. Phenocrysts consist of rounded quartz (2 to 15 percent) and subhedral albite (15 to 30 percent), and are about 0.8 mm in size. The albite commonly shows checker twinning. The groundmass is a microcrystalline (0.03 to 0.15 mm) aggregate of albite, quartz, and accessory apatite, sphene, zircon, and opaque material. Secondary minerals include sericite, calcite, kaolinite, and sporadic chlorite.

A typical quartz albitite is shown in figure 17. Chemical, normative, and modal data for this rock are given in table 10. CIPW normative quartz, albite, and orthoclase (recalculated to 100 percent) are plotted in figure 18 along with the corresponding data for alaskite.

The quartz albitite of the Frenchie Creek quadrangle differs from quartz keratophyre in the absence of epidote and in the paucity of chlorite and opaque material. A chemical analysis of a typical quartz keratophyre (Albers and Robertson, 1961) is shown for comparison (table 10).

The very few examples of quartz albitite that have been described in the geological literature occur either as minor dikes in granitic masses or as apophyses to granite (Johannsen, 1932). In particular, fine-grained quartz albitites are exceedingly rare. Browne (1920, p. 28–30; discussed by Johannsen, 1932, p. 375) described a "soda-aplite" from South Australia. Eskola (1914, p. 57–58) studied a nonporphyritic dike rock occurring as apophyses of oligoclase granite in the Orijarvi region of Finland, but this "porphyrite" contained 7.3 percent hornblende and 1 percent biotite.

---

[9] The altered alaskite of these plutons could be distinguished from recrystallized Mesozoic ash-flow tuff of the Sod House Tuff only with great difficulty; the contact of the two units is shown as gradational on the geologic map (pl. 1).

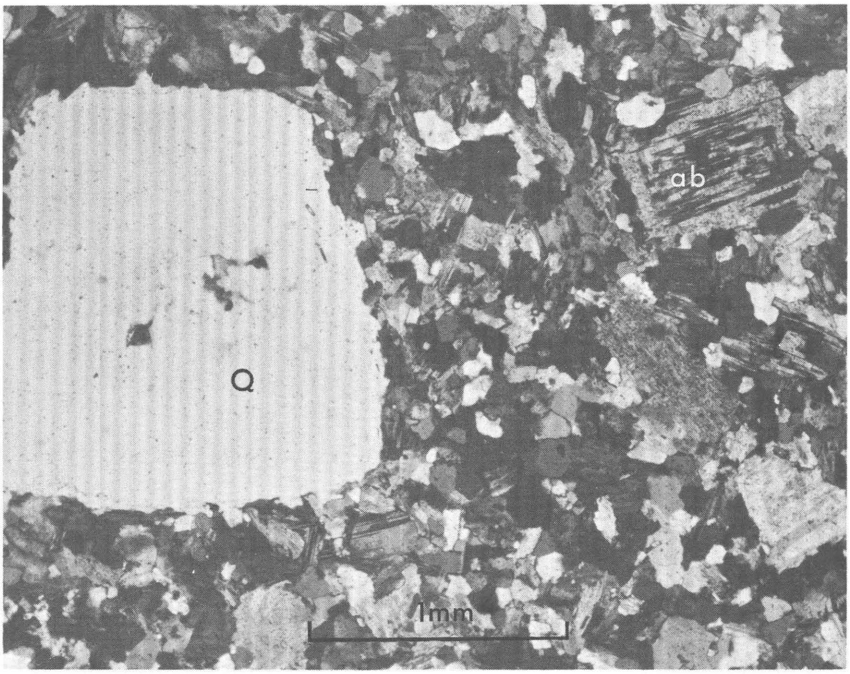

FIGURE 17.—Photomicrograph of Lower Cretaceous(?) quartz albitite (specimen H3583, table 10). × 35. Crossed polars. Note checker twinning in the albite (ab), the phenocryst of quartz (Q), and the granular groundmass of quartz and albite. Photomicrograph taken by R. B. Taylor.

The occurrence of the quartz albitite of the present report as sharply bounded dikes cutting diorite indicates that the dike material existed as a magma at the time of intrusion. A magma of quartz albitite composition, however, is difficult to reconcile with current theory and experiment in silicate chemistry. Quartz albitite plots far from the central low-temperature part of the Q-Or-Ab diagram at any water pressure (fig. 18). This anomalous chemical composition is particularly striking when considered in the light of its Differentiation Index of 96.96 (compare Thornton and Tuttle, 1960, figs. 16–17, p. 679). Therefore one must either postulate magmatic processes that have not yet been duplicated in the laboratory, or assume that the quartz albitite was emplaced as a rock of alaskitic composition (fig. 18) and was selectively albitized and leached of potash by late-stage deuteric solutions.

Several considerations suggest the probability of the second alternative. To the writer's knowledge, no natural glasses with chemical compositions approaching that of quartz albitite have been described. Devitrified soda-rich rhyolites have been described (for example, Morozewicz, 1925), but the work of Battey (1955) and of Terzaghi

(1948) leads one to question the assumption that devitrification of glassy rocks need be isochemical. In short, Bowen's criterion (1956, p. 132) for the existence of a natural soda-rich silicic liquid has not yet been met.

Petrographic evidence for the existence of deuteric solutions related to alaskite (p. 56) also supports the second alternative and suggests that the quartz albitite originally could have been of alaskitic composition. Although a transition from alaskite to quartz albitite cannot be demonstrated, a small dike between Sod House and Duff Creeks (E. 280,550, N. 2,038,350) shows features of both rock types, and may be an intermediate variety. This dike contains phenocrysts of albite, quartz, and partly kaolinized orthoclase in a fine-grained micrograntic groundmass of these same minerals. Coarse-grained muscovite and opaque granules form pseudomorphs after biotite. Whole-rock X-ray diffraction study showed that the rock is low in potash feldspar compared to normal alaskite, but this is partly owing to the partial kaolinization of orthoclase.

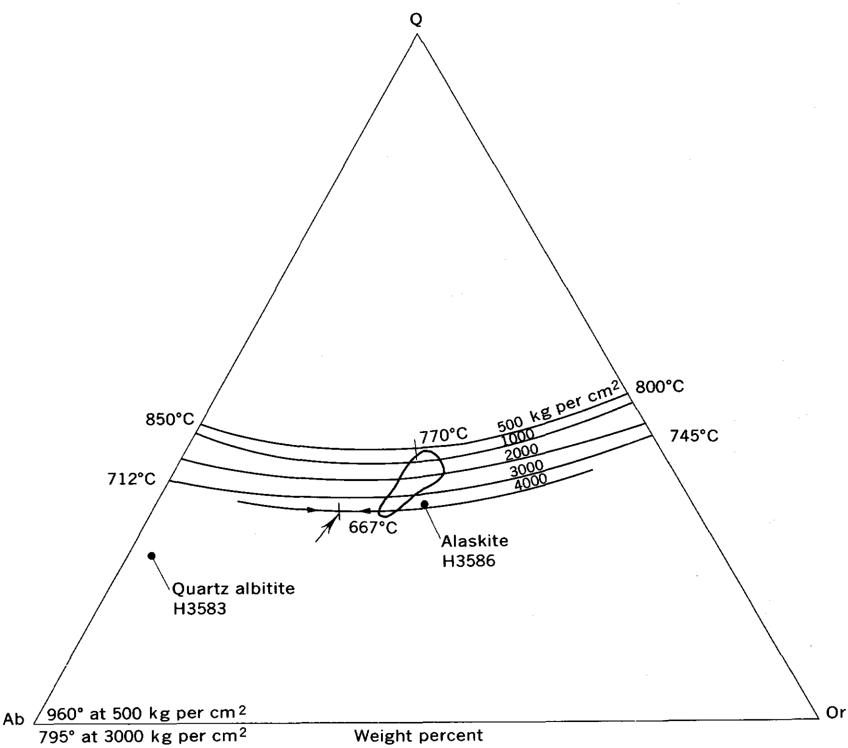

FIGURE 18.—Diagram showing the relations of alaskite and quartz albitite to the quartz-feldspar cotectics in the experimental system SiO_2–$KAlSi_3O_8$–$NaAlSi_3O_8$–H_2O at varying water pressures. CIPW normative percentages are plotted. Experimental diagram taken from Tuttle and Bowen (1958, figs. 22, 25, 38, and 42). Outlined area is the 6–7 percent maximum of normative quartz, orthoclase, and albite of 571 intrusive rocks listed by Washington (1917) that carry 80 percent or more Q+Or+Ab.

735–726 O–64–5

The presence of checker twinning in the albite suggests a replacement origin. Similar twinning is common in secondary albite of many keratophyres and albite granites (for example, Battey, 1955; Albers and Robertson, 1961; and Gilluly, 1933). Checker twinning, however, is not necessarily evidence of a replacement origin (Tilley, 1919, p. 328–329; Gilluly, 1933, p. 73).

Two features of the quartz albitite, however, argue strongly for a magmatic origin. The first is the petrographic and mineralogic uniformity of the rock type in a number of separate intrusions. This contrasts with the variations reported by Battey (1955). Secondly, the sharp contacts of the quartz albitite against apparently unaltered diorite [20] would require extremely selective alteration.

MISCELLANEOUS DIKE ROCKS

Several types of intermediate intrusive rock occur as dikes or irregular masses emplaced in Lower Cretaceous(?) plutons or in Paleozoic sedimentary rocks. These hypabyssal porphyries probably are minor variants related to the Early Cretaceous(?) plutonic episode.

Altered dacite or rhyodacite porphyry is common as dikes emplaced in granodiorite in Hand-me-down and Little Cottonwood Creeks. This pinkish-gray rock is made up of phenocrysts (0.2 to 1.0 mm) of plagioclase, clinopyroxene, and a second mafic mineral (now completely replaced by penninite) in an aphanitic felsic groundmass containing abundant cryptocrystalline alteration products. A variety containing several percent disseminated pyrite intrudes the Valmy Formation (Ordovician) just northeast of the mouth of Cottonwood Canyon.

Several masses of highly altered light-green dacite(?) were emplaced in quartzite of the Brock Canyon Formation in upper Cottonwood Canyon. This rock type contains about 30 percent phenocrysts of sericitized and chloritized plagioclase and of anhedral quartz, in an aphanitic chlorite-rich groundmass with much secondary iron staining.

MAGMATIC AND DEUTERIC EVOLUTION

Chemical variation of the Lower Cretaceous(?) plutonic rocks of the Frenchie Creek quadrangle is shown in figure 19. These plots of oxide weight percent versus Differentiation Index (Thornton and Tuttle, 1960) show a general trend of magmatic differentiation with an overprint of deuteric alteration.

The high soda and low potash of specimen H3583 (quartz albitite) probably are due to almost complete albitization (p. 57–59). Soda

[20] Further study of these sharp contacts and the adjacent diorite is suggested. Comparison of diorite specimens taken at increasing distances from the quartz albitite dike west of Duff Creek would be particularly informative.

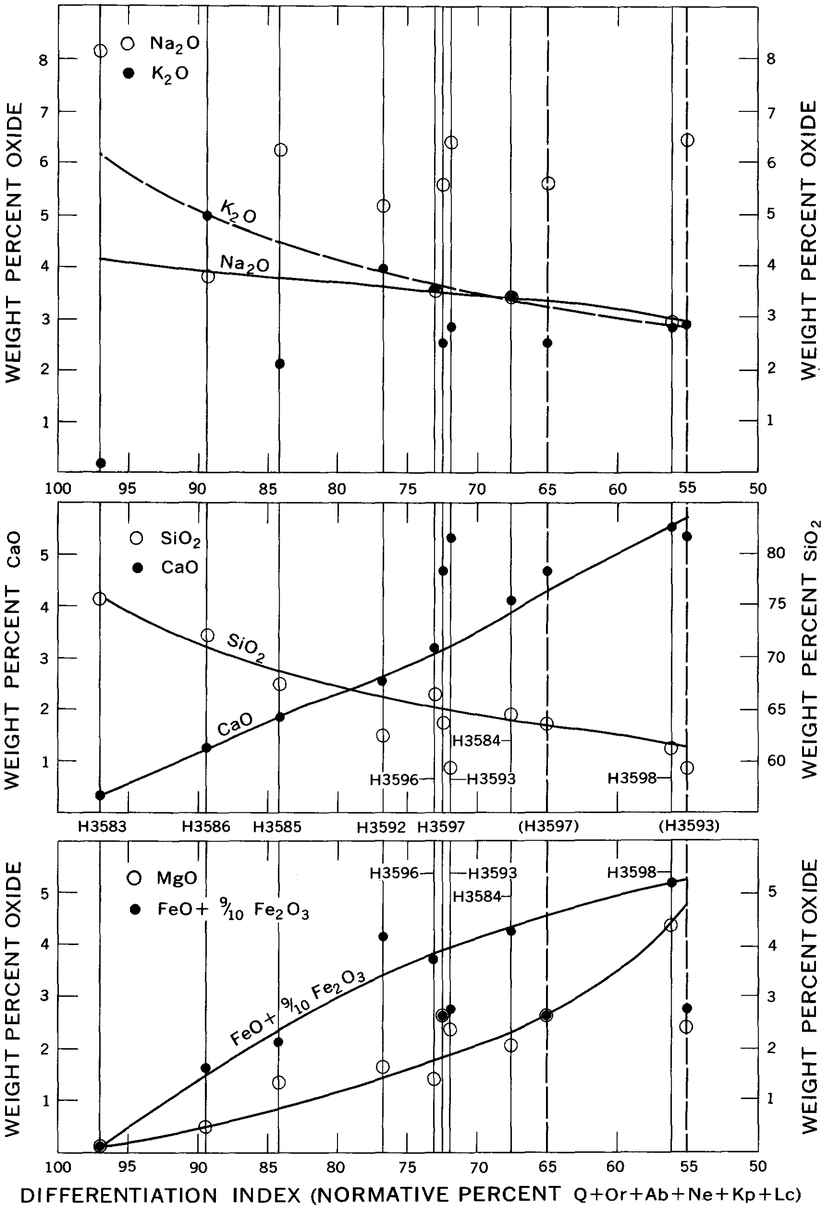

FIGURE 19.—Diagram showing the variation of Na_2O, K_2O, SiO_2, CaO, MgO, and (FeO +9/10 Fe_2O_3) with Differentiation Index for Lower Cretaceous(?) plutonic rocks. The curved lines show the probable course of magmatic differentiation and were estimated from the data depicted on the diagram. Dashed vertical lines for specimens H3593 and H3597 are at fictitious assumed Differentiation Indices.

and potash of specimen H3585 (red porphyritic granodiorite) are aberrant but to a lesser degree, reflecting the partial replacement of potash feldspar by albite in this rock (similar to that illustrated in fig. 16). The high Na_2O of specimen H3592 (rhyodacite porphyry unit) also is due to partial albitization.

Specimens H3593 (fine-grained monzodiorite) and H3597 (granodiorite) are wildly aberrant, probably owing to deuteric alteration. The albitization that was one process in this alteration would cause the Differentiation Index to appear high relative to the original magmatic composition. The original unaltered composition can be estimated by fitting the oxide percentages to the curves at lower Differentiation Indices. This is shown also in figure 19. If a Differentiation Index of 65 is assumed for specimen H3597, the CaO, MgO, and SiO_2 anomalies are negligible, although the FeO + 9/10 Fe_2O_3 and Na_2O anomalies are still appreciable. If specimen H3593 is shifted to a Differentiation Index of 55, CaO, SiO_2, and K_2O anomalies are reduced, although Na_2O is still high and both FeO + 9/10 Fe_2O_3 and MgO low. This low magnesia and total iron may in part be due to the leucocratic nature of specimen H3593 (color index=15) compared to specimen H3598, a granodiorite (color index=24.5) showing little evidence of deuteric alteration.

Thus it appears that the deuteric alteration of the Lower Cretaceous(?) intrusives of the Frenchie Creek quadrangle has involved introduction of Na_2O with depletion primarily in FeO and Fe_2O_3, but with some loss of K_2O and MgO.

The loss of iron is particularly significant in view of the hydrothermal iron deposits of the Modarelli mine and of the Frenchie Creek area. Although the total quantity of iron lost by the intrusive rocks through deuteric alteration cannot be estimated owing to the difficulty of recognizing iron loss in specimens for which there is no chemical data, the loss may be sufficient to account for the iron concentrated in the hydrothermal deposits.

The course of crystallization and deuteric alteration of a typical individual pluton is visualized as follows. The pluton was injected as a magma, probably already carrying abundant crystals of plagioclase and clinopyroxene. Continued crystallization of these anhydrous phases, along with quartz and potash feldspar, caused an increase in water pressure in the residual silicate liquid, ultimately exceeding the saturation pressure for water in the liquid at the existing temperature and load pressure. A separate aqueous vapor phase formed at this time. Had this vapor phase been concentrated in pockets, the resulting rock would have been pegmatitic or miarolitic (small pegmatites and a few miarolitic rocks are found locally in the

Frenchie Creek quadrangle). But the vapor phase probably was pervasive throughout the magma and served as a ready reactant in the alteration of clinopyroxene to various hydroxide-bearing silicates and of plagioclase to sericite. Simultaneously, this vapor phase provided ready mobility for iron, sodium, and potassium ions. Crystallization of the quartz-plagioclase-potash feldspar groundmass from the coexisting silicate liquid was completed concomitantly with the vapor phase alteration (compare Jahns and Burnham, 1962).

The existence of a vapor phase in addition to a liquid phase implies neither a large quantity of vapor nor a high water content of the total magma (considered as a crystal-liquid-vapor mush). The only requirement is that the last part of the liquid to crystallize be saturated in water; this necessarily involves a high percentage of water in the residual liquid.

HYDROTHERMAL ALTERATION

Sporadic hydrothermal alteration affected granodiorite and adamellite of the Duff Creek chonolith on the east side of the Cortez Mountains from Sheep Creek south to the quadrangle boundary. The intensity of this alteration is quite variable, and the distribution is very irregular and could not be shown on the geologic map. Approximately 25 percent of the plutonic rock in Doc, Lamb, Deer, and Sheep Creeks was altered. In addition, the sedimentary rock in the area has been kaolinized (fig. 13). This alteration probably is related to the kaolinization and sericitization that affected much of the Pony Trail Group.

Typical altered plutonic rock is white, light gray, or yellow, with white kaolinite pseudomorphs after plagioclase in a megascopically textureless groundmass of kaolinite and quartz. Pervasive limonite staining occurs sporadically. Most outcrops show irregularly disseminated limonite; a few outcrops of white altered rock have joints marked by resistant yellowish-brown selvages of limonite ½ to 4 inches in width. A subordinate altered variety consists of white clay pseudomorphs in a bright-red hematite-rich groundmass.

Petrographic and X-ray diffraction study showed that these kaolinized rocks once were plutonic rocks and are not metasomatized sandstones. The large (1 to 7 mm) pseudomorphs after plagioclase consist of cryptocrystalline kaolinite, quartz, sericite, and calcite. Sericite flakes are alined along relic cleavage and outline relic zoning. There are all gradations from euhedral pseudomorphs to very irregular masses of kaolinite. The groundmass is made up of kaolinized plagioclase laths (some of which contain remnants of feldspar), dirty anhedral interlocking quartz, intergranular sericite and kaolinite, minor potash feldspar, and pervasive irregular limonite stain. The only primary minerals unaffected by the alteration are zircon and apatite, both found as euhedral prisms.

Hemley's work (1959) on the hydrolysis of mica to kaolinite plus silica showed that kaolinite breaks down to pyrophyllite plus boehmite at about 352°C at 15,000 pounds per square inch total pressure in an 0.65 m KCl aqueous solution. The equilibrium temperature probably would increase with decreasing electrolyte strength, for Roy and Osborn (1954) found kaolinite stable at 15,000 psi pure water pressure up to 405°C. where it decomposed to hydralsite (about $2Al_2O_3 \cdot 2SiO_2 \cdot H_2O$; the phase is not found in nature). Regardless of which experimental situation is most nearly applicable to natural occurrences (Hemley's seems the better approximation), the formation of kaolinite is clearly a postmagmatic phenomenon.

Kaolinization in the Frenchie Creek quadrangle affected a number of different primary rock types (plutonic, volcanic, and sedimentary) with little regard for formational boundaries. This situation, combined with an extrapolation of the above experimental data, indicates that kaolinization took place somewhat after the late-magmatic deuteric alteration. The hydrothermal fluids that brought about kaolinization, however, probably were ultimately derived from the Lower Cretaceous(?) plutons.

CENOZOIC IGNEOUS ROCKS

RHYODACITE FLOWS

Rhyodacite flows of probable Cenozoic age occur only at the west end of the Dry Hills. The land is generally low and rolling; the more resistant flows crop out as subhorizontal ledges. Flow foliation is contorted and shows no systematic relation to flow unit boundaries. The attitudes of flow units shown on the geologic map (pl. 1) are based on continuous ledges and on aerial-photograph interpretation.

Most of the flows are brown and contain 20 to 35 percent phenocrysts of fresh zoned plagioclase (about An_{50}) and of a mafic mineral wholly altered to iron oxides. Randomly oriented plagioclase laths, opaque granules, and interstitial feldspar were identified in the aphanitic groundmass material. Vitreous dark-green flows containing a perlitic glassy groundmass occur sporadically. Phenocrysts in these hyalopilitic rocks consist of zoned labradorite (An_{67-50}), very fresh clinopyroxene, and pseudomorphs of chlorite and iron oxides (after olivine or hypersthene).

Indices of refraction of 10 fused beads from two samples were all between 1.51 and 1.52, indicating a probable silica content (by approximation from fig. 7 of Williams, Turner, and Gilbert, 1954) of 65 to 70 percent. Comparison of this silica percentage with the silica percentages given by Nockolds (1954, table 2) suggests that these specimens are rhyodacites (less probably dellenites). This conclusion is supported by the similarity of the phenocryst mineralogy of these Cenozoic flows and that of the chemically analyzed rhyodacite (specimen H3600, table 6) from the Frenchie Creek Rhyolite.

A few light-green ash-flow tuffs occur interbedded with the rhyodacite flows in the northern part of the outcrop area. These tuffs contain phenocrysts of plagioclase (zoned from andesine to oligoclase), quartz, and biotite in a partly crystalline groundmass showing uncollapsed pumice fragments and undistorted shards. X-ray diffraction study showed this groundmass, which makes up almost 90 percent of the rock, to be rich in cristobalite and clinoptilolite. The range of indices of refraction of five fused beads from one sample (1.49 to 1.50) indicates a probable silica content of 72 to 75 percent (from Williams, Turner, and Gilbert, 1954, fig. 7) and suggests that the ash-flow tuffs are rhyolitic.

These rhyodacite flows and subordinate rhyolite ash-flow tuffs are nowhere in contact with other rock types, except along faults. The absence of intrusive rocks and the presence of glass and cristobalite suggest that these volcanic rocks were erupted after the Early Cretaceous(?) period of plutonic activity, deformation, iron mineralization, and alteration. The stratigraphic relation of these rocks to the Cenozoic dellenite ash-flow tuffs is unknown.

DELLENITE ASH-FLOW TUFFS

Several hundred feet of welded ash-flow tuffs caps the low hills in the northwestern part of the quadrangle. These tuffs are younger than the Lower Cretaceous(?) granodiorite upon which they lie unconformably, but are older than Quaternary faulting.[21]

These ash-flow tuffs are dellenites, both petrographically and chemically (table 11). Phenocrysts, constituting up to 45 percent of the rock, consist of sanidine, zoned plagioclase (An_{30-40}), bipyramidal quartz, and biotite. The groundmass is composed of glass with a few microlites of biotite, quartz(?), and an opaque mineral. The glass of one specimen has partly devitrified to spherulites of cristobalite and potash feldspar (confirmed by X-ray diffraction). A foliation (eutaxitic) is produced by collapsed pumice fragments, highly welded and compacted shards, and biotite flakes.

[21] After the completion of this report, R. L. Armstrong (1963, p. 156) reported a potassium-argon biotite date of 27^{+4}_{-2} m.y. on a sample (Armstong's sample YAG 208; collected from the same locality as sample H3591, table 11) of dellenite ash-flow tuff. Comparison of this analytical age with recent compilations of the geological time scale (Kulp, 1961; Holmes, 1960) indicates a late Oligocene age for the dellenite ash-flow tuff.

TABLE 11.—*Chemical analysis, norm, and mode of Cenozoic dellenite ash-flow tuff*

[Specimen H3591; location, E. 263,900, N. 2,078,700. Standard rock analysis by C. L. Parker]

Chemical analysis (weight percents)		CIPW norm (weight percents)		Mode (volume percents)	
SiO_2	69.11	Q	25.69	Quartz	4.4
Al_2O_3	14.80	or	27.52	Sanidine	2.7
Fe_2O_3	1.05	ab	28.30	Plagioclase	[1] 21.1
FeO	1.26	an	10.66	Biotite	8.3
MgO	.68	C	.34	Hornblende	1.2
CaO	2.31	en	1.69	Opaque	0.3
Na_2O	3.35	fs	.96	Apatite	0.2
K_2O	4.66	mt	1.53	Groundmass	[2] 61.8
H_2O^+	1.83	il	.67		
H_2O^-	.12	ap	.26	Total	100.0
TiO_2	.35	cc	.02		
P_2O_5	.12				
MnO	.06	Total	97.64		
CO_2	.01				
Total	99.71				

[1] Andesine composition.
[2] Almost all glass, with a few minute quartz(?) grains and biotite flakes.

DIABASE DIKES

Pliocene(?) diabase dikes are found along the Crescent fault in the southwestern part of the Frenchie Creek quadrangle. The location and orientation of these dikes were probably determined by strains accompanying basin-and-range deformation and are discussed on p. 73–74.

The diabase dikes are hypabyssal intrusives and commonly contain a glassy or cryptocrystalline mesostasis. Ophitic texture is poorly developed; several samples show an intersertal texture in thin section, and in hand specimen could readily be mistaken for basalts.

These dikes are part of an extensive swarm occurring on the northwest side of the Cortez Mountains in the Frenchie Creek, Crescent Valley, and Cortez quadrangles. A similar swarm occurs along the north side of the Roberts Creek Mountains (20 miles south of the Frenchie Creek quadrangle), and is probably related. These dike swarms appear to have been feeders for extensive basalt flows which cover parts of the southeast slopes of the Shoshone Range and the Cortez and Simpson Park Mountains (H. Masursky, written commun., 1962). On the basis of fossils in both underlying and overlying sedimentary rocks, these basalts can be no older than late Miocene and no younger than early Pleistocene (H. Masursky, oral commun., 1963).

Chemical and mineralogical data for a specimen of an olivine-bearing tholeiitic diabase are given in table 12. These data suggest that the diabase is somewhat transitional to an alkali olivine diabase.

Table 13 compares this specimen with normal tholeiitic basalt and normal alkali basalt of Nockolds (1954) and with the parental tholeiite, high-alumina basalt, and alkali olivine basalt of Kuno (1960). Figure 20 shows the relation of the specimen to Kuno's three basalt types.

Inasmuch as alkali olivine basalts and high-alumina basalts are rare in nonorogenic continental regions (Kuno, 1960, p. 121), a further study of the basaltic province to which the diabase specimen belongs would be of petrologic interest. Absence of olivine in thin sections of two other diabase dikes suggests that the magmatic province as a whole may be distinctly tholeiitic.

CENOZOIC SEDIMENTARY ROCKS

HAY RANCH FORMATION

The Hay Ranch Formation was named by Regnier (1960, p. 1199–1203), who considered it to be middle Pliocene to middle Pleistocene in age. It crops out extensively in the Pine Valley quadrangle, but in the Frenchie Creek quadrangle it crops out only in the southeast corner. The formation is overlain by Quaternary pediment gravel and silt, and presumably extends under these unconsolidated deposits toward the Cortez Mountains.

According to Regnier (1960, p. 1189), the Hay Ranch Formation comprises "several thousand feet of lacustrine clay, limestone, and rhyolitic ash with basin-border facies of conglomerate and fanglomerates." The only rock type exposed in the Frenchie Creek quad-

TABLE 12.—*Chemical analysis, norm, and mode of olivine-bearing diabase*

[Specimen H3582; location E. 250,850, N. 2,016,550. Standard rock analysis by C. L. Parker]

Chemical analysis (weight percents)		CIPW norm (weight percents)		Mode (volume percents)	
SiO_2	48.40	Q		Bytownite	[1] 47.7
Al_2O_3	16.54	or	2.61	Diopsidic augite	[2] 20.1
Fe_2O_3	3.01	ab	18.50	Olivine	15.7
FeO	6.07	an	33.97	Fresh	(1.6)
MgO	8.50	wo	7.13	Serpentine	(14.1)
CaO	10.67	en	20.76	Opaque	[3] 2.5
Na_2O	2.19	fs	7.47	Mesostasis	[4] 14.0
K_2O	.44	fo	.22		
H_2O^+	1.55	fa	.08	Total	100.0
H_2O^-	1.17	mt	4.36		
TiO_2	.85	il	1.61		
P_2O_5	.22	ap	.49		
MnO	.16	cc	.16		
CO_2	.07				
		Total	97.36		
Total	99.84				

[1] An_{76},. $\alpha=1.5670$. $2V_z=86.1°$ (high-temperature optics).
[2] $Ca_{42}Mg_{41.5}Fe_{16.5}$. $\beta=1.692$. $2V_z=50.6°$.
[3] Polished section showed predominant magnetite, with subordinate ilmenite and minor chalcopyrite.
[4] Cryptocrystalline chlorite(?), with subordinate glass(?), feldspar microlites, opaque dust, and opaque granules.

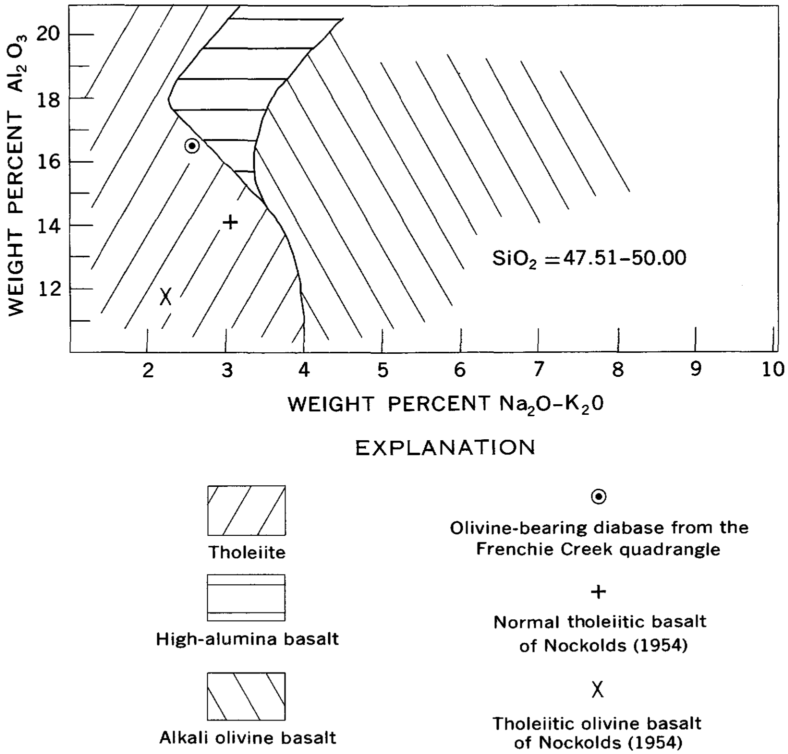

FIGURE 20.—Diagram showing the relation of the olivine-bearing diabase (specimen H3582) to the three basaltic magma types. Diagram adapted from Kuno (1960, fig. 5, p. 130).

rangle is white-weathering green siltstone, probably tuffaceous, containing a few unidentifiable chips of verterbrate fossils.

QUATERNARY DEPOSITS

OLDER ALLUVIUM

An extensive pediment on the west side of Pine Valley is capped with unconsolidated alluvial deposits of probable Pleistocene age. The detritus is poorly sorted and reflects closely the rock types of adjacent parts of the Cortez Mountains. The presence of much tan silt and pebbly sand at depths of 1 to 3 feet below the pediment surface suggests that much of the pebble- and cobble-size material on the surface may be lag gravel.

Contrary to the conclusion of Regnier (1960, p. 1204), this pediment extends onto bedrock of the Cortez Mountains, as shown on plate 1 of the present report by the numerous patches of bedrock that protrude through older alluvium. Pediment gravel unconformably overlying rocks of the Pony Trail Group is exposed in a gravel pit

TABLE 13.—*Comparison of olivine-bearing diabase from the Frenchie Creek quadrangle with three basaltic magma types*

	Tholeiitic basalt	H3582	High alumina basalt	Alkali olivine basalt
Normative hypersthene	[1] 33.62 [2] 27.0	28.23	[1] 22.62	[1] 8.21 [2] 10.0
Normative olivine	[1, 2] 0.0	.30	[1] 4.29	[1] 16.73 [2] 16.5
Picotite inclusions in olivine.	[3] Absent	Absent	[3] Present	[3] Present.
Zoning in olivine	[3] do	do	?	[4] Do.
Percent SiO_2	[1] 49.78 [2] 50.83	48.40	[1] 50.19	[1] 48.11 [2] 45.78
MgO/CaO	[1] 0.653 [2] 0.607	0.796	[1] 0.703	[1] 0.892 [2] 0.873
Exsolution lamellae in clinopyroxene.	[4] Present	Absent	?	[4] Absent.
Reaction relation of olivine and pyroxene.	[3, 4] do	? [5]	[3] Present or absent.	[3, 4] Do.
Plagioclase composition.	Anorthite [3] to bytownite.	Bytownite to labradorite.	Bytownite [3]	Labradorite [3] to andesine.
Nature of pyroxene	Augite and orthopyroxene [3, 4] (+ pigeonite).	Diopsidic augite	Augite [3] (rarely pigeonite).	Titanaugite; [3] titaniferous diopside.[4]

[1] Kuno (1960, table 6, p. 141).
[2] Nockolds (1954, table 7, p. 1021, columns 7 and 9).
[3] Kuno (1960, table 2, p. 126).
[4] Wilkinson (1956, p. 735–737).
[5] Hypersthene was not detected in thin section, but may have been altered to serpentine along with the outer parts of the olivine crystals.

just east of the Frenchie Creek quadrangle along the Modarelli mine road, and along the road just south of the Hall Ranch in Big Pole Creek.

Gravel deposits perched 25 to 75 feet above the stream level in Big Pole and Little Pole Creeks apparently are correlative with older alluvium capping the pediment.

YOUNGER ALLUVIUM

Poorly sorted Recent alluvial detritus derived from adjacent bedrock forms broad bajadas along the margins of Crescent Valley (fig. 22). Boulders as much as 15 feet in diameter are found basinward from the Crescent fault, and probably in part were moved to their present location by rockfall from nearby quartzite cliffs (fig. 21).

The central part of Crescent Valley is covered with playa silts and clays; coarse detritus is absent or nearly so. Low sinuous ridges at the west end of the quadrangle are interpreted as beach lines produced during periods when there was standing water in Crescent Valley.[22]

Gravity studies by D. R. Mabey (oral commun., 1962) suggest that the thickness of sedimentary fill in Crescent Valley exceeds 5,000 feet near the southwest corner of the Frenchie Creek quadrangle, but decreases to the northeast. This basin fill undoubtedly includes Tertiary deposits at depth.

[22] Similar beach lines, as well as relic sand spits, are well developed in the Grass Valley playa of the Cortez quadrangle, where they have been studied in detail by Harold Masursky.

STRUCTURAL GEOLOGY

ANTLER OROGENY

In the Frenchie Creek quadrangle, the Late Devonian to Early Pennsylvanian Antler orgeny (Roberts and others, 1958) affected only the Valmy Formation (Ordovician). This formation is restricted to a small part of the map area (pl. 1), but probably underlies much of the Brock Canyon Formation. By extrapolation from the Crescent Valley quadrangle (Gilluly and Gates, 1964), the Valmy Formation of the Frenchie Creek quadrangle is considered to be wholly allochthonous and part of the upper plate of the Roberts thrust, which presumably is present at depth, at least in the southwestern part of the quadrangle.

The structural features related to the Antler orogeny could not be distinguished from those produced in later periods of deformation. Presumably the orogeny involved complex thrusting and folding similar to that observed in the Shoshone Range (Gilluly, 1954; 1960a; 1960b).

EARLY CRETACEOUS(?) DEFORMATION

Emplacement of the Duff Creek chonolith and related plutons in the Early Cretaceous(?) produced a number of structural features. Those directly attributable to forcible intrusion of plutonic rock have been described on p. 40–46. Several other structural features do not show this direct relation, but nevertheless they appear to have formed contemporaneously with intrusion during an Early Cretaceous(?) episode of plutonic activity and deformation.

In the Frenchie Creek area, rocks of the Pony Trail Group generally dip northwestward, and an anticline and a syncline are inferred east of Frenchie Creek. This geometry is incompatible with the southeastward tilting that characterized basin-and-range deformation in the Frenchie Creek and surrounding quadrangles, and must have formed at an earlier date, possibly in the Early Cretaceous(?).

Silicified shear zones in the Frenchie Creek area and some of the faults in the Modarelli mine area appear to have been in existence before hydrothermal iron mineralization. If, as the writer infers, the iron mineralization occurred shortly after emplacement of the Lower Cretaceous(?) plutons, these faults and shear zones may well have formed during the Early Cretaceous(?) period of intrusion and deformation.

The age of the gentle folds near the mouths of Brock and Cottonwood Canyons is uncertain. Their proximity to the Brock Canyon pluton and the location of this pluton in a syncline suggest contemporaneity with intrusion. However, the possibility that the folds are subsidiary to the Crescent fault and are therefore of Cenozoic age cannot be ruled out, particularly since the fold axes are approximately perpendicular to the Crescent fault.

BASIN-AND-RANGE DEFORMATION

There are three major basin-and-range fault blocks in the Frenchie Creek quadrangle (fig. 1). One block forms the Cortez Mountains and extends under the pediment gravels of Pine Valley. A second composite block forms the Dry Hills and the assumed bedrock beneath the Tumbleweed Flat part of Crescent Valley. Bedrock of a third block is exposed northwest of the Frenchie Creek quadrangle in the Shoshone Range and probably extends under the alluvium in the northwesternmost corner of the quadrangle. All three of these blocks are tilted southeastward and are bounded on the northwest by high-angle normal basin-and-range faults of late Cenozoic age.

The Cortez Mountains block is bounded on the northwest by the Crescent fault, which brings Quaternary alluvium of Crescent Valley into tectonic contact with the bedrock of the Cortez Mountains. Throw on the fault exceeds 10,000 feet in the Crescent Valley and Cortez quadrangles (Masursky, 1960, p. B283), and probably is of similar magnitude in the southwestern part of the Frenchie Creek quadrangle. The topographic expression of the Crescent fault dies out to the northeast in the Carlin quadrangle. This fact suggests that the throw of the fault decreases to the northeast. To the southwest in the Cortez quadrangle, the fault branches into several faults of lesser throw (Masursky, 1960).

In the southwestern part of the Frenchie Creek quadrangle, the Crescent fault is marked by a single trace, oriented roughly N. 50° E. Internal structures of the range are truncated along a prominent fault scarp (fig. 21). Movement on the fault has produced faceted spurs, the higher parts of which are modified by erosion (fig. 22). The fault surface is generally concealed by colluvium, but is exposed just southwest of the mouth of Cottonwood Canyon. Here the surface is represented by large striated faces of brecciated Ordovician chert (fig. 23). The strike of the faces averages N. 75° E., but varies 10° either way owing to undulations measuring 2 to 4 feet from crest to crest. Dip of the fault surface is 60° N., and both slickensides and undulations plunge 55° at 310° azimuth.

Northeast of Cottonwood Canyon the Crescent fault is represented by two sets of faults. One set strikes about N. 80° E., the other N. 10° to 40° E. The intersections of the two fault sets commonly are areas of complex faulting, as at Hand-me-down and Sod House Creeks. High-angle faults related to the Crescent fault extend from these areas into the Cortez Mountains. These faults commonly have a pronounced topographic expression and die out towards the crest of

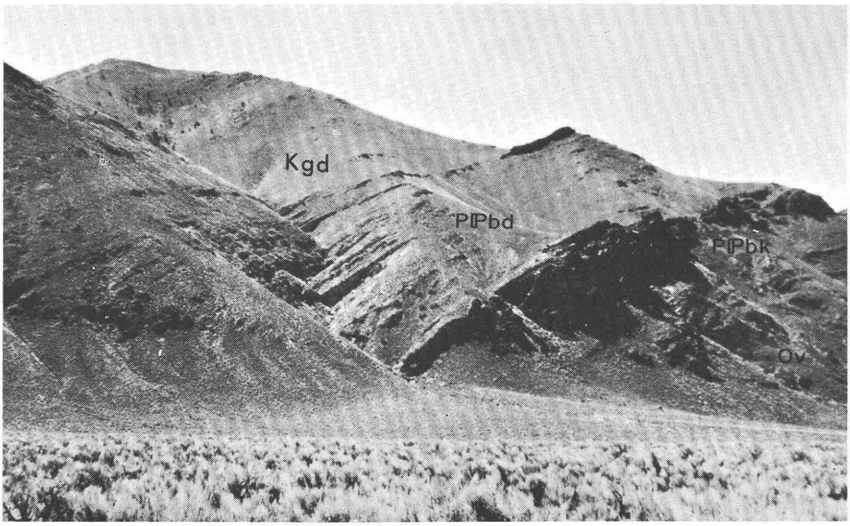

FIGURE 21.—Photograph of the Cresent fault between Brock and Cottonwood Canyons. Note the truncation of the internal structure of the Cortez Mountains by the Crescent fault, as well as the position of the fault trace 100 to 300 feet above the valley floor. Ov, Valmy Formation; PPbk, conglomerate member of the Brock Canyon Formation; PPbd, dolomite member of the Brock Canyon Formation; Kgd, Brock Canyon pluton. All the beds dip to the left and away from the observer.

the range. Faulting basinward from the Crescent fault is indicated by the small pediments just west of the topographic scarp at Sod House Creek and east of Frenchie Creek. Presumably the bedrock of these pediments is bounded on the northwest by faults subsidiary to the Crescent fault.

There are two zones of silicified rock along the Crescent fault north of Hand-me-down Creek. The zone exposed at E. 270,000, N. 2,030, 000 consists of angular fragments as much as 10 inches across of a silicified and argillized Early Cretaceous(?) plutonic rock in a matrix of cryptocrystalline quartz. The zone is 25 to 50 feet thick, and extends for about 1,000 feet along the fault. Many shear surfaces in the silicified breccia dip approximately 65° NW.; slickensides are perpendicular to the strike of the fault. The silicified zone is bounded to the southeast by unaltered plutonic rock; the contact is covered. Parts of the zone consist of intricately banded white bull quartz.

The second zone, extending from E. 265,100, N. 2,058,500 to about E. 268,300, N. 2,028,500, consists primarily of massive hematite-stained vuggy white quartz. The vugs are surrounded by crudely concentric banding in the quartz. Some vugs are elongate and form radiating clusters; these may be casts of a mineral now removed by solution. Banding in less vuggy quartz dips 60° to 85° N., probably parallel to the fault plane. A breccia of completely silicified fragments in a cryptocrystalline quartz matrix is subordinate to the massive banded quartz.

There are several springs along the Crescent fault. The springs at the prospect cuts half a mile west of Hand-me-down Creek are warm and sulfurous. Sulfur and gypsum are being deposited from steam rising from these springs (p. 80). Argillized zones occur along the fault, occasionally in conjunction with the small springs, and are commonly sites of prospect pits. With the exception of the sulfur prospects west of Hand-me-down Creek, these pits show no significant mineralization.

There are at least 14 diabase dikes near the Crescent fault in the southwest corner of the Frenchie Creek quadrangle (pl. 1). There are no dikes north of Little Cottonwood Creek. The swarm extends southwestward along the Crescent fault into the Crescent Valley and Cortez quadrangles, where the dikes are more abundant and more closely spaced. In the Frenchie Creek quadrangle the dikes are localized at or near the Crescent fault; no diabase is found farther than 1½ miles from the fault. The 11 most prominent dikes all extend to within a third of a mile of the fault trace, are oriented approximately perpendicular to the trace, and are subvertical.

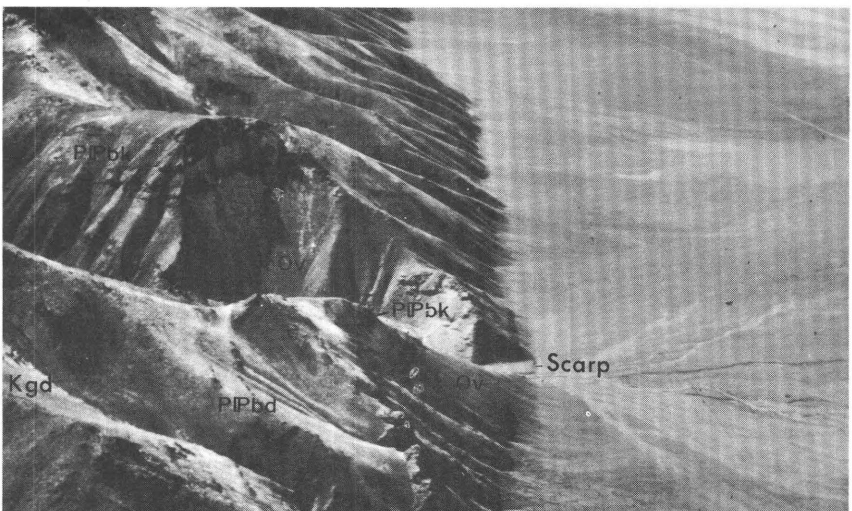

FIGURE 22.—Oblique aerial photograph of view southwest along the Crescent fault. Note the small Recent fault scarp in alluvium at the mouth of Brock Canyon. Ov, Valmy Formation; PPbk, conglomerate membei of the Brock Canyon Formation; PPbd, dolomite member of the Brock Canyon Formation Kgd, Brock Canyon pluton.

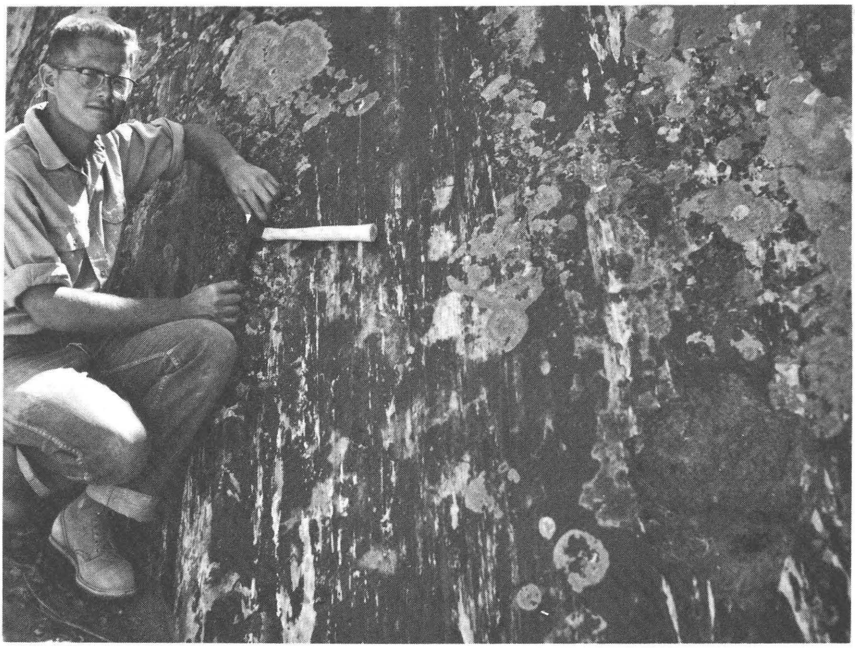

FIGURE 23.—Photograph of slickensides on the Crescent fault just southwest of the mouth of Cottonwood Canyon. The rock is brecciated chert of the Valmy Formation (Ordovician). The hammer handle approximates the N. 75° E. strike of the fault, which dips 60° basinward. Circular patches are lichen and pits in the outcrop.

The spatial and geometric relations of the dikes to the Crescent fault suggest that the dikes were emplaced in extension fractures produced by the same stress system responsible for the Crescent fault. The coincidence of the dike swarm with that part of the fault having maximum throw indicates that the fractures may have been produced by arching of the Cortez Mountains block along an axis approximately perpendicular to the trace of the fault. The Crescent fault, as well as the Dry Hills fault, however, has an anomalous northeasterly trend in relation to the general northerly trend of the basin-and-range faults in north-central Nevada. This suggests that the extension fractures may have been formed by resolution of regional east-west extension of the Basin and Range province (Thompson, 1960) into extension in both a 140° azimuth (perpendicular to the fault trace) and a 50° azimuth (perpendicular to the dikes).

A prominent fault scarp in alluvium is found along the Crescent fault at the mouth of Brock Canyon (fig. 22). Alluvium has been uplifted about 13 feet. There are similar scarps in alluvium about half a mile west of Hand-me-down Creek. These scarps indicate Recent movement on the Crescent fault.

The time of initiation of the Crescent fault is unknown. That the fault existed before emplacement of diabase dikes is indicated by the distribution of the dikes and by their geometric relation to the fault. The dikes appear to have been feeders for the Pliocene(?) basalt flows found on the southeast side of the Cortez Mountains in the Horse Creek Valley quadrangle (p. 66). Therefore, the faulting began before extrusion of the basalts in the Pliocene(?).

The Cortez Mountains are bounded on the southeast by overlapping Quaternary alluvium. Bedrock of the Cortez Mountains block, however, probably extends under the Cenozoic fill of Pine Valley, and may be bounded by a concealed normal fault in the middle of Pine Valley (Regnier, 1960, p. 1204). Discontinuous Recent fault scarps, 7 to 18 feet high, are present in alluvium at or near the contact of the pediment alluvium and the bedrock of the Cortez Mountains. These scarps are marked by heavy growth of phreatophytes (predominantly greasewood) and by a few springs. Low rounded bedrock domes protrude through the pediment alluvium southeast of the mountains. Rock types of these domes are similar to rock types of the adjacent mountains. This similarity indicates that displacement along the Recent faults is minor. This faulting may be due to adjustments consequent upon tilting of the Cortez Mountains block and filling of Pine Valley with sediments.

The northeastward-trending faults that cut the Brock Canyon Formation in upper Cottonwood Canyon are related to basin-and-range deformation. The age of these faults relative to the Deer Camp pluton cannot be directly determined owing to poor exposures of the contact of adamellite and sedimentary rock. The faults, however, cut upper Tertiary(?) gravels in the northern part of the Horse Creek Valley quadrangle (H. Masursky, oral commun., 1961).

Many of the northward- and northwestward-trending faults in the Big Pole Creek-Frenchie Creek area are probably of Cenozoic age. Those that delimit the surface outcrop of the Modarelli iron deposit, however, in part predate Early Cretaceous(?) iron mineralization and have undergone renewed movement at a later time.

The Dry Hills fault block is bounded on the northwest by the Dry Hills fault, which extends from Hot Springs Point in the Crescent Valley quadrangle at least as far as the Humboldt River in the Beowawe quadrangle (fig. 1). Surface expression of the fault in the Frenchie Creek quadrangle generally consists only of alluvial scarps 10 to 15 feet high. Near the west margin of the quadrangle, however, the fault is marked by a prominent linear bedrock scarp. This scarp truncates internal structure of the Dry Hills, in particular the conglomerate beds of the Brock Canyon Formation at E. 252,600, N.

735-726 O-64-6

2,072,600. The intersection of this ridge and the fault is marked by several prospect holes in brecciated and limonite-stained conglomerate and quartzite. Along the fault farther to the west, in the Crescent Valley quadrangle, there are several hot springs in which sulfur has been extensively deposited.

The Dry Hills fault block comprises two major subblocks. The larger one is an L-shaped block forming the high peaks north of Willow Corral Pass as well as the lower hills southwest of the pass. The smaller one is a wedge-shaped block lying between the larger block and the Dry Hills fault. The fault inferred to bound this wedge on the east is masked by alluvium in the Frenchie Creek quadrangle but is marked by a small alluvial scarp in the Beowawe quadrangle.

The wedge-shaped sub-block is broken by many small high-angle faults showing no preferred orientation. Displacement on any single fault probably does not exceed several hundred feet. These faults are nowhere exposed, but their existence is indicated by the erratic dips of the Cenozoic dellenite ash-flow tuffs. The dips are not original, as is shown in several localities by the restriction of ash-flow tuff to one side of a valley. If the dips of the ash-flow tuff reflected underlying pre-tuff topography, there should be tuff at approximately the same level on both sides of the valley.

The trace of the fault separating the Cenozoic rhyodacite flows at the west end of the Dry Hills from the main granodiorite and quartzite mass of the Dry Hills is nowhere exposed, for it follows talus-filled valleys. The absence of alluvial scarps, the northwest trend, and the presence of a faultline scarp on the downthrown side all suggest that movement on the fault may have been restricted to the late Tertiary. Possibly the fault is coeval with the flows and marks the northeast boundary of a volcano-tectonic depression. The flows are bounded in part on the southwest by a similar fault, bringing Valmy Formation (Ordovician) into contact with the Cenozoic flows (Gilluly and Gates, 1964).

The northeastward-trending normal faults in the Cenozoic flows at the west end of the Dry Hills delimit small fault blocks tilted southeastward. These faults are marked by veins of banded white calcite, generally from 3 to 10 feet wide, but locally as much as 35 feet wide. Brecciated fragments included in the calcite are primarily Cenozoic flow rock, with a few Paleozoic chert (the Valmy Formation is exposed at the western tip of the Dry Hills in the Crescent Valley quadrangle) and Cenozoic dellenite ash-flow tuff fragments. The veins have a pronounced dilatational character consistent with their interpretation as fillings along normal faults.

The L-shaped sub-block of the Dry Hills bends sharply near Willow Corral Pass. Although the present topographic form of the hills is probably due to late Cenozoic faulting, preexisting structural features may have controlled the position of the faults in this area, and thus may have localized the topographic bend. These features are (1) a general contact of granodiorite and white alaskitic dellenite porphyry, (2) sandstone screens in the granodiorite and along the contact of the granodiorite and the porphyry, and (3) presence of the Pony Trail Group, which is found nowhere else in the Dry Hills. Association of these prefaulting inhomogeneities with the bend appears more than fortuitous.

Owing to poor exposures, a complex fault system extending south-southeastward from Willow Corral Pass cannot be ruled out. Intrusive relations, however, are suggested by the irregular distribution of rock types and by the absence of any evidence of late Cenozoic faulting.

The general N. 30° W. trend of the belt of sandstone screens in the Willow Corral Pass area is similar to the trend of the northeast contact of the Cenozoic flows at the west end of the Dry Hills and to the general trend of the northeast contact of the Duff Creek chonolith. All three of these northwestward-trending features may represent Mesozoic tectonic lineaments followed by later intrusion and (or) faulting.

MINERAL DEPOSITS

IRON MINERALIZATION

The iron ore deposits of the Modarelli mine and of the Frenchie Creek area were studied by Shawe and others (1962) in 1953. The reader is referred to their report for data on mine and prospect ownership and location, mine history, and mining methods. The report also contains geologic maps at 1:2,400 of the Modarelli mine area and of the Frenchie Creek prospect (pls. 18 and 20).

The present writer's mapping in the Frenchie Creek quadrangle has revised the stratigraphic relations given by Shawe and others (1962). Volcanic rocks of only one age are found in the Modarelli mine area. The "upper Miocene and lower Pliocene younger series volcanic rocks" of Shawe and others (1962) correspond to the present writer's Mesozoic Big Pole Formation and Sod House Tuff, and the "Eocene(?) or Oligocene(?) older series volcanic rocks" to the overlying Mesozoic (most probably Jurassic) Frenchie Creek Rhyolite (see p. 20–37 for a detailed discussion of the volcanic stratigraphy).

The iron ore deposits occur almost exclusively in the Frenchie Creek Rhyolite. The other two formations of the Pony Trail Group were also hydrothermally altered and enriched in iron,[23] but ore-grade

[23] The introduction of iron is expressed in the green ash-flow tuffs by goethite replacing sanidine (fig. 6) and by high ferric iron in the chemical analysis (No. H3599, table 6). Sporadic introduction of red earthy hematite affected the volcanic wackes of the Big Pole Formation (p. 23).

material has been found in only one outcrop of the Sod House Tuff, and none has been found in the Big Pole Formation.

MODARELLI MINE

The Modarelli mine is in a deposit of ore and sub-ore material having a triangular shape in plan (Shawe and others, 1962, pl. 18). The deposit is sharply bounded on the northeast and south by high-angle faults. Although post-ore movement is demonstrated by slickensides on massive hematite, these faults probably existed before mineralization and served to localize the ore-bearing fluids. The northwest contact of the deposit is gradational. A conspicuous silicified zone which crops out from E. 308,600, N. 2,046,800 to E. 310,050, N. 2,047,650 may have controlled in part the extent of mineralization on this side of the deposit.

The ore consists primarily of massive martite, with subordinate remanent magnetite. Much and possibly all the ore may have been deposited as magnetite and later oxidized to hematite. Gangue minerals include quartz, calcite, and apatite. The ore replaced rhyodacite and rhyolite of the Frenchie Creek Rhyolite. Horses of waste rock are found throughout the deposit. According to Shawe and others (1962, p. 99): "Only the southeastern half of the deposit is ore; most of the remainder is too low grade to presently constitute ore, although it contains zones of ore-grade material."

The conspicuous northward-trending fault about 1,200 feet east of the mine was mapped by Shawe and others (1962, pl. 17) as downthrown on the east. The interpretation of the present writer is that this fault is upthrown on the east and that movement along it has brought the Big Pole Formation in contact with the Frenchie Creek Rhyolite. The sense of movement on this fault is critical in regard to possible eastward extrapolation of the known iron deposit. The eastward-facing faultline scarp along this fault can be interpreted as due either to differential erosion or to late minor movement in a sense opposed to that of the major movement.

Production in 1951–52 totaled 263,000 long tons of ore averaging 57.8 percent iron (Shawe and others, 1962, p. 97); 118,000 long tons was shipped in 1955–56, and 14,900 long tons in 1959–61.[24] Total production through 1961 was 395,900 long tons.

MISCELLANEOUS PROSPECTS

Outcrops of hematite and magnetite are scattered throughout the Frenchie Creek Rhyolite in the Frenchie Creek area. Although many of these outcrops are of ore grade, their small size and irregular distribution make them of dubious economic potential.

[24] Production and grade figures furnished by and published with the permission of J. R. Simplot Co.

Much of the Frenchie Creek Rhyolite in Frenchie Creek has been silicified, kaolinized, and brecciated. Discontinuous silicified shear zones 25 to 100 feet wide range in strike from N. 65° E. to N. 60° W., and dip steeply northward. These zones are almost barren of ore minerals west of Frenchie Creek, but east of the creek localize magnetite-hematite ore at the Frenchie Creek and Imperial prospects.

At the Jackson prospect, hematite has selectively replaced individual beds of volcanic wacke interbedded with rhyodacite and rhyolite flows of the Frenchie Creek Rhyolite.

The Big Pole Creek prospect and the smaller prospects about one-fifth of a mile northeast differ from the other iron ore deposits in the lesser degree of alteration of magnetite to hematite. The ore minerals occur with quartz as vuggy open-space fillings in a breccia containing fragments of gray rhyolitic flow rock.

The sole occurrence of ore-grade material in the Sod House Tuff is southwest of Sheep Creek at E. 297,250, N. 2,023,750. Magnetite rimmed by hematite and goethite forms the matrix of a breccia containing fragments of ash-flow tuff and of Lower Cretaceous(?) plutonic rock.

GENESIS OF IRON ORE

The iron now concentrated as deposits of hematite and magnetite in volcanic rocks of the Mesozoic Pony Trail Group probably was derived from deuterically altered Lower Cretaceous(?) plutonic rock. The plutons commonly show petrographic features of deuteric alteration, and the chemical analyses of altered specimens show appreciable loss of iron (p. 60–63).

The iron liberated in this alteration presumably was transported to the Frenchie Creek-Modarelli mine area by hydrothermal fluids. The zones of shearing and brecciation that provided channelways for these fluids probably formed during the Early Cretaceous(?) plutonic episode, although the zones may in part be related to the Mesozoic volcanic episode.

Restriction of ore-grade deposits to brecciated flow rocks of the Frenchie Creek Rhyolite is apparently due to the relative ease of fracture of these brittle flow rocks, as compared to the punky ash-flow tuffs of the Sod House Tuff and the granular volcanic wackes of the Big Pole Formation.

Hydrothermal iron mineralization was apparently contemporaneous with the sericitization of the Sod House Tuff and with the kaolinization of the Brock Canyon Formation, the Pony Trail Group, and Lower Cretaceous(?) plutonic rocks. This mineralization and alteration probably occurred during the Cretaceous.

MISCELLANEOUS MINERAL DEPOSITS

BARITE

Coarsely crystalline barite is found with quartz in sporadic veins and irregular masses both in the Frenchie Creek Rhyolite and in Lower Cretaceous(?) plutonic rock. The known occurrences are small and probably uneconomic; barite commonly is seen only in float.

The largest deposit is found in silicified rhyolite(?) in Frenchie Creek at E. 299,500, N. 2,044,850, and has been prospected by an adit and a shaft (both now inaccessible). The barite occurs as anastamosing subvertical veins as wide as 15 inches in a vertical shear zone 50 feet wide striking N. 85° E. This shear zone is similar to those that localize iron ore at the Frenchie Creek and Imperial prospects (p. 79).

Horizontal veins about 5 inches wide found near the mouth of Hand-me-down Creek at E. 265,200, N. 2,027,800 consist of alternating bands of barite and quartz $\frac{1}{2}$ to 3 inches wide. Barite also occurs with quartz in coarsely crystalline vuggy masses showing no banding. Host rock at this locality is light-gray Lower Cretaceous(?) adamellite.

COPPER MINERALS

Copper minerals occur only sporadically in the Frenchie Creek quadrangle and have little or no economic potential. Several copper prospects near E. 298,200, N. 2,026,200 in Sheep Creek Canyon are in brecciated flows near the top of the Big Pole Formation. Supergene malachite, cuprite, and azurite occur in the matrix of the breccia. Tiny (<0.5 mm) chalcopyrite grains are enclosed in the cuprite and appear to be relics of the primary ore mineral. Prospects at E. 304,600, N. 2,052,100 near the Crescent fault east of the Frenchie Ranch and E. 299,400, N. 2,045,500 in Frenchie Creek show a little malachite in brecciated flow rock of the Frenchie Creek Rhyolite.

SULFUR

Warm sulfurous springs issue from two old opencuts along the Crescent fault just southwest of Hand-me-down Creek. These cuts were dug no earlier than 1900 and possibly as late as 1940. Both are in a gouge of altered and comminuted Lower Cretaceous(?) plutonic rock. Sulfurous steam rises from several natural cavities in the floor near the face of the larger cut. Moist euhedral crystals of sulfur and gypsum (identification confirmed by X-ray diffraction) cover the face above the cavities. These crystals must have been deposited after the opencut was dug. They appear to be slowly growing at the present time by direct deposition from the rising sulfurous steam.

CONCLUSION

SUMMARY OF GEOLOGIC HISTORY

In early Paleozoic time, the Frenchie Creek quadrangle was presumably the site of carbonate deposition, whereas eugeosynclinal conditions existed some tens of miles to the west. During the Late Devonian to Early Pennsylvanian Antler orogeny, the eugeosynclinal rocks were thrust eastward over the carbonate rocks.

Near-shore marine conglomerate, sandstone, and dolomite were deposited unconformably on allochthonous Ordovician eugeosynclinal rocks during the Late Pennsylvanian or Permian. The products of sedimentation gradually shifted to continental claystones, siltstones and sandstones. An abrupt influx of feldspathic detritus in the Permian (Triassic?) probably reflected igneous activity in the Dry Hills, where a complex of altered intermediate volcanic flows and hypabyssal intrusives formed at this time.

The late Paleozoic sedimentation may have continued uninterrupted into the early Mesozoic, for a thick sequence of unfossiliferous Mesozoic volcanic wacke in the Cortez Mountains shows some similarity to the Permian(?) arkose. Deposition of this volcanic wacke was followed by extrusion of silicic ash-flow tuffs and of rhyodacite and rhyolite flows (probably Jurassic), and by intrusion of a few related rhyolite(?) plugs.

Plutons ranging in composition from diorite to alaskite and quartz albitite were emplaced by forcible intrusion during the Early Cretaceous(?). This plutonic episode was accompanied by intense local deformation and by deuteric alteration of the intrusive rock, and was closely followed by complementary hydrothermal alteration and iron mineralization in the country rock.

During Late Cretaceous and early Tertiary time continental beds were deposited in Pine Valley, but most of the Frenchie Creek quadrangle probably was uplifted and eroded.

In Cenozoic time, rhyodacite flows and dellenite ash-flow tuffs were extruded in the Dry Hills, and diabase dikes were emplaced in the Cortez Mountains during the Pliocene(?). Continental deposition continued in Pine Valley and possibly in Crescent Valley. Normal faulting began during the Cenozoic and has continued to the present.

RECOMMENDATIONS FOR FURTHER STUDY

The Beowawe 15-minute quadrangle, just north of the Frenchie Creek quadrangle, has not been studied to date, although a recent (1957) topographic may at 1:62,500 is available. Geologic mapping of the Pony Trail Group in the Beowawe quadrangle would supplement the stratigraphic relations suggested in the present report, as well as those forthcoming from current studies in the Carlin and Pine Valley quadrangles, and would probably clarify the relation of the Mesozoic Pony Trail Group to the Permian(?) igneous complex of the Dry Hills. The iron ore deposits of the Beowawe quadrangle would also be a field of investigation.

The hydrothermal alternation problems in the Frenchie Creek-Modarelli mine area have scarcely been touched in the present report. A topical study of this alteration and its relations to the ore deposits, the plutonic rocks, and the host rock types would be most instructive. Such an investigation would necessarily involve geologic mapping in Frenchie Creek at a scale at least as large as 1:6,000. Whole-rock X-ray diffraction techniques would be indispensable for study of the aphanitic holocrystalline rocks of the Pony Trail Group, and semiquantitative spectrographic studies would be advisable. Recent developments in quantitative analysis of light major elements by X-ray spectroscopy (Baird and others, 1962) and in trend surface analysis (Whitten, 1961) could be extensively applied in the study of these altered rocks.

Such a topical investigation could well be expanded to include the Barth iron mine in the Beowawe quadrangle, and might profitably be combined with a regional stratigraphic review of the Pony Trail Group. Such studies would best begin after completion of areal geologic mapping in the Beowawe quadrangle and in the neighboring Carlin and Pine Valley quadrangles.

MEASURED SECTIONS

Type section of the Brock Canyon Formation measured in the upper part of Cottonwood Canyon from E. 277,850, N. 2,006,900 to E. 271,850, N. 2,002,550

[The lower parts of this stratigraphic section lie a few hundred feet inside the Horse Creek Valley quadrangle. The writer extended his geologic mapping into the Horse Creek Valley quadrangle in order to tie into this section and make use of the stratigraphic relations shown in it. The northern part of the Horse Creek Valley quadrangle has since been mapped by Harold Masursky]

	Thickness (ft)	*Distance from base of member to base of unit (ft)*
Lower Cretaceous(?):		
Hand-me-down pluton:		
Red porphyritic adamellite		
Intrusive contact.		
Upper Pennsylvanian or Permian:		
Brock Canyon Formation:		
Arkose member:		
5. Arkosic wacke, gray, fine-grained, silty, composed of detrital plagioclase and subordinate quartz in clay- to silt-size matrix material containing much plagioclase; secondary tremolite and calcite, locally as clots as much as ½ in. in size; alternating gray calcareous arkosic siltstone; upper 35 ft covered by float of red porphyritic adamellite; thickness only approximate owing to obscure bedding and to lack of structural control	900	730
4. Arkosic arenite, light-gray, very fine to medium-grained, composed of subrounded detrital quartz and plagioclase in a cement of plagioclase, quartz, and calcite; subordinate gray calcareous arkosic siltstone; obscure bedding	300	430
3. Arkosic siltstone, dark-gray, calcareous, chloritic; obscure lamination; lower 5 ft is light purplish-gray	200	230
2. Sandstone, light-gray, very fine grained, feldspatic, calcareous; gray calcareous siltstone at top; mostly float	140	90
1. Sandstone, light-gray (limonite-stained), medium- to coarse-grained, poorly sorted, calcareous, feldspathic; subordinate fine-grained white sandstone and dark-gray quartzite	90	0
Total arkose member	1, 600	
Contact conformable.		

Type section of the Brock Canyon Formation measured in the upper part of Cottonwood Canyon from E. 277,850, N. 2,006,900 to E. 271-850 N. 2,002,550—Con.

	Thickness (ft)	Distance from base of member to base of unit (ft)
Upper Pennsylvanian or Permian—Continued		
Brock Canyon Formation—Continued		
Claystone member:		
16. Siltstone, yellowish-gray, calcareous and dolomitic; subordinate reddish-gray claystone and white (limonite-stained) fine- to medium-grained calcareous sandstone; float of black quartzite near base	180	1,701
15. Covered; alluvium of Cottonwood Creek	165	1,536
14. Quartzite, black, fine- to medium-grained, poorly sorted; contains subangular quartz grains and as much as 10 percent subrounded chert grains; forms a prominent ledge	7	1,529
13. Claystone, reddish- and yellowish-gray, silty; subordinate black medium-grained quartzite (compare unit 14)	265	1,264
12. Claystone, reddish- and yellowish-gray, silty, as float; a few small outcrops of yellow-weathering white medium-grained quartzite	85	1,179
11. Sandstone, black, fine- to medium-grained poorly sorted, thin-bedded, calcite-cemented; contains subrounded quartz grains; locally quartzitic; subordinate yellowish-gray siltstone and yellowish-gray fine- to medium-grained sandstone	111	1,068
10. Siltstone, yellowish-gray; subordinate reddish-gray claystone and light yellowish-gray fine-grained quartzite	52	1,016
9. Sandstone, light yellowish-gray, medium-grained; contains subrounded quartz grains and a few chert grains; locally quartzitic; subordinate yellowish-gray siltstone and reddish-gray claystone	82	934
8. Claystone, reddish- and yellowish-gray, silty; subordinate yellowish-gray medium-grained calcite-cemented sandstone; float	70	864
7. Quartzite, light yellowish-gray, medium-grained, poorly sorted, thin-bedded, calcarcous; contains subrounded quartz grains and a few hematite grains; black medium-grained poorly sorted quartzite is common near base of unit	145	719

Type section of the Brock Canyon Formation measured in the upper part of Cottonwood Canyon from E. 277,850, N. 2,006,900 to E. 271,850, N. 2,002,550—Con.

	Thickness (ft)	Distance from base of member to base of unit (ft)
Upper Pennsylvanian or Permian—Continued		
Brock Canyon Formation—Continued		
Claystone member—Continued		
6. Sandstone, light yellowish-gray, fine- to medium-grained, calcareous; dark reddish-gray claystone; reddish-gray fine-grained silty sandstone; all float	237	482
5. Sandstone, yellowish- and reddish-gray, fine-grained, poorly sorted; rich in chert grains; a few ledges as much as 1 ft thick of medium-grained white (limonite-stained) quartzite with as much as 20 percent chert grains	88	394
4. Sandstone, reddish-gray, and reddish-gray siltstone and claystone, in alternating beds; light yellowish-gray fine-grained quartzite with abundant chert grains (compare unit 3); 1-ft-thick ledge of white (limonite-stained) coarse-grained quartzite rich in chert grains occurs at the base of the unit	13	381
3. Sandstone, white, fine-grained, calcite-cemented; subordinate light yellowish-gray fine-grained quartzite and dark reddish-gray fine-grained poorly sorted silty sandstone; abundant chert grains in the quartzite and reddish-gray silty sandstone; all float	24	357
2. Siltstone, yellowish-gray, sandy; fine-grained tan quartzite; local reddish-gray claystone; minor black quartzite (compare unit 1); subordinate lithic arenite, with subangular granules of black chert and gray quartzite; all float	212	145
1. Siltstone, yellowish-gray; black medium-grained quartzite; subordinate pebble conglomerate, with clasts mostly of gray chert but a few of black fine-grained quartzite; minor light-gray coarse-grained quartzite, with a few chert granules; minor reddish-gray claystone; mostly float	145	0
Total claystone member	1,881	
Contact conformable.		

Type section of the Brock Canyon Formation measured in the upper part of Cottonwood Canyon from E. 277,850, N. 2,006,900 to E. 271,850, N. 2,002,550—Con.

	Thickness (ft)	Distance from base of member to base of unit (ft)
Upper Pennsylvanian or Permian—Continued		
Brock Canyon Formation—Continued		
Dolomite member:		
6. Conglomerate, light-gray; consists of subrounded pebbles of gray chert and a few pebbles of dark-gray very fine grained quartzite in a medium- to coarse-grained quartzitic matrix; also light-gray (limonite-stained) quartzite containing subrounded quartz grains and about 10 percent subangular chert granules; the quartzite is found as beds and lenses 1 to 6 in. thick in the cliff-forming conglomerate; minor float of dark-gray fine- to medium-grained quartzite; top of member is above a prominent conglomerate ledge	285	483
5. Conglomerate and quartzite; conglomerate is in beds 1 to 6 ft thick and consists of subrounded gray chert granules and pebbles, with rare white fine-grained quartzite pebbles, in a medium- to coarse-grained limonite-stained quartzitic matrix; the interbedded quartzite is similar to this matrix and forms lenticular beds, in part gradational into conglomerate; the unit as a whole forms prominent irregular ledges	45	438
4. Covered; float from unit 5	145	293
3. Dolomite, dark-gray, medium-bedded; weathers light-gray; forms sporadic low rounded outcrops; float consists of dark-gray dolomite and yellowish-gray dolomitic siltstone; 700 ft south-southeast along the strike this unit is represented by two zones of dolomite and yellowish-gray dolomitic siltstone, separated by 57 ft of friable sandstone; farther to the south-southeast along the strike are conspicuous black stylolitic quartzites	108	185
2. Quartzite, fine-grained; featureless slope with no outcrops	100	85
1. Quartzite, light-gray, medium- to coarse-grained, poorly sorted; ripple marks on bedding surfaces; mostly float	85	0
Total dolomite member	768	
Contact conformable.		

Type section of the Brock Canyon Formation measured in the upper part of Cottonwood Canyon from E. 277,850, N. 2,006,900 to E. 271,850, N. 2,002,550—Con.

	Thickness (ft)	*Distance from base of member to base of unit (ft)*
Upper Pennsylvanian or Permian—Continued		
Brock Canyon Formation—Continued		
Conglomerate member:		
17. Lithic arenite, dark-gray to black, poorly sorted; contains about 50 percent angular to rounded chert grains of coarse sand to granule size, and 50 percent subrounded quartz grains predominantly of fine sand size	13	601
16. Conglomerate and quartzite; conglomerate is dark gray and contains gray chert pebbles and occasional light-gray fine-grained quartzite pebbles in a quartzitic matrix; quartzite is light gray and medium grained with prominent stylolites and crossbedding; extensive irregular intertonguing of quartzite and conglomerate; conglomerate forms prominent ledges separated by swales of quartzite float	267	334
15. Conglomerate; consists of pebbles and granules predominantly of dark-gray chert, also occasional clasts of white chert and fine-grained quartzite; interbedded lithic fragment-rich quartzite, as two beds, each 4 ft thick	38	296
14. Covered	20	276
13. Conglomerate, dark-gray; consists of pebbles of gray chert in a light-gray, medium-grained, quartzitic matrix; about 10 percent interbedded light-gray medium-grained thick-bedded quartzite	50	226
12. Covered	30	196
11. Conglomerate and quartzite (compare unit 13)	66	130
10. Conglomerate, dark-gray; consists of rounded pebbles and cobbles of light-gray to dark-gray chert in a gray matrix of fine- to medium-grained subrounded quartz grains	7	123
9. Quartzite, dark-gray to black, fine-grained, thin-bedded, thinly laminated; well-formed stylolites	6	117
8. Conglomerate (compare unit 10)	6	111
7. Quartzite (compare unit 9)	5	106

Type section of the Brock Canyon Formation measured in the upper part of Cottonwood Canyon from E. 277,850, N. 2,006,900 to E. 271,850, N. 2,002,550—Con.

	Thickness (ft)	Distance from base of member to base of unit (ft)
Upper Pennsylvanian or Permian—Continued		
Brock Canyon Formation—Continued		
Conglomerate member—Continued		
6. Conglomerate (compare unit 10)	4	102
5. Lithic arenite, dark-gray to black; consists of 40 to 80 percent rounded quartz grains of fine to medium sand size and 20 to 60 percent subangular to rounded chert grains of very coarse sand and granule size; grades locally into conglomerate	40	62
4. Conglomerate, dark-gray; consists of rounded pebbles of dark-gray chert, light-gray chert, and light-gray medium-grained quartzite, in a light-gray medium-grained quartzitic matrix	15	47
3. Covered	12	35
2. Lithic arenite (compare unit 5)	25	10
1. Conglomerate (compare unit 4)	10	0
Total conglomerate member	614	
Total Brock Canyon Formation	4, 900	

Unconformity [based on mapping of Harold Masursky (oral commun., 1961)]
Ordovician:
Vinini Formation (upper beds only):
Black and purple shale, with subordinate black chert.

Supplementary stratigraphic section 1 of the Brock Canyon Formation measured on the east side of Brock Canyon near the mouth from E. 245,700, N. 2,015,200 to E. 247,450, N. 2,014,450

	Thickness (ft)	Distance from base of member to base of unit (ft)
Lower Cretaceous(?):		
Brock Canyon pluton:		
Granodiorite and tonalite	-------	-------
Intrusive contact.		
Upper Pennsylvanian or Permian:		
Brock Canyon Formation:		
Dolomite member:		
14. Quartzite, light-gray, fine- to coarse-grained, poorly sorted; contains subrounded quartz grains; grades into minor pebbly quartzite; minor olive-gray (limonite-stained) siliceous siltstone; uppermost quartzite ledges are limonite-stained and recrystallized	210	766

Supplementary stratigraphic section 1 of the Brock Canyon Formation measured on the east side of Brock Canyon near the mouth from E. 245,700, N. 2,015,200 to E. 247,450, N. 2,014,450—Continued

	Thickness (ft)	*Distance from base of member to base of unit (ft)*
Upper Pennsylvanian or Permian—Continued		
Brock Canyon Formation—Continued		
Dolomite member—Continued		
13. Quartzite, light-gray, coarse-grained; contains some granules of chert; grades into light-gray conglomerate, consisting of cobbles and pebbles of gray chert in a quartzitic matrix	66	700
12. Dolomite, light-gray, very thinly laminated; in part brecciated, with much calcite in the breccia matrix	4	696
11. Quartzite, light-gray, fine- to medium-grained; contains rounded quartz grains; float	45	651
10. Conglomerate; consists of pebbles of subrounded gray chert and a few of gray quarzite; thin to medium bedded; alternating medium- to coarse-grained calacite-cemented sandstone	23	628
9. Siltstone, dark-gray, red- and green-weathering, sandy; basal part siliceous; minor gray fine-grained quartzite; mostly float	57	571
8. Conglomerate and quartzite; conglomerate consists of subrounded to subangular pebbles of gray chert, with a few clasts of gray and pink fine-grained quartzite; matrix is badly weathered and vuggy; vugs are lined with calcite and limonite; quartzite is light gray, fine grained, and is in lenticular beds some 4 in. to 2½ ft thick, some of which are detached and incorporated in overlying conglomerate beds; unit forms prominent cliffs	52	519
7. Quartzite, tan, fine-grained; abundant float of purple siltstone, weathering reddish gray or bright green, in upper half of unit; interbedded pebbly coarse-grained quartzites in lower 15 ft	80	439

Supplementary stratigraphic section 1 of the Brock Canyon Formation measured on the east side of Brock Canyon near the mouth from E. 245,700, N. 2,015,200 to E. 247,450, N. 2,014,450—Continued

	Thickness (ft)	*Distance from base of member to base of unit (ft)*
Upper Pennsylvanian or Permian—Continued		
Brock Canyon Formation—Continued		
Dolomite member—Continued		
6. Quartzite, white, fine- to coarse-grained, thin- to medium-bedded; contains thin laminae in some beds; subrounded quartz grains; coarser variety has abundant intergranular limonite stain, limonite in finer variety is restricted to fractures; quartzite grades into thick-bedded conglomerate, consisting of pebbles of gray chert and a few of light-gray fine-grained quartzite, in a quartzitic matrix; conglomerate beds are more common in the lower 50 ft; top of unit marked by scattered chips of black siltstone	110	329
5. Siltstone and quartzite; siltstone is brown near base, black in middle, and light gray near top of unit; quartzite is dominant in the higher parts of the unit and is gray and fine grained, with a few beds rich in chert grains	90	239
4. Quartzite, light bluish-gray, very fine grained, thinly laminated, delicately crossbedded; mostly float; upper 3 ft of unit is conglomerate (compare unit 6)	23	216
3. Quartzite, light-gray to white, medium- to coarse-grained; contains subrounded quartz grains; alternates with and grades into conglomerate (compare unit 6)	16	200
2. Dolomite, dark-gray, thinly laminated; contains black chert nodules as much as 2 in. in size; individual beds form low outcrops, separated by swales of dark-gray to black siltstone, badly fractured and highly stained by limonite	130	70
1. Quartzite; in lower half light-gray, medium- to coarse-grained, poorly sorted, with subangular to subrounded quartz grains; in part brecciated; grades upward into dark-gray to black fine-grained quartzite, badly fractured, highly stained by limonite; gradational contact with siltstone of unit 2	70	0
Total dolomite member	976	

Supplementary stratigraphic section 1 of the Brock Canyon Formation measured on the west side of Brock Canyon near the mouth from E. 245,700, N. 2,015,200 to E. 247,450, N. 2,014,450—Continued

	Thickness (ft)	Distance from base of member to base of unit (ft)
Probable thrust contact (parautochthonous relation).		
Conglomerate member:		
3. Quartzite and conglomerate; quartzite is dark gray to black, stylolitic, medium grained, and contains about 20 percent chert grains; conglomerate is dark gray to black and consists of 40 to 60 percent rounded dark-gray chert pebbles in a dark-gray to black medium-grained quartzitic matrix; conglomerate is more abundant near top of unit, and grades laterally into coarse-grained lithic arenite; near base of the unit is minor light-gray brecciated quartzite, with introduced barite and clay; unit forms prominent cliff	122	162
2. Dolomite, dark-gray; weathers light gray; very thin bedded to medium bedded, with thin laminae within beds; poor outcrops partly covered by float from unit 3	64	98
1. Dolomite, dark-gray to black; weathers light gray; thick bedded to massive; local wild contortion; brecciation of selected beds; ubiquitous closely spaced fractures, particularly in the lower beds; forms prominent ledges and low cliffs	98	0
Total conglomerate member	284	
Total Brock Canyon Formation	1, 260	

Thrust contact (modified unconformity).

Middle Ordovician:

Valmy Formation (upper beds only):

The upper 98 ft consists of dark- and light-gray quartzite and subordinate black siltstone, fractured throughout; brecciation is dominant in the upper 33 ft; much secondary calcite, clay, and limonite in fractures; grades downward into light greenish-gray fine- to medium-grained poorly sorted quartzite only slightly brecciated; below are typical siltstones, cherts, and quartzites of the Valmy Formation.

735-726 O-64-7

Supplementary stratigraphic section 2 of the Brock Canyon Formation measured on the west side of Brock Canyon near the mouth from E. 245,450, N. 2,012,800 to E. 244,500, N. 2,012,250

	Thickness (ft)	Distance from base of member to base of unit (ft)
Upper contact and much section removed by Recent erosion.		
Upper Pennsylvanian or Permian:		
Brock Canyon Formation:		
Conglomerate member:		
10. Quartzite, light-gray, medium- to coarse-grained, thin- to medium-bedded, stylolitic; contains small white specks of secondary calcite; subordinate (less than 10 percent) interbedded conglomerate (compare unit 9)	158	313
9. Conglomerate; consists of dark-gray, subrounded to rounded chert pebbles and subordinate light-gray fine-grained quartzite pebbles in a light-gray medium-grained quartzitic matrix	18	295
8. Quartzite (compare unit 10), with subordinate interbedded conglomerate (compare unit 9)	61	234
7. Covered	58	176
6. Dolomite, dark-gray, fine-grained, massive, recrystallized; weathers light gray and forms prominent cliff; much irregular brecciation, in part as veins, with the breccia cemented by dolomite; near base the dolomite weathers yellowish brown and is laminated	65	111
5. Breccia containing fragments of dark-gray siltstone as much as ¼ in. in diameter in an aphanitic carbonate-rich matrix	10	101
4. Dolomite, medium dark-gray, brecciated; veinlets of white calcite and a pale orange silty material; upper contact covered; lower contact is an irregular shear surface	30	71
3. Siltstone, medium dark-gray to dark-gray, tough; highly stained by limonite along closely spaced fractures; intensely brecciated in upper 15 ft	38	33
2. Dolomite breccia; consists of angular to lenticular fragments of medium dark-gray dolomite as much as 5 in. in diameter in a light-gray dolomitic matrix	4	29

Supplementary stratigraphic section 2 of the Brock Canyon Formation measured on the west side of Brock Canyon near the mouth from E. 245,450, N. 2,012,800 to E. 244,500, N. 2,012,250—Continued

	Thickness (ft)	Distance from base of member to base of unit (ft)
Upper Pennsylvanian or Permian—Continued		
Brock Canyon Formation—Continued		
Conglomerate member—Continued		
1. Interlayered quartzite and dolomite; quartzite is medium light gray to dark gray, fine to very fine grained, and is intensely fractured and brecciated, particularly within 1 ft of the base of the unit; dolomite consists almost entirely of recrystallized mineral dolomite, with minor tremolite; dolomite occurs as lenticular sheared layers 1 to 3 in. thick, as irregular masses several feet in diameter, and as part of the matrix of the brecciated quartzite; no dolomite in the upper 9 ft of the unit; brecciation and shearing decrease upward from the base	29	0
Total exposed conglomerate member	471	------
Total exposed Brock Canyon Formation	471	------
Thrust contact.		
Middle Ordovician:		
Valmy Formation (upper part only):		
Quartzite, medium-gray to dark-gray, very fine grained to silty; contains subrounded relic detrital quartz grains and subordinate chert grains; chert grains appear in thin section to have been deformed and squeezed into spaces between quartz grains; slickensided shaly partings	37	------
Conglomerate; consists of subrounded granules and pebbles of dark-gray chert in a fine- to medium-grained quartzitic matrix rich in detrital chert grains	23	------
Siltstone and lithic wacke; siltstone is medium dark gray to black; lithic wacke is very poorly sorted and consists of 40 to 70 percent dark-gray subangular coarse sand- to granule-size chert fragments and 30 to 60 percent angular medium- to coarse-grained quartz grains; upper 13 in. forms prominent ledge	13	------
Quartzite, siltstone, and chert; quartzite is medium gray and fine grained; siltstone is dark gray with many closely spaced limonite-filled fractures; chert is dark gray; upper 90 ft of unit intermittently brecciated	-------	------

REFERENCES CITED

Albers, J. P., and Robertson, J. F., 1961, Geology and ore deposits of east Shasta copper-zinc district, Shasta County, California: U.S. Geol. Survey Prof. Paper 338, 107 p.

Armstrong, R. L., 1963, Geochronology and geology of the eastern Great Basin in Nevada and Utah: New Haven, Conn., Yale Univ., Ph.D. thesis, 202 p.

Baird, A. K., MacColl, R. S., and McIntyre, D. B., 1962, A test of the precision and sources of error in quantitative analysis of light, major elements in granitic rocks by X-ray spectography: Advances in X-ray Analysis, v. 5, p. 412–422, New York, Plenum Press.

Bateman, P. C., 1961, Granitic formations in the east-central Sierra Nevada near Bishop, California: Geol. Soc. America Bull., v. 72, No. 10, p. 1521–1537.

Battey, M. H., 1955, Alkali metasomatism and the petrology of some keratophyres: Geol. Mag. [Great Britain], v. 92, p. 104–126.

Bowen, N. L., 1956, The evolution of the igneous rocks: New York, Dover Publications, 332 p.

Brown, Merle, 1960, Climate of Nevada: U.S. Weather Bur., Climatography of the United States no. 60–26, 15 p.

Browne, W. R., 1920, The igneous rocks of Encounter Bay, South Australia: Royal Soc. South Australia Trans., v. 44, p. 1–57.

Buddington, A. F., 1959, Granite emplacement with special reference to North America: Geol. Soc. America Bull., v. 70, no. 6, p. 671–747.

Daly, R. A., 1933, Igneous rocks and the depths of the earth: New York, McGraw-Hill Book Co., 508 p.

Dott, R. H., Jr., 1955, Pennsylvanian stratigraphy of Elko and northern Diamond Ranges, northeastern Nevada: Am. Assoc. Petroleum Geologists Bull., v. 39, no. 11, p. 2211–2305.

Emmons, S. F., 1877, Descriptive geology [of the] Cortez Range [Nevada]: U.S. Geol. Explor. 40th Parallel (King), v. 2, p. 570–589.

Eskola, Pentti, 1914, On the petrology of the Orijarvi region in southwestern Finland: Comm. Géol. Finlande Bull., no. 40, 277 p.

——— 1954, A proposal for the presentation of rock analyses in ionic percentage: Acad. Sci. Fennicae Annales, Helsinki, ser. A 3, Geol.–Geog., no. 38, 15 p.

Fails, T. G., 1960, Permian stratigraphy at Carlin Canyon, Nevada: Am. Assoc. Petroleum Geologists Bull., v. 44, no. 10, p. 1692–1703.

Gilluly, James, 1933, Replacement origin of the albite granite near Sparta, Oregon: U.S. Geol. Survey Prof. Paper 175–C, p. 65–81.

——— 1954, Further light on the Roberts thrust, north-central Nevada: Science, v. 119, p. 423.

——— 1960a, A folded thrust in Nevada—inferences as to time relations between folding and faulting: Am. Jour. Sci., v. 258–A (Bradley volume), p. 68–79.

——— 1960b, Structure of Paleozoic and early Mesozoic rocks in the northern part of the Shoshone Range, Nevada: Art. 119 *in* U.S. Geol. Survey Prof. Paper 400–B, p. B265.

Gilluly, James, and Gates, Olcott, 1964, Tectonic and igneous geology of the northern Shoshone Range, Nevada: U.S. Geol. Survey Prof. Paper 465, 151 p. (in press).

Hamilton, W. B., 1956, Geology of the Huntington Lake area, Fresno County, California: California Div. Mines Spec. Rept. 46, 25 p.

Hemley, J. J., 1959, Some mineralogical equilibria in the system K_2O–Al_2O_3–SiO_2–H_2O: Am. Jour. Sci., v. 257, p. 241–270.

Holmes, Arthur, 1960, A revised geological time scale: Edinburgh Geol. Soc. Trans. v. 17, pt. 3, p. 183–216.

Howell, J. V., chm., 1960, Glossary of geology and related sciencies, with supplement: 2d ed., Washington, Am. Geol. Inst., 397 p.

Jahns, R. H., and Burnham, C. W., 1962, Experimental studies of pegmatite genesis—a model for the crystallization of granitic pegmatites [abs.]: Geol. Soc. America Spec. Paper 68, p. 206–207.

Johannsen, Albert, 1932, A descriptive petrography of the igneous rocks; V. 2, The quartz-bearing rocks: Chicago, Chicago Univ. Press, 428 p.

King, Clarence, 1878, Systematic geology: U.S. Geol. Explor. 40th Parallel (King), v. 1, 803 p.

King, Clarence [and others], 1876, Geological and topographical atlas: U.S. Geol. Explor. 40th Parallel (King), scale 1:250,000.

Kulp, J. L., 1961, Geologic time scale: Science, v. 133, p. 1105–1114.

Kuno, Hisashi, 1960, High-alumina basalt: Jour. Petrology [London], v. 1, no. 2, p. 121–145.

Lehner, R. E., Tagg, K. M., Bell, M. M., and Roberts, R. J., 1961, Preliminary geologic map of Eureka County, Nevada: U.S. Geol. Survey Mineral Inv. Field Studies Map MF–178, scale 1:200,000 [1962].

Masursky, Harold, 1960, Welded tuffs in the northern Toiyabe Range, Nevada, *in* Short papers in the geological sciences: U.S. Geol. Survey Prof. Paper 400–B, p. B281–B283.

Morozewicz, J., 1925, Die Kommandorinseln: Warsaw, Mianowski-Kasse, 230 p.; reviewed *in* Neues. Jahrb. Mineralogie, Geologie, und Paläontologie, 1928, v. 2, p. 145–154.

Noble, J. A., 1948, High-potash dikes in the Homestake mine, Lead, South Dakota: Geol. Soc. America Bull., v. 59, no. 9, p. 927–939.

Nockolds, S. R., 1954, Average chemical compositions of some igneous rocks: Geol. Soc. America Bull., v. 65, no. 10, p. 1007–1032.

Nolan, T. B., Merriam, C. W., and Williams, J. S., 1956, The stratigraphic section in the vicinity of Eureka, Nevada: U.S. Geol. Survey Prof. Paper 276, 77 p.

Peterson, D. W., 1961, AGI data sheet 23: GeoTimes, v. 5, no. 6, p. 30–36.

Pettijohn, F. J., 1957, Sedimentary rocks: 2d ed., New York, Harper & Bros., 718 p.

Read, H. H., 1957, The granite controversy: New York, Interscience Publishers, 431 p.

Regnier, Jerome, 1960, Cenozoic geology in the vicinity of Carlin, Nevada: Geol. Soc. America Bull., v. 71, no. 8, p. 1189–1210.

Roberts, R. J., 1951, Geology of the Antler Peak quadrangle, Nevada: U.S. Geol. Survey Geol. Quad. Map GQ–10, scale 1:62,500.

Roberts, R. J., Hotz, P. E., Gilluly, James, and Ferguson, H. G., 1958, Paleozoic rocks of north-central Nevada: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 12, p. 2813–2857.

Ross, C. S., and Smith, R. L., 1961, Ash-flow tuffs—their origin, geologic relations, and identification: U.S. Geol. Survey Prof. Paper 366, 81 p.

Roy, Rustum, and Osborn, E. F., 1954, The system Al_2O_3–SiO_2–H_2O: Am. Mineralogist, v. 39, p. 853–885.

Shawe, F. R., Reeves, R. G., and Kral, V. E., 1962, Iron ore deposits of northern Nevada, Pt. C *of* Iron ore deposits of Nevada: Nevada Bur. Mines Bull. 53, p. 79–128.

Smith, J. R., and Yoder, H. S., Jr., 1956, Variations in X-ray powder diffraction patterns of plagioclase feldspars: Am. Mineralogist, v. 41, no. 7–8, p. 632–647.

Smith R. L., 1960, Zones and zonal variations in welded ash flows: U.S. Geol. Survey Prof. Paper 354–F, p. 149–159.

Steele, Grant, 1960, Pennsylvanian-Permian stratigraphy of east-central Nevada and adjacent Utah, *in* Intermountain Assoc. Petroleum Geologists Guidebook 11th Ann. Field Conf., east-central Nevada, 1960: p. 91–113.

Swineford, Ada, Frye, J. C., and Leonard, A. B., 1955, Petrography of the late Tertiary volcanic ash falls in the central Great Plains: Jour. Sed. Petrology, v. 25, no. 4, p. 243–261.

Tatlock, D. B., 1961, Rapid quantitative estimates of quartz and total iron in silicate rocks by X-ray diffraction: Art. 145 *in* U.S. Geol. Survey Prof. Paper 424–B, p. B334–B337.

Terzaghi, R. D., 1948, Potash-rich rocks of the Esterel, France: Am. Mineralogist, v. 33, p. 18–30.

Thompson, G. A., 1960, Problem of late Cenozoic structure of the Basin Ranges: Internat. Geol. Cong., 21st, Copenhagen 1960, pt. 18, p. 62–68.

Thornton, C. P., and Tuttle, O. F., 1960, Chemistry of igneous rocks I. Differentiation index: Am. Jour. Sci., v. 258, no. 9, p. 664–684.

Tilley, C. E., 1919, The petrology of the granitic mass of Cape Willoughby, Kangaroo Island, Pt. 1: Royal Soc. South Australia Trans., v. 43, p. 316–341.

Tröger, W. E., 1956, Optische Bestimmung der gesteinsbildenden Minerale; Teil 1, Bestimmungstabellen, 3 Auflage: Stuttgart, E. Schewizerbart'sche Verlag., 147 p.

Truesdell, A. H., 1962, Study of natural glasses through their behavior as membrane electrodes: Nature, v. 194, p. 77–79.

Tuttle, O. F., and Bowen, N. L., 1958, Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2–H_2O: Geol. Soc. America Mem. 74, 153 p.

Washington, H. S., 1917, Chemical analyses of igneous rocks published from 1884 to 1913: U.S. Geol. Survey Prof. Paper 99, 1201 p.

Whitten, E. H. T., 1961, Quantitative distribution of major and trace components in rock masses: Am. Inst. Mining Metall. Petroleum Engineers Trans. (Mining), v. 220, p. 239–246.

Wilkinson, J. F. G., 1956, Clinopyroxenes of alkali olivine-basalt magma: Am. Mineralogist, v. 41, no. 9–10, p. 724–743.

Williams, Howel, Turner, F. J., and Gilbert, C. M., 1954, Petrography—an introduction to the study of rocks in thin sections: San Francisco, W. H. Freeman and Co., 406 p.

Winchell, A. N., and Winchell, Horace, 1951, Description of minerals, Pt. 2 *of* Elements of optical mineralogy—an introduction to microscopic petrography: 4th ed., New York, John Wiley and Sons, 551 p.

Woods, M. D., and Eckelmann, F. D., 1962, Occurrence and significance of flow layering in a rhyolite sheet in Pennsylvanian sedimentary rocks of the Narragansett Basin [abs.]: Geol. Soc. America Spec. Paper 68, p. 302.

Zirkel, Ferdinand, 1876, Microscopical petrography: U.S. Geol. Explor. 40th Parallel (King), v. 6, 297 p.

INDEX

[Italic page numbers indicate major references]

○