# Geology of the Klondyke Quadrangle Graham and Pinal Counties Arizona

GEOLOGICAL SURVEY PROFESSIONAL PAPER 461

# Geology of the Klondyke Quadrangle Graham and Pinal Counties Arizona

*By* FRANK S. SIMONS

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*Includes a part of the Basin and Range province and several small base-metal mining areas*

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[Plate is in pocket]

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# GEOLOGY OF THE KLONDYKE QUADRANGLE, GRAHAM AND PINAL COUNTIES, ARIZONA

By Frank S. Simons

## ABSTRACT

The Klondyke quadrangle is in Graham and Pinal Counties, southeastern Arizona, about 55 miles northeast of Tucson and 45 miles southeast of Globe. There are no settlements of appreciable size in the quadrangle.

The Klondyke area is in the Basin and Range province and comprises three main physiographic elements—the Galiuro Mountains along the west side of the area, the Santa Teresa-Turnbull Mountains block along the east side, and the Aravaipa Valley lying between. The Galiuro Mountains are mainly a thick pile of Tertiary and Cretaceous(?) volcanic rocks and minor amounts of older sedimentary and plutonic igneous rocks; the Santa Teresa Mountains consist almost entirely of granite of Tertiary age, and the Turnbull Mountains of sedimentary, igneous, and metamorphic rocks of various ages; and Aravaipa Valley is underlain by conglomerate and alluvium of Tertiary age and Quaternary alluvium.

The rocks of the region range in age from Precambrian to Recent and have been divided into 14 formations of layered rocks, both sedimentary and volcanic, 4 formations of plutonic igneous rocks, and 1 formation of metamorphic rock. Precambrian rocks are the Pinal Schist, composed of graywacke, shale, sandstone, and silicic to intermediate volcanic rocks moderately metamorphosed to quartz-muscovite-chlorite schist, hornfels, and quartzite; Laurel Canyon Granodiorite, intrusive into Pinal Schist; and small dikes, sheets, and irregular bodies of diabase that intrude both formations. Paleozoic rocks are a largely conformable sequence that aggregates about 1,300 feet in thickness and includes, from oldest to youngest, the Bolsa Quartzite of Middle Cambrian age, Martin Formation of Late Devonian age, Escabrosa Limestone of Mississippian age, and Horquilla Limestone of Middle Pennsylvanian age. The only paleontologically dated formation of post-Pennsylvanian age is the Pinkard Formation of Late Cretaceous (Colorado) age, mainly sandstone and shale. The Pinkard is overlain disconformably by andesitic pyroclastic rocks of the Williamson Canyon Volcanics, which, in turn, is overlain unconformably by the silicic and intermediate volcanic rocks of the Horse Mountain Volcanics, the lower part of which may be of latest Cretaceous age. Two other formations, the Buford Canyon Formation of the Santa Teresa Mountains and the Glory Hole Volcanics of the Galiuro Mountains, are assigned tentatively to the Mesozoic and Cenozoic because they cannot be dated closely. One granitoid pluton, the Copper Creek Granodiorite, is Late(?) Cretaceous or Tertiary, and two others, the Goodwin Canyon Quartz Monzonite and the Santa Teresa Granite, are referred to the Tertiary. Overlying unconformably the Copper Creek Granodiorite is a thick section of intermediate to silicic volcanic rocks, the Galiuro Volcanics, also referred to the Tertiary; this formation is divided into 12 units. All the aforementioned rocks are cut by dikes of silicic to intermediate composition; these dikes are especially numerous in the Turnbull Mountains. The youngest rocks include a thick section of highly indurated conglomerate, the Hell Hole Conglomerate, along the east side of the Galiuro Mountains; extensive deposits of older alluvium along the southwest flank of the Santa Teresa and Turnbull Mountains and the east flank of the Galiuro Mountains; terrace deposits and lake beds along Aravaipa Valley; and valley fill and flood-plain deposits along present stream courses. The aggregate thickness of post-Precambrian sedimentary and volcanic rocks is 17,000–19,000 feet, but only a few thousand feet or less is exposed in any one place. Approximately 48 percent of the quadrangle is underlain by conglomerate and alluvium of Tertiary and Quaternary age, 31 percent by volcanic rocks of Mesozoic and Cenozoic age, 11 percent by Late(?) Cretaceous or Tertiary granitoid rocks, and 10 percent by Paleozoic and Precambrian rocks.

The geologic structure is complicated locally but does not seem to be complex. Steeply dipping normal faults of small to moderate displacement are the characteristic structures. Four principal groups of structures, only one of which is widespread, are recognized. The oldest structures, of Precambrian age, are folds and schistosity in the Pinal Schist and local gneissosity in the Laurel Canyon Granodiorite; these structures trend generally northeast and are truncated by Cambrian sedimentary rocks along a major unconformity. Two subsequent structural trends of post-Pennsylvanian and pre-Tertiary age are obscure, and little is known about them. The earlier trend, of pre-Late Cretaceous age, is indicated by easterly to northeasterly trending folds in limestone of Pennsylvanian age, which are cut off by Cretaceous sedimentary rocks along a pronounced unconformity. The later trend, of Late(?) Cretaceous or early Tertiary age, is indicated by poorly defined eastward-trending folds in Late Cretaceous sedimentary rocks and Late(?) Cretaceous or Tertiary volcanic rocks, which in turn are truncated by Late(?) Cretaceous to Tertiary volcanic rocks. The principal structures are of Tertiary age and are mainly faults of north-northwesterly to northwesterly trend. A few folds of similar trend are assigned to this group of structures. Some of the faults have displacements of as much as several thousand feet, but most are small. It seems likely that many of these faults formed as a result of emplacement of the Santa Teresa and Goodwin Canyon granitoid plutons. The youngest formation involved in this faulting and folding is the Hell Hole Conglomerate, which is believed to be of middle to late Tertiary age.

The present arrangement of mountains and valley probably was established prior to the deposition of the Hell Hole Conglomerate, and the only subsequent major modification of this arrangement seems to have been the westward diversion of ancestral Aravaipa Creek antecedent to the latest uplift of the Galiuro Mountains.

The mineral deposits of the quadrangle comprise a varied group of vein deposits, replacement deposits in Paleozoic carbonate rocks, and breccia-pipe deposits. The principal metals of the veins and replacement deposits are lead, zinc, copper, and silver, and of the breccia pipes, copper and molybdenum. The deposits are divided into four geographic groups—Aravaipa, Grand Reef, Table Mountain–Fourmile Creek, and Copper Creek.

The deposits of the Aravaipa and Grand Reef groups are quartz-sulfide bodies along low-dipping faults (the principal example is the Head Center mine), quartz-specularite-fluorite-sulfide aggregates along steeply dipping breccia reefs (Grand Reef mine), or narrow quartz-sulfide fissure fillings along faults in volcanic rocks. The only common sulfide minerals are galena, sphalerite, chalcopyrite, and pyrite, and virtually the only gangue minerals are quartz or amethyst, specularite, and fluorite. Most veins are a few feet or less in width and a few hundred feet long. Most of the veins strike between N. and N. 25° W., but the productive Sinn Fein-Head Center-Iron Cap structure strikes nearly east. Mineralization may have taken place during emplacement of the Santa Teresa Granite.

Veins of the Table Mountain–Fourmile Creek group are composed of supergene copper minerals that fill short and very narrow steeply dipping fissures in volcanic rock. Most of these veins strike between N. 60° W. and W. The Table Mountain deposit is unusual: Jasperoid and jasperoid breccia in the Escabrosa Limestone contain irregular pods and films of supergene copper minerals, mostly chrysocolla, along joints, faults, and weathered surfaces.

Little is known about the replacement deposits of the Aravaipa region. These deposits consist of sphalerite and galena that have replaced Escabrosa Limestone, Horquilla Limestone, or tactite derived from either. Chalcopyrite and pyrite are very scarce. The sulfide minerals form veinlets, disseminations, and small irregular masses in the host rocks. The tactite is made up of garnet, epidote, johannsenite, calcite, and sparse fluorite and quartz. The replacement deposits are not obviously related to any intrusive igneous rock.

The breccia-pipe deposits of the Copper Creek area are essentially vertical, circular or elliptical cylinders of breccia lithologically identical to the wall rocks, Copper Creek Granodiorite or Glory Hole Volcanics. Breccia fragments range in shape from angular to somewhat rounded and are strongly altered to quartz and sericite. Contacts with wallrocks are sharp and usually not faulted. Ore minerals are mainly chalcopyrite and molybdenite which, for the most part, are interstitial to the fragments. Pyrite is widely distributed in the pipes, and tourmaline is present in a few. The breccias appear to have formed practically in place, but their origin is conjectural. Alteration and mineralization may be related to intrusions of a biotite latite porphyry facies of the Copper Creek Granodiorite.

The total production from mineral deposits in the Klondyke quadrangle probably has been less than $10 million, and only two or perhaps three mines (Head Center, Childs-Aldwinkle, and possibly the Grand Reef) have yielded more than a million dollars worth of ore.

## INTRODUCTION

### LOCATION AND ACCESSIBILITY

The Klondyke quadrangle is in Graham and Pinal Counties, southeastern Arizona, about 55 miles northeast of Tucson and 45 miles southeast of Globe; the western one-fifth of the quadrangle is in Pinal County (fig. 1). The quadrangle is enclosed by parallels 32°45′ and 33°00′ and meridians 110°15′ and 110°30′, and has an area of about 250 square miles.

According to Barnes (1960, p. 129), Klondyke was named by settlers who had returned from the Klondike gold rush. The region was settled, however, long before the Klondike rush. Klondyke may be reached from a point on U.S. Highway 70 between Safford and Globe over 34 miles of good gravel road, and also is accessible from Willcox, on U.S. Highway 666, over 63 miles of gravel road that locally may be difficult or impassable after heavy rains. A third route, seldom used for access to Klondyke, is the Stockton Pass Road to Fort Grant, which leaves U.S. Highway 666 between Willcox and Safford and joins the Willcox-Klondyke road 31 miles southeast of Klondyke. A good gravel road extends from the valley of the San Pedro River up Copper Creek as far as the Glory Hole, Bluebird, and Childs-Aldwinkle mines, and a branch of this road leads south to Sombrero Butte and the valley of the San Pedro. A rough jeep road leads from the valley of the San Pedro River near the mouth of Aravaipa Creek to the Table Mountain mine, and a very poor road connects this mine with the Aravaipa Valley-Klondyke road at the mouth of Turkey Creek. Another rough jeep road extends from the valley of the Gila River near Geronimo up Goodwin Canyon to the Cobre Grande mine. From a point on old U.S. Highway 70 about 7 miles east of Coolidge Dam, a fair truck road leads south to Old Deer Creek and the Princess Pat mine.

Within the Aravaipa Valley, good gravel roads connect Klondyke with the Lackner Ranch in the canyon of Fourmile Creek, the Salazar Ranch just northeast of the confluence of Aravaipa and Turkey Creeks, the Sanford Ranch on Old Deer Creek, and Aravaipa. Many other roads in diverse states of repair lead to various ranches, mines, and stock tanks. It is probable that no point in the quadrangle is more than 3 miles from a jeep or truck road.

Some 47 square miles of the quadrangle, mainly in the northeast quarter, is within Crook National Forest.

There are no settlements within the quadrangle, and the nearest sizable town is Safford, 50 miles east of Klondyke by road. Klondyke, near the center of the quadrangle, consists of a store and gas pump, a school-

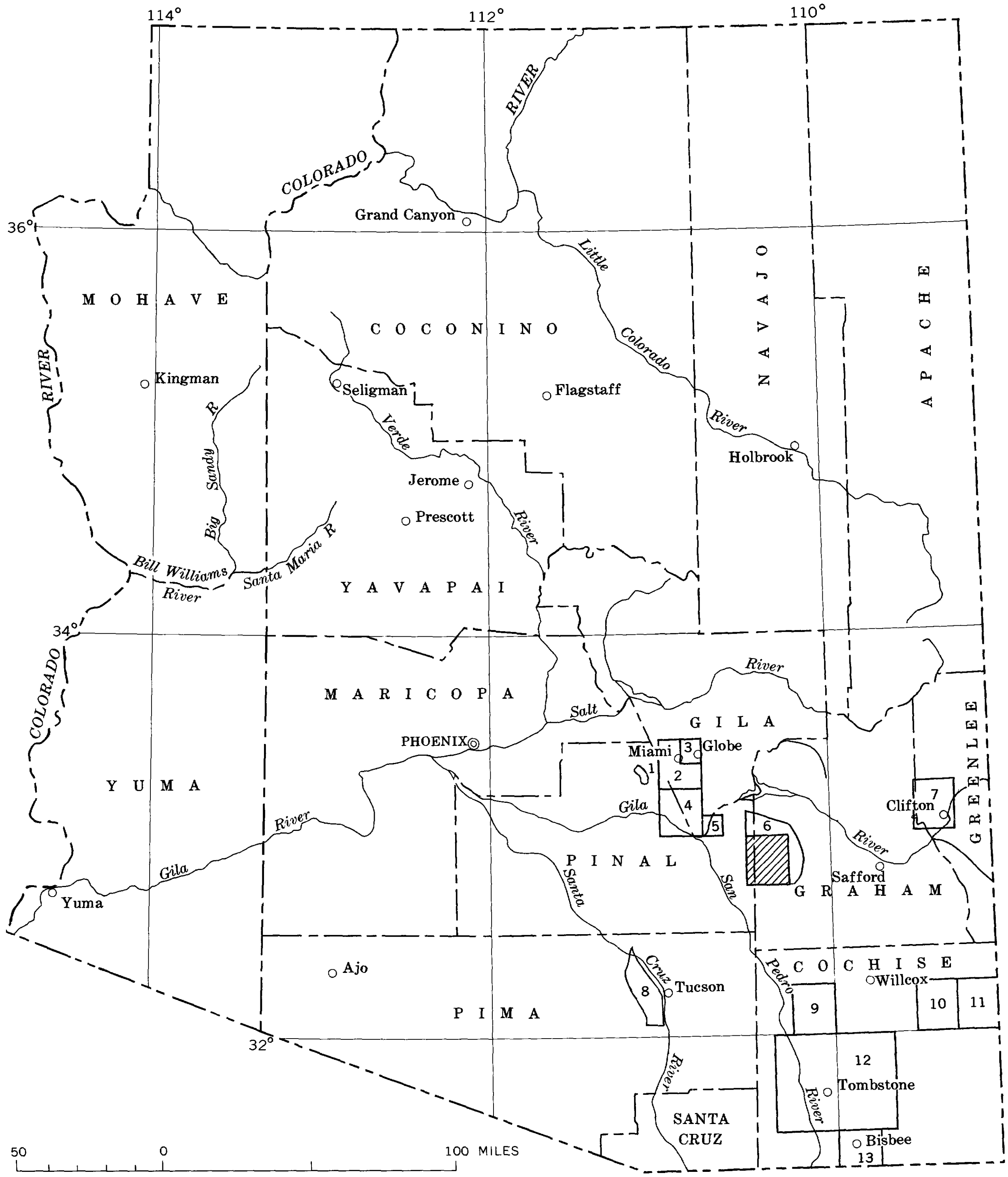


FIGURE 1.—Index map of Arizona showing location of the Klondyke quadrangle and of nearby areas on which detailed geologic studies have been published.

1. Superior district (Short and others, 1943)
2. Globe-Miami district (Ransome, 1903, 1904a)
3. Globe 7½′ quadrangle (Peterson, 1954)
4. Ray quadrangle (Ransome, 1919, 1923)
5. Christmas area (Ross, 1925b; willden, 1964)
6. Aravaipa-Stanley districts (Ross, 1925a)
7. Clifton-Morenci district (Lindgren, 1905a, 1905b)
8. Tucson Mountains (Brown, 1939)
9. Dragoon quadrangle (Cooper and Silver, 1964)
10. Cochise Head quadrangle (Sabins, 1957b)
11. Vanar quadrangle (Sabins, 1957b)
12. Central Cochise County (Gilluly, 1956)
13. Bisbee district (Ransome, 1904b, 1904c)

house, and a teacher's house. Aravaipa, once the center of mining activities of the Aravaipa district, is abandoned (1960) except for a caretaker employed by the Athletic Mining Co. New Aravaipa, a short distance north of Aravaipa and the former camp of the company, has been completely abandoned since 1958. Copper Creek, a good-sized settlement when the mines of the Copper Creek area were active, is completely abandoned, and nearly all the buildings except those of the Old Reliable mine are in ruins. A number of ranch houses, perhaps 20 in all now inhabited, are scattered along Aravaipa Valley and its tributaries. The only important economic activity of the region is cattle raising.

## PHYSICAL FEATURES

The Klondyke region is in that part of Arizona referred to by Ransome (1923) as the Mountain region of the Basin and Range province, lying between the Plateau province to the northeast and the Plains region of the Basin and Range province to the southwest. According to the scheme of Fenneman (1931, pl. 1), the region is in the Mexican Highland section of the Basin and Range province. The most recent contribution to Arizona physiography (Heindl and Lance, 1960, fig. 2) recognizes only two physiographic provinces; the Klondyke region falls into the Basin and Range province.

The dominant physical features of the Klondyke region are the Galiuro Mountains, which make up the western one-quarter of the quadrangle, and the Santa Teresa and Turnbull Mountains, covering the northeastern one-quarter. These mountain masses are separated in the southern half of the quadrangle by the Aravaipa Valley and in the northern half by Lone Cedar Mesa and by other extensive alluviated areas dissected by tributaries of Aravaipa Creek and Hawk Canyon. In the remainder of this report, the open valley of Aravaipa Creek upstream from Stowe Gulch will be referred to as Aravaipa Valley, and its deep and narrow canyon downstream from Stowe Gulch as Aravaipa Canyon; this nomenclature follows that of the Klondyke quadrangle map. Altitudes in the quadrangle range from 2,860 feet where Aravaipa Creek leaves the quadrangle to 7,150 feet at Cobre Grande Mountain in the Turnbull Mountains and 7,275 feet on Pinnacle Ridge in the Santa Teresa Mountains.

The Galiuro Mountains lie along the western margin of the quadrangle and separate the valleys of Aravaipa Creek and San Pedro River. On their west side, outside the quadrangle, they rise rather steeply above the valley of the San Pedro River, but on the east they merge so imperceptibly with the conglomerate and alluvium of Aravaipa Valley that no sharp line can be drawn to mark their edge. If the geologic boundary between volcanic rocks and younger rocks be taken as the east edge of the mountains, then within the quadrangle they range in width from 9 miles along the south edge of the quadrangle to less than a mile along Horse Camp Canyon.

North of Aravaipa Canyon, the Galiuro Mountains are a rolling grass-covered upland broken only locally by eminences such as Lookout Mountain, which rises 500 feet or so above the general land level. For 5 to 6 miles south of Aravaipa Canyon the Galiuro Mountains are a strikingly level-topped tableland that slopes gently north and is deeply dissected by Wire Corral Draw, Virgus, Parsons, and Oak Grove Canyons, and the canyon of Turkey Creek. Farther south the Galiuro Mountains lose their mesalike character and become instead a rather formless mass having a west-northwest trending summit of fairly uniform altitude punctuated by a number of low but steep-sided knobs, the highest of which, Little Table Mountain, rises to an altitude of 6,254 feet. The topographic contrast between the northern and southern parts of the range is directly related to their geological makeup; the northern part is underlain by gently dipping silicic and intermediate volcanic rocks of greatly different resistances to erosion which have given rise to a terrain of mesas, benches, and cliffs, whereas the rocks farther south, particularly on the east side of the range, are dominantly a monotonous assemblage of intermediate volcanic rocks whose uniformity of resistance to erosion is expressed by the lack of any salient landforms. In the Copper Creek region, the rather disordered terrain of the Copper Creek basin, underlain by granodiorite and metamorphosed intermediate volcanic rocks, is surmounted by a prominent cliff and bench topography carved on generally flat-lying volcanic rocks. Viewed from the valley of the San Pedro River, the upper part of the range rises impressively above the intervening hilly lowlands. This mountain front, only a small part of which lies within the Klondyke quadrangle, is clearly described by Davis and Brooks (1930).

The Santa Teresa and Turnbull Mountains are a continuous mountain mass that constitutes the divide between the valleys of Aravaipa Creek and Gila River. No natural division between these mountains exists, but in this report the Santa Teresa Mountains are considered to be separated from the Turnbull Mountains by Black Rock Canyon on the north and Laurel Canyon on the west; they are thus a rather small mountain block made up principally of granite of Tertiary age from which all their high peaks have been carved. The Santa Teresa Mountains extend eastward beyond the quadrangle as far as Jackson Mountain, dying out between Black Rock and Telegraph Washes in the Jackson Mountain quadrangle. In their high areas the Santa Teresa Mountains are a jumble of ragged peaks, narrow ridges, and deep valleys that combine to produce a very rugged terrain.

The Turnbull Mountains are a moderately rugged mountain mass underlain by a variety of sedimentary, metamorphic, and volcanic and plutonic igneous rocks. They extend north and east of the Klondyke quadrangle and culminate in Mount Turnbull (7,970 ft high), about 10 miles southwest of Bylas on U.S. Highway 70.

Along the north edge of the quadrangle, a line of hills including Lone Cedar Mesa and Lookout Mountain forms the low divide between the Aravaipa drainage area and that of Hawk Canyon, which leads directly to the Gila River below Coolidge Dam.

Aravaipa Valley enters the quadrangle near the southeast corner and extends diagonally across the quadrangle in a northwesterly direction. From a short distance below the confluence of Aravaipa Valley and Stowe Gulch to the west edge of the quadrangle and a considerable distance beyond, Aravaipa Creek is perennial, maintaining an appreciable flow of water throughout the year, and has carved a deep canyon across the Galiuro Mountains. Water appears very suddenly in the canyon, so that the creek achieves its full flow within a few tens of feet downstream from a dry bed. The abrupt appearance of water is clearly due to a change of bedrock; above the point where water appears, the floor of Aravaipa Valley is unconsolidated or only slightly consolidated alluvium of unknown thickness (but surely more than 100 ft), whereas at the point and below, the canyon is narrow, the alluvial cover thin, and the bedrock highly indurated conglomerate. The nature of the juncture between thick alluvium and conglomerate is not certain, but is surmised to be a fault.

Above the confluence of Aravaipa Valley and Stowe Gulch, Aravaipa Creek occupies a broad open valley and is dry except after rains, when it may carry a very large volume of water.

On both sides of Aravaipa Valley, extensive surfaces underlain by partly consolidated alluvial deposits slope gently valleyward. On the southwest side of the valley between Fourmile Creek and the southeast corner of the quadrangle, the alluvium is deeply dissected but many of the remaining long and narrow ridges have accordant summits. On the northeast side of the valley, however, extensive erosion has largely destroyed any former accordant summits that might have existed, although a few are preserved along upper Klondyke Wash.

The flood plain of Aravaipa Creek above Stowe Gulch is generally between half a mile and a mile wide. On this flood plain the present river course is incised as much as 3 or 4 feet. Along Aravaipa Valley, particularly on the northeast side between Buford Canyon and Stowe Gulch, a well-defined series of terraces lies at heights above the present flood plain of from about 200 feet at the upper end of the valley to 50 feet at the lower end. A few remnants of a second terrace level perhaps 100 feet higher are preserved in the extreme southeast corner of the quadrangle.

## CLIMATE AND VEGETATION

The Klondyke region has the warm dry climate typical of the Arizona part of the Basin and Range province. Precipitation, mostly as rain, ranges from an estimated 14 to 17 inches at Klondyke in the Aravaipa Valley to probably 20 inches or more around Cobre Grande Mountain, almost 4,000 feet higher. Nearly half the precipitation in the region occurs during July, August, and September, and a large part of the remainder during December, January, and February. April, May, and June are excessively dry, much less than an inch of precipitation per month having been reported for Klondyke or any nearby station.

Temperatures range from moderate during the winter to high or very high during the summer. No temperature data are available for Klondyke itself, but at nearby places of comparable altitude summer temperatures of 110°–116°F have been reported, and temperatures in excess of 100°F are not uncommon during June, July, and August. Nighttime temperatures of freezing or slightly below are common during December to March or even April; the lowest temperature recorded at any nearby place is 7°F.

Vegetation of the Klondyke region is principally that of the Upper Sonoran zone, but small areas are in the Lower Sonoran or Transition zones. Typical plants of the Upper Sonoran are juniper and piñon pine; those of the Lower Sonoran are mesquite, catclaw, and giant cactus (saguaro), and that of the Transition is ponderosa pine. The principal valleys of the area support locally heavy growths of mesquite, and along watercourses, particularly Aravaipa Canyon and Turkey Creek, are large stands of cottonwood, sycamore, and hackberry. Lower slopes carry yucca, sotol, beargrass, ocotillo, pricklypear, and agave ("mescal"), whereas higher slopes support dominantly piñon and juniper. Some north-facing slopes, particularly those along Old Deer Creek, are covered with a dense growth of scrub live oak, manzanita, serviceberry, and other shrubs. Ponderosa pine is limited to the upper parts of Cobre Grande Mountain. Various small cacti of the hedgehog type are common at all altitudes below about 6,500 feet. Along lower Aravaipa Creek, saguaro cactus makes its appearance, and cholla, paloverde, and saguaro are abundant on the alluvial plain at the western foot of the Galiuro Mountains.

A great variety of wildflowers appear in April if winter rainfall has been normal; the most conspicuous flowers are vervain, lupine, thistlepoppy, goldpoppy, globemallow, paperflower, desert marigold, wild four-o'clock, Indian paintbrush, groundsel, larkspur, wild heliotrope, evening primrose, wild onion, and sego lily. Along watercourses, prominent displays of penstemon, yellow columbine, and monkey flower may be seen occasionally. Filaree is widespread and provides valuable spring forage.

### FIELDWORK AND ACKNOWLEDGMENTS

During 1957, 1958, and 1959, a total of about 8 months was spent in the fieldwork leading to this report, and an additional 2 weeks was spent in a field check in 1960. In the fall season of 1957 and the spring seasons of 1958 and 1959, I was ably assisted by David B. Brooks, and in the fall season of 1958, by Robert Pullen. Mapping was done both on a topographic base at a scale of 1:48,000 and on aerial photographs at an approximate scale of 1:20,000. Data were transferred directly from photographs to base map with the aid of a stereoscope. All but one of the stratigraphic sections were measured by hand-leveling; the exception was measured by steel tape and compass. Most mine maps were made using tape and compass; a few small underground workings were mapped by pace and compass. Less than 2 weeks was spent in mine mapping, mainly because access to the principal mines of the Aravaipa district was not permitted.

Fieldwork was facilitated by the courtesies and cooperation of many residents of Aravaipa Valley. In particular, I am indebted to Mr. and Mrs. Clay Turnbull, Mrs. May Davidson, and Mr. and Mrs. Elton Kidd, whose hospitality made my stay in the region much more pleasurable than it might otherwise have been. Herb Hatter, a longtime resident of the area, and Elton Kidd made available to me their knowledge of former mining activity in the district. To the many ranchers who permitted me access to their roads and ranges, I render grateful acknowledgment.

All mineral identifications by use of the X-ray spectrometer were made by Theodore Botinelly of the U.S. Geological Survey.

### PREVIOUS WORK

The only previous general geologic work in the region was a reconnaissance study of the Aravaipa and Stanley mining districts by Ross (1925a), which established the basic stratigraphy and structure of the region. This report is particularly valuable for its descriptions of mines and prospects, many of which are not open for study at the present time. The Klondyke and adjacent quadrangles were mapped in reconnaissance in 1956 (Creasey and others, 1961), and certain parts were mapped by Wilson for inclusion in the Graham-Greenlee Counties sheet (Wilson and others, 1958) and the Pinal County sheet (Wilson and others, 1959) of the geologic map of Arizona. Notes on the geology of the region appear in the comprehensive work of Darton (1925, p. 271–276) and in a short paper of Courtright (1958). Thomssen and Barber (1958) have described a partial section of Escabrosa Limestone at the Table Mountain mine. The physiography of the west flank of the Galiuro Mountains is well described by Davis and Brooks (1930). Brief descriptions of mines in the Aravaipa district have been published by Denton (1947b) and Wilson (1950), and papers on the geology and ore deposits of Copper Creek have been published by Weed (1913) Kuhn (1938, 1941, 1951), and Denton (1947a).

### SCOPE OF THE REPORT

Geologic mapping of the Klondyke quadrangle (pl. 1) was undertaken principally as part of a study of the highly productive mineralized region that includes the great copper deposits of Globe-Miami, Ray, and San Manuel. Early reports of Ransome (1903, 1904a, 1916, 1919, 1923) and Ross (1925a, 1925b) provided a foundation on which to base more detailed work, some of which has been published (Short and others, 1943; Peterson, Gilbert, and Quick, 1951; Peterson, 1954; Peterson and Swanson, 1956; and Creasey and others, 1961). Known ore deposits of the Klondyke quadrangle are small, but it was believed that more detailed geological mapping of it and adjacent quadrangles would aid in understanding the regional setting of the known major ore deposits. Because the principal mines of the Aravaipa district could not be studied in detail, the present report, insofar as the ore deposits are concerned, amplifies only slightly the pioneer work of Ross. Many of the other mines, particularly the shaft mines, were inaccessible at the time of this study.

In this report, the longest sections are on the post-Paleozoic rocks, which crop out over more than 85 percent of the quadrangle; in particular, the volcanic rocks are discussed in considerable detail. The small discontinuous outcrops of Paleozoic formations furnish only meager evidence of regional significance. Outcrop areas of Precambrian rock are somewhat more extensive, but it was concluded that the additional data of regional importance obtainable from their detailed study would not be commensurate with the great expenditure of time required by such a study.

## GEOLOGY

### SUMMARY OF GEOLOGIC FEATURES

The rocks of the Klondyke region range in age from Precambrian to Recent and embrace a great variety of lithologic types. They have been divided into 19 formations, including 14 of layered rocks both sedimentary and volcanic, 4 of plutonic igneous rocks, and 1 of metamorphic rocks; one volcanic formation is subdivided into 12 units and one other formation into 2 members.

Rocks of Precambrian age include schist, hornfels, and moderately metamorphosed sedimentary and volcanic rocks and coarsely porphyritic granodiorite. Paleozoic rocks are entirely of sedimentary origin and are dominantly limestone and quartzite, and minor amounts of conglomerate, shale, and marl; they aggregate about 1,300 feet of strata, including about 300 to 400 feet of quartzite of Cambrian age, as much as 150 feet of marl, limestone, shale, and sandstone of Devonian age, 300 to 500 feet of limestone of Mississippian age, and 400 feet of limestone of Pennsylvanian age. The only rocks known unequivocally to be of Mesozoic age are as much as 900 to 1,000 feet of sandstone and shale of early Late Cretaceous (Colorado) age. A sequence of intermediate volcanic rocks as much as 2,500 to 3,000 feet thick, and another of silicic to intermediate volcanic rocks possibly 3,000-4,000 feet thick, may be of Late(?) Cretaceous or Tertiary age. The aggregate thickness of rocks of Late Cretaceous or Tertiary age is therefore about 6,500 to 8,000 feet. Two other sequences of dominantly volcanic rock cannot be dated closely but are probably of Cenozoic or Mesozoic age. A granodiorite pluton is considered to be of Tertiary or Late(?) Cretaceous age. Rocks of probable Tertiary age include sizable plutons of granite and quartz monzonite, as much as 6,500 feet of lithologically diverse volcanic rocks in the Galiuro Mountains, numerous silicic dikes, and as much as 2,000 feet of highly indurated conglomerate. At least two distinct formations of Quaternary alluvium, totaling at least 800 feet in thickness, are recognized, in addition to lakebeds as much as 100 feet thick and terrace deposits of two or possibly three ages. The aggregate thickness of post-Precambrian sedimentary and volcanic rocks is about 17,000 to 19,000 feet, but only a few thousand feet or less of beds is exposed in any one continuous section.

The geologic structure is complicated locally but does not seem to be complex. The earliest structures, folds and schistosity in the Precambrian rocks of the Santa Teresa and Turnbull Mountains, trend about northeast. An obscure structural trend of post-Pennsylvanian, pre-Cretaceous age, reflected by folds in limestone of Pennsylvanian age in the Turnbull Mountains, strikes approximately east to northeast, and another obscure easterly trend of Late Cretaceous(?) age is shown by poorly defined folds in Upper Cretaceous sedimentary and volcanic rocks. Most of the structures, principally faults of a north-northwest to northwest trend, are younger than Late Cretaceous, but the lack of fossils in rocks of post-Colorado (early Late Cretaceous) age precludes any but relative dating of these late structures. In the Santa Teresa and Turnbull Mountains, the main faults seem to be earlier than or contemporaneous with the emplacement of granite and quartz monzonite plutons of Tertiary age. Mineralization in these mountains is believed to have taken place at about the same time as emplacement of the plutons. The granodiorite pluton in the Copper Creek district may be about the same age as those in the Santa Teresa and Turnbull Mountains. Ore deposits of Copper Creek are younger than the granodiorite but cannot be dated closely. Volcanic rocks of the Galiuro Mountains are younger than the granodiorite and may postdate the Copper Creek mineral deposits.

The present arrangement of mountain masses and valley presumably originated in middle Tertiary time with the erosion or down-faulting of an ancestral northwesterly trending Aravaipa Valley. Two extensive sequences of valley fill have accumulated along this former valley; the earlier fill is well indurated, folded, and faulted, whereas the later appears to be unaffected by diastrophism. Faults in the Galiuro Mountains and faults and folds in the older valley fill of Aravaipa Valley are roughly parallel to some earlier structures and trend about north-northwest.

The Galiuro Mountains were uplifted in late Tertiary time on a fault or group of faults along their west flank, and erosion of Aravaipa Canyon presumably began at that time. Within the Klondyke quadrangle, however, no folding or faulting younger than the later sequence of valley fill has been recognized. Canyon cutting by Aravaipa Creek below Stowe Gulch and flood-plain formation above Stowe Gulch continued until very recent time; at present Aravaipa Creek is slightly incised into its flood plain, and no bedrock is exposed along the canyon bottom downstream from Stowe Gulch.

The geologic formations mapped in the three broad areas of the quadrangle—Galiuro Mountains, Aravaipa Valley, and Santa Teresa-Turnbull Mountains—are summarized in the following table.

*Summary of geologic formations of the Klondyke quadrangle, Arizona*

| Age | | Formation | | | | Thickness (feet) | Lithology and Location |
|---|---|---|---|---|---|---|---|
| | | Galiuro Mountains | | Aravaipa Valley | Santa Teresa and Turnbull Mountains | | |
| Quaternary | Recent | Younger alluvium | | Younger alluvium | Younger alluvium | 80? | Unconsolidated flood-plain deposits along Aravaipa Creek, and alluvium along its tributaries and Copper Creek. |
| Quaternary | Recent or Pleistocene | Not exposed | | Lake beds and terrace deposits<br>—Unconformity— | Not exposed | 100? | Unconsolidated gravel capping terraces 50-200 ft above Aravaipa Valley; weakly consolidated brown sandy to silty lake deposits. In Aravaipa Valley and tributaries. |
| Quaternary or Tertiary | Pleistocene or Pliocene | Not recognized | | Older alluvium | Older alluvium | 700+ | Partly consolidated essentially flat-lying alluvium along southwest flank of Santa Teresa and Turnbull Mountains and northeast flank of Galiuro Mountains. |
| | | | | —Unconformity— | | | |
| Tertiary | Late or middle | Hell Hole Conglomerate | | Hell Hole Conglomerate | Not recognized | 2,000+ | Well-indurated buff conglomerate, locally strongly deformed, along northeast flank of Galiuro Mountains. Composed mainly of volcanic debris; includes few beds of tuff and ash. |
| | | —Unconformity— | | | | | |
| Tertiary | Middle | Galiuro Volcanics | Upper tuff unit | | | 200–300 | Coarse-grained light-colored rhyolitic tuff, mostly near Aravaipa Canyon. |
| | | | —Local unconformity | | | | |
| Tertiary | Middle | Galiuro Volcanics | Upper andesite unit | | | 100–500 | Dark fine-grained olivine andesite or basaltic andesite lava and agglomerate, north of Aravaipa Canyon. |
| | | | —Local unconformity | | | | |
| Tertiary | Middle | Galiuro Volcanics | Quartz latite unit of Hawk Canyon | | | 0–200 | Reddish coarse-grained porphyritic quartz latite in upper Hawk Canyon. |
| Tertiary | Middle | Galiuro Volcanics | Rhyolite-obsidian unit | | | 0–700 | Obsidian, obsidian agglomerate, vitrophyre, and minor tuff and breccia in lower part; light-colored fine-grained rhyolite in upper part. North of Aravaipa Canyon. |
| Tertiary | Middle | Galiuro Volcanics | Tuff unit of Hawk Canyon | | | 0–100 | Light-colored massive silicic vitric-crystal tuff in upper Hawk Canyon. |
| Tertiary | Middle | Galiuro Volcanics | Intermediate andesite unit | Not exposed | Not recognized | 150–450 | Mostly coarse-grained porphyritic olivine andesite or basaltic andesite, minor fine-grained to porphyritic andesite. Along and south of Aravaipa Canyon. |
| Tertiary | Middle | Galiuro Volcanics | White tuff unit | | | 0–100 | Massive coarse-grained vitric-lithic silicic tuff, locally welded at top. South of Aravaipa Canyon. |
| Tertiary | Middle | Galiuro Volcanics | Upper welded tuff unit | | | 75–200+ | Pinkish cliff-forming massive vitric or vitric-crystal rhyolite welded tuff. Includes porphyritic rhyolite lava of Black Butte. Lower walls of Aravaipa Canyon, and extensive stripped surfaces along Parsons and Virgus Canyons. |
| | | | —Local disconformity? | | | | |
| Tertiary | Middle | Galiuro Volcanics | Lower tuff unit | | | 0–550 | Heterogeneous assemblage of light-colored silicic tuff and welded tuff, hornblende andesite, and a thin flow of olivine basalt. South of Aravaipa Canyon. |
| Tertiary | Middle | Galiuro Volcanics | Biotite dacite unit | | | 0–400 | Reddish porphyritic dacite, andesite, and latite flows, locally cliff forming. Upper Parsons and Oak Grove Canyons. |
| | | | — Disconformity— | | | | |
| Tertiary | Middle | Galiuro Volcanics | Lower welded tuff unit | | | 250–350 | Brownish vitric-crystal biotite latite welded tuff. Upper Virgus, Parsons, and Oak Grove Canyons. |
| | | | —Local unconformity? | | | | |
| Tertiary | Middle | Galiuro Volcanics | Lower andesite unit | | | 1,300+ | Red to gray fine-grained andesite and olivine andesite flows, flow breccia, and agglomerate; latite lava and tuff; minor coarse-grained porphyritic olivine andesite, tuff and conglomerate. Includes several pyroclastic cones and breccia pipes. Summit of Galiuro Mountains. |
| | | | Unconformity | | | | |

*Summary of geologic formations of the Klondyke quadrangle, Arizona*—Continued

| Age | | Formation: Galiuro Mountains | Formation: Aravaipa Valley | Formation: Santa Teresa and Turnbull Mountains | Thickness (feet) | Lithology and Location |
|---|---|---|---|---|---|---|
| Age relationship and relative stratigraphic position of some units unknown | Tertiary | Not recognized | Not exposed | Goodwin Canyon Quartz Monzonite | | Light-colored equigranular to porphyritic quartz monzonite and granite, subordinate diorite. Head of Goodwin Canyon. Age relative to that of Santa Teresa Granite unknown. |
| | Tertiary | Not recognized | Not exposed | Santa Teresa Granite | | Pale-red medium-grained equigranular perthite leucogranite. Santa Teresa Mountains. |
| | Tertiary or Late(?) Cretaceous | Copper Creek Granodiorite [Intrusive contact] | Not exposed | Not recognized | | Grayish medium-grained porphyritic granodiorite of Copper Creek basin. Contains numerous breccia pipes. Age relative to that of Santa Teresa Granite or Goodwin Canyon Quartz Monzonite unknown; all may be of nearly the same age. |
| | Tertiary or Late(?) Cretaceous | Not recognized | Horse Mountain Volcanics | Horse Mountain Volcanics [Angular unconformity] | 3,000+ | Silicic lava, tuff, welded tuff, obsidian, and vitrophyre; subordinate andesite and dacite. Lenticular conglomerate at base, locally fossiliferous. Numerous necks and vent breccias. Southwest flank of Santa Teresa and Turnbull Mountains. |
| | Tertiary or Late(?) Cretaceous | Not recognized | Not exposed | Williamson Canyon Volcanics [Disconformity] | 2,500+ | Nondescript massive pyroclastics, porphyritic lavas, and flow breccia, probably mostly andesitic or dacitic. Local basal conglomerate. Head of Williamson Canyon and along Old Deer Creek. |
| | Cenozoic and Mesozoic | Not recognized | Not exposed | Buford Canyon Formation: Volcanic member | 1,500+ | Dark fine-grained altered flows and flow breccia of andesite or basalt; minor silicic pyroclastic rocks. |
| | Cenozoic and Mesozoic | Not recognized | Not exposed | Buford Canyon Formation: Conglomerate member [Unconformity] | 700+ | Moderately indurated conglomerate with interlayered andesite or basalt flows and silicic pyroclastics. Buford Canyon and Klondyke Wash. Age relative to that of Horse Mountain or Williamson Canyon Volcanics unknown. |
| | Cenozoic and Mesozoic | Glory Hole Volcanics [Unconformity?] | Not exposed | Not recognized | 1,500+ | Heterogeneous, probably mostly andesite or dacite pyroclastics, subordinate flows, and flow breccias. Numerous breccia pipes. Copper Creek region. Age known only to be post-Mississippian, pre-Miocene(?). |
| Late Cretaceous | | Pinkard(?) Formation [Unconformity] | Not exposed | Pinkard Formation [Angular unconformity] | 900–1,000? | Gray to olive graywacke, feldspathic sandstone, siltstone, and shale, minor quartzite and conglomerate. Sparingly fossiliferous. Iron Cap mine and along Old Deer Creek. |
| Carboniferous | Pennsylvanian | Not exposed | Not exposed | Horquilla Limestone [Disconformity] | 350–400 | Gray to light-gray thin-bedded fine-grained fossiliferous limestone, subordinate coarse-grained and thick-bedded limestone. Aravaipa and Landsman Camp areas. |
| Carboniferous | Mississippian | Escabrosa Limestone [Disconformity] | Not exposed | Escabrosa Limestone [Disconformity] | 300–400 | Light- to medium-gray thick- to thin-bedded medium- to fine-grained limestone; some crinoidal, oolitic, or cherty limestone. Locally cliff forming. Aravaipa and Landsman Camp areas, Table Mountain mine, Copper Creek basin. |
| Devonian | | Martin Formation [Disconformity?] | Not exposed | Martin Formation [Disconformity] | 0–150 | Variegated marl, limestone, dolomite, shale, and sandstone. Aravaipa and Landsman Camp area, Copper Creek basin. |
| Cambrian | | Bolsa(?) Quartzite | Not exposed | Bolsa Quartzite [Unconformity] | 300–400 | Light-colored massive cliff-forming orthoquartzite and grit; basal conglomerate, purplish shaly partings. Aravaipa and Landsman Camp areas, Quartz Hill, Copper Creek region?. |
| Precambrian | | Not exposed | Not exposed | Diabase | | Dikes, sheets, and irregular bodies intruding Pinal Schist and Laurel Canyon Granodiorite. |
| Precambrian | | Not recognized | Not exposed | Laurel Canyon Granodiorite [Intrusive contact] | | Coarse-grained porphyritic granodiorite, commonly containing prominent phenocrysts of pink perthite. Local red granophyre and siliceous granite facies. Laurel and Tule Canyons region. |
| Precambrian | | Pinal(?) Schist | Not exposed | Pinal Schist | ? | Schistose graywacke, quartz-muscovite-chlorite schist, quartzite, metavolcanics, and hornfels. Santa Teresa and Turnbull Mountains; Galiuro Mountains?. |

## PRECAMBRIAN ROCKS

### PINAL SCHIST

The name Pinal Schist was given by Ransome (1903, p. 23) to the basement rock of the Pinal Range southwest of Globe and was later applied by him and others to similar rocks in the Bisbee district (Ransome, 1904b, p. 24–27), the Clifton-Morenci district (Lindgren, 1905a, p. 56), the Ray and Miami districts (Ransome, 1919, p. 32–37), the Aravaipa and Stanley districts (Ross, 1925a, p. 13–15), central Cochise County (Gilluly, 1956, p. 10–11), the Dos Cabezas and Chiricahua Mountains (Sabins, 1957b, p. 1320–1321), the Dragoon quadrangle (Cooper and Silver, 1964), and elsewhere. In the Klondyke quadrangle, the bulk of the rocks assigned to the Pinal are weakly metamorphosed graywackes, shales, and volcanic rocks or their hornfels equivalents; however, quartz-muscovite or quartz-muscovite-chlorite schist makes up much of the Pinal southeast of Buford Canyon.

The Pinal Schist crops out in five principal areas: (1) along the southwest flank of the Santa Teresa Mountains between Waterfall Canyon and the east edge of the quadrangle, the largest and best exposed body of the Pinal, (2) at the Dogwater mine and along Laurel Canyon north of the Grand Reef mine, (3) from the northeast flank of Imperial Mountain northwestward to beyond Aravaipa, (4) from Copper Canyon northward to beyond Landsman Camp, and (5) at and near Cobre Grande Mountain. A very small area of rocks in the Copper Creek region is tentatively correlated with the Pinal. A total of about 8.5 square miles, or about 3.5 percent of the quadrangle, is underlain by Pinal Schist.

The metasedimentary rocks of the formation are in general only moderately resistant to erosion, as they tend to break down easily to small chips and flakes and consequently erode to gentle slopes and rounded summits. Some of the schist terrane southeast of Buford Canyon, however, is moderately rugged, and the two large quartzite layers near Buford Canyon hold up steep-sided ridges that are visible for miles. The metavolcanic rocks and hornfels that make up much of the formation in the Imperial Mountain and Landsman Camp areas are so closely jointed that they break down very readily and erode to gentle slopes, except where protected by overlying resistant Bolsa Quartzite; outcrops of these rocks are everywhere poor, as they tend to be covered by their own blocky weathered debris. The rocks of Cobre Grande Mountain are moderately schistose, but apparently are somewhat indurated as a result of intrusion by Laurel Canyon Granodiorite and Santa Teresa Granite, and are obviously more resistant to erosion than might otherwise be expected.

Neither the bottom nor the top of the Pinal is exposed in the quadrangle, and no estimate of total thickness can be made. In places the rocks are so tightly folded that not even an estimate of thickness within limited areas would be meaningful, and over considerable areas the rocks are hornfels or metavolcanics having no discernible bedding. In the Buford-Waterfall Canyons region, both schistosity and bedding invariably stand at high angles, and it seems likely that the thickness is many thousands of feet. In this area and in that adjoining it to the east in the Jackson Mountain quadrangle, I believe that very detailed mapping might reveal the stratigraphy of the Pinal, so that a reasonably reliable measurement of partial thickness could be made; however, no such mapping was done during the fieldwork on which this report is based.

The Pinal is intruded by Laurel Canyon Granodiorite, by Santa Teresa Granite, and probably by Goodwin Canyon Quartz Monzonite, although most of the contacts with the quartz monzonite appear to be faults. The Pinal is also cut by dikes and irregular bodies of diabase and intruded by many silicic dikes. It is overlain unconformably by Bolsa Quartzite, Buford Canyon Formation, and older alluvium. Contacts with all other formations are faults.

The Pinal Schist was deposited, subjected to at least one orogeny, intruded by Laurel Canyon Granodiorite, and deeply eroded prior to the deposition of Bolsa Quartzite of Middle Cambrian age. On geological evidence, therefore, it is much older than Middle Cambrian, and presumably is of early Precambrian age, possibly correlative with the Vishnu Schist of the Grand Canyon and the Yavapai Series of the Mazatzal Mountains, Bagdad, and Jerome (Anderson and Creasey, 1958, p. 44–45).

#### LITHOLOGY

Very little time was spent on the Pinal Schist during fieldwork, and no systematic study of lithology or structure was made. In view of this lack of detailed information and of the lithologic diversity of the formation, description of the rocks will be limited to that of only a few rock types.

The Pinal of the Waterfall Canyon-Buford Canyon area consists principally of somewhat schistose feldspathic graywacke, quartz-muscovite-chlorite schist, and quartzite grit or conglomerate. Immediately southeast of Buford Canyon, the rock is mainly medium-gray [1] to greenish-gray schist that is tightly folded and pervasively crumpled on a minute scale. Numerous veins, pods, and irregular masses of quartz lie along the schistosity or transgress it. Schistosity trends northeast and is either vertical or dips steeply southeast, whereas the minor folds plunge 30°–50° SW.

A thin section of the schist shows it to be made up of interlocked and sutured grains of quartz 0.02–0.1 mm across, muscovite, and chlorite, in order of decreasing abundance. Muscovite forms grains 0.5–1 mm long and clearly is in two generations, one along the principal cleavage direction and a second along wrinkles that cross the schistosity at an angle of about 60° (fig. 2). Chlorite is an optically negative, weakly

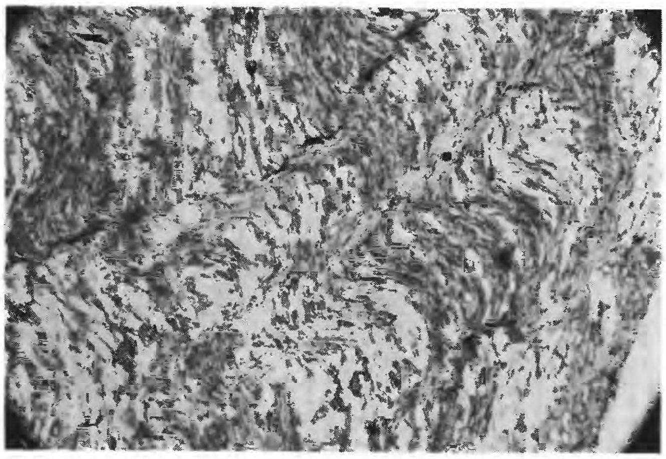

FIGURE 2.—Photomicrograph of quartz-muscovite-chlorite schist of Pinal Schist, showing two generations of muscovite. Earlier generation is along principal cleavage direction (upper left to lower right), later generation of coarser muscovite crosses earlier at an angle of about 60° (upper right to lower left). Plane-polarized light, × 37.5.

birefringent variety faintly pleochroic in pale green and yellow. Minor minerals include iron ore, apatite, blue-gray tourmaline, zircon, and biotite. The rock is completely recrystallized but originally may have been a sandy shale.

The quartzite of the Pinal is a highly resistant rock that forms two prominent parallel outcrops, one about 1.5 miles long that strikes northeast through Quartz Hill northwest of Buford Canyon, and another less than a mile long that lies along the southeast contact of the quartz-muscovite-chlorite schist southeast of the canyon. The bed on Quartz Hill dips 60°–80° SE. and is 550 feet thick where it crosses the head of Buford Canyon. The rock is a white to light-gray or purplish pebbly crossbedded orthoquartzite in which the only minerals identifiable with a hand lens are quartz, sericite, and iron ore. On the southeast side of Quartz Hill the upper(?) part of the quartzite is a breccia composed of fragments of sugary quartzite 1–2 cm across in a matrix of quartzite.

It seems possible that the two large quartzite units are the same and are on the limbs of a large isoclinal fold, but additional fieldwork in the adjoining Jackson Mountain quadrangle would be required to test such an hypothesis. The quartzite was referred to by Ross (1925a, p. 13–14) as quartzitic schist. In the Klondyke quadrangle, the rock locally does have a vague schistosity much less prominent than in the Buford Hill region to the east, where the rock becomes decidedly schistose. Similar quartzite has been described by Sabins (1957b, p. 1321) from the Pinal Schist of the northern Chiricahua Mountains.

The Pinal northwest of Quartz Hill is a rather monotonous assemblage of grayish-olive, gray, or light brownish-gray moderately schistose feldspathic graywacke that erodes to subdued topography and weathers a dull brown or greenish brown. Bedding is obscure at best and over most of the area has been obscured by metamorphism. The graywacke consist of angular or subangular grains of quartz, very dusty sericitized sodic plagioclase feldspar, and abundant fine-grained interstitial sericite, chlorite, and epidote. A little potassium feldspar may be in the matrix but was not identified with certainty in any rock. Rock fragments seem to be scarce, but a little chert was seen in one thin section. Minor minerals are apatite and iron ore. Grain size ranges from 0.02–0.05 mm in some rocks to 0.2–0.5 mm in others.

In general, the degree of metamorphism as revealed by the microscope is slight; quartz shows small overgrowths in some rocks, adjoining quartz grains may have sutured borders, and a vague schistosity can be discerned in most rocks. However, one specimen collected from Klondyke Wash near the line between secs. 3 and 4, T. 7 S., R. 20 E., is considerably more metamorphosed. It is a dark-gray or greenish-black fine-grained and slightly schistose rock in which millimeter-size grains of quartz and feldspar are visible. Microscopically, this rock is a schistose granulitic feldspathic graywacke composed mainly of ragged fragments of quartz and plagioclase feldspar 0.5–2 mm across that are embedded in a fine-grained groundmass of quartz, chlorite, and epidote. Plagioclase is thoroughly saussuritized sodic andesine or oligoclase. Chlorite is an optically positive variety having very low birefringence. A few fragments of chert(?) and a little iron ore and pale blue-green hornblende are accessories. Schistosity is imparted by elongate aggre-

[1] In this report, the nomenclature of the Rock-color Chart of the National Research Council (Goddard and others, 1948) is followed.

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gates of quartz and chlorite in parallel intergrowth; these commonly have formed in pressure shadows along the schistosity at the ends of quartz and feldspar fragments (fig. 3).

FIGURE 3.—Photomicrograph of schistose granulitic feldpathic graywacke of the Pinal Schist. Fine-grained rudely layered aggregates of quartz and chlorite (light-colored) have developed in pressure shadows at opposite sides of a quartz clast (white). Vague schistosity trends from upper right to lower left. Matrix is granulitic aggregate of quartz, chlorite, and epidote. Plane-polarized light, × 160.

Farther north in the same general area, the Pinal contains fine-grained bluish-gray and purple metasedimentary rocks in which graded bedding and crossbedding are preserved.

The Pinal in the vicinity of the diabase body northeast of Quartz Hill is a well-sorted and slightly schistose feldspathic sandstone or protoquartzite made up mostly of quartz and having small amounts of sericitized potassium feldspar, plagioclase feldspar, and iron ore, and traces of chlorite and epidote. Quartz grains are as much as 0.5 mm across, but most are about 0.02 mm in diameter; they have sutured borders where in contact with each other, and scalloped edges elsewhere.

The Pinal of Laurel Canyon north of the Grand Reef mine is so thoroughly converted to hornfels at the contacts with Laurel Canyon Granodiorite and Santa Teresa Granite that its original nature is uncertain. Two types of hornfels believed to be metasedimentary rocks and a third believed to have been a porphyritic rhyolite will be described in the section on contact effects of the Laurel Canyon Granodiorite (p. 17).

In the Copper Canyon-Landsman Camp area, the Pinal is composed principally of hornfels, although slightly schistose rocks also crop out here and there. The bulk of the schistose rocks appear to be metavolcanics. Schistosity for the most part trends northeast, although not so consistently as in the Waterfall Canyon-Buford Canyon region. All the rocks are jointed, in places highly so.

A moderate red hornfels from Tule Canyon where it crosses the line between secs. 29 and 32, T. 5 S., R. 20 E., is a fine-grained granular aggregate of quartz, plagioclase feldspar (albite), and subordinate potassium feldspar, chlorite, and sericite. A few quartz grains attain a size of 0.1–0.3 mm, but the bulk of the rock is made up of grains 0.01–0.02 mm across. This rock may have been a fine-grained feldspathic and slightly shaly sandstone.

A greenish-gray fine-grained faintly schistose metadacite(?) from Tule Canyon 1,200 feet above its confluence with Copper Canyon consists almost entirely of grains of altered sodic plagioclase feldspar less than a millimeter across in a very fine-grained greenish groundmass. The feldspar contains much sericite and chlorite, and many grains are bent or broken. Groundmass minerals include green biotite, chlorite, abundant tiny quartz eyes 0.02–0.1 mm across, and veinlets and patches of strongly pleochroic epidote.

A fine-grained moderately schistose dusky yellow green rock from the north fork of Tule Canyon is made up of epidote, muscovite, carbonate, and minor iron ore, chlorite, and apatite. Fine-grained granular quartz appears to be a secondary constituent. This rock is so throughly reconstituted that its original character is doubtful, but it may have been an andesite or dacite.

An amphibolite from the same area is a greenish-gray fine-grained schistose rock in which only pale-greenish feldspar and dark-green amphibole are recognizable in hand specimen. Microscopically, about 50 percent of the rock is brownish-green hornblende in prisms less than 0.5 mm long, 10 percent is sericitized sodic plagioclase feldspar and aggregates of albite and epidote, and 40 percent is a very fine grained and dusty mesostasis that may be a mixture of hornblende and plagioclase. Apatite is the only accessory mineral. The hornblende is pleochroic with $X =$ colorless, and $Y = Z =$ pale brownish green; the extinction angle $Z \wedge c$ is 24°. Presumably the rock is a metabasalt or meta-andesite.

The Pinal of Cobre Grande Mountain is a light-colored moderately schistose rock made up principally of quartz and muscovite. A specimen from the westernmost part of the outcrop is a grayish red-purple finely laminated very fine grained dense rock, partly bleached at and near the surface of the outcrop to a pale pink. Microscopic study shows it to be composed almost entirely of quartz and muscovite in grains

0.01–0.02 mm across. Quartz also forms sparse eyes and lenses of coarser grain size. Iron ore and a little chlorite are accessories. The abundance of quartz, the lack of relict phenocrysts, and the fine grain size indicate that the rock is probably a metamorphosed shale or siltstone.

The only possible occurrence of Pinal Schist in the Copper Creek region is just west of the old Tew Ranch at the middle of the line between secs. 1 and 12, T. 8 S., R. 18 E. An area about 900 feet long and 300 feet wide is underlain by fine-grained cream-colored, gray, white, or pink thin-bedded siltstone that at one place strikes N. 40°–70° E. and dips 35°–40° NW. These rocks are cut by a dike 4 feet wide of grayish-green nondescript rock, perhaps diabase, having small phenocrysts of altered feldspar. At one place just north of Copper Creek, the rocks have a rude cleavage, but elsewhere they seem to be almost unmetamorphosed. The beds were checked for carbonate with dilute hydrochloric acid at several places, but none was found. Assignment to the Pinal is made solely on the basis of the presence of cleavage, inasmuch as in the Klondyke quadrangle no sedimentary or volcanic rocks of other than Precambrian age show any trace of cleavage. The beds conceivably could belong to the Martin Formation, although they do not resemble closely the rocks half a mile northwest that are assigned with greater confidence to the Martin, but it seems most unlikely that they could belong to any of the other rock units of the region.

### LAUREL CANYON GRANODIORITE

A coarse-grained porphyritic biotite granodiorite unlike any other rock in the quadrangle crops out from a point half a mile north of the Grand Reef mine to a mile northeast of Landsman Camp. This rock is here named Laurel Canyon Granodiorite, for the good exposures along Laurel Canyon at the south end of the outcrop area. An outlier half a mile long and several smaller ones are engulfed in Santa Teresa Granite in the NE¼ T. 6 S., R. 20 E.; and two small areas of granitoid gneiss along the east edge of the quadrangle in secs. 13 (unsurveyed) and 24, T. 7 S., R. 20 E., are correlated with the Laurel Canyon on the basis of lithology. About 10 square miles, or 4 percent of the quadrangle, is underlain by Laurel Canyon Granodiorite.

The granodiorite is only moderately resistant to erosion, and its outcrop area coincides roughly with the area of subdued relief, shown clearly on the topographic map, east and southeast of Imperial Mountain. In a few places, such as near and east of the Tenstrike mine where the granodiorite is cut by closely spaced dikes, in Laurel Canyon where the upper wall on the southeast side is in Santa Teresa Granite, and at the head of Tule Canyon where the granodiorite is protected by resistant quartzite and limestone, slopes are steep, but nowhere is the terrain rugged. Outcrops are only fair except along the principal stream courses, where they may be good.

The Laurel Canyon Granodiorite intrudes Pinal Schist, is overlain unconformably by Bolsa Quartzite and older alluvium, and is intruded by diabase and Santa Teresa Granite; contacts with all other formations—Horse Mountain Volcanics and pre-Cretaceous sedimentary rocks other than Bolsa Quartzite—are faults. The contact with Pinal Schist is seldom well exposed, but its intrusive character is established by limited exposures of the contact in upper Tule Canyon and by the presence of xenoliths of Pinal in the granodiorite. North of the Grand Reef mine, the nature of the contact is obscured by many silicic dikes, but seems to be intrusive, the schistosity of the Pinal persisting to within 10 feet or less of the contact. Evidence bearing on the time of emplacement of the granodiorite with respect to that of metamorphism of the Pinal is not conclusive. In several places the granodiorite transects the schistosity of the Pinal, whereas elsewhere, particularly in upper Tule Canyon, the granodiorite and its red-rock facies are metamorphosed to the same degree as the Pinal and locally are so schistose as to be practically indistinguishable from it. The granodiorite may have been emplaced near the end of the orogenic period during which the schistosity of the Pinal was developed, so that only locally did it undergo comparable deformation.

The unconformity at the base of the Bolsa Quartzite is well exposed on the southeast side of a hill near the south edge of sec. 32, T. 5 S., R. 20 E.

The intrusive character of the contact with Santa Teresa Granite is indicated by the irregular trace of the contact, by a few granite dikes that cut Laurel Canyon Granodiorite near the contact, and by the previously noted blocks of granodiorite engulfed in granite.

Pebbles of red granitoid rock are abundant in the basal conglomerate of the Horse Mountain Volcanics, and presumably were derived from the red facies of the Laurel Canyon Granodiorite.

The Laurel Canyon is known on geological evidence to be older than the Bolsa Quartzite of Middle Cambrian age. Inasmuch as a long period of erosion must have intervened between emplacement of the granodiorite and deposition of the Bolsa, it seems likely that the granodiorite is of Precambrian age. The granodiorite intrudes Pinal Schist of early Precambrian age, and locally is metamorphosed to the same degree as the Pinal. The granodiorite is intruded in turn by dikes and small irregular bodies of diabase that appear to be restricted to the Precambrian rocks at Klondyke and are known elsewhere in southeastern Arizona to be of late Precambrian (post-Apache Group) age. In summary, the Laurel Canyon Granodiorite is younger than the Pinal Schist, probably is older than the Apache Group, and presumably is of early Precambrian age, although admittedly there is little evidence by which to date it more closely than simply Precambrian.

### LITHOLOGY

The Laurel Canyon Granodiorite varies considerably in appearance from place to place, but most commonly it is a gray or pinkish-gray porphyritic rock characterized by large phenocrysts of pink potassium feldspar. Modes of six rocks, made with a point counter, appear in table 1; the first three modes are granodiorites, the next two quartz diorites, and the last is a peculiar variant perhaps best named biotite anorthosite.

A chemical analysis and norm of the rock of column 1 follow, together with the chemical composition and norm of Nockolds' (1954) biotite adamellite for comparison; in this and succeeding norms, the normative minerals wollastonite, enstatite, and ferrosilite, are used instead of diopside, wollastonite, and hypersthene. A semiquantitative spectrographic analysis of the same rock appears in table 2, column 1.

TABLE 1.—*Modes of Laurel Canyon Granodiorite*

| Mineral | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Quartz | 30 | 22.5 | 31 | 26.5 | 28.5 | -------- |
| Plagioclase feldspar | 45 | 51 | 41 | 55.0 | 61.0 | 79.5 |
| Perthite | 21 | 21.5 | 24 | 7.0 | 4.0 | 3.0 |
| Biotite | 4 | 5 | -------- | 11.5 | 6.5 | 17.5 |
| Hornblende | -------- | -------- | 4 | -------- | -------- | -------- |

1. Granodiorite, Laurel Canyon, SW¼ sec. 21, T. 6 S., R. 20 E. Chemical analysis and norm appear on p. 15.
2. Granodiorite, SE¼ sec. 20, T. 6 S., R. 20 E., near contact with Pinal Schist.
3. Granodiorite, SW¼ sec. 15, T. 6 S., R. 20 E., near contact with Santa Teresa Granite.
4. Quartz diorite, Black Rock Canyon, NW¼ sec. 10, T. 6 S., R. 20 E.
5. Quartz diorite, outlier, sec. 11, T. 6 S., R. 20 E.
6. Biotite anorthosite, center sec. 9, T. 6 S., R. 20 E.

Except for having a somewhat lower ratio of $K_2O$ to $Na_2O$, the Laurel Canyon rock is very similar chemically and normatively to Nockolds' biotite adamellite; however, in no measured mode does potassium feldspar make up more than 40 percent of the total feldspar, so that, following Nockolds' classification, the rock would be termed granodiorite.

In the freshest rocks the texture is hypidiomorphic to allotriomorphic granular. In many rocks, however, the original texture has been so changed as to be unrecognizable.

The principal minerals are plagioclase feldspar, orthoclase perthite, quartz, and usually biotite. Hornblende is a major constituent in a few places. Accessory minerals include iron ore, sphene, apatite, epidote,

TABLE 2.—*Semiquantitative spectrographic analyses, in percent, of rocks from the Klondyke quadrangle, Arizona*

[Symbols: d, barely detected and concentration uncertain. Also looked for but not found in any sample: Ag, As, Au, Bi, Cd, Dy, Er, Eu, Gd, Ge, Hf, Hg, Ho, In, Ir, Li, Lu, Os, Pd, Pr, Pt, Re, Rh, Ru, Sb, Sm, Ta, Tb, Te, Th, Tl, Tm, U, W, Zn. Not looked for in any sample except No. 2: Al, Ca, Fe, K, Mg, Mn, Na, P, Si, Ti. Not looked for in any sample: Cs, Rb. Analysts: Samples 1-7, 9-11, Nancy M. Conklin, U.S. Geol. Survey; sample 8, Paul R. Barnett, U.S. Geol. Survey. Laboratory number in parentheses]

| Chemical element | 1 (F2673) | [1] 2 (280594) | 3 (F2676) | 4 (F2675) | 5 (F2674) | 6 (F2681) | 7 (F2682) | 8 (G2965) | 9 (F2680) | 10 (F2679) | 11 (F2678) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| B | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0015 | -------- | -------- | -------- |
| Ba | .07 | .015 | .03 | .07 | .015 | .15 | .07 | .07 | 0.03 | 0.03 | 0.07 |
| Be | .0003 | .00015 | .0003 | 0 | .0003 | 0 | .00015 | .003 | .0003 | .0003 | 0 |
| Ce | 0 | 0 | 0 | 0 | 0 | d | d | .015 | d | d | 0 |
| Co | .0007 | 0 | 0 | .0015 | 0 | .003 | .003 | .00015 | 0 | 0 | .003 |
| Cr | .0015 | .0015 | .00015 | .003 | 0 | .00015 | .003 | .00015 | .0003 | 0 | .003 |
| Cu | .0015 | .0007 | .00007 | .015 | .0015 | .007 | .03 | .007 | .0003 | .0003 | .007 |
| Ga | .0007 | .003 | .0015 | .0015 | .0015 | .0015 | .0015 | .0015 | .0015 | .0015 | .0015 |
| La | .003 | 0 | .007 | 0 | 0 | .007 | .007 | .007 | .007 | .007 | .003 |
| Mo | 0 | 0 | d | 0 | 0 | 0 | 0 | .0003 | 0 | d | 0 |
| Nb | .0015 | .003 | .003 | 0 | .003 | .0015 | .0015 | .0015 | .003 | .003 | .0015 |
| Nd | 0 | 0 | 0 | 0 | 0 | d | .015 | .007 | d | .015 | 0 |
| Ni | .0015 | 0 | 0 | .003 | 0 | .0015 | .007 | 0 | 0 | 0 | .003 |
| Pb | .003 | .0015 | .0015 | d | .007 | .0015 | d | .003 | .003 | .0015 | 0 |
| Sc | .0007 | d | .0007 | .0015 | 0 | .0015 | .0015 | .0007 | .0007 | .0007 | .003 |
| Sn | 0 | 0 | 0 | 0 | 0 | 0 | 0 | .0007 | 0 | 0 | 0 |
| Sr | .03 | .003 | .015 | .15 | .003 | .15 | .15 | .03 | .007 | .0015 | .15 |
| V | .007 | .015 | .0015 | .015 | 0 | .03 | .03 | .0015 | .0015 | 0 | .07 |
| Y | 003 | 0 | .003 | .0015 | .003 | .003 | .003 | .003 | .003 | .003 | .003 |
| Yb | .0003 | 0 | .0003 | .00015 | .0003 | .0003 | .0003 | .0003 | .0007 | .0003 | .0003 |
| Zr | .015 | .03 | .03 | .03 | .015 | .03 | .03 | .03 | .03 | .03 | .015 |

[1] Also determined: 0.07 Ca, 0.15 Fe, 3 K, 0.15 Mg, 0.03 Mn, 0.3 Na, 0 P, and 0.7 Ti.

1. Laurel Canyon Granodiorite; SW¼ sec. 21, T. 6 S., R. 20 E.
2. Contaminated granite facies of Laurel Canyon Granodiorite; W½ sec. 21, T. 6 S., R. 20 E.
3. Biotite quartz latite vitrophyre of the Horse Mountain Volcanics; center sec. 18, T. 6 S., R. 20 E.
4. Copper Creek Granodiorite; NE¼ sec. 10, T. 8 S., R. 18 E.
5. Santa Teresa Granite; NW¼ sec. 33, T. 6 S., R. 20 E.
6. Andesite, lower andesite unit of the Galiuro Volcanics; west edge sec. 13, T. 7 S., R. 18 E.
7. Porphyritic ("turkey-track") andesite, top of lower andesite unit of Galiuro Volcanics; N½ sec. 27, T. 7 S., R. 18 E.
8. Welded biotite quartz latite tuff, lower welded tuff unit of the Galiuro Volcanics; center N½ sec. 27, T. 7. S, R. 18 E.
9. Welded rhyolite tuff, upper welded tuff unit of the Galiuro Volcanics: NE¼ sec. 35, T. 6 S., R. 18 E.
10. Rhyolite vitrophyre, rhyolite-obsidian unit of the Galiuro Volcanics; NW¼ sec. 27, T. 5 S., R. 18 E.
11. Olivine andesite, upper andesite unit of the Galiuro Volcanics; center east edge sec. 36, T. 5 S., R. 18 E.

*Chemical analyses, in percent, of Laurel Canyon Granodiorite and average biotite adamellite*

| Bulk analysis | | | Normative minerals | | |
|---|---|---|---|---|---|
| Constituent | 1 | 2 | Mineral | 1 | 2 |
| $SiO_2$ | 71.09 | 71.03 | Q | 29.76 | 27.7 |
| $Al_2O_3$ | 14.29 | 14.31 | or | 25.02 | 27.8 |
| $Fe_2O_3$ | 1.07 | .95 | ab | 28.82 | 28.3 |
| Feo | 1.17 | 1.96 | an | 8.34 | 8.6 |
| MgO | .98 | .75 | C | 1.02 | .5 |
| CaO | 1.81 | 1.89 | en | 2.40 | 1.9 |
| $Na_2O$ | 3.43 | 3.33 | fs | .66 | 2.2 |
| $K_2O$ | 4.18 | 4.66 | mt | 1.62 | 1.4 |
| $H_2O+$ | .60 | .50 | il | .61 | .8 |
| $H_2O-$ | .28 | -------- | ap | -------- | .3 |
| $TiO_2$ | .32 | .39 | fl | .16 | -------- |
| $P_2O_5$ | .09 | .17 | | | |
| MnO | .09 | .06 | | | |
| $CO_2$ | .02 | -------- | | | |
| Cl | .02 | -------- | | | |
| F | .18 | -------- | | | |
| Subtotal | 99.62 | -------- | -------- | -------- | -------- |
| Less O | .08 | -------- | -------- | -------- | -------- |
| Total | 99.54 | -------- | -------- | -------- | -------- |
| Powder density | 2.66 | -------- | -------- | -------- | -------- |

1. Laurel Canyon Granodiorite, SW¼ sec. 21, T. 6 S., R. 20 E. Laboratory No. F2673. Analyst, Dorothy F. Powers, U.S. Geol. Survey.
2. Biotite adamellite (Nockolds, 1954, table 2, col. 2).

a little zircon, and, locally, dark tourmaline. The plagioclase is generally about oligoclase in composition and is slightly zoned. It commonly is sericitized to varying degrees. Pale-red (10*R* 6/2) orthoclase perthite may form individual phenocrysts as much as 3 cm across, or narrow zones along quartz-plagioclase or plagioclase-plagioclase contacts, or formless grains interstitial to the other minerals. The orthoclase phenocrysts contain many tiny inclusions; under the oil immersion lens these inclusions appear to be some form of iron oxide that presumably has exsolved to produce the characteristic pink color of the mineral. Quartz occurs as discrete large shapeless grains, as graphic intergrowths with orthoclase, and as small grains along borders of other minerals. Biotite is a dark-brown variety that may be fresh or may show ragged outlines and partial alteration to aggregates of biotite, apatite, sphene, iron ore, and pale-green amphibole or chlorite. Hornblende is abundant in only one specimen, in which it probably has replaced biotite. The hornblende is a light-colored variety in which pleochroism X = light yellow brown and Z = pale green.

The abundant stringers of fine-grained granular quartz that cut earlier minerals suggest that this rock has undergone mild dynamic metamorphism of intensity only sufficient to modify slightly the original texture.

A dark-gray porphyritic variety from the center of sec. 9, T. 6 S., R. 20 E., consists mainly of light-gray plagioclase feldspar, in grains as much as 5 mm across, and greenish-black biotite. The mode of this rock appears in table 1, column 6. Microscopically the rock has a hypidiomorphic granular and strongly cataclastic texture. Plagioclase is about $An_{10}$ and is slightly sericitized. Crystals are bent or broken and are cut by narrow mylonite seams. Biotite makes up an interstitial aggregate with iron ore and some very pale green amphibole, and has formed after the deformation of the plagioclase. Sparse potassium feldspar is interstitial to plagioclase. This rock might be called a biotite anorthosite.

The sizable lobe of Laurel Canyon Granodiorite in secs. 28 and 29, T. 5, S., R. 20 E., consists in large part of reddish porphyritic granitoid rock that appears to be a local border facies of the Laurel Canyon Granodiorite. In places, the contact between red rock and Pinal Schist is marked by a transition zone of schistose red rock or, at one place in upper Tule Canyon, by strongly sheared mixed rock in which contorted lenses of schistose red rock are enclosed in schist, and vice versa. It seems clear that at least some of the schistosity of the Pinal must have been impressed upon it after emplacement of the red rock, which locally is as highly schistose as the Pinal.

In hand specimen, the red rock consists of millimeter-size grains of moderate- to pale-red feldspar and sparse quartz phenocrysts, commonly having square outlines. Microscopically, the feldspar is granophyric orthoclase perthite in grains 0.5–2 mm across; about 75–95 percent of the rock is granophyre. The feldspar is so crowded with tiny reddish inclusions as to be nearly opaque. Plagioclase feldspar is scarce and is considerably sericitized; it is probably in the compositional range $An_{0\text{-}10}$, but is so cloudy that precise determination was not feasible. Quartz phenocrysts have undulatory extinction. A little sericite and quartz are in narrow veinlets and along grain boundaries.

Small amounts of red granitoid rock occur elsewhere in the Laurel Canyon Granodiorite. A coarse-grained porphyritic quartz diorite from the head of Stowe Gulch in sec. 4, T. 6 S., R. 20 E., is composed of centimeter-size grains of moderate-red feldspar, somewhat smaller rounded grains of quartz, and biotite. Microscopically, the rock has a hypidiomorphic granular texture having most grains in the size range of 1–5 mm. Red feldspars are orthoclase perthite and albitic plagioclase, both so crowded with minute inclusions of iron oxide that they appear pinkish in thin section. Orthoclase feldspar also occurs interstitially with quartz as granophyre. Green biotite is partly altered to chlorite and epidote. Sphene is a sparse accessory.

In most outcrops the granodiorite is a massive apparently structureless rock. In places, however, the rock is gneissic; in particular, sizable areas west-northwest and north of Black Rock Spring, in Stowe Gulch north of Imperial Mountain, and southeast of Buford Canyon, are underlain by strongly gneissic Laurel Canyon Granodiorite. The gneissosity generally strikes between N. 30° E. and N. 60° E. and dips 80°–90° S., about parallel to the schistosity of the Pinal Schist.

In a few places the granodiorite is slightly schistose, the schistosity being imparted mainly by closely spaced fractures along which variable amounts of mica have formed. The most schistose rock is that in the hanging wall of a quartzite unit of the Pinal Schist southeast of Buford Canyon. The rock is a light-colored coarse-grained aggregate of quartz, pink potassium feldspar, white plagioclase feldspar, and biotite, cut by closely spaced rudely parallel fractures along which considerable fine-grained green mica has formed. No recrystallization other than of mica seems to have taken place although the feldspar grains have been broken or even granulated. Similar rock crops out at several places in the area of low relief north of Black Rock Spring; it is characterized by large quartz augen and abundant greenish mica along surfaces of shear planes. In other places, schistosity is less marked and the original rock is modified only by pervasive shearing and little or no development of mica. The locally schistose nature of the red-rock facies of the granodiorite was mentioned earlier.

Inclusions seem to be scarce, but rounded masses of equigranular dark rock (autoliths?) as much as 2 feet across are common in the granodiorite in the W½ sec. 16, T. 6 S., R. 20 E., and schlieren of the same rock type, striking N. 80° E. and dipping 65° N., occur in the north half of the same section. Xenoliths of Pinal Schist were seen near the Laurel Canyon-Pinal contact north of the Grand Reef mine, and an inclusion of the same formation 50 feet long and 20 feet wide is exposed in Cottonwood Canyon in the SE. cor. sec. 33, T. 5 S., R. 20 E.

Only one dike that may be of Laurel Canyon Granodiorite was recognized, although others may have been overlooked. A dike of pale-red coarsely porphyritic granodiorite cuts Laurel Canyon Granodiorite near the line between secs. 8 and 9, T. 6 S., R. 20 E. The rock has a hypidiomorphic and strongly cataclastic texture and is made up principally of strongly sericitized bent and broken grains of sodic plagioclase and rounded grains of quartz with undulatory extinction. Plagioclase is cut by narrow streaks of quartz-feldspar mylonite. Potassium feldspar is restricted to grain boundaries of other minerals and probably constitutes less than 10 percent of the rock. Accessory minerals are apatite, carbonate in veinlets, blackish-green tourmaline, and epidote that replaces plagioclase.

In the area around Black Rock Spring, the granodiorite contains aggregates of tourmaline and quartz that may compose as much as 80 percent of the rock. Disseminated tourmaline is not common elsewhere.

Silicified and tourmalinized breccia zones cut the granodiorite in a number of places in the SW¼ sec. 15, T. 6 S., R. 20 E. These rocks have a black matrix in which are scattered irregular patches of quartz and fragments of wallrock. The dark matrix consists of quartz and thickly disseminated euhedral grains of tourmaline ranging in size from dust to prisms 0.5 mm long. The tourmaline is pleochroic, O = grayish blue, deep greenish blue, or nearly black, and E = pale yellow brown to nearly colorless. The refractive index O is about 1.675, which indicates pure schorlite (Winchell and Winchell, 1951, p. 466). Strongly pleochroic epidote is associated with the tourmaline.

Alteration features along the contact with Santa Teresa Granite will be described in the section on that granite (p. 65–66).

Two small bosses of a rather peculiar siliceous granite crop out within the Laurel Canyon Granodiorite in the W½ sec. 21, T. 6 S., R. 20 E. The rock does not resemble either the Laurel Canyon or the Santa Teresa Granite, but appears on the geologic map as part of the Laurel Canyon. The rock is a light-gray medium-grained granite that weathers to conspicuous rusty outcrops. It is composed of an allotriomorphic-granular aggregate of rounded conspicuous quartz grains 1–5 mm across, similar-sized subhedral crystals of gray perthitic potassium feldspar, and subordinate cream-colored interstitial material that may be plagioclase feldspar. In a thin section of a specimen from the smaller boss, most of the feldspar is orthoclase-oligoclase microperthite; in addition, a few millimeter-size grains of plagioclase are scattered through the rock, mostly as inclusions in perthite. Accessory minerals are sparse very pale brown phlogopite, colorless garnet, yellow-brown rutile, and a little andalusite(?).

The north contact of the larger boss dips 60° N. and is marked by several feet of fine-grained medium-gray pyritic selvage. Along the south contact is a narrow zone of abundant specularite veinlets which at one place has been prospected by a shallow pit. Near the middle of the north contact the boss is cut by veinlike streaks and irregular small radiating sheafs of blue to colorless corundum enclosing numerous small equant grains of dark-brown rutile. Microscopically, the granite in this area has an allotriomorphic-granular texture, and consists of irregular grains of quartz and orthoclase as much as 2 mm across, poikilitic or sieve-textured andalusite in subhedral to anhedral prisms 0.5–3 mm long, and abundant granular sericite that probably has replaced feldspar. A modal analysis gave 37 percent quartz, 3 percent orthoclase, 13 percent andalusite, 45 percent sericite-quartz groundmass, and 2 percent accessories, mostly coarse sericite, corundum, and a little apatite and zircon.

The stock is in part obviously a contaminated rock, and appears to have assimilated appreciable amounts of aluminous material, as attested by the abundant andalusite and less abundant corundum. The association corundum-rutile is a peculiar one for which no ready explanation is available; possibly the rutile was acquired from metasedimentary beds of the Pinal Schist, which may underlie the stock.

A semiquantitative spectrographic analysis of the granite is given in table 2, column 2; no unusual chemistry is revealed by the analysis.

#### CONTACT EFFECTS OF LAUREL CANYON GRANODIORITE

Only one rock unit, the Pinal Schist, is intruded by Laurel Canyon Granodiorite. In Laurel Canyon north of the Grand Reef mine, the Pinal is thoroughly converted to dark, dense hornfels, but the metamorphism, possibly resulting from emplacement of Laurel Canyon Granodiorite, cannot be separated from that perhaps consequent upon later intrusion of Santa Teresa Granite. Southwest of the Santa Teresa Mountains, however, where the Pinal is intruded solely by granite, the contact effects are not marked, and it appears therefore that much of the intense metamorphism in Laurel Canyon may indeed be attributed to the granodiorite.

Two rocks from the contact zone were examined in thin section. A dark-gray hornfels from just north of the Grand Reef mine consists of roughly equidimensional grains 0.01–0.05 mm across of quartz, chlorite, sericite, potassium feldspar, iron ore, and apatite. A few grains of quartz and iron ore are as large as 0.1 mm. Layering due to concentrations of various minerals along certain planes is well developed and may represent the original bedding of a siltstone or mudstone.

A distinctly layered medium-gray gneissic granulite from near the point common to Pinal Schist, Laurel Canyon Granodiorite, and Santa Teresa Granite in the SW. cor. sec. 21, T. 6 S., R. 20 E., is composed mainly of quartz and biotite, which are concentrated in alternating wavy layers. In thin section the rock has a well-defined granulitic texture. It is made up of grains 0.02–0.05 mm across of quartz and brownish-yellow biotite, subordinate cloudy potassium feldspar, iron ore, and apatite, and abundant prisms of andalusite as much as 2.5 mm long (fig. 4). Quartz also forms coarser grained eyes and lenses. The andalusite is strongly pleochroic, X = deep pink and Y = Z = colorless, and the metacrysts are zoned, being darker pink in the cores than at the rims. The granulite is so thoroughly recrystallized that the nature of the parent rock is not evident; it may have been a shaly arkosic sandstone.

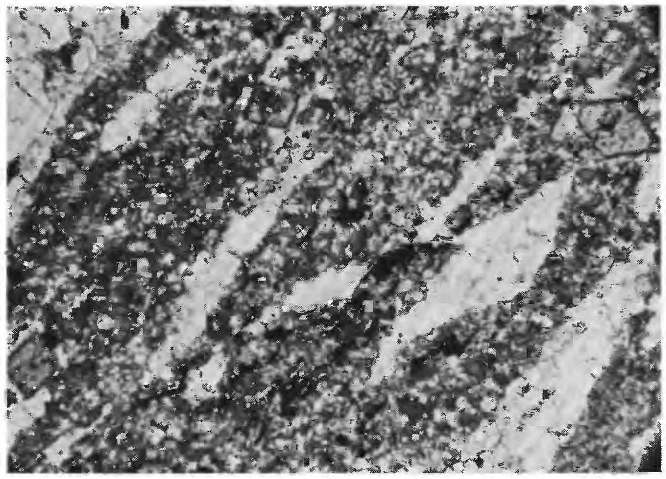

FIGURE 4.—Photomicrograph of gneissic biotite-quartz-andalusite granulite of the Pinal Schist. Rock consists almost entirely of quartz (light gray), biotite (dark gray), pink andalusite (diamond-shaped cross sections with strong relief), and sparse iron ore (black). Quartz and biotite grains are mostly 0.02–0.05 mm across. Plane-polarized light, × 41.

A vertical lens of Pinal Schist 150 feet long, 6–8 feet wide, and striking N. 25° W. is enclosed in Laurel Canyon Granodiorite in the NE. cor. sec. 20, T. 6 S., R. 20 E. The rock is a finely laminated dark-gray and medium light-gray fine-grained hornfels having sparse prominent millimeter-size phenocrysts of feldspar and quartz. Laminae are crumpled on a small scale. The light-colored layers are crowded with tiny whitish spheres and ellipsoids that resemble spherulites. In thin section the rock is made up almost entirely of a very fine grained aggregate apparently consisting of potassium feldspar and quartz in grains mostly less than 0.02 mm across. Grains of dusty quartz 0.2–0.3 mm across constitute a few thin layers. Feldspar phenocrysts are of very dusty perthite. The quartz phenocrysts have the typical rounded and embayed appearance of those of volcanic rocks, and the laminae curve around phenocrysts in a manner reminiscent of flow layering (fig. 5). The faint preservation of flow layering, together with the relict spherulitic structures, now completely recrystallized, and the nature of the phenocrysts, all indicate that the rock is a metamorphosed porphyritic and probably glassy rhyolite.

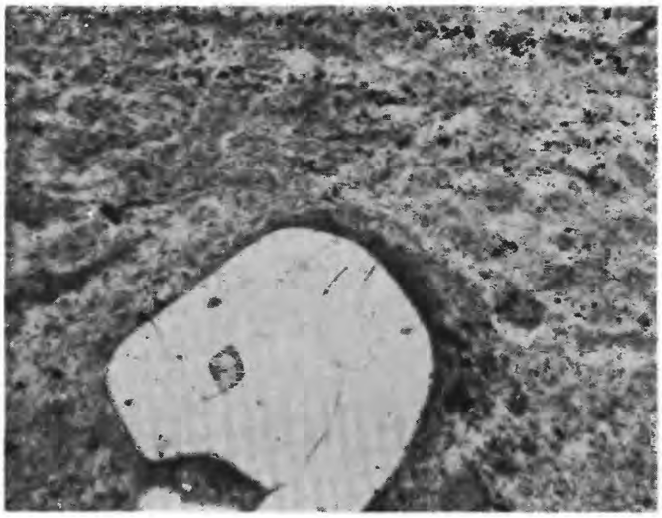

FIGURE 5.—Photomicrograph of metarhyolite of Pinal Schist from inclusion in Laurel Canyon Granodiorite. The rounded quartz phenocryst (white) is embedded in a faintly spherulitic groundmass of completely devitrified glass with faint flow layering that curves around the phenocryst. Plane-polarized light, × 50.

Pinal Schist of the Imperial Mountain-Aravaipa area and the Copper Canyon-Landsman Camp region is intruded by Laurel Canyon Granodiorite and converted to hornfels over wide areas. These regions are so far from the nearest outcrops of Santa Teresa Granite that it would seem logical to attribute all the metamorphism to the Laurel Canyon; moreover, the associated Paleozoic rocks are completely unmetamorphosed, suggesting that the metamorphism is indeed of Precambrian age. Because no attempt was made to distinguish metamorphism related to the granodiorite from that due to regional metamorphism, these rocks were described in the section on the Pinal Schist (p. 12).

### DIABASE AND OPHITIC GABBRO

The Pinal Schist and Laurel Canyon Granodiorite are intruded by dikes, gently dipping sheets, and irregular bodies of diabase and ophitic gabbro throughout their outcrop areas. These intrusives are numerous but small, the largest sheet being about 1,700 feet in longest dimension, and consequently they make up much less than 1 percent of the outcrop areas of their host rocks. Except where steep-walled gullies have been cut through diabase bodies, outcrops are very poor, and commonly the presence of diabase is evidenced only by float and reddish soil.

Inasmuch as the diabase and ophitic gabbro intrusives are confined to Precambrian hosts, they all are presumed to be of Precambrian age, probably late Precambrian.

Diabase in the Pinal Schist occurs mainly either as gently inclined sheets(?) lying nearly perpendicular to the schistosity of the wall rocks, or as irregular bodies whose contacts are too poorly exposed to permit more precise description, but which may also be sheet-like in form. One of the largest sheets(?) is that in the center of sec. 3 (unsurveyed), T. 7 S., R 20 E. Only the upper contact is exposed; it is a roughly planar surface striking about N. 70° E. and dipping 25°–35° S. The sheet(?) is at least several tens of feet thick. In Laurel Canyon Granodiorite, dikes are the most abundant form of diabase, but irregular bodies are not uncommon, particularly in sec. 4, T. 6 S., R. 20 E. and in secs. 28 and 29, T. 5 S., R 20 E.

The diabase is the typical dark-gray or greenish-black fine- to medium-grained rock composed of plagioclase feldspar ($An_{45-70}$), clinopyroxene (augite having an optic angle of 40°–45° in all sections studied), olivine, and iron ore. Pyroxene commonly is partly or completely altered to green amphibole. Biotite was noted in one thin section of a dike. The diabase grades with increasing grain size and less well-developed diabasic texture into ophitic gabbro.

The large sheet(?) in sec. 3, T. 7 S., R. 20 E., is greenish-black medium-grained diabase. Microscopically, the rock is made up of 1–2 mm laths of slightly zoned cloudy plagioclase (about $An_{50-60}$) set in a coarse-grained ophitic matrix of partly uralitized colorless augite. Olivine is not abundant and may be nearly fresh or may be completely altered to aggregates of iron ore, chlorite, and greenish amphibole; it is optically negative chrysolite having an optic angle near 90°. Iron ore in subhedral grains as much as a millimeter across is the only accessory mineral. A modal analysis of a specimen collected 5 feet below the upper contact gave 60 percent plagioclase, 20 percent pyroxene, 9 percent alteration products, 7 percent iron ore, and 4 percent olivine. Near the contact the rock is more altered and contains abundant epidote in addition to chlorite and sericite.

In the diabase mass just northeast of Quartz Hill, pyroxene is nearly completely pseudomorphed by green hornblende, and plagioclase ($An_{60-70}$) is strongly sericitized. The amphibole has an extinction angle $Z \wedge c$ of 22° and is pleochroic, with X=pale brown, Y=green, and Z=dark green to bluish green.

A greenish-gray diabase that forms a dike 60 feet wide near the point common to secs. 16, 17, 20, and 21, T. 6 S., R. 20 E., also consists almost entirely of plagioclase feldspar and amphibole, and accessory iron ore and apatite. The amphibole does not form pseudomorphs after ophitic pyroxene but rather aggregates of crisscrossing slender prisms. It is moderately pleochroic, X=colorless, Y=light green, and Z=green; the extinction angle $Z \wedge c$ is 18°.

The Pinal Schist south of Landsman Camp contains considerable diabase in masses too small and too poorly exposed to map. The typical diabase of this area is a dark greenish-gray coarse-textured and thoroughly altered rock. Plagioclase feldspar has been converted to a nearly opaque aggregate of sericite and zoisite; and pyroxene, if originally present at all, is now represented by fine-grained aggregates of pale-green hornblende. Cores of feldspar grains are completely altered, but the few rims preserved are about $An_{20}$ in composition.

In general, the diabase bodies have caused little or no alteration in their wall rocks. However, schistosity of the Pinal overlying the diabase sheet(?) in sec. 3 has been destroyed for 10–20 feet above the contact, and appreciable amounts of epidote and chlorite have formed in the lowermost few feet of Pinal.

## PALEOZOIC ROCKS

Rocks of Paleozoic age exposed in the Klondyke quadrangle include, from oldest to youngest, the Bolsa Quartzite (Middle Cambrian), Martin Formation (Upper Devonian), Escabrosa Limestone (Mississippian), and Horquilla Limestone (Pennsylvanian). The total outcrop area of Paleozoic rocks is about 4.6 square miles, or about 1.8 percent of the quadrangle. The aggregate maximum thickness of measured sections is about 1,300 feet, but the top of the Horquilla Limestone is everywhere an unconformity so that the original thickness of the Horquilla is unknown. The Paleozoic section therefore is thinner than in the Ray-Miami region to the northwest (Ransome, 1916, pl. 25; 1919, pl. 13) and in the Santa Catalina Mountains to the southwest (Stoyanow, 1936), and is much thinner than in the Little Dragoon Mountains to the south (Cooper and Silver, 1964) and in the Dos Cabezas Mountains to the southeast (Sabins, 1957b, table 1). On the other hand, it is somewhat thicker than the section at Clifton-Morenci, 50 miles east (Lindgren, 1905a, p. 58–59).

Ross (1925a) recognized a quartzite of Cambrian age which he correlated hesitantly with the Troy Quartzite of the Apache group (the Troy Quartzite is now separated from the Apache Group and both are considered to be of late Precambrian age), Martin Limestone, and Tornado Limestone (now abandoned and rocks formerly assigned to it are subdivided into the Escabrosa Limestone and Horquilla Limestone).

Darton (1925, p. 263) noted "Bolsa quartzite, Abrigo limestone, Martin and Tornado limestone, and various crystalline rocks" in the Turnbull Mountains and in the region about Stanley and Aravaipa; the Abrigo was not recognized either by Ross or by me. Darton (1925, p. 29, 272–273, fig. 86c) believed the sedimentary rocks, principally quartzite, in the Copper Creek area to belong to the Apache Group. The age of the quartzite is indeterminate, but I believe the other sedimentary rocks of the region to be rather of Devonian, Mississippian, and Cretaceous(?) ages.

## CAMBRIAN SYSTEM

### BOLSA QUARTZITE

The name Bolsa Quartzite was given by Ransome (1904b, p. 28) to the basal quartzite of the Cambrian in the Bisbee region. It since has been extended to correlative rocks of central Cochise County (Gilluly, 1956, p. 14–15), the eastern Dos Cabezas and Chiricahua Mountains (Sabins, 1957a, p. 469–472), and the Little Dragoon Mountains, Johnny Lyon Hills, and Winchester Mountains (Cooper and Silver, 1964).

Farther north, the basal quartzites of Paleozoic age have received several names, and several tentative correlations have been proposed.

At Clifton-Morenci, 55 miles east-northeast of Klondyke, the basal quartzite of the Paleozoic section was named Coronado Quartzite by Lindgren (1950a, p. 59), who mentioned (p. 62) the "* * * Bisbee equivalent Mr. Ransome refers to as the Bolsa quartzite * * *." Such a correlation was suggested tentatively by Darton (1925, p. 45) and accepted for the most part by Stoyanow (1936, p. 478–479) and Lochman-Balk (1956, p. 544).

On Tornado Peak in the Christmas region, 25 miles northwest of Klondyke (Peterson and Swanson, 1956, p. 358), in the Globe quadrangle (Peterson, 1954), and in the Castle Dome area (Peterson and others, 1951, p. 16–17), the basal quartzite of the Paleozoic has been referred to as Troy Quartzite.

The Troy Quartzite was named by Ransome in his report on the Ray and Miami districts (Ransome, 1919, p. 44) and was considered by him to be the uppermost formation of the Apache Group, which he believed to be of Cambrian, and possibly also Ordovician and Silurian, age. Darton (1925, p. 32, 36–37) believed that (1) the Troy was in part of Cambrian age; (2) it "* * * in most places includes in its upper part or is overlain by a much younger sandstone, doubtless equivalent to * * * the Bolsa-Abrigo beds"; and (3) "* * * near the east end of the Mescal Mountains, its upper part overlaps the edge of the Dripping Spring quartzite and becomes the basal formation of the sedimentary series, corresponding to the Bolsa quartzite of the region not far southeast * * *."

At present, Ransome's original Apache Group, as well as some but not all of his Troy Quartzite, are considered to be of late Precambrian age, and some of his Troy Quartzite is known to be of Cambrian age. (See for instance, Stoyanow, 1936, p. 472–476 and table 1; Shride, 1961.)

The Bolsa Quartzite crops out in seven principal areas, and in addition several small outcrops of quartite also are referred to the Bolsa. The principal areas are the top of the ridge east of Aravaipa, the northeast flank of Imperial Mountain, the southeast side of the hill east of Tule Spring, the ridge between Tule and Copper Canyons, the ridge 2,000 feet northwest of Landsman Camp, the divide between Tule Canyon and the Middle Fork of Goodwin Canyon, and the W½ sec. 16, T. 5 S., R. 20 E. A small body of quartzite correlated with the Bolsa lies on the northwest side of Quartz Hill in the Buford Canyon area, and a few small outcrops of quartzite in the Copper Creek drainage are tentatively correlated with the Bolsa. The total outcrop area of the formation is about 1.3 square miles, or only about 0.5 percent of the quadrangle.

The Bolsa is very resistant to erosion and typically forms steep cliffy slopes that rise abruptly above the much more easily eroded Precambrian rocks on which the formation rests. Although the base of the Bolsa tends to be covered by blocky quartzite debris, it nevertheless is sufficiently well exposed in several places to leave no doubt about the nature of the basal contact.

Complete sections of Bolsa Quartzite are exposed on the northeast flank of Imperial Mountain, where a thickness of 287 feet was measured; in the lower part of Copper Canyon, where the thickness is estimated to be about 400 feet; and on the ridge northwest of Landsman Camp, where the thickness is estimated to be about 350 feet. The section northwest of Cobre Grande Mountain appears to be considerably thicker, but the rocks here are folded and may be repeated by strike faults, although none was recognized in the southeastern part of the outcrop; hence no estimate of thickness would be meaningful.

The Bolsa rests unconformably on the Pinal Schist and Laurel Canyon Granodiorite, both of Precambrian age. It is overlain disconformably by the Martin Formation and is overlain unconformably by Galiuro Volcanics and Horse Mountain Volcanics. In sec. 16, T. 5 S., R. 20 E., it is intruded by Goodwin Canyon Quartz Monzonite. Contacts with other formations are faults.

The small and disconnected outcrops of the base of the Bolsa do not permit much generalization about the nature of the surface on which the formation was deposited, but the absence of granodiorite pebbles in the basal conglomerate, even where the Bolsa rests directly on granodiorite, suggests that the surficial rocks were weathered so much that only the most resistant rocks—quartzite and quartz—have survived as pebbles. A similar inference was drawn by Lindgren (1905a, p. 61) with respect to the surface on which the presumably correlative Coronado Quartzite was deposited at Clifton-Morenci.

#### LITHOLOGY

The Bolsa Quartzite consists dominantly of clean, light-colored massive crossbedded quartzite and quartzite grit, overlying a basal quartzite conglomerate of variable thickness. Brown or maroon quartzite and purple micaceous sandstone are found locally. The upper part of the formation on Imperial Mountain has some beds of purplish feldspathic quartzite, as do the outcrops in the Middle Fork of Goodwin Canyon and near the junction of the Landsman Camp and Tule Spring roads, but most of the formation is clean orthoquartzite. In a general way, the lower part of the formation is more pebbly than the upper. Beds range from a fraction of an inch to several tens of feet in thickness, and average perhaps several feet thick. Bedding is recognizable in most places, but locally, such as in much of the upper part of the section northwest of Cobre Grande Mountain, it is either indistinct or completely lacking. On Imperial Mountain, bedding in places is accentuated by thin partings of purple micaceous quartzite. The Bolsa weathers to a brownish or rusty color, which together with the rough blocky outcrops is distinctive.

A thin section of finely layered light-gray and pale reddish-brown quartzite from northwest of Cobre Grande Mountain (unit 5, p. 22) shows the rock to be a well-sorted orthoquartzite composed of subrounded to subangular grains of quartz 0.15–0.2 mm in diameter. A few grains are nearly a millimeter across. The very sparse cement, less than 5 percent of the rock, is muscovite. Quartz grains may be interlocked or have slightly sutured contacts, but the degree of recrystallization is slight.

The base of the Bolsa is well exposed at several places. On the southeast side of the hill east of Tule Spring (SE¼SW¼ sec. 32, T. 5 S., R. 20 E.), a basal pebble conglomerate 20 feet thick rests on Laurel Canyon Granodiorite. Most of the pebbles are 1–2 inches in diameter, but a few cobbles attain a size of 6 inches. They are rounded to subangular and are of white quartz and red, violet, or gray quartzite, set in a coarse sandy matrix.

Near the mouth of Copper Canyon, about 2,000 feet northwest of the preceding locality, the base of the Bolsa consists of pebbly quartzite rather than conglomerate. The contact here is somewhat faulted but appears to be essentially depositional. North of Copper Canyon, the basal conglomeratic quartzite of the Bolsa is about 65 feet thick and consists of rounded to subrounded pebbles 1–2 inches in diameter embedded in a matrix of brownish-green coarse-grained quartzite. A few cobbles are as large as 6 inches across. From 30 to 50 percent of this basal section is made up of pebbles, of which about half are quartz and half are quartzite.

Northwest of Cobre Grande Mountain at the head of Tule Canyon, the Bolsa rests on a somewhat irregular surface carved on the red granophyre facies of the Laurel Canyon Granodiorite. The basal beds are conglomerate, conglomeratic quartzite, and micaceous sandstone, ranging in aggregate thickness from a few feet to perhaps 80 feet. At one place near the southeast end of the outcrop, the base is a coarse-grained conglomerate containing boulders as much as 18 inches across, overlain by purple to white cross-bedded coarse grit containing quartz pebbles.

On the north side of the hill half a mile southeast of Aravaipa, the basal conglomerate of the Bolsa is about 9 feet thick and consists of subrounded to subangular pebbles as much as 3 inches across of quartzite and quartz set in a matrix of quartzite grit.

The quartz pebbles of the basal conglomerate of the Bolsa presumably were derived from quartz lenses and pods in the Pinal Schist, but the source of some of the quartzite pebbles is less certain; the only quartzite in the Pinal of the Klondyke region is dominantly white, although it does contain a little darker colored quartzite similar to that making up many pebbles of the conglomerate.

The only possible occurrences of Bolsa Quartzite in the Copper Creek area are in secs. 1 and 12, T. 8 S., and sec. 34, T. 7 S., both R. 18 E. Along the south edge of the quadrangle in sec. 1 are several outcrops of hard coarse-grained orthoquartzite intruded by Copper Creek Granodiorite and overlain unconformably by the lower andesite unit of the Galiuro Volcanics. The quartzite is at least 200 feet thick and the base, if exposed, lies outside the Klondyke quadrangle. The lower part of the section consists of gray gritty quartzite in beds 1–8 feet thick having sparse dark-gray shaly partings. The beds weather to a rusty brown color. White, pink, and light-gray quartzite make up the rest of the section.

In the center of sec. 1, several xenoliths of quartzite are enclosed in Copper Creek Granodiorite. These xenoliths are of light-gray to white massive vitreous orthoquartzite having ferruginous cement; the rock weathers to rusty-red. The largest and most northerly xenolith is several hundred feet long and consists of a lower 25 feet of gray thick-bedded massive quartzite, a middle 40 feet of dark crossbedded and wavy-bedded quartzite, and an upper 10 feet of white to light-gray thin-bedded quartzite. Bedding strikes N. 10° E. and dips 20°–25° W. The xenolith some 600 feet farther south is 150 feet long and 10–15 feet thick and consists of dark-colored vitreous quartzite striking N. 35° E. and dipping 85° NW. A small patch of coarse-grained quartzite underlies the Martin Formation in the W½ sec. 1. This quartzite may belong to either the Bolsa or the Martin, but because of its small outcrop area, it is grouped with the Martin on the geologic map.

A thin slice of gray coarse-grained vitreous quartzite, pebble quartzite, and quartzite breccia lies along the north side of an east-striking fault zone in the W½ sec. 34, T. 7 S., R. 18 E. The slice is as much as 150 feet wide and is 800–900 feet long. Bedding is too obscure for measurement in most places; in the saddle near the west end of the outcrop, pebbly quartzite strikes N. 60°–70° W. and dips 50°–55° S., and elsewhere bedding seems to dip steeply south. Along the south side of the quartzite and extending beyond it to the east and west is a black-stained silicified fault breccia. Westward from the end of the quartzite sliver the fault may be nearly along an intrusive contact between Copper Creek Granodiorite and Glory Hole Volcanics. A second very small mass of quartzite crops out in the canyon 500 feet north of the main lens.

Field relations in the Klondyke quadrangle give no clue to the source of the quartzite lens. It crops out more than 500 feet above the lowest outcrops of Glory Hole Volcanics in Dry Camp Canyon, and some 2 miles from the nearest outcrop of even remotely similar rock of known stratigraphic position. The small outcrop north of the lens seems to be overlain by Glory Hole Volcanics, but exposures are inadequate to prove the depositional nature of the contact. Perhaps mapping now in progress in the Holy Joe Peak quadrangle to the west will furnish some evidence regarding the source of the quartzite. On the admittedly very tenuous basis of lithology, the quartzite is assigned to the Bolsa, but it conceivably could be part of the Cretaceous Pinkard(?) Formation.

The following measured sections of the Bolsa Quartzite illustrate the lithology of the formation; the first is a complete section, and the second is believed to be nearly complete.

*Section of Bolsa Quartzite on the northeast side of Imperial Mountain, NE¼ sec. 6, T. 6 S., R. 20 E.*

Escabrosa Limestone:

Limestone, light-gray, without chert. 30 ft thick, top is erosion surface. At base, few feet of marl, possibly of Martin Formation.

Disconformable contact.

| Bolsa Quartzite: | Thickness (feet) |
|---|---|
| 1. Quartzite, brown, brownish-green, or brownish-gray; rusty bed at top. Some chlorite(?) in matrix | 3½ |
| 2. Quartzite, brown; mostly thick bedded, but a few thin beds | 5 |
| 3. Quartzite, light-gray, light-brown, cream-colored, or white, thick-bedded | 6½ |
| 4. Quartzite, purple, feldspathic, matrix rather rusty | 4 |
| 5. Quartzite grit, dark-weathering; cavernous surface. Grains as much as 3–4 mm in diameter | 5 |
| 6. Quartzite, massive, crossbedded; weathers brown to purple, becoming darker toward top. Few thin beds, some as much as 12–18 in. thick | 10½ |
| 7. Quartzite grit, light greenish-gray | 1½ |
| 8. Same as unit 6 | 11 |
| 9. Covered | 9 |
| 10. Quartzite, white to pale-violet or light-brown | 8 |
| 11. Covered; probably a rusty-weathering grit, not very quartzitic | 5 |
| 12. Quartzite, light-gray to light-purple, crossbedded, massive, cliff-forming | 17½ |
| 13. Covered | 3½ |
| 14. Quartzite, light-buff; a few dark-brown coarse-grained layers as much as 6 in. thick | 7 |
| 15. Quartzite, light-buff, cream-colored, or white; crossbedded | 12½ |
| 16. Same as unit 15 but more massive; cliff-forming | 24 |
| 17. Quartzite, buff, pink, or cream-colored; crossbedded; conspicuous thin beds of brown quartzite | 20½ |
| 18. Covered, probably quartzite | 16½ |
| 19. Dike(?), light grayish-green porphyritic rhyolite | 11½ |
| 20. Quartzite, light- to pinkish-gray and purplish cast; well-bedded | 15½ |
| 21. Covered | 3 |
| 22. Pebble conglomerate | 2 |
| 23. Dike(?), light-green to pink fine-grained porphyritic rhyolite | 10 |
| 24. Covered | 5½ |
| 25. Sandstone, interlayered pebble beds | 10 |
| 26. Sandstone, dark-red and black cast. Crossbedded, conglomeratic, having most pebbles less than 1 cm across | 2 |
| 27. Quartzite, light pinkish-gray, pebbly | 3½ |
| 28. Covered | 43 |
| 29. Quartzite, pebbly | 2½ |
| 30. Covered | 8½ |
| 31. Sandstone, purple | 2 |
| 32. Quartzite, pebbly | 6 |
| 33. Conglomerate; general dark-purple aspect; well-bedded. Rounded to subangular pebbles of white quartz and red quartzite in dark-purple quartzite matrix. Most pebbles less than 1 in. across, some as large as 3–4 in | 13 |
| Total Bolsa Quartzite | 308½ |

Unconformity.

Pinal Schist:

Phyllitic schist, brown to grayish-green.

*Section of Bolsa quartzite near the point common to secs. 20, 21, 28, and 29, T. 5 S., R. 20 E., 1.2 miles northwest of Cobre Grande Mountain*

Laurel Canyon Granodiorite:

Red granophyre facies.

Fault contact.

| Bolsa Quartzite: | Thickness (feet) |
|---|---|
| 1. Quartzite, brown, poorly exposed | 18 |
| 2. Quartzite, white, massive, no bedding | 31 |
| 3. Covered; possible fault | 20 |
| 4. Quartzite, white, massive, cliff-forming; little indication of bedding | 88 |
| 5. Quartzite, interbedded light-gray and pale reddish-brown, finely layered, distinctive | 10 |
| 6. Quartzite, white, clean, massive, cliff-forming. Numerous very thin dark grit seams that reveal bedding. Very few pink layers, no pebbles | 68 |
| 7. Quartzite, variegated white, cream-colored, buff, and light-purple, crossbedded. Conspicuously alternating dark and light layers. Beds in lower part less than 1 ft thick; becomes lighter colored and more thin-bedded toward top | 21 |
| 8. Coarse grit, variegated purple, buff, and cream-colored, rusty- or purple-weathering, well-bedded, cliff-forming. Scattered fragments of white, pink, and red quartz. Few pebble beds with subrounded to angular pebbles of red quartzite and white quartz as much as 3 in. across. Toward top, becomes less pebbly, more quartzitic, crossbedded, more purple | 68 |
| 9. Sandstone, grit, and siltstone, dark-purple, thin-bedded, micaceous. Rather silty; may be tuffaceous | 8 |
| 10. Conglomerate, dark-purple. Rounded to subangular pebbles of white quartz 1–2 in. in diameter, in fine-grained purple matrix. Near base, few cobbles as much as 5 in. across | 5 |
| Total exposed Bolsa Quartzite | 337 |

Unconformity.

Laurel Canyon Granodiorite:

Red granophyre facies; somewhat schistose, vertical schistosity trends N. 30° E.

### AGE

No fossils were found in the Bolsa Quartzite, and consequently its correlation with the Bolsa of areas to the south and southeast is made entirely on the basis of lithology and stratigraphic position. The quartzite rests unconformably on Pinal Schist and Laurel Canyon Granodiorite of Precambrian age and is overlain by fossiliferous rocks of Devonian and Mississippian age.

In 1963, after this report was completed, a field conference was held with Medora Krieger of the U.S. Geological Survey, who had been mapping in the Holy Joe Peak quadrangle, which adjoins the Klondyke quadrangle to the west. As a result of this conference, we agree that the Bolsa Quartzite as mapped in the Klondyke quadrangle may include beds of late Precambrian age (Troy Quartzite) as well as beds of Cambrian age.

## DEVONIAN SYSTEM

### MARTIN FORMATION

The Martin Limestone was named by Ransome after Mount Martin in the Bisbee region (Ransome, 1904b, p. 33). In a later study of Devonian and Mississippian rocks of east-central Arizona, Huddle and Dobrovolny (1952) retained the name Martin for the Devonian rocks but, in recognition of the large proportion, 40–50 percent, of terrigenous material in these rocks, they preferred to use the name Martin Formation. This name also was applied by Cooper (1957, p. 580) to Devonian rocks near Johnson Camp, 50 miles south of Klondyke. Sabins (1957a, p. 475–480), in his study of the eastern part of the Dos Cabezas Mountains and the northern part of the Chiricahua Mountains, 70 miles southeast of Klondyke, proposed the name Portal Formation for a sequence of shale and limestone of Late Devonian age, lithologically rather different from the Martin Limestone of the type locality; he suggested that the Portal may be correlative with the Morenci Shale (Lindgren, 1905a, p. 66–69), which consists of a lower black fine-grained limestone and an upper black shale unit.

In the Klondyke quadrangle, the Bolsa Quartzite and Escabrosa Limestone are separated by a sequence of marl, limestone, shale, and sandstone, generally less than 100 feet thick. No identifiable fossils were found in these beds, so that their assignment to the Devonian is based entirely on lithology, stratigraphic position, and geology of other regions in southeastern Arizona where paleontological data are available. On Packwood Peak, 2 miles north of the Klondyke quadrangle, Ross (1925a, p. 20–21) found about 100 feet of unfossiliferous black shale and black dense limestone between quartzite of Cambrian age and Tornado Limestone (Escabrosa and Horquilla Limestones of this report). These beds appear to resemble the Morenci Shale, but no lithologically similar beds were observed farther south. In the discussion of Huddle and Dobrovolny, the measured section of the Martin Formation nearest to Klondyke is about 30 miles to the northwest on Tornado Peak, but the rocks at Klondyke are more similar lithologically to the upper member of the formation as described by them (Huddle and Dobrovolny, 1952, p. 75–76) than to the Morenci Shale, the Portal Formation, or the type Martin Limestone; therefore the name Martin Formation will be used in this report to include all the sedimentary rocks lying between the uppermost quartzite beds of the Bolsa Quartzite and the basal massive gray limestone of the Escabrosa Limestone.

The Martin Formation crops out or is inferred to be present everywhere between the Bolsa Quartzite and the Escabrosa Limestone. It is shown on the geologic map to underlie about a dozen areas near and northeast of Aravaipa, none of which is larger than 0.025 square mile, and it also underlies a small area in the Copper Creek basin. Other outcrops of Martin Formation, such as at the Table Mountain mine and along certain Bolsa-Escabrosa contacts, are too small to show on the map. The total outcrop area of the Martin is only about 0.2 square mile, or less than 0.1 percent of the quadrangle.

The Martin Formation is the least resistant to erosion of the Paleozoic rocks and seldom is well exposed except along gullies where rapid erosion has stripped it of debris from the overlying rocks. The best exposures are along the west side of the hill southeast of Aravaipa. Much of the Martin is covered by caliche derived from the overlying Escabrosa Limestone.

The Martin ranges in thickness from a few tens of feet to about 150 feet; on the northeast side of Imperial Mountain the Martin, if present, is only a few feet thick. Inasmuch as the various sections cannot be correlated closely from place to place, it is not possible to say whether this considerable variation in thickness is due to disconformity at the top, or at the base, or at both. If the green fissile shale found in most of the sections is everywhere at the same stratigraphic position, then the upper contact must be disconformable, inasmuch as the thickness of the Martin between the green shale and the base of the Escabrosa ranges from 15 feet, or perhaps even less, to 125 feet. In view of the lithologic variations of the Martin, however, it seems rather unlikely that the green shale does indeed maintain a constant stratigraphic position.

#### LITHOLOGY

The Martin Formation includes rocks of diverse lithology—limestone, dolomite, marl, shale, and sandstone—but for the most part consists of variegated marl and limestone. Pink to red or maroon fine-grained dolomite and limestone are characteristic of the uppermost part of the formation, and variegated marl and shale are characteristic of the lower part.

The most characteristic rock of the Martin is a highly fissile green shale that rarely crops out, but upon weathering yields abundant distinctive small sharp-edged chips and flakes. This rock may constitute practically the entire Martin Formation, as for example on the ridge south of the Iron Cap mine, but more commonly is subordinate to variegated marl and limestone. Similar shale was noted long ago by Campbell (1904, p. 243) in Ash Creek Canyon northwest of the Klondyke quadrangle, where it rests on sandstone and conglomerate of Cambrian age and underlies limestone of Carboniferous age; Campbell considered the shale to be the uppermost rock of Cambrian age. Ross (1925a, p. 18) reported banded greenish-gray shale associated with quartzite of Cambrian age on a hill east of Aravaipa but believed it to underlie the quartzite; such a relation was not observed during this study, and it seems possible that the rocks referred to belong to one of several small bodies of the Martin Formation that are in fault contact with Bolsa Quartzite. According to Huddle and Dobrovolny (1952, p. 73, 75–76), green shale typically is found in the upper part of their upper member of the Martin Formation; the sections nearest to Klondyke in which the shale is found are at Superior, 50 miles to the northwest, at Gold Gulch in the Castle Dome region, about 13 miles north-northeast of Superior, and probably at Tornado Peak, 30 miles to the northwest. Ransome (1919, p. 45–46) noted 15–20 feet of yellow calcareous shale at the top of the Martin Limestone in the Ray-Globe region.

In a gulch about half a mile south-southeast of Aravaipa, limestone of the Martin is partly dolomitized. The dolomite weathers to a faint green, yellow, or cream that contrasts markedly with the light-gray of the limestone. Dolomite-limestone contacts are very sharp, and the dolomite is slightly brecciated, presumably as a result of a volume change due to dolomitization. Figure 6 is a sketch of a loose block of the Martin showing the relation of dolomite to limestone.

In the Table Mountain mine area, pale to moderate reddish-brown dolomite underlying typical Escabrosa may belong to the Martin. The rock has a fine-grained

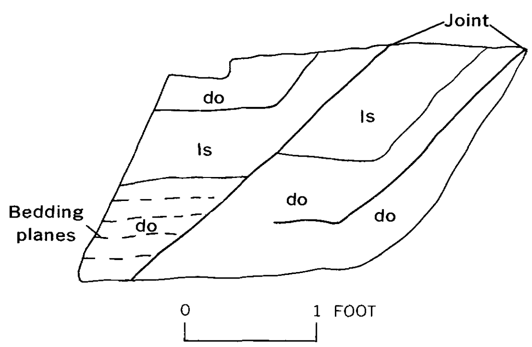


FIGURE 6.—Sketch of loose block of dolomitized limestone of the Martin Formation showing relation of dolomite to limestone (do, dolomite; ls, limestone). From outcrop area 2,500 feet south-southeast of Aravaipa.

sugary texture and consists of interlocked grains of dolomite 0.2–1 mm across.

Rocks assigned to the Martin Formation in the Copper Creek basin crop over a small area in the N½ sec. 1, T. 8 S., R. 18 E. Their base is an intrusive contact with Copper Creek Granodiorite, and they are overlain disconformably by Escabrosa Limestone. The original thickness of the Martin is not known but in the present exposures ranges from 0 to perhaps 150 feet. The lowest beds of the Martin are fine-grained siltstone or mudstone, now converted to dark hornfels. The bulk of the formation consists of cream, yellow, pale-green, purple, gray, dark-red, or pink thin-bedded impure limestone and thin clastic beds that weather out in ribs; a little red or purple shale also is interbedded with the limestone. Most of these rocks have been converted in some degree to hornfels. At one place, about 20 feet of fissile green shale lies near the top of the formation, overlain by very impure limestone.

A very small outcrop of greenish-gray shale (not shown on the geologic map) crops out in a gulch about 1,500 feet south of the old Tew Ranch. The shale may belong to the Martin Formation, inasmuch as Bolsa(?) Quartzite dipping toward the shale crops out farther up the gulch, separated from the shale by a lobe of Copper Creek Granodiorite.

The following measured sections of the Martin Formation will give some idea of the lithologic variation within the formation. Only the first is a nearly complete section, but for the most part it is poorly exposed; the second is believed to be nearly complete and is more adequately exposed.

*Section of the Martin Formation in the NE¼ sec. 31, T. 5 S., R. 20 E.*

Escabrosa Limestone.
Disconformable contact.

| Martin Formation: | *Thickness (feet)* |
|---|---|
| 1. Marl, brownish-gray and shaly | 15 |
| 2. Shale, green, marly, fissile | 35 |
| 3. Shale, green; marly at top | 15 |
| 4. Caliche-covered; probably green shale | 25 |
| 5. Shale and sandy shale, green | 5 |
| 6. Same as unit 5, some grit at top; weathering green | 5 |
| 7. Same as unit 5 | 10 |
| 8. Sandstone, rusty-brown; beds 6–12 in. thick | 5 |
| 9. Marl | 5 |
| Total thickness Martin Formation | 120 |

Fault contact; Bolsa Quartzite exposed a short distance off line of measured section.
Horse Mountain Volcanics.

*Section of Martin Formation 1,000 feet east-southeast of Aravaipa*

Escabrosa Limestone.

Limestone, mottled-gray and greenish-gray, massive- to wavy-bedded, fossiliferous. Unit 15, p. 29

Disconformable contact.

| Martin Formation: | Thickness (feet) |
|---|---|
| 1. Limestone, pink, thin-bedded, silty; 2-ft bed of massive dolomitic limestone at top. Upper few feet has scattered hematite concretions 1–2 in. across | 8 |
| 2. Marl, pink, gray, or white, thin-bedded | 36 |
| 3. Shale, maroon, fissile; passes upward into pink and gray thin-bedded marl | 14½ |
| 4. Shale, olive-green, fissile | 2 |
| 5. Poorly exposed; probably mostly variegated marl | 22 |
| 6. Marl, greenish yellow at bottom, changing to pink at top | 4½ |
| 7. Caliche-covered; no outcrop | 21 |
| 8. Marl, greenish-yellow | 5½ |
| 9. Covered; probably mostly greenish-yellow marl | 12 |
| 10. Shale, green, fissile; weathers to abundant small chips and flakes | 12 |
| Total exposed Martin Formation | 137½ |

Fault contact.

Escabrosa Limestone.

*Section of Martin Formation 2,000 feet southeast of Aravaipa*

Escabrosa Limestone.

Limestone, dark-gray, massive, fine-grained.

Disconformable contact.

| Martin Formation: | Thickness (feet) |
|---|---|
| 1. Dolomite, orange, pink, or red. Crinoid stems | 2 |
| 2. Marl, pink | 1½ |
| 3. Limestone, orange-pink, hard, silty. Iron-stained patches and hematite concretions less than 1 in. across | 1 |
| 4. Marl, pink | 13 |
| 5. Limestone, pinkish-brown, dolomitic and probably silty; forms low cliff | 2 |
| 6. Marl, pink or white | 4½ |
| 7. Marl, pink or white, thin-bedded; some harder silty limestone | 5½ |
| 8. Covered; probably at least 15 ft of pink marl overlying at least 15 ft of green fissile shale | 30 |
| Total exposed Martin Formation | 59½ |

Fault contact.

Bolsa Quartzite.

*Section of Martin Formation 2,500 feet south-southeast of Aravaipa*

Escabrosa Limestone.

Limestone, mottled-gray and greenish-gray; beds 2–6 in. thick, thin partings of slightly pinkish clastic limestone. Few crinoid stems and fragments of brachiopods.

Disconformable contact.

| Martin Formation: | Thickness (feet) |
|---|---|
| 1. Limestone, pink to red or dark-red, some pink marl. At top, 10-in. bed of fine-grained maroon limestone with abundant crinoid stems and few poorly preserved pelecypods(?) | 6½ |
| 2. Marl, pink, soft and shaly; passes upward into limestone | 5 |
| 3. Marl, pink, soft and shaly. Upper 2 ft has numerous bright-red disk-shaped calcareous concretions 1–3 in. across | 5 |
| 4. Marl, soft, pink, shaly | 3½ |
| 5. Marl, grayish-pink, fissile; soft but more resistant than overlying or underlying beds | 6½ |
| 6. Marl, variegated, dominantly pink. At base, well-bedded pinkish to pale greenish-gray marl | 7½ |
| Total exposed Martin Formation | 34 |

Fault contact.

Horse Mountain Volcanics.

*Section of Martin Formation near junction of roads to Aravaipa, Tule Spring, and Landsman Camp, center NW¼ sec. 31, T. 5 S., R. 20 E.*

Horse Mountain Volcanics.

Unconformity.

| Martin Formation: | Thickness (feet) |
|---|---|
| 1. Limestone, gray with faint pinkish cast, weathers brown | 17 |
| 2. Shale, green, fissile | 33 |
| 3. Sandstone, greenish-gray | 3 |
| 4. Marl, light-gray. Few thin beds of light-gray limestone weathering buff | 28 |
| 5. Limestone, gray, pink, or buff, marly. Few poorly preserved pelecypods | 33 |
| Total exposed Martin Formation | 114 |

Disconformable contact.

Bolsa Quartzite.

### AGE

No identifiable fossils were found in the beds assigned to the Martin Formation, but elsewhere in southeastern Arizona the Martin is known to be of Late Devonian age. A collection of corals made by C. D. Walcott from limestone near the upper Deer Creek coal field, presumably from a locality a few miles northwest of the Klondyke quadrangle, was examined by Edwin Kirk (Ross, 1925a, p. 21), who assigned them to the Martin Limestone. The stratigraphic position of the limestone from which this collection was made is not known, so that the fossils merely establish the presence of Martin Formation in a nearby area. Lithologic and stratigraphic data supporting correlation of the beds in the Klondyke quadrangle with the Martin already have been presented.

## MISSISSIPPIAN SYSTEM

### ESCABROSA LIMESTONE

The name Escabrosa Limestone was given by Ransome (1904b, p. 42) to thick-bedded limestone of Early Mississippian age in the Bisbee district. The formation has since been recognized in many places in southeastern Arizona.

The Escabrosa underlies at least 10 principal areas at and east of Aravaipa, none of which is larger than about a quarter of a square mile in extent, and it also crops out over very small areas in as many other places. In addition, a small body of highly altered fine-grained fetid crinoidal limestone southeast of Monkey Spring in the South Fork of Goodwin Canyon is assigned dubiously to the Escabrosa; this rock is now largely converted to garnet and epidote. Finally, the Escabrosa Limestone underlies nearly half a square mile at and northwest of the Table Mountain mine in sec. 15, T. 7 S., R. 18 E., and two smaller areas in the northern part of the Copper Creek basin. The total outcrop area of the Escabrosa is less than 2 square miles, or a little less than 1 percent of the quadrangle.

The Escabrosa Limestone is rather resistant to erosion and characteristically forms moderately steep slopes punctuated at intervals by low cliffs. It does not, however, seem to be as impressive a cliff former as in the Bisbee region and the Dos Cabezas and Dragoon Mountains.

Complete sections of Escabrosa Limestone are exposed on hill 5328 in the NE¼ sec. 31, T. 5 S., R. 20 E., where the calculated thickness is about 300 feet, and on the ridge northwest of Landsman Camp, in the NE¼ sec. 30, T. 5 S., R. 20 E., where the formation is calculated to be about 350 feet thick. A section believed to be nearly complete was measured in Arizona Gulch about 2,200 feet northwest of Aravaipa; at this place the Escabrosa is 381.5 feet thick. The limestone mapped as Escabrosa about three-fourths mile north of Cobre Grande Mountain appears to be somewhat thicker, but the rocks here are folded and attitudes are difficult to obtain, so that no reliable estimate of thickness is available; moreover, much of the outcrop area could not be examined owing to heavy brush, and consequently some of the limestone may be Horquilla rather than Escabrosa, although this possibility seems rather unlikely. At the Table Mountain mine, Thomssen and Barber (1958) measured 508 feet of Escabrosa Limestone; this thickness is a minimum, as the upper contact is an erosional unconformity. All other sections of Escabrosa Limestone are faulted or otherwise incomplete.

The Escabrosa Limestone rests disconformably on the Martin Formation and is overlain disconformably by the Horquilla Limestone and unconformably by the Pinkard Formation, Horse Mountain Volcanics, Galiuro Volcanics, and older alluvium. In the Copper Creek basin it is intruded by Copper Creek Granodiorite. Contacts with other formations are faults, except perhaps the contact with Goodwin Canyon Quartz Monzonite in the SE¼ sec. 21, T. 5 S., R. 20 E. This contact is shown as a fault on the geologic map because the limestone appears to be unaltered, whereas elsewhere the Horquilla Limestone intruded by quartz monzonite is widely converted to tactite; however, the Escabrosa is generally a very pure carbonate rock and alteration might consist only in marmarization, in which case its effects might easily be overlooked in the field.

The base of the Escabrosa was mapped at the base of the lowest massive gray limestone of the sequence overlying the Bolsa Quartzite. The basal beds characteristically are mottled gray and faint greenish gray. A few tens of feet, locally as much as 150 feet, of poorly exposed beds intervene between undoubted Bolsa and undoubted Escabrosa, and these beds have been assigned on the basis of lithology and stratigraphic position to the Martin Formation. (See p. 23.)

In the region around Aravaipa the Escabrosa is overlain disconformably by Horquilla Limestone. No evidence of unconformity was found, and indeed, distinction between the two limestones was based on the presence of abundant fusulinids in the Horquilla together with minor changes in lithology, rather than on any clearcut stratigraphic break between them. Nevertheless, the fact that no fossils of Early Pennsylvanian age were found suggests a hiatus between the Escabrosa and the Horquilla; a similar hiatus was noted by Gilluly (1956, p. 35–36) in central Cochise County.

At the Table Mountain mine, the Escabrosa is overlain unconformably by the lower andesite unit of the Galiuro Volcanics, and in the Copper Creek basin it is overlain unconformably by the same andesite and also by conglomerate and tuffaceous sandstone of the Pinkard(?) Formation. In both these places the uppermost part of the Escabrosa is a massive very resistant jasperoid breccia that must have formed a local stripped surface on which the younger rocks were deposited.

#### LITHOLOGY

The bulk of the Escabrosa Limestone is light to medium gray and thick to thin bedded. Thick beds of coarse-grained crinoidal limestone are conspicuous, but they constitute less than half of the formation, the rest being medium- to fine-grained or lithographic thin-bedded limestone. In the upper part of the formation, some beds have a faint pinkish cast on fresh surfaces. Chert is very scarce in the lower part of the section, and is not abundant anywhere except locally at the Table Mountain mine and in the Copper Creek basin. Dolomite is not abundant but makes up a few thin beds throughout the formation, particularly in the lower and middle parts. A thick cliff-forming bed of gray oolitic limestone caps hill 5328 in the NE. cor. sec. 31, T. 5 S., R. 20 E., and oolitic rocks are not uncommon elsewhere in the formation. Terrigenous sedimentary rocks are very scarce: a few feet of calcareous sandstone crops out just above the base of the section southeast of Aravaipa, in the NE¼ sec. 30 and the NE¼ sec. 31, T. 5 S., R. 20 E., and near the Table Mountain mine; a bed of brown orthoquartzite lies about 50 feet below the top of the formation on the ridge between Landsman Camp and Williamson Canyon; and a bed 25 feet thick of very fine grained dark-brown sandstone is intercalated near the top of the formation on the ridge just northwest of Landsman Camp.

The basal beds of the Escabrosa are rather distinctive. They are gray mottled with faint greenish gray, are 6–24 inches thick with wavy or lenticular bedding, commonly have small concretions of red hematite and flakes of red mud, may contain corals, brachiopod fragments and crinoid stems, and may be fetid. In the measured section 1,500 feet east-southeast of Aravaipa, the base of the Escabrosa is a grayish-red (5*R* 4/2) dolomitic limestone having abundant tiny fossils and fossil fragments. Microscopically, this rock consists entirely of carbonate in grains 0.2–1.0 mm across; these form an interlocking aggregate of angular anhedrons with a few scattered well-formed rhombs, presumably of dolomite.

In several places the basal limestone beds are overlain by calcareous sandstone as much as 9 feet thick. A specimen from 2,000 feet southeast of Aravaipa is a grayish-pink rock composed of quartz grains 0.05–0.5 mm across, cemented by calcite. The larger quartz grains are rounded, whereas the smaller ones are subangular. All the quartz grains are single crystals but may show wavy extinction. Overgrowths are not common. Some of the quartz grains have slightly scalloped edges, suggesting minor replacement by calcite. Part of the calcite may be detrital but much of the coarser calcite is molded around the quartz grains and, if originally clastic, has been notably recrystallized.

Field tests with dilute hydrochloric acid show that dolomitic limestone is much more abundant than dolomite, but some apparently nearly pure dolomite does occur here and there. Yellowish-gray fine-grained dolomite 35 feet above the base of the Escabrosa 2,000 feet southeast of Aravaipa is made up entirely of interlocking grains of dolomite 0.1–0.2 mm across; many of these grains are euhedral rhombs. Light-gray to faintly pink dolonite from the measured section 1,500 feet east-southeast of Aravaipa (unit 11, p. 29) is almost identical but somewhat less even textured, most grains being 0.1–0.3 mm across with a few 1 mm across.

The buff to dark-brown orthoquartzite that lies about 50 feet below the top of the Escabrosa on the ridge northwest of Landsman Camp is a very well sorted rock made up almost exclusively of angular to subrounded grains of quartz 0.6–0.8 mm across. Accessory minerals are rounded zircon, iron ore in grains 0.2–0.5 mm across, and very sparse muscovite, biotite, and blue-gray tourmaline. The cementing material is iron oxide.

The Escabrosa of the Table Mountain mine area includes very fine grained or lithographic limestone as well as the more typical light-gray coarse-grained crinoidal limestone. Along the west side of the outcrop immediately below the Galiuro Volcanics, the limestone is stained pink; the limestone here has beds 1–6 inches thick composed almost entirely of crinoid fragments, and also contains knots and thin lenses of light-gray chert. Fossils include crinoid stems as much as a centimeter in diameter, small corals, and very poorly preserved small brachiopods.

In the Table Mountain mine area and the Copper Creek basin, a massive layer of jasperoid breccia 50–100 feet thick is intercalated in the Escabrosa, and a similar jasperoid crops out half a mile west-southwest of Landsman Camp. In the Table Mountain region, the jasperoid is well exposed only along the west side of the Escabrosa outcrop, where it is as much as 100 feet thick; at the north end of the outcrop, where it is 50–60 feet thick; and near the mine, where it is 20–25 feet thick and is the principal ore-bearing rock. In the mine area the jasperoid commonly underlies the surface on which the Galiuro Volcanics were deposited. The precise stratigraphic position of the jasperoid is

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not known but is probably about 150 feet above the base of the Escabrosa along the west side of the outcrop. Inasmuch as Thomssen and Barber (1958) report no comparable rock in their measured section of more than 500 feet in the Table Mountain mine area (p. 30 this report), the jasperoid is presumed to be highly lenticular. The jasperoid is a massive nonbedded gray to white rock, locally mottled red and brown, and is made up of an unsorted jumble of angular fragments of white or gray jasperoid cemented by jasperoid, and less commonly by quartz, chrysocolla, and other oxide copper minerals. Below the massive jasperoid in the mine area, the Escabrosa is light gray and fine grained and contains abundant light-gray chert in layers or irregular stubby lenses a few inches thick; chert may constitute as much as a third of the formation. Where it contains much chert the Escabrosa is a brownish-weathering dolomitic limestone.

Limestone, metamorphosed limestone, and chert assigned to the Escabrosa Limestone underlie a small area in the Copper Creek basin in secs. 1 and 2, T. 8 S., and sec. 35, T. 7 S., both R. 18 E. The Escabrosa ranges in thickness from 0 to perhaps 200 feet and averages about 150 feet within the larger of its two main outcrop areas.

The basal part of the formation is gray to white coarse-grained limestone with some thin silty lamellae and fine-grained brown, yellow, or cream lithographic limestone. The carbonate rocks weather to various tones of pink, yellow, cream, or gray. In the upper part of the carbonate sequence are several beds of pink or purple impure limestone and one bed of bright-red limestone. A dark-gray limestone at the top of the sequence contains small spirifers, crinoid stems, and small cup corals that together with the lithologic characteristics suggest correlation with the Escabrosa.

The upper part of the Escabrosa is a layer of gray jasperoid breccia 10–20 feet thick that apparently constituted a local erosional platform on which the overlying rocks were deposited; the jasperoid, although very thin, persists along almost the entire length of the Escabrosa outcrop. It is composed entirely of various-sized angular blocks of jasperoid in a fragmental matrix of the same rock. The rock resembles the jasperoid at the top of the Escabrosa in the Table Mountain mine area, described previously.

The following sections of Escabrosa Limestone were measured; only the first is a nearly complete section.

*Section of Escabrosa Limestone on the ridge 1,500 feet west of Aravaipa*

Horquilla Limestone:
Limestone, light-gray, medium-bedded, fine-grained. Unit 16, p. 33.)

Disconformable contact.

| Escabrosa Limestone: | *Thickness (feet)* |
|---|---|
| 1. Limestone, medium-gray; beds ½ to 2 ft thick; cliff forming. Some fine-grained beds with pinkish cast. Crinoid stems, sparse lenses and nodules of pinkish-gray chert | 57 |
| 2. Similar to unit 1, but abundant nodules and lenses of pink chert, becoming less abundant toward the top. Cherty limestone is pink to pinkish gray and fine grained | 58½ |
| 3. Limestone, dark-gray, coarse-grained, crinoidal. Upper part covered | 13½ |
| 4. Dolomite, light-gray, medium-bedded, fine-grained; weathers faint buff | 9 |
| 5. Limestone, light-gray, thick-bedded, coarse-grained, crinoidal. Few nodules of pink chert | 50½ |
| 6. Mostly covered, but elsewhere resembles unit 7. Some pinkish-gray limestone | 17 |
| 7. Limestone, medium-gray, medium-to thick-bedded, fine-grained, slightly silty. Lenses of finely laminated light-gray chert as much as 10 ft long and 1 ft thick. Irregular concentrations of clastic material. Becomes light gray, coarser, less silty, and crinoidal toward top | 51 |
| 8. Mostly covered; probably mainly light-gray medium-bedded dolomitic limestone | 20 |
| 9. Limestone, gray, massive, several highly fossiliferous beds 4–6 in. thick. Collection 18156–PC. Few thin beds and lenses of light-gray, finely laminated chert | 12½ |
| 10. Limestone, dark-gray; beds 1–6 in. thick. Abundant irregular nodules of silty limestone that weather buff to dark brown and stand out in strong relief on weathered surfaces | 26 |
| 11. Limestone, light-gray, medium- and wavy-bedded, crinoidal. At top, bed of light-gray dolomitic limestone 1 ft thick | 19 |
| 12. Limestone, dark-gray, thick-bedded, fine-grained, slightly fetid. Stubby lenses of silty material a few feet long and a few inches thick. Irregularly disposed small patches of brownish clastic material. Numerous small white cup corals and crinoid stems | 18½ |
| 13. Limestone, gray, thin- and wavy- bedded, faintly laminated | 21 |
| 14. Dolomite, light-gray, fine-grained; weathers faint buff | 2½ |
| 15. Limestone, gray, thick-bedded | 6 |
| Total exposed Escabrosa Limestone | 382 |

Fault contact; base of formation believed to be within a few tens of feet of lowest exposure.
Escabrosa Limestone and Horse Mountain Volcanics.

*Section of Escabrosa Limestone 1,500 feet east-southeast of Aravaipa*

Bolsa Quartzite.
Fault contact.

| | Thickness (feet) |
|---|---|
| 1. Limestone, thick-bedded, coarse-grained, crinoidal. Top 3 ft or so is pink to gray dolomite | 19½ |
| 2. Limestone, dark-gray, massive, cliff-forming. Numerous pods of clastic material, presumably calcareous mud balls and flakes | 5½ |
| 3. Limestone; pinkish gray and medium grained at base, becoming gray and fine grained toward top. Almost devoid of bedding | 35½ |
| 4. Dolomite, dark- to light-gray, locally pinkish; weathers pink or greenish yellow | 13 |
| 5. Limestone, gray, massive. Abundant irregular concentrations of clastic material at top | 10 |
| 6. Limestone, gray, massive, cliff-forming. Small amounts of clastic material. Few coral colonies near top | 13 |
| 7. Limestone, medium-gray, medium-bedded, crinoidal | 5½ |
| 8. Mostly covered; probably pinkish-gray to gray dolomitic limestone, grading into limestone at top | 18½ |
| 9. Limestone, pinkish, coarse-grained, dolomitic; weathers pale yellowish brown | 1½ |
| 10. Covered; probably light-gray fine-grained dolomite | 11 |
| 11. Dolomite, light-gray to faintly pink, massive, medium-grained to sugary. Highly crinoidal; bedding revealed by layers of crinoid fragments | 17½ |
| 12. Dolomite and dolomitic limestone, light-gray to gray or faintly pink, thin- to medium-bedded, coarse-grained, highly crinoidal | 8 |
| 13. Covered | 9½ |
| 14. Limestone, light-gray, thin-bedded, very sandy; weathers nearly white | 8 |
| 15. Limestone, mottled-gray and greenish-gray, massive- to wavy-bedded, fossiliferous. Abundant hematite concretions in lower 4 ft. Basal 1 ft is grayish-red, highly fossiliferous dolomitic limestone | 8½ |
| Total exposed Escabrosa Limestone | 184½ |

Disconformable contact.
Martin Formation:
Unit 1, p. 25.

*Section of Escabrosa Limestone southeast of Tule Spring, SW cor sec. 32, T. 5 S., R. 20 E.*

Horquilla Limestone:
Limestone, medium-gray; beds 6–18 in. thick; fine grained, crinoidal. Distinctive red to maroon irregular layers and patches of impure limestone that weather into pronounced relief. No fusulinids, but such lithology through a thickness of more than 25 ft strongly suggests that these beds belong to the Horquilla.

Disconformable contact.
Escabrosa Limestone:

| | Thickness (feet) |
|---|---|
| 1. Limestone; gray with pinkish cast; thick-bedded. Sparse chert. Poor outcrops | 10½ |
| 2. Covered; probably thick-bedded light-gray limestone; similar to unit 3 | 31½ |
| 3. Limestone, light-gray, thick-bedded | 9½ |
| 4. Limestone; gray with pink tinge; thick-bedded. Few nodules of pink chert or jasper near top | 7½ |
| 5. Limestone; gray with faint pink tinge, weathering very light gray; thick bedded with fine laminations; fine-grained. Thin intraformational conglomerate and a little white chert at top | 7 |
| 6. Limestone; light-gray with numerous dark-gray blotches 1–2 mm across; very thick bedded. Scattered small irregular nodules that may have been corals. Few fossil mollusks in fine-grained layer 9 ft above base | 14 |
| 7. Limestone, light-gray; beds 1–4 ft thick, mostly fine grained, but some coarse-grained beds | 26 |
| 8. Limestone, light-gray to pink; weathers light gray; thick bedded and medium grained at base, grading upward into medium and wavy bedded and fine grained at top. Knots and wavy beds of red chert in upper part. Many small fossils at base | 16 |
| 9. Limestone, dark-gray, coarse-grained | 3 |
| 10. Limestone, pinkish-gray or light-gray, massive and thick-bedded, medium-grained | 18 |
| 11. Limestone, light-gray; beds 6–18 in. thick; medium-grained. Irregular lenses of dark-gray chert as much as 1 ft thick. Sparse knots of white chert | 5 |
| 12. Conglomerate; angular to subrounded fragments of black, red, and gray chert mostly less than 3 cm across, in matrix of limestone. Thin layers of wavy-bedded and crossbedded gray limestone | 5 |
| Total exposed Escabrosa Limestone | 153 |

Caliche-covered slope.
Fault contact.
Bolsa Quartzite.

*Section of Escabrosa Limestone along the west side of Virgus Canyon*

[Quoted from Thomssen and Barber (1958)]

| Escabrosa Limestone: | *Thickness (feet)* |
|---|---|
| 1. Dolomite, grayish-pink, fine-grained, few thin reddish chert lenses; top covered | 46 |
| 2. Limestone, light-gray, coarse-grained, fossiliferous; beds 1 to 2 ft thick. *Pentremites elongatus* and two other species of *Pentremites*(?) found near middle | 80 |
| 3. Limestone, gray, fine- to medium-grained, fossiliferous; abundant 1 to 8 in. pinkish chert lenses; beds a few to 18 in. thick | 127 |
| 4. Limestone, gray, medium-grained, fossiliferous; few small calcite and quartz geodes near base, cliff-forming | 36 |
| 5. Dolomite, tan to pink, fine-grained, weathering to smooth surface; contains coral and crinoid fragments, many quartz geodes up to 2 in.; few thin, reddish chert lenses, white nodules; beds 1 to 3 ft thick; limestone lens 0 to 5 ft thick near top of unit. Small lenses of limestone composed chiefly of *Homalophyllum*(?) sp. locally along contact between this unit and unit 6 | 85 |
| 6. Dolomite, tan to gray, medium-grained, weathering to rough, pitted surface; contains crinoid fragments, few quartz geodes up to 2 in.; beds 1 to 3 ft thick; top bed weathers to splotchy brown and gray | 90 |
| 7. Quartzite [coarse calcareous sandstone], pink to tan; crossbedded in 1 to 2 ft beds; subrounded grains cemented by [sparse] calcite, quartz; top 6 in. fossiliferous, including tooth of *Psephodus* [a sharklike fish] | 9 |
| 8. Dolomite, dark-tan, medium-grained, weathering to rough, pitted surface; contains crinoid fragments, few quartz geodes up to 3 in. Similar to unit 6 | 19 |
| 9. Dolomite, buff to tan with pinkish cast, medium-grained, weathering to smooth surface; contains 1 to 5 in. quartz geodes, thin chert lenses, crinoid fragments; beds 1 to 2 ft thick; base covered | 16 |
| Total exposed Escabrosa limestone | 508 |
| Covered (mostly thin-bedded reddish shale and some red dolomite of Martin limestone, few feet of tan Escabrosa dolomite at top) | 30 |

Martin limestone

Dolomite, reddish, fine-grained, fossiliferous; beds 1 to 6 in. thick interbedded with reddish shale 1 to 2 in. thick; few quartz geodes up to 2 in.; top and base covered.

### ALTERATION OF ESCABROSA LIMESTONE

North and northeast of Landsman Camp, the Escabrosa Limestone has been converted to tactite over an irregular area 2,000 feet long and as much as 1,500 feet wide. The alteration does not seem to be controlled by faults, fractures, or favorable beds, and no pattern of alteration was recognized. The principal rocks are garnetite and epidotite, but masses of specularite, locally copper stained, also have formed. The garnetite is a yellowish-green to yellowish-brown rock that weathers dark brown. It has numerous small vugs lined with tiny garnet crystals. Aside from a few quartz veinlets, the rock consists entirely of birefringent twinned garnet in grains 0.05–0.5 mm across. The refractive index of this garnet is $1.880 \pm 0.005$ and indicates a variety very high in andradite (Winchell and Winchell, 1951, p. 485).

The epidotite is composed almost exclusively of euhedral prisms of strongly pleochroic epidote 0.1–0.5 mm long in a matrix of calcite. A little iron ore is the only accessory mineral. The refractive index $\beta$ of the epidote is about $1.76 \pm 0.005$, indicating about 35 percent or a near-maximum amount of the iron end member of the clinozoisite-epidote series (Winchell and Winchell, 1951, p. 449).

At several places the Escabrosa has been replaced by pods, lenses, or irregular masses of coarsely crystalline johannsenite. This mineral was seen at the Black Hole prospect northwest of Aravaipa, near the inclined shaft of the No. 1 mine just southwest of Aravaipa, and along the Cobre Grande trail northeast of Landsman Camp, to mention only a few localities. Near the Cobre Grande trail, several sill-like bodies of johannsenite replace Escabrosa Limestone within a stratigraphic thickness of about 100 feet. The "sills" may be several feet thick and are composed entirely of radiating aggregates of johannsenite weathered superficially to black.

### AGE

Fossils collected from two localities in the Escabrosa Limestone were examined by J. T. Dutro, Jr., of the U.S. Geological Survey, who reports (written commun., 1961) as follows:

Collection 18156–PC (from unit 9 of stratigraphic section, p. 28):

*Zaphrentites*? sp.
Small horn coral, indet.
*Lyroporella*? sp.
*Cystodictya*? sp.
*Rhipidomella*? sp.
*Orthotetes*? aff. *O. keokuk* Hall
*Chonetes* aff. *C. loganensis* Hall and Whitfield
"*Productella*" sp.
Productoid brachiopod, indet.
*Spirifer* cf. *S. forbesi* Norwood and Pratten
sp.
*Platyceras* (*Platyceras*) sp.
*Straparollus* (*Euomphalus*) cf. *S.* (*E.*) *subplanus* (Hall)

Collection 17987–PC (from near top of formation, below fusulinid-bearing beds of the Horquilla Limestone, 400 ft southeast of BM 4563 at Aravaipa, center sec. 36 (unsurveyed), T. 5 S., R. 19 E):

- Echinoderm debris, indet.
- *Rhipidomella* sp.
- *Chonetes* sp.
- *Echinoconchus* sp.
- *Ovatia*? sp.
- Buxtonid brachiopod, indet.
- Dictyoclostid brachiopod, indet.
- *Spirifer* aff. *S. leidyi* Norwood and Pratten
- *Crurithyris* sp.
- Subulitacean gastropod, indet.
- Molluscan fragments, indet.
- Phillipsid trilobite, indet.

On collection 18156–PC, Dutro comments as follows:

> This * * * collection * * * contains a fossil assemblage of Early Mississippian (Osage) age. The species are similar to those found in the uppermost part of McKee's member B of the Redwall limestone of the Grand Canyon area. The abundance of large, alate spiriferoid brachiopods is a regionally distinctive feature at this level in the Mississippian of Arizona and New Mexico. This assemblage has been fairly definitely correlated with early Osage faunas from the mid-continent region.

Dutro discusses collection 17987–PC as follows:

> This is probably an early Upper Mississippian assemblage and, therefore, could come from high in the Escabrosa or, perhaps, represent a Black Prince equivalent.

The following invertebrate fossils were identified in collections from the Table Mountain mine area by Prof. Halsey Miller, of the University of Arizona (Thomssen and Barber, 1958):

- *Platycrinus*? sp.
- *Homalophyllum*? sp.
- *Pentremites elongatus*
- *Pentremites*? sp.
- Crinoid columnals and calyxes
- Corals
- Brachiopods
- Gastropods

*Pentremites elongatus* is of Early Mississippian (Osage) age. The extinct sharklike fish *Psephodus* (unit 7, p. 30) occurs in Carboniferous and Lower Permian rocks in North America. Thomssen and Barber conclude that the Table Mountain mine section represents the lower part of the Escabrosa Limestone.

The Escabrosa Limestone as mapped in the Klondyke quadrangle thus includes beds ranging in age from Early Mississippian to early Late Mississippian and may include beds equivalent to parts of the Paradise Formation (Hernon, 1935) and the Black Prince Limestone (Gilluly and others 1954, p. 13–15).

## PENNSYLVANIAN SYSTEM

### HORQUILLA LIMESTONE

The name Naco Limestone was applied by Ransome (1904b, p. 44–46) to limestone of Pennsylvanian age overlying the Escabrosa Limestone in the Bisbee district. As a result of later work, the Naco Limestone of central Cochise County was divided into six formations and was designated Naco Group (Gilluly and others, 1954, p. 16). In the Klondyke quadrangle, only the lowest of these formations, the Horquilla Limestone, is present.

The Horquilla Limestone underlies about a dozen areas in the E½ T. 5 S., R. 19 E., and the W½ T. 5 S., R. 20 E., none of which is as much as half a square mile in extent. The largest outcrop area is between Williamson and Tule Canyons north of Landsman Camp, and the other principal outcrops are at and just west of Aravaipa, immediately east of Tule Spring, and at the head of the Middle Fork of Goodwin Canyon. The total area underlain by Horquilla Limestone is somewhat less than 1.5 square miles, or about 0.5 percent of the quadrangle.

No good sections of Horquilla Limestone are available for detailed stratigraphic measurement, as in all the outcrop areas the formation is either folded and faulted or is incomplete. The most amenable section is that exposed along Arizona Gulch and its contiguous ridges west of Aravaipa, where a section 406 feet thick was measured. The sections east of Williamson Canyon and east of Tule Spring appear to be about the same thickness. A section 347 feet thick was measured northeast of Landsman Camp; the total thickness may well be greater but the upper part of the section is too folded to permit measurement.

The Horquilla Limestone rests disconformably on Escabrosa Limestone; the nature of the contact was mentioned in the discussion of the Escabrosa. The Horquilla is overlain unconformably by Pinkard Formation, Horse Mountain Volcanics, and older alluvium, and is intruded by Goodwin Canyon Quartz Monzonite at the head of the Middle Fork of Goodwin Canyon. Contacts with all other formations are faults.

#### LITHOLOGY

The Horquilla Limestone consists principally of gray or light-gray thin- to thick-bedded fine grained limestone and of scattered coarser grained beds. Throughout the section most of the beds have a pinkish tinge on fresh surfaces. Chert is not abundant except locally. The base of the Horquilla was placed in mapping immediately below a sequence of medium- to thin-bedded limestone, which contains abundant knots of orange-red to pink chert, thinly laminated white to cream-colored cherty limestone, or pink siliceous clastic material irregularly disposed throughout (fig. 7). Within this sequence or immediately above it, fusulinids are abundant, and in absence of the pinkish limestone, the fusulinid-bearing beds were taken to mark the contact between Horquilla and Escabrosa Limestones. At the Horquilla-Escabrosa contact in the NE¼ sec. 31, T. 5 S., R. 20 E., the Horquilla seems to be lighter colored and finer grained than the Escabrosa, but these differences are not sufficiently great to be of much use in mapping. Fossils are much more abundant in the Horquilla, or at least seem to be, inasmuch as many of the Horquilla fossils are pink or coral colored, whereas those of the Escabrosa are nearly the same color as the enclosing rocks. Almost identical beds of coarse crinoidal limestone occur in both formations.

FIGURE 7.—Specimen of Horquilla Limestone from base of section west of Aravaipa, showing clastic material (light gray) irregularly disposed in limestone (dark gray). Specimen is 9 inches high.

The bulk of the Horquilla is limestone, but the formation has small amounts of other rocks. For example, the top of the Horquilla on the hill east of Tule Spring consists of 4–5 feet of calcareous grit overlain by 5 feet of gray massive coarse-grained sugary dolomite having a rough weathered surface. The grit is composed of rounded to subangular grains of quartz, calcite, and red chert 1–3 mm across, set in a matrix of limestone. Thin beds containing angular pebbles of limestone are interlayered with the grit. In the narrow outcrop immediately east of Aravaipa, the Horquilla contains a little intraformational conglomerate and marl, and a bed of calcareous sandstone 5 feet thick. This sandstone consists of grains 0.2–0.5 mm across of quartz and sparse chert cemented by calcite. Quartz grains originally were rounded but now are interlocked by prominent overgrowths of quartz in optical continuity with the parent grain. Some of the calcite is fine grained and may represent clastic grains, but most is coarse and obviously is cementing material. The rock is estimated to contain about 60 percent quartz and 40 percent calcite. Southwest of the Iron Cap mine the Horquilla contains a few beds as much as 15 feet thick of light buff thin-bedded fine-grained sandstone or siltstone that weather dark brown or brownish black.

The following section of Horquilla Limestone was measured on the ridge due west of Aravaipa; this section may be as thick as any in the quadrangle, and is the only reasonably complete one not greatly disturbed by faulting or folding. The section is a continuation of the measured section of Escabrosa Limestone on page 28.

*Section of Horquilla Limestone on the ridge 2,000 feet west of Aravaipa*

Horse Mountain Volcanics.
Angular unconformity.
Horquilla Limestone:

| | *Thickness (feet)* |
|---|---|
| 1. Limestone, light-gray, thick-bedded, fine-grained, fossiliferous. Lenses and nodules of gray chert as much as 10 in. thick. Beds as much as 10 ft thick. Some coarse-grained crinoidal limestone | 80 |
| 2. Covered | 30 |
| 3. Limestone, gray, medium-bedded, coarse-grained | 7½ |

*Section of Horquilla Limestone on the ridge 2,000 feet west of Aravaipa*—Continued

| Horquilla Limestone—Continued | Thickness (feet) |
|---|---|
| 4. Limestone, pinkish-brown, fine-grained, probably slightly dolomitic; weathers conspicuously mottled pink and gray. Some beds nearly maroon. Abundant fragments of fossils. Bed of calcareous grit at top | 6 |
| 5. Limestone, gray or pinkish-gray, thin-bedded, fine-grained; weathers light gray. Abundant poorly preserved spirifers | 20½ |
| 6. Limestone, gray, medium-bedded, coarse-grained; becomes light gray toward top. Very abundant fragments of fossils at base; white crinoid stems and brown spirifers | 13 |
| 7. Limestone, gray, thick-bedded, fine-grained. Sparse chert. Abundant tiny fragments of white crinoid stems; at top, abundant poorly preserved pink to cream-colored brachiopods 5–10 mm across | 40½ |
| 8. Limestone, dark-gray to pinkish-gray, thin-bedded, fine-grained; becomes lighter colored toward top; weathers light gray to gray. Sparse lenses of gray chert in lower part; abundant chert nodules in upper 25 ft, weathering brown or rusty brown. Abundant fragments of white or pink crinoid stems | 51½ |
| 9. Limestone, gray; bright-red mottling near base; thick-bedded, fine-grained. Few chert concretions near base; weathers buff to brown; becomes more cherty toward top. Thin bed with abundant large cup corals (as much as 6 in. long, 2 in. in diameter) 16 ft above base | 23 |
| 10. Limestone, gray to pinkish-gray, thick-bedded. Abundant tiny fragments of white crinoid stems; few fragments of pink brachiopods | 9½ |
| 11. Limestone, light-gray, thin-bedded. Abundant cream-colored to buff clastic material that when weathered resembles chert | 8 |
| 12. Limestone, light-gray, thick-bedded. Irregular knots of white, rusty-weathering chert at top. Abundant fusulinids, few brachiopods and cup corals | 9 |
| 13. Limestone, light-gray, thick-bedded; mottled red near top. Pink silicic clastic material in lower part | 31 |
| 14. Poorly exposed; mostly gray limestone with red mottling | 25 |
| 15. Limestone, gray; contains as much as 50 percent red, pink, or rusty-colored silicic clastic material | 24 |
| 16. Limestone, light-gray, medium-bedded (less than 1 ft thick), fine-grained; lenses and knots of irregularly disposed pink silicic clastic material. Abundant fragments of pink crinoid stems and brachiopods, few fusulinids. Conspicuous gray and pink or cream mottling on bedding surfaces | 27½ |
| Total exposed Horquilla Limestone | 406 |

Disconformable contact.

Escabrosa Limestone:

Limestone, medium-gray, thick-bedded, cliff-forming; some fine-grained beds with pinkish cast. Unit 1, page 28.

*Section of Horquilla Limestone on ridge 4,000 ft northeast of Landsman Camp, across line between secs. 20 and 29, T. 5 S., R. 20 E.*

Top of measured section; further measurement not feasible owing to structural complications.

| Horquilla Limestone: | Thickness (feet) |
|---|---|
| 1. Limestone; medium gray with faint pinkish cast; coarse grained, massive. Some limestone breccia | 26 |
| 2. Limestone, medium-gray, fine-grained, massive; weathers light gray. Irregular rounded nodules of gray chert, weathers black | 21 |
| 3. Dolomitic limestone, medium-gray, fine-grained; weathers light buff. Very abundant gray cup corals in upper 6 in | 3 |
| 4. Limestone, medium-gray, medium-grained, crinoidal; lenses of black chert as much as 6 in. thick | 19 |
| 5. Limestone, light-gray, medium-grained, medium-bedded; weathers light gray. Locally cliff forming. Grades upward into fine-grained limestone. Sparse nodules of light-gray chert in lower part, more abundant in upper part | 58 |
| 6. Limestone, dark-gray, fine-grained, thick-bedded, resistant; weathers light gray. Sparse gray chert; weathers black. Few fossils 20 ft below top | 60 |
| 7. Limestone, light-gray, coarse-grained, massive, crinoidal; weathers gray. Very sparse lenses of black chert in lower part, becoming more abundant toward top | 47 |
| 8. Limestone, light-gray, medium-grained; small irregular knots of calcareous clastic material weathering black to gray. Upper part resembles intraformational conglomerate, with irregular rounded blocks of limestone 1–6 in. across enclosed in sparse matrix of clastic limestone | 3 |
| 9. Limestone, light-gray, fine-grained, thin-bedded; abundant fine-grained greenish-gray silty material | 10 |
| 10. Limestone, dark-gray, fine- to medium-grained; beds 1–6 in. thick; weathers light gray. Contains a few beds 1–3 in. thick of black-weathering limestone. Some beds of clastic limestone that weather brown | 20 |
| 11. Poorly exposed; includes medium-gray fine-grained massive limestone, dark-gray medium-grained limestone, wisps and irregular small nodules of gray chert that weathers black | 42 |
| 12. Same as unit 9 | 8 |
| 13. Mostly covered, probably limestone. Basal 2 ft medium-gray medium-grained massive limestone with fusulinids and scarce fragments of brachiopods | 15 |
| 14. Same as unit 9. Basal 1 ft has abundant crinoid columnals and fragments of white brachiopods | 15 |
| Total measured Horquilla Limestone | 347 |

Disconformable contact.

Escabrosa Limestone:

Limestone, medium-gray, fine-grained, wavy-bedded; beds 6 in. to 2 ft thick; weathers light gray to greenish gray. Irregular knots of white to gray chert.

#### ALTERATION OF HORQUILLA LIMESTONE

In several places the Horquilla has been converted to garnetite, epidotite, or garnet-epidote tactite, or has been replaced by small pods or lenses of johannsenite. Most of these silicate masses are not closely related spatially to intrusive rocks, and the source of the added material is even more problematical than usual.

A large mass of Horquilla (and Escabrosa?) Limestone at the head of the Middle Fork of Goodwin Canyon has been changed to greenish-yellow fine-grained dense garnetite. The alteration is presumably due to emanations from the Goodwin Canyon Quartz Monzonite, which is in contact with the garnetite along its north and southeast sides. Only tiny remnants of limestone are preserved in the garnetite, but one of these yielded fusulinids identified tentatively by R. C. Douglass, of the U.S. Geological Survey, as "a primitive form of *Triticites* of the kind found in the Missourian series of the mid-continent. This would place them in the upper part of the Horquilla formation or lowermost part of the Earp formation" (Gilluly and others, 1954, p. 16–23). The garnet is moderately birefringent and has a refractive index of 1.880 ± 0.005, indicating a very high proportion of andradite (Winchell and Winchell, 1951, p. 485).

At the Lead King mine in Stowe Gulch (center north edge sec. 6, T. 6 S., R. 20 E.) Horquilla Limestone is replaced by small amounts of coarsely crystalline johannsenite.

#### AGE

Collections of fossils from three localities in the Horquilla Limestone were examined by J. T. Dutro, Jr., who reports (written commun., 1961) as follows:

Collection 17985–PC (from limestone remnant in large mass of tactite NE¼ NE¼ sec. 20, T. 5 S., R. 20 E.):

Echinoderm debris, indet.
*Fenestella* sp.
*Penniretepora* sp.
Branching bryozoans, indet.
*Spirifer* aff. *S. rockymontanus* Marcou
*Composita* sp.
*Phricodothyris*? sp.
*Dielasma*? sp.

Collection 17986–PC (base(?) of formation, just southwest of hill 5328, NE¼ sec. 31, T. 5 S., R. 20 E.):

algae, undet.
*Tetrataxis* sp.
*Millerella* sp.
*Fusulinella* sp.
Horn coral, indet.
Echinoderm debris, indet.
*Rhombopora* sp.
*Fenestella* sp.
*Prismopora* sp.
*Mesolobus* cf. *M. striatus* (Weller and McGehee)
*Echinoconchus semipunctatus* (Shepard)
*Linoproductus* cf. *L. prattenianus* (Norwood and Pratten)
*Juresania* cf. *J. nebrascensis* (Owen)
*Antiquatonia* cf. *A. coloradoensis* (Girty)
*Antiquatonia* sp.
*Spirifer* cf. *S. occidentalis* Girty
sp.
*Composita* cf. *C. subtilita* Hall
*Phricodothyris* cf. *P. perplexa* (McChesney)
Pectenoid pelecypods, undet.
Bellerophontacean gastropods, undet.
Bone fragments, indet.

Collection 17988–PC (approximately 400 feet above the base of the formation in Arizona Gulch, NE¼ sec. 35 (unsurveyed), T. 5 S., R. 19 E.):

*Syringopora* cf. *S. multattenuata* McChesney
*Caninia* (s.l.) sp.
*Chaetetes* cf. *C. milleporaceous* Milne-Edwards and Haime
Large crinoid stem, indet.
Echinoid spines, indet.
*Tabulipora* sp.
"*Marginifera*" sp.
*Antiquatonia* cf. *A. coloradoensis* (Girty)
*Spirifer* cf. *S. occidentalis* Girty
cf. *S. rockymontanus* Marcou
*Composita subtilita* (Hall)
*Phricodothyris*? sp.
*Dielasma*? sp.

Dutro discusses these collections as follows:

*Collection 17985–PC.*—All this material is badly altered. Of the bryozoans Helen Duncan states: "On an objective basis, about all one can say is that the assemblage is post-Ordovician Paleozoic. From what we know of bryozoan distribution in the Paleozoic rocks in the southwest, the beds are probably Upper Paleozoic." The brachiopods appear to be of Pennsylvanian aspect, as reported from the Horquilla limestone elsewhere.

*Collection 17986–PC.*—This varied assemblage is definitely of Middle Pennsylvanian age (probably early Des Moines) and represents beds low in the Horquilla as described in central Cochise County (Gilluly and others, 1954, p. 32–33; collections from lower 200 feet).

*Collection 17988–PC.*—The *Syringopora* is a species that ranges from the Middle Pennsylvanian into the lower Permian. *Chaetetes milleporaceous* is a common fossil in the Middle Pennsylvanian and is generally considered to be a guide to rocks of that age. The brachiopods are species described from the lower part of the Horquilla formation (Gilluly and others, 1954, p. 32–33). The assemblage doubtless represents lower Horquilla equivalents.

The Horquilla Limestone in the Klondyke quadrangle thus appears to be entirely or almost entirely of Middle Pennsylvanian age.

## CRETACEOUS SYSTEM

### PINKARD FORMATION

The Pinkard Formation was named by Lindgren (1905a, p. 73) after Pinkard Gulch, 2 miles west of Morenci, which is about 55 miles east-northeast of Klondyke. Ross (1925a, p. 28) did not use the name in his description of the Upper Cretaceous sedimentary rocks of the Aravaipa and Stanley districts because "* * * of the great distance of the Aravaipa-Stanley region from known outcrops of the Pinkard formation, the large amount of volcanic material in the beds of this region, and other lithologic differences * * *." However, the amount of volcanic material in this formation as mapped in the Klondyke quadrangle is negligible, the rocks are rather similar lithologically to those at Morenci, and the fossil evidence at least suggests correlation, so that use of the same name would seem to be permissible.

The Pinkard Formation crops out mainly along Old Deer Creek, in the upper Middle Fork of Goodwin Canyon, and to the east of the Iron Cap mine in T. 5 S., R. 20 E. The north side of the ridge west of the Iron Cap mine is in part a dip slope on a thin layer of Pinkard Formation dipping about 25° N. Two other small areas of rocks tentatively correlated with the Pinkard Formation are in secs. 1, 2, and 12, T. 8 S., R. 18 E., in the Copper Creek basin. The total area underlain by Pinkard Formation is only about 1.5 square miles, or less than 1 percent of the quadrangle.

The base of the Pinkard Formation is exposed only along the valley and ridge east of the Iron Cap mine, mainly along the south edge of sec. 20, T. 5 S., R. 20 E., where the formation rests unconformably on folded Horquilla Limestone, and in the Copper Creek area, where the formation overlies unconformably Escabrosa Limestone. Elsewhere the formation is in fault contact with older rocks or is intruded by Goodwin Canyon Quartz Monzonite or Copper Creek Granodiorite. The Pinkard is overlain disconformably by Williamson Canyon Volcanics and unconformably by Galiuro Volcanics.

No good section of the Pinkard Formation was found in the Klondyke quadrangle. The formation, like the overlying Williamson Canyon Volcanics, is much disrupted by faults, and exposure for the most part are poor, so that only very unreliable estimates of thickness can be made. The best apparently unfaulted partial section is on the ridges just east of the Princess Pat mine in sec. 13 (unsurveyed), T. 5 S., R. 19 E., where at least 900 feet of beds is exposed. A thickness of 900–1,000 feet was estimated along a north-trending section in the center of the S½ sec. 20, T. 5 S., R. 20 E. Campbell (1904, p. 246) estimates the thickness of Cretaceous sedimentary rocks in the Deer Creek basin at 400 to 500 feet, and Ross (1925a, p. 27) estimates the average thickness of sedimentary material at 500 feet or more, and notes (p. 26) that the thickness on the northeast side of Rawhide Mountain, north of the Klondyke quadrangle and 3 to 4 miles northwest of Lone Cedar Mesa, may be more than 700 feet.

#### LITHOLOGY

Very little time was devoted to study of the Pinkard Formation, and only a brief description of the rocks will be given.

The Pinkard Formation is made up of a variety of gray, dark-gray, olive or brown fine- to medium-grained clastic sedimentary rocks and very subordinate conglomerate and calcareous sandstone. The principal rock types are lithic graywacke, feldspathic sandstone and quartzite, and dark siltstone and shale.

The basal part of the section on the high ridge east of the Iron Cap mine consists mainly of olive to brown, dirty sandstone, feldspathic quartzite, and greenish-gray to dark-gray or black shale and finely layered siltstone. Conglomerate made up of pebbles of chert and quartzite less than an inch across is a minor component. In thin section, a nondescript rather fine grained grayish-olive rock consists of angular to subrounded grains of quartz 0.1–0.3 mm across, scattered grains of chert, muscovite, and chloritized mafic minerals, and sparse biotite, iron ore, zircon, apatite, tourmaline, and sphene. No plagioclase feldspar was recognized, and staining with sodium cobaltinitrite revealed no potassium feldspar. The matrix is a yellowish-brown very fine grained aggregate of moderate birefringence and low refractive index ($<1.54$), possibly a clay; much of the matrix may originally have been shale fragments, but some has no discernible fragmental texture and probably was a fine mud. The rock is a lithic graywacke but is peculiar in its apparent total lack of feldspar.

The upper part of the section east of the Princess Pat mine is composed of greenish-brown massive and somewhat tuffaceous quartz-rich sandstone, and olive-colored massive siltstone and sandy siltstone that weather to tiny fragments. In the first canyon east of the mine, the formation includes hard white orthoquartzite and a bed 10 feet or so thick of red pebble conglomerate composed of rounded to subrounded pebbles of red or white quartzite and red or gray chert in a matrix of red impure quartz sand. Farther east, just north of the center of sec. 18, T. 5 S., R. 20 E., the section includes fine-grained olive-colored sandstone, black shale having a blocky fracture, and light-gray fine-grained calcareous sandstone.

On the knob shown by closed contour 5450 near the west center edge of sec. 17, T. 5 S., R. 20 E., the top of the section is massive well-bedded very light gray to white quartzite 20 feet thick, overlying brown blocky shale. These rocks strike northwest and dip

30°–40° SW. Microscopically, the quartzite consists of grains of quartz 0.1–0.5 mm across, most of them in the range 0.2–0.4 mm. The quartz grains are interlocked, but contacts are only slightly sutured; some grains have inclusion-crowded cores and clear quartz overgrowths. They are cemented by a material of low refractive index that is shown by staining with sodium cobaltinitrite to be a potassium mineral, probably feldspar; the presence of potassium feldspar was suggested but not unequivocally confirmed by X-ray study. Perhaps 15–20 percent of the rock is cement. The most satisfactory name for this rock is orthoquartzite, but in view of the large amount of feldspar cement the name feldspathic quartzite or protoquartzite might also be applied.

Rocks exposed at the north edge of the quadrangle along the ridge near the east side of sec. 17, T. 5 S., R. 20 E., are well-bedded grayish-olive siltstone and pale-olive to dusky-yellow sandstone; these rocks weather to reddish or brownish hues much darker than the fresh rock. In thin section, the sandstone is made up of angular to subangular grains of quartz and chert that range from 0.1 mm to 0.6 mm across but are mostly in the range 0.2–0.3 mm. The rock is estimated to contain about 40 percent quartz and 20 percent chert; the remainder is cement, largely epidote. Blue tourmaline is a scarce detrital mineral. Quartz grains have irregular scalloped overgrowths that accentuate the original irregularities. Some grains are clear, whereas others have lines of minute inclusions. Although much of the chert is clearly detrital, a considerable amount is interstitial to quartz grains and molded around them, indicating that it formed subsequent to sedimentation. The epidote may have formed by recrystallization of an aggregate of calcite, clay, and iron oxide.

A thin section of siltstone from the same locality reveals angular grains of quartz 0.03–0.12 mm across, enclosed in a very fine grained pale-yellow matrix that appears to consist mainly of chloritic shale. Blue tourmaline and euhedral zircon are sparse accessory minerals. Quartz grains have overgrowths of quartz in optical continuity with the parent grain. The rock is cut by veinlets of a pale-green chlorite of very low birefringence and negative optic sign, perhaps daphnite or aphrosiderite.

Conglomerate crops out in at least two places near the center of sec. 20, T. 5 S., R. 20 E. Near the saddle 800 feet south of the center of sec. 20, the conglomerate consists of angular fragments of light-gray to black chert an inch or less across, in a sandy matrix of quartz and detrital chert.

At the edge of the quadrangle, in sec. 17, T. 5 S., R. 20 E., the Pinkard Formation is intruded by Goodwin Canyon Quartz Monzonite and converted to hornfels; the contact crosses the Goodwin Canyon jeep road about 900 feet southeast of the divide between the Middle Fork of Goodwin Canyon and Old Deer Creek.

A mass of light-olive garnetite south of Old Deer Creek and on the line between secs. 17 and 18, T. 5 S., R. 20 E., is probably derived from Pinkard Formation, as no remnants of limestone were found, and bedding where preserved is suggestive of shale rather than of limestone. The rock consists entirely of sugary to fine-grained dense weakly birefringent garnet with a refractive index of about 1.865, indicating a variety having a high proportion of the andradite molecule (Winchell and Winchell, 1951, p. 485).

A small area in upper Copper Creek basin northeast of the Bluebird mine is underlain by almost flat-lying clastic sedimentary rocks correlated tentatively with the Pinkard Formation. These rocks unconformably overlie Escabrosa Limestone and are overlain with apparent conformity by the lower andesite unit of the Galiuro Volcanics. The most easterly outcrops are of light-gray altered and chalky crystal tuff, red interbedded grit, conglomerate, and breccia containing fragments of quartzite, and at the top, about 25 feet of breccia composed of fragments of quartzite, chert, and quartz in a ferruginous matrix. Over most of the area, however, the sequence is made up of a very poorly sorted basal conglomerate 10–15 feet thick overlain successively by 40–50 feet of greenish-gray fine- to coarse-grained hard tuffaceous sandstone, apparently with some shale in the lower part, and by thin interbedded grit and cobble or pebble quartzite conglomerate. These rocks rarely crop out and for the most part erode to gentle slopes lying between the resistant Escabrosa Limestone and the Galiuro Volcanics. The basal conglomerate is made up of rounded to subangular boulders as much as 3 feet across of gray quartzite and subordinate chert in a matrix of coarse quartz sand. Locally the matrix is a very dark, almost black, material that contrasts strikingly with the gray boulders. In places the conglomerate fills channels cut in jasperoid breccia of the Escabrosa Limestone. The sandstone weathers brown and contains abundant blackish patches that probably are plant remains. The upper grit beds are made up of quartz, feldspar, and rock fragments.

Several small outcrops of clastic sedimentary rocks in sec. 12, T. 8 S., R. 18 E., are correlated with the Pinkard(?) Formation on the very tenuous basis of lithology. The largest outcrop, south of Copper Creek and just southwest of the old Tew Ranch, consists of hard massive white vitreous orthoquartzite in the lower part, overlain by gray wavy-bedded orthoquartzite, light-gray thin-bedded sandstone having white noncarbonate cement, a biotitic arkosic sandstone, and a little tuffaceous sandstone or tuff at the top of the exposed section. These beds weather brown. They lie either flat or dip gently northeast. The presence of arkosic sandstone and tuffaceous rocks suggests correlation with the Pinkard(?) Formation rather than the Bolsa Quartzite. In other outcrops, the rocks range in lithology from vitreous orthoquartzite to red arkosic sandstone and white pebbly grit; the beds are from 1 inch to 1 foot thick.

#### AGE

A small molluscan-coral fauna was collected by S. C. Creasey, of the U.S. Geological Survey, from a calcareous sandstone bed 12–18 inches thick that crosses the road to the glory hole of the Iron Cap mine in the SE¼SE¼ sec. 19, T. 5 S., R. 20 E. This fauna was reported on by John B. Reeside, Jr., of the U.S. Geological Survey as follows:

USGS lot 26368 [report MD-56-89]:
- *Cladophyllia?* sp.
- "*Arca*" (*Breviarca*) aff. *B. depressa* (White)
- *Ostrea* sp., fragments
- *Plicatula* sp.
- *Lucina?* sp.
- *Dosiniopsis* n. sp.
- *Corbula* sp.

A supplementary collection from the same locality made by D. B. Brooks and me was examined by W. A. Cobban, of the U.S. Geological Survey, who reports as follows:

This collection is chiefly composed of *Dosiniopsis* n. sp. and "*Arca*" (*Breviarca*) aff. *B. depressa* (White). All species noted are the same as those listed by Reeside in MD-56-89.

Another collection by Creasey from near the base of the formation on the crest of a ridge in the SW¼SE¼ sec. 20 was reported on by Reeside as follows:

USGS lot 26367:
- *Haplostiche texana* (Conrad)?
- *Cardium?* sp.
- *Tellina?* sp.

Reeside comments as follows on the two collections studied by him:

* * * Lot 26367 has not yielded much information and I have not assigned it definitely. A single mold of a large foraminifer suggests *Haplostiche texana* (Conrad) which would be of Washita age comparable to that of the Sarten sandstone of New Mexico. However, a single mold is not reliable and the species usually is abundant, if present at all.

Lots 26368 and 26369 [the latter locality is not in Klondyke quadrangle] contain the same faunal assemblage, and in my judgment C. P. Ross' published lot [Ross, 1925a, p. 27] belong to the same assemblage.

In the two new lots "*Arca*" (*Breviarca*) aff. *B. depressa* (White) is Stanton's *Trigonarca* sp. and *Dosiniopsis* n. sp. is Stanton's *Callista* (*Dosiniopsis?*) n. sp. These are the abundant forms in all three lots.

Certain species are lacking here that are found in all the lots collected farther north and considered distinctive of Colorado age; likewise really distinctive forms for a Washita age are also lacking. Nothing in lots 26368 and 26369 would warrant a distinction between late Early Cretaceous (Washita) and early Late Cretaceous (Colorado), but the forms in Ross' lot 11235 called by Stanton *Glauconia coalvillensis* (Meek), now called *Cassiope coalvillensis*, and *Exogyra laeviuscula* Roemer seem to be correctly identified and are widespread in the Colorado group. I would accept them as indicating an early Colorado age for the whole fossil assemblage.

Fossils collected by Lindgren from a calcareous sandstone of the Pinkard Formation 2.5 miles south-southwest of Morenci were reported on by T. W. Stanton as follows (Lindgren, 1905a, p. 74):

- *Mactra* sp. related to *M. warrenana* M. & H.
- *Corbula* sp.
- *Cardium* sp.
- *Astarte?* sp.
- *Cyrena?* sp.
- *Turritella* sp.
- *Dentalium* sp.
- *Glauconia coalvillensis* Meek
- *Pugnellus fusiformis* Meek

The last two species are characteristic forms of the Colorado group, which elsewhere are known only in the upper part of the Fort Benton formation and its equivalents.

Fossils collected by Ross in Garden Gulch in the Stanley region about 5 miles northwest of lot 26368 of this report were determined by Stanton as follows (Ross, 1925a, p. 27):

- *Exogyra* sp. related to *E. laeviuscula* Roemer
- *Trigonarca* sp. related to and possibly identical with *T. depressa* (White).
- *Callista* (*Dosiniopsis?*) n. sp.
- *Glauconia coalvillensis* (Meek)
- *Turritella* sp.
- Undetermined gastropods belonging to one or two other genera.

These fossils belong to an Upper Cretaceous fauna of Colorado group age found in the lower part of the Mancos shale in northwestern New Mexico and southeastern Utah. Arizona collections representing about the same horizon have been received from the vicinity of Morenci * * *

There seems to be little doubt that the Pinkard Formation of the Morenci region and the rocks in Garden Gulch northwest of Stanley Mountain are of about the same age; inasmuch as Ross shows these rocks to extend without break from Garden Gulch southeastward into the Klondyke quadrangle, the equivalent age of the Klondyke rocks also appears to be established, even though no fossils distinctive of Colorado Group age have been found in them to date.

## MESOZOIC AND CENOZOIC ERAS

### GLORY HOLE VOLCANICS

A thick nearly flat-lying sequence of volcanic and metavolcanic rocks that crops out in the southwest corner of the quadrangle northwest of Copper Creek is here named Glory Hole Volcanics, after the Glory Hole mine in the S½ sec. 3, T. 8 S., R. 18 E. These rocks occupy an area of slightly more than 3 square miles, or a little more than 1 percent of the quadrangle.

The base of the formation is exposed at only one place (N½ sec. 2, T. 8 S., R. 18 E.), and the total thickness is not known. A section about 1,500 feet thick is exposed on the south flank of the Galiuro Mountains northwest of Copper Creek in secs. 34 and 35, T. 7 S., and secs. 2 and 3, T. 8 S., both R. 18 E., and at least 700 feet of volcanic rocks is exposed in Dry Camp Canyon at the west edge of the quadrangle. The rocks for the most part are inclined at less than 10°, although locally the dip may attain 15° to 20°.

The Glory Hole Volcanics are overlain by the Galiuro Volcanics along a contact that lies at altitudes of from 4,950 feet at the head of Dry Camp Canyon to 5,100 feet at the west edge of the quadrangle and 5,350 feet at its most southeasterly point and that attains a maximum altitude of 5,650 feet near the center east edge of sec. 34. The contact appears to be conformable, or at most disconformable, at its southeast end and also at places in Dry Camp Canyon, whereas elsewhere, such as at the west edge of the quadrangle or on the high ridge between Dry Camp Canyon and Copper Creek, it is unconformable. The local apparently conformable nature of this contact is unexpected in view of the fact that the Glory Hole Volcanics are older than, and are intruded by, Copper Creek Granodiorite, whereas the Galiuro Volcanics are younger than the granodiorite and rest unconformably on it; the contact must represent time sufficient to have permitted the unroofing of the Copper Creek pluton in addition to an unknown but presumably appreciable amount of erosion of the pluton itself.

#### LITHOLOGY

The Glory Hole Volcanics comprise a rather drab and heterogeneous group of tuffs, welded tuffs, breccias, lavas, and flow breccias probably dominantly of andesitic or dacitic composition. Pyroclastic rocks are much more abundant than lavas or flow breccias, particularly in the lower part of the section. Colors are mostly light to medium gray, brown, grayish purple, or purple. Although a few layers are resistant enough to be cliff formers, the formation in general is less resistant than the overlying Galiuro Volcanics and forms steep slopes only where protected by the younger rocks. In general the formation seems to be poor in mafic minerals; a little altered biotite and hornblende(?) were recognized in thin sections, and one flow of hornblende andesite crops out in Dry Camp Canyon, but in most rocks the mafic constituents are very scarce and are so completely altered that identification is impossible.

The section of Glory Hole Volcanics exposed on the long ridge in the E½ sec. 34, T. 7 S., and sec. 3, T. 8 S., both R. 18 E., is nearly 1,500 feet thick and is made up generally of a lower dominantly pyroclastic section and an upper section dominantly of lavas and flow breccias. A suite of specimens collected along this ridge comprises the following rocks, in ascending stratigraphic order:

1. Rhyodacite or quartz latite(?) welded tuff. A red-purple (5*RP* 3/2) rather coarsely fragmental rock having euhedral crystals of plagioclase feldspar as much as 5 mm across and sparse slightly smaller rounded grains of quartz, together with abundant fragments of various dark-colored rocks and light-colored pumice(?) as much as a centimeter across, set in a dense stony matrix. In thin section, the plagioclase grains are sericitized and seem to be about $An_{20-30}$ in composition. Mafic material includes a little biotite and many indeterminate aggregates of alteration products having rims of iron oxide. Lithic fragments are of biotite-quartz granulite and quartz-muscovite schist, both presumably derived from the Pinal Schist. Fragments thought to have been pumice are completely devitrified and are almost indistinguishable from the matrix; some are partly replaced by carbonate. The matrix is also completely devitrified to an aggregate somewhat finer-grained than that making up the former pumice fragments. Bent and flattened shards are still visible in plain light. Ramifying veinlets of carbonate and quartz cut the rock. Staining with sodium cobaltinitrite shows that potassium minerals are abundant in the matrix. In the field this rock has the dense tough aspect characteristic of hornfels, and was believed to have been mildly metamorphosed by Copper Creek Granodiorite, which crops out half a mile south and east; however, the only corroboratory microscopic evidence is the very fine-grained granular appearance of the devitrification products, which in unmetamorphosed rocks are commonly poorly defined and show a patchy birefringence.
2. Light- to greenish-gray solidly welded dacite(?) tuff or breccia, having millimeter-size grains of plagioclase feldspar, quartz, and altered biotite(?),

and dark-colored lithic fragments as much as a centimeter across. The matrix, as well as some greenish lenticular fragments that possibly were pumice, is completely devitrified, and no fragmental texture is visible in hand specimen. This rock is typical of a section of tuff and breccia about 600 feet thick, between altitudes 4,400 and 5,000 feet.

3. Pale red-purple rhyodacite or quartz latite(?) welded tuff, uppermost part of the section described in (2) above. Millimeter-size grains of plagioclase feldspar, iron ore, and sparse quartz, abundant angular fragments of medium- to dark-gray volcanic rock, and numerous white to rusty-colored flattened pumice lapilli are set in a pale-red prominently layered stony matrix. Under the microscope the fragmental nature of the matrix is seen to be clearly preserved. Shards are flattened and bent around coarse components and are only partly devitrified. Pumice lapilli are partly flattened and are more devitrified than the matrix. In addition to crystals of sericitized plagioclase feldspar ($An_{0-10}$) and fragments of quartz, there are sparse subhedral aggregates of chlorite having narrow rims of solid black iron oxide, whose cross section suggests that they probably are completely altered hornblende. Iron ore grains are mainly in the accidental fragments. Staining with sodium cobaltinitrite shows appreciable amounts of potassium minerals in the matrix.

4. Coarse-grained massive cliff-forming tuff or breccia having abundant lapilli of grayish-green pumice and less abundant whitish lithic fragments enclosed in a pale-red vitric-crystal matrix. Altitude about 5,100 feet. In thin section, the matrix consists of very fine grained dusty devitrified glass, apparently containing a high proportion of quartz. The only crystal components are grains of highly sericitic plagioclase feldspar ($An_{0-10}$) and clots 1–2 mm across of epidote and carbonate; some of these clots replace feldspar, whereas other curved or irregular aggregates appear to have replaced pumice. Some of the pumice fragments contain plagioclase feldspar microlites. The lithic fragments are sericitic pilotaxitic volcanic rock. Staining with sodium cobaltinitrite reveals only small amounts of potassium minerals in the matrix. The rock probably is within the range rhyodacite-dacite. Half a mile farther east this rock is represented by a grayish-pink somewhat more crystal-rich cliff-forming vitric lapilli tuff. This tuff attains a maximum thickness of perhaps 150–200 feet and wedges out to the east below the Galiuro Volcanics. It is partly welded, and the brown pumice lapilli are notably flattened. In thin section, crystals or fragments 0.5–1.5 mm across of altered plagioclase feldspar ($An_{30-35}$) and sparse quartz, apatite, and bleached biotite, together with pumice lapilli and a few lithic fragments are embedded in a very fine grained aggregate of granular thoroughly devitrified glass. The groundmass shards are visible in reflected light, and some are very dusty and show up also in transmitted light. Pumice lapilli are vaguely outlined and are almost indistinguishable from the matrix. Lithic fragments are of quartz-muscovite schist undoubtedly derived from the Pinal Schist. Plagioclase grains are altered to sericite and epidote, and epidote also forms rosettes as much as 0.5 mm across in the matrix. Staining with sodium cobaltinitrite shows that the fine-grained matrix contains an appreciable proportion of potassium minerals. This rock seems to be a rhyodacite, or possibly a quartz latite.

5. Massive greenish-gray flow breccias, about 300 feet thick. At an altitude of 5,250 feet this flow breccia is cut by a pale yellowish-brown very fine grained vertical dike 15–20 feet wide that strikes N. 55° E. and has a very restricted strike length.

6. Yellowish-gray to white cliff-forming fine-grained vitric quartz latite(?) tuff about 20 feet thick. Altitude 5,400 feet. This rock consists almost entirely of very fine grained patchily devitrified glass and some darker dusty and less devitrified areas. Quartz is an abundant devitrification product. There are a few feldspar microlites less than 0.1 mm long, most and probably all of which are plagioclase. Although no potassium mineral was recognized, as much as 25–50 percent of the slide is stained yellow by sodium cobaltinitrite.

7. Medium-gray andesite(?) lava flow breccia, contains sparse phenocrysts of pinkish plagioclase feldspar, approximately 100 feet thick. The microscope reveals a few phenocrysts of plagioclase feldspar 0.5–2 mm long set in a pilotaxitic groundmass of sericitic plagioclase laths (about $An_{20}$?) 0.1–0.3 mm long, iron oxide granules, and very fine grained colorless interstitial material, probably devitrified glass together with a very little potassium mineral revealed by sodium cobaltinitrite stain. The feldspar phenocrysts are thoroughly altered to epidote and sericite and appear to be in the compositional range $An_{10-0}$; some aggregates of epidote probably are pseudomorphs after feldspar.

At the top of the section in Dry Camp Canyon, in the center of the SE¼ sec. 27, T. 7 S., R. 18 E., is a grayish-red (10*R* 4/2) well-bedded hard vitric-lithic dacite(?) welded tuff-breccia containing abundant rock fragments and phenocrysts of quartz and feldspar set in a dense stony groundmass of devitrified glass shards and pumice fragments. A crude columnar jointing is discernible. The top of this bed is a surface of erosion beneath the Galiuro Volcanics. In thin section, millimeter-size subhedral crystals and fragments of dusty sericitic plagioclase feldspar ($An_{20-30}$) and sparse quartz, as well as fragments of volcanic rock, quartz-muscovite schist, and devitrified pumice, are enclosed in a very fine grained fragmental matrix of brownish to yellowish devitrified glass having a refractive index less than 1.54. Shards are bent and crushed and only faintly visible. Pumice fragments contain small feldspar phenocrysts and numerous tiny pods of quartz that may be fillings of former bubbles. The composition of this tuff presumably is somewhere near dacite. Beneath the tuff, and extending to the bottom of the canyon some 300 feet below, are light-gray breccias made up of angular to subrounded fragments 0.5–10 cm across of red, gray, or purple volcanic rocks in a fine-grained matrix of whitish devitrified glass.

The easternmost outcrops at the head of Dry Camp Canyon are a breccia made up of fragments several centimeters across of light-gray fine-grained platy silicic lava in a fine-grained gray stony matrix. Farther west along the canyon the rocks are dominantly light colored—light gray to yellowish brown—tuffs, breccias, and welded tuffs, usually containing phenocrysts of plagioclase feldspar and commonly containing sparse quartz grains also. However, there is at least one flow of greenish-gray hornblende andesite similar to that of the Williamson Canyon Volcanics; the rock has prisms of fresh hornblende as much as 5 mm long and smaller grains of greenish altered plagioclase feldspar.

To the northwest, on the 5,100-foot nose in the center of the SW¼ sec. 27, the top of the formation is a white to yellowish-gray thin-bedded partly welded vitric tuff containing only a few lithic fragments.

On the top of hill 5170, in the NW¼ sec. 34, T. 7 S., R. 18 E., the formation includes thick-bedded silicic breccia having very fine grained porous and glassy matrix. Breccia fragments average less than an inch across, but some are as large as 8–10 inches across. In the canyon to the west the rocks are converted to dark dense hornfels near a small body of gray Copper Creek Granodiorite; phenocrysts are still visible in the hornfels. At the junction of this gully and Dry Camp Canyon, however, the rocks are only slightly altered; they include nondescript light-gray to light-violet fine-grained porphyritic volcanics, possibly tuffs, and sheared porphyritic andesite flow breccia containing abundant irregular pods of epidote. The shears trend about N. 30° E. and dip 50° SE.

#### ALTERATION OF GLORY HOLE VOLCANICS

Over an area approximately coincident with the rock shown as hornfels on the geologic map, the Glory Hole Volcanics, and the small bodies of Copper Creek Granodiorite that intrude them, are cut by a series of fractures along many of which are narrow zones of bleaching and alteration. Most of the fractures trend within 20° of east. These alteration zones are conspicuously lighter in color than their host rocks and at first glance resemble silicic dikes. They range in width from a few inches to 15 feet, but generally are 1–3 feet wide. The longest is perhaps 1,000 feet, but most can be traced only a few hundred feet. The bleached zones curve, split, and join each other to produce an anastomosing outcrop pattern.

The rocks along the canyon in the southwest corner of the quadrangle have been bleached extensively at intervals between the mouth of the canyon and the line between secs. 10 and 3, T. 8 S., R. 18 E. Some areas of bleaching are several hundred feet wide along the canyon bottom. Farther north, the alteration zones are more widely spaced and are narrow, and at less than a thousand feet north from the same section line, the volcanic rocks are practically unaltered.

The bleached zones extend to uneven distances from their parent fractures, and at their outer edges show gradational contacts with the darker hornfels. Some bleached rock forms irregular lenses having abrupt terminations. All stages of bleaching are shown ranging from incipient, in which dark lenses, squares, or triangles of parent rock are left between a network of narrow bleached fractures, to complete, in which no dark rock is left. The texture of the host rock may be preserved vaguely, or alteration may be so intense that no original texture survives.

The bleached rock of the alteration zones is made up mostly of fine-grained quartz and sericite. Pyrite is disseminated along some of the zones, and jarosite presumably derived from pyrite forms conspicuous yellow spots in a few. Some of the sericite is in grains visible with a hand lens, but most is in microscopic scales only 0.01–0.02 mm across. Quartz is somewhat coarser, but the largest grains are generally less than 0.2 mm across.

Along several alteration zones, and also associated with several breccia pipes (see p. 27), are small bodies of brownish porphyritic rock that does not closely resemble Copper Creek Granodiorite; these rocks are so altered that their nature is uncertain, but they appear to be about biotite-hornblende quartz monzonite in composition.

No clear relation of alteration zones to breccia pipes is evident; some of the zones lead into breccias, whereas others are isolated simple zones of bleached rock. Nevertheless, the alteration is so similar to that which affects rocks of the breccia pipes (see p. 128) that both may plausibly be attributed to the same agencies.

#### AGE

The age of the Glory Hole Volcanics is uncertain and is considered here as Mesozoic and Cenozoic. They are intruded and metamorphosed by the Copper Creek Granodiorite, biotite from which has been dated by the potassium-argon method at 68 million years (see p. 56), and are considerably older than the Galiuro Volcanics, which have not been dated accurately but may be of Miocene age. Some of the lava flows of the Glory Hole Volcanics are lithologically similar to lavas of the Williamson Canyon Volcanics, which are thought to be possibly of Late(?) Cretaceous or Tertiary age; but the bulk of the formation does not resemble very closely the Williamson Canyon, and there is no compelling evidence for correlation of the two formations on the basis of lithology. The Glory Hole Volcanics are probably younger than the clastic sedimentary rocks northeast of the Bluebird mine, which have been assigned on the basis of lithology to the Cretaceous Pinkard Formation, although they are known only to be of post-Mississippian age.

Gilluly (1956, p. 68–70) describes quartz keratophyre tuffs from near South Pass in the Dragoon Mountains and assigned them to the Cretaceous(?), suggesting that they may be of pre-Bisbee (Early Cretaceous-Comanche) age; these rocks seem to be very similar to the lower part of the Glory Hole Volcanics. Comparison of the Bronco Volcanics (Cretaceous or early Tertiary) of the Tombstone region (Gilluly, 1956, p. 87–90) and the Glory Hole Volcanics does not strongly suggest correlation of these two formations. Cooper and Silver (1964) also describe similar rocks from Walnut Gap in the Dragoon quadrangle to the south, where they underlie unconformably rocks of the Bisbee Group, and Cooper and Silver believe these rocks to be of Triassic or Jurassic age; this age is also possible for the Glory Hole rocks.

### BUFORD CANYON FORMATION

A sequence of sedimentary and volcanic rocks that crop out in three places in the northeast part of T. 7 S., R. 20 E., is here named Buford Canyon Formation, after Buford Canyon where they are best exposed. These rocks occupy an area of about a square mile, or about 0.4 percent of the quadrangle, in Buford Canyon and in the south and middle branches of Klondyke Wash, northeast of the Silver Coin mine. The formation is divided on the basis of lithology into a lower conglomerate member and an upper volcanic member.

The thickness of the conglomerate member was not measured precisely in the field; however, it is at least 700 feet thick in Buford Canyon and ranges from 200 to 600 feet thick in Klondyke Wash. Throughout its area of outcrop the conglomerate member, or volcanic rocks intercalated in it, rests with marked angular unconformity on Pinal Schist. It is overlain either conformably by the volcanic member or unconformably by older alluvium.

No accurate measurement of the thickness of the volcanic member was made, but it seems to be at least 1,500 feet thick in both Buford Canyon and Klondyke Wash. The top of the volcanic sequence is not exposed at any place, and the member is everywhere overlain with pronounced angular unconformity by older alluvium.

The Buford Canyon Formation trends northwest, and beds dip from 30°–65° SW in the region northeast of the Silver Coin mine to 45°–80° SW in Buford Canyon.

#### LITHOLOGY

##### CONGLOMERATE MEMBER

The conglomerate member of the Buford Canyon Formation is a poorly sorted, fairly well bedded, and moderately indurated conglomerate or breccia made up almost entirely of fragments of Pinal Schist. The fragments range in size from sand to boulders as much as 3–4 feet across, and are generally angular. The predominant rock types are white to light-gray vein quartz and greenish-gray muscovite-chlorite-quartz schist. Less abundant rocks include pink or red granite and granite gneiss; gray to brown quartzite, some of which resembles Bolsa Quartzite and some of which is a coarse-grained highly vitreous rock probably derived from quartzite layers in the Pinal; and porphyritic andesitic or basaltic volcanic rocks. Fragments of volcanic and granitic rock, and grains and granules of quartz and pink feldspar derived from granite, are more abundant in the upper layers of the conglomerate. Interlayered with the conglomerate at several horizons are andesitic or basaltic lava flows and flow breccias, as well as pyroclastic rocks more silicic in composition. The member has an overall greenish-red cast, owing to the abundance of fragments of green schist and to the ubiquitous coatings of iron oxide on the fragments.

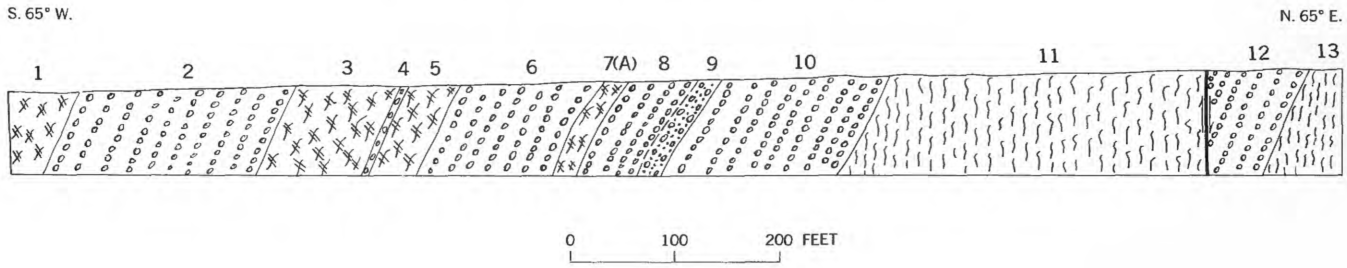


FIGURE 8.—Generalized geologic section showing relations of Buford Canyon Formation and Pinal Schist along Buford Canyon in sec. 14 (unsurveyed), T. 7 S., R. 20 E. Line of section trends N. 65° E. (A) is location of rock described in text. 1, Volcanic member of the Buford Canyon. 2–10, Conglomerate member of the Buford Canyon: 2, conglomerate; 3, purple, red, or dull green scoriaceous lava and flow breccia; prominent joint set strikes N. 20° E., dips 60° E. 4, conglomerate; 5, amygdaloidal volcanics; 6, conglomerate; more varied lithology than basal beds; contains abundant pink granite; 7, coarse-grained olivine basalt; 8, conglomerate; angular to subangular pebbles and cobbles of quartzite and quartz in matrix of schist fragments; 9, red grit and pebble conglomerate; angular fragments of quartzite and Pinal Schist; 10, coarse-grained conglomerate, boulders as much as 18 inches across; mostly schist, white quartz, and gneiss of Pinal Schist. 11, Pinal Schist. 12, conglomerate member of the Buford Canyon. 13, Pinal Schist.

A somewhat generalized section of the conglomerate member and associated rocks as exposed along Buford Canyon is shown on figure 8, and the basal beds of the member are shown on figure 9.

A very dusky red-purple coarse-grained olivine basalt is intercalated in the conglomerate at the place marked (A) in the section, figure 8. This rock as seen under the microscope is made up principally of altered plagioclase feldspar in grains as much as a millimeter long, interstitial very pale green clinopyroxene, in part ophitic, and considerable 0.2–1 mm euhedral grains of altered olivine. Interstitial to the other minerals are abundant devitrified glass and iron ore. Feldspar is much altered to sericite, pyroxene is partly replaced by carbonate and chlorite, and olivine is completely converted to aggregates of serpentine and iron ore.

The lower part of the conglomerate near the northwest corner of the outcrop in secs. 2 and 3 contains considerable tuff. The base of the member is a

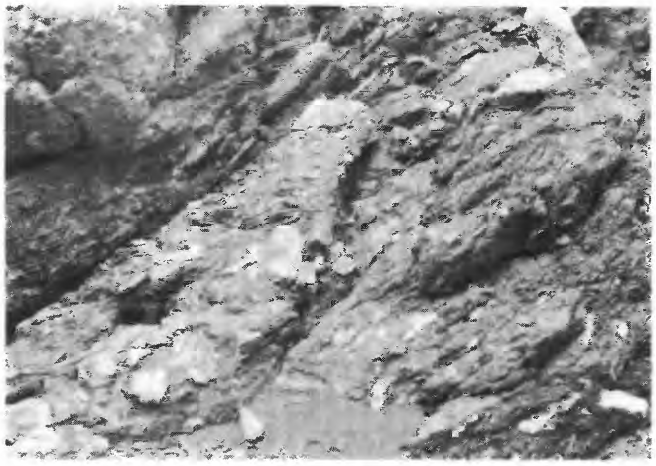

FIGURE 9.—Basal beds of the conglomerate member of the Buford Canyon Formation in sec. 14, T. 7 S., R. 20 E., looking N. 35° W. The quartzite cobble at the center is 8 inches in longest dimension. White fragments are largely vein quartz, and the bulk of the dark material is muscovite-chlorite-quartz schist.

lenticular bed 115–120 feet in maximum thickness of very dusky red-purple hard vitric crystal quartz latite tuff containing abundant millimeter-size flecks of epidote. A second lenticular bed of similar tuff 85–90 feet thick lies 75 feet higher in the section. In thin section, a specimen from this upper bed consists of anhedral crystals 0.5–1.5 mm across of sericitized and argillized oligoclase ($An_{25\text{-}30}$), perthitic sanidine, and quartz, in a matrix of patchily devitrified somewhat welded glass shards. Accessory minerals include epidote replacing feldspar, iron ore, chlorite, and scarce zircon and apatite.

In the center of the SW¼ sec. 2 (unsurveyed) T. 7 S., R. 20 E., the conglomerate member has a thin lenticular layer of tuff at the base. At one place the section consists, from bottom to top, of 25 feet of light-gray soft rhyodacite(?) crystal-lithic tuff and 30 feet of very dusky red purple hard-welded crystal-vitric biotite dacite(?) tuff, overlain by coarse-grained reddish-gray conglomerate containing subrounded to rounded boulders of volcanic rock, granite, and quartzite as much as 3–4 feet across. The rhyodacite tuff consists of angular to subrounded grains 0.5–2 mm across of quartz, calcic oligoclase, completely bleached and dusty biotite(?), and quartz muscovite schist, and minor potassium feldspar, iron ore, sphene, apatite, and epidote, in a very fine grained groundmass of slightly devitrified volcanic ash. About half the rock consists of crystals. The dacite tuff is made up of subhedral to anhedral or broken grains of oligoclase-andesine as much as 2.5 mm long, smaller grains of bleached biotite, and a little quartz, iron ore, and sphene, in a fragmental and thoroughly welded groundmass of devitrified glass shards.

Farther southeast, in the NE¼ sec. 11 (unsurveyed), the conglomerate has a few feet of light-gray silicic tuff at the base and a lens of light-gray biotite latite tuff 50–150 feet above the base; this lens is as much as 40–50 feet thick and has an outcrop length of nearly half a mile.

#### VOLCANIC MEMBER

Rocks of the volcanic member are predominantly dark—gray, greenish gray, red, or purple—fine-grained or sparsely porphyritic vesicular or amygdaloidal basalt or andesite flows and flow breccias. Pyroclastic units, some of which are as silicic as rhyodacite, are very subordinate. All the rocks appear to be altered to a considerable extent, and many are characterized by abundant amygdules and veinlets of epidote. Some flows have scoriaceous tops.

A typical representative is a grayish red-purple to very dusky red purple dense fine-grained flow breccia with abundant dark-red flecks of altered olivine. Microscopically the rock contains euhedral phenocrysts 0.5–1.5 mm across of olivine in a trachytic groundmass of oligoclase microlites 0.15–0.2 mm long, iron oxide dust, pyroxene granules, a little brown biotite, and abundant devitrified glass. The olivine is completely altered to iron oxide, serpentine, carbonate, and "bowlingite," and feldspar microlites are partly altered to carbonate.

A very similar-appearing rock from the top of the section in the gulch southeast of the Silver Coin mine is a very dusky red purple dense lava containing sparse feldspar phenocrysts 1–4 mm across. Under the microscope this rock is seen to contain euhedral sanidine grains, some prismatic aggregates of opaque material 0.5–1 mm long that probably were pyroxene, and sparse plagioclase feldspar in a groundmass of very dusty partly devitrified glass having a refractive index less than 1.54. Quartz forms veinlets in the groundmass. The rock is presumably a latite or trachyte.

A rock from about 500 feet above the base of the member in the south branch of Klondyke Wash above the Silver Coin mine is a medium-gray very fine-grained lava having a faint pinkish cast, in which only sparse small grains of feldspar can be recognized in hand specimen. In thin section, the rock consists almost entirely of a trachytic mass of sericitized and saussuritized plagioclase feldspar, mostly in grains 0.1 mm or less across. Scattered through the rock are globular clusters of opaque material that conceivably could have been olivine, as well as a few small crystals of clinopyroxene. Accessory minerals include epidote in narrow veinlets and small ellipsoidal pods, and iron ore. This rock is too altered to be named satisfactorily, but it might have been an olivine basalt.

#### AGE

The age of the Buford Canyon Formation is not known with even the accuracy of a geologic era. The formation rests on the early Precambrian Pinal Schist, is faulted against Horse Mountain Volcanics at one place in Klondyke Wash, is overlain by older alluvium of Pliocene or Pleistocene age, and appears to be unfossiliferous. Presumably it is of Mesozoic and Cenozoic age, since no similar rocks are found in the Paleozoic sequence anywhere in southeastern Arizona. Correlations of the conglomerate member with the conglomerate at the base of the Horse Mountain Volcanics, and correspondingly, of the volcanic member with the Horse Mountain Volcanics, certainly suggest themselves, but seem rather unlikely for the following reasons:

1. The conglomerate member of the Buford Canyon consists almost entirely of Precambrian rocks and rests directly on Pinal Schist, whereas the basal conglomerate of the Horse Mountain Volcanics contains fragments of younger rocks, particularly limestone, and rests on Paleozoic and Mesozoic rocks.
2. The conglomerate member of the Buford Canyon contains interstratified lava flows and pyroclastic rocks, whereas the conglomerate of the Horse Mountain does not.
3. The Buford Canyon Formation generally dips more steeply than 35°, commonly 55°–60°, whereas the beds of the Horse Mountain, except in the vicinity of Horse Mountain itself, commonly dip less than 35°.
4. The volcanic rocks of the Buford Canyon Formation are dominantly andesitic or basaltic and seem to be much more altered than the Horse Mountain Volcanics, which are dominantly silicic. Furthermore, they do not include the coarse porphyritic ("turkey-track"; see p. 50) andesite that commonly is at or near the base of the Horse Mountain Volcanics.

Similar considerations apply to a possible correlation between the Buford Canyon Formation and the Galiuro Volcanics. The lower andesite unit of the Galiuro Volcanics resembles to some extent the volcanic member of the Buford Canyon, but rocks of the latter are much more altered, dip much more steeply, and are associated with thick conglomerates, which are lacking in the Galiuro Volcanics.

The Buford Canyon Formation is cut by the Quartz Hill fault (p. 106), which in turn appears to end against Santa Teresa Granite. In addition, the Buford Canyon Formation is cut by several dikes probably consanguineous with the granite. The for-

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mation therefore is very likely older than the Santa Teresa Granite.

Ross (1925a) groups the Buford Canyon rocks with the volcanic rocks of Stanley Butte, north of the Klondyke quadrangle (the Horse Mountain volcanics of this report, in part), and suggests a possible Miocene age. I believe, on the admittedly very tenuous grounds outlined above, that the Buford Canyon rocks are older than either the Horse Mountain Volcanics or the Galiuro Volcanics.

No lithologic or stratigraphic basis could be established for correlating the Buford Canyon rocks with the Williamson Canyon Volcanics, which crop out 10 miles north-northwest; the latter are predominantly nondescript massive and practically featureless andesitic agglomerates, tuffs, and flow breccias that do not resemble in any way the volcanic rocks of the Buford Canyon Formation. However, it seems at least possible that the two sequences are approximately the same age.

## CRETACEOUS OR TERTIARY SYSTEMS

### WILLIAMSON CANYON VOLCANICS

A sequence of rather nondescript andesitic[2] or dacitic volcanic rocks crops out northeast of Horse Ridge and along the divide between Williamson Canyon and Old Deer Creek. These rocks are here named Williamson Canyon Volcanics. They occupy an area of less than 2 square miles, or less than 1 percent of the quadrangle.

The Williamson Canyon Volcanics are in general massive and practically devoid of flow layering or bedding, so that attitudes commonly are difficult or impossible to measure and the thickness of the formation is not known accurately. The base of the formation is well exposed in Old Deer Creek about 2,000 feet east of the Princess Pat mine (NW¼ sec. 13 (unsurveyed), T. 5 S., R. 19 E.) where it dips about 45° S. The dip seems to be nearly the same for about 1,500 feet to the south. If the dip is assumed to be uniform between the base of the formation and the base of the Horse Mountain Volcanics on Horse Ridge, then the thickness of the Williamson Canyon Volcanics at this locality would be about 2,500 feet. Farther east, the base of the formation is not well exposed but appears to range in dip from 20° to 50° S. and SW.; outcrop widths across the strike are more than half a mile, but exposures are so poor and reliable attitudes so scarce that no estimate of thickness was feasible. It seems likely, however, that the formation is at least 2,500 feet thick, and it might be as much as 3,000 feet thick. Campbell (1904, p. 246–247) reports that possibly as much as 1,000 feet of andesite overlies Cretaceous sedimentary rocks in the Deer Creek coal basin northwest of the Klondyke quadrangle. Ross (1925a, p. 26–27) does not give any specific figure for the thickness of Cretaceous volcanic rocks but implies that perhaps as much as 1,000 feet of volcanics is present in the Aravaipa-Stanley region. Courtright (1958) reports that about 2,000 feet of clastic breccia and conglomerate overlies Upper Cretaceous sedimentary rocks 2 miles southeast of Stanley.

Wherever the base is exposed or its depositional character can be surmised, the Williamson Canyon Volcanics overlie the Pinkard Formation. The contact exposed just north of the quadrangle boundary, in the gulch along which the road from U.S. Highway 60 to the Princess Pat mine enters Old Deer Creek, appears disconformable. The base of the volcanics is a conglomerate 10–12 feet thick and made up of rounded to subrounded boulders as much as 18 inches across of red, gray, or white quartzite and subordinate gabbro, red granite, and Horquilla Limestone in a well-indurated matrix of coarse-grained tuff-breccia. The conglomerate dips about 25° N., and overlies a thick gray quartzite of the Pinkard Formation. A second outcrop of conglomerate 200 feet farther south is probably the same bed repeated by either a fault or a fold; the exposures are inadequate to permit a choice between these alternatives. Similar conglomerate appears in the south wall of Old Deer Creek opposite the mouth of this gulch, where it dips 35° W. and rests on gray quartzite, and about 4,000 feet farther east in Old Deer Creek, where it consists of rounded boulders as much as 18 inches across of quartzite, granitoid rocks, Horquilla Limestone, and gneiss in a matrix of gray tuff.

North of the trail junction in the center of the N½ sec. 20, T. 5 S., R. 20 E., boulders of calcareous sandstone containing a few very poorly preserved molluscs may have been weathered from a conglomerate at the base of the volcanics, but no outcrop was found. Northeast of the Iron Cap mine the base of the formation is difficult to map because of local interlayering of volcanic rocks and sandstone containing rounded fragments of drab volcanic material; the volcanic rocks appear to rest conformably or, at most, disconformably on sandstone.

Coarse-grained conglomerate composed largely of boulders of granite, and limestone and quartzite of Paleozoic age is reported by Campbell (1904, p. 247) to mark a zone of transition from sedimentary to volcanic rocks in the Deer Creek coal field and else-

[2] Although a few chemical analyses of the Horse Mountain and Galiuro Volcanics are available, most of the rock names used in this and succeeding sections on volcanic rocks are based on study of thin sections.

where; and Ross (1925a, p. 25–26) also notes conglomerate beds, apparently largely within the sedimentary sequence.

Courtright (1958) found a conglomerate composed largely of well-rounded quartzite cobbles at the base of his clastic breccia and conglomerate section in Hawk Canyon 4 miles west of Stanley.

In general, then, the basal contact of the Williamson Canyon Volcanics appears to be a disconformity, but so few structural data are available on either the volcanics or the underlying sedimentary sequence that the nature of the contact is certainly not established unequivocally. Campbell (1904, p. 246–247) states that sedimentary and volcanic material are interstratified locally in the Deer Creek coal field, apparently for the most part within the transition zone between sedimentary and volcanic rocks, and Ross (1925a, p. 25) reports lava near the base of the sedimentary sequence but does not give precise localities. Except in the vicinity of the Iron Cap mine, no transition zone or interlayering of volcanic and sedimentary rocks was recognized in the Klondyke quadrangle, nor did Courtright (1958) recognize any sedimentary beds lithogically comparable to the Upper Cretaceous rocks within his overlying clastic breccia-conglomerate sequence in the Stanley region a few miles north.

The Williamson Canyon Volcanics are overlain unconformably by Horse Mountain Volcanics from the north edge of the quadrangle southeastward for about 2 miles; farther east the contact is a fault. In Old Deer Creek the strike of the Williamson Canyon Volcanics is at an angle of 65°–70° with that of the Horse Mountain Volcanics.

#### LITHOLOGY

The Williamson Canyon Volcanics are mainly green, gray, or grayish-purple massive and rather featureless pyroclastic rocks—agglomerates, tuffs, tuff-breccias, and so forth—containing subordinate lava flows and flow breccias. The lavas are porphyritic but seldom show large feldspar crystals, the most prominent phenocrystic mineral being hornblende. Planar structures such as flow layering, bedding, or intraformational contacts are inconspicuous or lacking. Although the rocks are generally well indurated, they weather to rather subdued low rounded outcrops. Weathered surfaces are commonly brown to yellow, and are much lighter colored than fresh surfaces. The fragmental nature of many of the rocks is not immediately apparent in many outcrops owing to the lithologic similarity of fragments and matrix as well as to indistinct boundaries between them. The Williamson Canyon Volcanics differ considerably in appearance from the overlying Horse Mountain Volcanics and are characterized by sizable fresh phenocrysts of hornblende, a mineral almost entirely lacking in the younger rocks.

The best exposures of the Williamson Canyon rocks are along the ridge north of the Iron Cap mine, in the E½ sec. 19, T. 5 S., R. 20 E. The section appears to be dipping 55°–65° NNE., and includes the following rocks, in ascending stratigraphic order:

1. Medium-gray to grayish red-purple hornblende latite containing prominent pink grains of potassium feldspar as much as 5 mm across.
2. Dusky yellow-green fine-grained well-sorted crystal tuff. In thin section, about 40 to 50 percent of this rock consists of euhedral crystals and fragments of altered plagioclase feldspar 0.2–2 mm long and a few small aggregates of chlorite, sphene, and magnetite, possibly the remains of biotite. The matrix material is a nondescript dusty fine-grained assemblage of chlorite, epidote, and feldspar; staining with sodium cobaltinitrite reveals considerable potassium-bearing material in the matrix. Plagioclase is thoroughly altered to sericite and epidote, or is replaced pseudomorphically by carbonate or carbonate and epidote; these latter minerals also form veinlets.
3. Grayish-red to dark greenish-gray agglomerate composed of angular to subrounded fragments as much as several inches across embedded in a coarse well-indurated matrix of crystal-lithic hornblende andesite or latite tuff. This rock type is dominant in the section.
4. Medium-gray porphyritic hornblende andesite or dacite that weathers to a pale yellowish brown. This rock has prisms of hornblende as much as 6–7 mm long set in a stony matrix. Under the microscope, euhedral phenocrysts of altered plagioclase feldspar 0.2–1 mm across, euhedral prisms of hornblende, and abundant small grains of clinopyroxene are set in a groundmass of dusty devitrified glass. Accessory minerals include abundant iron ore, a little apatite, and sparse carbonate. Plagioclase shows strong oscillatory zoning through a range $An_{60-20}$; the cores are considerably altered to a fine-grained material of moderate birefringence and refractive index near 1.56, possibly hydromica. Hornblende is a greenish-brown variety containing inclusions of pyroxene, feldspar, and apatite, and prominent narrow rims of opaque iron oxide granules. The extinction angle $Z \wedge c = 12°–14°$, and the pleochroism is X=pale greenish yellow to nearly colorless; Z=light greenish brown to brownish green. The

pyroxene is a colorless augite having an extinction angle $Z \wedge c = 42°–44°$; lamellar twins parallel to 100 are common. The groundmass contains considerable quartz, and staining with sodium cobaltinitrite reveals a little potassium feldspar as well; the aggregate refractive index of the groundmass is less than 1.54.

5. Dark-gray dense fine-grained andesite in which only sparse small grains of feldspar and greenish clots of pyroxene are identifiable in hand specimen. Microscopically, the rock has an amygdaloidal porphyritic texture and a pilotaxitic groundmass. Phenocrysts as much as 2 mm across of highly altered plagioclase feldspar, much-altered smaller grains of pyroxene(?) almost completely replaced by carbonate, and aggregates of iron-ore granules are enclosed in a mesh of oligoclase microlites. Amygdules have rinds of carbonate and cores of extremely fine grained chlorite. The plagioclase phenocrysts are so completely altered to carbonate, chlorite, and clay as to be indeterminable. Quartz occurs in the groundmass as a secondary mineral associated with carbonates and chlorite. A little potassium-bearing material in the groundmass becomes visible after staining with sodium cobaltinitrite.

The section of Williamson Canyon Volcanics exposed along the gully just east of the line between secs. 19 and 20, T. 5 S., R. 20 E., is 450–500 feet thick and includes the following rocks, from bottom to top: gray to brown rather nondescript lava, flow breccia, and tuff; dark greenish-gray porphyritic hornblende andesite containing prominent phenocrysts of fresh hornblende as much as 5 mm long and smaller grains of plagioclase feldspar in a fine-grained matrix; light olive-gray fine-grained tuff or siltstone and grayish yellow-green crystal-vitric tuff; nondescript khaki-colored tuff; typical dark-colored agglomerate having a tuffaceous matrix; dark-gray porphyritic pyroxene andesite; purple to brownish-green coarsely porphyritic andesite; and a little dark greenish-gray to dark-gray porphyritic pyroxene andesite flow breccia that weathers yellowish gray.

On the divide at the head of Williamson Canyon, a lens 2–3 feet thick of pebble conglomerate or breccia is intercalated in greenish-gray tuff. The conglomerate is composed largely of fragments of a fine-grained silicic volcanic rock. It provides one of the very few reliable measurements of attitude found in the formation.

The rock underlying the small patches of older alluvium in the W½ sec. 19, T. 5 S., R. 20 E., is greenish to purplish or purplish-gray agglomerate and flow breccia. The matrix of one of the flow breccias is a very dusky red-purple fine-grained rock in which small phenocrysts of plagioclase feldspar and hornblende can be identified with a hand lens. The rock also has numerous small irregular patches of a peculiar blue-green apparently amorphous material. In thin section, the matrix rock is a fine-grained amygdaloidal porphyritic andesite(?) containing phenocrysts 0.5–1 mm long of altered plagioclase feldspar, yellow to greenish-brown hornblende, and clinopyroxene, set in a very fine grained and dusty pilotaxitic groundmass of tiny oligoclase-andesine laths. Amygdules are of very fine grained greenish to brownish material (chlorite?) and carbonate, together with a little epidote. The plagioclase phenocrysts are about $An_{30-40}$ in composition and have thoroughly argillized cores and fresh rims. Hornblende has conspicuous narrow granular rims of opaque iron oxide.

In sec. 18, T. 5 S., R. 20 E., three small bodies of limestone crop out in a terrane of volcanic and sedimentary rocks of the Williamson Canyon and Pinkard. The most westerly of these, near the west edge of sec. 18, is a lenticular body about 300 feet long and 100 feet in maximum width that trends N. 60°–65° W. It is made up of somewhat brecciated and silicified cherty foraminiferal Horquilla Limestone that strikes N. 20°–30° W., and is vertical. The limestone is along a steeply dipping contact between Williamson Canyon Volcanics to the south and Pinkard Formation to the north. The two limestone bodies to the east are somewhat smaller and trend about north. The more easterly is a downward-tapering lens of Horquilla Limestone about 200 feet long that appears to be entirely bounded by faults. The other limestone lens also seems to be bounded by faults; however, at both places, poor exposures and heavy brush make it difficult to determine the exact relations.

No satisfactory explanation of these limestone lenses has occurred to me. They all are at or near the contact between the Williamson Canyon Volcanics and the Pinkard Formation and could conceivably be landslide blocks that originally lay at or near the base of the volcanic rocks and subsequently have been involved in, or even may have localized, minor faulting; that Horquilla Limestone was exposed at the outset of deposition of the volcanics is attested by sizable rounded boulders of that limestone in the basal conglomerate of the volcanic sequence. It seems most unlikely that the limestone bodies were brought into their present positions as slices along high-angle faults. The depth to Horquilla Limestone underlying the Pinkard Formation is not known but may well be as much as 1,000 feet; on the other hand, the faults bounding the easternmost limestone lenses seem to have displacements of, at most, a few hundred feet, and the westernmost lens provides little evidence of faulting of any appreciable magnitude. Similar bodies of limestone crop out along and near the south end of the line between secs. 19 and 20, T. 5 S., R. 20 E., but here a fault of large magnitude separates the volcanics from the Pinkard Formation, and the Horquilla Limestone must be very close to the surface; nevertheless, these bodies too could possibly be landslide blocks at the base of the volcanics. It also seems most unlikely that the limestone lenses are the remnants of a now almost completely eroded thrust sheet; thrust faulting would have taken place during an interval between deposition of the Pinkard Formation and the Williamson Canyon Volcanics, yet nowhere in the Klondyke quadrangle nor elsewhere to the north or northwest is there any good evidence of a major structural break between these two formations.

In summary, the origin of these limestone lenses is conjectural, but their common occurrence at or very near the same stratigraphic horizon—the base of the Williamson Canyon Volcanics—lends at least some support to the idea that they are of landslide origin.

#### AGE AND CORRELATION

No fossils have been found in the Williamson Canyon Volcanics nor have any absolute age determinations been made. The formation rests disconformably on sedimentary rocks of early Late Cretaceous age and is overlain unconformably by the Horse Mountain Volcanics, whose basal rocks, at least, are believed with some reservations to be of Late(?) Cretaceous or Tertiary age. The formation therefore may be of Late Cretaceous age or younger.

The tuff and breccia mapped by Ransome in the southeast corner of the Ray quadrangle just southwest of Christmas and assigned by him to the uppermost Cretaceous (Ransome, 1919, p. 56–57) are dark-green or reddish- gray epidotized pyroxene andesites. Except for the predominance of pyroxene rather than of hornblende, these rocks are rather similar to the Williamson Canyon Volcanics but do not at all resemble the Glory Hole Volcanics described in a preceding section.

The Cretaceous(?) volcanic rocks Gilluly described (1956, p. 68–69) from South Pass in the Dragoon Mountains include hornblende andesites that are similar petrographically to those of the Williamson Canyon Volcanics; however, these rocks are probably older than the Bisbee Group, of Early Cretaceous (Comanche) age, although the evidence for their age is not conclusive. The hornblende andesite flow breccias and tuffs of the lower part of the Bronco Volcanics of the Tombstone area (Gilluly, 1956, p. 87–90) also resemble petrographically the Williamson Canyon Volcanics. Gilluly discusses the possible correlation of the Bronco Volcanics and Ross's Cretaceous volcanic rocks, which include the Williamson Canyon Volcanics of this report, but concludes that the evidence therefor is not persuasive. A principal obstacle to this correlation is the lack of fossiliferous rocks of Late Cretaceous age in the Tombstone region, and the consequent impossibility of fixing the maximum age of the Bronco Volcanics more closely than post-Comanche.

### HORSE MOUNTAIN VOLCANICS

#### DISTRIBUTION

An extensive and thick sequence of dominantly silicic volcanic rocks makes up a nearly continuous belt of outcrops that extends along the southwest side of the Turnbull and Santa Teresa Mountains from the northern boundary of the Klondyke quadrangle south-southeastward to Waterfall Canyon, a distance of about 10 miles. Isolated outcrops in Klondyke Wash indicate that the belt extends at least 2 miles farther southeast. The maximum width of this belt is about 2.5 miles. Silicic rocks of the same sequence also make up a chain of five outcrops extending from the center of sec. 26, T. 6 S., R. 19 E., north-northwestward for 6 miles to Old Deer Creek. These rocks are here named Horse Mountain Volcanics, after Horse Mountain, 2 miles north of Aravaipa, where a great thickness is well exposed. About 9.7 square miles, or 4 percent of the quadrangle, is underlain by the formation.

#### THICKNESS

The total thickness of the Horse Mountain Volcanics is unknown, as the upper limit is either the present land surface or an angular unconformity with Hell Hole Conglomerate or older alluvium. At least 400 feet of gently dipping volcanic rocks is exposed on hill 4412 in the SW cor. sec. 20, T. 6 S., R. 20 E., 1 mile northwest of the Grand Reef mine. On Imperial Mountain in sec. 6, T. 6 S., R. 20 E., the section is undoubtedly thicker, but the attitude of the rocks is uncertain in all but the lower part of the section and no accurate measurement was possible; the minimum thickness is estimated at 600 feet, and the total thickness may be twice as great. At the type locality on Horse Mountain, measurement of a section is complicated by faulting, highly contorted flow layering, and obscure bedding, but it seems likely that at least 3,000 feet of volcanic rocks is present, and the thickness may be well in excess of 4,000 feet.

#### STRATIGRAPHIC RELATIONS

The base of the Horse Mountain Volcanics is exposed in three general areas.

South, west, and north of Aravaipa, the volcanics rest unconformably on Horquilla Limestone or, less commonly, on Escabrosa Limestone, Martin Formation, Bolsa Quartzite, Laurel Canyon Granodiorite, or Pinal Schist. The contact between volcanics and gently dipping Horquilla Limestone is well exposed in Arizona Gulch about three-quarters of a mile west of Aravaipa; here layering in the volcanics and bedding of the limestone are parallel.

In the region between Tule Spring and a point on the divide between Williamson Canyon and Arizona Gulch half a mile or so west of Landsman Camp, the volcanic rocks for the most part lie unconformably on Escabrosa Limestone. At one place three-quarters of a mile southwest of Landsman Camp, they rest on Horquilla Limestone; and along a tributary gulch of Williamson Canyon in the W½ sec. 30, T. 5 S., R 20 E., they rest on various Paleozoic rocks.

Between the vicinity of the Head Center mine, in Williamson Canyon, and the north edge of the quadrangle, a distance of nearly 2 miles, the Horse Mountain Volcanics rest unconformably on Williamson Canyon Volcanics, except at one place just northeast of the mine where they overlie Horquilla Limestone. Along much of its outcrop in this area, the base of the Horse Mountain is marked by a distinctive red highly lenticular pebble and cobble conglomerate.

Throughout the entire southern two-thirds of the outcrop area in T. 6 and 7 S., R. 20 E., the base of the Horse Mountain Volcanics is not exposed, and the rocks are in fault contact with Pinal Schist, Laurel Canyon Granodiorite, Bolsa Quartzite, Escabrosa Limestone, and Buford Canyon Formation.

In the principal outcrop area, between Lone Cedar Mesa and Waterfall Canyon, the volcanics are overlain unconformably by older alluvium. Along the chain of outcrops 2 to 3 miles southwest of this area, they are overlain unconformably by Hell Hole Conglomerate on the southwest and by older alluvium on the northeast; the northeast side of these hills is probably a fault-line scarp or fault scarp, now nearly buried by older alluvium.

Several local unconformities probably exist within the Horse Mountain Volcanics, but at only a few places were they recognized. In the canyon southeast of the Imperial Mountain road, in the SE¼ sec. 7, T. 6 S., R. 20 E., at least 100 feet of coarse-grained tuff dipping 20° SE. overlies a welded tuff sequence on the northwest side of the canyon and dips directly into the same welded tuff on the southeast side of the canyon; apparently the coarse-grained tuff was deposited in a valley eroded in the older tuff and subsequently has been tilted about 20°.

About a mile south, orange well-bedded coarse-grained breccia and light-gray quartz-rich partly welded lithic-vitric tuff, perhaps ejected from a vent to the southwest, unconformably overlie a sequence of purple volcanics and appear to have been deposited in a southwesterly sloping earlier valley. These pyroclastic rocks dip 10°–20°. They are grouped with the Horse Mountain Volcanics on the geologic map.

#### LITHOLOGY

The Horse Mountain Volcanics include a heterogeneous assemblage of lava, tuff, and agglomerate ranging in composition from andesite to rhyolite, as well as small amounts of conglomerate and breccia. Silicic rocks of rhyolitic to dacitic composition predominate over most of the outcrop area, but andesite is abundant at the base of the section in the type locality and in the general vicinity of Aravaipa and Williamson Canyon. The rocks south of Imperial Mountain are largely silicic, and the isolated outcrops southwest of the Turnbull Mountains consist entirely of silicic rocks.

In view of the very erratic distribution of rocks of diverse composition, no attempt was made to map the different rock types within the Horse Mountain sequence. In a very general way, the less silicic rocks are more abundant in the lower part of the section, and the rocks at the base are almost invariably andesitic.

In Old Deer Creek and on Horse Ridge, the base of the Horse Mountain Volcanics is marked by a lenticular reddish conglomerate 100–180 feet thick. Thin conglomerates made up mainly of limestone fragments constitute the base of the Horse Mountain at several places near Aravaipa and west and southwest of Landsman Camp.

The andesites include dark-gray coarsely porphyritic lava and gray to purple porphyritic lavas and tuffs. The lavas have phenocrysts of plagioclase and brown biotite, and the groundmass minerals are sodic plagioclase, iron oxide, and apatite. A little potassium feldspar also may occur in the groundmass. All the phenocryst minerals are altered to a greater or lesser extent. No pyroxene or amphibole was identified in either hand specimen or thin section, although completely altered remnants in several rocks may possibly have been one of these minerals.

The silicic rocks probably range in composition from rhyolite to rhyodacite or dacite, but only one chemical analysis is available to substantiate the determinations based on thin section study. The rocks are mostly fine grained lavas, and subordinate tuff and welded tuff. They are generally light- to medium-colored—white, cream, yellow, orange, brown, reddish brown, red, and light green—and some are highly resistant to erosion. The only common phenocryst minerals in both lavas and tuffs are sanidine, usually microperthitic, sodic plagioclase, brown biotite, and quartz. Some pyroxene or amphibole may be represented by sparse aggregates of alteration minerals, but in general they seem to be very rare; green hornblende was seen in one lava and an associated tuff, and clinopyroxene appears in two vitrophyres from widely separated areas. Biotite commonly is blackened, that is, rendered more or less opaque in thin section owing to abundant tiny inclusions of iron oxide, and feldspar phenocrysts may be somewhat sericitized. Groundmass minerals include potassium feldspar, quartz, iron ore, and apatite, as well as a little sphene and zircon, mainly as inclusions in biotite. In many rocks the groundmass is glassy, spherulitic, or patchily devitrified, and consequently is of indeterminate mineralogy.

#### CONGLOMERATE

From the north edge of the quadrangle southeastward for about 1½ miles along the northeast flank of Horse Ridge, the base of the Horse Mountain Volcanics is a highly lenticular bed of reddish to purplish-red conglomerate. Where this conglomerate crosses Old Deer Creek, it is about 180 feet thick; and in the saddle northeast of Horse Mountain, it is 100–125 feet thick; immediately southeast of the saddle the conglomerate pinches out abruptly, to appear again half a mile farther southeast at a place northeast of the Head Center mine. Both in Old Deer Creek and on Horse Mountain, the conglomerate overlies unconformably purple agglomerate and fine-grained rocks of the Williamson Canyon Volcanics. In Old Deer Creek the conglomerate is overlain by coarse-grained porphyritic andesite, whereas on Horse Ridge it is overlain by porphyritic lava and tuff of andesitic to rhyolitic composition.

In Old Deer Creek the conglomerate strikes N. 35°–40° W. and dips 60°–75° SW. Most of the constituent pebbles are 1–2 inches across, but some boulders are as large as 2 feet. In addition to abundant fragments of limestone and pinkish granite, there are numerous pieces of greenish tuff derived from the immediately underlying Williamson Canyon Volcanics. The matrix is sandy. A short distance downstream (west) of the principal outcrop, the upper 20 feet of the conglomerate is repeated by faulting.

On Horse Mountain the conglomerate strikes N. 45° W. and dips 70°–75° SW. It consists of angular to subangular pebbles and cobbles of moderate red granite and gray limestone and subordinate fragments of maroon limestone, gray sandstone, dark-gray quartz diabase, and very little volcanic material, all set in a well-indurated matrix of red sand. Most fragments are 2–3 inches across, but some are as large as 6 inches. Sorting is fair.

A rather similar conglomerate, together with a little sandstone and shale, is exposed over an area just north of the Arizona mine. The field relations are not clear, but the conglomerate seems to rest on a small inlier of Horquilla Limestone and to be overlain by volcanic rocks. The conglomerate is a poorly sorted aggregate of angular to subrounded pebbles of limestone and red granite in a coarse-grained quartz-rich sandy matrix.

A small patch of conglomerate 3,500 feet west of the Arizona mine probably rests on Horquilla Limestone, although the nearest exposure of limestone is several hundred feet to the east. The conglomerate is made up of rounded pebbles and cobbles as much as 4 inches across of limestone and lesser amounts of quartzite, chert, reddish granite, and volcanic rocks in a red soft sandy matrix.

Similar conglomerate also crops out about 1,500 feet northeast of the Head Center mine, where it strikes N. 45° W. and dips 65°–70° SW. The conglomerate rests unconformably on Horquilla Limestone and is overlain by dacite and andesite. The conglomerate here is well consolidated, is about 10 feet thick, and consists of subangular to subrounded pebbles, cobbles, and a few boulders as much as 3 feet across in a matrix of coarse sand. The fragments consist mostly of gray fossiliferous Horquilla Limestone, red and brown sandstone, red marl, and red fine-grained biotite granite.

Limestone conglomerate marks the base of the Horse Mountain at several places near Aravaipa, where the volcanics rest on limestone. The conglomerate that overlies Horquilla Limestone just west and north of the Panama mine and south of new Aravaipa consists of closely packed angular to subangular fragments 0.5–3 inches across of gray fusulinid-bearing Horquilla Limestone, and subordinate red, brown, or white chert and red and pink limestone, in a matrix of limestone sand. A few boulders are 6–8 inches across. The conglomerate seems to be at most a few tens of feet thick. In a south-sloping tributary of Arizona Gulch just east of the Orejana mine, a conglomerate about 75 feet thick rests on Horquilla Limestone. The lower part of the conglomerate consists of angular to subrounded fragments of limestone 2–12 inches across in a brown sandy matrix, and the upper part consists of rounded to subrounded pebbles of varied lithology in a maroon to greenish-brown matrix.

On the ridge half a mile west of Landsman Camp, a conglomerate lens 90–100 feet thick lies at the base of the Horse Mountain Volcanics and appears to fill a local basin in Escabrosa Limestone. The conglomerate dips 70° SW. It is composed of angular to subangular pebbles and cobbles 1–3 inches across of Horquilla Limestone, dark-gray crinoidal limestone (Escabrosa?), quartzite, red limestone, and chert in a matrix of brown calcareous sand. A few cobbles attain a size of 8 inches.

The southeasternmost exposure of the basal conglomerate of the Horse Mountain is in a valley about seven-tenths of a mile southwest of Landsman Camp, where some 8 feet of red conglomerate rests unconformably on Horquilla Limestone. The conglomerate consists of angular to subangular pebbles an inch or so across of limestone, chert, and purple porphyritic volcanic rock in a sandy matrix. A few cobbles are as much as 10 inches across.

Layers of conglomerate or breccia also are interbedded with the Horse Mountain Volcanics at several places, particularly northwest of Williamson Canyon. A breccia that crops out about three-quarters of a mile west-northwest of Horse Mountain is composed of angular fragments of gray and purple volcanic rock as much as a foot long in a yellow tuffaceous matrix.

#### ANDESITE

Rocks of andesite or basaltic andesite composition crop out mainly in the area between Tule Spring (SE¼ sec. 31, T. 5 S., R. 20 E.) and Arizona Gulch-Williamson Canyon. A few andesitic lavas and tuffs occur northeast of Horse Mountain and also farther south, near Imperial Mountain and northwest of the Grand Reef mine, but they are much subordinate to more silicic rocks.

A very coarse grained porphyritic andesite is exposed at several places between Tule Spring and the Arizona mine and is well exposed near Aravaipa. This rock is at the base of the section half a mile southwest of Landsman Camp and in Old Deer Creek and is just above the base northeast of the Head Center mine; elsewhere it may be interlayered with more silicic rocks or its relations to other volcanics may be obscure. Neither the thickness nor the areal extent of individual flows is known, and no attempt was made to delineate separate flows, as the erratic distribution of outcrops suggested that such an attempt would have been futile.

The rock is a dark—very dusky red purple to grayish red-purple—lava containing large phenocrysts of plagioclase feldspar set in a fine-grained groundmass. The phenocrysts are as much as 2–3 cm across and are strikingly platy, with the ratio of diameter to thickness being somewhere near 10:1. They commonly are oriented parallel to one another and are prominent indicators of flow layering; locally, however, the plagioclase plates are randomly oriented, and in recognition of the fancied similarity of the outcrop pattern of these phenocrysts to the tracks of a large bird, the rock is commonly known as "turkey-track" andesite and is so referred to in at least one publication (Denton, 1947b, p. 14). During early stages of fieldwork, it appeared that this rock might be a clue in correlating the volcanic rocks of the Turnbull and Santa Teresa Mountains with those of the Galiuro Mountains, but the occurrence of megascopically similar lava flows at two and perhaps three widely separated horizons in the Galiuro Volcanics has shown that no close correlation, if indeed any at all, is possible on such a basis.

In the one place where a contact was clearly exposed, in Old Deer Creek, the andesite rests on conglomerate and is slightly reddened at the base but shows no basal flow breccia or fine-grained selvage; these features, together with the presence of large thin platy and presumably friable phenocrysts of feldspar, suggest that the lava was not extremely viscous and that the phenocrysts are intratelluric. In thin section, a specimen from the valley just southeast of Aravaipa consists of large euhedral grains of finely twinned practically unzoned labradorite (about $An_{55}$) and a few grains of magnetite 0.5 mm or less across in a fine-grained intergranular groundmass of oligoclase-andesine laths, iron ore, sparse pale chlorite, a few needles of what may be apatite, and a little quartz in irregular patches that appear to be secondary or deuteric. No olivine, pyroxene, amphibole, or mica was recognized. The contrast between the large feldspar plates and the fine-grained groundmass is striking; there are no phenocrysts of intermediate size.

Similar rocks also make up parts of the Galiuro Mountains and will be described at greater length in a succeeding section. (See p. 72.) In addition, dikes of the same or similar rock are found over an area much larger than that now occupied by lava; if these dikes were feeders for lava flows, then this peculiar rock may also have cropped out north of the Silver Coin mine; between Goat Canyon and Cottonwood Canyon; near Black Rock Spring (sec. 9, T. 6 S., R. 20 E.); and possibly elsewhere.

Purplish-gray to dark-gray and gray lava and tuff of andesitic composition crop out on Horse Mountain, along Williamson Canyon, in the vicinity of Aravaipa, and south of hill 5569 (SW¼ sec. 30, T. 5 S., R. 20 E). They are quantitatively much subordinate to the more silicic rocks. The lavas are porphyritic rocks containing phenocrysts of sodic plagioclase feldspar ($An_{10-20}$) and biotite 1–3 mm across in a matrix of sodic plagioclase microlites, apatite, iron ore, and devitrified glass. Feldspar grains are commonly altered to sericite, epidote, and carbonate. Quartz is not abundant and seems to be largely of secondary origin. Potassium feldspar is rare or absent. The tuffs are crystal-rich and somewhat lighter colored than the lavas but consist of the same minerals plus, in a few rocks, sparse phenocrysts of sanidine.

RHYOLITE, DACITE, AND RELATED ROCKS

The bulk of Horse Mountain, Horse Ridge, and hill 5569 to the southeast is made up of light-colored silicic lavas and tuffs. Along the crest of Horse Ridge and for considerable distances down the slopes the lavas have steeply inclined flow layering, 60° or more and predominantly to the southwest. Only a few rocks will be described in detail.

The summit of Horse Mountain is made up of a pale-red (*5R* 6/2) porphyritic and spherulitic rhyolite. The microscope reveals phenocrysts of perthitic sanidine as much as 3 mm across, a few small highly altered grains of plagioclase, and a little biotite in a microspherulitic glass groundmass now devitrified to an aggregate of quartz and potassium feldspar. Quartz also occurs as sparse irregular grains or aggregates, some of which may be phenocrysts and others concentrations formed deuterically.

To the north and northwest of Warm Spring, which is in Old Deer Creek 2 miles northwest of Aravaipa, the Horse Mountain Volcanics comprise a varied group of lava, tuff, flow breccia, agglomerate, and vent fillings ranging in composition from rhyolite to andesite. A mottled reddish-brown and gray rhyolite vitrophyre flow breccia about half a mile northwest of Warm Spring contains a few rounded 1–2 mm phenocrysts of quartz in a groundmass characterized by striking concentrically layered spherulites as much as 2 cm across. In thin section, both spherulites and radiolites are present, both apparently consisting entirely of quartz and potassium feldspar; the mineralogy of the spherulites was confirmed by X-ray determinations. Abundant veinlets of quartz cut the spherulites and also mark the contacts between glass and devitrified glass. Some of the quartz veins have a central thread of opal. Associated with this vitrophyre is a spectacular rock made up of spherical or ellipsoidal pink lithophysae as much as 3 cm across in a matrix of highly vesicular greenish-yellow devitrified glass.

Near and southwest of Warm Spring the section includes a considerable amount of waterlaid tuff, tuffaceous sandstone, and conglomerate. The tuffs are variegated buff, pink, and red rocks that may attain a local thickness of 30 feet. They consist of grains 0.1–2 mm across of perthitic sanidine, quartz, sodic plagioclase, and blackened biotite, and fragments of volcanic rock. Some have a very dusty matrix of glass that is devitrified to coarse-grained patches of quartz and feldspar, or to spherulitic or radiolitic aggregates.

The rock forming the bold outcrops above the Sinn Fein mine is a varicolored pink, grayish-pink, and orange fine-grained flow-banded rhyolite containing sparse phenocrysts of quartz and feldspar. Flow layering strikes N. 80° W. and dips 30° N. In thin section the rhyolite is made up of rounded phenocrysts of quartz and microperthitic sanidine 0.1–1 mm across and euhedral magnetite 0.05–0.1 mm across in a patchy and streaky groundmass of glass, which is devitrified to an aggregate of quartz and alkali feldspar. Quartz phenocrysts have a late narrow spongy rim in optical continuity with the core.

The upper slopes of hill 5569 are underlain by light-colored fine-grained lavas having highly contorted and generally steeply dipping flow layering. A pale red-purple prominently layered rock from the ridge south of the hill is made up of glomerophenocrysts of microperthitic sanidine as much as 5 mm across and a few 1–2 mm grains of oligoclase, deep red-brown blackened biotite, and quartz, imbedded in a spherulitic groundmass that constitutes about 75 percent of the rock. The spherulites, 1–2 cm across, are made up principally of quartz and potassium feldspar according to X-ray determinations. In addition to the spherulites there are also many colorless feathery aggregates or radiolites of the same minerals. This rock is probably either a quartz latite or a rhyolite.

On the northwest side of Stowe Gulch in the NE¼ sec. 1, T. 6 S., R. 19 E., the lowest part of the section is composed of agglomerate and purplish-gray crystal tuff (base not exposed), overlain successively by pale-green fine-grained waterlaid and crossbedded rhyolite or quartz latite crystal-vitric tuff; perhaps 200 feet of coarse probably waterlaid breccia composed of angular to subrounded fragments as much as 6 inches across of silicic volcanic rock; tuff, breccia, and red and purple lavas having prominent flow layering;

platy siliceous lavas; and massive prominently spherulitic silicic lava that makes up the bulk of the hill eight-tenths of a mile southeast of Aravaipa. The attitude of the section is variable, but the rocks in general dip 20°–30° NW., W., or S.

The spherulitic lava is a rather peculiar appearing rock consisting of gray to pink and gray spherical, elliptical, or botryoidal spherulites in a darker colored pale reddish-purple to light greenish-gray matrix. In outcrop the lava is an extremely massive rock that shows no trace of flow layering. The spherulites are mostly less than a centimeter across and constitute from 25 to 50 percent of the rock. The only phenocrysts are of microperthitic sanidine in grains 1–2 mm across. The groundmass consists of spherulites, apparently composed entirely of potassium feldspar, and interstitial patchily devitrified glass, now an aggregate of quartz and feldspar.

The section of Horse Mountain Volcanics exposed on the west side of Imperial Mountain is characterized by marked variability in attitude and lithology, and no detailed sequence could be worked out; in general the rocks are tuffs and welded tuffs near the southwestern base of the mountain, and lavas in the higher parts. The tuffs are well-bedded light- to medium-colored vitric-crystal silicic types, ranging in grain size from very fine to coarse.

A typical coarse-grained quartz latite or latite from near the southwest base of the mountain is a moderate-red to grayish-red rock containing prominent phenocrysts of potassium and plagioclase feldspar. In thin section the rock contains subhedral to anhedral phenocrysts and glomerophenocrysts of clear sanidine and subordinate albite in a spherulitic matrix. The spherulites are as much as a centimeter across and constitute perhaps half of the rock. They are composed of an extremely fine grained intergrowth of what X-ray examination reveals to be potassium feldspar and quartz commonly radiating from a crystal that has acted as a nucleus. The reminder of the groundmass is an aggregate of about equal parts of quartz and potassium feldspar. Quartz also occurs in veinlets. This rock is so thoroughly devitrified that its origin is uncertain; no shards or pumice fragments are preserved, and the massive character is suggestive of lava, but the rock could be a completely welded vitric-crystal tuff.

Most of the bedrock in lower Laurel Canyon south and west of the Grand Reef mine is a light-gray biotite-rich quartz latite. Some of this rock has light-colored streaks containing more than the average amount of quartz, and some has very fine flow layering, but much of the rock is so massive that neither its attitude nor its nature is readily apparent in the field. Under the microscope, the streaky variety is seen to contain phenocrysts several millimeters across of sanidine and sodic oligoclase, and smaller grains of brownish biotite in a very fine grained groundmass of devitrified glass. Numerous small lenticular patches of quartz are probably deuteric, formed as a result of migration of quartz into newly formed vesicles. Accessory minerals include apatite, rare sphene as inclusions in biotite, and iron ore. The massive rock is similar to the streaked type except that a little quartz occurs as phenocrysts.

Welded tuff and breccia are prominent constituents of the Horse Mountain Volcanics west of the Dogwater mine and to the south in Waterfall Canyon. The rocks in Waterfall Canyon are gently dipping massive to well-layered red, brown, yellow, and gray well-indurated intricately jointed tuff and breccia that exfoliate along the bedding. The westernmost outcrops are pale yellowish-brown to pale-brown thoroughly welded vitric-crystal rhyolite and quartz latite tuffs. In thin section they consist of phenocrysts 1–2 mm long of sanidine, sodic plagioclase, and brown biotite, and smaller and less abundant grains of quartz in a fragmental and solidly welded groundmass of slightly devitrified glass shards and pumice lapilli. The only accessory minerals are hematite and magnetite. Rock fragments in general are scarce. The rocks in the canyon southwest of the Dogwater mine are similar (fig. 10).

In the south-central part of T. 5 S., R. 19 E., Arizona Gulch for more than half a mile is a deep and rugged gorge cut in a complex and highly resistant section of silicic lava and tuff. Figure 11 is a sketch section based on a pace-and-compass traverse through the gorge, and includes notes on the various rocks. The western part of the section dips more or less uniformly west at 35°–50° and is 650–700 feet thick. In the eastern part, the attitudes are so irregular and flow layering so contorted that no accurate measurement of thickness is possible; however, dips are dominantly westerly, and it seems likely that the eastern part of the section is about 1,000 feet thick. The total thickness of the Arizona Gulch section then would be 1,650–1,700 feet, but a more realistic estimate, considering the uncertainties of measurement, would be 1,400–1,800 feet.

The most characteristic rock of the eastern part of the section is a pinkish-gray fine-grained lava having conspicuous light-gray dense wavy streaks a few millimeters thick and a centimeter or so apart. Flow-layering as defined by the gray streaks is highly contorted. The only phenocrysts identifiable in hand specimen are millimeter-size grains of brown biotite

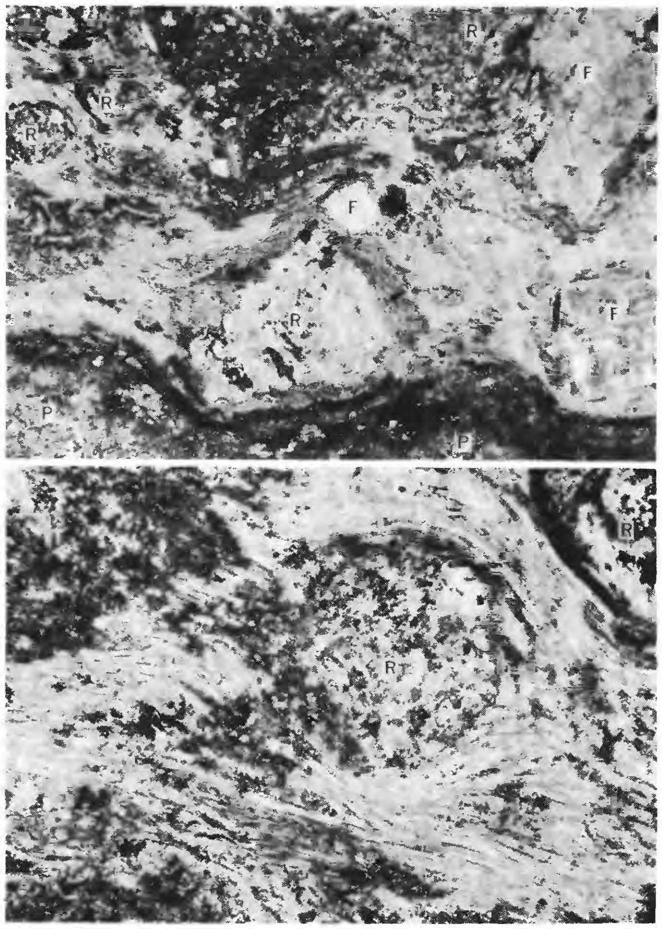


FIGURE 10.—Above, photomicrograph of solidly welded quartz latite(?) tuff, Horse Mountain Volcanics in canyon southwest of the Dogwater mine. F, perthitic sanidine; R, rock fragment; P, devitrified pumice fragment. Light-colored streaks are devitrified layers of glass shards, interlayered with darker glass. Note bending of shards around mineral and rock fragments. Plane-polarized light, × 38. Below, detail of upper left corner of top photograph, showing bending of shards around rock fragment. Plane-polarized light, × 120.

and plagioclase feldspar, which occur in both the pinkish-gray rock and the gray streaks. The rock is dotted with spheroidal to elongate or sausagelike vesicles as much as a centimeter thick and several centimeters long, always lined with quartz on which is perched in some places aggregates of the cottony or fibrous zeolite mordenite (ptilolite). The spheroidal vesicles may be expansions of the gray streaks or may be entirely isolated. The pinkish-gray material seems to be devitrified spherulitic glass. The gray streaks are a fine-grained aggregate of quartz and potassium feldspar(?) that are more completely crystallized than the pink rock, perhaps owing to concentration of volatiles that occurred during extrusion; the quartz-lined vesicles seem to be genetically similar to the streaks, differing only in that filling did not keep pace with gas expansion, and there is a complete gradation from elongate streaks through elongate vesicles to spheroidal vesicles.

The large isolated hill of volcanic rock in secs. 23 and 26, T. 6 S., R. 19 E., is made up of lava, welded tuff (believed to range in composition from rhyolite to latite), and obsidian. Rocks of several types crop out on this hill, but most are either light-gray to grayish red-purple fine-grained sparsely porphyritic lava or pale red-purple to moderate-red welded vitric-crystal tuff and fine-grained breccia.

The lavas generally show well-developed flow layering. They are composed of phenocrysts of sanidine and brown biotite, with subordinate amounts of sodic plagioclase and quartz, in a matrix of spherulitic or patchily devitrified glass. Accessory minerals include sphene, apatite, iron ore, clinopyroxene, and in one

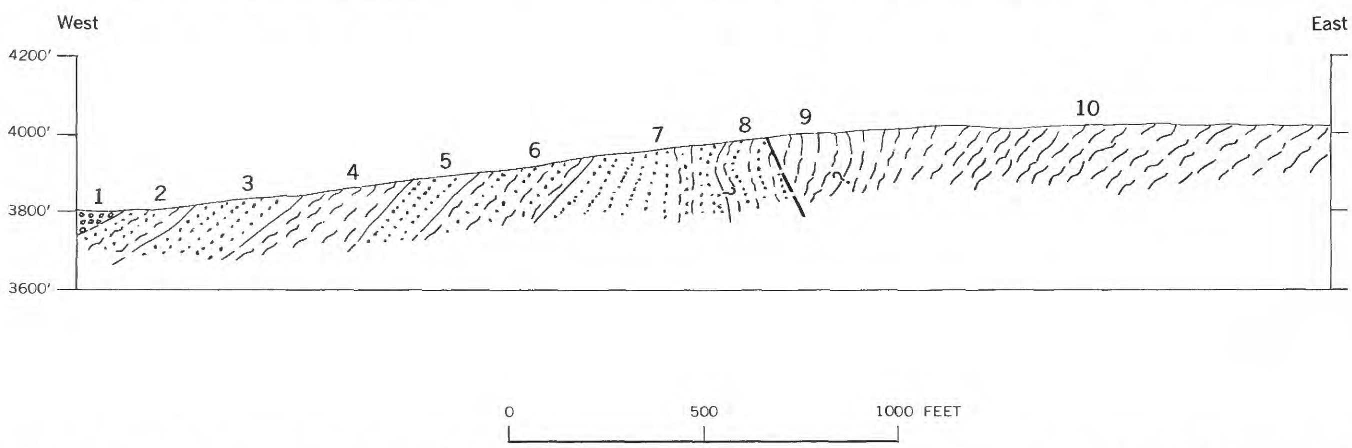


FIGURE 11.—Sketch section showing lithology of Horse Mountain Volcanics in the gorge of Arizona Gulch. Based on a pace and compass traverse. 1, Hell Hole Conglomerate. 2, Light-gray biotite rhyolite with contorted flow layering. 3, Buff, cream-colored, or pink coarse-grained massive tuff and breccia, with some biotite rhyolite. 4, Light-gray very hard porphyritic biotite rhyolite with abundant quartz phenocrysts and contorted flow layering. 5, Cream-colored, buff, or yellow coarse-grained lithic tuff with abundant fragments of purple lava. 6, Pinkish-gray very hard well-bedded welded tuff. At top, abundant lithophysae 0.5–1.0 inch across. Basal 40–50 feet is red spherulitic vitric welded tuff. 7, Pale greenish-yellow coarse vitric tuff, some green obsidian and lithophysae-rich rock. Upper 15–20 feet crowded with small lithophysae. 8, Light-gray hard thick-bedded welded tuff; eastern part is red spherulitic rock. 9, Greenish-yellow biotite vitrophyre; black or streaked black-and-red obsidian and vitrophyre with geodes of salmon-colored, orange, or cream opal. 10, Red spherulitic welded tuff at west end; rest of section is gray or pink streaked rhyolite with contorted flow layering.

trachytic rock, green hornblende. Sanidine commonly is microperthitic and may have cores of sodic plagioclase. X-ray examination of the spherulites revealed them to consist of alpha cristobalite, plagioclase feldspar, and potassium feldspar. Biotite is usually somewhat blackened, but always is a brown variety.

Some of the outcrops along the east side of the hill at its north end are bright red, and as seen from the road from Aravaipa Valley to Aravaipa are very striking. On a fresh surface the rocks are gray, white, pink, or red stony to sugary fine-grained devitrified rhyolite with sparse phenocrysts of altered feldspar and quartz. They are finely laminated in places, and seem to dip gently northwest. The red color is apparently due to disseminated hematite, and no evidence was found that the hematite might have been formed by oxidation of pyrite or other sulfide minerals.

#### GLASSY ROCKS

Obsidian and vitrophyre ranging from orange through brown to nearly black are rather common in the Horse Mountain Volcanics, particularly in the upper parts of the section. They occur as thick stubby lenses interlayered with lava, tuff, or welded tuff; as bombs in agglomerate; and as blocks in vent fillings. The refractive index of all the volcanic glasses collected over an area extending from the north edge of the quadrangle to somewhat south of the Tenstrike mine, a distance of almost 8 miles, is within the range 1.495–1.499. These indices correspond to glasses that may range in composition from rhyolite to andesite (George, 1924; Tröger, 1956, p. 13). However, most natural glasses having such indices contain from 70 to 76 percent silica and are rhyolitic. Presumably therefore the glasses in the Horse Mountain are dominantly of rhyolitic composition.

The refractive index of glass from the following localities was measured: (1) Bomb from vent agglomerate, SE¼ sec. 15 (unsurveyed), T. 5 S., R. 19 E., about a quarter of a mile south of the quadrangle boundary. This rock is a black and brownish-orange eutaxitic vitrophyre, containing millimeter-size crystals of plagioglase ($An_{45}$) and prisms and needles of clinopyroxene 0.1–1 mm long, in a slightly devitrified yellowish glass base having many perlitic cracks. Rounded, resorbed, and "motheaten" grains of oligoclase as much as 3 mm across are probably xenocrysts; (2) greenish-brown biotite-rich vitrophyre from the prominent knob 2,000 feet west of Horse Mountain. This rock is interlayered with varicolored silicic welded tuff and lava; (3) grayish-green (10*GY* 5/2) hard brittle perlitic rhyolite or trachyte vitrophyre, 60 feet from the east contact of a coarse vitric tuff unit in the lower narrows of Arizona Gulch; (4) black biotite quartz latite vitrophyre, center of sec. 18, T. 6 S., R. 20 E. This rock is a solidly welded vitric-crystal tuff that forms a thick lens in a sequence of tuff and welded tuff; (5) massive waxy brown obsidian from a layer 5–6 feet thick at base of tuff-agglomerate, a quarter of a mile southwest of the Tenstrike mine; and (6) dark-brown biotite latite vitrophyre from the center of sec. 23, T. 6 S., R. 19 E., interlayered with red flow breccia. This rock contains phenocrysts as much as 5 mm across of a feldspar believed to be anorthoclase, biotite containing inclusions of apatite and zircon, and pale-green clinopyroxene, in a spherulitic glassy matrix crowded with trichites.

A chemical analysis and norm of the biotite quartz latite vitrophyre from sec. 18, T. 6 S., R. 20 E., is given below, and the chemical composition and norm of Nockolds' (1954) average alkali rhyolite and average dellenite (= quartz latite) are also given for comparison. A semiquantitative spectrographic analysis appears in table 2, column 3.

*Chemical analyses, in percent, of biotite quartz latite, average alkali rhyolite, and average dellenite*

| Bulk analysis | | | | Normative minerals | | | |
|---|---|---|---|---|---|---|---|
| Constituent | 1 | 2 | 3 | Mineral | 1 | 2 | 3 |
| $SiO_2$ | 71.46 | 74.57 | 70.15 | Q | 31.92 | 31.1 | 26.1 |
| $Al_2O_3$ | 12.72 | 12.58 | 14.41 | or | 27.80 | 27.8 | 26.7 |
| $Fe_2O_3$ | .94 | 1.30 | 1.68 | ab | 28.30 | 35.1 | 30.9 |
| FeO | .31 | 1.02 | 1.55 | an | 4.17 | 2.0 | 9.5 |
| MgO | .22 | .11 | .63 | C | .61 | ------ | ------ |
| CaO | .86 | .61 | 2.15 | hl | .23 | ------ | ------ |
| $Na_2O$ | 3.40 | 4.13 | 3.65 | wo | ------ | .1 | .2 |
| $K_2O$ | 4.72 | 4.73 | 4.50 | en | .50 | .3 | 1.6 |
| $H_2O+$ | 3.67 | .66 | .68 | fs | ------ | .6 | .8 |
| $H_2O-$ | .98 | ------ | ------ | mt | .46 | 1.9 | 2.5 |
| $TiO_2$ | .21 | .17 | .42 | hm | .64 | ------ | ------ |
| $P_2O_5$ | .03 | .07 | .12 | il | .46 | .3 | .8 |
| MnO | .07 | .05 | .06 | ap | ------ | .2 | .3 |
| $CO_2$ | .02 | ------ | ------ | | | | |
| Cl | .06 | ------ | ------ | | | | |
| F | .05 | ------ | ------ | | | | |
| Subtotal | 99.72 | ------ | ------ | ------ | ------ | ------ | ------ |
| Less O | .03 | ------ | ------ | ------ | ------ | ------ | ------ |
| Total | 99.69 | ------ | ------ | ------ | ------ | ------ | ------ |
| Powder density | 2.38 | ------ | ------ | ------ | ------ | ------ | ------ |

1. Biotite quartz latite vitrophyre, Horse Mountain Volcanics, center sec. 18, T. 6 S., R. 20 E. Laboratory No. F2676. Analyst, Dorothy F. Powers, U.S. Geol. Survey.
2. Average alkali rhyolite plus rhyolite obsidian (Nockolds, 1954, table 1, col. 4).
3. Average dellenite plus dellenite obsidian (Nockolds, 1954, table 2, col. 2).

#### VENTS

Several roughly circular, elliptical, or elongate bodies of coarse- to fine-grained completely unsorted fragmental material are interpreted as fillings of former volcanic vents. The vent fillings are somewhat more resistant to erosion than their wallrocks, and commonly stand well above their surroundings. They are generally less than 200 feet across.

A vent filling shown by the small closed 4500 contour near the center of the west edge of sec. 7, T. 6 S., R. 20 E., is 200–250 feet long, 30–40 feet wide, and has a horizontal section similar to that of a boomerang, concave to the northwest. The vent material is light-gray to pink silicic devitrified glass characterized by closely packed botryoidal compound spherulites as much as several inches across composed of quartz and plagioclase feldspar. The matrix interstitial to the spherulites is tuffaceous. Country rock is steep-dipping purplish welded tuff.

The tiny closed 4550 contour near the center of the west edge of sec. 17, T. 6 S., R. 20 E., marks a small breccia-filled vent that may have been the source of the massive coarse-grained orange breccia and tuff to the northeast. The neck is about 150 feet long in a northerly direction, 50 feet wide, and dips steeply east. It is near the south end of a prominent breccia-filled fissure that trends north from the vent to the top of the ridge and then swings abruptly to the northwest and extends at least as far as the next main valley. On the northwest slope of the ridge, the fissure filling dips 50° SW. and is as much as 200 feet wide. Material filling the vent and fissure consists of fragments of welded tuff and porphyritic volcanic rock as much as a foot across, enclosed in a fine-grained matrix of fragmental devitrified glass.

The small closed 4600 contour in the NE¼NE¼ sec. 18, T. 6 S., R. 20 E., marks a breccia-filled vent about 200 feet across. The breccia is composed of rounded fragments 3–4 inches across of very fine grained devitrified glassy rock, sparse crystals of quartz and feldspar, and a few fragments as much as a foot long of purple porphyritic latite or dacite. Rocks near the vent are coarse-grained vitric-lithic tuff and agglomerate containing blocks of welded tuff a foot across, and fragments of quartz.

An elongate neck several hundred feet long, trending north-northwest, crops out near the edge of the volcanic belt on the west side of sec. 20, T. 6 S., R. 20 E. The neck cuts nearly flat-lying well-consolidated pale-red rhyolitic vitric tuff, now completely devitrified and spherulitic. The neck is made up of blocks of silicic lava as much as 3 feet across in a matrix of vitric tuff. Layering within the neck is contorted but seems to strike about N. 60° W. and dip 65°–80° NE. The tuff matrix is a pale-red somewhat chalky looking rock consisting of fragments 1–2 mm across of quartz and perthitic sanidine in a groundmass of patchy quartz and potassium feldspar resulting from the devitrification of glass. Devitrification around quartz grains commonly has produced an overgrowth of quartz in optical continuity. Sparse former mafic minerals are now represented by epidote.

Other vents recognized include: (1) a poorly defined vent near the west edge of the outcrop area of Horse Mountain Volcanics about a quarter of a mile south of the quadrangle boundary, (2) several vents on the knob at the north end of Horse Ridge, and a breccia-filled fissure vent 30 feet wide that trends north-northwest along the west side of this knob, (3) a steeply dipping breccia-filled vent on the west side of the hill half a mile west of Horse Mountain, possibly along the same fissure as (2), and (4) a vague area of rust-stained breccia and spherulitic lava in the valley just west of the Orejana mine.

In certain areas the Horse Mountain Volcanics seem to have been bleached by fumarolic action. Vertical whitish alteration zones cutting almost flat-lying reddish welded quartz latite or latite vitric-crystal tuff and breccia are especially well displayed in the canyon that slopes southwest from the Dogwater mine. These bleached zones are of variable width, usually only a few feet. Contacts between bleached and unbleached rock are generally vague, and tongues of bleached rock may extend a few inches into unbleached rock. In places the contacts are along minor fractures that apparently guided alteration. The color difference presumably is due to the oxidation state of iron; in thin section, the principal difference between bleached and unbleached rock is the color of the partly devitrified fragments of glass and pumice, which are light brown to yellow in the unbleached rock and colorless in the altered zones.

#### AGE AND CORRELATION

A red sandstone having calcite cement is exposed in the SW¼SE¼ sec. 19, T. 5 S., R. 20 E., about 1,800 feet east-northeast of the Head Center mine. This sandstone appears to lie approximately along the strike of an outcrop of the basal conglomerate of the Horse Mountain Volcanics and a few hundred feet to the southeast of the conglomerate. The sandstone contains poorly preserved fragments of mollusks identified by W. A. Cobban, of the U.S. Geological Survey, as *Ostrea* sp. Because of poor exposures and heavy brush, I am uncertain that the sandstone is indeed part of the Horse Mountain Volcanics; but if it is, then the lowest part of the formation was deposited in part in a marine environment and presumably is of pre-Tertiary age.

No additional direct evidence of the age of the Horse Mountain is available, as no other fossils were found and no absolute age determinations have been made. Stratigraphic evidence permits only an approximate maximum age assignment. The formation is known to be appreciably younger than early Late Cretaceous (Colorado), as it overlies unconformably the Williamson Canyon Volcanics, which in turn rest disconformably on the Pinkard Formation, of Colorado age.

It is overlain with marked unconformity by the Hell Hole Conglomerate, of presumed middle or late Tertiary age, and by older alluvium. West and northwest of the Grand Reef mine the Horse Mountain Volcanics are cut by silicic dikes believed to be comagmatic with the Santa Teresa Granite, zircon from which has been assigned a lead-alpha age of 60 ± 10 million years (p. 63).

The Horse Mountain Volcanics, then, are no older than late Late Cretaceous, and appear to be no younger than early Tertiary, and I have no data that would permit a closer estimate than Late(?) Cretaceous or Tertiary.

The gross lithology of the Horse Mountain Volcanics is similar to that of the Galiuro Volcanics, although the stratigraphy of the Horse Mountain is much more obscure. Both formations contain the distinctive "turkey-track" andesite flows and large amounts of silicic welded tuff. The Horse Mountain probably consists for the most part of rocks more silicic than andesite, although the proportions of the various rocks are not known accurately, whereas the Galiuro Volcanics are made up of approximately equal amounts of andesite and more silicic rocks. However, the principal outcrop areas are separated by 2–7 miles of terrain underlain by younger rocks, and no sequence that would permit unequivocal correlation was recognized. The Galiuro Volcanics are younger than the Copper Creek Granodiorite, whereas there is some suggestion that the Horse Mountain Volcanics are older than the Santa Teresa Granite. If the two plutonic rocks are of about the same age, then the Horse Mountain Volcanics are older than the Galiuro Volcanics. As noted previously, the age of the Horse Mountain has not been closely determined, whereas that of the Galiuro Volcanics, although also uncertain, is almost surely middle Tertiary. In summary, correlation of the Horse Mountain Volcanics with the Galiuro Volcanics is certainly suggested but cannot be firmly established or refuted with the data at hand.

### COPPER CREEK GRANODIORITE

The lower part of the canyon of Copper Creek, in the southwest corner of the Klondyke quadrangle, is cut in a massive resistant plutonic igneous rock that is here named Copper Creek Granodiorite. Although the granodiorite crops out over an area of only about 2 square miles, or less than 1 percent of the quadrangle, it is known to extend more than 3 miles farther south into the Galiuro Mountains quadrangle (Wilson and others, 1959).

Over much of its outcrop area, the granodiorite is a fresh, rather hard rock that erodes to moderate slopes and smoothly rounded hills and ridges. A deep and rugged canyon has been carved in the granodiorite by Copper Creek between the old Tew Ranch (SE¼ sec. 1, T. 8 S., R. 18 E.) and the south edge of the quadrangle, particularly around the Childs-Aldwinkle mine and the abandoned settlement of Copper Creek.

The granodiorite shows narrow chilled margins against its wallrocks at several places. In the center of sec. 1, the granodiorite is a fine-grained greenish-gray rock near several inclusions or roof pendants of coarse-grained Bolsa(?) Quartzite. South of the Copper Prince mine, the granodiorite has a chilled margin 2–3 feet wide against Glory Hole Volcanics. Near the Old Reliable mine, the contact with hornfels of the Glory Hole Volcanics is gradational, the change from dark granodiorite to coarse-grained hornfels taking place within an interval of less than 10 feet. Finally, where granodiorite intrudes Glory Hole Volcanics near the west edge of the quadrangle in sec. 34, T. 7 S., R. 18 E., it may have a very thin chilled border marked by rounded inclusions of volcanics in granodiorite and by narrow dikes of granodiorite cutting volcanics.

No structures were recognized in any of the wallrocks that might be attributed to emplacement of the granodiorite, and the smoothly sinuous contact along the west and north sides of the main granodiorite mass also suggests that emplacement was permissive rather than forceful. Stoping may have played some role, but at the level of exposure the only blocks whose origin might be ascribed to stoping are those of quartzite in the center of sec. 1, T. 8 S., R. 18 E., near or along the contact between granodiorite and Galiuro Volcanics.

The granodiorite intrudes rocks of Precambrian(?), Paleozoic, and Mesozoic (Cretaceous?) ages and is overlain unconformably by the Galiuro Volcanics of Tertiary age and, in two small areas, by alluvium. Geological evidence indicates that it is probably of Late(?) Cretaceous or early Tertiary age. A potassium-argon age determination on biotite from the granodiorite made by S. C. Creasey (written commun., 1962) of the U.S. Geological Survey gave a calculated age of 68 million years (Late Cretaceous or early Tertiary).

#### LITHOLOGY

The Copper Creek Granodiorite varies somewhat in mineralogical composition and appearance from place to place, but less so than the other plutonic igneous rock formations of the quadrangle. In general, it is a greenish-gray to brownish-gray or pale-red medium-grained porphyritic and slightly cataclastic rock composed of plagioclase feldspar, quartz, potassium feldspar, and biotite. The plagioclase is generally $An_{35-45}$

and rarely is as calcic as $An_{50}$; zoning is confined to narrow rims and is normal. Potassium feldspar and quartz are usually interstitial to plagioclase and seldom form phenocrysts. Biotite forms small euhedral phenocrysts or interstitial anhedrons. Pale-green amphibole is found in some specimens, and clinopyroxene in others, but neither is either widespread or abundant. Accessory minerals are sphene, iron ore, apatite, and zircon. Modes of nine specimens of Copper Creek Granodiorite, made with a point counter, are given in table 3; five of these rocks are granodiorite, one is a quartz monzonite, and three might be called either granodiorite or quartz monzonite.

TABLE 3.—*Modes of Copper Creek Granodiorite*

| Constituent | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8[1] A | 8[1] B | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Quartz | 19.5 | 26.5 | 23 | 25 | 22 | 26 | 20.5 | 1.5 | 31 | 20 |
| Plagioclase feldspar | 48.5 | 42.5 | 51.5 | 40 | 49 | 41.5 | 41.5 | 31.5 | 31.5 | 51 |
| Potassium feldspar | 21.5 | 14 | 21 | 27 | 18 | 27 | 28 | ------ | 30 | 11.5 |
| Biotite | 5 | 16 | 1 | 2 | 3 | 1.5 | 4 | 7.5 | 7.5 | 16 |
| Pyroxene | 4 | ------ | ------ | ------ | ------ | 1.5 | 3 | ------ | ------ | ------ |
| Other | 1.5 | 1 | 3.5 | 6 | 8 | 2.5 | 3 | ------ | ------ | 1.5 |
| Groundmass | ------ | ------ | ------ | ------ | ------ | ------ | ------ | 59.5 | ------ | ------ |

[1] Column A is measured composition; column B is calculated using an estimated mineralogical composition for the groundmass of 50 percent quartz, 50 precent potassium feldspar.

1. Granodiorite, hill west of Childs-Aldwinkle mine.
2. Granodiorite, haulage level, Childs-Aldwinkle mine.
3. Granodiorite, Copper Creek, NW¼ sec. 12, T. 8 S., R. 18 E.
4. Quartz monzonite, canyon west of Bluebird mine, center sec. 2, T. 8 S., R. 18 E.
5. Granodiorite, Bluebird mine.
6. Granodiorite, west edge sec. 34, T. 7 S., R. 18 E.
7. Quartz monzonite, west edge sec. 34, T. 7 S., R. 18 E.
8. Quartz monzonite, Copper Prince mine.
9. Granodiorite, Copper Giant mine.

A chemical analysis and norm of Copper Creek Granodiorite from the canyon just north of the Old Reliable mine in sec. 10, T. 8 S., R. 18 E. are given below, together with chemical compositions and norms of Nockolds' (1954) average granodiorite and average tonalite for comparison. A semiquantitative spectrographic analysis of the same rock is in table 2, column 4.

Typical granodiorite makes up most of the hill between the Copper Prince mine and the Childs-Aldwinkle mine. A specimen from the summit of the hill is a medium- to brownish-gray medium-grained rock containing conspicuous shiny plates of biotite. Plagioclase feldspar, quartz, biotite, and pyroxene are identifiable with a hand lens. The rock has a seriate porphyritic texture containing phenocrysts of plagioclase feldspar 1–5 mm across. The mode is given in table 3, column 1. Microscopically, the plagioclase is about $An_{40}$. Pyroxene forms sparse ragged and poikilitic grains a few millimeters long, partly replaced by pale-green hornblende.

*Chemical analyses, in percent, of Copper Creek Granodiorite, average granodiorite, and average tonalite*

| Bulk analysis | | | | Normative minerals | | | |
|---|---|---|---|---|---|---|---|
| Constituent | 1 | 2 | 3 | Mineral | 1 | 2 | 3 |
| $SiO_2$ | 62.28 | 66.88 | 66.15 | Q | 14.58 | 21.9 | 24.1 |
| $Al_2O_3$ | 16.41 | 15.66 | 15.56 | or | 16.12 | 18.3 | 8.3 |
| $Fe_2O_3$ | 2.24 | 1.33 | 1.36 | ab | 34.58 | 32.5 | 33.0 |
| FeO | 2.58 | 2.59 | 3.42 | an | 18.35 | 16.4 | 20.8 |
| MgO | 2.72 | 1.57 | 1.94 | wo | 1.63 | ------ | .3 |
| CaO | 4.66 | 3.56 | 4.65 | en | 6.80 | 3.9 | 4.9 |
| $Na_2O$ | 4.12 | 3.84 | 3.90 | fs | 4.71 | 2.9 | 4.1 |
| $K_2O$ | 2.69 | 3.07 | 1.42 | mt | 3.25 | 1.9 | 2.1 |
| $H_2O+$ | .61 | .65 | .69 | il | 1.37 | 1.1 | 1.2 |
| $H_2O-$ | .17 | ------ | ------ | ap | ------ | .5 | .5 |
| $TiO_2$ | .71 | .57 | .62 | | | | |
| $P_2O_5$ | .17 | .21 | .21 | | | | |
| MnO | .08 | .07 | .08 | | | | |
| $CO_2$ | .13 | ------ | ------ | | | | |
| Cl | .03 | ------ | ------ | | | | |
| F | .05 | ------ | ------ | | | | |
| Subtotal | 99.65 | ------ | ------ | ------ | ------ | ------ | ------ |
| Less O | .03 | ------ | ------ | ------ | ------ | ------ | ------ |
| Total | 99.62 | ------ | ------ | ------ | ------ | ------ | ------ |
| Powder density | 2.75 | ------ | ------ | ------ | ------ | ------ | ------ |

1. Copper Creek Granodiorite, just north of Old Reliable mine, NE¼, sec. 10, T. 8 S., R. 18 E. Laboratory No. F2675. Analyst, Dorothy F. Powers, U.S. Geol Survey.
2. Average granodiorite (Nockolds, 1954, table 2, col. 4).
3. Average tonalite (Nockolds, 1954, table 2, col. 5).

On this same hill within the dominant gray granodiorite are numerous small bodies of fine-grained light-pink to pinkish-gray granitoid rock that appears to differ from the darker rock only by having less mafic minerals. One such body about 5 feet across is crudely circular in plan and has concentric layering grading from coarse grained at the center to fine grained at the edge. Other masses of the light-colored rock show conspicuous flow structure. These rocks were not studied in detail and their origin is uncertain, but they do not appear to be fragmented dikes and more probably are autoliths.

Near the portal of the haulage level of the Childs-Aldwinkle mine, the granodiorite is a medium-gray porphyritic rock having a framework of plagioclase feldspar phenocrysts 1–4 mm long and interstitial quartz, abundant biotite, and potassium feldspar. The mode is shown in table 3, column 2.

An amphibole-bearing variety of granodiorite from west of the Bluebird mine is a light brownish-gray hard fresh rock that contains, in addition to the usual minerals, a little colorless amphibole much altered to carbonate. The extinction angle $Z \wedge c$ is 15°. The mode of this rock is in table 3, column 4. A very similar rock makes up most of the isolated outcrop of Copper Creek Granodiorite on the west edge of sec. 34, T. 7 S., R. 18 E. This rock contains grains of colorless pyroxene as much as a millimeter long that are partly altered to colorless amphibole.

Several varieties of Copper Creek Granodiorite were recognized that differed in texture or color from the typical rock, but in view of the appreciable time and effort that would have been required, no attempt was made to map them separately. Inasmuch as these rocks differ from normal granodiorite principally in proportions rather than kinds of minerals, it seems reasonable to consider them comagmatic varieties of the granodiorite.

A pale-red (10*R* 6/2) sparingly porphyritic rock from sec. 34, T. 7 S., R. 18 E., has bent or broken grains of plagioclase feldspar in a fine-grained granular matrix of quartz and dusty potassium and plagioclase feldspar. The mode is given in table 3, column 6. A medium dark-gray fine-grained rock from the same locality also is cataclastic and contains colorless pyroxene as well as biotite. Although plagioclase feldspar and the mafic minerals are the only ones identifiable with a hand lens, the microscope shows large amounts of quartz and potassium feldspar that form a fine-grained aggregate interstitial to plagioclase. The mode is given in table 3, column 7.

The wallrock of the Copper Prince mine is a rather distinctive light olive-gray, conspicuously porphyritic biotite quartz monzonite(?). It consists of phenocrysts 1–4 mm across of whitish slightly argillized and sericitized plagioclase feldspar (about $An_{40}$), abundant ragged grains of biotite as much as 6–7 mm across, sparse rounded and partly resorbed grains of quartz, and very few phenocrysts of potassium feldspar, all set in a fine-grained pale-red granular groundmass of quartz and potassium feldspar. Biotite is much altered to chlorite (penninite). The mode of this rock is given in table 3, column 8. Both the prominent porphyritic texture and the granular groundmass distinguish this variety from the bulk of the Copper Creek Granodiorite.

Dark- to medium-gray porphyritic rock having more than the usual amount of biotite in the groundmass occurs at several places in and around the Copper Creek pluton.

A variety very rich in biotite is cut by the breccia pipe at the Copper Giant mine. This rock is medium gray with a faint pinkish cast, and has a porphyritic and strongly cataclastic texture. The mode is given in table 3, column 9. Quartz, perthitic orthoclase, and biotite form an allotriomorphic groundmass among phenocrysts of plagioclase feldspar ($An_{40-45}$) and biotite. Some biotite grains have faint pleochroic halos around tiny indeterminate inclusions.

Just south of the Klondyke quadrangle and about a quarter of a mile south of the old Copper Creek post office, the granodiorite is intruded over an area perhaps 70 feet across by a dark biotite-rich rock. Most contacts between granodiorite and biotite rock are gradational or vague, and the granodiorite appears to have been partly assimilated by the darker rock; a few contacts are sharp. Some of the biotite rock forms narrow dikes having a semblance of flow structure along their borders. Several inclusions of pink granodiorite are dotted with small rosettes of black tourmaline.

A granitoid dike 2 feet wide having narrow chilled selvages cuts Copper Creek Granodiorite in the SW. cor. sec. 2, T. 8 S., R. 18 E. The dike resembles typical granodiorite but is lighter in color. Phenocrysts of sericitized plagioclase feldspar, microperthitic orthoclase, and biotite are enclosed in an allotriomorphic base of quartz and potassium feldspar. The plagioclase is about $An_{20}$ in composition, considerably more sodic than that of the typical granodiorite, but otherwise the dike is mineralogically very similar to the granodiorite and presumably they are consanguineous.

Dikes of granodiorite also cut rocks of the Pinkard(?) Formation in the NE. cor. sec. 2, T. 8 S., R. 18 E., and intrude Glory Hole Volcanics in the W½ sec. 34, T. 7 S., R. 18 E., and at several places in secs. 3 and 10, T. 8 S., R. 18 E. Narrow dikes of light-colored granodiorite cutting Glory Hole Volcanics are particularly well displayed near the Old Reliable mine.

A small boss, presumably an offshoot of Copper Creek Granodiorite, intrudes Glory Hole Volcanics on the ridge about 500 feet north of the "3" in sec. 3. The boss is 100–150 feet across and is nearly circular in plan. It consists of a core about 50 feet across of medium-grained gray diorite and a nearly complete rim 25–50 feet wide of a siliceous porphyritic rock, apparently a border facies of the core rock. Other even smaller bosses of granitoid rock intrude Glory Hole rocks about 1,200 feet to the southeast.

#### CONTACT EFFECTS OF COPPER CREEK GRANODIORITE

Wallrocks of the Copper Creek Granodiorite have been metamorphosed in varying degree along the entire length of the intrusive contact. Contact metamorphic phenomena are most marked along the southwestern part of the contact with Glory Hole Volcanics, but also are noticeable where the wallrocks are Paleozoic sedimentary rocks.

Where the granodiorite intrudes Paleozoic rocks, contact effects may be discernible for only a few feet from the contact or may extend for several tens of feet; in general the contact metamorphism is not extensive. Siltstone or mudstone of the Martin Formation is converted to dense fine-grained black hornfels that weathers brown; fissile shale is altered to slaty hornfels; and the impure carbonate rocks are changed to yellow, brown, or honey-colored marble or hornfels.

Escabrosa Limestone near the east end of its outcrop is converted to dense light-gray to green hornfels in which only a little garnet and epidote can be identified with a hand lens; the Escabrosa at this place is separated from the nearest outcrop of granodiorite by about 50 feet of the Martin. Farther west, several tens of feet of Escabrosa are altered to dense fine-grained wollastonite hornfels.

A rather thick section of metamorphosed Escabrosa(?) Limestone is exposed in a canyon about 3,000 feet north of the Bluebird mine. Figure 12*A* is a sketch showing the rocks exposed in the west wall of this canyon, and figure 12*B* illustrates one of the rock types. The limestone hornfels of figure 12*B* has a cavernous weathered surface resembling that typically formed on cherty limestone, but in this rock the more resistant ribs are of limestone.

The sequence of sedimentary rocks in secs. 1 and 2, T. 8 S., R. 18 E., is intruded at two places by a porphyritic rock that does not closely resemble any of the other dike or sill rocks. A light-brown to light brownish-gray sill-like body and a narrow dike cut dark-colored hornfels of the Martin formation in the NW¼ sec. 1. Microscopically, the sill rock consists of phenocrysts 1–3 mm across of highly altered plagioclase feldspar and of biotite(?) completely altered to chlorite and iron ore. The groundmass is a fine-grained granular aggregate of quartz, potassium feldspar, and biotite. Plagioclase phenocrysts are altered to carbonate, sericite, and chlorite, and are near albite in composition. The rock has the typical dense tough aspect and the fine-grained granular makeup of hornfels; it possibly is an intrusive body older than the Copper Creek Granodiorite and metamorphosed by the granodiorite at the same time as its wallrocks.

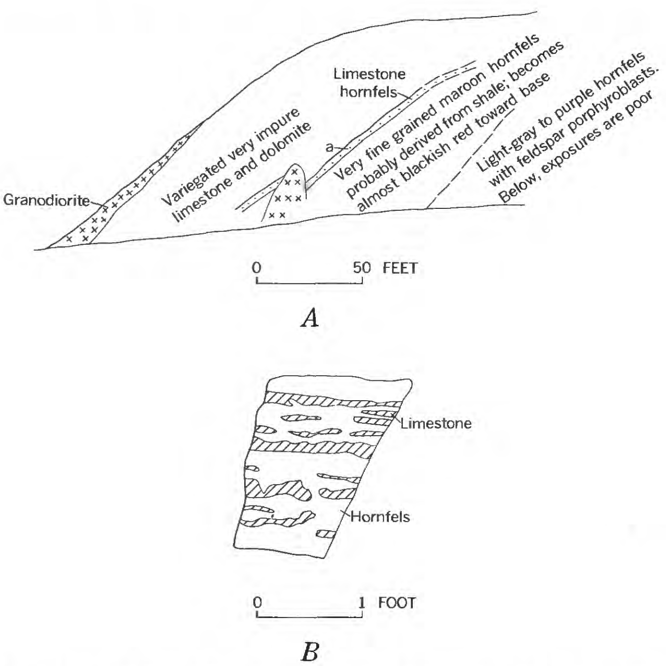


FIGURE 12.—*A*, Sketch of metamorphosed Escabrosa(?) Limestone exposed in the west wall of a canyon 3,000 feet north of the Bluebird mine. *B*, Limestone hornfels from bed at point "a."

The Glory Hole Volcanics are extensively metamorphosed to hornfels in the southwest corner of the quadrangle and to a lesser extent in the NW¼ sec. 34, T. 7 S., R. 18 E. Contact relations are particularly well exposed in the south-sloping canyon in the center of sec. 2, T. 8 S., R. 18 E., and therefore a suite of specimens of metavolcanic rocks was collected along the canyon for a distance of 2,000 feet from the granodiorite and was examined microscopically.

The rock 2,000 feet north of the contact is a grayish-red andesite flow breccia, containing rounded to subangular fragments of fine-grained dark rock 1–2 cm across enclosed in a lighter-colored matrix. Microscopically the rock is much altered but apparently was a porphyritic lava having a hyalopilitic or pilotaxitic groundmass. Feldspar phenocrysts are saussuritized and are now albite; mafic minerals are altered to pale-green chlorite; and the fine-grained dusty groundmass contains considerable carbonate and chlorite. A few rounded aggregates of epidote probably are amygdules.

At a distance of 1,700 feet from the granodiorite, the flow breccias are darker, their fracture is more hackly, and the outlines of the fragments are somewhat blurred although still plainly visible, particularly on waterworn surfaces. Microscopically, little change is evident except that the plagioclase phenocrysts are fresher and are $An_{45-50}$ in composition.

Four hundred feet farther south the flow breccias are clearly converted to hornfels, but the original breccia texture is preserved although only faintly. The rocks are dark gray to dark purplish gray and are very hard and brittle. In thin section, feldspar phenocrysts (about $An_{50}$) are fresh and the groundmass has a vaguely granular texture. Another 500 feet farther south the first narrow dikes of granodiorite cut the metavolcanic rocks, which here contain large fragments of pink coarse granite and light-gray quartzite. One of these dikes about 2.5 feet wide has sharp walls and numerous rounded or vaguely outlined inclusions of metavolcanic rock; the granodiorite may have assimilated the matrix of a former agglomerate or flow breccia, but the primary texture of the enclosing volcanics is completely obliterated and their original nature is not known. The dike is of light brownish-gray biotite granodiorite containing appreciable amounts of a colorless amphibole replacing pyroxene.

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At 700 feet from the granodiorite, the metavolcanics are dark greenish-gray medium-grained dense brittle hornfels cut by prominent northeastward-trending vertical joints. No fragments are visible in the hornfels. Microscopically the rock is a plagioclase-biotite-pyroxene quartz granulite, and most grains are in the size range 0.02–0.2 mm (fig. 13). The plagioclase is about $An_{35}$, has albite and pericline twins, and has numerous inclusions of biotite, pyroxene, and potassium feldspar. Biotite is mostly in granular aggregates containing inclusions of all the other minerals plus apatite; some rounded aggregates may be recrystallized amygdules, as they have no apatite inclusions. Sparse ragged grains of colorless clinopyroxene have rims of pale-green amphibole. Quartz forms scattered irregular patches that do not appear to be original phenocrysts. Potassium feldspar is scarce, and except for inclusions in plagioclase is restricted to the fine-grained parts of the rock, presumably the groundmass of the original volcanic rock.

A specimen of hornfels collected 450 feet from the granodiorite is medium dark-gray massive hornfels similar to that just described but much coarser grained. Most grains are larger than 0.05 mm across, and many are 1–3 mm across; the largest grains probably are original phenocrysts. Biotite forms grains as much as 2 mm across and appears to be entirely of metamorphic origin.

Within 300 feet of the contact the metavolcanic rocks are intimately laced with granodiorite dikes ranging in width from a fraction of an inch to a foot. The dikes have sharp, generally straight, walls and appear to occupy joints; however, some dikes may pinch and swell like veins and may turn very abrupt corners. The very sharp nature of the dike-hornfels contacts is illustrated in figure 14. The hornfels is a coarse-grained plagioclase-biotite-pyroxene-amphibole-orthoclase-quartz-iron ore granulite with most grains 0.1–0.2 mm across; the granodiorite is a light brownish-gray rock, near quartz monzonite in composition as shown by the mode given in table 3, column 4.

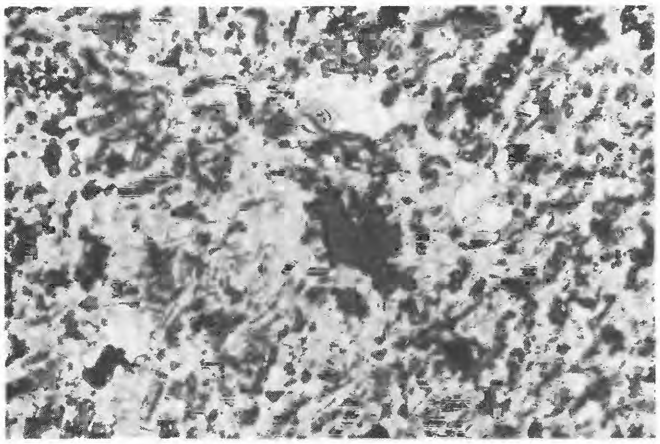

FIGURE 13.—Photomicrograph of plagioclase-biotite-pyroxene-quartz granulite in Glory Hole Volcanics. Dark grain at center is only biotite in field. Rock consists of clinopyroxene (medium gray, strong relief), plagioclase feldspar (light gray), and quartz (white, irregular interstitial areas), with minor iron ore (black). Original flow layering of lava is shown by plagioclase microlites alined vaguely from upper right to lower left. Plane-polarized light, × 50.

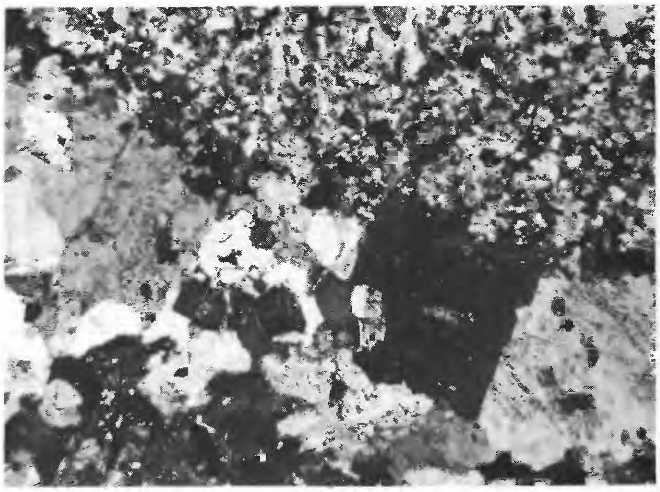

FIGURE 14.—Photomicrograph of sharp contact between dike of Copper Creek Granodiorite (lower left) and hornfels derived from Glory Hole Volcanics (upper right). Crossed nicols, ×22.5.

Porphyritic flow breccias, tuff, and welded tuff(?) along the canyon in the southwest corner of the quadrangle are intruded by small bodies of granodiorite and converted to hornfels or granulite. The granodiorite masses are generally less than 100 feet across and are not shown on the geologic map. All these rocks are pyritized to varying degrees. The coarse fragmental nature of some of the volcanic rocks is clearly preserved, although the borders of the fragments may be blurred owing to metamorphism. In one thin section, faint layering suggests that the original rock was a lava or densely welded tuff.

A medium dark-gray rather coarse grained hornfels proved microscopically to be a plagioclase-biotite granulite consisting of a mesh of plagioclase prisms 0.3–0.6 mm long and having interstitial yellowish-brown biotite, quartz, iron ore, and apatite. The plagioclase shows strong oscillatory zoning, from $An_{25-35}$ over most of the crystals to $An_{10-20}$ at the rims.

The rocks shown as hornfels in the NW. cor. sec. 34 are an intimate mixture of fine-grained granodiorite and metavolcanics to the southeast and become predominantly volcanic at the edge of the quadrangle. The granodiorite here is a pale-red to yellowish-gray porphyry containing small phenocrysts of feldspar and pyroxene(?) set in a fine-grained matrix.

#### ALTERATION OF COPPER CREEK GRANODIORITE

In this section, alteration of the Copper Creek Granodiorite not related to the breccia pipes of Copper Creek will be noted briefly; description of the strong alteration in and near the pipes will be included in the discussion of the pipes themselves.

Over most of its outcrop area, the Copper Creek Granodiorite is fresh except for the usual weathering. In several areas, however, the rock is somewhat altered; the largest of these is along Copper Creek, beginning at the line between secs. 11 and 12, T. 8 S., R. 18 E., and extending for 3,000 feet or so to the west-southwest.

Westward from the concrete dam just east of the old settlement of Copper Creek, the granodiorite is essentially unaltered and has fresh glassy feldspar phenocrysts. Eastward from the dam, feldspar phenocrysts begin to show some clouding, and at the mouth of the large canyon that slopes south from the Bluebird mine, feldspars are cloudy and pale green. Between this canyon and the point where the canyon of Copper Creek bends to the north in the NE cor. sec. 11, T. 8 S., R. 18 E., the granodiorite is cut by several nearly vertical fractures that trend N. 80°–90° E. and are marked by iron oxide and sparse copper stain. The rock is mottled pale red and olive green and has prominent fresh phenocrysts of biotite and sparse disseminated chalcopyrite; some of the chalcopyrite grains have dark rims, presumably of chalcocite. Microscopically, the feldspar crystals in this zone are near albite-oligoclase in composition rather than andesine and are very dusty, owing perhaps to irresolvable inclusions of zoisite or a related mineral.

Northward from the aforementioned bend for a distance of 500–600 feet, the granodiorite is considerably altered. The general aspect of the rock changes from gray to pink, biotite is completely altered to a pale-green or nearly colorless aggregate, and rosettes of tourmaline are locally very abundant, particularly along flat joints. The tourmaline zone is about 300 feet wide along the canyon and fades out southward into gray granodiorite and northward into pyritized granodiorite. The tourmalinized rock is light-colored —pinkish gray to yellowish gray—and has a dull luster on fresh surfaces. It is cut by closely spaced vertical fractures that strike N. 70° E. and have sparse thin films of copper oxide minerals. In thin sections, feldspar phenocrysts are altered to cloudy albite. Tourmaline forms prisms as much as 2 mm long and is a variety pleochroic in pale blue gray, and colorless. The refractive indices are $O = 1.663$ ($\pm$ 0.004), $E = 1.634$ ($\pm$ 0.002); $O-E = 0.029$, indicating a schorlite having about 30 percent of the dravite end member (Winchell and Winchell, 1951, p. 466).

Northward from the tourmalinized rock, the granodiorite is more strongly altered and has dusty plagioclase and a little carbonate and sericite. Approximately midway in the north-northeastward-trending reach of Copper Creek in the NE cor. sec. 11, T. 8 S., R. 18 E., the granodiorite is strongly silicified and pyritized for a distance of about 100 feet along the canyon and has the typical yellowish-brown outcrop of pyritic rock. The rock containing the most pyrite is greenish gray to light brownish gray and has a dull appearance. It contains irregular small blebs of pyrite from which tiny veinlets extend out into the host rock. Plagioclase phenocrysts are dull gray, a few large grains of biotite are unaltered, and the interstitial material contains considerable sericite. Microscopically, the pyritic rock has moderately sericitized plagioclase and sparse large quartz grains that must be of secondary origin.

To the north and east, the pyritic zone fades out gradually and the granodiorite once more has the milky feldspar grains and pale-greenish altered biotite seen south of the pyrite zone. A specimen of light brownish-gray granodiorite has sericitized phenocrysts of albite-oligoclase, a little disseminated carbonate, and scattered large grains of secondary quartz. Where Copper Creek crosses the line between secs. 11 and 12, the granodiorite is again an almost unaltered pale-red to light brownish-gray rock containing only slightly carbonatized and sericitized plagioclase and slightly chloritized biotite.

Between the Childs-Aldwinkle and Old Reliable mines, the granodiorite is cut by many east-trending joints along which the rock has been chloritized for several centimeters outward from the joint. The original fracture commonly is marked by a film of specular hematite. The contact between chloritized and fresh granodiorite is sharp. Just northwest of the west summit of the hill between the two mines, the granodiorite is chloritized along near-vertical joints that trend N. 75°–90° E. and are marked by faint copper stains. Within the chloritized zones, plagioclase phenocrysts are altered almost completely to sericite and some chlorite, and mafic minerals are converted to aggregates of chlorite and iron ore, but orthoclase is only slightly sericitized. The chlorite is a variety having positive elongation and shows ultra blue and brown interference colors between crossed nicols.

Similar chloritized and iron-stained fractures traverse the granodiorite near the mouth of the canyon just east of the Childs-Aldwinkle mine; some of these fractures have a central film of quartz and pyrite(?).

East of the Childs-Aldwinkle mine, light-gray fresh granodiorite is cut by numerous joints marked by stains of iron oxide; the joints trend N. 80° E. and dip 85°–90° S. Finally, along the road to Sombrero Butte for a distance of several hundred feet south of the old Copper Creek post office, the granodiorite has milky feldspars and is cut by many chloritized fractures.

In a few places, fresh granodiorite is partly replaced by rosettes of black tourmaline. About 1,500 feet north of the Bluebird mine, a zone of light pinkish-gray fine-grained biotite granodiorite 30 feet or so in width and perhaps 500 feet long contains abundant rosettes 1–5 cm across of greenish-black tourmaline. This zone strikes N. 60°–65° E. To the northwest, the tourmalinized granodiorite grades into normal granodiorite through a horizontal distance of about 150 feet, whereas to the southeast the boundary is more abrupt. The southeast edge of the tourmaline zone has been prospected by an adit.

## TERTIARY SYSTEM

### SANTA TERESA GRANITE

The high and rugged peaks of the Santa Teresa Mountains, which rise northeast of Klondyke, are carved from what is here named the Santa Teresa Granite. Pinnacle Ridge, altitude 7,275 feet and the highest point in the Klondyke quadrangle, is at the southeast end of the Santa Teresa Mountains. The granite forms a single large mass that extends from Waterfall and upper Buford Canyons northward to the South Fork of Goodwin Canyon. Except for several dikes, the only other occurrence of Santa Teresa Granite is a very small outlier in the NE¼ sec. 9, T. 6 S., R. 20 E. About 17 square miles, or 7 percent of the quadrangle, is underlain by Santa Teresa Granite.

The granite is one of the formations of the region most resistant to erosion, as attested by the ragged peaks and steep slopes characteristic of its outcrop area, but on a smaller scale the rock weathers to rounded outcrops encrusted with several inches or more of partly disintegrated rock, and consequently hand specimens of fresh rock are virtually impossible to obtain. These rounded outcrops are characteristic of both the coarser grained granite and the aplitic facies so abundant along Black Rock, Cottonwood, and Goat Canyons.

No attempt was made to systematically map structures within the Santa Teresa Granite. No well-defined planar or linear structures were noted; in a rock like this granite, equigranular and nearly devoid of platy or prismatic minerals, such structures might be expected to be either obscure or absent. On the other hand, jointing is prominent, particularly in the westward-protruding lobe between Laurel and Waterfall Canyons. In a very general way, joints in the north, central, and southeastern parts of the granite mass trend northwest and dip steeply northeast, whereas those in the Laurel Canyon lobe have an eastward trend.

The Santa Teresa Granite is in contact with only four rock units. It intrudes Pinal Schist and Laurel Canyon Granodiorite, both of Precambrian age, and also is in fault contact with these rocks and probably with Goodwin Canyon Quartz Monzonite. In addition it is overlain unconformably by older alluvium. The contact between Santa Teresa Granite and Goodwin Canyon Quartz Monzonite is exposed only near the east edge of the quadrangle in the NE¼ sec. 1, T. 6 S., R. 20 E., and the SW¼ sec. 36 and SE¼ sec. 35, T. 5 S., R. 20 E. For half a mile or so northwest from the quadrangle border, the contact is marked by a zone of shearing as much as 100 feet wide, and is probably a fault; the Santa Teresa Granite to the southwest is a somewhat contaminated phase with abundant epidote, and the Goodwin Canyon is a coarse-grained biotite granite cut by shears that trend west-northwest and dip steeply north. A series of pits have been dug along the contact zone. Farther northwest the contact is not exposed but is believed to be along the South Fork of Goodwin Canyon. No evidence was found bearing on the relative ages of the two rocks.

Several dikes of Santa Teresa Granite cut Precambrian rocks. The largest is a dike that extends for at least a mile along the east side of VABM 5385 in the SW¼ sec. 16, T. 6 S., R. 20 E., and the longest is a dike that passes through the knob east of VABM 5385 and extends from Laurel Canyon north-northwestward to near the head of Black Rock Canyon, a distance of about 3 miles. This latter dike is 60 feet wide in Laurel Canyon, where it has a selvage of quartz porphyry a few feet wide against Laurel Canyon Granodiorite. With increasing distance from the granite mass, the central part of the dike loses its granitoid texture and gradually becomes more porphyritic and hence indistinguishable from the many quartz porphyry dikes of the region.

Dikes probably consanguineous with the Santa Teresa Granite cut Horse Mountain Volcanics; however, none of these dikes is traceable directly into the granite, so that evidence for age relations between granite and volcanics is not unequivocal. No other geologic information is available on the age of the granite relative to that of any other formation at Klondyke.

A lead-alpha age determination on zircon from the Santa Teresa Granite by T. W. Stern, of the U.S. Geological Survey (rep. No. WA–93 of 10/23/61), gave a calculated age of 60 ± 10 million years, or early Tertiary.

No evidence was found that forceful intrusion played any role in the emplacement of the Santa Teresa Granite except possibly in the formation of the Waterfall Canyon breccia reef (p. 110); such evidence might be difficult or impossible to recognize where the wallrock is massive Laurel Canyon Granodiorite but should be more or less clearly displayed where the wallrock is the much more easily deformed Pinal Schist. Southwest of Pinnacle Ridge the contact of the granite cuts approximately at right angles across the foliation of the Pinal for 2 miles, but no disturbance of the Pinal that might be attributed to emplacement of the granite was observed.

#### LITHOLOGY

The Santa Teresa Granite is a monotonously uniform very pale red (10*R* 7/2) to very pale red purple (5 *RP* 7/2) or grayish-pink equigranular rock. The bulk of the Santa Teresa Mountains is made up of a medium-grained facies of the granite, whereas much of the terrain along Holdout, Black Rock, Cottonwood, and Goat Canyons is underlain by an aplitic facies. The rock in the canyon of Holdout Creek near the east edge of the quadrangle is a porphyritic biotite-hornblende-quartz monzonite rather than a granite. Along much of the contact with Laurel Canyon Granodiorite and Pinal Schist in Black Rock, Cottonwood, and Goat Canyons, the Santa Teresa Granite is darker colored—greenish, yellowish, or grayish—where it is believed to have assimilated appreciable amounts of wallrock. No attempt was made to map the various facies.

The Santa Teresa Granite, over most of its outcrop area, is a light-colored granite made up almost entirely of orthoclase microperthite and quartz. Modal analyses of seven specimens and of an aplite dike in the granite are given in table 4; these analyses were made with a point counter. The sparse accessory minerals include iron ore, biotite, sphene, apatite, zircon, epidote, and fluorite.

A chemical analysis and norm of the Santa Teresa Granite are given below, together with the chemical composition and norm of Nockolds' (1954) average alkali granite for comparison. A semiquantitative spectrographic analysis of the same rock appears in table 2, column 5.

TABLE 4.—*Modes of Santa Teresa Granite*

| Mineral | 1 | 2 | 3 | 4 | 5 | 6 | | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| Quartz | 31 | 37 | 38 | 30 | 40 | 7.0 | [1] 38.5 | 30 | 41 |
| Microperthite | 67 | 62 | 61 | 53 | 59 | 3.5 | 35.0 | 25 | 59 |
| Granophyre | | | | 17 | | 43.5 | | | |
| Groundmass | | | | | | 19.5 | | | |
| Accessories | 2 | 1 | 1 | <1 | 1 | 3.0 | 3.0 | 5 | <1 |
| Plagioclase feldspar | | | | | | 23.5 | 23.5 | 40 | |

[1] Calculated; proportions of quartz and potassium feldspar in both granophyre and groundmass estimated to be about equal.

1. Rocky Top.
2. Upper Black Rock Canyon, near contact with Laurel Canyon Granodiorite.
3. Upper Holdout Creek, near contact with Laurel Canyon Granodiorite.
4. Upper Klondyke Wash, near contact with Pinal Schist.
5. South side of Pinnacle Ridge, near contact with Pinal Schist.
6. Holdout Creek, near east edge of quadrangle.
7. North edge sec. 11, T. 6 S., R. 20 E.
8. Aplite dike in Santa Teresa Granite, south slope of Pinnacle Ridge.

*Chemical analyses, in percent, of Santa Teresa Granite and average alkali granite*

| Bulk analysis | | | Normative minerals | | |
|---|---|---|---|---|---|
| Constituent | 1 | 2 | Mineral | 1 | 2 |
| $SiO_2$ | 76.27 | 73.86 | Q | 36.72 | 32.2 |
| $Al_2O_3$ | 12.11 | 13.75 | or | 30.58 | 30.0 |
| $Fe_2O_3$ | 1.05 | .78 | ab | 27.77 | 29.3 |
| FeO | .17 | 1.13 | an | 1.11 | 2.8 |
| MgO | .14 | .26 | C | .71 | 1.4 |
| CaO | .36 | .72 | en | .35 | .6 |
| $Na_2O$ | 3.29 | 3.51 | fs | | 1.1 |
| $K_2O$ | 5.19 | 5.13 | mt | | 1.2 |
| $H_2O+$ | .34 | .47 | hm | .96 | |
| $H_2O-$ | .30 | | il | .30 | .5 |
| $TiO_2$ | .17 | .20 | ap | | .3 |
| $P_2O_5$ | .02 | .14 | fl | .16 | |
| MnO | .05 | .05 | | | |
| $CO_2$ | .01 | | | | |
| Cl | .06 | | | | |
| F | .14 | | | | |
| Subtotal | 99.67 | | | | |
| Less O | .07 | | | | |
| Total | 99.60 | | | | |
| Powder density | 2.62 | | | | |

1. Santa Teresa Granite near Dogwater mine, NW1/4 sec. 33, T. 6 S., R. 20 E Laboratory No. F2674. Analyst, Dorothy F. Powers, U.S. Geol. Survey.
2. Average alkali granite (Nockolds, 1954, table 1, col. 3).

The Santa Teresa Granite on the prominent peak called Rocky Top (sec. 1, T. 6 S., R. 20 E.) is typical. It is a medium-grained equigranular pinkish-gray rock composed almost entirely of quartz and potassium feldspar and containing scattered prominent aggregates 1–2 mm across of well-crystallized epidote and violet fluorite. Microscopically, the rock is a microperthite granite consisting of anhedral grains of orthoclase microperthite 1–3 mm across, interstitial quartz, sparse clusters of epidote and fluorite, and a little brownish-green biotite and iron ore. The mode is given in table 4, column 1. The microperthite is largely the string variety, but there is also a little patch microperthite (fig. 15). The plagioclase component is about oligoclase in composition. Proportions of orthoclase and plagioclase in the microperthite seem to be about equal.

The aplitic facies is developed typically along upper Black Rock Canyon. Here the aplitic granite is a very pale red (10*R* 7/2) sugary grained rock containing sparse tiny cavities lined with pale-lavender

FIGURE 15.—Photomicrograph of string microperthite in Santa Teresa Granite. White plagioclase feldspar about oligoclase in composition; light-gray orthoclase; dark-gray quartz. Crossed nicols, × 120.

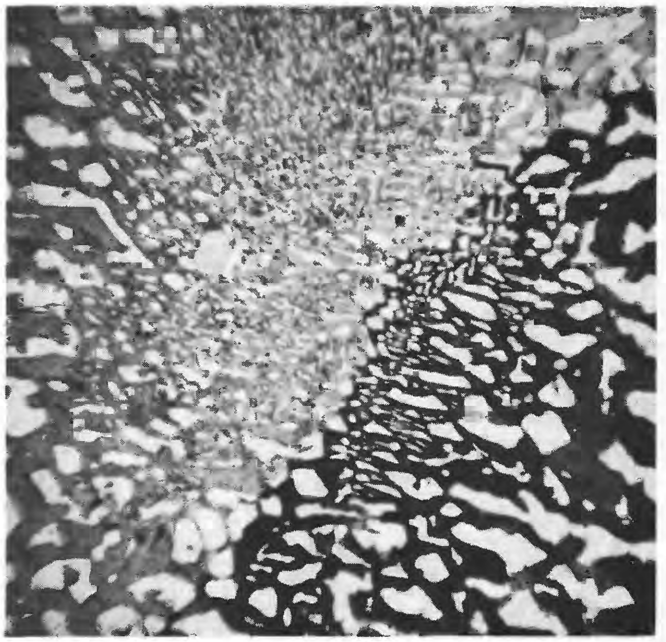

FIGURE 16.—Photomicrograph of granophyre in the Santa Teresa Granite. All blebs of quartz (white) in field have same optical orientation. Individual blebs cross grain boundary of host microperthite (light or dark gray), and thus indicate that quartz of the granophyre has replaced microperthite. Crossed nicols, × 44.

fluorite. The mode is given in table 4, column 2. In thin section the rock is made up of 0.5–2 mm grains of orthoclase string and patch microperthite, and quartz that occurs both interstitially and in vermicular intergrowths with microperthite. Accessory minerals include pale greenish-brown biotite, sphene, iron ore, a little fluorite associated with sphene, and very sparse zircon.

The granite from upper Klondyke Wash west of Pinnacle Ridge is a very pale red (5*R* 7/2) aplitic rock that differs from the typical Santa Teresa Granite by containing an appreciable amount of a granophyric intergrowth of quartz and microperthite. The mode appears in table 4, column 4. The microscope reveals subhedral to anhedral grains of orthoclase microperthite and abundant quartz both interstitial to microperthite and also in granophyric intergrowths with it. The microperthite grains are mostly 0.5–1 mm across, but a few attain a size of 2–3 mm. Very sparse biotite, iron ore, and sphene are accessories. Individual patches of quartz in the granophyre transgress grain boundaries of the host microperthite, suggesting that at least some of the texture is of replacement origin (fig. 16). However, some of the granophyre in which the optical orientation of the quartz is controlled by individual grains of host mineral may be a result of simultaneous crystallization of quartz and feldspar.

The Santa Teresa Granite is ordinarily nonporphyritic, nevertheless, porphyritic varieties occur in a few places. Just south of Black Rock Canyon near the line between secs. 10 and 15, T. 6 S., R. 20 E., a border facies of the granite is a pinkish-gray rock containing euhedral to subhedral phenocrysts of potassium feldspar and quartz 1–4 mm across and scattered smaller euhedral plates of biotite set in a fine-grained, possibly aplitic, groundmass. The phenocrysts appear to make up only 15–20 percent of the rock.

The quartz monzonite facies of Holdout Creek is a yellowish-gray rather coarse-grained porphyritic rock made up of euhedral phenocrysts as much as 5 mm across of cream-colored somewhat chalky plagioclase feldspar, pale pinkish-gray fresh potassium feldspar, and quartz, together with a few percent of biotite and hornblende. The mode of this facies appears in table 4, column 6. Microscopically the rock has a hiatal porphyritic and cataclastic texture. Phenocrysts of very dusty and slightly sericitic plagioclase feldspar (near albite in composition), microperthitic orthoclase, brown biotite, and green hornblende are set in a groundmass made up mainly of very fine grained granophyre. Some granophyre rims phenocrysts to form aggregates resembling spherulites in many volcanic rocks. Scattered at random through the granophyre are patches of a fine-grained granular aggregate of quartz and potassium feldspar, referred to in table 4 as groundmass. Hornblende is moderately pleochroic, with X = light yellow green to nearly colorless, Y = light brownish green, and Z = yellow green or bluish green. The extinction angle $Z \wedge c$ is 22°. Accessory minerals include sphene in grains as much as 0.5 mm long, apatite in slender prisms, epidote, iron ore, and abundant zircon.

In the vicinity of the small mass of Pinal Schist at the north edge of sec. 11, T. 6 S., R. 20 E., a quartz monzonite or granodiorite facies of the Santa Teresa Granite is a mottled pale-red to light-gray medium-grained rock composed mostly of bluish-gray plagioclase feldspar, quartz, and pinkish potassium feldspar. Microscopically, the granite has a slightly cataclastic hypidiomorphic granular texture, and many sutured grain borders. Plagioclase is a low-calcium variety near $An_{5\text{-}10}$. Potassium feldspar does not form phenocrysts but instead shapeless patches in plagioclase and irregular layers as much as 0.5 mm wide along contacts between plagioclase and quartz. The mode is given in table 4, column 7.

Aplite dikes are very abundant in the Santa Teresa Granite but are inconspicuous in outcrop because they are the same color as the granite and are mineralogically practically identical with it. A typical dike from the south side of Pinnacle Ridge near the contact with Pinal Schist is a pinkish-gray even-grained sugary rock containing a few phenocrysts of feldspar as much as 5 mm across. The mode is given in table 4, column 8. In thin section the rock has an aplitic or panallotriomorphic granular texture, and has grains of microperthite and quartz averaging about 0.5 mm in diameter. Sphene is a fairly abundant accessory, commonly occurring in aggregates with iron ore and fluorite.

#### CONTACT EFFECTS OF SANTA TERESA GRANITE

The Santa Teresa Granite intrudes Pinal Schist along Laurel Canyon, along the southwest side of Pinnacle Ridge, in the upper parts of Cottonwood and Goat Canyons, and in the South Fork of Goodwin Canyon. Along these contacts the granite commonly has an aplitic border phase, and rocks of the Pinal are converted to hornfels, but in most places the contact effects do not extend more than a few tens of feet from the contact, and in some places, such as sec. 35, T. 6 S., R. 20 E., contact metamorphism is negligible.

Only in the Laurel Canyon area is the Pinal metamorphosed for any appreciable distance from the contact and here it is likely that the metamorphism is superimposed on an earlier one resulting from the emplacement of Laurel Canyon Granodiorite in Precambrian time. Just north of the Grand Reef mine, a fine-grained border facies of the granite intrudes nondescript green or brown Pinal Schist having a hackly fracture. The Pinal is darkened, and bedding and vertical cleavage are almost obliterated, for more than 300 feet from the contact. The Pinal also is cut by several silicic dikes probably consanguineous with the granite.

The Pinal Schist is altered in a similar but less intense fashion along the southwest slope of Pinnacle Ridge, where the contact strikes N. 50° W. and dips 30° SW. The Pinal southwest of the contact is almost nonschistose and is darker than normal. The granite is the fine-grained border facies containing abundant micrographic intergrowths of quartz and microperthite. (See p. 64.) A specimen of Pinal Schist collected about 10 feet from the contact is a medium dark-gray dense rock in which a few millimeter-size grains of quartz are the only components identifiable with a hand lens. In thin section the rock consists of angular to subangular clastic grains 0.2–0.5 mm across of quartz and sericitized feldspar, some and perhaps most of which is plagioclase, set in a very fine grained sugary groundmass. Minor components include chert fragments, iron ore, chlorite (penninite), sericite, and apatite. A few veinlets of quartz, epidote, and chlorite cut the hornfels. The rock has a vague layering that may represent bedding. Originally the rock probably was a feldspathic graywacke, now somewhat silicified and whose groundmass is recrystallized.

The small outcrop, shown on the geologic map as Pinal Schist, at the north edge of sec. 11, T. 6 S., R. 20 E., is of fine-grained granulitic gneiss cut by numerous dikes of aplitic Santa Teresa Granite as much as 18 inches wide. The foliation strikes N. 60° E., and the dikes are mainly along this direction, dipping 60°–70° NW. The gneiss is a medium light-gray rock having numerous closely spaced wavy black laminae and an uneven granoblastic texture. The light-colored layers are composed of quartz, dusty and faintly twinned albite, and possibly some orthoclase, in grains most of which are 0.02–0.05 mm across; the largest porphyroblasts are about 2 mm across. The dark layers are mostly of very fine grained brown biotite and contain a little apatite, iron ore, and sphene; the biotite is partly altered to chlorite (penninite). The original nature of the rock is not evident; it may have been a feldspathic graywacke, but it also could have been derived from Laurel Canyon Granodiorite.

From a point half a mile north of the Grand Reef mine northward for nearly 5 miles, the Santa Teresa Granite intrudes Laurel Canyon Granodiorite. The southernmost part of the contact is sharp, and there appears to have been little alteration associated with the emplacement of the granite. Locally, for example in the SW¼ sec. 10, T. 6 S., R. 20 E., Laurel Canyon Granodiorite is cut by aplite dikes as much as a foot wide that must be offshoots of the Santa Teresa Granite; and in the SW¼ sec. 15, the granodiorite is cut by several dikes of Santa Teresa Granite, one of which is 80 feet wide and has aplitic selvages.

Over a large area in the north half of T. 6 S., R. 20 E., however, where the roof of the Santa Teresa pluton seems to have been rather flat, so much Laurel Canyon Granodiorite appears to have been assimilated by Santa Teresa Granite that a transition zone of appreciable thickness separates rocks that can be assigned confidently to one or the other formation; in much of this area the location of the contact is arbitrary. Along Cottonwood Canyon, for example, a zone at least 800 feet wide is underlain by rocks that could belong to either formation; and near the head of the South Fork of Goodwin Canyon, rocks believed to be contaminated Santa Teresa Granite are more than a mile from the nearest outcrop of either Laurel Canyon Granodiorite or Pinal Schist.

Modes of several rocks from Cottonwood and Goat Canyons made with a point counter, are presented in table 5. The rocks of the transition zone are characterized in particular by abundant graphic intergrowths of quartz and microperthite, which are either scarce or lacking in the normal facies of both rocks, and by the lack of a distinct or easily described texture or color.

TABLE 5.—*Modes of rock from the transition zone between Santa Teresa Granite and Laurel Canyon Granodiorite*

| Mineral | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Quartz | 13 | 14 | 40 | 39 | 43 |
| Microperthite | ------- | ------- | 29 | 42 | 39 |
| Graphic quartz-orthoclase | 68 | ------- | ------- | ------- | [1] 52 |
| Plagioclase | 17 | 19 | 30 | 16 | 15 |
| Granophyre | ------- | 65 | ------- | ------- | [2] 3 |
| Other | [2] 2 | [3] 2 | [3] 1 | [4] 3 | ------- |

[1] Not included in summation; includes about 50 percent of the quartz and 75 percent of the microperthite reported in the mode.
[2] Mostly biotite.
[3] Mostly epidote.
[4] Iron ore, epidote, and biotite.

1. Cottonwood Canyon, center sec. 3., T. 6 S., R. 20 E.
2. Ridge between Cottonwood and Goat Canyons, W½ sec. 2, T. 6 S., R. 20 E.
3. Same as (2).
4. Southwest side of west fork, Goat Canyon, NE. cor. sec. 3, T. 6 S., R. 20 E.
5. NW. cor. sec. 1, T. 6 S., R. 20 E.

In secs. 3, 10, and 11, T. 6 S., R. 20 E., several large blocks of Laurel Canyon Granodiorite are engulfed in Santa Teresa Granite. The large elongate xenolith of Laurel Canyon Granodiorite between Cottonwood and Goat Canyons in sec. 11 is in fault contact with aplitic Santa Teresa Granite along both sides; the fault along the northeast side dips 75°–80° NE. and is marked by sheared rocks in both walls. The intrusive contact at the northwest end is almost flat. The granodiorite here is a medium-gray, otherwise nondescript rock that is typical of the transition zone. The mode is given in table 1, column 5. A thin section shows that biotite forms ragged aggregates and is dispersed along grain boundaries and disseminated in feldspar; it appears to be in a process of disintegration brought about by emplacement of the granite.

### GOODWIN CANYON QUARTZ MONZONITE

A sizable area in the northeast corner of the Klondyke quadrangle along the upper parts of the Middle and South Forks of Goodwin Canyon in T. 5 S., R. 20 E., is underlain by a granitoid rock that is here named Goodwin Canyon Quartz Monzonite. It is much more variable in lithology than the Santa Teresa Granite and ranges in composition from leucogranite to diorite. About 8 square miles, or 3 percent of the quadrangle, is underlain by this rock.

The quartz monzonite is only moderately resistant to erosion, less so than the Santa Teresa Granite, and erodes characteristically to fairly steep sided hills and ridges having a sparse cover of vegetation.

No effort was made to record internal structures of the quartz monzonite. The rock is cut by joints that have a north-northwestward trend, roughly parallel to those in the Santa Teresa Granite, and for the most part are vertical.

The contact between quartz monzonite and Bolsa Quartzite, Horquilla Limestone, and the Pinkard Formation in the north-central part of T. 5 S., R. 20 E., is shown on the geologic map as intrusive. Although no contacts are exposed in the area, the contact metamorphic features displayed by both the Horquilla and the Pinkard leave little doubt that such is the relation; by analogy, the contact with the Bolsa is also intrusive. The quartz monzonite is in fault contact with Pinal Schist, Escabrosa Limestone, Santa Teresa Granite, and, in secs. 20 and 21, with Bolsa Quartzite. It is thus known to be of post-early Late Cretaceous (Colorado) age and is considered of Tertiary age, but its age relative to that of the Santa Teresa Granite is unknown; presumably these two granitoid rocks are of about the same age.

#### LITHOLOGY

The Goodwin Canyon Quartz Monzonite varies considerably in mineralogical composition and texture, ranging from equigranular granite, quartz monzonite, and diorite to porphyritic granite and granodiorite and ophitic diorite. Modes of nine rocks, made with a point counter, are given in table 6.

The most common rock type along the South Fork of Goodwin Canyon is a coarse-grained pinkish-gray granite, ranging in composition to near quartz monzonite. The rock is made up of crystals of pink potassium feldspar as much as a centimeter across and smaller grains of quartz and white plagioclase feldspar and is speckled with 1–2 mm grains of biotite. Microscopically, the rock has a hypidiomorphic texture dominated by orthoclase-oligoclase microperthite and quartz. Plagioclase is albite-oligoclase. Greenish-brown biotite forms clusters with sizable grains of sphene and apatite. Iron ore is a minor accessory. The mode of a specimen from near the U.S. National Forest gate in the SE¼ sec. 35 is given in table 6, column 1, and that of a similar rock from the prominent knob half a mile southeast of Monkey Spring in sec. 27 appears in column 2 of the same table.

TABLE 6.—*Modes of Goodwin Canyon Quartz Monzonite.*

| Mineral | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Quartz | 28 | 27.5 | 35 | 38 | 8 | 32 | 30 | 31 | ------ |
| Microperthite | 46 | 56 | 40 | 35 | ------ | 24 | 25 | 14 | ------ |
| Plagioclase feldspar | 24 | 15.5 | 24 | 24 | 22 | 43 | 41 | 54 | 59 |
| Accessories | 2 | 1 | 1 | 3 | 3 | 1 | 4 | 1 | 2 |
| Groundmass | ------ | ------ | ------ | ------ | 67 | ------ | ------ | ------ | ------ |
| Pyroxene | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | 21 |
| Amphibole | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | 18 |

1. Granite, SE¼ sec. 35.
2. Granite southeast of Monkey Spring, sec. 27.
3. Porphyritic aplitic granite, E½ sec. 22.
4. Quartz monzonite, Middle Fork Goodwin Canyon, NE cor. sec. 20.
5. Porphyritic quartz monzonite, NW¼ sec. 22.
6. Granodiorite, northeast of Monkey Spring.
7. Granodiorite, northeast of Monkey Spring (average of two modes).
8. Granodiorite, northeast of Monkey Spring.
9. Diorite, 2,000 ft north of Monkey Spring.

A similar but somewhat finer grained light brownish-gray quartz monzonite underlies a large part of sec. 16. It was not examined in thin section but appears to consist of roughly equal proportions of pink perthite, gray plagioclase feldspar, and quartz, and contains about 5–10 percent of dark minerals, mostly if not entirely biotite.

Pinkish-gray aplitic granite crops out on the high ridge in the E½ sec. 22. Phenocrysts of pinkish-gray potassium feldspar and quartz as much as 7–8 mm across are set in an aplitic groundmass. Microscopically the rock has a fine-grained hypidiomorphic granular groundmass, and is made up of very fine grained microperthite, slightly cloudy albite-oligoclase, and quartz, together with a few somewhat dispersed or vague aggregates of epidote, sphene, iron ore, and apatite that may represent altered biotite. The mode appears in table 6, column 3. Another thin section of a finer grained aplitic granite contains a little biotite and a few spongy grains of allanite partly replaced by epidote. The allanite is strongly pleochroic, with X = yellowish green, Y = greenish brown, and Z = very dark reddish brown, and Z >Y >X.

A pale-red (5*R* 6/2) quartz monzonite facies crops out in the Middle Fork of Goodwin Canyon in the NE. cor. sec. 20. In this area and for at least a quarter of a mile farther down the canyon to the northeast, the quartz monzonite has abundant dark inclusions. The pale-red quartz monzonite has a medium-grained granitoid texture made up of approximately equal amounts of pink potassium feldspar, white to very pale green plagioclase feldspar, and quartz. Microscopically the rock has a moderately cataclastic hypidiomorphic-allotriomorphic granular texture and consists of crystals 1–2 mm across of microperthite, strongly sericitized albite-oligoclase, quartz, sparse epidote in veinlets and small patches, and a little iron ore (fig. 17). The mode appears in table 6, column 4.

The inclusions in the reddish rock are of medium dark-gray fine-grained rock composed almost entirely of hornblende, epidote, and plagioclase feldspar. The rock has a panidiomorphic texture and grains about 0.2 mm across. Hornblende has an extinction angle $Z \wedge c$ of 16° and shows weak zoning and some multiple twins. It is pleochronic, X = pale yellow and Z = pale bluish green. The plagioclase is about $An_{20}$. Iron ore is the only other mineral. The rock is an oligoclase-hornblende lamprophyre, or spessartite.

A strongly porphyritic rock underlies a large area between the Middle Fork of Goodwin Canyon and the Cobre Grande copper deposits. A typical example is a yellowish-gray to white rock containing white or chalky phenocrysts of feldspar as much as 5 mm across and smaller grains of quartz set in a fine-grained matrix. In thin section the phenocrysts are euhedral grains of dusty epidotized and sericitized plagioclase feldspar, and quartz. Sphene in grains as much as 0.5 mm across is an abundant accessory min-

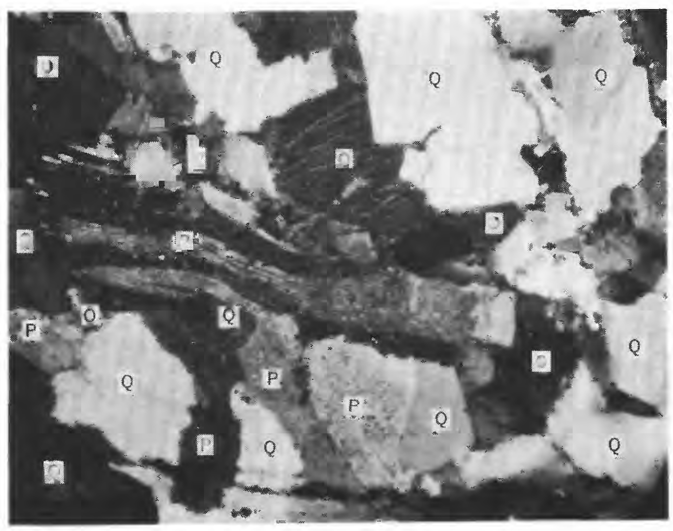

FIGURE 17.—Photomicrograph of cataclastic Goodwin Canyon Quartz Monzonite. Large grain of plagioclase feldspar (P) is bent and broken. Other minerals are orthoclase microperthite (O) and quartz (Q). Crossed nicols, × 44.

eral. The groundmass is a nearly unresolvable aggregate of quartz and potassium feldspar(?). The mode as given in table 6, column 5 sheds little light on the composition of this rock, but it presumably is near quartz monzonite.

A large part of the Goodwin Canyon Quartz Monzonite northeast of Monkey Spring is light-colored porphyritic granodiorite. This facies is made up of phenocrysts 1–5 mm across of very dusty perthite and sericitized plagioclase feldspar; interstitial large poikilitic grains of quartz 1–4 mm across, in micropegmatitic intergrowths with feldspar; and accessory sphene, epidote, and apatite. Biotite occurs as sparse tiny inclusions in the cores of plagioclase crystals. In one specimen, pale-green hornblende forms ragged clots that may be disrupted inclusions of lamprophyre similar to that described previously. The plagioclase is mostly oligoclase, but in one rock it is zoned normally from $An_{55}$ in the cores to $An_{10}$ at the rims; the cores are extensively altered to sericite, whereas the rims are clear. In another rock, nonperthitic orthoclase fills interstices between plagioclase grains. Modes of these granodiorites are given in table 6, columns 6, 7, and 8; the rocks of columns 6 and 7 are very close to quartz monzonite in composition.

Small amounts of a greenish-gray to dark-gray dioritic rock occur here and there in the quartz monzonite, both as inclusions and as larger bodies of uncertain origin. One such mass crops out about 2,000 feet north of Monkey Spring near the line between secs. 22 and 27; this body is perhaps 1,000 feet long. It ranges lithologically from a greenish-gray medium-grained diorite, composed largely of plagioclase feldspar, to a coarse-grained rock containing ophitic grains of uralitized pyroxene as much as a centimeter across. Microscopically the medium-grained rock has an intergranular or vaguely ophitic texture, and contains colorless pyroxene interstitial to millimeter-size grains of weakly zoned labradorite ($An_{50-60}$). Much of the pyroxene is altered to colorless amphibole having an extinction angle $Z \wedge c$ of 16°–17°. A few small aggregates of biotite and sphene are accessory. An approximate mode is given in table 6, column 9; the percentage of combined pyroxene and amphibole is accurate, but their relative proportions probably are not.

The rock exposed near the spring in the Middle Fork of Goodwin Canyon in the NW¼ sec. 21 is a greenish-black diorite containing ophitic grains of hornblende as large as 1 cm across. As seen under the microscope, crystals 0.5–1 mm long of plagioclase feldspar are enclosed in an ophitic base of uralitic hornblende. The feldspar is zoned normally from $An_{60}$ in the cores to $An_{40}$ at the rims; many grains are bent or broken. Hornblende forms both large ophitic grains and fine-grained aggregates. It is pleochroic and X = pale yellow brown, Y = light blue green, and Z = deep blue green. Iron ore is a common accessory. A striking feature of one thin section is the veinlet of hornblende shown on figure 18.

#### CONTACT EFFECTS OF GOODWIN CANYON QUARTZ MONZONITE

In the north-central part of T. 5 S., R. 20 E., Horquilla Limestone for as much as 1,500 feet from its contact with Goodwin Canyon Quartz Monzonite is converted to massive garnetite. Were it not for the preservation of a few small remnants of fossiliferous limestone within the garnetite, the identity of the limestone would be unknown, as in general the replacement by garnet is complete. The garnetite consists of fine-grained (generally less than 1 mm) light-olive moderately birefringent garnet having a refractive index of about 1.875, indicating a variety very high in andradite (Winchell and Winchell, 1951, p. 485).

The Pinkard Formation on the ridge in the E½ sec. 17 consists of well-bedded dark-colored siltstone and sandstone. Near the contact with the quartz monzonite in the NE cor. sec. 17, the Pinkard is converted to typical hornfels. Exposures of the contact rocks are so poor that no study was attempted.

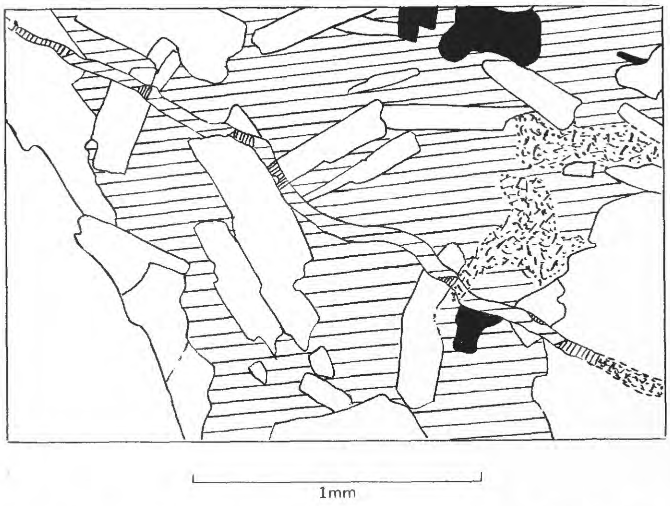


FIGURE 18.—Sketch of photomicrograph of veinlet of hornblende in in ophitic hornblende diorite facies of the Goodwin Canyon Quartz Monzonite. Widely spaced crosshatching represents cleavage of a single grain of uralitic hornblende; stippled areas are felted mesh of fine-grained hornblende. White, plagioclase feldspar; black, iron ore. Where vein walls are hornblende, veinlet is a single grain in optical continuity with the host; the darker color of the host is due to dark inclusions. Where walls are plagioclase feldspar, parts of veinlet consist of same hornblende but in cross-fiber relation (closely spaced crosshatching) to vein walls.

## GALIURO VOLCANICS

### DISTRIBUTION

The Galiuro Mountains extend along the entire west edge of the Klondyke quadrangle and constitute the divide between Aravaipa Valley to the east and the valley of the San Pedro River to the west. In the Klondyke quadrangle the mountains are made up almost entirely of a thick section of gently dipping volcanic rocks of Tertiary age. The principal occurrences of other rocks are small areas of Paleozoic sedimentary rocks at the Table Mountain mine, Paleozoic and Cretaceous(?) sedimentary rocks in upper Copper Creek, and about 6 square miles of older volcanic rocks and granodiorite in the Copper Creek area. The belt of outcrops of volcanic rocks is continuous over a north-south distance of somewhat more than 17 miles, and ranges in width from less than a mile in lower Horse Camp Canyon to about 5 miles at the north and south edges of the quadrangle. These rocks are correlated tentatively with the Galiuro Volcanics of Cooper and Silver (1964) and are referred to as such in this report. About 63 square miles, or 25 percent of the quadrangle, is underlain by Galiuro Volcanics.

Some of the rocks of the Galiuro Volcanics, particularly some very coarsely porphyritic andesite, resemble those of the Horse Mountain Volcanics of the Turnbull and Santa Teresa Mountains. However, the two areas of outcrop are separated by from 2 to 7 miles of terrain underlain by younger rocks, and no sequence that would permit an unequivocal correlation has been recognized; therefore it has seemed preferable to describe separately the rocks of the two formations, noting the various points of similarity.

The Galiuro Volcanics are known to extend southeastward for some 50 miles, as far as the southeast end of the Winchester Mountains, a name applied to the southeast prong of the Galiuro Mountains. They are also known to extend northward into the Stanley quadrangle, northwestward into the Christmas quadrangle (Wilden, 1964), and westward into the Holy Joe Peak quadrangle.

### THICKNESS

The entire section of the Galiuro Volcanics is not exposed at any one locality, and the lenticular nature of several of the major units within the formation precludes any precise estimate of thickness. Local minimum thicknesses are 700 feet on the north side of Lookout Mountain, 1,000 feet in Aravaipa Canyon at the west edge of the quadrangle, 750 feet in the deepest part of Oak Grove Canyon, and 1,250 feet on the southwest side of Little Table Mountain. The sum of the maximum thicknesses of the principal units exposed between Ash Creek, near the north edge of the quadrangle, and the base of the formation at the head of Copper Creek is about 5,600 feet; and to this total probably should be added an uncertain but appreciable thickness, at least 900 feet, of andesitic rocks that occur only in and near Fourmile Creek.

### STRATIGRAPHIC RELATIONS

The base of the Galiuro Volcanics is exposed in only two places. In the southwest corner of the quadrangle, from the west edge of the map area southeast for 2.5 miles, the formation rests disconformably or unconformably on Glory Hole Volcanics. Farther southeast along the same contact, the Galiuro Volcanics overlie unconformably Escabrosa Limestone, clastic sedimentary rocks of presumed Cretaceous age, Martin Formation, Copper Creek Granodiorite, and Bolsa(?) Quartzite. The Glory Hole and Galiuro Volcanics so closely resemble each other along much of their contact, particularly at the head of Dry Camp Canyon (secs. 27 and 34, T. 7 S., R. 18 E.) that the separation of the two formations was made somewhat arbitrarily. Locally, a bed of conglomerate 5–10 feet thick, overlain in places by a few feet of red tuff, intervenes between the andesite flows of the Galiuro Volcanics and the uppermost welded tuff of the Glory Hole Volcanics.

In the vicinity of the Table Mountain mine (sec. 15, T. 7 S., R. 18 E.), the Galiuro Volcanics rest on Escabrosa Limestone and to a minor extent on beds that may belong to the Martin Formation.

Along almost the entire east edge of their outcrop area, the Galiuro Volcanics are overlain with marked unconformity by Hell Hole Conglomerate or are in fault contact with the conglomerate. Small outliers of conglomerate cap the volcanics in upper Booger Canyon (east edge sec. 25, T. 5 S., R. 18 E.) and just north and south of Aravaipa Canyon.

Some evidence points to the likelihood of two or possibly three unconformities within the Galiuro Volcanics at the following stratigraphic horizons: (1) Base of upper andesite. The upper andesite unit of the Horse Canyon region rests on the rhyolite-obsidian unit in the northern part of the outcrop area, but a very similar andesite overlies the intermediate andesite unit in the eastern part of the Aravaipa Canyon section, and this intermediate andesite in turn underlies the rhyolite-obsidian unit farther down the canyon; if the two upper andesites are indeed the same, then either the rhyolite-obsidian unit is extremely lenticular or there is an unconformity between it and the overlying upper andesite. (2) Base of upper tuff. A coarse-grained tuff, the upper tuff unit, overlies the rhyolite-obsidian unit north of Ash Creek and also just north of Aravaipa Canyon. At Aravaipa Canyon the tuff also overlaps the contact between upper andesite and the underlying rhyolite-obsidian unit, and the contact is clearly unconformable, but the regional extent is uncertain; farther south the upper tuff rests on the intermediate andesite, and both the upper andesite and the rhyolite-obsidian unit are missing, but whether as a result of erosion or nondeposition could not be determined. (3) Top of lower andesite. At the south end of the outcrop area, the upper part of the lower andesite unit contains 800–900 feet of heterogeneous andesitic lavas, flow breccias, and tuffs that are missing farther north. Furthermore, at one place welded tuff correlated doubtfully with the lower welded tuff unit rests directly on rocks that elsewhere are overlain by several hundred feet of lower andesite. Although the exact relations among the various volcanic rocks exposed in the Right Prong of Fourmile Creek could not be worked out satisfactorily, it seems likely that an unconformity of at least local extent exists at the top of the lower andesite unit.

### LITHOLOGY

The Galiuro Volcanics are divided on the basis of lithology into 12 major units, 3 of which have subunits of more restricted occurrence.

The formation is made up of lavas ranging in composition from rhyolite to olivine andesite or basaltic andesite, tuff of approximately the same compositional range but in which the silicic types greatly predominant, welded tuff of rhyolitic to quartz latitic composition, and coarse silicic pyroclastic rocks. If the aggregate thickness of the formation is taken as 6,500 feet, then andesite and olivine andesite account for about 3,100 feet, or 48 percent of the thickness; silicic lava, tuff, and welded tuff for about 2,400 feet, or 37 percent; rhyolitic lava and obsidian for about 700 feet, or 10.5 percent; and coarse silicic tuffs for about 300 feet, or 4.5 percent. If a broad division is made into andesite on one hand and more silicic rocks on the other, then the proportions would be approximately 48 percent of the andesite group and 52 percent of the more silicic rocks.

The various units will be described in ascending stratigraphic order.

### LOWER ANDESITE UNIT

The most extensive lithologic unit of the Galiuro Volcanics is the lower andesite, which crops out over an area of about 27 square miles near the southwest corner of the quadrangle. The summit of the Galiuro Mountains from the west edge of the quadrangle southeastward for nearly 7 miles is underlain by the lower andesite unit. Included in the unit and shown separately on the geologic map are a subunit of silicic lava and subordinate tuff, three small accumulations of dominantly pyroclastic rocks believed to be fossil ash cones, and a sequence of heterogeneous silicic volcanic rocks.

In many places the lower andesite unit is more than 1,000 feet thick. In a valley tributary to Copper Creek in the eastern part of sec. 36, T. 7 S., and sec. 1, T. 8 S., both R. 18 E., an estimated 1,300 feet of lower andesite overlies Paleozoic and Mesozoic rocks and Copper Creek Granodiorite. On the southwest slope of Little Table Mountain, about 1,150 feet of lower andesite is exposed between the underlying Glory Hole Volcanics and the overlying lower welded tuff unit; and on the north side of the mountain, a similar thickness of andesite rests on Paleozoic rocks of the Table Mountain mine area. At the south edge of the quadrangle along a tributary of Copper Creek, the lower andesite is more than 900 feet thick.

The basal contact of the lower andesite was described briefly in the section on stratigraphic relations (p. 69). At the Table Mountain mine in secs. 15 and 22, T. 7 S., R. 18 E., the andesite rests on an irregular surface of considerable relief cut on limestone or jasperoid of the Escabrosa Limestone or on the Martin(?) Formation. Locally, as in the westernmost branch of Virgus Canyon in sec. 15, the base of the andesite is a thin conglomerate composed almost entirely of small fragments of limestone and jasperoid; the conglomerate fills shallow channels on the underlying limestone, and the limestone itself is altered to a pinkish color for 1–3 feet below the contact.

In Copper Creek, the lower andesite rests in erosional unconformity on Copper Creek Granodiorite and to a lesser extent on Bolsa Quartzite and on arkosic sandstone and quartzite of possible Cretaceous age. The base of the andesite is indurated red conglomerate having a tuffaceous matrix, in beds 0.5–3 feet thick. The lower part of the conglomerate contains abundant angular fragments of Copper Creek Granodiorite together with quartzite and volcanic rocks. Locally the granodiorite has a red or tan weathered zone just below the volcanics. Prevolcanic local relief on the granodiorite was at least 100 feet, and the valleys in part at least were filled with conglomerate prior to eruption of the andesite.

Near the head of Dry Camp Canyon in sec. 27, T. 7 S., R. 18 E., the base of the unit is a thin bed of red tuff that rests on welded rhyolitic tuff and breccia assigned to the Glory Hole Volcanics. In the SW. cor. sec. 26 is an outcrop 200–500 feet long and 10–15 feet thick of clean white quartzite, most of which is pervasively brecciated. This rock lies between the basal flows of the lower andesite and the upper silicic tuff and breccia of the Glory Hole Volcanics, but the field relations are obscure because of poor exposures. The intimate brecciation of the quartzite suggests that the outcrop may be that of a large landslide block; no other explanation comes to mind. The nearest occurrence of similar quartzite is a little more than 2 miles southeast, where coarse-grained quartzite of unknown age forms large xenoliths in Copper Creek Granodiorite. Float boulders of similar rock were seen in uppermost Parsons Canyon in sec. 25, T. 7 S., R. 18 E., but the rock was not found in place.

Along its upper contact the andesite is overlain principally by the lower welded tuff unit in the northwestern part of the outcrop area and by Hell Hole Conglomerate in the eastern part.

The lower andesite is made up predominantly of a monotonous succession of red, purple, or gray andesite or basaltic andesite flows, flow breccias, and agglomerates 15–50 feet thick. Tuff is not abundant, and most tuffs are light colored and appear to be more silicic than andesite. The lavas are dense fine-grained rocks, generally containing small phenocrysts of olivine, and many are vesicular or amygdaloidal. The flows commonly have a red or orange flow breccia at the base and a scoriaceous top. A lens of buff to violet tuffaceous conglomerate 200–300 feet long and less than 5 feet thick is intercalated in the andesite flows on the ridge between Parsons and Virgus Canyons in sec. 23, T. 7 S., R. 18 E.

On the ridges between the Table Mountain mine and Little Table Mountain, the bulk of the lower andesite unit, at least 800 feet thick, consists of fine-grained reddish-gray or grayish-red platy lavas containing phenocrysts of plagioclase feldspar and sparse olivine. Included in this section is an accumulation of coarse agglomerate, consisting of blocks of black lava as much as 2 feet across embedded in a light-green or red fragmental matrix; this rock probably is a vent- or near-vent-agglomerate. Locally west of the mine, the base of the unit is a purplish-gray to black fine-grained flow breccia containing phenocrysts of olivine only. On the prominent knob about half a mile west of the mine, the andesite contains a red open-textured coarse agglomerate made up of fragments 2–5 cm across of purplish-black vesicular porphyritic andesite in a sparse fragmental matrix. The rocks between here and the Escabrosa Limestone to the north are gray and grayish-red flows of olivine andesite.

The upper part of the lower andesite unit in upper Oak Grove Canyon is a sequence of highly laminar fine-grained gray to dark reddish-purple lava flows that weather a blotchy bright red and are cut by prominent joints perpendicular to the lamination. Some of the flows contain abundant red phenocrysts of a completely altered mafic mineral, probably olivine, and a few small plagioclase feldspar phenocrysts in a stony groundmass; others are platy vesicular rocks that do not contain phenocrysts. On the hill shown by the 5,000-foot contour on the west edge of sec. 13, T. 7 S., R. 18 E., a sequence of at least five andesite flows, each about 20 feet thick, is capped by a platy grayish-red vesicular andesite containing sparse phenocrysts of feldspar and pyroxene. In thin section, crystals of these minerals together with some of iron ore are set in a fine-grained intergranular matrix composed of plagioclase microlites about 0.05 mm long, pyroxene, iron ore, and considerable interstitial irresolvable material of low relief and birefringence, probably potassium feldspar. Plagioclase phenocrysts are 0.2–0.5 mm across and are about $An_{60-65}$ in composition. Colorless clinopyroxene forms phenocrysts as much as 0.5 mm across; some is in aggregates with plagioclase and iron ore.

A chemical analysis and norm of the rock from the top of hill 5000 follow, together with the chemical composition and norm of Nockolds' (1954) average doreite for comparison. A semiquantitative spectrographic analysis of the same rock is given in table 2, column 6.

*Chemical analyses, in percent, of andesite and average doreite*

| Bulk analysis | | | Normative minerals | | |
|---|---|---|---|---|---|
| Constituent | 1 | 2 | Mineral | 1 | 2 |
| $SiO_2$ | 57.59 | 56.00 | Q | 10.68 | 7.2 |
| $Al_2O_3$ | 16.70 | 16.81 | or | 17.24 | 15.6 |
| $Fe_2O_3$ | 6.55 | 3.74 | ab | 34.06 | 29.9 |
| FeO | .99 | 4.36 | an | 18.90 | 22.2 |
| MgO | 2.15 | 3.39 | wo | 1.74 | 4.1 |
| CaO | 5.27 | 6.87 | en | 5.40 | 8.5 |
| $Na_2O$ | 4.05 | 3.56 | fs | -------- | 3.0 |
| $K_2O$ | 2.87 | 2.60 | mt | -------- | 5.3 |
| $H_2O+$ | .72 | .92 | hm | 6.55 | -------- |
| $H_2O-$ | 1.02 | -------- | il | 2.28 | 2.4 |
| $TiO_2$ | 1.37 | 1.29 | ti | .39 | -------- |
| $P_2O_5$ | .38 | .33 | ap | 1.01 | .8 |
| MnO | .10 | .13 | | | |
| $CO_2$ | .01 | -------- | | | |
| Cl | .01 | -------- | | | |
| F | .06 | -------- | | | |
| Subtotal | 99.84 | -------- | -------- | -------- | -------- |
| Less O | .03 | -------- | -------- | -------- | -------- |
| Total | 99.81 | -------- | -------- | -------- | -------- |
| Powder density | 2.71 | -------- | -------- | -------- | -------- |

1. Andesite flow in lower andesite unit, Galiuro Volcanics, west edge sec. 13, T. 7 S., R. 18 E. Laboratory No. F2681. Analyst, Dorothy F. Powers, U.S. Geol. Survey. The rock is chemically similar to both latite and andesite and might therefore be called rhyoandesite.
2. Average doreite (Nockolds, 1954, table 5, col. 2).

The thick section of lower andesite in sec. 36, T. 7 S., and sec. 1, T. 8 S., both R. 18 E., is made up for the most part of numerous flows 20–50 feet thick of highly vesicular purplish-gray fine-grained olivine andesite having prominent red scoriaceous tops and bottoms. A specimen from near the base of the unit is a grayish-red (10*R* 4/2) practically nonporphyritic slightly amygdaloidal rock that in thin section contains only sparse phenocrysts 0.1–0.5 mm across of altered olivine in an intersertal groundmass. Olivine is altered to pseudomorphs of weakly pleochroic yellow to brown iddingsite. The groundmass consists of plagioclase microlites (about $An_{40}$) 0.1–0.3 mm long and interstitial iron ore, olivine, pyroxene, and considerable devitrified brownish glass.

Just southwest of the large outcrop of the latite subunit in the NE¼ sec. 33, T. 7 S., R. 19 E., the south fork of the Right Prong of Fourmile Creek is floored for 2,000 feet upstream by a coarse-grained grayish-red (10*R* 4/2) very uniform andesite that probably is the center of a thick flow, although it could possibly be a sill within the unit. Microscopically, the rock consists principally of plagioclase feldspar ($An_{50-55}$, zoned to $An_{0-10}$ at the rims) and clinopyroxene in a hypidiomorphic aggregate of crystals 1–5 mm across. A few grains of blackish-orange iron oxide may be altered olivine. The pyroxene is a colorless type in which $Z \wedge c = 43°$; multiple twins are common. A very small amount of potassium-bearing material occult in the groundmass is revealed by staining with sodium cobaltinitrite.

On Little Table Mountain the top of the lower andesite immediately underlying the lower welded tuff is a flow 50–60 feet thick of coarsely porphyritic ("turkey-track") andesite, having a scoriaceous top, that weathers to very rough outcrops. This rock type is widely distributed in the Galiuro Volcanics as well as in the Horse Mountain Volcanics of the Turnbull Mountains.

A specimen from the middle of the flow is a dark-gray highly vesicular rock. In thin section, it contains euhedral phenocrysts of plagioclase feldspar ($An_{55-65}$) 2–10 mm across, and smaller grains of olivine in an intergranular groundmass. The plagioclase phenocrysts show multiple oscillatory zoning within a narrow range. Olivine is completely altered to orange iddingsite. One small phenocryst of clinopyroxene was seen, but otherwise pyroxene seems to be confined to the groundmass, which consists of a mesh of plagioclase microlites ($An_{20}$) and interstitial iron ore, pyroxene, and fine-grained potassium feldspar(?).

A chemical analysis and norm of this rock are given below, together with the chemical composition and norm of Nockolds' (1954) average doreite for comparison. A semiquantitative spectrographic analysis of the same rock is in table 2, column 7.

*Chemical analyses, in percent, of porphyritic "turkey-track" andesite and average doreite*

| Bulk analysis | | | Normative minerals | | |
|---|---|---|---|---|---|
| Constituent | 1 | 2 | Mineral | 1 | 2 |
| $SiO_2$ | 52.45 | 56.00 | Q | 4.38 | 7.2 |
| $Al_2O_3$ | 16.99 | 16.81 | or | 16.12 | 15.6 |
| $Fe_2O_3$ | 6.11 | 3.74 | ab | 31.96 | 29.9 |
| FeO | 2.88 | 4.36 | an | 21.41 | 22.2 |
| MgO | 3.10 | 3.39 | wo | 3.36 | 4.1 |
| CaO | 7.02 | 6.87 | en | 7.70 | 8.5 |
| $Na_2O$ | 3.79 | 3.56 | fs | ------- | 3.0 |
| $K_2O$ | 2.71 | 2.60 | mt | 4.41 | 5.3 |
| $H_2O+$ | .86 | .92 | hm | 3.04 | ------- |
| $H_2O-$ | 1.08 | ------- | il | 3.50 | 2.4 |
| $TiO_2$ | 1.79 | 1.29 | ap | 1.68 | .8 |
| $P_2O_5$ | .67 | .33 | | | |
| MnO | .13 | .13 | | | |
| $CO_2$ | .13 | ------- | | | |
| Cl | .01 | ------- | | | |
| F | .07 | ------- | | | |
| Subtotal | 99.79 | ------- | ------- | ------- | ------- |
| Less O | .03 | ------- | ------- | ------- | ------- |
| Total | 99.76 | ------- | ------- | ------- | ------- |
| Powder density | 2.79 | ------- | ------- | ------- | ------- |

1. Porphyritic "turkey-track" andesite, Little Table Mountain (N½ sec. 27, T. 7 S., R. 18 E.), at top of lower andesite unit, Galiuro Volcanics. Laboratory No. F2682. Analyst, Dorothy F. Powers, U.S. Geol. Survey.
2. Average doreite (Nockolds, 1954, table 5, col. 2).

Except for having a somewhat lower silica content and a much higher ratio of ferric to ferrous iron (probably to be explained in part by the abundance of magnetite and the scarcity of pyroxene), the Little Table Mountain rock is chemically very similar to average doreite.

Nearly identical "turkey-track" andesite crops out in the same stratigraphic position on west side of the east fork of Oak Grove Canyon near the south end of the line between secs. 17 and 18, T. 7 S., R. 19 E.

Some of the "turkey-track" andesite exposed in the lower Right Prong of Fourmile Creek is pillow lava, having irregular somewhat flattened pillows as much as 5–6 feet long. The individual pillows have a prominent concentric layering, and a scoriaceous rim marked by large platy plagioclase phenocrysts oriented parallel to the surface of the pillow and a massive core having less uniformly oriented plagioclase plates. Small amounts of grayish-red silty material fill interstices among the pillows. The rock from the cores is a brownish-gray andesite rather typical of the "turkey-track" type. It is made up of euhedral plagioclase feldspar plates 0.5–1.5 cm across and scattered millimeter-size grains of altered olivine in a fine-grained matrix. Microscopically the plagioclase phenocrysts are completely altered to sodic plagioclase, probably nearly pure albite, and carbonate, and olivine is completely altered to carbonate, serpentine, and iron oxide. The intersertal groundmass consists of plagioclase microlites thoroughly altered to carbonate, and interstitial pale-brown devitrified glass, iron ore, hematite, and apatite. The material interstitial to the pillows is made up of angular fragments, mostly less than 0.1 mm across, of quartz and feldspar in a very fine grained matrix of dusty granular quartz.

The rocks along the northeastward-trending ridge in the SE¼ sec. 4, T. 8 S., R. 19 E., southeast of Mescal Peak include the following, from bottom to top:

1. Dark-purple conspicuously porphyritic andesite containing scattered grains of bronze-red (altered olivine?) and greenish (altered pyroxene?) mafic minerals. Includes some tan to buff porphyritic vesicular andesite or latite containing quartz amygdules, and also some grayish-green or olive coarse-grained porphyritic andesite that weathers to well-developed spheroids.
2. A gray, green, or purple massive flow of porphyritic andesite about 300 feet thick, becoming vesicular and amygdaloidal toward the top. In thin section, an olive-gray (5*Y* 3/2) rock from near the center of the flow has a hypidiomorphic texture. It is made up of about 75 percent plagioclase feldspar ($An_{52-55}$, zoned near the rims to albite) in grains as much as 5 mm long, and 25 percent colorless clinopyroxene in grains 0.5–2 mm across, a little iron ore, abundant tiny needles of apatite, and appreciable amounts of a yellow micaceous mineral of moderate birefringence and refractive index $>1.54$, possibly nontronite. The immediately overlying rock has sparse interstitial pale-brown slightly devitrified glass that may represent original material from which the yellow micaceous mineral was derived.
3. A monotonous sequence of thin flows of purple or gray vesicular porphyritic andesite, about 300 feet thick.
4. A thick flow of gray porphyritic andesite containing rusty red phenocrysts of plagioclase feldspar, flows and flow breccias of red to purple porphyritic andesite containing pyroxene phenocrysts altered to an apple-green aggregate, and dark-purple fine-grained andesite containing abundant vesicles lined with a green micaceous mineral, perhaps celadonite.
5. A cliff-forming flow a few tens of feet thick of violet to grayish-purple medium-grained andesite containing sparse phenocrysts of biotite and of pyroxene(?) altered to a greenish or cream-colored aggregate.
6. On the crest of the Galiuro Mountains, at the south edge of sec. 4, T. 8 S., R. 19 E., about 200 feet of grayish-red (5*R* 4/2) platy porphyritic andesite having well-developed flow layering. In thin section, this rock contains phenocrysts of plagioclase feldspar ($An_{45}$) as much as 3 mm across, and sparse smaller grains of altered clinopyroxene and iron ore in a matrix of very dusty devitrified glass. Plagioclase phenocrysts are rounded and are strongly zoned to albite near the rims.

The summit of Mescal Peak itself is made up of grayish-red hard porphyritic andesite flows and flow breccias containing numerous small quartz amygdules. Southwest of hill 5648, to the southwest of Mescal Peak, the upper part of the unit contains at least 9 reddish to purplish flows of porphyritic pyroxene andesite 10–30 feet thick that dip 8°–10° NE.

Farther south of Mescal Peak, as far as the quadrangle boundary, the crest of the Galiuro Mountains is made up of a pile of red or purple vesicular and sparsely porphyritic andesite flows, some containing large quartz amygdules. The rocks on the 6,000-foot hill on the south edge of the quadrangle in sec. 9, T. 8 S., R. 19 E., are reddish-purple flat-lying very platy fine-grained to sparsely porphyritic andesites. A specimen from this hill is a streaked dusky red to pale-red porphyritic rock having a very fine grained groundmass. Microscopically, this rock has euhedral phenocrysts of zoned plagioclase feldspar ($An_{45-20}$) and smaller sparse grains of clinopyroxene set in a dusty pilotaxitic groundmass of plagioclase microlites (about $An_{20}$) 0.02–0.05 mm long. Along the flow layering are lenses a millimeter or so thick of coarse granular quartz, which may be fillings of stretched vesicles. Toward the northwest, the sequence includes some greenish-gray hard sandy tuff and purplish tuff and breccia in the upper part, and also some tuff and breccia near the base, overlying the ash cone of Copper Creek. (See below.)

From the vicinity of the Lackner Ranch, at the confluence of the Right and Left Prongs of Fourmile Creek, southeastward to the quadrangle edge, the unit includes flat-lying light-gray, tan, white, or pinkish fine-grained porphyritic rocks of uncertain composition, possibly latite, in addition to the usual purple, red, or gray porphyritic and amygdaloidal andesites.

A rather heterogeneous group of silicic lavas and subordinate tuffs that crop out principally along the Right Prong of Fourmile Creek and its tributaries is intercalated in the lower andesite and is shown separately on the map. The dominant rock type appears to be latite. Rocks assigned to this subunit have a total outcrop area of only about 1.5 square miles, most of which is in secs. 20, 28, 29, and 32, T. 7 S., R. 19 E.

The latite subunit is highly lenticular and varies so much in thickness that a figure for average thickness would have little meaning. On the southwest side of the hill in the SE¼ sec. 29, where the contacts are best exposed, the subunit has a maximum thickness of

200–250 feet, but on the southeast side of the same hill it pinches out. The large isolated outcrop farther south in sec. 32 has a maximum thickness of nearly 500 feet, which also diminishes to zero half a mile northeast. At the head of Turkey Creek in the north part of sec. 29 the latite has an apparent thickness, calculated from the dip of the basal contact, of about 800 feet, but this figure seems excessive in comparison with thicknesses elsewhere.

The basal contact of the latite, wherever exposed, appears to be conformable. The base is well exposed in the deep canyon tributary to the Right Prong of Fourmile Creek in the SE¼ sec. 32, T. 7 S., R. 19 E., where flow breccia and purple andesitic tuff of the lower andesite are overlain in sharp contact by 1–2 feet of green silicic tuff of the latite subunit. All the rocks are fresh, and no evidence was found of an erosional unconformity at the top of the andesite. Half a mile or so farther north, on the north side of the Right Prong, brown stony devitrified vitrophyre and coarse-grained flow breccia of the latite subunit rest on practically flat-lying dark-purple amygdaloidal andesite. The base of the outcrop in the NE¼ sec. 33 is also a flow breccia.

The upper contact of the latite, although locally conformable, is disconformable in most places. On the southeast side of hill 5500 in the SE¼ sec. 29, the latite is overlain by "turkey-track" andesite that dips about 10° N.; the surface on the latite slopes as steeply as 60° and the andesite appears to fill an old valley eroded in the latite. On the north and west sides of the same hill, the latite, dipping 20°–30° E., is overlain by flat-lying welded tuff correlated rather doubtfully with the lower welded tuff unit, and several hundred feet of lower andesite apparently is missing.

The latite subunit in the central part of sec. 20, T. 7 S., R. 19 E., is a heterogeneous assemblage of laminated gray and purple porphyritic latite lavas, massive red and yellow agglomerate, and other rocks that dip about 30° NE. Farther south, in the N½ sec. 29, the subunit is made up mostly of purple to gray finely laminated (almost slaty) very fine grained lava containing phenocrysts of biotite and feldspar. The rock has a clear ring when struck with a hammer. The base of the subunit is several tens of feet of welded breccia. West of hill 5500 in the SE. cor. sec. 29, the subunit consists of very fine grained streaked gray and red practically nonporphyritic lavas containing many tiny flecks of biotite(?). South of this hill the subunit includes a layer 25–30 feet thick of brown vitrophyre containing abundant pods of red devitrified material usually 2–10 cm across.

The latite in sec. 32 consists, from bottom to top, of 1–2 feet of green silicic tuff, 8–10 feet of chaotic coarse-grained breccia, 10–15 feet of brown laminated somewhat devitrified biotite obsidian, and gray to violet slaty lava containing abundant quartz-lined bubbles. The breccia consists of angular blocks as much as several feet across of pale-green fine-grained stony or almost glassy volcanic rock in a slightly darker fragmental matrix of the same material; phenocrysts are scarce in both blocks and matrix. The uppermost lava is a very fine grained laminated vesicular and porphyritic latite(?) containing abundant phenocrysts of biotite and feldspar.

The small isolated outcrop of the subunit in the S½ sec. 33 consists of rhyolite flow breccia.

Near the center of the line between secs. 27 and 28, the base of the latite subunit is 20–25 feet of distinctive greenish to cream-colored lithic-vitric rhyolite tuff breccia. The tuff contains crystals of quartz and feldspar and numerous angular fragments as much as 4 cm across of purple and red very fine grained volcanic rock. Some fragments are of light-violet porphyritic rhyolite containing large phenocrysts of feldspar. Most of the fragments are probably cognate. The tuff-breccia is overlain by a massive silicic rock, perhaps a completely welded version of a similar rock.

The mass of latite in the NE¼ sec. 33, T. 7 S., R. 19 E., is a thick stubby lens of lava having highly contorted flow layering. At the southeastern tip of the outcrop in the south fork of the Right Prong, both the top and the bottom contacts of the latite are exposed; and at the north end of the outcrop, the basal contact is poorly exposed in the north folk of the Right Prong; elsewhere only the upper contact crops out. The highly lenticular shape of the mass and the contorted flow laying suggest that it is a near-vent accumulation of viscous lava, but no vent was recognized. A specimen from near the center of the outcrop is a streaked pale-red (5*R* 6/2) and light-gray dense fine-grained rock containing a few 1–2 mm phenocrysts of feldspar and biotite. Under the microscope, crystals of sanidine perthite, sodic plagioclase, blackened biotite, and a little apatite and iron ore are set in a patchily birefringent groundmass having an aggregate refractive index less than 1.54. The feldspar phenocrysts are rather altered and tend to tear out of the thin section during grinding, so that only a few integral grains remain. Sanidine grains have scattered irregular perthitic inclusions of plagioclase and also are rimmed with very finely twinned plagioclase feldspar of uncertain origin. The composition of the groundmass is uncertain, but probably both potassium and plagioclase feldspar are present. Although there are no true microlites, there is nevertheless a suggestion of flow laying indicated by vague incipient grains of some feldspar.

The three narrow northwestward-trending tongues mapped as latite submit in the E½ sec. 28 are faulted parts of a single lens of streaked red and gray biotite rhyolite intercalated in the lower andesite unit. The rock is rather different from the rest of the latite subunit; it contains much more biotite and has a strong textural resemblance to welded tuff, and is probably a little higher in the section inasmuch as it rests in part on "turkey-track" andesite which elsewhere rests on the latite; however, it is grouped with the latite as it probably represents about the same interruption in the effusion of andesitic lavas that constitute the bulk of the lower andesite unit.

An accumulation of dominantly pyroclastic volcanic rocks in the SW¼ sec. 5, T. 8 S., R. 19 E., is interpreted as a fossil volcanic cone. The cone has a small core or neck of dark-gray very fine grained hard volcanic rock that is exposed only in the bottom of Copper Creek in the narrow gorge just southwest of the closed 5,000-foot contour in the center of the SW¼ sec. 5. Arranged around this core and having quaquaversal dips of 10°–45° is an accumulation of tuff, breccia, agglomerate, and volcanic conglomerate. In the northeast part of the outcrop, the pyroclastic section consists, from top to bottom, of 16 feet of cream-colored well-sorted crossbedded thoughly indurated clean sandy vitric tuff, 15–20 feet of well-bedded pale greenish-yellow vitric tuff and vitric-lithic tuff and breccia, and an unknown thickness of purple fine-grained to sandy andesitic tuff. At least the upper part of the sequence is waterlaid, and perhaps accumulated in shallow water near the postulated source vent. In this section a pale-red (5*R* 6/2) tuff near the top is composed almost entirely of subrounded to subangular grains of devitrified glass 0.2–0.5 mm in diameter, and sparse cement of iron oxide and very fine grained quartz. Scattered grains of biotite, sodic plagioclase, and iron ore are the only crystal components. The glass has a refractive index well below 1.54.

Conglomerate is well exposed upstream from the core and is a blue-gray, violet, or grayish-purple coarse-grained well-indurated rock made up of angular to subrounded fragments 2–10 cm across of gray, red, or purple fine-grained vesicular volcanic rock in a fine-grained matrix of pepper-and-salt tuff.

The rock of the core is dark gray and has a faint red cast. It contains only widely scattered phenocrysts of feldspar 1–2 mm across. In thin section the rock is composed of laths of plagioclase feldspar ($An_{40-45}$), mostly 0.05–0.2 mm long, set in a very fine grained somewhat devitrified glassy groundmass crowded with granules of iron ore. A similar rock makes up the large dike just southwest of the neck.

Adjoining the core is a dark-red coarse-grained vent breccia made up of rounded to subgrounded fragments of dense or vesicular core rock as much as 2 feet across, mostly less than 3–4 inches across. The fragments are enclosed in a red dusty matrix. Poorly developed, nearly vertical columnar joints cut the breccia.

Another accumulation of tuff and breccia believed to possibly represent part of a much-eroded fossil ash cone is in the N½ sec. 31, T. 7 S., R. 19 E., along and on the north side of the Right Prong of Fourmile Creek. It consists of red or purple fine- to medium-grained well-bedded andesite tuff, and some conglomerate consisting entirely of fragments of andesite. The highest beds exposed are purple sandy tuff and a thin brick-red conglomerate. These beds dip 25°–35° in a general easterly direction and are overlain unconformably by nearly flat-lying red, dark-red, or gray highly amygdaloidal porphyritic olivine andesite flows and flow breccias. The unconformity between tuffs and lavas on the knob in the center of the NE¼ sec. 31 is shown on figure 19.

A third possible ash cone, exposed over an area of only about 500 by 800 feet, is just north of the center of sec. 7, T. 8 S., R. 19 E., in a northwesterly sloping tributary of Copper Creek. It consists of red to purple soft tuff and agglomerate that have quaquaversal dips of 25°–35°.

At least five breccia pipes cut the lower andesite unit in the SW¼ sec. 27 and NW¼ sec. 34, T. 7 S., R. 19 E. An elliptical pipe 500–600 feet long is exposed in a gully near the top of the divide between Turkey Creek and the Right Prong of Fourmile Creek in the NW¼ SW¼ sec. 27. The pipe trends about N. 30° W. and has almost vertical walls; one tongue projects a short distance eastward. The northeast contact is marked by many orange-stained slick-


FIGURE 19.—Sketch of unconformity between tuff and overlying lava on knob shown by the closed 5050-foot contour, NE¼ sec. 31, T. 7 S., R. 19 E. Looking S. 20° W.

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ensided surfaces and seems to dip inward. In one outcrop the breccia is faintly layered, striking N. 15° E. and dipping 35° E.

The breccia is a reddish-orange, orange, pink, or white rather fine grained aggregate of angular fragments of white to light-gray chalky rhyolite or trachyte, some orange and gray glassy spherulitic tuff, and a very few small grains of feldspar, quartz, and biotite(?) in a very fine grained fragmental, probably vitric, matrix. Some fragments of brownish-pink porphyritic trachyte(?) are as much as 2 feet across; the feldspar phenocrysts of these fragments are chalky and indeterminate.

The most westerly of a group of four pipes near the line between secs. 27 and 34, T. 7 S., R. 19 E., is a few tens of feet across and crops out as a very steep sided knob rising abruptly above the surrounding rocks. The pipe is made up of angular to subrounded fragments of cream-colored, pink, or red fine-grained much altered silicic volcanic rock in a pale red-purple to light-gray dense fine-grained fragmental matrix cemented by opal. The red color of the matrix is due to very finely divided hematite disseminated in the opal. The volcanic fragments attain a size of 18 inches, but most are less than an inch across.

A sequence of heterogeneous silicic volcanic rocks lies between the lower andesite unit or the latite subunit and the overlying Hell Hole Conglomerate for about half a mile along the north side of the Right Prong of Fourmile Creek in the SW¼ sec. 27, T. 7 S., R. 19 E. These rocks include obsidian, red and buff silicic tuff, and some lavas. At the Lackner Ranch at the mouth of the Right Prong, massive agglomerate and well-bedded semiconsolidated sandy crystal and lithic tuff of rhyolitic or latitic composition, overlain with apparent conformity by Hell Hole Conglomerate, may be part of the same sequence. A chaotic accumulation of coarse-grained rhyolitic pyroclastic material just southwest of the mouth of the Right Prong is thought to mark a vent. These silicic rocks rest on, and possibly are much younger than, the lower andesite unit, but they cannot be correlated with any other unit of the Galiuro Volcanics, and therefore are shown on the geologic map as a subunit of the lower andesite.

### LOWER WELDED TUFF UNIT

A well-exposed and lithologically distinctive vitric-crystal biotite latite welded tuff crops out along a narrow belt from the west edge of the quadrangle in sec. 10, T. 7 S., R. 18 E. eastward for 4 miles, and marks the division between the dominantly silicic upper part of the Galiuro Volcanics and the dominantly andesitic lower part. The area of outcrop of the lower welded tuff is only about 2 square miles, but the considerable extensions down the dip along the bottom of Virgus, Parsons, and Oak Grove Canyons suggest that it probably underlies an additional area of at least 4–5 square miles. Furthermore, erosional outliers on Little Table Mountain and on a hill in the W½ sec. 20, T. 7 S., R. 19 E., and presumed outliers of the same unit on the north side of the Right Prong of Fourmile Creek in secs. 28 and 29, T. 7 S., R. 19 E., indicate that the total areal extent within the quadrangle may have been as much as 20 square miles. Finally, the unit is known to cap Holy Joe Peak, 2.3 miles west of the Klondyke quadrangle; it therefore crops out over an area 6–7 miles long in an easterly direction and 3–4 miles wide.

The lower welded tuff ranges in thickness from about 250 feet along most of its outcrop to possibly as much as 350 feet where it crosses Parsons Canyon. The outlier in sec. 20, T. 7 S., R. 19 E., is about 175 feet thick without the top being present, and the outlier farther southeast is somewhat thinner. The section on Little Table Mountain is only about 55 feet thick, but a considerable part of the unit has been eroded off, as the highest outcrops are solidly welded tuff. The base of the unit is well exposed in several places, but the upper contact seems everywhere to be a surface of at least moderate erosion, inasmuch as the nonwelded tuff that ordinarily constitutes the top of a welded tuff sheet was not recognized anywhere.

Perhaps the best exposures of the basal part of the lower welded tuff are on Little Table Mountain in secs. 22 and 27, T. 7 S., R. 18 E. Here the tuff rests on a layer of "turkey-track" andesite that constitutes the top of the lower andesite unit and completely encircles the southeast end of Little Table Mountain. A diagrammatic columnar representation of the Little Table Mountain section appears on figure 20.

As shown in the section, 2–3 feet of basal whitish to cream-colored nonwelded tuff grades upward successively into orange slightly welded tuff, brown partly welded tuff, black vitrophyric welded tuff, and typical reddish strongly welded tuff. The tuff section below the vitrophyre is 10–15 feet thick, and the vitrophyre is 15–20 feet thick. The contact between partly welded tuff and vitrophyric welded tuff is sharply gradational, the transition taking place within a stratigraphic interval of about a foot. In this same interval, the color changes gradually upward from brown through streaked brown and black to black. The brown tuff weathers to angular blocks, whereas the vitrophyre erodes to rough rounded outcrops. The specific gravity of the basal nonwelded tuff is about 1.88, increasing to 2.26 about 8 feet above the base,

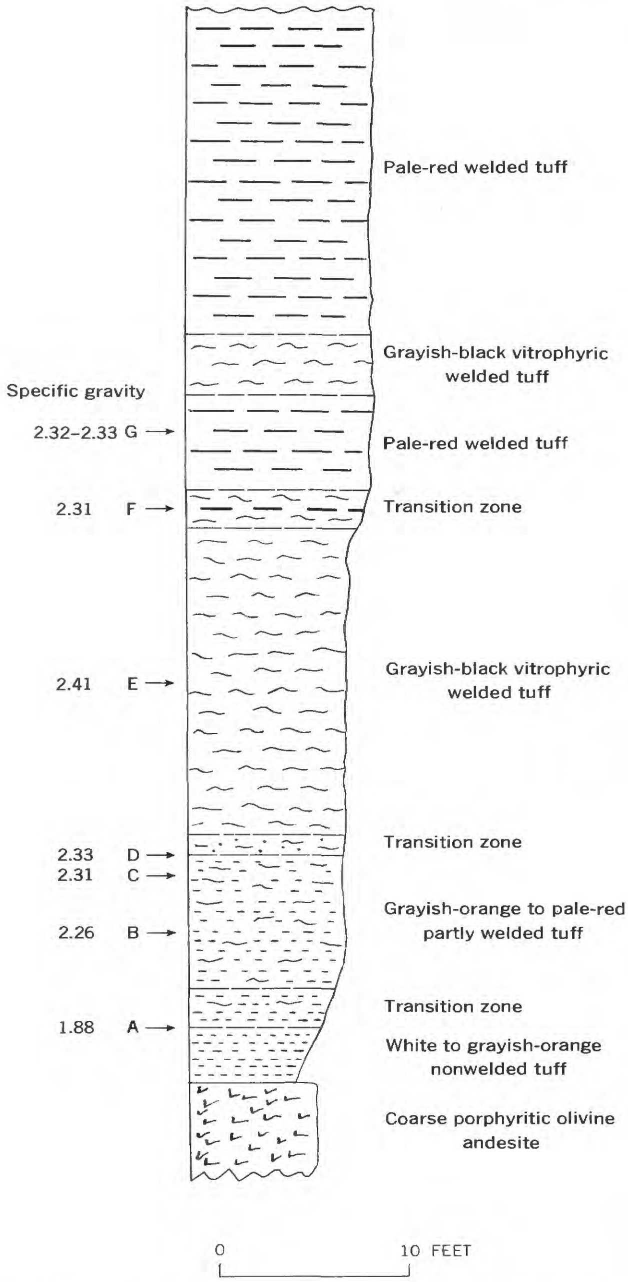


**Figure 20.—Columnar section of the lower welded tuff unit, southeast end of Little Table Mountain. Letters at left of column refer to specimens examined microscopically.**

to 2.31 about 11 feet above the base, and to 2.41 in the black vitrophyre. Above the vitrophyre layer the bulk of the welded tuff has a rather uniform specific gravity of 2.31–2.33.

A series of seven of the various rock types making up the section were collected, and notes on their petrography follow. Locations of the various specimens are shown by letters on figure 20.

A. Grayish-orange nonwelded tuff, a soft rather porous fine-grained even-colored rock. In thin section, euhedral phenocrysts of biotite and fragments of plagioclase feldspar ($An_{35\text{-}40}$), sanidine, and sparse clinopyroxene, magnetite, and rock fragments are embedded in a fragmental matrix of fresh or only very slighty devitrified glass shards (fig. 21, top). Most of the coarse fragments are less than 1 mm across, and some crystals are as large as 2 mm. The clinopyroxene occurs mainly in aggregates with magnetite and apatite that appear to be accidental, perhaps derived from the underlying lower andesite unit. Among the lithic fragments there are a few of arkose, possibly derived from Cretaceous(?) sedimentary rocks that are known to underlie the Galiuro Volcanics at the head of Copper Creek, 2.5 miles southeast.

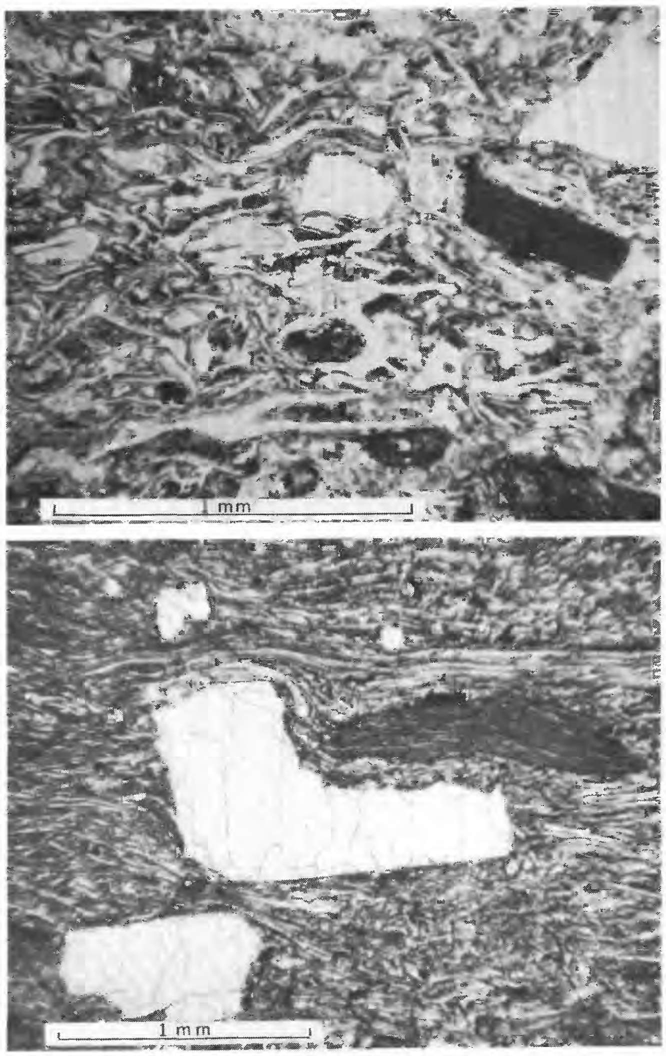


Figure 21.—Photomicrographs of biotite quartz latite tuff, lower welded tuff unit of Galiuro Volcanics, Little Table Mountain. Plane-polarized light, × 30. Above, nonwelded tuff 3 feet above base of unit. Outlines of glass shards are clearly preserved; shards are only slightly bent around rock and mineral grains. Glass is slightly devitrified. Below, partly welded tuff, 11 feet above base of unit. White grains are quartz, dark lenticle to right of large quartz grain is pumice. Shards are strongly bent around quartz grains but outlines are clearly preserved. Pumice fragments are partly collapsed but still easily recognizable. Glass is almost undevitrified.

Walls of shards are of very pale buff glass, and cores are of slightly devitrified colorless glass.

B. Somewhat more indurated than (A) but otherwise very similar in hand specimen. The principal increase in specific gravity from nonwelded to welded tuff takes place in the interval between (A) and (B). Under the microscope, walls of glass shards are of a clear brownish-yellow glass that contrasts strongly with the slightly devitrified colorless material of the cores. Shards are bent around crystals and rock fragments, and pumice fragments are partly collapsed; the rock is very slightly welded.

C. A moderate-brown (5*YR* 4/4) hard brittle rock having conchoidal fracture and waxy or dull vitreous luster on fresh surfaces. Microscopically the rock is made up of the same minerals as (A) and (B), set in a matrix of welded glass shards and collapsed pumice fragments (fig. 21, bottom). Grains of plagioclase feldspar ($An_{40}$) are as much as 2 mm across. Some biotite plates are bent or broken, but most are undamaged. Lithic fragments include several accidental aggregates of clinopyroxene, magnetite, and apatite. The shards are mostly colorless, are practically fresh, and are noticeably bent around the coarser components; some have brown cores, and a few have yellow walls. Pumice fragments are much collapsed but are still recognizable.

D. A streaked moderate-brown and black rock, has conchoidal fracture and a waxy luster, transitional between (C) and (E). In thin section the rock resembles (C). Biotite plates are only slightly bent or not at all, and are perfectly fresh. Shards are sharply bent around phenocrysts and rock fragments. Most shards are colorless, although a few have brown cores, and all are undevitrified.

E. Grayish-black vitrophyric welded tuff, has a vitreous luster and hackly conchoidal fracture. Under the microscope, the rock is seen to have a very conspicuous eutaxitic texture and a few perlitic cracks, but glass shards are still plainly visible. Biotite grains are euhedral, fresh, and generally undamaged. Phenocrysts of other minerals are fragments. Lithic fragments are scarce and are mostly of devitrified glassy rocks. Pumice fragments, some as much as 5 mm long, are flattened and collapsed, but their structure is preserved. All the glassy constituents are undevitrified. The glass has a refractive index of about 1.500, which suggests a silica content near 70 percent.

F. A streaked black and pale-red rock, transitional between (E) and (G). The black streaks still have a vitreous luster, but the pale-red layers are dull or stony. In thin section the rock resembles (E), except that perlitic cracks are much more abundant and devitrification more noticeable. Many shards have cores of brown glass. Biotite is slightly reddened but otherwise is unaltered. Pumice fragments, some as much as a centimeter long, are considerably devitrified and are cut by many perlitic cracks.

G. Pale-red, solidly welded tuff, has abundant grains of plagioclase feldspar, sanidine, and biotite 0.5–3 mm across, embedded in a stony matrix. This rock type makes up the bulk of the lower welded tuff unit. Microscopically, the rock is densely welded; glass shards and pumice fragments are dusty and their outlines are indistinct. Biotite grains are noticeably reddened along certain cleavage planes and at the rims. Shards are slightly devitrified, and collapsed and bent fragments of pumice commonly have walls of finely laminated light and dark slightly devitrified glass and structureless thoroughly devitrified cores. In addition, numerous tiny lenticular segregations of very fine grained clear colorless birefringent material, some of which is quartz, have formed parallel to the eutaxitic layering and also very commonly have formed as streaks extending away from phenocrysts along the layering in a manner perhaps analogous to that of minerals that have recrystallized in pressure shadows of foliated metamorphic rocks.

A chemical analysis and norm of rock (G) follow, together with the chemical composition and norm of Nockolds' (1954) average dellenite (= quartz latite) for comparison. A semiquantitative spectrographic analysis of the same rock is given in table 2, column 8.

*Chemical analyses, in percent, of biotite quartz latite welded tuff and average dellenite*

| Bulk analysis | | | Normative minerals | | |
|---|---|---|---|---|---|
| Constituent | 1 | 2 | Mineral | 1 | 2 |
| $SiO_2$ | 65.17 | 70.15 | Q | 25.20 | 26.1 |
| $Al_2O_3$ | 14.67 | 14.41 | or | 27.80 | 26.7 |
| $Fe_2O_3$ | 2.04 | 1.68 | ab | 25.15 | 30.9 |
| FeO | .22 | 1.55 | an | 6.12 | 9.5 |
| MgO | 1.40 | .63 | C | 2.45 | ------- |
| CaO | 1.44 | 2.15 | wo | ------- | .2 |
| $Na_2O$ | 2.97 | 3.65 | en | 3.50 | 1.6 |
| $K_2O$ | 4.73 | 4.50 | fs | ------- | .8 |
| $H_2O+$ | 3.48 | .68 | mt | ------- | 2.5 |
| $H_2O-$ | 2.73 | ------- | hm | 2.04 | ------- |
| $TiO_2$ | .49 | .42 | il | .46 | .8 |
| $P_2O_5$ | .10 | .12 | ti | .59 | ------- |
| MnO | .07 | .06 | ap | ------- | .3 |
| $CO_2$ | .01 | ------- | fl | .07 | ------- |
| Cl | .05 | ------- | | | |
| F | .11 | ------- | | | |
| Subtotal | 99.68 | ------- | ------- | ------- | ------- |
| Less O | .05 | ------- | ------- | ------- | ------- |
| Total | 99.63 | ------- | ------- | ------- | ------- |
| Powder density not determined | ------- | ------- | ------- | ------- | ------- |

1. Biotite quartz latite welded tuff, lower welded tuff unit, Galiuro Volcanics, center N½ sec. 27, T. 7 S., R. 18 E. Laboratory No. G2965. Analyst, June W. Goldsmith, U.S. Geol. Survey.
2. Average dellenite plus dellenite obsidian (Nockolds, 1954, table 2, col. 2).

A section of the lower welded tuff at the south end of the outcrop east of Parsons Canyon in sec. 14, T. 7 S., R. 18 E. consists, from bottom to top, of a few feet of pink biotite latite tuff that rests on purplish to red vesicular stony andesite flow breccia, 15–20 feet of dark-gray latite vitrophyre, and 90–95 feet of red biotite latite welded tuff. The rocks are similar petrographically to those of Little Table Mountain.

In the SE¼ sec. 18, T. 7 S., R. 19 E., at the east end of the principal outcrop area, the lower welded tuff appears rather different. A specimen collected near the end of the outcrop is a pale-red (*5R* 6/2) fine-grained crystal-rich biotite latite welded tuff. This rock is so conspicuously streaked with gray that it resembles a lava as much as a welded tuff. In thin section, crystal fragments and a few rounded phenocrysts 0.5–2 mm across of thoroughly blackened reddish biotite, zoned plagioclase feldspar ($An_{30-35}$), and sanidine are set in a slightly devitrified glassy groundmass so solidly welded that almost no shards are visible. There are a few vague suggestions of collapsed pumice. The gray streaks so marked in hand specimen are lenticular bodies, at most a few millimeters thick, that have cores of quartz and rims composed of a patchy aggregate of sanidine and very fine grained cristobalite(?).

In the west fork of Virgus Canyon, near the north end of the outcrop in sec. 3, T. 7 S., R. 18 E., the lower welded tuff has a thin layer of vitrophyre about 6–8 feet below the contact with the overlying coarse-grained pink tuff of the lower tuff unit; and in the east fork of the same canyon, near the line between secs. 10 and 11, the unit is capped by several feet of vitrophyre overlain along a very sharp contact either by coarse pink tuff of the lower tuff unit or by the biotite dacite unit. In both places the vitrophyre appears almost identical with that near the base of the welded tuff. Its relation to the underlying rock is not known; possibly it represents the remnants of higher welded tuff layer within the unit.

The large outlier of lower welded tuff on a hill in the W½ sec. 20, T. 7 S., R. 19 E., is correlated with the main outcrop on the basis of similar lithology. It consists of about 150 feet of pink tuff and coarse-grained red welded tuff having a little vitrophyre near the base, capped by about 20 feet of red hard welded tuff and, at the top, 5 feet of vitrophyre. The significance of this upper vitrophyre, as of that farther northwest, is not known; it may be near the base of a second welded tuff layer, most of which has been eroded away.

The rocks shown on the geologic map in secs. 28 and 29, T. 7 S., R. 19 E., north of the Right Prong of Fourmile Creek, as part of the lower welded tuff are correlated somewhat hesitantly with that unit on the basis of lithology; they are about 1.5 miles southeast of the nearest outcrop of undoubted lower welded tuff and are interlayered with a rather different group of rocks. On the hill in the SE cor. sec. 29, they overlie latitic volcanic rocks and are overlain by andesitic lavas. The supposed lower welded tuff consists, from bottom to top, of 60 feet of massive streaked red and gray solidly welded biotite latite tuff, having most fragments less than 3 cm across, becoming less welded toward the top, 10–15 feet of grayish-brown coarse-grained biotite rhyolite or latite vitrophyre containing large phenocrysts of potassium feldspar, and 65 feet of rock, probably soft tuff, that does not crop out.

#### BIOTITE DACITE UNIT

A rather poorly defined sequence of dacitic or andesitic flows is intercalated between the lower welded tuff unit and the lower tuff unit over an area extending from the east branch of Virgus Canyon eastward and southeastward toward the head of Turkey Creek, a distance of somewhat more than 4 miles. In sec. 20, T. 7 S., R. 19 E., this sequence rests on latite of the lower andesite unit. These rocks are referred to as the biotite dacite unit, after the rock type that seems to be dominant; however, the lithology of the unit varies considerably. The biotite dacite crops out over an area of about 3 square miles.

The thickness of the unit is variable. At the west end of its outcrop, it lenses out, so that from the east branch of Virgus Canyon westward to the quadrangle boundary, the lower welded tuff is overlain directly by the lower tuff. Eastward, the biotite dacite thickens appreciably and probably attains its maximum thickness in Oak Grove Canyon, where it may be as much as 400 feet thick. Farther southeast the unit may be equally thick, but attitudes are irregular and difficult to determine, and furthermore the unit is so similar lithologically to the lower andesite unit that the distinction between them is arbitrary to a considerable degree.

The unit is made up principally of grayish-red porphyritic lava flows of variable composition. The flows always have phenocrysts of plagioclase feldspar and biotite, and nearly always have hornblende and some quartz. Potassium feldspar is rather scarce. The dominant rock type appears to be biotite dacite, but some of the rocks may be andesite, on the one hand, or quartz latite or latite, on the other. The walls of Oak Grove Canyon, in the NW¼ sec. 7, T. 7 S., R. 19 E., are made up of at least two flows of grayish-red to grayish-purple porphyritic biotite dacite, each 150–200 feet thick. These flows are massive cliff-forming rocks having inconspicuous columnar jointing, and weather to olive-brown ragged outcrops. In the same canyon, in the SE¼ sec. 12, T. 7 S., R. 18 E., the basal part of the unit is made up of 15–25 feet of buff to maroon agglomerate, biotite rhyolite vitrophyre, and pink agglomeratic rhyolite that separates it from the underlying lower welded tuff unit. The low ridge that extends some 2,000 feet east-northeast from the center of sec. 17, T. 7 S., R. 19 E., is capped by layered rhyolite flows, rhyolite welded tuff, and rhyolite vitrophyre. These rocks apparently constitute an irregular thick lens within the biotite dacite unit, although the relations with the biotite dacite, in particular the upper contact of the lens, are not clear. Finally, in the vicinity of hill 4764, in the NE¼ sec. 20, T. 7 S., R. 19 E., the biotite dacite unit includes some beds of coarse-grained tuff-agglomerate and vitrophyre.

The biotite dacite exposed along the boundary between secs. 12 and 13, T. 7 S., R. 18 E., is a grayish-red to brownish-gray porphyritic rock containing prominent phenocrysts of plagioclase feldspar as much as 5 mm long, smaller grains of biotite and hornblende, and locally, many clots a centimeter or less in diameter of a fine-grained feldspar-pyroxene aggregate, all set in a dense groundmass. In thin section a grayish-red variety is composed of 1–3 mm euhedral phenocrysts of andesine ($An_{40-45}$), partly resorbed and somewhat blackened crystals of biotite 0.5–1 mm across, abundant brown hornblende, and clinopyroxene in a pilotaxitic groundmass of tiny oligoclase laths less than 0.05 mm long and a little interstitial devitrified glass. Accessory minerals include prisms of apatite as much as 0.2 mm long and much iron oxide dust. Plagioclase phenocrysts are zoned normally to rims as sodic as $An_{20}$. They contain inclusions of pyroxene and hornblende; some have inclusion-rich rounded cores and overgrowths of sodium-rich plagioclase whose external shape is euhedral. Hornblende is moderately pleochroic in brownish yellow and greenish brown and has well-defined narrow sooty borders. It has an extinction angle of 8°, indicating that it is a variety of oxyhornblende. Pyroxene is a colorless type having an extinction angle $Z \wedge c$ about 43°; some occurs as grains less than 0.5 mm long that form clots 2–3 mm across. The plagioclase-pyroxene clots consist of these minerals plus magnetite and apatite, and seem to be small autoliths; however, they are very similar to accidental fragments in the underlying lower welded tuff unit, and may indeed be xenoliths.

The biotite dacite that underlies the coarse-grained basal tuff of the lower tuff unit in the east fork of Virgus Canyon is a well-jointed coarsely porphyritic lava having a rough surface and a local relief of more than 50 feet. In hand specimen the rock is a rather nondescript brownish gray (*5YR* 5/1) and has phenocrysts of plagioclase feldspar 1–2 mm long and smaller grains of quartz, biotite, and hornblende(?) in a fine-grained stony matrix. Hornblende(?) grains have narrow borders of darker material that may be the sooty rims noted around hornblende in the rock just described.

The rocks capping the knob in the SE. cor. sec. 29, T. 7 S., R. 19 E., are correlated provisionally with the biotite dacite unit on the basis of their similar stratigraphic position, although lithologically they are rather dissimilar to that unit. They comprise, from bottom to top, at least 5 feet of grayish-red sandy and very dirty well-bedded tuff; 50 feet or so of purple massive cliff-forming porphyritic andesite, containing phenocrysts of plagioclase feldspar and epidote-green altered mafics, and quartz-lined vesicles; 35 feet of dark grayish-purple tuff and breccia containing subordinate flow breccia and flows; and 70 feet of grayish-red (*5R* 4/2) porphyritic andesite similar to that a mile or so northeast in the upper part of the lower andesite unit. Between this sequence and the underlying lower welded tuff unit is 65 feet of rock, probably soft tuff, that does not crop out; this concealed section is grouped with the lower welded tuff on the geologic map.

On the northwest side of upper Wire Corral Draw, the top of the biotite dacite unit is a peculiar breccia 10–20 feet thick made up of angular to rounded blocks from a few inches to several feet across of pale-olive to dusky yellow lava containing interstitial veinlike or irregular masses of pale reddish-brown sandy mud. The lava has innumerable small vesicles lined with tiny crystals of a mineral that is probably a zeolite. Some of the blocks have a vague resemblance to pillows—a somewhat rounded or ellipsoidal shape having a thin vesicular rim on a solid core—whereas others are obviously fragments. The interstitial material is slightly harder than the lava. The blocks of lava also are traversed by a network of pale reddish-brown veins of variable width, generally less than 5 cm, that evidently formed by oxidation of the parent rock along cracks. The fact that these veins and the interstitial sandy material are almost identical in color suggests that the interstitial material itself may have been formed in part or entirely by fragmentation of the lava. The gross texture of the rock is one that might have been formed as a result of subaqueous extrusion onto, or near-surface intrusion into, unconsolidated sediments.

Along Oak Grove Canyon for about 750 feet above the confluence with the east fork (secs. 6 and 7, T. 7 S., R. 19 E.), the rocks below the lower tuff unit are a peculiar assemblage of purple platy andesite having pilotaxitic texture, red porphyritic andesite, coarse-grained varicolored flow breccia, hard olive-green porphyritic andesite or basalt, green and purple agglomerate, and dark greenish-black porphyritic basalt. These rocks are cut by veinlets of calcite and quartz. They are unlike any others in the Galiuro Volcanics of the immediate surroundings; they seem to dip rather steeply to the northeast, as much as 45°, and may belong to an older sequence of volcanic rocks. On the geologic map they are grouped with the biotite dacite unit entirely on the basis of their stratigraphic position below the lower tuff.

#### LOWER TUFF UNIT

All the rocks between the biotite dacite unit or the lower welded tuff unit and the upper welded tuff unit are designated as the lower tuff unit. This rather heterogeneous group includes silicic tuffs, silicic welded tuffs, a thin but extensive flow of olivine andesite at or near the top of the unit, and hornblende andesite that constitutes the base of the unit at one place. The lower tuff crops out along Virgus, Parsons, and Oak Grove Canyons and Wire Corral Draw over an area of several square miles and is presumed to underlie at least 6 square miles within the quadrangle.

The lower tuff is about 550 feet thick in Parsons Canyon and about 500 feet thick in the middle fork of Virgus Canyon, and seems to be of comparable thickness in Wire Corral Draw. Between Wire Corral Draw and Oak Grove Canyon, the lower tuff thins rapidly, apparently against a high area on the underlying biotite dacite unit, and pinches out completely in the east fork of Oak Grove Canyon a short distance above the confluence with the main canyon.

A section of the lower tuff unit in the east wall of Parsons Canyon, in the NE¼ sec. 35, T. 6 S., R. 18 E. is about 300 feet thick and is made up, from bottom to top, of (1) 100 feet of massive soft and porous, white to light-gray, pink, or orange vitric tuff containing scattered crystals of quartz and feldspar in a matrix of pumice and glass fragments 1–5 cm across; (2) 50 feet of buff, pink, or white massive slightly welded vitric biotite rhyolite tuff, which erodes to a prominent cliff that extends for about 2 miles to the south along the walls of Parsons Canyon and then eastward into Wire Corral Draw; (3) 75 feet of soft partly welded tuff; (4) 25 feet of gray andesite; (5) 20–30 feet of pink coarse-grained rather hard vitric rhyolite tuff that forms a prominent cliff to the north along the canyon; and (6) 25 feet of light-colored tuff containing two thin interbedded layers of welded tuff.

The andesite (unit 4) below the pink tuff is a grayish-red porphyritic lava containing small phenocrysts of green pyroxene and red olivine. The top of the flow is a highly vesicular red breccia containing abundant calcite amygdules. In this section, phenocrysts of clinopyroxene as much as a millimeter across and smaller grains of olivine and sparse plagioclase feldspar ($An_{45}$) are embedded in an intergranular groundmass of plagioclase laths ($An_{45}$) 0.1–0.2 mm long containing interstitial iron ore and scarce olivine and pyroxene. Olivine is completely altered to red-orange iddingsite. Plagioclase phenocrysts are strongly zoned and may be as sodic as $An_{10}$ at the rims. The groundmass contains many needles of a mineral so thin that no optical data could be obtained; it may be clinopyroxene or apatite. In absence of a chemical analysis, this rock might be classified as either olivine andesite or basaltic andesite.

Farther south along Parsons Canyon, in the SE. cor. sec. 35, T. 6 S., R. 18 E., the lower tuff consists of three units each made up of an upper orange hard tuff and a lower soft tuff; each of these units is 125–150 feet thick. The lower tuff seems to become more lithic in nature toward the south, and contains increasing amounts of fragments of volcanic rock 2–10 cm across.

At the stream junction in the NW¼ sec. 2, T. 7 S., R. 18 E., somewhat more than 300 feet of the lower tuff is exposed. The unit is made up, from bottom to top, of 90 feet of pale-buff to gray soft tuff, 10 feet of pink hard tuff, 75 feet of gray soft tuff, 25 feet of pink to orange hard tuff, 50 feet of soft tuff, 20 feet of olivine andesite, and 50 feet of interbedded hard and soft tuff, overlain by the upper welded tuff unit.

At section corner 4557 near the south end of the outcrop in upper Parsons Canyon, the lower tuff consists of about 375 feet of cliff-forming coarse-grained tuff at the base, overlain successively by 125 feet of gray soft vitric biotite quartz latite tuff, partly welded at the top; 20–25 feet of amygdaloidal porphyritic olivine andesite; and 20 feet of soft to partly welded massive vitric-crystal biotite rhyolite tuff. A hand specimen of the basal part of the uppermost tuff is a moderate grayish-orange-pink (10*R* 7/2) rather soft rock made up of millimeter-size grains of feldspar, biotite, and quartz, and scattered lithic fragments as much as 5 mm across, in a groundmass of glass shards and some pumice lapilli. In thin section, crystals and fragments of plagioclase ($An_{20}$), sanidine, slightly blackened biotite, and quartz, and somewhat rounded fragments of vitrophyre, obsidian, and andesite are embedded in a matrix of dusty fresh glass shards, mostly colorless but a few yellow to orange. No welding is evident.

Many small erosional outliers of the lower tuff rest on the biotite dacite unit in secs. 11 and 12, T. 7 S., R. 18 E. They are composed mainly of buff vitric-lithic rhyolite tuff containing lapilli of maroon and purple volcanic rock 1–2 cm across. The outliers are well stratified at the base but massive elsewhere, and seem to have been deposited subaerially.

In Virgus Canyon, the upper part of the unit is a hard rhyolite welded tuff having prominent columnar jointing in the upper 8–10 feet. Below this rock is a pink massive vitric rhyolite tuff having one bed 8–10 feet thick that shows incipient columnar jointing and may be slightly welded.

Along Virgus Canyon in sec. 3, T. 7 S., R. 18 E., the basal part of the lower tuff is a pink coarse-grained massive quartz-rich vitric-lithic tuff at least 20 feet thick, overlain by gray or pink coarse-grained vitric tuff that has a basal layer 30–40 feet thick and at least two other thinner layers of harder welded tuff. The pink has many fragments 1–5 cm across of red, purple, or gray andesite. It thickens markedly toward the south end of the outcrop area; on hill 4857 in the SE¼ sec. 10, T. 7 S., R. 18 E., it is more than 300 feet thick and erodes to massive rounded outcrops. On this hill, and over a considerable area to the south, the pink tuff is overlain by a partly welded vitric rhyolite tuff of a distinctive gray color, made up of crystals of quartz and feldspar, probably sanidine, and lapilli of purple volcanic rock and white pumice in a gray to light-buff pumiceous matrix. Abundant small rusty mafic grains may have been biotite. The gray tuff is overlain by a thick section of gray, buff, or pinkish-buff mostly massive cliff-forming vitric biotite rhyolite tuff having some thin pinkish welded units, and this tuff is overlain by a thin flow of purple to gray amygdaloidal andesite. The highest beds of the unit are 20 feet of gray to pale-buff coarse-grained vitric tuff-agglomerate consisting of fragments of pink and brownish pumice in a fine-grained matrix.

In Oak Grove Canyon the most northerly outcrops of the lower tuff unit are a light-gray massive vitric tuff containing scattered angular fragments of purple, gray, or red volcanic rock 2–5 cm across. On the ridge northwest of Black Butte, the lower tuff is a coarse-grained pink rock generally less than 50 feet thick that fills irregularities on the surface of the underlying biotite dacite unit.

Two outcrops of tuff in the N½ sec. 20, T. 7 S., R. 19 E., are 2 miles southeast of the nearest outcrops of unequivocal lower tuff but are correlated with this unit on the basis of stratigraphic position and lithology. The rock here is a pink coarse-grained vitric-crystal biotite rhyolite tuff about 150 feet thick that rests on the biotite dacite unit.

The bottom of Parsons Canyon in the SW¼ sec. 25 and the SE¼ sec. 26, T. 6 S., R. 18 E., is cut in light brownish-gray porphyritic hornblende andesite that is shown as part of the lower tuff on the geologic map. The andesite is a massive resistant rock that formed a hill at the time the lower tuff was deposited; local relief on the andesite hill is at least 150 feet, and the tuff between the andesite and the upper welded tuff unit over the top of the hill on the east side of Parsons Canyon is only a few feet thick. The andesite has well-developed mostly flat flow layering defined particularly by the phenocrysts of hornblende. Locally the andesite seems to be a breccia, having irregular knots of fresh rock enclosed in slightly altered rock, and at the top it has a prominent flow breccia about 50 feet thick. The andesite therefore appears to be a lava, and no evidence was seen that it is made up of more than a single flow at least 150 feet thick. In hand specimen the rock contains large brown phenocrysts of hornblende as much as 5 mm long and millimeter-size grains of feldspar in a dense fine-grained groundmass. In thin section, hornblende is considerably altered and has dusty black rims. It is strongly pleochroic, Z= golden brown and X=very pale yellow brown. The extinction angle $Z \wedge c$ is near zero, indicating that the mineral is oxyhornblende. Plagioclase phenocrysts are 0.2–1 mm across, are euhedral, and show strong oscillatory zoning within the range $An_{50-60}$. The groundmass consists mainly of plagioclase ($An_{35-40}$) microlites 0.05–0.2 mm long, and a little interstitial devitrified glass and iron ore. Microlites show very well defined flow structure.

#### UPPER WELDED TUFF UNIT

The lowest cliffs along Aravaipa Canyon between Old Deer Creek and the west edge of the quadrangle are cut in a silicic welded tuff that will be referred to as the upper welded tuff unit. Two to four miles farther south, this rock underlies several extensive very evenly stripped surfaces that slope gently north; the surface east of Parsons Canyon has a notably uniform slope over a length of nearly 2 miles, and the surface between Parsons and Virgus Canyons is even more remarkably uniform although not so long. The total outcrop area of the upper welded tuff is about 3 square miles, but the unit must underlie at least 9–10 square miles within the quadrangle. The rhyolite of Black Butte is grouped with the upper welded tuff on the geologic map and is shown as a subdivision of that unit.

The upper welded tuff seems to be rather uniform in thickness over appreciable areas. Along Aravaipa Canyon it averages nearly 200 feet thick, and the base is not exposed at any place. Northwest of Black Butte the welded tuff is 150 feet thick. In sec. 35, T. 6 S., R. 18 E., 3 miles south of Aravaipa Canyon, the thickness has diminished to 75–100 feet.

The lower contact, on the lower tuff unit, is conformable in most places; but in Oak Grove Canyon at the east edge of its outcrop area, the lower tuff is only a few tens of feet thick, and in places the upper welded tuff rests directly or almost directly on the biotite dacite unit. The upper contact, with the white tuff unit, seems to be perfectly concordant wherever the white tuff is exposed. North of Black Butte the white tuff is missing and the upper welded tuff unit is very thin and is overlain by the rhyolite of Black Butte.

The welded tuff, particularly the upper half of the unit, is very resistant and typically erodes to nearly vertical cliffs. Columnar jointing is well developed in the upper one-third to one-half of the cliffs, and the joint surfaces are stained a conspicuous orange that is characteristic of outcrops of the unit.

The upper welded tuff as exposed in Aravaipa Canyon is a grayish-pink to grayish orange-pink massive vitric or vitric-crystal rhyolite tuff containing scattered euhedral grains of biotite and feldspar 1–2 mm across. Lithic fragments other than pumice are sparse and generally are less than a centimeter across, whereas many pumice lapilli are 1–2 cm across. Weathered surfaces are cavernous, commonly orange, and may have conspicuous crusts of yellow lichens. Along the center of the south edge of sec. 14, T. 6 S., R. 18 E., the welded tuff is about 200 feet thick and has a solidly welded top less than 10 feet thick overlying a thick massive rock in which the pumice lapilli are collapsed but which is not so thoroughly welded. In thin section a specimen from the top of the unit at this place consists of euhedral grains 0.5–1 mm across of sanidine, plagioclase feldspar ($An_{20-25}$), blackened biotite, and angular fragments of the same minerals plus dark felsitic volcanic rock and pumice in a matrix of glass shards. Quartz was not recognized in the thin section but is fairly abundant in the hand specimen. Pumice lapilli are 5 mm or more in length and are devitrified with the formation of axiolites. Glass shards are 0.1–0.5 mm long and are plainly recognizable although thoroughly welded and devitrified. The entire matrix of the rock is very dusty.

The upper welded tuff is well exposed in a deep east-sloping tributary canyon of Parsons Canyon in the NE¼ sec. 35, T. 6 S., R. 18 E. It is a light grayish-purple biotite rhyolite welded tuff, in which most components are less than 5 mm across. The lower part has many flattened vesicles, many 15 cm or more across, lined with quartz crystals. Under the microscope, the rock is a vitric-crystal tuff having grains 0.5–1 mm across of sanidine, plagioclase feldspar, gold-brown slightly blackened biotite, and sparse quartz in a fine-grained groundmass of slightly devitrified glass shards and pumice. The shards are well preserved, as are delicate original structures of the pumice, and the rock is much less welded than that along Aravaipa Canyon.

The upper welded tuff from Parsons Canyon has been analyzed chemically with the results shown in the following table; the chemical composition and norm of Nockolds' (1954) average calc-alkali rhyolite is also given for comparison. A semiquantitative spectrographic analysis of the same rock appears in table 2, column 9. The Parsons Canyon rock is somewhat lower in lime than Nockolds' average rock, but otherwise the two analyses are very similar.

*Chemical analyses, in percent, of rhyolite welded tuff and average calc-alkali rhyolite*

| Bulk analysis | | | Normative minerals | | |
|---|---|---|---|---|---|
| Constituent | 1 | 2 | Mineral | 1 | 2 |
| $SiO_2$ | 72.92 | 73.66 | Q | 30.96 | 33.2 |
| $Al_2O_3$ | 13.37 | 13.45 | or | 31.14 | 31.7 |
| $Fe_2O_3$ | 1.36 | 1.25 | ab | 28.82 | 25.1 |
| FeO | .02 | .75 | an | 2.78 | 5.0 |
| MgO | .51 | .32 | C | 1.02 | .9 |
| CaO | .53 | 1.13 | en | 1.30 | .8 |
| $Na_2O$ | 3.42 | 2.99 | mt | -------- | 1.9 |
| $K_2O$ | 5.29 | 5.35 | hm | 1.44 | -------- |
| $H_2O+$ | .63 | .78 | il | -------- | .5 |
| $H_2O-$ | 1.04 | -------- | ru | .22 | -------- |
| $TiO_2$ | .22 | .22 | ap | -------- | .2 |
| $P_2O_5$ | .03 | .07 | | | |
| MnO | .07 | .03 | | | |
| $CO_2$ | .04 | -------- | | | |
| Cl | .01 | -------- | | | |
| F | .06 | -------- | | | |
| Subtotal | 99.52 | -------- | -------- | -------- | -------- |
| Less O | .03 | -------- | -------- | -------- | -------- |
| Total | 99.49 | -------- | -------- | -------- | -------- |
| Powder density | 2.57 | -------- | -------- | -------- | -------- |

1. Upper welded tuff unit, Galiuro Volcanics; Parsons Canyon NE¼ sec. 35, T. 6 S., R. 18 E. Laboratory No. F2680. Analyst, Dorothy F. Powers, U.S. Geol. Survey.
2. Average calc-alkali rhyolite plus rhyolite obsidian (Nockolds, 1954, table 1, col. 2).

Northwest of Black Butte, the upper welded tuff is separated from the underlying biotite dacite unit by a thin irregular layer of coarse-grained pink tuff that fills irregularities in the surface of the biotite dacite (fig. 22). Local relief on the biotite dacite surface is more than 100 feet.

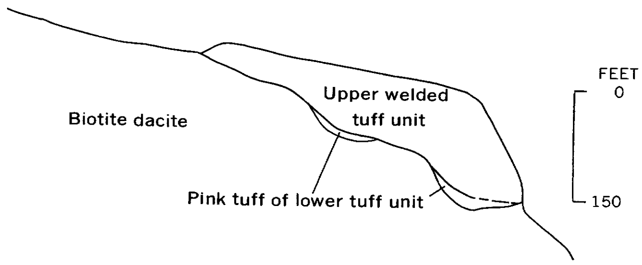


FIGURE 22.—Sketch showing relations of some lithologic units of the Galiuro Volcanics on the ridge northwest of Black Butte (N½ sec. 7, T. 7 S., R. 19 E.). Looking west. Not to scale horizontally.

Black Butte, a very prominent landmark on the boundary of secs. 7 and 8, T. 7 S., R. 19 E., is a tabular mass of pale-red to pale red-purple porphyritic rhyolite. The rhyolite seems to rest either on the biotite dacite, on a pink tuff of the lower tuff unit that locally overlies the dacite, or, for a very short distance, on the upper welded tuff, and lies approximately parallel to the bedding of the pink tuff. Flow layering is contorted and steep; at the summit the flow layering strikes N. 10° E. and is vertical. Figure 23 is a sketch of Black Butte, looking S. 10° E. Black Butte is probably an erosional remnant of a lava flow rather than a plug or dike, but the accessible exposures do not provide conclusive evidence.

In thin section the rhyolite of Black Butte contains euhedral to somewhat rounded phenocrysts of sanidine as much as 4 mm across and slightly rounded or resorbed grains of quartz 1–2 mm across. The only dark minerals are a few tiny grains of highly altered biotite(?) and sparse iron ore. The groundmass is a fine-grained devitrified patchy aggregate of potassium feldspar, quartz, sparse spherulites or radiolites, and considerable black iron-oxide dust that is concentrated in very thin fairly conspicuous flow layers. The microscopic examination seems to corroborate the field inference that the rhyolite is a flow rather than an intrusive rock.

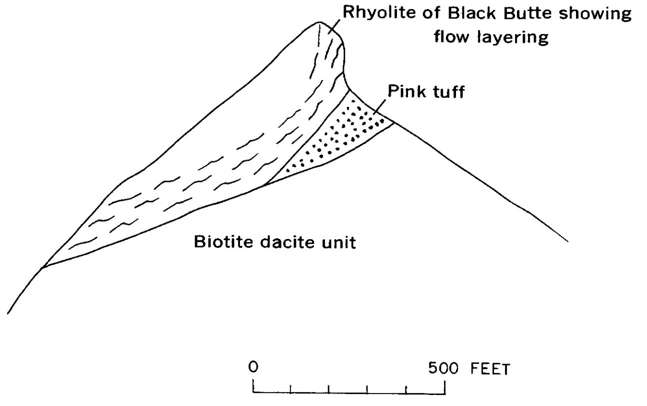


FIGURE 23.—Sketch of Black Butte, looking S. 10° E. Horizontal and vertical scales are the same.

WHITE TUFF UNIT

A thin bed of white tuff separates the upper welded tuff unit from the overlying intermediate andesite unit. The white tuff crops out in the walls of Aravaipa Canyon, where its upper part is in conspicuous contrast to the overlying dark-colored andesite, and also forms a continuous belt of outcrops between the edge of the quadrangle in sec. 34, T. 6 S., R. 18 E., and Parsons Canyon, 3 miles northeast. Except in the southern part of its outcrop area, where it is partly welded, the white tuff is rather soft and characteristically erodes to gentle slopes having poor outcrops. The white tuff in Aravaipa Canyon is not shown separately on the geologic map but rather is combined with the upper welded tuff unit inasmuch as its outcrop width is too small to be shown effectively at map scale. The total area of outcrop of the white tuff is less than 1 square mile, but it undoubtedly underlies at least 6 square miles in the quadrangle.

The white tuff varies considerably in thickness but ordinarily is 50–100 feet thick. In the south wall of Aravaipa Canyon west of Parsons Canyon and also opposite the mouth of Booger Canyon, the white tuff is about 100 feet thick; and in the northern part of sec. 23, T. 6 S., R. 18 E., it is about 40 feet thick. Farther south along Parsons Canyon, the tuff is 100 feet thick. In Virgus Canyon the white tuff is 60 feet thick.

The white tuff is a massive coarse-grained vitric-lithic tuff composed mostly of rock fragments and white pumice, together with abundant tiny plates of biotite and scattered millimeter-size crystals of feldspar. The lithic fragments are generally a centimeter or less across and are of light to dark-gray or dark-red fine-grained volcanic rock; they make up perhaps 5–10 percent of the rock. The pumice is in fragments ranging in size from dust to a few centimeters, and seems to be completely devitrified.

Southward from the mouth of Parsons Canyon, the white tuff becomes coarser grained and more indurated; and in the deep tributary canyon in the NE¼ sec. 26, T. 6 S., R. 18 E., it has 2–3 feet of very pale red purple solidly welded vitric-lithic biotite rhyolite tuff at the top. The welded tuff has a pronounced eutaxitic texture defined by wavy compressed fragments of devitrified pumice. In thin section the rock consists of crystals and fragments 0.5–2 mm across of sanidine, biotite, and sparse plagioclase (about $An_{20}$) and quartz, together with a few lithic fragments, in a pumiceous matrix. Biotite is completely blackened and is identifiable only in hand specimen. Large pumice lapilli, some 2–3 cm long, are devitrified to an aggregate of spherulites. The fine-grained pumiceous matrix is strongly eutaxitic, but the individual fragments are still plainly visible; all are devitrified to some extent.

The possibility was considered that the white tuff is merely the upper part of the lower welded tuff unit, but the fact that the upper part of the white tuff is welded locally indicates that it is a separate deposit, although perhaps only very slightly younger than the lower welded tuff.

###### INTERMEDIATE ANDESITE UNIT

The intermediate andesite unit crops out in three separate areas: along the north edge of the quadrangle in a narrow discontinuous belt extending about 4.5 miles eastward from the northwest corner of the quadrangle, along the middle parts of the walls of Aravaipa Canyon from Parsons Canyon and Old Deer Creek westward to the quadrangle border, and south of Aravaipa Canyon along Virgus Canyon and on the divide between Virgus and Parsons Canyons. The total area of outcrop is only about 2.6 square miles, but the unit may underlie as much as 25 square miles or more within the quadrangle.

The intermediate andesite attains a thickness of as much as 450 feet but in most places is 150–250 feet thick. The thickness is fairly uniform over considerable areas, and both the lower contact with the white tuff unit and the upper contact with the upper tuff unit, the upper andesite unit, the rhyolite-obsidian unit, and the tuff unit of Hawk Canyon appear to be conformable.

Rocks included in the intermediate andesite are mainly gray to dark-red very coarsely porphyritic "turkey-track" olivine andesite, and minor amounts of red to gray porphyritic to aphanitic andesitic lavas.

At the mouth of Paisano Canyon and elsewhere to the west along Aravaipa Canyon, the upper half of the intermediate andesite erodes to prominent cliffs showing well-developed columnar jointing. The lower half is massive and apparently is less resistant to erosion. The lower part of the unit commonly is a conspicuous red, whereas the top may be orange.

Along the north edge of the quadrangle, the intermediate andesite unit consists of a platy olivine andesite at the bottom, an intermediate coarse porphyritic andesite, and an upper dark-purple platy olivine andesite. Microscopically, these rocks contain phenocrysts of plagioclase feldspar ($An_{50-60}$) 1–3 mm long and smaller grains of clinopyroxene, altered olivine, and iron ore in an intersertal or pilotaxitic groundmass of plagioclase laths, clinopyroxene granules, olivine, apatite, iron ore, and glass.

Near Anderson Spring in the east fork of Hawk Canyon, the intermediate andesite is a grayish-red amygdaloidal very coarsely porphyritic rock ("turkey-track") containing platy phenocrysts of feldspar 2–2.5 cm across and smaller red grains of olivine. In thin section the rock is made up of euhedral plagioclase ($An_{65}$) and olivine in an intersertal groundmass of andesine microlites 0.05–0.2 mm long and interstitial abundant iron ore, dusty brownish devitrified glass, and a little olivine. The plagioclase phenocrysts show a striking oscillatory zoning within a very narrow compositional range; more than 60 alternations were counted in a single phenocryst. Olivine phenocrysts are 0.2–1 mm across and are completely altered to red-orange iddingsite.

At the mouth of Booger Canyon, the intermediate andesite is 150–200 feet thick and is a very massive rock having no discernible flow layering. The upper part of the unit consists of about 30 feet of gray coarsely porphyritic "turkey-track" andesite underlain by at least 35 feet of the same rock but red. Locally the andesite is overlain by coarse-grained red-orange lithic tuff and agglomerate.

Just west of the mouth of Booger Canyon, a flow of amygdaloidal olivine andesite about 25 feet thick makes up the top of the intermediate andesite unit below the overlying upper tuff unit. The flow appears to wedge out to the west. This olivine andesite is a dark-gray to very dusky red-purple rock containing millimeter-size phenocrysts of plagioclase feldspar and red-brown olivine, and amygdules of white calcite as much as 0.5 cm across. The top of the flow is blocky and locally is a sort of intraformational breccia 2–4 feet thick consisting of irregular fragments of andesite in a matrix of brown sand composed mostly of glass. Some of the fragments have a fine-grained chilled selvage, whereas others are clearly pieces broken off previously cooled rock. The breccia is overlain by a thin well-bedded water-laid tuff. It seems likely that the flow was subaqueous and that the breccia, fine and coarse components alike, is simply the disrupted top of the flow; in general aspect the breccia resembles a mudflow.

###### TUFF UNIT OF HAWK CANYON

A light-colored massive silicic tuff overlies the intermediate andesite unit near the head of Hawk Canyon and extends westward to the quadrangle edge as a thin discontinuous bed between the andesite and the overlying rhyolite-obsidian unit. The tuff unit of Hawk Canyon is about 100 feet thick west of Hawk Canyon, but at the head of Horse Camp Canyon it diminishes in thickness abruptly to about 20 feet. At the head of the north fork of Ash Creek, it is also 20 feet thick; and farther west near the quadrangle boundary, it is only 10 feet thick; in these areas the outcrop is too narrow to show at map scale. A stubby lens of similar tuff seems to be interlayered with the intermediate andesite about 750 feet north of Anderson Spring; possibly the southwest contact with the andesite is a fault, but no evidence of faulting was found.

The tuff of Hawk Canyon is rather heterogeneous as to color and grain size, but in general is a yellow, cream-colored, or pink massive coarse-grained rather friable rock that weathers to a very rough surface; the massive rough and cliffy outcrops just west of Anderson Spring are typical.

On the north side of Lookout Mountain, the tuff of Hawk Canyon is a massive yellowish-gray vitric rhyolite tuff having prominent outcrops and a very rough weathered surface. It is composed of millimeter-size somewhat rounded grains of quartz, feldspar, and volcanic rock in a glassy or pumiceous matrix. Some rock fragments are 5 mm across. Locally in the Lookout Mountain area, the coarse-grained tuff is overlain by a medium-grained well-indurated very pale red purple (5*RP* 7/2) crystal-vitric rhyolite tuff. This rock consists of angular fragments 0.2–0.5 mm across of quartz and sanidine, and lesser amounts of plagioclase feldspar and a little slightly blackened biotite, in a matrix of devitrified glass. Iron ore is a very sparse accessory.

The tuff of Hawk Canyon at the head of Horse Camp Canyon is a yellow coarse-grained vitric rhyolite tuff about 20 feet thick, characterized by numerous small fragments of brown to purple fine-grained volcanic rock. It consists almost entirely of angular to subrounded fragments a millimeter or less across of slightly devitrified glass having a refractive index of about 1.495. Quartz grains 0.1–0.2 mm across are scattered through the glass. A little unidentified zeolite(?) is also present.

In the northwest corner of the quadrangle, the tuff of Hawk Canyon is about 10 feet of rather soft massive grayish-yellow vitric-crystal rhyolite tuff composed of angular fragments 0.2–0.5 mm across of quartz, sanidine, and volcanic rock in a groundmass made up of fragments of devitrified glass 0.5–1 mm across. The groundmass is somewhat silicified.

The small lens of tuff north of Anderson Spring is similar to the main body. The base of the lens is a pale-red (10*R* 6/2) rather fine grained well-sorted crystal-vitric rhyolite tuff that dips 10°–15° N. and rests on coarse porphyritic andesite. Overlying this tuff is a yellowish-gray well-indurated very coarse grained crystal-vitric rhyolite tuff made up of 1–2 mm grains of quartz and feldspar, and abundant fragments 1–3 mm across of pumice, vitrophyre, and a little dark fine-grained volcanic rock in a pumiceous matrix. Iron ore and biotite are sparse accessories. The groundmass contains considerable amounts of a zeolite that X-ray examination shows to be heulandite.

###### RHYOLITE-OBSIDIAN UNIT

The rhyolite-obsidian unit crops out over an area of more than 10 square miles along the west edge of the quadrangle north of Aravaipa Canyon and is, next to the lower andesite, the most extensively exposed of the various units of the Galiuro Volcanics. Its base is exposed only along Aravaipa Canyon and near the north edge of the quadrangle; in both places it overlies the intermediate andesite unit. Over most of its outcrop area, it is overlain by either the upper andesite unit or the Hell Hole Conglomerate; in a few places it is overlain by the quartz latite unit of Hawk Canyon or the upper tuff unit.

The broad configuration of the rhyolite-obsidian unit is that of an elongate north-trending lens that pinches out to the south in the interval between the north and south walls of Aravaipa Canyon. In the north wall of the canyon, the lens has a maximum thickness of about 450 feet; the west edge of the lens is overlapped by the upper tuff unit about 1,000 feet east of the quadrangle boundary (fig. 24), and the east edge is overlapped at Paisano Canyon by the upper andesite unit. Northward, the rhyolite-obsidian unit attains an outcrop width of at least 3 miles and a thickness estimated at as much as 700 feet.

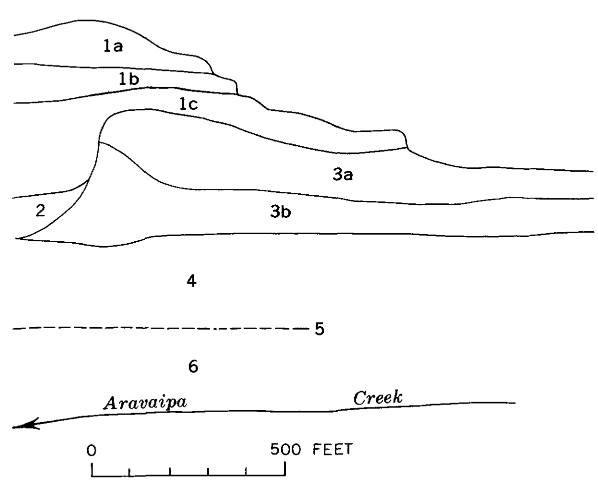


FIGURE 24.—Sketch of stratigraphic relations of some units of the Galiuro Volcanics in the north wall of Aravaipa Canyon near the west edge of sec. 15, T. 6 S., R. 18 E. 1, Upper tuff unit; a, upper coarse subunit; b, white tuff subunit; c, lower coarse subunit. 2, Upper andesite unit. 3, Rhyolite-obsidian unit; a, rhyolite lava; b, obsidian, vitrophyre. 4, Intermediate andesite unit. 5, White tuff unit. 6, Upper welded tuff unit.

The rhyolite-obsidian unit has a rather diverse lithology, but the lower part is mostly light- to dark-colored obsidian, obsidian agglomerate, and vitrophyre, and the upper part is dominantly light-gray very fine grained dense stony lavas. Subordinate light-colored tuff and breccia locally are at the base of the unit and also higher in the obsidian-rich part of the unit. Both rhyolite and obsidian are characterized by well-developed and extremely irregular flow layering that commonly dips rather steeply and changes attitude abruptly. No systematic arrangement of flow layering was detected, either in the obsidian or in the overlying rhyolite flows. No attempt was made to map separately the obsidian and obsidian agglomerate, on one hand, and the rhyolite lavas, on the other. In several places, obsidian agglomerate at the base of the unit grades upward into massive obsidian, and the agglomerate appears to be in part rather a flow breccia at the base of a very thick obsidian flow.

The unit is well exposed at the mouth of Booger Canyon, where it consists of a lower obsidian agglomerate 60–90 feet thick, an intermediate massive obsidian 30–85 feet thick having highly contorted flow layering and abundant lithophysae, and an upper sequence of light purplish-gray rhyolite flows cut by poorly developed vertical joints. In this area the obsidian is a cliff former. The obsidian agglomerate overlies olivine andesite of the intermediate andesite unit along a very flat contact, marked locally by a layer 8–10 feet thick of fine-grained yellowish-gray vitric tuff that fills minor irregularities on the surface of the andesite. On the ridge between the mouths of Booger and Paisano Canyons, the upper part of the unit is obsidian that overlies the rhyolite lavas. On Lookout Mountain, in secs. 13 and 24, T. 5 S., R. 18 E., the lowest rocks exposed are platy, finely laminated siliceous lavas having contorted flow layering, overlain successively by interlayered siliceous stony lava and obsidian, a very conspicuous irregular layer 50–75 feet thick of dark obsidian that completely encircles the west peak of Lookout Mountain, and obsidian agglomerate that makes up the bulk of the mountain. In the NW¼ sec. 15, at the northwest corner of the quadrangle, the section overlying the tuff unit of Hawk Canyon consists of a basal obsidian agglomerate overlain by obsidian and fine-grained siliceous lava. A sketch of a section of the rhyolite-obsidian unit exposed in the southwest wall of lower Ash Creek is shown on figure 25.

The obsidian is commonly a black rock containing thin streaks of moderate-red glass. Phenocrysts may be absent or may be abundant enough for the rock to be termed vitrophyre. The phenocrysts are dominantly potassium feldspar; quartz is less abundant and may be lacking in some rocks, and biotite, clinopyroxene, hornblende, iron ore, and sphene are very scarce. The refractive index of the glass is 1.495–1.500, suggesting that the silica content is in excess of 70 percent. The obsidian commonly has abundant geodes, and in places such as the N.E. cor. sec. 24, T. 5 S., R. 18 E., quartz-lined geodes 1–2 feet across are abundant.

On hill 4319 south of Bates Canyon at the west edge of sec. 27, T. 5 S., R. 18 E., a well-defined although thin layer of streaked red and black vitrophyre overlies a thick sequence of obsidian agglomerate and is overlain by silicic lava. As seen in thin section, this vitrophyre has euhedral phenocrysts and angular to subrounded fragments of weakly zoned sanidine 0.1–0.5 mm long and a few 0.1–0.3 mm grains of clinopyroxene and biotite in a matrix of streaked glass. The glass has a texture apparently resulting from fragmentation during flowage; it is made up of pulled-out streaks of brown to colorless isotropic glass embedded in very slightly devitrified cloudy glass. The refractive index of the glass is 1.496, suggesting a very high silica content, but there are no quartz phenocrysts.

A chemical analysis and norm of this vitrophyre follow, together with the chemical composition and norm of Nockolds' (1954) average alkali rhyolite for comparison. A semiquantitative spectrographic analysis of the same rock is given in table 2, column 10.

*Chemical analyses, in percent, of rhyolite vitrophyre and average alkali rhyolite*

| Bulk analysis | | | Normative minerals | | |
|---|---|---|---|---|---|
| Constituent | 1 | 2 | Mineral | 1 | 2 |
| $SiO_2$ | 72.33 | 74.57 | Q | 29.58 | 31.1 |
| $Al_2O_3$ | 12.94 | 12.58 | or | 27.80 | 27.8 |
| $Fe_2O_3$ | 1.13 | 1.30 | ab | 34.58 | 35.1 |
| FeO | .19 | 1.02 | an | 1.67 | 2.0 |
| MgO | .18 | .11 | C | .41 | ------- |
| CaO | .41 | .61 | wo | ------- | .1 |
| $Na_2O$ | 4.10 | 4.13 | en | .40 | .3 |
| $K_2O$ | 4.69 | 4.73 | fs | ------- | .6 |
| $H_2O+$ | 2.98 | .66 | mt | .23 | 1.9 |
| $H_2O-$ | .18 | ------- | hm | .96 | ------- |
| $TiO_2$ | .19 | .17 | il | .46 | .3 |
| $P_2O_5$ | .02 | .07 | ap | ------- | .2 |
| MnO | .10 | .05 | fl | .07 | ------- |
| $CO_2$ | .01 | ------- | | | |
| Cl | .06 | ------- | | | |
| F | .10 | ------- | | | |
| Subtotal | 99.61 | ------- | ------- | ------- | ------- |
| Less O | .05 | ------- | ------- | ------- | ------- |
| Total | 99.56 | ------- | ------- | ------- | ------- |
| Powder density | 2.40 | ------- | ------- | ------- | ------- |

1. Rhyolite vitrophyre, rhyolite-obsidian unit, Galiuro Volcanics; NW¼ sec. 27, T. 5 S., R. 18 E. Laboratory No. F2679. Analyst, Dorothy F. Powers, U.S. Geol. Survey.
2. Average alkali rhyolite plus rhyolite obsidian (Nockolds, 1954, table 1, col. 4).

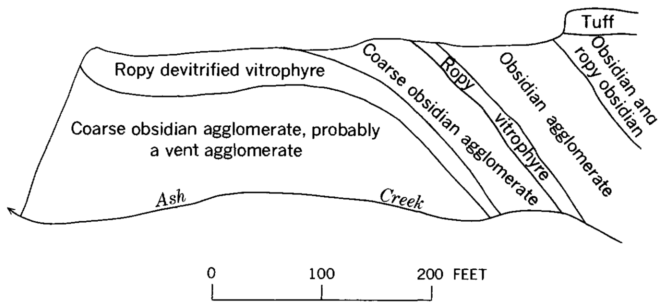


**Figure 25.**—Sketch of the southeast wall of Ash Creek in sec. 22, T. 5 S., R. 18 E., showing the sequence in the rhyolite-obsidian unit of the Galiuro Volcanics.

A conspicuously streaked vitrophyre from the north side of Lookout Mountain consists of strung-out fragments of black glass as much as a centimeter or two long in a matrix of brown glass. As seen under the microscope, the glass shows evidence of partial oxidation and brecciation during flowage; fragments of colorless vitrophyre, brown obsidian, and streaked brown and colorless obsidian are enclosed in a brown matrix having pronounced flow structure.

The ropy devitrified vitrophyre shown on figure 25 is a streaked gray and light-brown rock containing a few millimeter-size phenocrysts of sanidine. In thin section the rock contains, in addition to the sanidine, sparse phenocrysts of quartz, dark-brown hornblende, biotite, and sphene. The groundmass is completely devitrified and contains spherulites and radiolites, presumably composed of feldspar and cristobalite. The radiolites commonly grow outward from a phenocryst.

The obsidian agglomerate is extremely variable in appearance from place to place. In the middle part of Booger Canyon, it is made up of angular to subangular blocks of laminated obsidian several feet across, in a pumiceous matrix. In this area it overlies conspicuously layered dark-gray and brown obsidian cut by dikelike seams of devitrified glass. Farther north, the agglomerate is conspicuously light colored and is made up of large blocks of black obsidian and white welded vitric tuff in a pumiceous matrix. Local very thick concentrations of the agglomerate, such as that in lower Ash Creek shown on figure 25, may well be accumulations in or near vents.

The tuff at the base of the unit near the mouth of Booger Canyon is a yellowish-gray (5*Y* 7/2) massive well-sorted sandy vitric tuff made up almost entirely of fragments of devitrified glass less than 0.5 mm across. Crystals 0.1–0.2 mm across of quartz, greenish-brown hornblende, biotite, clinopyroxene, and sanidine are scattered through the tuff, and locally the rock is cemented by considerable amounts of a nearly isotropic mineral shown by X-ray study to be heulandite.

The rhyolite lavas are a monotonous group of very fine grained rocks commonly having thin alternating light- and dark-gray flow layers. In general, phenocrysts are sparse and rather small, usually less than a millimeter across. Phenocrysts identifiable with a hand lens are mostly feldspar; biotite phenocrysts are rare, and those of other minerals are practically nonexistent. Flow layering in most places is contorted and locally is exceedingly so.

Rhyolite from the west fork of Horse Camp Canyon in the SW¼ sec. 34, T. 5 S., R. 18 E. is typical of the sequence. In thin section it consists mainly of a finely layered aggregate of sanidine, tridymite, and quartz containing sparse rounded phenocrysts of sanidine 0.5–1 mm long and a few microphenocrysts of biotite and magnetite. Individual flow layers are mostly less than a millimeter thick. Tridymite crystals are oriented more or less perpendicular to the flow layering and obviously are a result of devitrification of an originally glassy rock. Some of the layers have a core of quartz, a rind of sanidine, and an outer envelope of sanidine and tridymite. The presence of abundant tridymite was confirmed by X-rays.

Another rock from Horse Camp Canyon about a mile farther south is similar but has somewhat larger phenocrysts and thicker flow layers. Under the microscope it is seen to consist of rounded grains of sanidine 0.5–3 mm across and a few altered grains of pale-green clinopyroxene 0.5–1 mm long in a matrix of fine-grained spherulitic devitrified glass. The glass groundmass has numerous lenses and vuggy lenses made up of tridymite in wedge-shaped twinned crystals 0.2–0.4 mm long. The light-colored layers of the ground mass contain most of the identifiable tridymite, whereas the dark layers consist largely of spherulites. X-ray examination reveals the spherulites to be composed mainly of alpha-cristobalite and sanidine.

Specimens of rhyolite from lower Ash Creek, from the divide between Horse Camp Canyon and its west branch, and from upper Booger Canyon are similar to the Horse Camp Canyon rocks and will not be further described.

###### QUARTZ LATITE UNIT OF HAWK CANYON

A very coarse porphyritic quartz latite overlies the tuff unit of Hawk Canyon for about three-tenths of a mile east and a mile west of Hawk Canyon, and is overlain by the upper andesite unit. At the west end of its outcrop, the quartz latite rests directly on the rhyolite-obsidian unit or is separated from it by only a few feet of tuff of Hawk Canyon. The total area of outcrop is less than half a square mile.

In Hawk Canyon and on the north side of Lookout Mountain, the quartz latite is 150–200 feet thick. To the east, it thins rapidly and pinches out about 1,000 feet west of Anderson Spring. To the west, the quartz latite extends almost to the head of Horse Camp Canyon in the center of sec. 13, T. 5 S., R. 18 E., where it ends abruptly, apparently along a former high area on the rhyolite-obsidian unit, although the relations are not clear.

The quartz latite is a massive pale-red to moderate or grayish-red rock containing abundant phenocrysts 1–5 mm long of colorless to pink potassium feldspar, gray plagioclase feldspar, quartz, and biotite set in a fine-grained stony groundmass. Locally near the top, the quartz latite has numerous rounded inclusions several inches across of a fine-grained purple volcanic rock. As seen in thin section a specimen from the north side of Lookout Mountain has a hiatal porphyritic texture, containing euhedral to subhedral phenocrysts 0.5–3 mm across of quartz, oligoclase, sanidine, and light-brown biotite set in a very fine grained somewhat felsitic groundmass; the groundmass seems to be mostly plagioclase feldspar, iron oxide, and some unidentified potassium mineral that is apparent only after staining with sodium cobaltinitrite. Oligoclase phenocrysts have numerous inclusions of groundmass material. The rather sparse phenocrysts of sanidine have rims of oligoclase. Accessory minerals include yellowish-green hornblende, sphene, pyroxene, and iron ore. Considerable amounts of the groundmass consist of an optically positive zeolite identified with X-ray methods as heulandite. This same zeolite also forms a rind around a few quartz amygdules.

###### UPPER ANDESITE UNIT

The upper andesite unit has two principal areas of outcrops, one in the upper parts of Horse Camp, Booger, Paisano, Horse, and Black Canyons, where it covers about 4 square miles, and the other in the upper walls of Aravaipa Canyon and several adjoining small flat areas west of Parsons Canyon and between Old Deer Creek and Paisano Canyon.

Over most of the area north of Aravaipa Canyon, the andesite is the highest unit of the Galiuro Volcanics. For the most part, it overlies the rhyolite-obsidian unit; but around the head of Hawk Canyon, it also rests on the quartz latite unit of Hawk Canyon, which overlies the rhyolite-obsidian unit, and on the tuff unit of Hawk Canyon, which underlies the rhyolite-obsidian unit. Along Aravaipa Canyon the upper andesite rests directly on the intermediate andesite, except in Paisano Canyon. Near the mouth of this canyon, the relations of the upper andesite unit to the underlying rhyolite-obsidian and intermediate andesite units are discordant; on the south side of the canyon the upper andesite rests directly on intermediate andesite, whereas on the north side it overlies the rhyolite-obsidian. The dip of the base of the upper andesite in this area is southward, as is shown by the bedding of a thin layer of tuff at the base of the unit.

Between Paisano and Booger Canyons the upper andesite is missing, and the rhyolite-obsidian unit is overlain directly by Hell Hole Conglomerate.

The upper andesite unit ranges in thickness from about 100–200 feet opposite the mouth of Old Deer Creek, and 200 feet at the mouth of Paisano Canyon, to perhaps as much as 500 feet in Horse Canyon.

The unit is made up of dark-colored dense fine-grained locally amygdaloidal lava flows and, particularly in Horse Canyon, agglomerates. Sequences of flows may have red to black scoriaceous layers or agglomerates at the tops of individual flows, and agglomerates or flow breccias at the bottoms. The andesite may be finely laminated, or coarsely platy, or massive and blocky. Many flows seem to be 10–15 feet thick, but some are much thicker and one flow in the south wall of Aravaipa Canyon is about 100 feet thick. Small grains of plagioclase feldspar, red altered olivine, and sparse clinopyroxene are the only phenocrysts. The groundmass of all but one rock examined in thin section is intergranular; the andesite at the mouth of Booger Canyon has an ophitic groundmass. Amygdules are of calcite and zeolites, including stilbite and heulandite.

In the region north of Aravaipa Canyon, the base of the andesite commonly is marked by a bed of orange-pink, gray, buff, or red coarse-grained vitric-lithic or crystal-vitric tuff or breccia. The tuff is usually only a few feet thick but may attain a thickness of as much as 60 feet.

As seen in thin section, a platy medium-dark to dark-gray fine-grained olivine andesite from the ridge east of Booger Canyon at the center east edge of sec. 36, T. 5 S., R 18 E., is made up of sparse millimeter-size euhedral phenocrysts of plagioclase feldspar, grains of olivine 0.5 mm or less in diameter, and scattered grains of clinopyroxene, set in an intergranular groundmass of andesine microlites 0.02–0.1 mm long and granules of clinopyroxene and scarce olivine and iron ore. The olivine phenocrysts are completely altered to iddingsite. Plagioclase shows progressive zoning within a narrow composition range from about $An_{70}$ in the cores to $An_{60}$ at the rims. The pyroxene, probably augite, occurs as separate grains and also in ophitic clots with plagioclase. A variety of this rock from Paisano Canyon, half a mile southeast, contains abundant amygdules of calcite and stilbite.

A chemical analysis and norm of the rock from the east side of sec. 36 are appended, together with the chemical composition and norm of Nockolds' (1954) average andesite for comparison. A semiquantitative spectrographic analysis of the same rock appears in table 2, column 11.

*Chemical analyses, in percent, of andesite and average andesite*

| Bulk analysis | | | Normative minerals | | |
|---|---|---|---|---|---|
| Constituent | 1 | 2 | Mineral | 1 | 2 |
| $SiO_2$ | 53.95 | 54.20 | Q | 5.88 | 5.7 |
| $Al_2O_3$ | 17.06 | 17.17 | or | 9.45 | 6.7 |
| $Fe_2O_3$ | 4.24 | 3.48 | ab | 30.92 | 30.9 |
| FeO | 4.25 | 5.49 | an | 25.58 | 27.2 |
| MgO | 3.91 | 4.36 | wo | 5.34 | 4.2 |
| CaO | 8.04 | 7.92 | en | 9.80 | 10.9 |
| $Na_2O$ | 3.66 | 3.67 | fs | 2.24 | 5.3 |
| $K_2O$ | 1.60 | 1.11 | mt | 6.03 | 5.1 |
| $H_2O+$ | .40 | .86 | il | 2.74 | 2.4 |
| $H_2O-$ | .69 | -------- | ap | 0.67 | .7 |
| $TiO_2$ | 1.39 | 1.31 | | | |
| $P_2O_5$ | .29 | .28 | | | |
| MnO | .13 | .15 | | | |
| $CO_2$ | .03 | -------- | | | |
| Cl | .01 | -------- | | | |
| F | .05 | -------- | | | |
| Subtotal | 99.70 | -------- | -------- | -------- | -------- |
| Less O | .02 | -------- | -------- | -------- | -------- |
| Total | 99.68 | -------- | -------- | -------- | -------- |
| Powder density | 2.84 | -------- | -------- | -------- | -------- |

1. Olivine andesite, upper andesite unit, Galiuro Volcanics; center east edge sec. 36, T. 5 S., R. 18 E. Laboratory No. F2678. Analyst, Dorothy F. Powers, U.S. Geol. Survey.
2. Average andesite (Nockolds, 1954, table 6, col. 2).

The andesite from upper Horse Camp Canyon and the top of Lookout Mountain has sizable grains of olivine as the only phenocrysts. Microscopic examination show that the rock from Lookout Mountain has euhedral crystals of olivine 0.2–2 mm across in an intergranular groundmass of andesine laths 0.1–0.2 mm long containing interstitial granules of clinopyroxene, iron ore, and a little olivine. Large grains of olivine have a rim of iddingsite, whereas smaller grains are completely altered. The olivine has 2V about 90°, indicating a composition of about 90 percent forsterite.

An andesite from the large outcrop area east of Lookout Mountain has numerous xenocrysts of quartz 1–3 mm across. All the quartz grains are rimmed by pyroxene granules, and some have an inner rim of pyroxene and an outer rim made up of hornblende, biotite, and potassium feldspar set in quartz that is in optical continuity with the nucleus. Phenocrysts are plagioclase feldspar (about $An_{40-45}$) 2–3 mm long and clinopyroxene and olivine 0.1–0.2 mm across. Olivine is completely altered to iron oxide. Some plagioclase phenocrysts have irregular inclusion-filled rims that may represent zones of rapid growth (fig. 26). The groundmass is an intergranular aggregate of andesine laths, pyroxene, iron ore, sphene, biotite(?), and a little colorless glass.

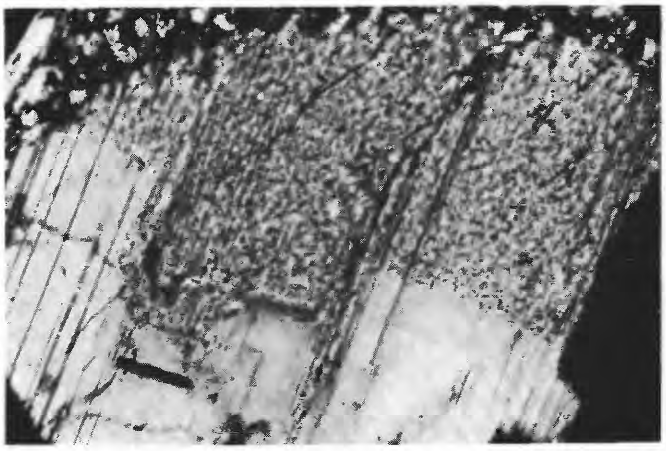

FIGURE 26.—Photomicrograph of part of rim of large phenocryst of plagioclase feldspar in upper andesite unit of Galiuro Volcanics. Mottled area is crowded with inclusions much smaller than the grains in the adjoining intergranular groundmass. This inclusion-filled zone may represent a period of rapid growth of the phenocryst. Note that narrow albite twin lamellae extend without interruption from clear plagioclase into inclusion-rich rim. Crossed nicols. × 120.

In the N½ sec. 23, T. 6 S., R. 18 E., the upper andesite is an irregular single slightly porphyritic flow 100 feet or more thick. The upper 30–40 feet is reddish-purple highly vesicular flow breccia, and the top of the flow is very irregular and dotted with spatter cones as much as 30–40 feet high. Columnar jointing is very inconspicuous. A specimen from about 40 feet below the top of the flow is a grayish-black rock containing phenocrysts of plagioclase feldspar, prominent red-orange crystals of olivine 1–2 mm across, and somewhat smaller grains of pyroxene. Underlying this flow is a well-bedded orange to red vitric-crystal or vitric-lithic tuff 5–50 feet thick. Some of the lithic fragments are as much as 0.5 cm across, but most are sand size or smaller. The tuff is composed mainly of grains 0.05–0.3 mm across of quartz, andesine-labradorite, clinopyroxene, and glass, together with a rather abundant reddish-brown mineral believed to be iddingsite, which probably was derived from the immediately underlying intermediate andesite.

#### UPPER TUFF UNIT

The highest rocks in the formation for which the stratigraphic position is known with certainty are a group of coarse-grained light-colored dominantly rhyolitic tuffs. These rocks crop out over an area of several square miles just south of, and to a lesser extent just north of, Aravaipa Canyon. A few much smaller outcrops are in the extreme northwest corner of the quadrangle in the upper part of Ash Creek. The thickness ranges from 200 feet on the south side of Aravaipa Canyon to 300 feet on the north side. The original thickness is unknown, as the upper limit of the tuff is everywhere a surface of erosion. Four subunits of the upper tuff were mapped during fieldwork, but because these are either of limited areal extent, or of limited thickness, or both, they are not differentiated on the geologic map.

The upper tuff is cut by vertical joints in places, for example near the west edge of the quadrangle south of Aravaipa Canyon, where the joints trend N. 10° E.

The lowest subunit is a very coarse grained tuff and agglomerate that constitutes the conspicuous light-colored cliffs immediately above the rhyolite-obsidian unit or the upper and intermediate andesite units. In its principal area of outcrop, in the region of mesas and flat-topped ridges immediately south of Aravaipa Canyon, this subunit attains a thickness of 100–150 feet. It is predominantly a coarse-grained lithic rhyolite tuff and interlayered fine-grained to sandy crystal-rich tuff. The lithic fragments are mostly of fine-grained rhyolite derived from the rhyolite-obsidian unit. On the geologic map a small area of conglomerate in the SE¼ sec. 33 and the SW¼ sec. 34, T. 6 S., R. 18 E., is grouped with the lowest subunit; this conglomerate is not found elsewhere in the Klondyke quadrangle. It is sandy or tuffaceous in its lower part, and is a very coarse grained conglomerate, containing boulders of andesite, "turkey-track" andesite, rhyolite welded tuff, and a little chert breccia, in its upper part.

In the north-central part of sec. 23, T. 6 S., R. 18 E., just south of Aravaipa Canyon, the base of the lowest subunit is a pale yellowish-brown porous well-bedded and presumably water-laid sandy vitric-crystal rhyolite tuff that overlies the blocky top of the upper andesite unit. A thin section of this tuff contains abundant grains 0.1–0.2 mm across of quartz and sanidine, and scattered crystals of plagioclase feldspar, green hornblende, and brown biotite, set in a fine-grained matrix of devitrified glass. Rock fragments are scarce.

The four isolated patches of coarse-grained tuff on the ridge between the mouths of Booger and Paisano Canyons consist of angular fragments 2–5 cm across of the immediately underlying rhyolite, set in a fragmental matrix of rock fragments and pumice.

On the butte in the NW cor. sec. 10, T. 6 S., R. 18 E., the lowest subunit consists of a lower coarse-grained tuff that dips 5°–10° NW. and an upper flat-lying agglomerate 40–50 feet thick. The agglomerate is a chaotic assemblage of blocks of medium-gray vitrophyre as much as 3 feet across and fragments of white and yellow pumice in a coarse pumiceous matrix. The glass of the vitrophyre has a refractive index of about 1.495, suggesting that the subunit here also is rhyolitic.

In the northwest corner of the quadrangle along Ash Creek, the tuff outcrops probably belong entirely to the lowest subunit, although this correlation is uncertain inasmuch as the outcrops are nearly 5 miles north of the type locality along Aravaipa Canyon. The tuff here is 20–100 feet thick and clearly fills valleys in the underlying rhyolite and obsidian agglomerate of the rhyolite-obsidian unit. It is a white to cream or yellowish-gray coarse-grained well-bedded friable vitric-lithic tuff made up of lapilli 2–3 cm or so across of varicolored obsidian, fine-grained rhyolite, pumice, and grains of quartz and feldspar, in a pumiceous matrix. A few fragments are as much as 6 inches across. Locally the base of the tuff is a few feet of breccia composed of obsidian fragments 2–5 cm across. In thin section a sandy dacitic facies of the tuff consists of 0.2–0.5 mm angular to subrounded grains of quartz and oligoclase, and 1–4 mm pieces of devitrified pumice and vitrophyre in a spongy matrix that seems to be almost entirely a granular aggregate of heulandite in grains 0.05–0.1 mm across; heulandite was identified with X-ray methods. Potassium feldspar and brown biotite occur sparingly. A little secondary quartz is molded on some pumice fragments.

Resting on the lowest subunit is a bed of white tuff that crops out over an area of several square miles just south of Aravaipa Canyon and attains a thickness of 30–90 feet. It is in general a white to cream coarse-grained massive vitric-lithic rhyolite tuff made up predominantly of angular to subrounded fragments of white pumice and gray obsidian in a matrix of white ash. Fragments of gray stony vitrophyre and red porphyritic andesite are minor components. Fragments are generally of lapilli size or smaller, but some are as large as 10 cm across. The pumice has a refractive index of about 1.495 and presumably contains more than 70 percent silica.

In secs. 10 and 15, T. 6 S., R. 18 E., north of Aravaipa Canyon, the white tuff subunit ranges in thickness from a few tens of feet to nearly 100 feet. It consists mainly of lapilli of white pumice 1–3 cm

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across, and a few pieces of obsidian, in a matrix of powdery pumice.

The upper coarse-grained subunit has the same general distribution as the white tuff subunit but has a smaller total outcrop area. South of Aravaipa Canyon, buff to grayish-brown well-bedded and cross-bedded porous and generally sandy rhyolitic tuff of this subunit caps many of the isolated buttes. Maximum thickness is about 110 feet. The principal components are angular to rounded fragments of obsidian, pumice, quartz, feldspar, stony vitrophyre, and reddish rhyolite and trachyte; one bed contains abundant euhedrons of biotite. Locally the basal part of the tuff is a coarse-grained unsorted lithologically heterogeneous conglomerate containing boulders as much as a foot across.

In most places the tuff becomes sandier and more crystal rich toward the top, but the uppermost 20 feet or so may be a coarse-grained lithic tuff containing fragments as much as 6–8 inches across. In the SW¼ sec. 23, T. 6 S., R. 18 E., the upper coarse-grained subunit consists of a basal 30 feet of sandy lithic-vitric tuff, becoming more lithic upward, 45 feet of lithic tuff, 15 feet of well-bedded sandy tuff containing scattered lithic fragments as much as 4 inches across, 20 feet of coarse-grained lithic tuff, and 1 foot of well-bedded waterlaid gray sandy vitric-crystal rhyolite or quartz latite tuff. In thin section this uppermost sandy tuff is made up of 0.2–0.5 mm angular to subangular grains of quartz, sanidine, oligoclase, and scarce biotite in a matrix of particles of devitrified glass. Minor components include a few fragments of spherulitic obsidian and welded tuff, scattered grains of sphene and green hornblende, and a little interstitial zeolite, probably stilbite.

North of Aravaipa Canyon, the upper subunit is a very coarse-grained well-bedded waterlaid lithic tuff 150–200 feet thick. It weathers buff and is a prominent cliff former. The tuff consists mostly of fragments of obsidian and a little rhyolite.

The uppermost subunit of the upper tuff is a buff to light-brown coarse-grained vitric-crystal rhyolite tuff composed of pumice lapilli 2–3 cm across, together with millimeter-size crystals of biotite, quartz, and feldspar, in a pumiceous matrix. The pumice has a refractive index of about 1.495. The contact with the underlying water-laid sandy tuff of the upper coarse-grained subunit is sharp and concordant and has no evidence of erosion or disturbance of any kind; it seems likely that the pumiceous tuff is of airfall origin and that it was deposited in shallow water.

#### AGE AND CORRELATION

The age of the Galiuro Volcanics is not known with any degree of certainty, as no fossils were found either in the formation or in the overlying rocks and as no determinations of absolute age have been made. The formation is known to be younger than the Copper Creek granodiorite, which intrudes rocks of Devonian(?), Mississippian, and Cretaceous(?) age and has been assigned a potassium-argon age of 68 million years. Subsequent to emplacement of the granodiorite, considerable erosion must have ensued to expose the granodiorite before extrusion of the basal andesite of the Galiuro Volcanics, and hence these are probably much younger than the granodiorite. They are overlain with marked angular unconformity by Hell Hole Conglomerate, and this unconformity must also represent an appreciable time interval, although perhaps shorter than the period required by the basal unconformity. Tentative assignment of the Galiuro Volcanics to the middle Tertiary would seem to do as little violence as possible to the meager data available at this time. On this hypothesis they would be younger than the Horse Mountain Volcanics, the lower part of which is believed to be of Late Cretaceous age.

#### DIKES AND SILLS

Dikes of various lithologies cut all rock units of the Klondyke quadrangle older than the Hell Hole Conglomerate. The dikes are particularly abundant in the Precambrian rocks, especially the Laurel Canyon Granodiorite, in which they locally may constitute as much as one-third to one-quarter of the terrane. On the other hand, dikes are very scarce in the Santa Teresa Granite, the Goodwin Canyon Quartz Monzonite, the Copper Creek Granodiorite, and the Glory Hole Volcanics; and in the Galiuro Volcanics, dikes are restricted to the lower andesite unit in the southwest part of the quadrangle. No dikes were seen in the outliers of Horse Mountain Volcanics northeast of Aravaipa Canyon.

The dikes range in composition from rhyolite to olivine andesite, but those of silicic composition—rhyolite, quartz latite, dacite, and so forth—are far more abundant than the others. Dike rocks are generally porphyritic, some conspicuously so, but several are aphanitic or only sparingly porphyritic. The dikes attain a width of a hundred feet or more, but the average width is only a few feet. The longest dike known to be a single body is about 2.5 miles long, but some members of the dike swarm along the west side of the Laurel Canyon Granodiorite may possibly be as much as 4 miles long. The silicic dikes are more resistant to erosion than the Pinal Schist, and many of the low knobs in the Pinal terrane southwest of the Santa Teresa Mountains are held up by dikes. In contrast, only rarely do dikes of the swarm in Laurel Canyon Granodiorite have any notable topographic expression.

The few sills of the quadrangle are all siliceous rocks. A sill 40 feet thick intrudes conglomerate interbedded with the volcanic member of the Buford Canyon Formation; another sill 5–6 feet thick intrudes shale of the Pinkard Formation in upper Old Deer Creek; and a third sill 10 feet thick intrudes Bolsa Quartzite southeast of Aravaipa.

In the Santa Teresa Mountains and in the Turnbull Mountains southeast of Imperial Mountain, most of the dikes have a strike within the range N. 00°–35° W. North of Imperial Mountain, probably more than half the dikes also strike within this range, but an appreciable number have entirely random strikes. The north-northwestward trend is parallel to the structural grain of the Horse Mountain Volcanics and to many of the faults that cut these and older rocks. No trend is dominant among the sparse dikes in the Galiuro Volcanics.

During fieldwork, the silicic dikes were subdivided insofar as was possible into several groups on the basis of various combinations of phenocrysts of quartz, potassium feldspar, and plagioclase feldspar. It did not prove feasible to retain this grouping in compiling the geologic map, however, because many dikes were of transitional lithology and could not be referred logically to one field group; consequently, all are shown by the same symbol. Lamprophyres and andesite dikes are shown as a separate group.

Little direct evidence of age relations among the various types of dikes, such as intersections of dikes of different lithologies, was found. Some indirect evidence, however, suggests several ages, one of which is much greater than the others. Dikes and sills of diabase or ophitic gabbro are restricted to the Precambrian rocks and presumably are of Precambrian age; diabase is a very common rock in the Precambrian of the northwestern Galiuro Mountains, the Ray region, the Sierra Ancha, and elsewhere in southeastern Arizona.

Several silicic dikes cut the Horse Mountain Volcanics, and it seems logical to assume therefore that most if not all the silicic dikes are younger than the Horse Mountain.

The widespread but rather scarce dikes of coarsely porphyritic ("turkey-track") andesite presumably belong to the period (or periods?) of igneous activity during which petrographically similar lavas were extruded in the Aravaipa area and the Galiuro Mountains region. In a composite dike in the NE¼ sec. 8, T. 6 S., R. 20 E., an earlier "turkey-track" dike is intruded by quartz porphyry. In upper Stowe Gulch just above the Lead King mine, a quartz porphyry dike 25 feet wide appears to be intruded along one wall of a wide dike of "turkey-track" andesite. One porphyritic andesite dike was seen in Klondyke Wash in an area remote from any similar lavas.

Several silicic dikes of the Turnbull and Santa Teresa Mountains end at or near the contact of their host rock with the Santa Teresa Granite, but only two, the prominent dikes through VABM 5385 and the knob east of it in the SW¼ sec. 16, T. 6 S., R. 20 E., are clearly offshoots of the granite itself. These two dikes change gradually along the strike from granite near the Santa Teresa Granite to quartz porphyry apparently identical with that making up many other dikes. The mineralogy of numerous silicic dikes—quartz, microperthite, and accessory biotite and sphene—suggests strongly that they are consanguineous with the granite. If dikes and granite are comagmatic, then the abundance of dikes northwest of the granite would suggest that the granite extends several miles northwest of its outcrop area beneath a gently sloping roof; that the roof is indeed rather flat is indicated by the contact with Precambrian rocks in Black Rock, Cottonwood, and Goat Canyons. The dikes provide the only evidence of age relations between Santa Teresa Granite and Horse Mountain Volcanics, as these two rocks are nowhere in contact.

No dikes can be related to the Goodwin Canyon Quartz Monzonite with any degree of certainty. Dikes in the area peripheral to the Goodwin Canyon are silicic rocks similar to those believed to be consanguineous with the Santa Teresa Granite, and no petrographic features distinctive enough to provide a basis for separation were recognized.

The various lithologic types of dikes will be described, and the general distribution of each type pointed out. Dikes, sills, and irregular bodies of diabase and ophitic gabbro were described earlier (p. 18). Inasmuch as no chemical analyses of dike rocks have been made, the nomenclature in the following section is based entirely on study of hand specimens and thin sections.

#### QUARTZ PORPHYRY AND RHYOLITE DIKES

The most widespread and abundant dikes are of quartz porphyry or rhyolite. They occur throughout the Turnbull and Santa Teresa Mountains, and a few also intrude the Galiuro Volcanics. Although these dikes cut all rocks older than the Hell Hole Conglomerate, they are very scarce in the Santa

Teresa Granite, and only one was noted in the Goodwin Canyon Quartz Monzonite.

As far as can be determined from study of thin sections, all these rocks have about the same composition, but they may be separated into two broad groups on the basis of texture; those designated as quartz porphyry dikes have abundant large phenocrysts of quartz and alkali feldspar, whereas those termed rhyolite dikes have only a few small phenocrysts.

The typical quartz porphyry is a pale-red, light brownish-gray, light olive-gray, or light-gray rock containing phenocrysts several millimeters across. Modal analyses of nine dike rocks show that percentage of phenocrysts ranges from 15–40, most of the rocks having 25–35 percent of phenocrysts. The ratio of quartz phenocrysts to feldspar phenocrysts is about 1:1 in three rocks and from 1:1 to 1:2 in six rocks.

Quartz phenocrysts almost invariably are rounded and embayed, and may have inclusions of groundmass material; in a few dikes the quartz phenocrysts are euhedral bipyramids. They commonly have a narrow vague rim of inclusion-filled quartz in optical continuity with the core. The feldspar phenocrysts are microperthitic sanidine; in some dikes the feldspar grains are clear, in others they are dusty, and in a few they have clear cores and dusty rims. The amount of plagioclase feldspar in the microperthite phenocrysts is variable, but may be as much as 50 percent.

Accessory minerals are very scarce; iron ore, sphene, and biotite were seen in several thin sections, and epidote and apatite in two sections. Sphene crystals attain a length of 1 mm; the others are less than a millimeter across.

The groundmass commonly shows a patchy birefringence typical of devitrified glass; many of the dikes have a coarsely spherulitic groundmass, and one dike had a groundmass made up of a confused mixture of spherulites and micrographic intergrowths. Spherulites may be isolated, or partial spherulites may form sheaflike rims around phenocrysts. Small grains of albitic plagioclase occur in the matrix of a few dikes, but plagioclase in general seems to be very scarce.

The rhyolite dikes are light-gray dense fine-grained rocks that contain sparse small phenocrysts. In some dikes, quartz is the only phenocrystic mineral, but generally phenocrysts of both quartz and feldspar are present. Flow layering is more evident in the rhyolite dikes than in the quartz porphyry dikes, and in some rhyolite dikes it is very well developed. The dikes commonly have a narrow darker chilled selvage, generally near grayish red purple.

#### ANDALUSITE APLITE DIKE

A dike of rather peculiar mineralogy intrudes Laurel Canyon Granodiorite on the low knob 1,000 feet east-northeast of VABM 5385, in the SW¼ sec. 16, T. 6 S., R. 20 E., and what is possibly the same dike crosses Laurel Canyon 1,700 feet to the southeast. On the knob the dike is cut by a younger dike of porphyritic Santa Teresa Granite; this intersection is one of the very few found in the quadrangle. The dike here is about 10 feet wide. In hand specimen the rock is light-gray, has a fine sugary grained aplitic texture, and contains sparse small phenocrysts of quartz and light-brown mica. In thin section a specimen from Laurel Canyon consists largely of a granular aggregate of quartz and dusty potassium feldspar in grains 0.05–0.1 mm across. Albitic plagioclase is sparsely scattered through the groundmass. Quartz also occurs as rounded grains 0.5–1 mm across having scalloped borders. Andalusite is fairly abundant as anhedral and poikilitic grains generally less than a millimeter long; rarely it is faintly tinged with pink. Sparse microphenocrysts of pinkish-brown phlogopite are grouped with apatite grains and have inclusions of the same mineral. Accessory minerals are apple-green spinel, commonly as inclusions in andalusite, and colorless isotropic garnet.

A specimen from the knob near VABM 5385 is similar microscopically but also has numerous very skeletal poikilitic grains of muscovite as much as 2 mm across. No spinel was seen in this rock.

#### TRACHYTE(?) DIKE

The center of the south end of the Arizona vein, in the W½ sec. 25 (not surveyed), T. 5 S., R. 19 E., is made up of a sparsely porphyritic rock probably near trachyte in composition. The width of the dike could not be determined closely but may be as much as 90 feet. The rock is moderate yellowish brown, weathers grayish red to black, and has a few altered phenocrysts of feldspar 1–2 mm long. Microscopically, most of the phenocrysts are of dusty potassium feldspar, the rest being very dusty plagioclase of indeterminate composition. There are also a few microphenocrysts of brown, somewhat blackened biotite, and some aggregate of chlorite and iron oxide whose shape suggests former hornblende. The groundmass has the typical texture and patchy birefringence of devitrified glass, and an aggregate refractive index less than 1.54. Small patches of quartz as well as feldspar crystallites are scattered through the groundmass.

###### QUARTZ LATITE DIKES

A few dikes of quartz latite cut Precambrian rocks north and south of the westward-protruding lobe of Santa Teresa Granite in the S½ T. 6 S., R. 20 E. These dikes are rather diverse in general aspect; they range in texture from porphyritic to fine grained and in color from light brownish gray to light olive gray and dark greenish gray. One dike 30 feet wide has 20 feet of prominently spherulitic rock in the hanging wall. Feldspar is the only mineral forming phenocrysts; sodic plagioclase is more abundant than potassium feldspar, which may be restricted to the groundmass. Quartz forms small phenocrysts in only one dike; in the others it is confined to the groundmass. The groundmass commonly shows the patchy birefringence typical of devitrified glass. Accessory minerals include much-altered biotite, apatite, and sparse sphene, zircon, and epidote.

###### DACITE DIKES

Silicic dikes characterized by phenocrysts of plagioclase feldspar and, rarely, of quartz, are second in abundance only to the quartz porphyry and rhyolite dikes. These dikes are grouped under the general title of dacite, but may well range in chemical composition from latite and quartz latite to andesite; the presence of undeterminable amounts of potassium feldspar in the groundmass precludes any more accurate classification based only on a study of hand specimens and thin sections.

The dacite dikes as so defined comprise a varied group of rocks ranging in texture from coarsely porphyritic to essentially nonporphyritic and in color from shades of grayish red and dark greenish gray through various lighter colors to moderate yellowish brown and light gray. Some show well-developed flow layering, but most are devoid of megascopic flow features. Dark selvages similar to those of the quartz porphyry and rhyolite dikes are shown by a few dacite dikes.

The dacite dikes have phenocrysts of sodic plagioclase feldspar as much as 5 mm across; less commonly, quartz and biotite occur as phenocrysts less than a millimeter across. Plagioclase phenocrysts are in the compositional range albite-sodic andesine, and almost invariably are either sericitized or altered to albite-epidote aggregates; in a sill in the Pinkard Formation, plagioclase is partly replaced by carbonate. Biotite usually has inclusions of sphene and apatite, and is altered to chlorite, epidote, and iron oxide. The groundmass may be spherulitic devitrified glass having the typical patchy birefringence of such material, or may have a pilotaxitic or trachytic texture. Groundmass minerals include quartz, feldspar, iron ore, biotite, apatite, sphene, and zircon.

An eastward-trending dike 2.5 miles long that cuts the lower andesite unit of the Galiuro Volcanics is one of the longest dikes of the quadrangle. It is 30 to 100 feet thick and has well-developed flow layering. The dike is a pale-red rock containing conspicuous phenocrysts of plagioclase feldspar and quartz several millimeters across. Microscopically, the rock contains euhedrons and glomerophenocrysts of zoned oligoclase ($An_{25-30}$), rounded and deeply embayed phenocrysts of quartz, and sparse grains of dark-brown biotite in a very dusty faintly birefringent matrix containing microphenocrysts of plagioclase, biotite, and iron ore. Staining with sodium cobaltinitrite reveals considerable potassium feldspar occult in the groundmass. Plagioclase phenocrysts have clear cores, a very dusty inner rim, and a narrow clear outer rim, and apparently are zoned in normal order.

###### HORNBLENDE DACITE AND LAMPROPHYRE DIKES

A few dikes of the Klondyke quadrangle have green hornblende as their principal mafic mineral. These dikes are widely scattered; most of them intrude Laurel Canyon Granodiorite north and west of Laurel Canyon, but several intrude Santa Teresa Granite near the north end of its outcrop area and one is known to cut Copper Creek Granodiorite west of the Bluebird mine. Most of these dikes are light colored—pale olive, greenish gray, grayish green, or light gray—but those cutting Santa Teresa Granite are dark greenish gray to grayish black. The dikes generally are porphyritic and have phenocrysts of plagioclase feldspar and, less commonly, of hornblende.

Thin sections of the typical hornblende dacites show phenocrysts of oligoclase (in one section, andesine) and pale-green hornblende in a fine-grained intergranular groundmass of oligoclase microlites, hornblende granules, interstitial potassium feldspar, and generally a little quartz. Accessory minerals include sphene, apatite, iron ore, and chlorite. The groundmass may be very dusty. Hornblende is a pale-green or blue-green variety; in one section the pleochroism is X=very pale yellow, Y=yellowish green, and Z=pale bluish green, and the extinction angle $Z \wedge c$ is 18°.

The dark dikes that intrude Santa Teresa Granite contain phenocrysts as much as a centimeter across of zoned plagioclase feldspar ($An_{30-60}$) and smaller phenocrysts of green hornblende set in an intergranular groundmass of plagioclase microlites with granules of hornblende, pyroxene, iron ore, and scattered small patches of quartz. Biotite occurs in the groundmass of one rock, and potassium feldspar in that of another.

Accessory minerals are apatite, epidote, and sphene. Large grains of hornblende have cores of colorless pyroxene which clearly has been replaced by hornblende.

The dike near the Bluebird mine in the Copper Creek region is a light olive-gray rock having phenocrysts of feldspar, hornblende, and biotite. Microscopically, the feldspar forms glomerophenocrysts several millimeters across; it is strongly zoned in the compositional range oligoclase-andesine, but no reliable determination could be made. Hornblende is a very pale green to practically colorless variety having an extinction angle $Z \wedge c = 16°$. Brown biotite forms ragged grains a millimeter or so long. The groundmass consists of oligoclase microlites, hornblende, iron ore, a little quartz and potassium feldspar, and sparse apatite.

#### PORPHYRITIC ANDESITE DIKES

Dikes of coarsely porphyritic andesite, lithologically very similar to the "turkey-track" lava flows of the Galiuro and Horse Mountain Volcanics, crop out at a few places in the Santa Teresa, Turnbull, and Galiuro Mountains. Several are clustered in and near the fossil ash cone in the Galiuro Volcanics of the Right Prong of Fourmile Creek. Others cut the conglomerate member of the Buford Canyon Formation in Klondyke Wash, the Laurel Canyon Granodiorite west of Black Rock Spring, the Santa Teresa Granite on the ridge between Cottonwood and Goat Canyons, and the Pinal Schist in upper Stowe Gulch. The andesite dikes attain a width of 25 feet but are generally less than 10 feet wide. The largest was traced for about half a mile. One of these dikes is well exposed in the Right Prong of Fourmile Creek in the NE¼ sec. 36, T. 7 S., R. 18 E., where it intrudes the lower andesite unit of the Galiuro Volcanics. This dike is 20–25 feet wide and is coarsely porphyritic from wall to wall.

The dikes are dark colored—dark greenish gray, very dusky red purple, or dark gray—but may have lighter colored selvages several feet thick. Their most striking features are the large platy phenocrysts of plagioclase feldspar, which attain a diameter of 2 cm. The ratio of diameter to thickness is seldom less than 10:1 and may be as much as 15:1. These feldspar plates ordinarily have random orientation, but near dike walls may be alined parallel to the walls.

Microscopically, the andesite dikes have a porphyritic texture and an intergranular groundmass. In some rocks the texture is seriate porphyritic, but in most there are few phenocrysts in the size range between 1 mm and the groundmass microlites. The plagioclase shows oscillatory zoning within a narrow range $An_{45-55}$, but zoning is not nearly so pronounced as in the phenocrysts of the similar lava flows (fig. 27). Pericline twinning is either scarce or nonexistent. The plagioclase is usually quite fresh, but in one section is crowded with pale-green inclusions (epidote?) and changed in composition from andesite-labradorite to albite. In several sections the principal mafic mineral is olivine in grains 0.5–1 mm across, highly altered to iron oxide and chlorite. Clinopyroxene forms small sparse phenocrysts in olivine-bearing dikes and also occurs in the groundmass. In a dike that cuts Santa Teresa Granite in the W½ sec. 2, T. 6 S., R. 20 E., the only mafic mineral is pale-green hornblende in ragged roughly equant to stubby prismatic aggregates as much as 5 mm across. The hornblende is weakly pleochroic, with X = almost colorless, Y = pale brownish green, and Z = pale green. The ragged outlines and granular appearance of the grains suggest that the hornblende was derived from pyroxene, but if so no remnants of the parent mineral are left. The groundmass of the porphyritic andesite dikes is commonly a mesh of plagioclase laths with interstitial iron ore, chlorite, and some dusty devitrified glass. Clinopyroxene granules occur in the groundmass of several dikes, and hornblende occurs in that of two others.

#### OLIVINE ANDESITE DIKE

A dike of grayish-red olivine andesite cuts the lower andesite unit of the Galiuro Volcanics in a northwestward-sloping tributary of Copper Creek; no other similar dikes were seen. The dike has light-gray chilled margins a few inches thick, and the walls are marked at several places by a thin film of chrysocolla. Petrographically, the dike resembles its wallrocks. Phenocrysts of oscillatorily zoned plagioclase

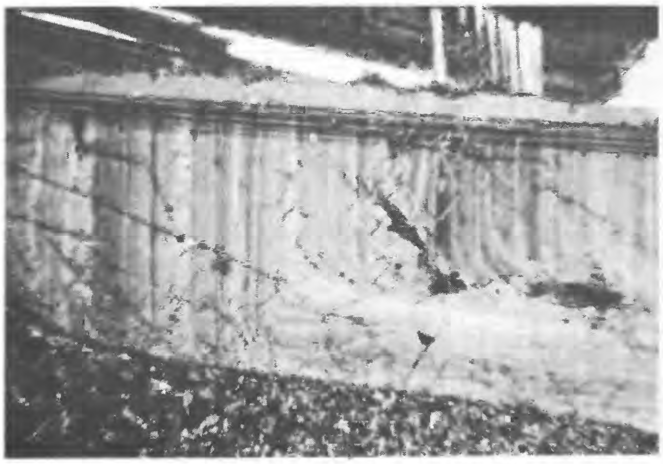

FIGURE 27.—Photomicrograph of oscillatorily zoned plagioclase feldspar phenocryst in dike of porphyritic ("turkey-track") hornblende andesite, NE¼ sec. 8, T. 6 S., R. 20 E. The feldspar is zoned within the narrow compositional range $An_{45-50}$. More than 70 pairs of zones can be counted in this crystal. Crossed nicols, × 30.

feldspar ($An_{60}$) 3–4 mm across, abundant skeletal grains of olivine 0.5–1 mm across, and sparse clinopyroxene prisms are set in an intersertal base of plagioclase, clinopyroxene, iron ore, and dusty devitrified glass. Olivine is completely altered to pale bowlingite having a refractive index less than 1.54.

#### CONTACT EFFECTS OF DIKES

With a very few exceptions the dikes appear to have had little or no effect on their wallrocks, even where these are limestone.

A vertical dike of porphyritic biotite dacite about 100 feet wide cuts Escabrosa Limestone in the SE¼ sec. 36 (unsurveyed), T. 5 S., R. 19 E., half a mile southeast of Aravaipa. For a few feet on either side of the dike the normally gray limestone is altered to a white, pink, or red dense rock apparently made up largely of irregular carbonate grains 0.01–0.05 mm across; this rock effervesces only slightly with dilute hydrochloric acid and presumably is dolomite.

A light-gray sparsely porphyritic quartz porphyry dike is intruded along a fault in Horquilla Limestone about 1,000 feet west of hill 5459 in the SW¼ sec. 32, T. 5 S., R. 20 E. The fault strikes north to N. 40° W. and dips 60° W. A little johannsenite is in the limestone adjacent to the dike. The fault itself is mineralized with quartz, specularite, and galena, and the johannsenite may be part of this mineral assemblage rather than a result of emplacement of the dike.

In the Cobre Grande mine area, limestone along a highly altered silicic dike 40–50 feet wide has been converted for several tens of feet away from the dike into epidote-johannsenite tactite.

### MISCELLANEOUS INTRUSIVE IGNEOUS ROCKS

#### BIOTITE QUARTZ LATITE

A small body of biotite quartz latite(?) about 500 feet long in a northeasterly direction and perhaps 300 feet wide intrudes the volcanic member of the Buford Canyon Formation at the Silver Coin mine in Klondyke Wash, in the SW¼ sec. 11 (unsurveyed), T. 7 S., R. 20 E. It is bounded along the southeast side by the Silver Coin fault and vein, which strike N. 70° E. and dip 70° SE.

In hand specimen the rock is a medium light-gray porphyry containing phenocrysts of pink potassium feldspar as much as 5 mm across, smaller grains of whitish plagioclase feldspar, abundant tiny crystals of altered biotite, and scattered millimeter-size grains of quartz, all set in a fine-grained holocrystalline matrix. Microscopically, the rock has a fine-grained hypidiomorphic-granular texture. Orthoclase occurs both as euhedral phenocrysts and in the groundmass. Quartz forms embayed anhedral phenocrysts that show undulatory extinction. Plagioclase phenocrysts are in the albite range of composition. They are very dusty and their cores are strongly altered to sericite. A little plagioclase also is in the groundmass. Biotite is nearly completely altered to chlorite. Accessory minerals are iron ore, apatite, and epidote. The groundmass consists largely of quartz and potassium feldspar, the quartz interstitial to much-corroded feldspar. The rock is cut by many postconsolidation fractures marked by narrow zones of microbreccia. Owing to alteration, the proportions of potassium and plagioclase feldspars could not be estimated closely, but seem to be approximately equal.

### HELL HOLE CONGLOMERATE

#### DISTRIBUTION

The Hell Hole Conglomerate underlies a broad belt along the east flank of the Galiuro Mountains, extending from about a mile south of the north edge of the Klondyke quadrangle to about a mile southeast of Fourmile Canyon. It is here named for the Hell Hole, in the lower reaches of Old Deer Creek, where more than 400 feet of conglomerate is well exposed. The belt of outcrop is 5 to 6 miles wide. A few small outcrops of what is probably the same conglomerate are found in stream courses along the southwest slope of the Santa Teresa Mountains, but elsewhere on this slope the conglomerate, if present, is buried by older alluvium. About 50 square miles, or 20 percent of the quadrangle, is underlain by Hell Hole Conglomerate.

#### THICKNESS

The total thickness of the Hell Hole Conglomerate is not known, as the upper limit could nowhere be determined closely. The conglomerate is at least 400 feet thick in the type locality and attains a thickness of at least 600 feet in Aravaipa Canyon between Turkey Creek and the Hell Hole. At The Chimney, on the southwest side of Aravaipa Canyon opposite the mouth of Martinez Canyon, the conglomerate is somewhat more than 400 feet thick. At none of these places is the base exposed. A maximum thickness of as much as 2,000 feet was scaled on a northeast-trending section between Wire Corral Draw to the southwest and Maroga Canyon to the northeast; along this section the upper limit of the conglomerate is everywhere a surface of erosion.

#### STRATIGRAPHIC RELATIONS

The Hell Hole Conglomerate rests unconformably on Galiuro Volcanics, and to a lesser extent on Horse Mountain Volcanics. In some places the unconformity on the Galiuro Volcanics is markedly angular, whereas elsewhere the bedding of the volcanics and conglomerate may be parallel even though the surface of the volcanics is one of considerable relief.

The unconformity is well shown, for example, where small outliers of flat-lying Hell Hole Conglomerate rest on the upper andesite unit of the Galiuro Volcanics in the SE¼ sec. 14, T. 6 S., R. 18 E. The base of the southwesternmost of these outliers dips steeply southeast, and that of the other patch dips steeply east.

In the NE¼ sec. 23, T. 6 S., R. 18 E., the Hell Hole rests on eroded coarse-grained tuff at the base of the upper tuff unit of the Galiuro Volcanics. It has a basal conglomerate 1–2 feet thick made up of angular fragments 6–8 inches across of various volcanic rocks. Although bedding of conglomerate and tuff are parallel, the contact is markedly discordant.

In Booger Canyon in the SE¼ sec. 36, T. 5 S., R. 18 E., the base of the Hell Hole is a chaotic assemblage of angular blocks of volcanic rock as much as a foot across that fills channels in the upper andesite unit of the Galiuro Volcanics.

In Old Deer Creek a mile or so northeast of its junction with Black Canyon, coarse-grained Hell Hole Conglomerate dipping about 9° SW. rests on gray to lavender platy rhyolite welded tuff of the Horse Mountain Volcanics that dips 30° W. The surface on the volcanics slopes about 45° NW., and the lower part of the conglomerate is a coarse-grained talus deposit composed entirely of fragments of the rhyolite. At the mouth of Old Deer Creek, the Hell Hole includes a fossil talus consisting of a chaotic assemblage of large angular blocks of agglomeratic "turkey-track" lava. The contact of talus with Galiuro Volcanics is vertical and probably is a fault of small displacement. Coarse-grained basal conglomerate crops out in Arizona Gulch west and south of the large isolated body of Horse Mountain Volcanics north of secs. 3 and 4, T. 6 S., R. 19 E.

Near the SW. cor. T. 5 S., R. 19 E., the upper andesite unit of the Galiuro Volcanics is cut by clastic dikes of Hell Hole Conglomerate.

Owing to relief on the preconglomerate surface, contacts between volcanics and conglomerate may be steep or even vertical and may simulate faults contacts to such an extent that unless exposures are excellent it may be impossible to determine the nature of the contact. For example, where the contact crosses Aravaipa Canyon near the mouth of Old Deer Creek, the horizontal conglomerate rests on a very smooth surface that dips 35° NE. and is exposed for a dip length of 200 feet; in the absence of good exposures this contact might well be interpreted as a fault. From Aravaipa Canyon for about 1.5 miles south along the west side of Parsons Canyon, the contact is a steeply dipping fault having a displacement of not more than 150 feet; and from Fourmile Creek southeast for a mile the contact appears to be a fault having unknown but possibly considerable displacement.

The original upper surface of the conglomerate may not be exposed in the Klondyke quadrangle, except possibly southeast of Fourmile Creek, where the contact between conglomerate and older alluvium appears conformable. The conglomerate is overlain along the Aravaipa Valley and some of its northeast-sloping tributaries by younger alluvium. On the left bank of Stowe Gulch, just upstream from Stowe Spring, is an outcrop 250 feet long of well-indurated well-bedded flat-lying pebble conglomerate that strongly resembles the beds of the Hell Hole. At this place the conglomerate is overlain by partly consolidated older alluvium. This outcrop is the most northeasterly known occurrence of highly indurated conglomerate, and is of some interest inasmuch as it suggests that the Hell Hole was deposited a considerable distance northeast of the present axis of Aravaipa Valley and then was buried by alluvium. In the rest of the outcrop area the upper limit of the conglomerate, where later alluvium is lacking, is the present land surface.

#### LITHOLOGY

The Hell Hole Conglomerate is in general a light-colored—cream, buff, orange, pink, brown, or light gray—moderately- to well-indurated rock composed of angular to rounded pebbles, cobbles, and occasional boulders of volcanic rock in an abundant sand or grit matrix. The volcanics are types exposed in the Galiuro Mountains, and some, such as certain andesites, are types not exposed, at present anyway, in the Santa Teresa and Turnbull Mountains; consequently, most if not all of the volcanic fragments probably came from the Galiuro Mountains. Fragments of rocks other than volcanic are scarce. One thin lens of cherty limestone, a thin bed of white volcanic ash, and a little vitric tuff were seen.

Outcrops of Hell Hole Conglomerate are commonly knobby and somewhat cavernous owing to weathering-out of pebbles or of pebble beds. The conglomerate stands in high, steep to vertical cliffs where cut by major streams, particularly Turkey Creek and its tributaries, Old Deer Creek and its tributaries, and Aravaipa Creek.

At the type locality the Hell Hole consists of buff to gray conglomerate interbedded at stratigraphic intervals of 2 to 3 feet with lentils of sandy material as much as a foot thick and several tens of feet long. Elsewhere the most common general aspect of the formation is that of a massive sandstone containing erratically distributed coarser components. Fragments of as much as boulder size commonly are concentrated in lenses or thin beds having a sandy and locally sparse matrix, but many also are isolated in sand-size material. Sandy material is ordinarily abundant, making up from 20 to nearly 100 percent of the rock, but it is not uncommon for the sandy matrix to be entirely lacking. In the major west-sloping tributary of Black Canyon south of hill 4509, the Hell Hole is a very coarse-grained completely chaotic rock containing many blocks of volcanic rock 5–6 feet across and 1 block estimated to be 60–70 feet long, set in a coarse-grained sandy matrix. In the tributary gully of Black Canyon south of Anderson Spring, and on the west side of Parsons Canyon in the NE$\frac{1}{4}$ sec. 23, T. 6 S., R. 18 E., the basal part of the conglomerate is a chaotic jumble of angular fragments of the immediately underlying bedrock, commonly as much as a foot across. Near the head of Turkey Creek, in sec. 21, T. 7 S., R. 19 E., the Hell Hole overlies andesite of the Galiuro Volcanics along a contact that dips 50°–60° E. Near the contact the conglomerate contains blocks of volcanic rock 5–10 feet across. Although coarse-grained conglomerate or breccia is commonly found at the base of the formation, similar material also was seen hundreds of feet higher in the section and several miles from any possible source area.

Bedding is usually well enough developed that attitudes may be easily determined, although in small outcrops it may be obscure. In some of the high cliffs the rock is so uniform that bedding is visible only where softer beds have been etched out as a result of differential erosion or where concentrations of lichens are growing along certain beds, as at The Chimney in Aravaipa Canyon (sec. 21, T. 6 S., R. 19 E.). In detail, bedding may be shown by sandy layers in conglomerate or by the orientation of flat pebbles or cobbles. Bedding appears to be rather uniform over large exposures, but on a small scale there is much interfingering of coarse- and fine-grained material, and large fragments may fill channels in fine-grained material. Crossbedding is common in beds composed of pebbles or sand, and is particularly well developed on the divide between Wire Corral Draw and Turkey Creek, where the Hell Hole consists of light-gray to buff sandstone having numerous gravel-filled channels.

Sorting ranges from good to poor, but as a general rule is that typical of fluviatile deposits rather than that characteristic of mudflows. In the type locality, the lowest exposed conglomerate is a very poorly sorted jumble of angular to rounded boulders as much as 3 feet across, but even here there are scarce but well-defined layers of sand. Near the mouth of Bear Canyon, the Hell Hole is a very poorly sorted practically nonbedded conglomerate or breccia composed almost entirely of angular to subrounded fragments of rhyolitic volcanics 1–3 feet across having a very open texture and almost no sandy matrix.

The coarse components of the Hell Hole Conglomerate are mostly angular to subangular, less commonly subrounded or rounded, fragments of volcanic rock. In the prominent pink outcrops along the southwest side of Aravaipa Valley in secs. 1 and 12, T. 7 S., R. 19 E., about 10 percent of the coarse components consist of greenish-gray to gray finely laminated phyllite or massive fine-grained hornfels that could be either Cretaceous or Precambrian (more likely Precambrian), together with a little aplite similar to that of the Santa Teresa Granite. Most of these fragments are less than 2 inches across, but a few are as large as 6 inches. In the grayish conglomerate beneath the prominent buff cliffs southeast of lower Fourmile Creek, pebbles of phyllite and diabase derived from rocks of Precambrian age make up a very small part of the coarse-grained material. These pebbles are of interest in that they could have come only from the Santa Teresa Mountains, whereas the bulk of the Hell Hole Conglomerate consists of volcanic rocks derived from the Galiuro Mountains.

The matrix material of the Hell Hole is dominantly sand or grit and has very little of the finer grain sizes. The constituents are mostly rock fragments, feldspar, quartz, and biotite. Cementing material wherever noted is calcite. At the mouth of Old Deer Creek, coarse-grained clear calcite is an abundant cement. Elsewhere, calcite may form narrow veinlets.

Pyroclastic rocks seem to be uncommon in the Hell Hole Conglomerate, and lavas are completely lacking. A bed 2 feet or so thick of yellowish-gray (5*Y* 8/1) vitric tuff is intercalated in the conglomerate in the W$\frac{1}{2}$ sec. 11, T. 7 S., R. 18 E. The tuff consists almost entirely of sand-size fragments of slightly devitrified glass having a refractive index of about 1.485. Accessory components include numerous tiny ragged and crinkled flakes of brown biotite, angular grains of feldspar, quartz, blue-green hornblende, and sphene, and a few fragments of volcanic rock.

Fine-grained white volcanic ash crops out near the mouth of Old Deer Creek about 35 feet above the creek bottom. The ash is a lens about 1 foot thick and a few tens of feet long. Joint and bedding surfaces in the ash are coated with calcite. The ash consists almost entirely of tiny (<0.05 mm) fragments of slightly devitrified glass having a refractive index of about 1.498. Brown biotite in thin flakes as much as 0.2 mm across, sparse minute fragments of quartz, and very scarce apatite constitute together less than 1 percent of the rock.

A lens of impure limestone and cherty limestone 3 to 4 feet in maximum thickness is exposed for about 300 feet near the base of the cliffs in Aravaipa Canyon a quarter of a mile below the mouth of Turkey Creek. The lens pinches out downstream and dips below the surface upstream. It is overlain and underlain by coarse-grained conglomerate containing boulders as much as a foot across. The lens in its thickest parts consists of an upper layer a few inches thick of silt and a lower layer of granular coarse-grained limestone containing lenses an inch or less thick of gray to grayish-red chert. The upper part of the limestone has very thin wavy beds showing diagenetic crumpling. The wavy bedding is accentuated by the chert lenses. A thin section reveals an extremely fine grained mixture of calcite, chalcedony rosettes, and sparse quartz. A few grains of calcite are as much as 0.3–0.4 mm across. Scattered spherical or ellipsoidal aggregates 0.2–0.4 mm in diameter of chalcedony having concentric structure resemble oolites; their origin is unknown.

Only a few days were devoted to study of the Hell Hole Conglomerate, and no criteria were recognized that would permit division of this thick unit. In a very general way, the rock in the upper parts of the cliffs of upper Turkey Creek, at the base of the cliffs along lower Turkey Creek, and again in the upper parts of the cliffs along Aravaipa Creek between Sand Wash and Turkey Creek is more sandy than elsewhere, but these finer grained beds also contain so much coarse material that no division seemed feasible. In the type locality the conglomerate seems to grade upward into finer grained material, but no break of formational significance is apparent. In Black Canyon the upper beds seem to be finer grained than those below, but boulders as much as 3–4 feet across are scattered throughout the section.

Possibly, although by no means probably, a very detailed study of conglomerate lithology would reveal some mappable subunits, such as members or lentils, but such a study would be very time consuming; it would be rather difficult in many areas of good outcrop owing to inaccessible terrain, and would be hampered seriously elsewhere by lack of outcrops.

#### AGE

The limestone from Aravaipa Canyon was examined for ostracodes and rhizopods by I. G. Sohn, of the U.S. Geological Survey, and for diatoms and other microorganisms by K. E. Lohman, of the Geological Survey, with negative results in both cases. No fossils have been found elsewhere in the Hell Hole Conglomerate; consequently, its age can be estimated only indirectly. It is considerably younger than the volcanic rocks of the Galiuro Mountains, as it was deposited on a surface of appreciable relief eroded on these volcanics. It is much more indurated than the older alluvium along the southwest side of the Santa Teresa Mountains and is strongly deformed along a narrow belt trending north-northwest along Aravaipa Valley, and therefore is inferred to be older than the alluvium; moreover, in at least one place a conglomerate correlated with the Hell Hole is overlain by older alluvium. No ore deposits are found in the Hell Hole. Available evidence does not seem to permit dating the Hell Hole more closely than middle or late Tertiary.

## QUATERNARY SYSTEM

### OLDER ALLUVIUM

The southwest flank of the Turnbull and Santa Teresa Mountains, as well as the northeast flank of the Galiuro Mountains southeast of Fourmile Creek, are covered by alluvial and colluvial deposits that form a low rolling terrain of some 52 square miles, or about 21 percent of the quadrangle. Some of the conglomerate on the lower parts of ridges southwest of Aravaipa Valley and northwest of Fourmile Creek in secs. 1, 12, 13, and 23, T. 7 S., R. 19 E., may also be older alluvium rather than Hell Hole Conglomerate as shown on the geologic map. In many places along upper Aravaipa Valley, low cliffs made up of these alluvial deposits rise abruptly from the valley fill. Alluvial deposits lie over a considerable range of altitude, from as high as 5,000 feet on the southwest flank of Horse Ridge, near the northern boundary of the quadrangle, to as low as about 3,300 feet near the confluence of Stowe Gulch and Aravaipa Creek. Exposures in general are poor, as the alluvium breaks down readily to form gentle slopes mantled with sand and gravel.

The older alluvium is at least 350 feet thick in the south half of sec. 26, T. 7 S., R. 20 E., is probably more than 500 feet thick on the west side of Stowe Gulch west of Stowe Spring, is at least 300 feet thick in Arizona Gulch a mile or so west-southwest of Aravaipa, and is more than 600 feet thick in Old Deer Creek 2 miles northwest of Aravaipa. Northwest of

Buford Canyon, in an unsurveyed area in what would be secs. 14 and 15, T. 7 S., R. 20 E., the alluvium may well be more than 700 feet thick. Along Squaw Creek and Rattlesnake Canyon the alluvium is 500–600 feet thick.

The older alluvium rests unconformably on rocks ranging in age from early Precambrian to Tertiary. Over most of its outcrop area, it overlies Horse Mountain Volcanics, Pinal Schist, Galiuro Volcanics, or Hell Hole Conglomerate. Its stratigraphic relations with the Hell Hole are obscure, as weathered or disintegrated Hell Hole can be distinguished only with difficulty, or not at all, from older alluvium; in the area along Black Canyon north of Old Deer Creek, and at the south end of the outcrop area of Hell Hole Conglomerate along Fourmile Creek, the location of the contact between older alluvium and Hell Hole Conglomerate is very uncertain.

From the Davidson Ranch southeast nearly to Klondyke, older alluvium is separated from Hell Hole Conglomerate by a strip half a mile to a mile wide of younger alluvium along Aravaipa Creek, and the contact relations are unknown. Possibly the fault north of Davidson Ranch continues up Aravaipa Valley, but evidence that it does so is lacking and therefore it is shown to extend only to sec. 36, T. 6 S., R. 19 E.

The older alluvium lies practically flat wherever bedding can be discerned. No faults are known to cut alluvium, but several faults that cut Horse Mountain Volcanics are buried by alluvium.

#### LITHOLOGY

The older alluvium consists for the most part of poorly bedded unconsolidated or only slightly consolidated sand and gravel. In contrast with the Hell Hole Conglomerate, whose fragments seem to be almost entirely of volcanic rocks, the older alluvium contains blocks of Precambrian and Tertiary granitic rocks, Precambrian metamorphic rocks, and Paleozoic sedimentary rocks, in addition to the predominant volcanic rocks derived from both the Turnbull-Santa Teresa and Galiuro Mountains. The fragments range in shape from angular to rounded and in size from sand to boulders. Locally, for example on the ridge between the Grand Reef and Dogwater mines, the alluvium contains immense blocks of Santa Teresa Granite.

Near the mouth of Klondyke Wash and for a mile or so up the wash, the alluvium consists of fairly well sorted massive slightly consolidated coarse and fine brown sand containing occasional pebble beds, all capped by coarse gravel. Farther up this wash, the alluvium is coarse-grained poorly sorted practically unbedded gray conglomerate containing a few sandy layers and little or no matrix. Boulders are as much as 2 feet across and are mostly Pinal Schist and minor Santa Teresa Granite, quartzite, volcanic rocks, vein quartz derived from Pinal Schist, and dike rocks. Although the alluvium is mostly unconsolidated, the abundance of flat-lying platy fragments of Pinal Schist makes the material stable enough to permit the existence of steep slopes 100 feet or more high.

In Upper Squaw Creek and Rattlesnake Canyon, the alluvium is fairly well consolidated and erodes to steep slopes several hundred feet high.

A small remnant of older alluvium rests on Horse Mountain Volcanics and Hell Hole Conglomerate on the west side of Stowe Gulch in sec. 26, T. 6 S., R. 19 E. It consists of partly consolidated well-bedded coarse brown sand and sandy gravel containing some cobbles as much as 6 inches across. The components are all volcanic rocks, many of them coated with black desert varnish. The alluvium here is not notably coarser grained near bedrock, and presumably was not derived from the immediately underlying rock.

In upper Squaw Creek, in secs. 7 and 8, T. 8 S., R. 20 E., the conglomerate contains numerous beds and seams of caliche as much as 2 inches thick.

The abundance of fragments of Precambrian rocks and Santa Teresa Granite, and the occasional presence of boulders of reef breccia indicate that most of the older alluvium northeast of Aravaipa Valley had its source in the Turnbull and Santa Teresa Mountains, as none of these rocks is exposed in the Galiuro Mountains to the west. In some places the older alluvium is coarser grained near the mountains, as witness the enormous blocks of granite near the Santa Teresa Mountains, but elsewhere no relation could be observed between nearness to presumed source and coarseness of components.

From the junction of Aravaipa Valley and Stowe Gulch northward to Old Deer Creek the older alluvium forms a belt 2 to 3 miles wide that is bounded along the west side by a discontinuous series of resistant low knobs of Horse Mountain Volcanics partly buried by Hell Hole Conglomerate. These knobs probably mark a fault-line scarp, or locally possibly an actual fault scarp, at least 6.5 miles long along the east side of an uplifted fault block. This scarp cannot be recognized north of Old Deer Creek. No evidence of faulting was seen anywhere along the contact between volcanic rocks and older alluvium, although this contact dips as steeply as 40° where it crosses Old Deer Creek; therefore, the fault is interpreted as being earlier than the older alluvium and the scarp as constituting the west margin of a local basin in which the alluvium was deposited.

#### CONDITIONS OF DEPOSITION

The older alluvium is a typical fluviatile deposit. The abundance of Precambrian and granitoid components in the southeastern part of its outcrop area northeast of Aravaipa Valley clearly indicates that here it was deposited by streams heading in the Santa Teresa Mountains. Southeast of Fourmile Creek most of the coarse components were derived just as clearly from the Galiuro Mountains. North of the low divide between Sand Wash and Stowe Gulch (sec. 14 and 23, T. 6 S., R. 19 E.), evidence for the source area is not clear, and the older alluvium has no obvious relation to present drainage. However, all the lithologic types in the alluvium crop out in the Turnbull Mountains and could have been derived from these mountains. The angular shapes and large sizes of the components in the alluvium along the southwest flank of the Santa Teresa and Turnbull Mountains indicate that the alluvium was deposited by rapidly flowing streams heading in a nearby area of high relief. Nothing in the general character of the older alluvium suggests that terrain or climate during the period of deposition differed greatly from those of the present time.

#### AGE AND CORRELATION

The original constructional slopes of older alluvium are still preserved over a large area southeast of Fourmile Creek and on spurs near the Santa Teresa Mountains, but deep valleys (for example, Long Hollow, Squaw Creek, Rattlesnake Canyon, Arizona Gulch, Stowe Gulch, Klondyke Wash, and Buford Canyon) have been cut through the alluvium. Aravaipa Creek has eroded a flood plain as much as a mile wide, which along the southern 10 miles or so of its length has been cut back into older alluvium, leaving steep bluffs as much as 250 feet high. The deep dissection of the older alluvium suggests that it is considerably older than the alluvial deposits of the present flood plain of Aravaipa Creek. No accurate age determination of the older alluvium has been possible, but presumably it is of late Pliocene or Pleistocene age.

The older alluvium apparently extends without interruption southeastward into Sulphur Spring Valley and around the southeast end of the Pinaleño Mountains into the valleys of San Simon Creek and Gila River. Some of the alluvial deposits in these valleys have been called Gila Conglomerate (Meinzer and Kelton, 1913, p. 25–28; Schwennesen, 1921, p. 7–8; Knechtel, 1938, p. 190–200) a name given by Gilbert (1875, p. 540–541) to alluvial deposits extending for many miles along the Gila River eastward from Safford. Inasmuch as no detailed studies have been made of the alluvial deposits southeast of the Klondyke quadrangle, and no fossils have been found in either the older alluvium or the Hell Hole Conglomerate, I have little evidence for referring to either or both of these formations as Gila Conglomerate. Some of the problems involved in the use of the term Gila Conglomerate have been stated by Heindl (1952, p. 115), who suggests that "use of the term 'Gila conglomerate,' through its application to several basins, to a variety of deposits (including lake beds), and to more than a single cycle of deposition, has inhibited understanding of the depositional and structural history of the basin deposits in this area."

#### TERRACE DEPOSITS AND LAKE BEDS

Small remnants of stream terraces are preserved near the axis of Aravaipa Valley, along both sides of Aravaipa Creek as well as in the lower reaches of some of its larger tributaries (fig. 28). Apparently two terrace levels are represented, one 50 to 200 feet above the present drainage and the other about 100 feet higher. Two thick patches of terrace deposits appear on the geologic map; on the other terraces the gravels are too thin to warrant being shown separately. The terrace deposits are probably of Pleistocene age but may be as young as Recent.

A few small patches of alluvium are preserved on the west side of Fourmile Creek near the Lackner Ranch; these may possibly be of the same age as the terrace deposits or may be older, possibly correlative with the older alluvium. They consist of at least 100 feet of brown unconsolidated locally well-bedded coarse gravel and sand overlying unconformably the Hell Hole Conglomerate. The gravel contains boulders as much as 3 feet across.

Small patches of brown sand and silt are exposed at several places in lower Stowe Gulch, in the unnamed gullies just east of Stowe Gulch, in lower Klondyke Wash, and on the southwest side of Aravaipa Valley south of Klondyke. They are probably lake deposits. It seems likely that these beds are considerably more widespread along the northeast side of Aravaipa Valley between Stowe Gulch and Buford Canyon but are masked by debris from overlying gravel.

The lake beds are very poorly exposed and their thickness is uncertain, but at least 100 feet of beds underlie the low hills east of Stowe Gulch in the NW¼ sec. 31, T. 6 S., R. 20 E., and the beds along the east side of Stowe Gulch in the NE¼ sec. 25, T. 6 S., R. 19 E., are at least 60 feet thick.

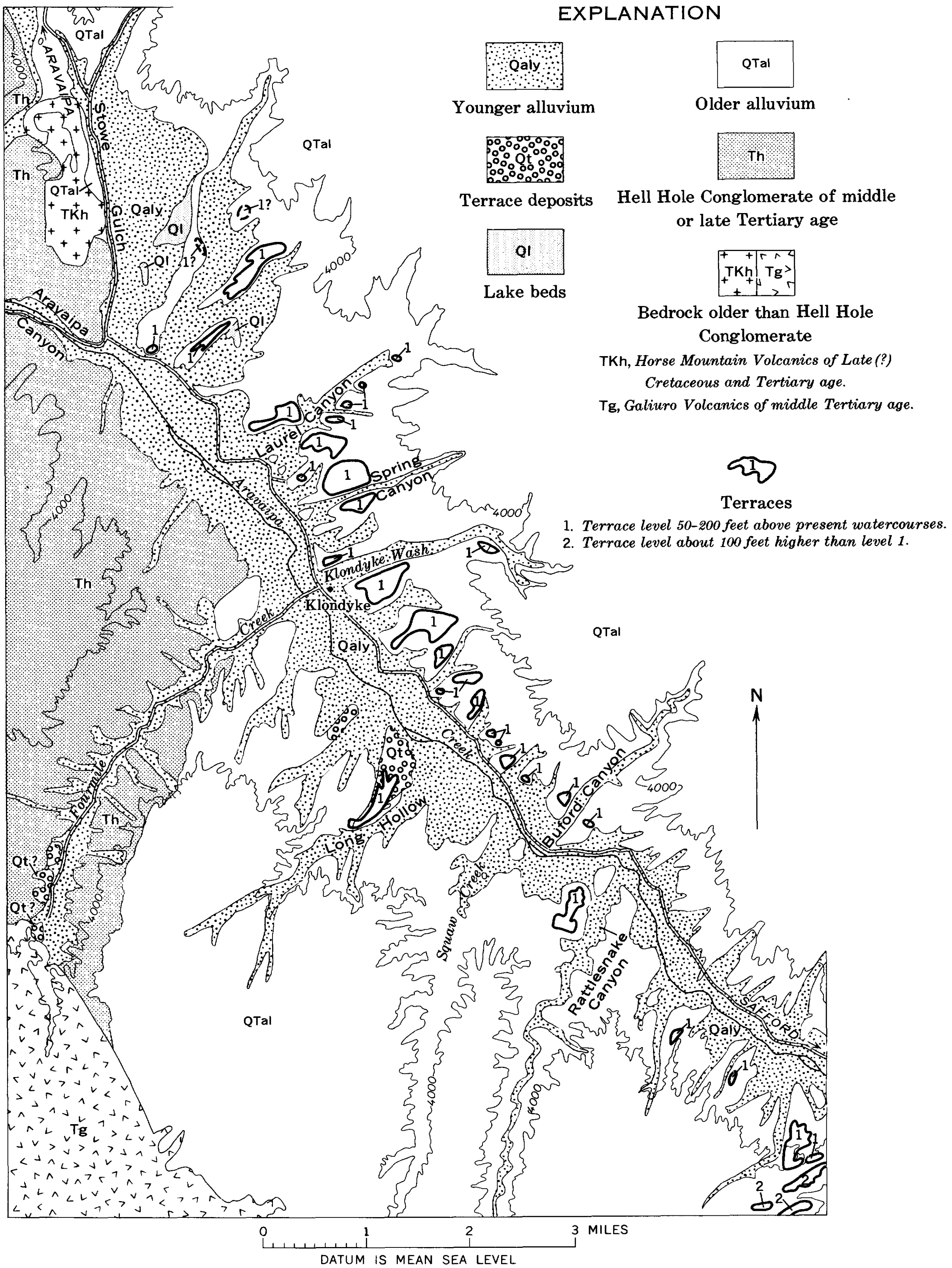


FIGURE 28.—Map of Aravaipa Valley, showing younger alluvium, lake beds, terrace deposits, and terraces.

The lake deposits consist of unconsolidated brown, very poorly bedded fine sand and silt, overlain by as much as 25 feet of brown to gray fairly well bedded coarse sand and pebble gravel. Along the east side of lower Stowe Gulch, a thin layer of coarse gravel containing boulders 2 feet or so across caps these beds. The finer sediments are composed of subrounded to angular grains from 0.01 to 0.2 mm across, and contain abundant calcite. The overlying sand and gravel is made up of volcanic and dike rocks, very scarce fragments of granodiorite and diabase derived from rocks of Precambrian age, and a little reef breccia.

The lake beds have been incised as much as 100 feet below their original upper surface but are so soft and easily eroded that the degree of dissection provides little measure of their age; they presumably are of Recent age, but may be as old as Pleistocene.

#### YOUNGER ALLUVIUM

The principal stream courses of the Klondyke quadrangle are floored with alluvium deposited by the present streams. Aravaipa Creek flows northwestward along a flood plain half a mile to nearly a mile across, from the east edge of the quadrangle as far as the Davidson Ranch (sec. 35, T. 6 S., R. 19 E.) where it enters a narrow canyon. From this point to the Salazar Ranch, 4.5 miles northwest, the flood plain is generally less than a quarter of a mile wide; and below the Salazar Ranch the Aravaipa Canyon is a gorge at most a few hundred feet wide. The main watercourse of Stowe Gulch, between its confluence with Aravaipa Creek and a point about 2.5 miles north, is along the west side of a broad flood plain. Old Deer Creek, Bear Canyon, Arizona Gulch, Turkey and Fourmile Creeks, Long Hollow, Klondyke Wash, and Buford and Rattlesnake Canyons have narrow floors mantled by recent alluvium. Other small canyons and gullies have only minor accumulations of alluvium, and some, such as Virgus Canyon in its middle course, are floored with bedrock covered only locally by thin alluvium.

About 17 square miles, or 7 percent of the quadrangle, is underlain by younger alluvium.

The thickness of the younger alluvium along stream courses is uncertain, but cutbanks along upper Aravaipa Creek are several feet high, as are terraces in the narrow canyon below the Davidson Ranch. In the wider parts of Aravaipa Valley for several miles northwest and southeast of Klondyke, the younger alluvium may be several tens of feet thick.

Over most of its outcrop area, younger alluvium rests unconformably on sedimentary and volcanic rocks of Tertiary or Quaternary age. Scattered small patches of alluvium rest on rocks of Precambrian, Paleozoic, or Mesozoic age.

Younger alluvium consists of unconsolidated poorly sorted fluviatile sand and gravel along present stream courses. It is important in the region as the principal source of water along the Aravaipa Valley below the Davidson Ranch and possibly above also. The alluvium is otherwise typical and warrants no further description.

The younger alluvium as defined is confined to the present stream courses and probably is entirely of Recent age.

### STRUCTURE

For convenience in discussion, the Klondyke quadrangle may be divided into three principal structural units: (1) the Santa Teresa and Turnbull Mountains, embracing approximately the northeast one-quarter of the quadrangle; (2) the Galiuro Mountains, along the west side of the quadrangle and occupying about one-quarter of it; and (3) Aravaipa Valley and related drainages, occupying about one-half of the quadrangle.

The structural evolution of the Santa Teresa-Turnbull Mountains region seems to have included at least four periods of deformation as recorded by major unconformities and faults. The earliest structural features, those of Precambrian age, are folds and schistosity of general northeasterly trend. A second period of deformation is indicated by folds in Paleozoic rocks, principally Horquilla Limestone, which are truncated by the overlying Cretaceous rocks; and a third period must have occurred subsequent to the deposition of the Cretaceous Pinkard Formation and the Williamson Canyon Volcanics but prior to the deposition of the Horse Mountain Volcanics, which rest unconformably on the Pinkard and Williamson Canyon. Structures of these two periods are obscure, and almost no information is available on them. A fourth period of deformation, to which probably all the many faults of the region can be attributed, took place subsequent to the deposition of the Horse Mountain Volcanics and the emplacement of the Santa Teresa Granite and Goodwin Canyon Quartz Monzonite.

For the Galiuro Mountains, meager data indicate two periods of deformation older than the Galiuro Volcanics and one younger than the volcanics; most of the structural features of the region belong to the latest period, and many of them also postdate the Hell Conglomerate, which rests unconformably on the Galiuro Volcanics. In the Copper Creek basin, deep erosion and possible deformation of post-Mississippian, pre-Cretaceous(?) age is indicated by an unconformity between gently folded Escabrosa Limestone and the overlying Pinkard(?) Formation. A succeeding period of minor faulting must have taken place prior to deposition of the Galiuro Volcanics, as faults which cut both Paleozoic and Cretaceous(?) rocks end against the volcanics. The Galiuro Volcanics are cut by a few faults, several of which also cut the younger Hell Hole Conglomerate.

Rocks of Aravaipa Valley are nearly undeformed except for a zone of monoclinal warping in the Hell Hole Conglomerate, several broad folds, a single fault restricted entirely to Hell Hole Conglomerate, and a fault that must have cut Hell Hole Conglomerate but is now buried and recognizable only by a fault line scarp.

### PRECAMBRIAN DEFORMATION

Deformation of Precambrian age is recorded in the Santa Teresa–Turnbull Mountains block by the more or less well-developed schistosity of the Pinal Schist and by local gneissic masses in the Laurel Canyon Granodiorite. Although no systematic study was made of foliation or lineation, enough observations are available to show that the schistosity has a dominant northeasterly trend and steep dips, 60°–90° in either direction. Although several departures from this northeasterly trend were recorded, particularly in the Pinal of the region between Tule Spring and Landsman Camp, the overall aspect suggests that axes of Precambrian deformation trended northeast, mainly between N. 30° E. and N. 60° E. This same general trend was observed earlier in the Aravaipa and Stanley districts by Ross (1925a, p. 40). Ransome notes a dominant east-northeast trend of schistosity in the Pinal of the Bisbee district (Ransome, 1904b, p. 25) and a northeast trend in the Ray-Miami region (Ransome, 1919, p. 34–35). In the Clifton-Morenci region, Pinal Schist in small outcrops near Pinal Point, 7–8 miles north of Morenci, strikes east (Lindgren, 1905a, p. 56; 1905b). In central Cochise County the Precambrian orogenic axes trend in the northeast quadrant (Gilluly, 1956, p. 123); in the northwestern Dos Cabezas Mountains, schistosity of the Pinal strikes about northeast (Cooper, 1960); and in the Little Dragoon Mountains, schistosity and fold axes in the Pinal trend in the northeast quadrant (Anderson, 1951, p. 1334–1335 and fig. 2; Cooper and Silver, 1954). Inasmuch as the principal structures of post-Laurel Canyon age in the Klondyke region trend north-northwest to northwest, the Precambrian and post-Precambrian axes are nearly at right angles to each other. At several places in southeastern Arizona, therefore, over an area 150 miles long in a northwest direction and as much as 80 miles wide, Precambrian structural features trend between north and east, and as Gilluly notes, are about at right angles to the trend of the dominant younger structural grain. However, along the northeast flank of the Dos Cabezas Mountains in the Cochise Head quadrangle, schistosity of the Pinal trends west to northwest and dips steeply in either direction (Sabins, 1957b, pl. 1). Clearly, more observations are needed, particularly in the extensive areas of Precambrian rocks in the Pinaleño Mountains, before any attempt can be made to synthesize the structural development of southeastern Arizona during the Precambrian.

### POST-PALEOZOIC AND PRE-CRETACEOUS DEFORMATION

At only one place in the Santa Teresa-Turnbull Mountains region are Cretaceous rocks believed to be in depositional contact with Paleozoic rocks. Along the south edge of secs. 19 and 20, T. 5 S., R. 20 E., the Pinkard Formation that strikes east and dips 15°–35° N. rests on folded Horquilla Limestone, some of which dips as steeply as 70° S. This contact is poorly exposed throughout its length of about a mile, but the fact that it dips northward more or less parallel to the bedding of the Pinkard Formation suggests that it is indeed depositional rather than a fault. Inasmuch as the Pinkard itself is gently folded, some of the folding of the Horquilla might be due to the same causes, but the Horquilla is so much more intensively folded that it seems likely to have undergone an earlier deformation. There is some suggestion also that fold axes in the Horquilla trend more northeasterly than those in the Pinkard, which trend about east.

Boulders of Precambrian granitoid rocks and gneiss make up part of the basal conglomerate of the Williamson Canyon Volcanics, which rest disconformably on the Pinkard Formation. Inasmuch as the Paleozoic section is much the same over the entire Aravaipa region, and the Precambrian surface on which the Paleozoic rocks were deposited appears to have been one of little or no relief, it seems likely that exposure of Precambrian rocks in post-Pennsylvanian time would be due to deep erosion of the Paleozoic rocks rather than to their nondeposition. These boulders indicate furthermore that rocks of Paleozoic and Precambrian age were exposed at the onset of Williamson Canyon volcanism. It seems unlikely that local deformation plus erosion sufficiently deep to strip a cover of hundreds of feet of Cretaceous rocks (plus hundreds of feet more of Paleozoic rocks also?) from the Precambrian basement rocks could have occurred during the presumably short interval marked by the disconformity; therefore I believe that (1) the Precambrian rocks of the boulders in the basal conglomerate of the Williamson Canyon were exposed prior to the deposition of the Pinkard Formation, and (2) the Pinkard must have been laid down on a surface of rather pronounced relief, so that older rocks were still exposed within a relatively short distance of where as much as a thousand feet or more of marine clastic rocks had been deposited.

In the Copper Creek basin of the Galiuro Mountains, rocks of the Pinkard(?) Formation rest directly on Escabrosa Limestone, and a considerable part of the Escabrosa as well as all of the Horquilla are presumed to have been eroded away prior to the deposition of the Pinkard(?). However, the Escabrosa and Pinkard(?) lie nearly parallel, so that their relations may record merely a period of erosion rather than provide in themselves evidence of pre-Pinkard orogeny.

### LATE(?) CRETACEOUS OR EARLY TERTIARY DEFORMATION

Evidence of deformation in the Santa Teresa-Turnbull Mountains block following deposition of the Williamson Canyon Volcanics and preceding the deposition of the Horse Mountain Volcanics is provided by the pronounced angular unconformity at the base of the Horse Mountain. The contact, which trends northwest, clearly transects the eastward-trending grain of the Pinkard and Williamson Canyon. The age of the Horse Mountain Volcanics is not certain, but the basal part at least may be of Cretaceous age; if so, then the unconformity records deformation of Late Cretaceous age.

The structure of the Pinkard and Williamson Canyon rocks is very poorly understood, mainly because the Williamson Canyon Volcanics provide so few reliable structural data, but the dominant structural feature appears to be an eastward-trending syncline whose axis is near the south edge of the outcrop area. Although this fold cannot be traced to closer than about half a mile from the contact of the Horse Mountain Volcanics, it appears to be cut off by that contact. The Pinkard also is folded on a small scale in the northeastern part of its outcrop area, but the area involved is small and outcrops are poor so that the nature of these folds is obscure. Presumably, considerably more data on the structure of the Cretaceous rocks will come to light when the much more extensive outcrop areas in the San Carlos Reservoir quadrangle to the north are studied.

Very little is known about the surface on which the Williamson Canyon Volcanics were deposited. However, the fact that Horse Mountain Volcanics rest unconformably not only on Williamson Canyon rocks but also on all the Paleozoic formations indicates either that (1) the Williamson Canyon was deposited on a surface of considerable relief and never was present within 1½ miles north or east of Aravaipa, or (2) a considerable amount of erosion, depending of course on the original thickness of the formation, must have ensued subsequent to its deposition in order to expose the Paleozoic rocks on which the Horse Mountain Volcanics now rest. The trend of the basal contact of the Horse Mountain argues rather strongly for the second alternative, but both may have been factors.

A few faults cannot be placed definitely in any period of deformation, and possibly may belong to either the Late(?) Cretaceous or early Tertiary structures or to the post-Horse Mountain structures. The north-trending Klondyke Wash fault, which brings Buford Canyon Formation against Pinal Schist along the east side of secs. 3 and 10 (unsurveyed), T. 7 S., R. 20 E. has an estimated throw [3] of 800–900 feet but does not offset two long silicic dikes that cross the prolongation of the fault half a mile farther north; moreover, a latite dike is intruded along the westernmost branch of the fault where it crosses Klondyke Wash in the NE¼ sec. 10. Where the Klondyke Wash fault crosses the more northerly canyon in the SE¼ sec. 3, it is marked by a breccia zone 35 feet wide. The northeastward-trending Quartz Hill fault that passes through Quartz Hill (SW¼ sec. 1 (unsurveyed), T. 7 S., R. 20 E.) and forms the northwest contact of the main outcrop of the quartzite member of the Pinal Schist has an estimated throw of 2,500–3,000 feet and a strike separation of about 2,800 feet in a right-lateral sense; yet the same two dikes apparently cross the fault without offset; although these dikes could not be traced within the quartzite itself, two short dikes similar lithologically to those northwest of the fault crop out a few hundred feet southeast of the quartzite and approximately along the strike of the main dikes. This fault appears to end to the northeast against an intrusive contact between Santa Teresa Granite and Pinal Schist. These data suggest that both these faults antedate the emplacement of the granite and its presumably consanguineous dikes. Inasmuch as the age of the Buford Canyon Formation is not known, the maximum age of the faults is uncertain.

The Landsman Camp fault is probably older in part than the Goodwin Canyon Quartz Monzonite, whose emplacement at one locality appears to have been guided by the fault. Early movement along the fault may have antedated the Horse Mountain Volcanics, but later movement in an opposite sense involved the volcanic rocks.

[3] "Throw" as used in this report is the vertical component of the dip separation (Crowell, 1959, p. 2670).

Several faults are clearly older than the silicic dikes and locally have dikes intruded along them. These include several faults, apparently of small displacement, ¼–½ mile west of Landsman Camp, a fault crossing the summit of the hill 3,000 feet east of Tule Spring, and two small faults in the SW¼ sec. 20, T. 5 S., R. 20 E. The Head Center–Sinn Fein fault and segments of the Grand Reef fault also have dikes along them, but these faults cut Horse Mountain Volcanics and therefore can be grouped with the post-Horse Mountain structures.

A northwestward-trending fault has been mapped from a point about half a mile north-northeast of Aravaipa to a point half a mile southeast of Tule Spring, a distance of 2 miles. This fault, here named the Tule Spring fault, joins the Tule Canyon fault (see below) just southeast of Tule Spring.

On the geologic map the fault is shown to be the southwest limit of a long, narrow, and discontinuous belt (<600 ft wide) of faulted, brecciated, and sheared Paleozoic rocks lying between Pinal Schist to the southwest and Horse Mountain Volcanics to the northeast. The fault dips gently to moderately northeast and brings younger rocks—Paleozoic sedimentary rocks and Horse Mountain Volcanics—over Pinal Schist, and to a lesser extent, over Bolsa Quartzite.

The Tule Spring fault seems to have a rather peculiar geometry. At its northwest end it dips steeply northeast; along its middle course it dips gently northeast, locally as little as 5°–10°; and at its southeast end it again dips as steeply as 55° or even more. Moreover, in its southeastern part, at least some of the movement involves volcanic rocks, whereas in its northwestern part the volcanics are younger than the fault and are not disturbed by it. The apparent conflict between relative ages of volcanic rocks and faulting can be resolved by postulating either that the volcanics involved in faulting are older than the bulk of the Horse Mountain Volcanics or that later movement has taken place along the southeastern part of the fault. Available evidence does not permit a logical choice between these alternatives. The faulted volcanics are rather different lithologically from the unfaulted volcanics farther northwest, being nondescript silicic rocks rather than andesites, and also appear to be lower in the section, so that they could be older than the Horse Mountain rocks. However, they are shown as Horse Mountain Volcanics on the geologic map.

Relative direction of movement along the fault has not been determined satisfactorily. The apparent displacement is normal and is so shown in section *D–D′*, plate 1, but the locally low dip of the fault (for example, north of Arizona Gulch) is difficult to explain by normal faulting. However, although normal faults of low dip seem to be rather uncommon, they have been recognized in northwestern Peru (Iddings and Olsson, 1928, p. 33; Travis, 1953, fig. 7), and several large examples in the Desert Range of southern Nevada have been described by Longwell (1945). The Tule Spring fault seems best interpreted as a normal fault having local low dip along which the principal movement took place prior to the deposition of the Horse Mountain Volcanics. The southeastern part may have been reactivated subsequent to the deposition of the volcanics, possibly attendant upon emplacement of the Santa Teresa Granite, but I favor the idea that two different ages of volcanic rocks are involved.

In the Copper Creek basin in the Galiuro Mountains block, faults that bring the Pinkard(?) Formation and Glory Hole Volcanics against Escabrosa Limestone are buried by Galiuro Volcanics, and the basal contact of the Galiuro Volcanics shows no offset. If correlation of some of the Copper Creek rocks with the Pinkard is correct, then these faults are of Cretaceous or early Tertiary age; inability to date the Galiuro Volcanics more closely than middle Tertiary prevents any close bracketing of the age of the faults.

#### STRUCTURAL FEATURES YOUNGER THAN THE HORSE MOUNTAIN VOLCANICS

Most of the structural features of the Klondyke region—dominantly faults, and subordinate folds—were formed after deposition of the Horse Mountain Volcanics. In the Santa Teresa-Turnbull Mountains block, deformation subsequent to the deposition of the Horse Mountain Volcanics is recorded by steep dips as much as 75° near the base of the formation, by the many faults that cut the volcanics and older rocks, and by minor folds in the volcanics. Practically all the faults in this block north of Klondyke Wash involve either Horse Mountain Volcanics or the Santa Teresa Granite and Goodwin Canyon Quartz Monzonite, both of which are probably younger than the volcanics. Faults cutting the Galiuro Volcanics also belong to this group of structures, inasmuch as the Galiuro Volcanics are thought to be the same age or younger than the Horse Mountain Volcanics. Faults and folds in the Hell Hole Conglomerate are clearly younger than the Horse Mountain and Galiuro Volcanics, inasmuch as these formations are overlain by the conglomerate.

Many of the faults of post-Horse Mountain age in the Santa Teresa and Turnbull Mountains, the faults along the northeast flank of the Galiuro Mountains,

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the buried fault in Aravaipa Valley, and the monoclinal warp and broad folds in Hell Hole Conglomerate are elements of the north-northwesterly structural grain that was first impressed upon the region probably at the time of emplacement of the Santa Teresa Granite.

#### SANTA TERESA-TURNBULL MOUNTAINS BLOCK

Aside from one poorly defined syncline and perhaps other even more obscure folds, the principal structural features of the Santa Teresa-Turnbull Mountain block are faults. These range in size from minor breaks to major structures such as the Grand Reef fault, which has been traced for at least 9 miles.

Many of the faults trend north-northwest to northwest, a few trend northwest, and several near the Head Center and Iron Cap mines trend about east. The trend of faults and dikes and the attitudes of the Horse Mountain Volcanics all combine to give a general impression of a north-northwesterly structural grain. Most ore deposits of the Aravaipa area are along faults of this trend.

Most faults of the block are simple structures of limited extent and do not merit individual descriptions. A few that are of particular interest because of their size or the information they yield will be described in approximate geographic order from south to north.

##### GRAND REEF FAULT

The Grand Reef fault, named for spectacular exposures of fault breccia at the Grand Reef mine in Laurel Canyon (E½ sec. 29, T. 6 S., R. 20 E.), is the principal structure between Waterfall Canyon and Imperial Mountain, a distance of about 5 miles. To the south of Waterfall Canyon, the fault is well exposed in the north branch of Klondyke Wash and is inferred to cross the south branch of the same wash just west of the Laclede mine, 2 miles south of Waterfall Canyon. East, north, and northwest of Imperial Mountain the fault splits into several lesser faults, the main one of which can be traced as far north as Aravaipa. North of Aravaipa, so many northwestward-trending faults cut Horse Mountain Volcanics and Paleozoic rocks that the identity of the Grand Reef fault is lost. In summary, the fault has been traced for at least 9 miles, and possibly for 12 miles, and has a stratigraphic throw that probably exceeds as a minimum the entire thickness of the Paleozoic section, perhaps 1,300 feet.

Between the north branch of Klondyke Wash and Imperial Mountain, the Grand Reef is a normal fault dipping 70°–90° W.; Horse Mountain Volcanics are in the hanging wall and Pinal Schist or Laurel Canyon Granodiorite is in the footwall. North of Imperial Mountain the dip is uncertain but is probably steep.

The Grand Reef fault is at no place a single fracture but rather is a zone of variable width marked more or less continuously by resistant silicified fault breccia and dike rock (these bodies of resistant breccia are common along faults in the Santa Teresa and Turnbull Mountains and will be referred to henceforth as breccia reefs). The fault zone ranges in width from a few feet to as much as 200 feet at the outcrop and at one place on the adit level of the Grand Reef mine is at least 150 feet wide. The Grand Reef structure at several places between Klondyke Wash and Imperial Mountain will be described briefly, in geographic order from south to north.

South fork of Klondyke Wash, just southwest of the Laclede mine: No breccia is exposed, but a fault inferred to be the Grand Reef fault, trending N. 30° W., passes between flow-layered latite or trachyte lava and flow breccia of the Horse Mountain Volcanics to the southwest and altered andesitic volcanic rocks of the Buford Canyon Formation to the northeast.

North fork, Klondyke Wash: The breccia reef is 10–12 feet wide, strikes N. 35°–45° W., and dips 80°–90° SW. Pinal Schist in the northwest wall near the fault is intruded by several dikes, one of which is cut by the fault. The breccia consists of angular fragments of dark-gray very fine grained andesite or latite as much as several inches across, cemented by dark yellowish-brown calcite and later veinlets of quartz. Microscopically, the breccia fragments consist of an intergranular aggregate of very dusty oligoclase laths 0.1–0.2 mm long, interstitial epidote, chlorite, and iron ore, and irresolvable birefringent material, some of which is probably potassium feldspar. The rock is cut by numerous quartz veinlets.

Waterfall Canyon: Vertical fault; breccia is 30 feet wide. The breccia is grayish-red highly silicified rock composed of angular lithic fragments a few centimeters across and grains of feldspar and quartz in a fine-grained matrix of quartz, minor amounts of fluorite, and possibly a little potassium feldspar. The rock fragments are so thoroughly silicified that their original lithology is practically obliterated; some appear to have been porphyritic silicic dike rock.

Junction claim, center N½ sec. 33, T. 6 S., R. 20 E.: Fault zone strikes N. 10° W. and dips 80° W. Consists, from west to east, of 8 feet of red breccia having finely layered chalcedony or opal along the footwall, 2 feet of light grayish-green brecciated and altered latite(?), and 2–6 feet of fine-grained green breccia, some of which may be rhyolite dike rock and some probably sheared Pinal Schist. (See fig. 40, p. 148.)

Grand Reef mine, Laurel Canyon: Fault strikes slightly east of north and is vertical. Breccia is 50–60 feet wide on the west side of Laurel Canyon. Perhaps 50 percent of the breccia is dike rock.

NE¼ sec. 29, T. 6 S., R. 20 E., just north of Grand Reef mine: Fault strikes N. 10° W. and dips 85° W. Finely laminated silicified breccia 8 feet wide along the east side of the fault zone.

Tenstrike mine area, SW¼ sec. 17, T. 6 S., R. 20 E.: Fault strikes N. 5°–25° W. and dips 70°–75° W. Fault zone is 200 feet wide in canyon to south of mine, where it consists of brecciated hard silicic welded tuff along west side, 75 feet of porphyritic dacite in center, and 50–75 feet of silicified breccia along the east wall, separated from massive Laurel Canyon Granodiorite by a layer of dark-green gouge. At the bottom of the Tenstrike shaft is a strong gouge-filled fracture that is part of the Grand Reef fault.

Just north of the Tenstrike shaft, the breccia consists of angular fragments of fine-grained cream-colored altered rhyolite(?) as much as several inches across, cemented by a very fine grained grayish-red material that is probably a mixture of quartz and hematite. Both fragments and matrix are cut by veinlets or irregular small bodies of quartz and fluorite. Some of the quartz veinlets have cores of supergene copper minerals, including malachite, and some small vugs are lined with quartz and pale-green cupriferous opal.

NW¼ sec. 17, T. 6 S., R. 20 E., north of Tenstrike mine: Breccia consists of blocks of Laurel Canyon Granodiorite and fine-grained porphyritic silicic dike rock (some blocks are more than a foot across) set in a fine-grained dark-gray matrix. The breccia is intruded by fine-grained very light gray porphyritic rhyolite, is cut by quartz veinlets, and locally contains small amounts of supergene copper minerals. Small vugs are lined with quartz, white calcite, fluorite, azurite, and malachite. The matrix consists of tiny fragments of sericitized granodiorite cemented by a fine-grained very uneven-textured aggregate of quartz, hematite, chlorite, fluorite, and sparse potassium feldspar. Hematite plates are less than 0.2 mm across. Feldspar was the earliest cementing material and was followed by quartz-hematite and fluorite. The rhyolite intruding the breccia has rounded phenocrysts of quartz set in a fine-grained groundmass in which tiny orthoclase laths less than 0.1 mm long are enclosed micropoikilitically in irregular quartz grains. The rhyolite is cut by sparse veinlets of quartz and chlorite. Petrographically, this rhyolite strongly resembles the high potash rhyolite dikes from the Homestake mine in South Dakota (Noble, 1948).

SW. cor. sec. 8, T. 6 S., R. 20 E.: Fault is marked by a wide zone of breccia and silicified rock. Volcanic rocks immediately west of the fault are so thoroughly altered as to be practically unrecognizable, and Laurel Canyon Granodiorite east of the fault is recognizable only because of its pale-olive color and large remnant quartz eyes. Microscopically, quartz grains of the granodiorite show sutured boundaries with each other, and plagioclase phenocrysts are bent and broken. The breccia consists of fragments mostly less than an inch across of ground-up granodiorite in a matrix of greenish-gray latite or dacite. The matrix is made up of quartz, oligoclase, chlorite, epidote, and potassium feldspar.

E½ sec. 7, T. 6 S., R. 20 E.: Fault has about 150 feet of ground-up or brecciated yellowish-gray Laurel Canyon Granodiorite in the east wall. Small grains of chalky feldspar are the only minerals recognizable in the granodiorite with a hand lens. Microscopically, the rock is a fine-grained aggregate of potassium feldspar, quartz, and disseminated chlorite, and has a few 1–2 mm grains of sodic plagioclase and perthite. Quartz occurs as discrete grains in a matrix of feldspar and also in veinlets. Staining with sodium cobaltinitrite shows that about half the rock is potassium feldspar, and therefore considerable amounts of potassium feldspar (and quartz) must have formed at the expense of plagioclase feldspar of the original granodiorite.

Imperial Mountain area: In the lowest prospect pit on the southwest side of Imperial Mountain the fault strikes N. 10° E., dips 70° W., and is marked by 40 feet of coarse-grained silicified breccia. The breccia consists of highly silicified rock fragments, quartz, hematite, and a little fluorite and barite. Along its east side the breccia has much specularite.

Near the next highest prospect shaft, the breccia is 300 feet wide and consists of silicified rock fragments and a little specularite and fluorite. The shaft is sunk in Laurel Canyon Granodiorite along the footwall of the breccia and is filled with water to within 10 feet of the surface. At the shaft, the breccia is made up of small angular fragments of brown fine-grained silicic porphyritic dike rock cemented by specularite, fluorite, and quartz.

At the lowest prospect shaft in the SE. cor. sec. 6, T. 6 S., R. 20 E., the fault strikes N. 50° W., dips 65°–70° W., and has 15 feet of breccia containing azurite, malachite, and a little fluorite and calcite. Laurel Canyon Granodiorite in the footwall is thoroughly ground up for at least 50 feet from the fault. The shaft has water at a depth of about 100 feet.

Farther north, the fault breccia is locally made up of small angular rock fragments set in a nearly black matrix of specularite, quartz, and fluorite (this highly distinctive rock is found along several faults in the Santa Teresa-Turnbull Mountains region and will be referred to henceforth as specularite breccia).

Several prominent breccia reefs split off the Grand Reef fault on the east side of Imperial Mountain. The most southerly reef strikes northward toward Tule Spring, as if to connect with the Tule Spring breccia reef to be described below, but could not be traced to within closer than a thousand feet of the most southerly exposure of the Tule Spring reef. The reef on Imperial Mountain and where it crosses Stowe Gulch consists mainly of rhyolitic rock and some sheared and discolored Laurel Canyon Granodiorite along the east side, and locally some specularite breccia. On the north side of Imperial Mountain, a vertical reef of specularite breccia 15–20 feet wide strikes north through the Lead King prospect area in Stowe Gulch and continues northwestward for nearly half a mile. Where this reef crosses Tule Canyon, it is 15 feet wide. The east wall grades through slightly brecciated hornfels of the Pinal Schist into massive hornfels. On the west side of the reef the Pinal is cut by a few narrow veinlets of similar breccia. The specularite breccia is composed of angular fragments as much as 1–2 inches across of pale-pink or cream-colored rock, probably silicified Pinal Schist, in a purplish-black matrix of specularite and quartz, or locally of nothing but specularite (fig. 29). The microscope reveals the matrix to contain abundant very small euhedral grains of a mineral that may be potassium feldspar adularia. Specularite plates are 0.1–0.3 mm across.

In the Dogwater mine area the Grand Reef fault is offset about 2,200 feet in a left-lateral sense by the Waterfall Canyon fault. Evidence to be presented in the immediately following section suggests that this displacement occurred during emplacement of the Santa Teresa Granite. Accordingly, the Grand Reef fault may be older than the granite or may be approximately contemporaneous with it. The abundance along the Grand Reef fault of silicic dike material presumably derived from the granite suggests that at least some of the reef material is of the same age as the granite; and if the evidence for the contemporaneity of the Waterfall Canyon breccia reef and the granite is accepted, then the similarity of much of the specularite breccia along the Grand Reef and Waterfall Canyon faults suggests that the Grand Reef breccia also is of approximately the same age as the granite.

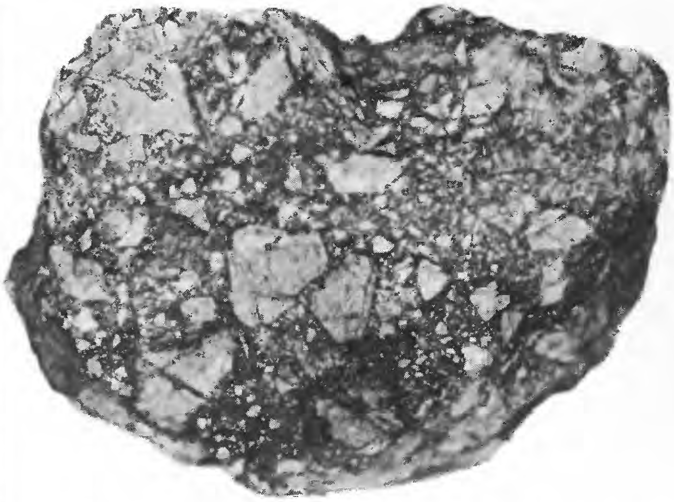

FIGURE 29.—Specimen of breccia from breccia reef in Tule Canyon near the confluence with Stowe Gulch. Light-colored angular fragments of silicified Pinal(?) Schist are set in a dark matrix of specularite, quartz, and adularia(?). Specimen is 5 inches wide.

###### WATERFALL CANYON FAULT

An eastward-trending fault marked by a prominent breccia reef offsets the Grand Reef fault and, for nearly 2.5 miles east of the Dogwater mine area (NW¼ sec. 33, T. 6 S., R. 20 E.), separates Santa Teresa Granite or Horse Mountains Volcanics and Pinal Schist. The reef dips 75°–90° S. and is as much as 50 feet wide. Offset of the Grand Reef fault by the Waterfall Canyon fault is about 2,200 feet left lateral. The breccia here and there contains fragments of Santa Teresa Granite, and is locally flanked to the north by several feet of ground-up silicified granite. In many places the breccia contains so much specularite that it has a dark-purple aspect.

At the Dogwater mine the breccia is a grayish-red rock composed of angular fragments of Pinal Schist, volcanic rock, and quartz that are cemented by quartz, fluorite, and hematite. A little chrysocolla is found here and there. Fragments and matrix alike are cut by quartz-fluorite veinlets. Just east of the Junction prospect, the breccia seems to be mainly of Pinal Schist, cemented by quartz, specularite, fluorite, calcite, and chlorite.

At an adit at the center of the N½ sec. 34, the breccia is 30 feet wide and consists of angular light-colored highly silicified rock fragments 5 cm or less across in a dark matrix of quartz, specularite, and a little potassium feldspar. Most, if not all, of the fragments are of Santa Teresa Granite. Near its east end the breccia consists of angular fragments of granite(?) cemented by quartz, hematite, and fluorite.

In the NW¼ sec. 35 the contact between Pinal Schist and Santa Teresa Granite changes strike abruptly from east to southeast, and from this bend southeast to the quadrangle boundary it is intrusive. Careful traverses in the area of granite east of the easternmost exposures of the breccia reef along the Waterfall Canyon fault failed to reveal any outcrops of breccia or any other evidence that the fault extends beyond the point at which the contact changes strike. Apparently, faulting and breccia formation took place prior to the final consolidation of the granite in this area; yet farther west, granite fragments make up part of the breccia reef, and brecciated granite is found along the north side of the fault. A plausible interpretation of this apparent anomaly is that the breccia reef marks the site of a preexisting fault along which the granite was intruded. Development of the westward-projecting lobe of granite between Waterfall and Laurel Canyons, possibly as a result of local westward-directed pressure within the granite magma, then caused shearing and brecciation of previously consolidated granite along the original contact, as well as the left-lateral displacement of the Grand Reef fault. The granite beyond the east end of the breccia reef, being still unconsolidated during formation of the lobe, would not be expected to retain any evidence of such displacement.

#### TULE CANYON FAULT

A well-defined fault extends for about 1½ miles north and northwest from the Tule mine, just southeast of Tule Spring. At its south end the fault strikes southward as if to connect with a branch of the Grand Reef fault, but appears rather to end against the Tule Spring fault. Where the fault crosses Tule Canyon, it strikes N. 30° W., dips 65° SW., and is marked by a prominent specularite breccia reef 70–80 feet wide. The breccia consists of fragments of purple porphyritic volcanic rock, mostly less than 6 inches across, cemented by quartz and specularite. The east wall of the reef is brecciated green phyllite of the Pinal Schist, striking N. 65° E. and dipping steeply southeast. For a distance of 50–60 feet from the reef the phyllite is cut by a network of veins of quartz and pink feldspar(?) as much as 6 inches wide and by later veinlets of specularite.

Farther north, the fault is exposed in a pit just north of the road to Landsman Camp, where it strikes N. 35° W. and dips 65° SW. The northeast wall of the fault is Pinal Schist, the southwest wall is Escabrosa Limestone. Between the walls of the fault is a thin slice of Bolsa Quartzite overlain by a few tens of feet of marl, presumably of the Martin Formation; both outcrops are too small to be shown at the scale of the geologic map.

The course of the Tule Canyon fault north of a point about half a mile north of Landsman Camp road is doubtful, but it probably extends as far as Williamson Canyon to connect with the fault between Horse Mountain Volcanics and Horquilla and Escabrosa Limestones in the NW¼ sec. 30, T. 5 S., R. 20 E.

Displacement along the Tule Canyon fault can be estimated only where the fault crosses the Landsman Camp road. At this place the stratigraphic throw is known to be at least 400 feet, the combined thickness of Bolsa Quartzite and Martin Formation cut out to bring Escabrosa Limestone against Pinal Schist. At both places where the dip could be measured, the fault shows displacement in a normal sense.

#### GOODWIN CANYON FAULT

The contact between Santa Teresa Granite and Goodwin Canyon Quartz Monzonite from the head of the west fork of Fisher Canyon at the east edge of the quadrangle northwestward for 2 miles is interpreted as a fault. This fault continues northwest for another three-quarters of a mile as the contact between Pinal Schist and Escabrosa(?) Limestone or quartz monzonite, and what is probably its continuation extends west-northwest for at least a mile to the head of the Middle Fork of Goodwin Canyon. The total length of the fault is then about 4 miles.

Evidence for the existence of the Goodwin Canyon fault is almost entirely indirect, as the fault is not exposed anywhere except possibly north of Rocky Top near the east edge of the quadrangle, where several pits have been dug along a sheared contact zone. Farther northwest, the very straight course of the South Fork of Goodwin Canyon is interpreted as being controlled by the fault. The limestone lens at Monkey Spring in the center of sec. 27, T. 5 S., R. 20 E., consists of fine-grained medium-gray fetid crinoidal limestone, probably Escabrosa, which has been almost completely converted to garnet-epidote tactite. Both contacts of this limestone with Pinal Schist are surely faults. The contact between limestone and quartz monzonite is not exposed, but the strong alteration of the limestone suggests that the contact is intrusive or, if a fault, is one of small displacement. Accordingly, the Goodwin Canyon fault is interpreted to form the southwest contact of the limestone lens.

The body of Escabrosa Limestone (including possibly some Horquilla Limestone) about three-quarters of a mile north of Cobre Grande Mountain is in contact with quartz monzonite along its entire northeast side. This contact is interpreted as a fault, inasmuch as the limestone along much of the contact appears to be unaltered, whereas elsewhere, carbonate rocks intruded by quartz monzonite are thoroughly converted to tactite (Escabrosa(?) Limestone at Monkey Spring, Horquilla (and Escabrosa?) Limestone in secs. 16, 17, and 20, T. 5 S., R. 20 E.). However, the Escabrosa Limestone is generally a very pure carbonate rock, and if contact alteration were limited to marmorization, its results might easily pass unrecognized. Moreover, an appreciable amount of epidote, pyroxene, and garnet have replaced limestone at various places near the Cobre Grande mine. If the contact is indeed a fault, it may be one of only small displacement. No fault could be traced through the Pinal terrane between the two bodies of limestone, but the two fault segments are approximately colinear, and therefore are connected with a dashed line on the geological map.

The nature of the contact between Bolsa Quartzite and quartz monzonite west of the Cobre Grande limestone block is uncertain; the contact is shown as intrusive but may instead be the westward continuation of the Goodwin Canyon fault.

#### COBRE GRANDE FAULT

The main adit of the Cobre Grande mine is along a northeastward-trending fault between Pinal Schist to the southeast and Escabrosa Limestone and Bolsa Quartzite to the northwest. Another adit a few hundred feet to the southeast was reported by Ross (1925a, p. 102–103) to have been more than 700 feet long and to have had limestone in the face; this adit begins in Pinal Schist and is now caved 180 feet from the portal. The Cobre Grande fault appears to end against the Goodwin Canyon fault just northeast of the main adit. It is known to extend for a little more than half a mile southwest of the adit, where it enters Laurel Canyon Granodiorite and could not be traced further; however, its course farther southwest may be marked in part by a silicic dike, and it may connect finally with the fault along the east side of the hill north of Copper Canyon.

The displacement along the Cobre Grande fault is not known, but the stratigraphic throw near the Cobre Grande mine must be in excess of 1,000 feet in order to cut out entirely the section of Paleozoic rocks on the northwest side of the fault. Displacement elsewhere along the fault cannot be estimated at all.

#### LANDSMAN CAMP FAULT

A fault of rather sinuous course has been traced from Landsman Camp eastward and northward to the head of the Middle Fork of Goodwin Canyon, a distance of about 2.5 miles. The southern part of this fault, as far north as the divide between Tule and Goodwin Canyons, is located fairly accurately, but the continuation to the north is shown with considerably less assurance owing mainly to poor exposures and heavy brush. The southernmost half mile of the fault has Escabrosa or Horquilla Limestone in the north or west wall and Pinal Schist or Laurel Canyon Granodiorite in the south or east wall. The fault is inferred to end to the west against the Iron Cap fault (see below), but exposures do not reveal the nature of the intersection, and indeed the Landsman Camp fault appears to change strike smoothly and become the Iron Cap fault; however, that it does not do so is suggested by the fact that the Landsman Camp fault dips nearly vertically at the only place where its dip could be measured, whereas the Iron Cap fault is believed to dip much more flatly to the west. In the Goodwin Canyon drainage the fault forms the contact between the Pinkard Formation and Williamson Canyon Volcanics to the west, and Paleozoic rocks, including tactite derived from the Horquilla (and Escabrosa?) Limestones, to the east.

In the E½ sec. 20, T. 5 S., R. 20 E., the fault for about 1,500 feet along the strike has Goodwin Canyon Quartz Monzonite in the east wall and a thin lens of hornfels, apparently derived from the Pinkard Formation, in the west wall. These relations suggest that the fault is of pre-quartz monzonite age and that it locally controlled the emplacement of the quartz monzonite; consequently, this segment of the fault is shown as an intrusive contact on the geologic map.

The course of the fault at its north end in the W½ sec. 16 is unknown; it probably bends sharply to the northwest to continue as the contact between Pinkard Formation and altered limestone. As noted in the preceding paragraph, the fault is believed to antedate the Goodwin Canyon Quartz Monzonite and presumably terminates against the quartz monzonite at its north end.

Displacement along the Landsman Camp fault could not be measured accurately, but at one place the base of the Bolsa Quartzite, here perhaps 350 feet thick, striking about perpendicular to the trace of the fault, and dipping 25°–30°, is brought against the lower part of the Horquilla Limestone; if the thickness of the Escabrosa Limestone in this area is taken as 350 feet, then this juxtaposition indicates a stratigraphic throw in excess of 750 feet.

Along most of the length of the fault, the north or west side is downthrown with respect to the south or east side, but along a south-southwestward-trending branch fault in the head of Tule Canyon east of Landsman Camp, Horse Mountain Volcanics resting on Pinal Schist on the east side of the fault are downthrown against older rocks on the west side. This branch fault is marked by a prominent quartz-specularite breccia reef as much as 50–75 feet wide. The breccia reef also lies along the main fault for a short distance. The branch fault and its breccia reef evidently reflect a later local reversal of movement on the Landsman Camp fault, possibly resulting from emplacement of the Santa Teresa Granite, with which at least one of the specularite breccia reefs (that along the Waterfall Canyon fault) appears to be related genetically.

#### IRON CAP FAULT

A south-trending fault is inferred to extend from near the Iron Cap mine (SE¼ sec. 19, T. 5 S., R. 20 E.) southward to a point just west of Landsman Camp, where it either becomes the Landsman Camp fault or, more likely, enters Pinal Schist and becomes unrecognizable. To the north the fault seems to terminate against an east-trending fault parallel to and just north of the Head Center fault. (See below.) The Iron Cap fault is not exposed at any place, but its existence is indicated by the abrupt termination of Bolsa Quartzite and Escabrosa Limestone on the west side of the canyon north of Landsman Camp, and by repetition of Horquilla and Escabrosa Limestones just northwest of Landsman Camp. The relation of the fault trace to topography indicates that, at least along its southern half, the fault dips about 25° to the west and is therefore a reverse fault.

In the lower walls of the canyon just north of Landsman Camp, Escabrosa Limestone dips gently, whereas on the ridge immediately to the west, Horquilla and Escabrosa Limestones are overturned and dip steeply south and southwest (see Section *I–I′*, pl. 1); this overturning probably resulted from drag in the footwall of the fault.

The relations between the Iron Cap fault and the Head Center and other faults appear to be complex and could not be worked out in detail, owing in part to lack of marker beds in the Horquilla Limestone near the Iron Cap mine and in lesser degree to lack of outcrops. These relations probably could have been solved more satisfactorily had access been granted to the Iron Cap mine, which seems to have been opened on a plexus of faults (Wilson, 1950, p. 56–58).

#### HEAD CENTER FAULT

The Head Center and Sinn Fein (new) mines are on an eastward-trending fault that has been traced from the Head Center mine east to the Iron Cap mine and west-southwest for nearly half a mile. The fault dips 25°–45° N. and over most of its length has Horquilla Limestone in the footwall and Horse Mountain Volcanics in the hanging wall; in the bottom of Williamson Canyon a slice of sheared volcanic rocks as much as 30 feet wide lies along the fault for a short distance. Along its eastern two-thirds the fault is intruded by a quartz porphyry dike, which is probably 100 feet wide where it crosses Williamson Canyon; farther east toward the Iron Cap mine, the dike is only 10 feet or so in width and contains few or no quartz phenocrysts. In Williamson Canyon the Head Center fault is marked by strongly shattered wallrocks and locally by as much as 20 feet of breccia. In the Sinn Fein mine the fault in many places has several feet of gouge along it.

Neither the direction nor the amount of movement along the fault is known, although the fact that younger rocks are in the hanging wall indicates that the throw has been in a normal sense. Wilson (1950, p. 54) believes that the Head Center fault zone is "genetically related to the Iron Cap thrusts" but does not specifically state that the Head Center fault is a thrust or reverse fault, and Denton (1947b, p. 4) states that "low-angle faults at the Head Center and Grand Central claims are generally considered to be of thrust origin." Detailed mapping in the Head Center mine might have resolved the problem; however, access was not permitted to this mine. The Sinn Fein mine does not provide any evidence as to direction or amount of movement.

Neither the Head Center nor the northwestward-trending fault that joins it about 2,000 feet west-southwest of the Head Center mine could be mapped farther west into Horse Mountain Volcanics. Although outcrops in the area west of the mine are only fair, it seems likely that one or the other fault might have been traceable, and therefore that the two faults may indeed end against each other as shown on the geologic map.

The east-trending fault 500–1,000 feet north of the Head Center fault is interpreted as being steeply dipping and as having a large horizontal component of displacement. Along the western part the fault, the base of the Horse Mountain Volcanics has been offset in a left-lateral sense for possibly as much as 1,800 feet; the amount of offset is uncertain because the reference contact could not be located closely on the north side of the fault. The fault was traced for more than 1,000 feet farther west into Horse Mountain Volcanics. In its eastern part the fault has Horquilla Limestone in the south wall and Williamson Canyon Volcanics in the north wall, and at two places has slices of Horquilla Limestone along it. The possible eastern extension of the fault lies entirely in Pinkard Formation and could not be traced, but its course may be indicated by a quartz porphyry dike that appears to end just west of the Landsman Camp fault. On the other hand, it is possible that the segment of the fault east of the Iron Cap fault is indeed a fault of small displacement that dies out to the east, whereas the segment west of the Iron Cap fault is a tear fault along which movement took place at the time the hanging-wall block of the Iron Cap fault was displaced relatively eastward.

#### GALIURO MOUNTAINS BLOCK

The gross structure of the Galiuro Mountains volcanic pile is a broad downwarp, the trough of which trends about east along Aravaipa Canyon. Both north and south from the canyon the volcanic rocks rise gently and dip 100–400 feet per mile.

The Galiuro Volcanics are cut by a few faults of small displacement, most of which are in the southwest part of T. 7 S., R. 19 E. In addition, the contact between volcanics and the overlying Hell Hole Conglomerate is marked in several places by faults, most and possibly all of which are probably about along the original depositional contact. In general, however, the Galiuro Volcanics are broken by very few faults, and in the entire region north of Aravaipa Canyon only a single fault of moderate displacement was found. The faults have a general north to northwest trend, which is about parallel to the structural grain of the Santa Teresa-Turnbull Mountains block.

Some measurement of displacement was obtained on two of the faults along the contact between Galiuro Volcanics and Hell Hole Conglomerate. The north-trending fault near the west edge of secs. 13, 24, and 25, T. 6 S., R. 18 E., has a stratigraphic throw of about 50 feet where it crosses Aravaipa Canyon, and a little more than a half a mile farther north it has no discernible displacement. Where this fault crosses Parsons Canyon to the south, it has a stratigraphic throw of perhaps 150 feet; but within half a mile farther south, it dies out completely. The stratigraphic throw of the fault in sec. 36, T. 6 S., and sec. 1, T. 7 S., both R. 18 E., as indicated by the displacement of the base of the upper welded tuff unit of the Galiuro Volcanics, is about 250 feet.

The fault along or near the contact between Galiuro Volcanics and Hell Hole Conglomerate, from a point a mile northwest of Fourmile Creek to a point about a mile southeast of the same creek, is marked at several places by gouge and breccia. At its northwest end the fault appears to die out completely in Hell Hole Conglomerate. Just east of the Left Prong of Fourmile Creek, the gouge is 50 feet thick and contains a little gypsum.

No major structural features were recognized in the Copper Creek region. Various minor structures were noted in preceding sections and their descriptions will not be repeated at this point. Breccia pipes of Copper Creek will be described in the section on ore deposits.

#### ARAVAIPA VALLEY BLOCK

The structural features of the Aravaipa Valley block, all of which involve rocks younger than the Horse Mountain Volcanics, were noted briefly in the introductory statement.

The most striking of these structures is an asymmetrical anticline in Hell Hole Conglomerate, traceable from the confluence of Old Deer Creek and Arizona Gulch south-southeastward almost to Klondyke, a distance of about 8 miles. The fold dies out to the northwest and probably also to the southeast, although it may continue for some distance southeast beneath the alluvium of Aravaipa Valley. Beds on the southwest flank of the fold lie nearly flat, whereas those on the northeast limb dip 10°–45° NE. and at one place just south of Maroga Canyon are overturned to 75° SW; the steeply dipping beds are well exposed for 3 miles along Aravaipa Canyon between Stowe Gulch and Martinez Canyon. The width of the zone of relatively steep dips is less than a mile and at most places is less than half a mile. The fold presumably is the surface expression of a buried fault of post-Hell Hole age, having the northeast side downthrown, and the overturned beds suggest that it may be a reverse fault.

The conglomerate is gently folded along northwestward-trending axes in the outcrop area northwest of Fourmile Creek. Among these folds, the most pronounced is a broad syncline whose trough lies near the course of Turkey Creek. This fold is traceable for about 5 miles and dies out in both directions. Dips within half a mile of the trough are less than 15° and in most places are less than 5°. The remaining folds are traceable definitely for only 1 to 3 miles and are even less pronounced.

The east boundary of the discontinuous line of low hills of Horse Mountain Volcanics that extends about 6 miles northward from near the confluence of Stowe Gulch and Aravaipa Valley is interpreted as a fault line scarp that faces east and marks a fault downthrown to the east. The striking alinement of the volcanic hills is the only evidence for the fault; the fault itself is not known to be exposed anywhere, and no rocks other than alluvium are exposed on the downthrown side within 1¼ miles of the fault as mapped. No evidence of faulting was seen along contacts between volcanics and older alluvium, even in Old Deer Creek where the contact dips as steeply as 40° E., and the trace of the fault appears to be completely buried by older and younger alluvium. Consequently, the fault probably antedates the older alluvium, and its scarp probably constituted the west margin of a local basin in which the alluvium was deposited. Admittedly, the hills could mark one side of a remarkably straight valley cut in Horse Mountain Volcanics, but the origin of such a valley would be so highly conjectural that in lieu of more evidence the fault interpretation seems preferable to me.

## GEOLOGICAL HISTORY

The geological history of the Klondyke region will be summarized in the following section, insofar as it can be synthesized from the rather fragmentary data available. Although no paleontologically dated rocks of Cenozoic age are known in the quadrangle, what seems to be a fairly eventful record of that era can be deciphered. For the pre-Cenozoic history, however, a more than piecemeal synthesis is precluded by discontinuous and limited exposures of the various Paleozoic and Mesozoic rock units and by widespread faulting of Tertiary age.

The earliest recognizable event in the geological history of the region was the deposition of the sedimentary and volcanic rocks of the Pinal Schist. These rocks—graywacke, shale, quartzite, and intermediate volcanic rocks—were then closely folded along axes that now trend about northeast, metamorphosed to green-schist grade, and, probably near the end of the orogeny, intruded by Laurel Canyon Granodiorite and locally converted to hornfels. At some time following deformation and metamorphism but preceding deposition of the Cambrian Bolsa Quartzite, both Pinal Schist and Laurel Canyon Granodiorite were intruded by small sheets and irregular bodies of diabase.

Although no direct evidence is furnished by rocks of the Klondyke region, it seems likely that metamorphism of the Pinal must have long antedated the Cambrian Period. No rocks of the late Precambrian Apache Group crop out within the quadrangle, but a great thickness of these rocks rest unconformably on the Pinal a short distance to the west in the Holy Joe Peak quadrangle. Accordingly, a sufficiently long time must have elapsed subsequent to the deformation of the Pinal, and prior to the deposition of the Bolsa, to permit deep erosion of the Pinal and deposition of the Apache Group.

During the Middle Cambrian, the area was flooded by a sea in which the sandy sediments of the Bolsa Quartzite were laid down. The absence of finer grained clastic and calcareous rocks characteristic of the Abrigo Formation, which conformably overlies the Bolsa both west and south of Klondyke, suggests that the area was near the north edge of the Bolsa sea and that consequently only the transgressive and regressive sandy near-shore facies were deposited at Klondyke.

No sedimentary rocks of Ordovician or Silurian age were recognized in the quadrangle nor were any fossils found in beds assigned to the Devonian Martin Formation on the basis of lithology and stratigraphic position. The Martin elsewhere in southeastern Arizona is of Late Devonian age. In the Klondyke area the formation rests disconformably on Bolsa Quartzite. The lack of evidence of either deposition or more than inconsequential erosion during the long period extending from the Middle Cambrian to the Late Devonian suggests that the area lay near sea level during that period.

During the Late Devonian, marl, limestone, and various clastic deposits of the Martin formation were laid down in a shallow sea. The formation is somewhat thinner than in the Globe area to the north and in the Little Dragoon Mountains to the south, but whether this thinness is due to erosion or to nondeposition is not known.

Elsewhere in southeastern Arizona, the Martin Formation does not include rocks of latest Devonian age, nor does the succeeding Escabrosa Limestone include beds of earliest Mississippian age, so that a hiatus has been inferred between the two formations. No evidence is available to either confirm or refute the existence of such a hiatus in the Klondyke area.

The Escabrosa Limestone was deposited in Mississippian time. This formation includes a few sandy beds and layers of dolomite but is dominantly of limestone, commonly crinoidal or oolitic. The age of the Escabrosa at Klondyke is Early to early Late Mississippian.

No rocks of latest Mississippian or Early Pennsylvanian age were found at Klondyke, and consequently a hiatus probably exists between the Escabrosa and the overlying Middle Pennsylvanian Horquilla Limestone. No evidence of unconformity between the Escabrosa and Horquilla was found, and consequently it is deduced that the region lay near sea level during the intervening period.

During the Middle Pennsylvanian, the area was covered by a shallow sea and the Horquilla Limestone was deposited. Most of this formation consists of carbonate rocks, but the basal limestone beds contain considerable fine-grained clastic material, and higher parts of the formation have a few beds of sandstone, calcareous sandstone, or siltstone. Although no record is preserved, it seems likely that rocks of Late Pennsylvanian and Permian age were deposited in the Klondyke region and subsequently have been completely removed by erosion.

At some time prior to the deposition of the Cretaceous Pinkard Formation, the Horquilla Limestone of the Aravaipa area, and presumably older rocks as well, were folded along axes that now trend about east to northeast. Very little evidence of this period of deformation is available, but folding seems to have been of only slight to moderate intensity. This post-Middle Pennsylvanian, pre-Late Cretaceous folding was followed by a period of erosion represented by the profound unconformity between the Horquilla Limestone and the overlying Pinkard Formation. In the Copper Creek region, rocks of the Pinkard(?) Formation rest directly on a thin sequence of Escabrosa Limestone; the fact that a substantial thickness of limestone of the Naco Group is present a few miles to the northwest in the Holy Joe Peak quadrangle suggests that extensive erosion in the Copper Creek area has removed not only all the Horquilla Limestone (and younger Paleozoic(?) formations but also several hundred feet of Escabrosa Limestone. The Glory Hole Volcanics of the Copper Creek region and the Buford Canyon Formation conceivably could have been deposited during this post-Paleozoic and pre-Late Cretaceous interval, but evidence is not available to date these rocks more closely than post-Paleozoic.

In the early part of the Late Cretaceous, the Klondyke area at least locally was covered by a sea in which perhaps a thousand feet or more of clastic rocks of the Pinkard Formation was deposited. So little of this formation is now preserved in the quadrangle that no idea can be gained about the extent of this sea; it is known to have covered a large area to the northeast, north, and northwest of the quadrangle, but its extent southeast of a line between Aravaipa and Copper Creek is not known. Some evidence was presented in the section on post-Paleozoic-pre-Cretaceous deformation that the surface on which the beds of the Pinkard were deposited was one of considerable relief.

The Pinkard Formation is the youngest paleontologically dated formation of the quadrangle; consequently, the subsequent geological history of the region depends entirely on interpretation of the sequence of events. The difficulty of correlating post-Pinkard rocks of the Santa Teresa and Turnbull Mountains with those of the Galiuro Mountains was noted in an earlier section, and this difficulty is of course none the less apparent when one attempts to correlate the geological histories of the two regions. Although the sequence of post-Pinkard events is fairly clear in both regions, the correlation of these sequences is extremely tenuous.

The time of extrusion of the Glory Hole Volcanics of the Copper Creek area is uncertain; their tentative assignment as Mesozoic and Cenozoic is based primarily on the fact that they are appreciably older than but apparently conformable with the Galiuro Volcanics, which are believed to be of middle Tertiary age.

The conglomerate and andesitic or basaltic volcanic rocks of the Buford Canyon Formation share this uncertainty of age with the Glory Hole Volcanics. Within the Klondyke quadrangle, no evidence was found that would permit dating of the Buford Canyon rocks more closely than Mesozoic or Cenozoic, more likely Mesozoic.

In the Santa Teresa-Turnbull Mountains region, deposition of the Pinkard Formation was succeeded by that of the Williamson Canyon Volcanics, dominantly andesitic pyroclastic rocks, which accumulated to a thickness of probably as much as 2,500–3,000 feet.

In very Late Cretaceous or early Tertiary time, the Williamson Canyon Volcanics and Pinkard Formation were folded along axes that now trend east to east-southeast, and then were deeply eroded. Almost nothing is known about this deformation. The original areal extent of the Williamson Canyon Volcanics is unknown; if they formerly were present south of Horse Mountain, they were completely removed by erosion during this period, inasmuch as over a sizable area between Aravaipa and Tule Spring the next succeeding formation rests directly on Paleozoic and Precambrian rocks.

In latest Cretaceous or early Tertiary time, several thousand feet of Horse Mountain Volcanics were extruded upon a surface carved across rocks ranging in age from Precambrian to Cretaceous. These volcanics are now preserved mainly along the southwest flank of the Santa Teresa and Turnbull Mountains, but outliers both to west and east indicate that their former areal extent must have been much greater.

Tilting and folding of the Horse Mountain Volcanics, as recorded mainly by the steep dips of the basal conglomerate of the formation northeast of Horse Ridge, is inferred to have taken place prior to the emplacement of the Santa Teresa Granite and Goodwin Canyon Quartz Monzonite, inasmuch as dikes which cut the volcanics and are believed to be comagmatic with these plutonic igneous rocks have a generally uniform strike and dip regardless of the attitude of their wallrocks. However, no unequivocal evidence of age relations between Horse Mountain Volcanics and Santa Teresa Granite has been found.

During very Late(?) Cretaceous or early Tertiary time, the Copper Creek Granodiorite was emplaced in the Copper Creek basin. The Copper Creek pluton may be approximately contemporaneous with the Santa Teresa Granite—Goodwin Canyon Quartz Monzonite plutons, although the absolute age data suggest that it may be a little older. There is no direct evidence of their relative ages, and their respective outcrop areas are more than 10 miles apart. The emplacement of the Copper Creek Granodiorite was accompanied by strong contact metamorphism of the wallrocks now exposed along its west and north sides. Carbonate rocks were converted to tactite, and pyroclastic and volcanic rocks to hornfels.

Perhaps during the early Tertiary, large bodies of silicic granitoid rock, the Santa Teresa Granite and Goodwin Canyon Quartz Monzonite, were intruded in the Santa Teresa and Turnbull Mountains.

Many of the faults at and northeast of Aravaipa probably formed at about the same time as the Santa Teresa Granite was intruded. Some faults were earlier and have along them dikes probably consanguineous with the granite; others, such as the Waterfall Canyon and Grand Reef faults, are approximately contemporaneous with the granite, and some faults may be later than the granite, although evidence is lacking that more than a very few do indeed postdate the granite. Emplacement of the Santa Teresa Granite was accompanied by the intrusion of many silicic dikes; some, including most of the dike swarm that cuts Laurel Canyon Granodiorite between Laurel Canyon and Tule Spring, appear to have been intruded before the granite had risen to the present level, whereas a few are clearly offshoots of the granite at the present level. The ore deposits of the Aravaipa district also may have formed at about this time, although admittedly there is very little evidence linking them with the Santa Teresa or Goodwin Canyon plutons, or with their associated dikes, or indeed with any igneous rock at all.

Neither the Santa Teresa nor the Goodwin Canyon plutons caused any extensive alteration of their wallrock except at the head of the Middle Fork of Goodwin Canyon, where a large mass of Horquilla (and Escabrosa?) Limestone was converted to garnetite along its contact with Goodwin Canyon Quartz Monzonite. Small bodies of tactite not obviously related to contacts with igneous rocks presumably were formed at the same time at several places around Aravaipa, Landsman Camp, and Cobre Grande Mountain.

If the Horse Mountain Volcanics are indeed older than the Santa Teresa Granite, then, aside from a few dark-colored dikes that intrude the granite, no unequivocal record of subsequent plutonic igneous activity or deposition of sedimentary or volcanic rock other than alluvium is preserved in that part of the Turnbull and Santa Teresa Mountains included in the Klondyke quadrangle.

The age of the breccia pipes of Copper Creek and their ore deposits is not known. These pipes cut both Glory Hole Volcanics and Copper Creek Granodiorite, but none is found in the Galiuro Volcanics. Several small veins of oxidized copper minerals are enclosed in the lower andesite unit of the Galiuro Volcanics, but whether these are related at all to the breccia pipe deposits, or, if so, whether they represent hypogene mineralization or are merely supergene leaks from prevolcanic mineral deposits at depth, is uncertain. The concentration of breccia pipes in or near the granodiorite body suggests some obscure structural or genetic relationship, and I favor the interpretation that the pipes are older than the Galiuro Volcanics.

After a period of erosion prolonged enough to permit deroofing of a medium-grained granodiorite, what is now the site of the Galiuro Mountains was covered by extensive outpourings of andesitic to rhyolitic lava, tuff, and welded tuff of the Galiuro Volcanics. The surface on which these volcanic rocks were extruded was initially one of considerable relief, but these topographic irregularities were erased early in the accumulation of the lower andesite unit of the Galiuro Volcanics, and succeeding units, aggregating several thousand of feet in thickness, were deposited on what must have been nearly original depositional surfaces of low relief.

Unless the Horse Mountain Volcanics can indeed be correlated with the Galiuro Volcanics, no clear record of this period of volcanism is preserved in the Santa Teresa or Turnbull Mountains. However, a dike of "turkey-track" andesite intruding Santa Teresa Granite in the W½ sec. 2, T. 6 S., R. 20 E., may have been a feeder for a similar lava flow now completely eroded away; if the Horse Mountain Volcanics antedate the granite, then this lava might have been part of the Galiuro Mountains volcanic pile. It seems at least possible, therefore, that the Galiuro Volcanics once extended far east of their present outcrop area.

The basal lower andesite unit of the Galiuro Volcanics is cut by several dikes, some of "turkey-track" andesite that almost surely were feeders for similar lava flows at the top of the unit and some of more silicic rock that may have fed silicic tuffs higher in the section. No dikes were found in the Galiuro Volcanics above the lower andesite unit.

Following extrusion of the Galiuro Volcanics, a wide and apparently steep-sided valley, trending about north-northwest and eventually to become the site of deposition of the Hell Hole Conglomerate, was formed. This valley must have been approximately along the present course of Aravaipa Valley as far north as Stowe Gulch, from which place it continued north-northwest, perhaps about along the line of hills of volcanic rock northeast of Aravaipa Canyon. The direction of slope of the valley is not known. Steep slopes on the Galiuro Volcanics beneath the Hell Hole Conglomerate south of Aravaipa Canyon suggest that the west wall of the valley was a fault scarp. No trace of this scarp could be recognized more than a mile or so north of Aravaipa Canyon, and indeed the rhyolite-obsidian and upper andesite units of the Galiuro Volcanics extend uninterruptedly eastward across any simple northerly extension. Little evidence is available on the nature of the bedrock surface along the east side of the valley, but that at hand does not strongly suggest that the surface was a fault scarp.

The period of valley formation was followed by one of aggradation during which the thick fluvial deposits of the Hell Hole Conglomerate were laid down by streams debouching from what, to judge by the coarseness of the debris, must have been fairly high mountains on both sides of the valley. The bulk of the Hell Hole debris was derived from volcanic rocks similar to those now exposed in the Galiuro Mountains. Most of the Hell Hole believed to have been deposited along the southwest flank of the Santa Teresa—Turnbull Mountain mass is now buried by alluvium, so that it is not accessible to provide evidence as to whether the Galiuro Volcanics did indeed once cover part or all of those mountains. Along lower Fourmile Creek southwest of Klondyke, some of the fragments in the Hell Hole Conglomerate are of rock types exposed at present only in the Santa Teresa Mountains, indicating that in these mountains the cover of Galiuro Volcanics, if it ever existed, was more or less completely stripped during the accumulation of the Hell Hole.

The principal structural features involving the Hell Hole Conglomerate trend north northwest and may have developed approximately contemporaneously during the late Tertiary. They include the buried fault along the east side of the hills of volcanic rock northeast of Aravaipa Canyon, the asymmetrical anticline along and north of Aravaipa Canyon, a few broad folds, and several faults along the contact between the conglomerate and Galiuro Volcanics.

As a result of faulting, a valley bordered along its west side by hills of Horse Mountain Volcanics and by an east-facing fault scarp appears to have developed along the west side of the Turnbull Mountains. This valley was then filled with older alluvium derived from the Turnbull and Santa Teresa Mountains, in part perhaps concomitantly with faulting but probably in large part after faulting had ceased. North of the northernmost volcanic hill, the relation between Hell Hole Conglomerate and older alluvium is obscure, and the two formations are so similar lithologically that the location of the contact between them is very uncertain. There is no evidence that the fault bordering this hypothetical valley continues very far southward from Stowe Gulch, and indeed the relation between Hell Hole Conglomerate and older alluvium along Aravaipa Valley between Stowe Gulch and Klondyke is not clear. Southeast of Klondyke the older alluvium appears to have been deposited along a broad valley approximately coincident with the present Aravaipa Valley. The contact between bedrock and older alluvium along the southwest flank of the Santa Teresa-Turnbull Mountains block is irregular, and many salients of bedrock extend southwestward along present-day valleys, beneath the alluvium. Dips of the contact indicate that the prealluvium terrain was one of considerable relief, locally sloping as much as 1,000 feet per mile.

At the end of the period of deposition of older alluvium, a belt 7–8 miles wide extending from the southeast corner of the quadrangle north-northwestward to Lone Cedar Mesa and beyond may have been a nearly featureless alluvium-floored broad valley, resembling that of the present but having less relief and perhaps no external drainage. If a through-flowing ancestral Aravaipa Creek existed, it probably did not occupy a course parallel to that of the present creek but rather one of more northerly course, leaving or entering the quadrangle somewhere around Lone Cedar Mesa rather than following the anomalous course across the Galiuro Mountains.

Deposition of older alluvium was followed by renewed erosion and downcutting by Aravaipa Creek and its tributaries. The most striking result of this erosion cycle has been the cutting of Aravaipa Canyon and its equally impressive tributaries, Parsons and Oak Grove Canyons. For more than 2 miles before it leaves the quadrangle, Aravaipa Canyon is flanked by extremely precipitous, locally vertical walls about 700 feet high carved in Hell Hole Conglomerate and Galiuro Volcanics. Oak Grove Canyon attains a maximum depth of about 750 feet, and Parsons Canyon for several miles is bordered by nearly vertical walls 300–500 feet high. During this period of erosion, canyons as much as 600 feet deep were cut in the older alluvium.

The present course of Aravaipa Creek from its confluence with Stowe Gulch for 6 miles westward to the quadrangle border clearly has no relation to the valleys or basins in which the Hell Hole Conglomerate and older alluvium were deposited. For its most westerly 2 miles however, the valley lies approximately along a structural low in the Galiuro Volcanics. A possible sequence of development, then, might be the following; the reader should understand that this sequence is not based on broad regional studies but merely on brief local observations and consequently should be regarded as an hypothesis:

1. Deposition of older alluvium along a north-northwest-trending valley or basin. The present site of Aravaipa Valley was eventually a broad alluviated area, perhaps not having external drainage. The Galiuro Volcanics must have extended farther west than at present, possibly covering what is now the valley of the San Pedro River.
2. Beginning of uplift of the Galiuro Mountains block, together with the alluviated valley, on a Basin and Range fault along the west flank of the range. Uplift at first was greater north and south of the present Aravaipa Canyon than at the canyon site, so that a broad east-trending synclinal warp was formed, its trough approximtaely along Aravaipa Canyon. If external drainage existed previously, downstream slopes of ancestral Aravaipa Creek were reversed by the differential uplift; the master stream may have been diverted westward toward the synclinal trough, or a closed basin may have formed temporarily east of the Galiuro Mountains.
3. Erosion of Aravaipa Canyon initiated either by overflow from a closed basin at the low point on its west rim or by the diverted ancestral Aravaipa Creek. At this stage the Aravaipa may have been flowing at an altitude not greatly different from its present altitude but a thousand feet or more higher in the stratigraphic section. The major tributaries of the Aravaipa probably came into existence at this time as watercourses consequent upon land surfaces sloping toward Aravaipa Canyon.
4. Continued uplift of the Galiuro Mountains. During this uplift, Aravaipa Creek was able to maintain its westerly course—in other words, it was antecedent to the later period of uplift—and cut its present canyon. The fault-block origin of the Galiuro Mountains and the antecedent nature of the present course of Aravaipa Creek were suggested long ago by Davis and Brooks (1930). The southwest-sloping tributaries of the Aravaipa, being, with the exception of Old Deer Creek, rather short and having small catchment basins, have not been able to keep pace with the downcutting of Aravaipa Creek, and their junctions with the master stream are strongly discordant. On the other hand, the north-sloping tributaries are longer, have larger catchment areas, and probably receive more rainfall in their high headwaters, and consequently now have accordant junctions with the Aravaipa.

Subsequent to this major period of downcutting the Aravaipa above Stowe Gulch has widened its flood plain to widths ranging from half a mile to nearly a mile, and has cut steep bluffs as much as 250 feet high in older alluvium and Hell Hole Conglomerate. At present the creek flows on its own alluvial deposits.

Farther south, beyond the limits of the Klondyke quadrangle, the Aravaipa is eroding headward into the broad alluviated pass between Aravaipa Valley and Willcox Playa (Meinzer and Kelton, 1913) and seems destined eventually to capture and provide exterior drainage for the entire playa area.

At some time during this period of flood-plain formation, Aravaipa Valley must have been blocked temporarily near the mouth of Stowe Gulch, and a lake several miles long was formed. This lake existed long enough for a thickness of 100 feet or more of sediments to be deposited in it; most of these sediments have since been flushed out, but a few small remnants are preserved in Stowe Gulch and along Aravaipa Valley between Stowe Gulch and Klondyke.

## MINERAL DEPOSITS

The mineral deposits of the Klondyke area embrace various types, including veins in many kinds of wall-rock, replacement deposits in Paleozoic carbonate rocks, and breccia pipes in metavolcanic and plutonic igneous rocks. Only two or perhaps three of the deposits found to date (Head Center, Childs–Aldwinkle, perhaps the Grand Reef) have yielded more than a million dollars worth of ore, and of these only the Head Center has an output of substantially more than a million dollars. Metals mined have been principally lead, zinc, copper, molybdenum, and silver.

The deposits may be divided conveniently on a geographic basis into four groups: Aravaipa, Grand Reef, Table Mountain-Fourmile Creek, and Copper Creek. None of the principal mines of the Aravaipa region was accessible during the period of this study. A few mines along the Grand Reef fault were open but many of the workings of the only large mine, the Grand Reef mine itself, were flooded or otherwise inaccessible. Underground workings of the only mine of any appreciable size in the Table Mountain-Fourmile Creek area, the Table Mountain mine, were largely inaccessible, and those that were open, together with the surficial exploratory workings, did not provide much information on the nature of the deposit. An appreciable proportion of the underground workings of mines in the Copper Creek district is still accessible, but most of the Childs–Aldwinkle, Glory Hole, and American Eagle mines and the lower stopes of the Copper Prince mine were not. Consequently, only very brief summaries of the geology of the vein and replacement deposits of the Aravaipa, Grand Reef, and Table Mountain-Fourmile Creek deposits will be given in this section. The breccia-pipe deposits of Copper Creek will be discussed in somewhat greater detail. Inasmuch as the ore deposits of the various areas have little in common, most of the descriptive material will be relegated to the succeeding section on individual mines and prospects.

A list of minerals reported from the ore deposits of the Klondyke area precedes the discussion of the deposits themselves in order to avoid duplication.

## MINERALOGY

Ore and gangue minerals of the Klondyke region are listed below in alphabetical order; minerals previously reported but not found during the present study are referred to footnotes. The principal minerals of the Aravaipa-Grand Reef, Table Mountain, and Copper Creek areas are tabulated following the alphabetical listing. Brief descriptions of individual minerals, the metallic or ore minerals grouped by principal metal contained, and the nonmetallic gangue minerals in alphabetical order conclude the section.

| *Mineral* | *Chemical formula* |
|---|---|
| Anglesite | $PbSO_4$ |
| Apatite [1] | $Ca_5F(PO_4)_3$ |
| Argentite | $Ag_2S$ |
| Atacamite [2] | $Cu_2Cl(OH)_3$ |
| Austinite [3] | $CaZnOHAsO_4$ |
| Azurite | $2CuCO_3 \cdot Cu(OH)_2$ |
| Barite | $BaSO_4$ |
| Bornite | $Cu_5FeS_4$ |
| Brochantite [4] | $Cu_4(OH)_6SO_4$ |
| Bromyrite [5] | $AgBr$ |
| Calcite | $CaCO_3$ |
| Cerargyrite [5, 6] | $AgCl$ |
| Cerussite | $PbCO_3$ |
| Chalcanthite | $CuSO_4 \cdot 5H_2O$ |
| Chalcocite | $Cu_2S$ |
| Chalcopyrite | $CuFeS_2$ |
| Chlorite | $(Mg, Fe, Al)_6(OH)_8(Si, Al)_4O_{10}$ |
| Chrysocolla | $CuSiO_3 \cdot 2H_2O$ |
| Conichalcite [3] | $CaCuOHAsO_4$ |
| Copper [4, 6] | $Cu$ |
| Cosalite [7] | $Pb_2Bi_2S_5$ |
| Covellite | $CuS$ |
| Cuprite [1] | $Cu_2O$ |
| Descloizite [6] | $PbZnOH(VO_4)$ |
| Dioptase | $Cu_6Si_6O_{18} \cdot 6H_2O$ |
| Enargite [1] | $Cu_3AsS_4$ |
| Epidote | $Ca_2(Al, Fe)_3(SiO_4)_3(OH)$ |
| Ferrimolybdite [1] | $Fe_2(MoO_4)_3 \cdot 8H_2O$? |
| Fluorite | $CaF_2$ |
| Galena | $PbS$ |
| Garnet | $Ca_3(Al, Fe)_2(SiO_4)_3$ |
| Gold [5] | $Au$ |
| Gypsum [1] | $CaSO_4 \cdot 2H_2O$ |
| Hematite | $Fe_2O_3$ |
| Jarosite | $KFe_3(SO_4)_2(OH)_6$ |
| Johannsenite | $CaMnSi_2O_6$ |
| Limonite | Hydrous iron oxide |
| Linarite [5] | $PbCu(OH)_2SO_4$ |
| Magnetite [5] | $Fe_3O_4$ |
| Malachite | $CuCO_3 \cdot Cu(OH)_2$ |
| Manganese oxides | |
| Mimetite [4] | $Pb_5Cl(AsO_4)_3$ |
| Molybdenite | $MoS_2$ |
| Olivenite [4] | $Cu_2AsO_4(OH)$ |
| Orthoclase [1] | $KAlSi_3O_8$ |
| Planchéite [3] | $3CuSiO_3 \cdot H_2O$ |
| Plumbojarosite | $PbFe_6(SO_4)_4(OH)_{12}$ |
| Pyrite | $FeS_2$ |
| Quartz | $SiO_2$ |
| Scheelite [2] | $CaWO_4$ |
| Sericite | $K_2Al_4(OH)_4(Si, Al)_8O_{20}$ |
| Silver [5, 6] | $Ag$ |
| Smithsonite [8] | $ZnCO_3$ |
| Sphalerite | $ZnS$ |
| Stromeyerite [6] | $CuAgS$ |
| Tenorite | $CuO$ |
| Tetrahedrite-Tennantite | $(Cu, Fe, Zn, Ag)_{12}(Sb, As)_4S_{13}$ |
| Tourmaline | Complex borosilicate of Al, Na, Li, Mg, Fe, Mn, Ca |
| Vanadinite | $Pb_5Cl(VO_4)_3$ |
| Willemite [3] | $Zn_2SiO_4$ |
| Wolframite [2] | $(Fe, Mn)WO_4$ |
| Wulfenite | $PbMoO_4$ |

1 Kuhn (1941).
2 Weed (1913).
3 Bideaux and others (1960).
4 Galbraith (1961), Galbraith and Brennan (1959).
5 Ross (1925a).
6 Kuhn (1951).
7 Galbraith and Brennan (1959).
8 Denton (1947b).

*Principal minerals of the Aravaipa-Grand Reef, Table Mountain, and Copper Creek areas*

| Aravaipa-Grand Reef area | Table Mountain mine |
|---|---|
| Anglesite | Barite |
| Azurite | Chrysocolla |
| Calcite | Quartz |
| Cerussite | Vanadinite |
| Chalcopyrite | |
| Chrysocolla | **Copper Creek area** |
| Epidote | Bornite |
| Fluorite | Chalcanthite |
| Galena | Chalcopyrite |
| Garnet | Chlorite |
| Hematite | Galena |
| Malachite | Molybdenite |
| Pyrite | Pyrite |
| Quartz | Quartz |
| Sphalerite | Sericite |
| Wulfenite | Tourmaline |

### COPPER MINERALS

*Atacamite.*—Weed (1913) reported atacamite from the Copper Reef prospect (location unknown, but apparently not the Copper Reef mine of the Stanley district (Ross, 1925a, p. 111–112)). The mineral also is reported by Galbraith and Brennan (1959, p. 45) to be found with olivenite on the main level of the Old Reliable mine in the Copper Creek district.

*Azurite.*—In the Aravaipa and Copper Creek districts azurite is a widespread but scarce supergene mineral. It appears to be much less abundant than chrysocolla or malachite

*Bornite.*—Bornite was recognized only at the Childs-Alwinkle mine, Copper Creek. According to Kuhn (1941, p. 532), it was the principal copper mineral in this mine at a depth of 800 feet.

*Brochantite.*—Galbraith and Brennan (1959, p. 63) listed brochantite as being found in the Copper Creek district.

*Chalcanthite.*—Hydrous copper sulfate, chalcanthite, is very abundant on walls of underground workings of the Copper Prince, Glory Hole, and Old Reliable mines in the Copper Creek region.

*Chalcocite.*—Although it is widespread, chalcocite is not an abundant supergene mineral in the Aravaipa and Copper Creek districts. It commonly forms thin films on pyrite.

*Chalcopyrite.*—Chalcopyrite is the most abundant hypogene copper mineral in both the Aravaipa and the Copper Creek districts and is the only one in most deposits. The largest body of chalcopyrite found to date is that of the Copper Prince mine at Copper Creek; it yielded several thousand tons of nearly pure chalcopyrite (Joralemon, 1952, p. 254).

*Chrysocolla.*—The hydrous copper silicate chrysocolla is the only abundant copper mineral at the Table Mountain mine and in the small veins of the Table Mountain-Fourmile Creek region. It also is present in small amounts in most, if not all, of the copper deposits in the Aravaipa and Copper Creek districts and is by far the most plentiful supergene copper mineral.

*Conichalcite.*—The rare basic copper-calcium arsenate conichalcite was identified at the Table Mountain mine by Bideaux and others (1960, p. 54). It occurs in vugs with malachite, planchéite, and willemite.

*Copper.*—Native copper is reported by Galbraith and Brennan (1959, p. 4) as twisted and wirelike masses in oxidized ore of the Copper Prince mine in the Copper Creek district. Small amounts also were identified by Kuhn at the Childs-Aldwinkle mine in the same district (Kuhn, 1938, p. 129).

*Covellite.*—Covellite is a scarce supergene mineral coating pyrite at several deposits in the Aravaipa and Copper Creek districts.

*Cuprite.*—Cuprous oxide, cuprite, was recognized by Kuhn (1941, p. 534) at the Childs-Aldwinkle mine, Copper Creek district and by Ross (1925a, p. 101) at prospects northeast of Landsman Camp.

*Dioptase.*—The rare and very beautiful hydrous copper silicate dioptase is fairly common in ore from the Table Mountain mine. The dumps of this mine are said formerly to have yielded excellent specimens, but they have been so thoroughly picked over by mineral collectors that sizable crystals are difficult to obtain. The mineral occurs in vugs in jasperoid of the Escabrosa Limestone.

*Enargite.*—Small amounts of enargite are associated with tennantite in the Childs-Aldwinkle breccia pipe in the Copper Creek district (Kuhn, 1941, p. 533).

*Linarite.*—See "Lead minerals," page 122.

*Malachite.*—In the copper deposits of the Klondyke region, malachite is a ubiquitous but rather scarce supergene mineral. It appears to be more abundant than azurite and much less abundant than chrysocolla.

*Olivenite.*—The basic copper arsenate olivenite is reported by Galbraith and Brennan (1959, p. 72) to be associated with atacamite on the main level of the Old Reliable mine in the Copper Creek district.

*Planchéite.*—The rare hydrous copper silicate planchéite is found in vugs in ore from the Table Mountain mine; it is associated with conichalcite, malachite, and willemite (Bideaux and others, 1960, p. 54).

*Stromeyerite.*—See "Silver minerals," page 123.

*Tenorite.*—Copper pitch ore, tenorite, is a widespread minor component of oxidized copper ore in the Aravaipa district.

*Tetrahedrite-tennantite.*—Minerals of the tetrahedrite-tennantite series have been reported from a few ore deposits in the Klondyke region. Kuhn (1941, p. 532–533) said that tennantite was an important ore mineral below a depth of 700 feet in the Childs-Aldwinkle mine, Copper Creek district. He also reported tennantite from the Bluebird mine in the same district (Kuhn, 1951, p. 65). Galbraith and Brennan (1959, p. 24) report tetrahedrite from the Grand Reef mine in the Aravaipa district. During the present study the mineral was recognized only in ore from the Bluebird mine, in which it is intimately associated with galena.

#### GOLD MINERALS

*Gold.*—Native gold is said by Ross (1925a, p. 71–72) to have been reported from quartz veins in the Santa Teresa Mountains. Several thousand ounces of gold has been produced from the Head Center mine in the Aravaipa district, but the nature of the occurrence of gold is not known. The Childs-Aldwinkle copper-molybdenum deposit also yielded several hundred ounces of gold.

#### IRON MINERALS

*Hematite.*—Specular hematite is a very abundant gangue mineral in vein deposits of the Grand Reef region. It is a major component of the Grand Reef and its branches, the Tule Canyon breccia reef, the Waterfall Canyon reef, and the Copper Bar-Sam Jones reef. It also is abundant at the Lead King and Cobre Grande mines and in the prospects northeast of Landsman Camp. According to Ross (1925a, p. 66–67), specularite replaces magnetite at the Landsman Camp prospects, whereas at the Cobre Grande mine, magnetite forms pseudomorphs after specularite.

*Jarosite.*—The hydrous iron-potassium sulfate jarosite is a minor oxidation product of pyrite at the Glory Hole and Old Reliable mines in the Copper Creek region, and probably at several other mines and prospects.

*Limonite.*—Hydrated iron oxide, limonite, is a common product of the oxidation of pyrite throughout the Klondyke region.

*Magnetite.*—Ross (1925a, p. 66–67, 103) reported magnetite to be a major component of the contact-metamorphic deposits of the Landsman Camp area and the Cobre Grande mine. Magnetite is replaced by specularite in the Landsman Camp area and replaces specularite at the Cobre Grande mine.

*Pyrite.*—Although pyrite is present in every sulfide ore assemblage seen in the Klondyke region, in general it is not abundant. The largest amounts of pyrite are in the breccia pipes and altered volcanic rocks of the Copper Creek area. Pyrite also is disseminated locally in Copper Creek Granodiorite.

#### LEAD MINERALS

*Anglesite.*—The lead sulfate anglesite is a common supergene mineral in several deposits of the Aravaipa district. It also is reported from the Bluebird mine in the Copper Creek district.

*Cerussite.*—Lead carbonate is, after anglesite, the most widespread supergene lead mineral in the Aravaipa and Copper Creek districts. It is said to have been very abundant at the No. 1 mine in the Aravaipa district.

*Cosalite.*—The lead-bismuth sulfide, cosalite, is reported by Galbraith and Brennan (1959, p. 26) to have been found at the Landsman claim, Aravaipa district, with calcite and diopside.

*Descloizite.*—The rare hydrous lead-zinc vanadate, descloizite, was identified by Kuhn (1951, p. 65) in ore from the Bluebird mine, Copper Creek.

*Galena.*—The only hypogene lead mineral recognized in the Aravaipa and Copper Creek districts is galena. It is the principal ore mineral in most mines of the Aravaipa district and in the Bluebird mine in the Copper Creek district. Traces of galena have been found in ore from the Childs-Aldwinkle breccia pipe in the Copper Creek district (Kuhn, 1941, p. 534). Ross (1925a, p. 63) reported that much of the galena from the Grand Reef and other mines contains microscopic blebs of argentite, and he surmises that most of the galena of the Aravaipa and Stanley districts is argentite-bearing. Galena commonly is associated with sphalerite, but only at the Iron Cap and Lead King mines (and probably in sulfide ore of the Head Center mine) are the two minerals present in comparable amounts; elsewhere sphalerite seems to be subordinate in amount to galena.

*Linarite.*—The basic lead-copper sulfate, linarite, was reported by Ross (1925a, p. 88) from the Tenstrike group of prospects in the Aravaipa district.

*Mimetite.*—The lead chloroarsenate, mimetite, was reported by Galbraith (1941) from the Table Mountain mine, where it is associated with quartz, vanadinite, and wulfenite.

*Plumbojarosite.*—The mineral plumbojarosite forms a small proportion of the oxidized ore from the Dogwater mine in the Aravaipa district and was identified tentatively in ore from the Silver Coin mine in the same district.

*Vanadinite.*—Lead chlorovanadate, vanadinite, is reported to have been abundant in one of the now inaccessible underground workings of the Table Mountain mine. It was found in dump material as small yellow to orange crystals interstitial to rudely crustified granular quartz that fills open spaces in brecciated chert. Galbraith and Brennan (1959, p. 73) report the vanadinite from this locality to be the arsenian variety endlichite.

*Wulfenite.*—The lead molybdate wulfenite is a widespread and locally abundant mineral in the Aravaipa district; it also has been reported from the Bluebird mine in the Copper Creek district (Kuhn, 1951, p. 65). It is very abundant in fractures in and along the Dogwater vein and also was seen at the Fairview, Sinn Fein, and Silver Coin mines, and at several prospects in Escabrosa and Horquilla Limestones.

#### MANGANESE MINERALS

*Johannsenite.*—The pale yellowish-brown to light olive-gray calcium-manganese pyroxene johannsenite is an abundant mineral in altered limestone of the Aravaipa region. It commonly forms botryoidal or spherulitic aggregates of radiating prisms or needles that weather black (fig. 30). Details on the occurrence of this mineral at Aravaipa are given by Simons and Munson (1963).

*Manganese oxides.*—Although manganese oxides are reported from various ore deposits in the Klondyke region, for the most part they are very scarce. They were noted at the Arizona and Head Center mines, where no primary manganese mineral was recognized, and at the No. 1 mine and several prospects where manganese oxides are derived from johannsenite. Kuhn (1951, p. 65) reports psilomelane from the Bluebird mine in Copper Creek.

#### MOLYBDENUM MINERALS

*Ferrimolybdite.*—The hydrous iron molybdate ferrimolybdite was a fairly abundant supergene alteration product of molybdenite in the upper parts of the Childs-Aldwinkle mine. It formed a yellow powder as well as aggregates of radiating fibers. The mineral was identified by Kuhn (1941, p. 534).

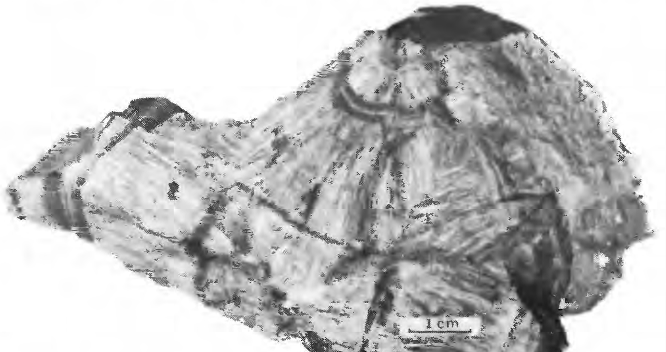


FIGURE 30.—Specimen of johannsenite from dump of the Black Hole prospect, 2,000 feet northwest of Aravaipa in the NW¼ sec. 36 (unsurveyed), T. 5 S., R. 19 E. Mineral forms clusters of fibers radiating from three principal centers (top, lower right, left end).

*Molybdenite.*—At the Childs-Aldwinkle mine in the Copper Creek region, molybdenite was a major ore mineral; during the period 1933–38, this mine yielded nearly 7 million pounds of molybdenite. The mineral also has been recognized in small amounts at the Old Reliable mine in the same district (Denton, 1947a, p. 5). According to Kuhn (1941, p. 532), molybdenite made up from 1 to 2 percent of the ore extracted from the Childs-Aldwinkle breccia pipe.

Analyses of the rhenium content of molybdenite of the Copper Creek region, presumably from the Childs-Aldwinkle mine, are given by Hiskey and Meloche (1940, table 7), who report 0, 27.5, and 40 ppm in three samples of molybdenite concentrate; and by Kaiser and others (1954, p. 18), who report 0, 0, and 20 ppm in three samples from the Childs-Aldwinkle mine. Galbraith and Brennan (1959, p. 21) state that the rhenium content in molybdenite concentrates from this mine, 320–580 ppm, is the highest so far known.

*Wulfenite.*—See "Lead minerals."

#### SILVER MINERALS

*Argentite.*—Ross (1925a, p. 62, 85, 97) reported argentite from several veins in the Aravaipa district; it was also found in ore from the Bluebird mine.

*Bromyrite.*—Ross (1925a, p. 98) stated that the silver bromide, bromyrite, was reported from the Orejana adit in the Aravaipa district.

*Cerargyrite.*—Horn silver, cerargyrite, was noted by Ross (1925a, p. 91) at the Windsor shaft in the Aravaipa district and is reported to have been found in the Orejana adit (Ross, 1925a, p. 98). It also was noted by Kuhn (1951, p. 65) at the Bluebird mine in the Copper Creek district.

*Silver.*—Native silver has been reported from the Laclede mine in the Aravaipa district (Ross, 1925a, p. 75, 86).

*Stromeyerite.*—The silver-copper sulfide, stromeyerite, is reported by Kuhn (1951, p. 65) from the Bluebird mine. According to Galbraith and Brennan (1959, p. 12) the mineral is associated with tennantite at depth in the mine.

#### TUNGSTEN MINERALS

*Scheelite.*—Weed (1913) reported scheelite from the Copper Prince breccia pipe in the Copper Creek district. It presumably is a product of the alteration of wolframite.

*Wolframite.*—Weed (1913) identified wolframite in ore from the Copper Giant and Copper Prince mines, Copper Creek. The mineral was not found during the

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present study, and no details on its occurrence are available.

### ZINC MINERALS

*Austinite.*—The rare basic zinc-calcium arsenate austinite is reported by Bideaux and others (1960, p. 53) to form intergrowths with conichalcite at the Table Mountain mine.

*Descloizite.*—See "Lead minerals," page 122.

*Smithsonite.*—Zinc carbonate, smithsonite, was noted in oxidized ore from the Head Center mine, Aravaipa district, by Denton (1947b, p. 5).

*Sphalerite.*—The only hypogene zinc mineral recognized in the Klondyke region is sphalerite. It is very abundant at the Iron Cap and Lead King mines of the Aravaipa district. In the Copper Creek region, small amounts of sphalerite were found in the Bluebird vein and the Childs-Aldwinkle breccia pipe; elsewhere at Copper Creek the mineral seems to be absent. The sphalerite of the Aravaipa district is a yellowish or greenish variety that is low in iron.

*Willemite.*—The zinc silicate willemite was identified by Bideaux and others (1960, p. 54) in vugs in ore from the Table Mountain mine; it was associated with conichalcite, planchéite, and malachite.

### NONMETALLIC GANGUE MINERALS

*Apatite.*—Kuhn (1941, p. 535) reported apatite to form crystals as much as 5 inches long on the lower and intermediate levels of the Childs-Aldwinkle mine.

*Barite.*—Barite in large plates is an abundant mineral at the Table Mountain mine and is reported by Galbraith and Brennan (1959, p. 57) from the Old Reliable mine in the Copper Creek district. It also was recognized in a barren breccia along the Grand Reef southeast of Imperial Mountain.

*Calcite.*—Although calcite is widespread, it is rarely an abundant gangue mineral in the Aravaipa and Copper Creek districts.

*Chlorite.*—In the Copper Creek district, chlorite is an abundant gangue mineral in several of the breccia-pipe deposits, particularly the Childs-Aldwinkle (Kuhn, 1941, p. 534–535) and Copper Prince mines.

*Epidote.*—Epidote is a very abundant gangue mineral in ore of the Lead King and Cobre Grande mines and in the prospects northeast of Landsman Camp, where together with garnet it replaces limestone. The epidote of the Landsman Camp prospects has a refractive index B of about 1.76 $\pm 0.005$, indicating that it is an iron-rich member of the clinozoisite-epidote series (Winchell and Winchell, 1951, p. 449).

*Fluorite.*—A common gangue mineral in veins of the Aravaipa district and the Grand Reef region is fluorite. In some veins it is second in abundance only to quartz. Most of the fluorite is colorless, but here and there it may be pale violet to purple.

*Garnet.*—Yellowish-green to yellowish-brown massive fine-grained garnet is an abundant gangue mineral at the Lead King and Cobre Grande mines and in the prospects northeast of Landsman Camp. It is associated commonly with epidote. The refractive index of the garnet from Landsman Camp is 1.880 $\pm 0.005$, indicating a variety very high in the $Ca_3Fe_2(SiO_4)_3$ (andradite) component (Winchell and Winchell, 1951, p. 485).

*Gypsum.*—Small amounts of gypsum were reported by Kuhn (1941, p. 535) from the Childs-Aldwinkle mine. The mineral appears to be extremely rare throughout the Klondyke region.

*Orthoclase.*—Kuhn (1941, p. 535) reported that crystals of orthoclase as much as 6 inches long are in a pegmatitic zone at the bottom of the Childs-Aldwinkle breccia pipe. Smaller grains of the mineral also line open spaces below a depth of 300 feet.

*Quartz.*—Although quartz is ubiquitous in the ore deposits of the Klondyke region, it is most abundant in the vein deposits of the Aravaipa district and the Grand Reef and in the breccia-pipe deposits of Copper Creek. Amethystine quartz having prominent comb structure is typical of many small quartz-sulfide veins near Aravaipa.

*Sericite.*—Sericite is a principal gangue mineral in the breccia-pipe deposits of Copper Creek and in the wallrocks of the Bluebird vein in the same district. Ross (1925a, p. 62) said that it is not an abundant mineral in the wallrocks of veins in the Aravaipa district, and my field observations support this conclusion; however, no detailed study of these wallrocks was carried out during the present investigation.

*Tourmaline.*—Although tourmaline is abundant in some of the breccia pipes of the Copper Creek region, apparently it is present in large amounts in only one productive pipe, the American Eagle. In several pipes it forms large masses of radiating black prisms that are interstitial to breccia fragments and also replaces them to some extent. The tourmaline from a pipe 1,500 feet southeast of the Bluebird mine has the following optical characters: $O=1.645$, $E=1.620$; pleochroism O=pale blue gray, E=very pale yellow. According to the chart of Winchell and Winchell (1951, p. 466), this tourmaline is probably near $dravite_{80}$–$schorlite_{20}$ in composition.

## VEIN DEPOSITS

Most of the productive ore deposits of the Aravaipa area and all those of the Grand Reef area are veins. All the deposits of the Table Mountain–Fourmile

Creek region, except part of the Table Mountain deposit, are veins, but none has yielded much ore. In the Copper Creek area the only productive vein has been the Bluebird.

The veins of the Aravaipa and Grand Reef regions are: (1) quartz-sulfide bodies along low-dipping faults that commonly have limestone in one or both walls (Grand Central, Head Center, Iron Cap, Sinn Fein); (2) quartz-specularite-fluorite-sulfide deposits along steeply dipping breccia reefs (Copper Bar, Dogwater, Grand Reef, Tenstrike, Windsor); and (3) narrow quartz-sulfide fissure fillings along faults or brecciated fault zones in volcanic rocks (Abe Reed, Arizona, Fairview, Laclede, Last Chance, Orejana, Princess Pat) or less commonly in other igneous rocks (Silver Coin).

The principal hypogene sulfide minerals are galena, sphalerite, chalcopyrite, and pyrite. Galena and sphalerite are abundant locally; pyrite is scarce and chalcopyrite appears to be present only in traces in most deposits. Quartz, together with amethystine quartz and chalcedony, is by far the most abundant hypogene vein mineral, and constitutes 99 percent or more of many of the veins. Fluorite and specularite are the only other common hypogene minerals; they are particularly abundant in the Grand Reef fault breccias (p. 108) and in the specularite breccia reefs (p. 110). Calcite was reported by Ross (1925a, p. 70–71) from veins in the Stanley district to the north and from the Princess Pat mine, but in general is very scarce. Barite also was reported by Ross (p. 71) from veins near Stanley Butte, but was not recognized except in small amounts in a barren breccia along the Grand Reef southeast of Imperial Mountain.

Many of the Aravaipa deposits are oxidized, some to a depth of several hundred feet, and in a few a substantial part of the ore produced consisted of supergene minerals. Anglesite appears to be the most abundant supergene ore mineral, but cerussite is reported from several deposits, and the No. 1 mine is said to have produced large amounts of "sand carbonate" ore. Wulfenite is a widespread and locally abundant mineral (Dogwater mine) whose supergene origin is open to some question. Supergene minerals of zinc were not seen, but smithsonite has been reported from the upper levels of the Head Center mine. Supergene copper minerals are found in nearly every vein outcrop in the area but are never abundant. Several supergene silver minerals have been reported but none was recognized during the present study.

No study was made of wallrock alteration in the Aravaipa and Grand Reef areas, but the principal alteration clearly has been silicification, as noted long ago by Ross (1925a, p. 62). However, along many veins such as the Abe Reed, Fairview, Last Chance, Orejana, and Windsor, wallrock appears to be virtually unaltered.

Vein structures are generally narrow, a few feet thick or less, but attain widths of as much as 8 feet in the Sinn Fein mine, 15 feet in the Head Center and Iron Cap veins, 30 feet in the Arizona vein, and 150 feet in the Grand Reef mine. Although many of the faults along which the veins were emplaced may be traced for hundreds or even thousands of feet, the veins themselves generally are much shorter, ordinarily occupying only a small fraction of the length of the parent fracture.

The largest ore shoot in the region was probably that of the Head Center mine, but its dimensions are unknown. The main ore shoot of the Grand Reef mine was about 120 feet long on the adit level, at least 270 feet high, and 15–30 feet wide. In the new Sinn Fein workings, the ore shoot was about 250 feet wide, 150 feet long, and as much as 8 feet thick. Most ore shoots seem to have been small, a few tens of feet in length and height and a few feet wide; explored parts of many veins have no ore shoots at all.

Veins of the Table Mountain—Fourmile Creek area consist of supergene copper minerals that fill short and very narrow fissures along steeply-dipping faults or fracture zones in the lower andesite unit of the Galiuro Volcanics. The only abundant copper mineral is chrysocolla; malachite is widespread but commonly is present only in small amounts; azurite is very scarce; and tenorite was identified tentatively at only one prospect. Most veins have no gangue, but a few contain traces of chalcedony, calcite, quartz, or specularite. The vein structures are narrow, a few feet at most and generally only a few inches thick, and most are traceable for only a few tens of feet along the strike; one fracture has been followed for at least 250 feet. The veins themselves are ordinarily only a few millimeters wide. None of them offers any promise of appreciable production.

The Bluebird lead-silver vein in the Copper Creek district is described, insofar as the nearly complete lack of data will permit, on page 167. It apparently was similar to the lead-silver veins of Aravaipa except that it contained small amounts of tetrahedrite, argentite, bornite, tourmaline, and chlorite.

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Most of the veins of the Aravaipa and Grand Reef regions strike northward, the preponderant strike direction lying between north and N. 25° W., or roughly parallel to the Grand Reef fault zone and the structural trend of the Turnbull and Santa Teresa Mountains. Only a few veins, notably at the Grand Reef mine (and the Grand Central mine also?) have been productive. A second group, comprising the Head Center-new Sinn Fein-Iron Cap veins and the Silver Coin vein, strikes east to east-northeast; the former vein system, along a fault dipping 30°–45° N. has been the most productive in the district. Structural and temporal relations between these two groups of veins are unknown.

No obvious spatial relation between ore deposits and intrusive igneous rocks, such as found in many mining districts, can be demonstrated in the Aravaipa-Grand Reef area. However, a possible genetic relation has been postulated between the Santa Teresa Granite and the Waterfall Canyon breccia reef (p. 111); this breccia, although almost unmineralized, resembles the breccia along the Grand Reef fault, which locally, as at the Grand Reef mine, is strongly mineralized; therefore it seems possible that ore formation is related somehow to emplacement of the Santa Teresa Granite. A second indirect line of evidence leads to a similar conclusion; all rock formations peripheral to the Santa Teresa granite pluton and as old or older than the Horse Mountain Volcanics contain ore deposits, whereas the granite itself appears to be devoid of ore deposits. Wallrock of the Head Center-Sinn Fein vein locally is a dacite or quartz porphyry dike which predates vein formation.

Most of the small copper veins in volcanic rocks of the Table Mountain–Fourmile Creek region strike between N. 60° W. and west, and all but a very few strike within the range N. 60° W.–S. 75° W. All veins dip steeply, mostly 80° or more. They have almost the same trend as the set of eastward-trending fractures that is widely developed in older rocks—Glory Hole Volcanics and Copper Creek Granodiorite—in the Copper Creek basin and whose origin could not be surmised. The source of the supergene copper minerals making up the veins is unknown; the veins may have formed at the same time, and their copper may have come from the same source, as the Copper Creek breccia-pipe deposits, but as noted on page 117 the veins may be younger than the pipes and their copper merely a surficial expression of prevolcanic deposits at depth.

### REPLACEMENT DEPOSITS

A few mines and prospects in the Aravaipa area have been opened on replacement deposits in limestone of Paleozoic age. The only productive deposit has been the Iron Cap (in part). A little ore has come from the Black Hole, Cobre Grande, and Lead King mines, and possibly some of the ore from the Ben Hur, Grand Central, and No. 1 mines was of replacement origin. Unfortunately, the mines that might have provided the most information on this group of deposits, the Black Hole, Iron Cap, and No. 1, were inaccessible during the present study; the only accessible mines were the Lead King and part of the Cobre Grande. Specimens of ore were found on dumps of the Black Hole and Iron Cap mines.

Host rocks of the replacement deposits are either Horquilla Limestone (Grand Central, Iron Cap, Lead King) or Escabrosa Limestone (Ben Hur, Black Hole, Cobre Grande, No. 1).

The only abundant ore minerals are sphalerite and galena. Chalcopyrite and pyrite are scarce. Gangue minerals, in addition to unreplaced calcite, include garnet, epidote, johannsenite, specularite, and sparse fluorite and quartz. Ross (1925a, p. 101–103) also reports magnetite from the Cobre Grande mine and the prospects northeast of Landsman Camp, and chlorite from Cobre Grande mine. The most characteristic mineral of the replacement deposits is johannsenite (probably the "actinolite" of Ross, 1925a, p. 66); it was seen at all the known replacement deposits except the Iron Cap and is very abundant at the Black Hole, Cobre Grande, and No. 1 mines. Specimens from the Black Hole dump show large botryoidal aggregates of radiating johannsenite prisms and small amounts of galena, pale-green sphalerite, and quartz concentrated around the surfaces of the botryoidal masses or in the irregular spaces between the masses.

At the Lead King mine, Horquilla Limestone is replaced by light-gray to white brecciated jasperoid for a distance of 60 feet along the main level, and also to a lesser extent along a branch working south of the incline (fig. 34). Neither the shape of the jasperoid mass nor that of the tactite bodies at this mine is known, but at most places the contacts between altered and unaltered limestone are faults that may have controlled replacement to some extent.

The relation of sulfide minerals to gangue could be determined only at the Lead King mine, where sphalerite clearly veins and replaces silicate minerals of the tactite and fills fractures and small open spaces in the jasperoid.

None of the replacement deposits noted in the foregoing summary seems to promise significant production. The largest deposit is the northwestward-trending zone of copper-bearing tactite of the Cobre Grande area (p. 136), but the average copper content appears, on the basis of field observation alone, to be very low. The prospects north and northeast of Landsman Camp are scattered over an area of altered limestone more than a thousand feet across, but the copper content practically everywhere seems insignificant. No other replacement deposits of appreciable size are known.

None of the mineral deposits of the Grand Reef, Table Mountain–Fourmile Creek, or Copper Creek areas is of the replacement type, unless some of the ore reported to have been found in now inaccessible workings of the Table Mountain mine does indeed replace Escabrosa Limestone.

Previous remarks on the origin of the Aravaipa and Grand Reef veins apply also to the replacement deposits. They are not typical contact metasomatic deposits; aside from the ubiquitous silicic dikes, most of which have caused little or no alteration of wall-rocks, no large bodies of intrusive igneous rock are exposed near any of them except Cobre Grande. The mineralogy of barren and metallized tactites is similar—in particular, both commonly contain johannsenite—and every gradation exists between them, and similarly most of the tactite bodies are not closely associated with intrusive igneous rocks. The broad areal association in the Aravaipa region of vein deposits, replacement deposits, and tactite suggests a common but at present undetermined source for their introduced constituents.

### BRECCIA PIPE DEPOSITS

The breccia-pipe group of ore deposits is restricted to the Copper Creek area. Most of the productive pipes are in the Klondyke quadrangle, but two, the American Eagle and Magna, are in the Galiuro Mountains quadrangle to the south. Several nonproductive pipes crop out in both the Galiuro Mountains quadrangle and the Holy Joe Peak quadrangle to the west. The Copper Creek pipes have been discussed ably by Weed (1913) and, more comprehensively, by Kuhn (1938, 1941, 1951). Most of the field observations and conclusions of these workers were amply substantiated during the present study.

The total number of breccia pipes in the entire Copper Creek and Sombrero Butte region is not known, and probably no objective total could be determined. Kuhn (1941, p. 517) mentions "100 to 125 pipes," and shows about that number on his map. Because of scale limitations, only pipes having a diameter of several tens of feet or more appear on plate 1; about 35 pipes are shown.

In view of the diversity of the pipes, detailed descriptions of individual pipes will be deferred, and only the features common to most or all of them will be stressed in the present section.

The breccia pipes in the Klondyke quadrangle are confined to the Glory Hole Volcanics and Copper Creek Granodiorite; a few, including the Copper Giant and Old Reliable pipes, are on or near a contact between these two formations.

Most of the breccia pipes are vertical or nearly vertical circular or elliptical cylinders of breccia whose vertical dimensions are many times greater than the horizontal dimensions in all examples for which data are available; a few pipes such as the Copper Giant are more irregular in plan. The pipes range in size from a few feet to perhaps 600 feet in diameter and may have vertical extents of at least as much as 850 feet. Some pipes have very prominent rusty outcrops projecting well above the enclosing rocks (figs. 50, 54), and outcrops of most others are conspicuous and easily recognized, but a few have little or no topographic expression.

The material of the pipes consists of angular to somewhat rounded fragments ranging in size from granules or pebbles to blocks many feet across. The fragments invariably are of the same rocks as the walls; most of the breccias are monolithologic, consisting entirely of either volcanic rock or granodiorite, but some, such as the Copper Giant, are made up of blocks of both rocks. The breccias are an unsorted chaotic jumble of large and small fragments in which are many voids which may or may not be partly filled with cementing material—quartz, sericite, or tourmaline. Pipes in granodiorite are made up of roughly equidimensional blocks and appear to be structureless, whereas those in volcanic rock commonly consist of somewhat platy fragments that have broken along bedding or flow layering and impart a rude gently dipping layering to the breccias (figs. 51, 54).

The degree of brecciation within the pipes is variable; in some, especially those in volcanic rock, the entire pipe is thoroughly broken up and the fragments are relatively small, whereas others, for instance the Copper Prince and Old Reliable pipes, contain appreciable volumes of almost unbrecciated rock within more completely fragmented material. The American Eagle mine is on what might be considered an incipient breccia pipe; country rock is fractured and altered, but the typical pipelike shape seems to have formed only slightly, if at all.

A rock rather different in appearance from Copper Creek Granodiorite is associated with several breccia pipes, including the Old Reliable and several small pipes northwest, north, and northeast of the old Copper Creek Post Office. The rock is a light-gray porphyry containing prominent phenocrysts of biotite and probably is near biotite latite in composition. Its field relations to the breccia pipes are not clear. At the Old Reliable outcrop a small mass of porphyry is entirely surrounded by breccia but no contacts are exposed. Underground in the Old Reliable mine, the porphyry is exposed near the portal of the upper level and also north of the main breccia pipe; locally the porphyry is itself brecciated but elsewhere it is unfractured, suggesting that it may have been intruded during formation of the breccia. In two of the pipes north of the Copper Creek Post Office, the porphyry forms a screen as much as 10–15 feet thick between breccia and granodiorite wall rock.

Microscopically, a specimen from the Old Reliable mine consists of phenocrysts 1–4 mm across of partly sericitized sodic plagioclase feldspar and abundant grains 0.5–1 mm across of chloritized biotite set in a fine-grained groundmass of sodic plagioclase microlites, potassium feldspar, biotite, and sparse iron ore. Quartz forms irregular patches that appear to be of secondary origin. Plagioclase microlites are alined to produce a well-defined flow structure.

Biotite-rich rocks are known from several places in the Copper Creek region (p. 58); most appear to be facies of the Copper Creek Granodiorite, but at one place south of Copper Creek Post Office the granodiorite is intruded in a very irregular manner by porphyritic biotite-rich rock. The biotite porphyry associated with the breccia pipes does not seem to be merely a facies of the granodiorite but has a texture typical rather of hypabyssal rocks and may have played a significant role in the origin of the pipes. (See p. 130–131.)

Contacts between breccia pipes and wallrock are remarkably sharp and for the most part are unmarked by any sign of movement—slickensides, grooves, chatter marks, gouge, and so forth. The east wall of the main pipe of the Glory Hole mine is smooth, as if some movement had taken place along it, and the Copper Prince pipe is bounded by a system of peripheral faults having local slickensides and gouge.

Wallrocks of the pipes may be virtually unfractured, or a narrow zone of fracturing much less intense than that within the pipes and fading out away from the pipes may intervene between pipe and unfractured wallrock; this zone is 10–15 feet wide in several examples. At all the explored pipes, the contact between pipe and wallrock could be placed within narrow limits, generally less than a foot. Natural exposures of these contacts are very scarce; the contacts usually are covered by debris from the pipe itself.

Little information is available on internal structures of the pipes, such as faults or joints. Outcrops are so strongly weathered that such structures, if present, are effectively concealed; underground, either exploitation has been so complete that little or no evidence is left, or exploration has been insufficient to provide much evidence. The breccia of the Copper Prince pipe is cut by several prominent eastward-trending faults and joints, and Kuhn (1941, p. 518–520) noted faults trending east, N. 10° W., N. 60° E., and N. 70° W. within the Childs-Aldwinkle breccia pipe.

Breccia fragments have been altered to varying degrees but the alteration, regardless of rock types or intensity, has been very similar in every pipe. In essence, alteration has tended toward reduction of all rocks of the breccias to fine-grained aggregates of quartz and sericite, both of which probably represent additions of hypogene material to the pipes. The south-central part of the pipe on the west summit of the hill west of the Childs-Aldwinkle mine consists of fragments of granodiorite converted almost entirely to granular quartz. In some pipes, and in some fragments of almost all pipes, this quartz-sericite alteration has been complete, whereas in many pipes the breccia fragments have only a rind of altered rock enclosing comparatively fresh cores. In addition to quartz and sericite, black tourmaline has formed in breccia fragments in a few pipes. Other minerals of the altered rocks, except of course the sulfides, appear to be products of the alteration of original minerals rather than to represent additions of new material.

In several pipes, breccia fragments originally angular in shape appear to have been rounded as a result of a combination of alteration and softening followed by spalling off of the softened angular corners; this process might be termed "hypogene exfoliation," as the results resemble those of exfoliation of outcrops of massive granular rocks.

Wallrocks of some pipes are cut by narrow rust- or copper-stained fractures. In granodiorite, these fractures may have thin selvages of chloritized rock.

The results of alteration as revealed by the microscope are monotonously similar from pipe to pipe. Orthoclase feldspar is replaced by sericite or quartz, in places vermicular, or both; plagioclase feldspar is converted more or less completely to sericite in some places having residual albite; and biotite is converted partly or completely to chlorite, iron ore, and rutile.

In the ore-bearing pipes, alteration of the breccia fragments differs in no essential respect from that in the barren pipes, except that in the Childs-Aldwinkle breccia, highly altered rinds of the fragments may contain disseminated chalcopyrite.

Similar quartz-sericite alteration has affected the Glory Hole Volcanics over a sizable area that includes most of the breccia pipes cutting that formation; this alteration was described on page 40.

The only hypogene sulfide minerals recognized were chalcopyrite, molybdenite, pyrite, and bornite.

Molybdenite was seen only at the Childs-Aldwinkle mine but has been reported also from the Old Reliable and Copper Prince mines and from several small pipes east and southeast of the Childs-Aldwinkle mine (Kuhn, 1941, p. 529–530). At levels of the Childs-Aldwinkle mine now accessible, molybdenite is restricted to interstices of the breccia, but Kuhn says that it also replaces country rock and other sulfide minerals.

Chalcopyrite was identified at the Childs-Aldwinkle, Copper Prince, and Old Reliable mines and in the pipe on the hill west of the Childs-Aldwinkle mine. Most chalcopyrite is interstitial to breccia fragments, but some is disseminated in outer altered shells of fragments in the Childs-Aldwinkle mine, and veins of chalcopyrite cut breccia in the Copper Prince mine.

Pyrite is not abundant in most pipes but seems to be widespread; many outcrops of breccia pipes are speckled with small cavities lined with iron oxide or jarosite that mark the former presence of pyrite. Pyrite may fill interstices between breccia fragments, or may form veinlets within fragments, or less commonly may be disseminated in the fragments. Locally, as in parts of the Copper Prince mine, appreciable amounts of pyrite fill open spaces in breccia. Pyrite is heavily disseminated through much of the rock on the dump of the adit at the Superior pipe. In the Glory Hole mine, stringers of pyrite cut wallrock near the pipes.

Bornite was seen only in the Childs-Aldwinkle mine in very small amounts; Denton (1947a) also reports bornite from the Old Reliable mine. Films of chalcocite on pyrite were noted in the Copper Prince and Old Reliable mines. Kuhn (1941, p. 533–534) reports tennantite, enargite, galena, and sphalerite from the Childs-Aldwinkle mine; and Denton (1947a) identified covellite and tetrahedrite from the Old Reliable mine. Weed (1913) noted wolframite in the Copper Prince mine and in now inaccessible workings on the Copper Giant pipe. Hypogene orthoclase, biotite, and apatite were reported by Kuhn from the lower levels of the Childs-Aldwinkle mine but were not found during the present study.

The origin of breccia pipes and pipe-shaped ore deposits is the subject of an extensive literature, which I do not intend to review here. Nor is an exhaustive discussion of the Copper Creek pipes warranted in this report on the basis of the evidence at hand. I propose simply to list some of the features of the pipes that any theory of origin should explain; this list will point toward several theories that seem to apply equally cogently to the Copper Creek pipes, and will indicate that a few others are untenable. These features are listed in a very general way in order of decreasing significance.

1. The breccia pipes are composed of the same rocks as their walls; as far as I know, no exotic fragments have been found in any pipe. Biotite latite porphyry appears to have been intruded into or along the contacts of several pipes.
2. Contacts between breccia and wallrock are very sharp, commonly are irregular in detail, and for the most part are not marked by any evidence of movement. A few contacts are smooth, suggesting at least some movement, and a very few are clearly faults marked by gouge and slickensides.
3. Breccia fragments appear to have been jostled somewhat, but little evidence of more than minor rotation was found. In some pipes in volcanic rock, original layers have been disrupted with very little differential movement among the resulting fragments; in other pipes, platy fragments impart a rude layering almost parallel to that of the wall rock.
4. Most of the pipes are circular or elliptical in plan; a few are more irregular.
5. Most of the pipes do not seem to have any clearly defined structural controls, such as intersections of fracture sets, and do not appear to be alined along any particular trend or trends. A few pipes in the northwestern part of the district are along strong fractures marked by quartz-sericite alteration. Some of the elliptical pipes are elongated northward or north-northwestward, but the elongation is not prominent. These observations agree with those of Weed (1913) but differ substantially from those of Kuhn (1941, p. 516, 518–525, 527), who believes that the pipes are at intersections of various fracture systems and in at least one place are alined along faults. Kuhn postulated four principal groups of steeply-dipping fractures within the Copper Creek district, the fractures striking respectively east, N. 60° E., N. 70°

W., and N. 10° W. During the present study, a set of fractures striking within 20° of east was recognized throughout the district and is particularly well displayed in the southwestern part, but no other well-developed pattern emerged. The Bluebird vein is along a fracture striking N. 55° E., and a small vein half a mile south-southeast of the Bluebird mine strikes N. 50° E., but fractures of this general orientation do not seem to be abundant.

6. Wallrocks are practically unbrecciated and unaltered. Around a few pipes, a narrow zone of mild fracturing lies between breccia and unfractured rock, and wallrock near a few pipes is cut by sparse fractures along which the rock has been altered and (or) pyrite deposited.
7. Breccia fragments are unsorted, ranging in size from granules to blocks many feet across and in shape from angular to rounded.
8. Most of the ore minerals are interstitial to breccia fragments, and only minor amounts of chalcopyrite are disseminated in the altered rinds of fragments. No shells of sulfide minerals like those described from the Bull Domingo and Bassick pipes (S. F. Emmons, 1896, p. 430–447) have been reported at Copper Creek.
9. In several pipes, angular fragments have rounded cores of relatively fresh rock rimmed by altered rock; some and perhaps all the rounded fragments appear to have originated by spalling off of the altered shells.
10. The Copper Creek pipes are scattered over an area perhaps 5 miles long in a north-northwesterly direction and about 2 miles wide. The productive pipes, however, with the exception of the Magna pipe 2 miles south of Copper Creek, are concentrated in an area slightly more than a mile across and centered between the Copper Prince and Childs-Aldwinkle mines. The total number of pipes probably exceeds 200.

Breccia pipes resembling in many respects those of Copper Creek have been described from various places. Some of these pipes are the Bull Domingo pipe at Silver Cliff southwest of Cañon City, Colo. (S. F. Emmons, 1896, p. 439–447; Spurr, 1923, p. 865–871), The Patch at the San Juan mine in the Central City district, Colorado (Bastin and Hill, 1917, p. 234–237; Spurr, 1923, p. 876–885; Walker, 1928, p. 977–978; Lovering and Goddard, 1950, p. 171, 181–183), the Cactus and O. K. chimneys in the San Francisco region, Utah (Butler, 1913, p. 172–178, 190; Butler and others, 1920, p. 516–518; Spurr, 1923, p. 872–875), the Black Mesa pipe northwest of Bagdad (Anderson and others, 1955, p. 40), and the Duluth pipe at Cananea, Mexico (Perry, 1961, p. 367–368). Ore deposits similar to the American Eagle, in what might be termed "incipient pipes," include the Jessie stockwork or pipe at Breckenridge, Colo. (Ransome, 1911, p. 144–147; Spurr, 1923, p. 887–888), the Alice stockwork in the Alice-Yankee Hill district 7 miles west-southwest of Central City, Colo. (Bastin and Hill, 1917, p. 323–325; Spurr, 1923, p. 885–888; Lovering and Goddard, 1950, p. 164–165) and the South Ibex stockwork at Leadville, Colo. (S. F. Emmons and others, 1927, p. 301–302). Various origins have been proposed, including brecciation at intersections of fractures (S. F. Emmons, Bastin and Hill), local intimate fissuring (Ransome, 1911), brecciation by shrinkage upon cooling of an igneous body followed by solvent action of ascending solutions (Butler, Butler and others), upward boring of a column of igneous fluids (Spurr), mineralization stoping (Locke, 1926), volcanic explosions with or without addition of volcanic rock (Walker; W. H. Emmons, 1938), upward punching of an igneous plug along preexisting zones of weakness (Lovering and Goddard), a combination of upward streaming of magmatic emanations through broken rock, accompanied or followed by upward thrusting of an underlying intrusive body (Burbank, 1941, p. 177–178; Anderson and others), and subsidence caused by withdrawal of magma from below (Perry, p. 368–370).

The origin of the Copper Creek pipes has been discussed briefly by Weed (1913) and at some length by Kuhn (1941, p. 525–528), who concludes that the breccias were formed at intersections of various fracture systems along which solutions rose, altered the brecciated rock, and deposited hypogene ore and gangue minerals; in some pipes these fluids dissolved some rock to produce open or incompletely cemented breccia, and in some pipes postmineral slumping has taken place.

An eclectic theory that would attempt to explain most of the features listed above might be somewhat as follows. Emplacement of the Copper Creek granodiorite pluton was followed by cooling of granodiorite and wallrocks sufficient to permit a pervasive system of contraction fractures to develop at and below the present level of observation. An elongate pluton, perhaps a biotite-rich facies of the granodiorite, was then intruded into the granodiorite; the breccia pipes are located above and along this body, and the productive pipes are concentrated over a large cupola on it. Fluids rising from the elongate pluton, probably for the most part along restricted escape routes determined by structures having no expression at the present surface, percolated through fractured granodiorite and metavolcanic rocks and altered them. Rounding of breccia fragments probably is caused mainly by spalling off of shells of altered rock, but might result in small part from abrasion.

Fragmentation and the formation of open spaces in the breccia may have resulted from softening (see fig.

56), disintegration, and flushing out, or solution and removal of material by ascending fluids; from slight upward thrusting of the breccia by magmatic gas, by an underlying intrusive plug, or by a combination of both; or from slumping resulting from removal of material, either breccia or intrusive rock, at depth. The relations shown in figure 57 suggest that perhaps both upthrusting and slumping played some part, and the small bodies of biotite latite porphyry associated with several pipes may have been the agents causing the upthrusting.

Apophyses of the pluton may have intruded some of the pipes, reaching the present level of observation in a few, such as the Old Reliable, to solidify as biotite latite porphyry (p. 128). Following formation of the breccia pipes, copper and molybdenum sulfides, together with abundant quartz and lesser amounts of other minerals, were deposited in open spaces between fragments; chalcopyrite and pyrite also formed as small grains disseminated in altered breccia fragments.

The thickness of cover above the present outcrop level of the pipes at the time of their formation is not known, but almost surely was at least 1,500 feet, the approximate vertical interval between the Old Reliable pipe and the highest outcrop of Glory Hole Volcanics. If the pipes postdate the Galiuro Volcanics (there is no direct evidence that they do), then the depth of cover may have been twice or even three times as much.

The nature of the restricted escape routes mentioned above is not known, but presumably these routes were above what must have been almost point sources (small cupolas?) of the fluids responsible for alteration and ore deposition in the pipes; they are what Burbank (1941, p. 177) calls vertical axes of greatest concentration of magmatic emanations.

The principal features failing of explanation in the foregoing synthesis are the sharp and unfaulted or unfractured contacts between breccia and wallrock and the circular or elliptical horizontal cross sections of most pipes. The interlocking curved fractures or the envelopes of vertically sheeted rock bounding pipes in the Red Mountain district of Colorado (Burbank, 1941, p. 172–173) are lacking in most of the Copper Creek pipes, and the contacts seem to mark simply the limit of penetration of fluids that worked outward from a nearly vertical and linear channel.

## MINES AND PROSPECTS

In this report, mines and prospects are divided into four geographic groups; Aravaipa, Grand Reef, Table Mountain–Fourmile Creek, and Copper Creek. The Aravaipa district embraces the first two of these groups.

### HISTORY AND PRODUCTION

The history of the Aravaipa district from its discovery in the 1870's until 1949 was summarized by Wilson (1950, p. 55–56) as follows; a few minor changes have been made by me:

*1870–89.*—District discovered in the 1870's. A small smelter was built at Aravaipa in the late 1870's by Col. W. C. Bridwell, but no data are available on production of this period.

*1890–95.*—Aravaipa Mining Co. sank the Arizona shaft and shipped two cars of ore from the Arizona, Orejana, or No. 1 claims.

*1890–1902.*—John W. Mackay developed the Grand Reef mine to a depth of 300 feet. Presumably some lead-silver and copper ore was shipped from other properties in the district.

*1903–15.*—Small-scale operations by lessees.

*1915–19.*—Grand Reef mine leased by local people who built a small mill and shipped ore and concentrate mined during earlier operations.

*1916.*—Lead carbonate ore, valued at $90,000, reported to have been shipped from the No. 1 mine.

*1919–20.*—Aravaipa Leasing Co. dewatered the Grand Reef mine and made some production.

*1921–24.*—Little activity in the district; no production reported for 1921 or 1922.

*1925–28.*—Grand Central Mining Co. acquired the properties of the Aravaipa Mining Co. in 1925 and built a flotation concentrator having a capacity of 90 tons per day. The plant operated for 5 months in 1927.

*1929–31.*—Production was mainly oxidized lead ore from the Grand Reef mine, which in 1931 was the second largest lead mine in Arizona.

*1932.*—Little activity, no production reported.

*1939–41.*—Grand Reef Mining Corp. in 1939 built a concentrator having a capacity of 100 tons per day. During 1941, the Calistoga Mining and Development Co. treated tailings from the Grand Reef mine.

*1942–49.*—Athletic Mining Co. acquired a group of claims around Aravaipa, developed the Iron Cap and Head Center mines, and in 1948 built a flotation concentrator having a capacity of 100 tons per day.

*1950–57.*—Athletic Mining Co. continues to be only major producer in the district. Operations ceased in 1957.

*1958–60.*—No appreciable production, some exploration in the Cobre Grande mine area and sporadic prospecting elsewhere.

Production of the Aravaipa district is given in the following table. Data for the years 1915–38 are taken from Wilson (1950, p. 57), those for 1939–58 from the Minerals Yearbooks of the U.S. Bureau of Mines.

TABLE 7.—*Production of the Aravaipa district from 1915 to 1958*

| Year | Tons of ore treated | Lead (pounds) | Zinc (pounds) | Copper (pounds) | Silver (fine ounces) | Gold (fine ounces) | Total value (dollars) |
|---|---|---|---|---|---|---|---|
| 1915–22 | 9,376 | 5,801,254 | ----- | 218,851 | 93,486 | 53 | 550,754 |
| 1923–28 | 15,798 | 2,433,782 | 1,214,797 | 25,856 | 10,274 | ----- | 266,794 |
| 1929–31 | 4,495 | 1,348,648 | ----- | 112,134 | 40,965 | 77 | 98,426 |
| 1932–38 | 135 | 55,622 | ----- | 3,172 | 2,037 | 2 | 3,043 |
| 1939 | 1,282 | 151,723 | ----- | 6,539 | 2,696 | 8 | 9,921 |
| 1940 | 537 | 37,600 | ----- | 5,858 | 2,264 | 1 | 4,187 |
| 1941 | 2,680 | 334,000 | ----- | 44,000 | 12,721 | 16 | 33,836 |
| 1942 | 1,295 | 305,400 | ----- | 6,000 | 3,853 | 22 | 24,698 |
| 1943 | 443 | 79,400 | 65,000 | 7,200 | 1,440 | 5 | 15,110 |
| 1944 | 4,117 | 361,000 | 616,000 | 19,000 | 2,302 | 12 | 103,726 |
| 1945 | 6,917 | 581,000 | 665,000 | 23,000 | 3,344 | 17 | 132,519 |
| 1946 | 7,407 | 834,000 | 304,500 | 76,000 | 8,969 | 125 | 162,889 |
| 1947 | 5,960 | 1,588,500 | 39,000 | 106,900 | 15,958 | 229 | 278,369 |
| 1948 | 31,146 | 2,283,200 | 2,196,000 | 105,600 | 17,240 | 195 | 746,104 |
| 1949 | 23,188 | 2,541,000 | 1,565,000 | 118,600 | 20,127 | 1,310 | 682,968 |
| 1950 | 21,630 | 2,995,000 | 1,842,000 | 83,300 | 16,104 | 664 | 721,030 |
| 1951 | 30,897 | 2,587,700 | 2,808,000 | 91,800 | 14,261 | 588 | 1,014,431 |
| 1952 | 22,618 | 1,729,200 | 2,630,000 | 225,900 | 18,495 | 129 | 790,903 |
| 1953 | 16,549 | 1,804,800 | 3,464,000 | 102,900 | 14,564 | 25 | 678,377 |
| 1954 | 19,230 | 1,624,000 | 2,732,000 | 141,000 | 17,140 | 25 | 575,527 |
| 1955 | 18,960 | 1,364,000 | 3,340,000 | 96,300 | 15,806 | 2? | 664,351 |
| 1956 | 18,449 | 832,000 | 2,370,500 | 125,900 | 11,118 | ----- | 518,952 |
| 1957 | 9,725 | 595,900 | 1,392,900 | 87,800 | 5,884 | ----- | 278,543 |
| 1958 [1] | ? | ----- | ----- | 2,000 | 97 | 1 | 412 |
| Total | 272,834 | 32,268,729 | 27,244,697 | 1,835,610 | 351,145 | 3,506 | 8,355,870 |

[1] Production from Graham County.

The only production from deposits in the Table Mountain—Fourmile Creek group has been from the Table Mountain mine, which between 1898 and 1928 is estimated to have yielded 400–600 tons of ore assaying more than 14 percent copper.

Histories and production of mines of the Copper Creek group are given by Kuhn (1938, p. 127; 1941, p. 528–529; 1951, p. 56–57) and Denton (1947a, p. 3–4), and their data are summarized below.

The earliest mining activity recorded dates from 1863, although the region is reported to have been prospected prior to that date. In 1863, high-grade silver-lead ore was mined from the Bluebird vein. During the period between 1903 and 1919, various deposits along Copper Creek, as well as the Bluebird mine, were explored by the Copper Creek Mining Co. and its successors, the Minnesota-Arizona Mining Co., and the Copper States Mining Co. (or the Copper States Metals Mining Co.). During 1907–09, the Calumet and Arizona Mining Co. explored the Copper Giant, Copper Prince, Glory Hole (or Globe), and Superior breccia pipes. The road from Mammoth to Copper Creek was built in 1908. The American Eagle and Old Reliable mines were exploited at some time between 1914 and 1919, and ore was treated in a mill on Copper Creek. The Childs-Aldwinkle mine was worked by the Arizona Molybdenum Corp. between 1933 and 1938, and by lessees in 1939.

Production from the Copper Creek group is summarized in the following table.

TABLE 8.—*Production of the Copper Creek district from 1863 to 1939*

| Mine | Period | Copper (pounds) | Molybdenite (pounds) | Lead (pounds) | Silver (fine ounces) | Gold (fine ounces) | Estimated value (dollars) |
|---|---|---|---|---|---|---|---|
| Bluebird | 1863–1920 | ----- | ----- | ----- | ----- | ----- | 150,000 |
| | 1926–39 | 200,000 | ----- | 4,000,000 | 119,000 | ----- | 350,000 |
| | 1948 | 2,100 | ----- | 31,200 | 1,085 | 3 | 6,000 |
| Childs-Aldwinkle. | 1933–38 | 5,859,033 | 6,946,782 | ----- | 26,938 | 723 | ----- |
| Copper Prince | 1937 | 1,227,667 | ----- | ----- | ----- | ----- | ----- |
| Copper States Mining Co.[1] | 1905–16 | 700,000 | ----- | ----- | 55,000 | ----- | ----- |
| Clark and Scanlon properties. | 1905–30 | 200,000 | ----- | ----- | 15,000 | ----- | ----- |
| Total | ----- | 8,188,800 | 6,946,782 | 4,031,200 | 217,023 | 726 | 506,000 |

[1] Source uncertain, but presumed to be the Old Reliable and American Eagle mines.

## ARAVAIPA GROUP

### MINES AND PROSPECTS OF THE ATHLETIC MINING COMPANY

The Athletic Mining Co. was the principal mine operator in the Aravaipa district between 1942 and 1957, at the end of which period all its properties were shut down. During the period of fieldwork on which this report is based, no responsible official of the company resided in the district, and consequently the company denied permission to enter or study its mines. As a result, descriptions of these deposits are necessarily brief and are based on surface observations, published material, and various written communications.

In addition to operating the Iron Cap and Head Center mines, the company in 1948 built a flotation concentrator having a capacity of 100 tons per day. The concentrator is in the SW¼ sec. 6, T. 7 S., R. 20 E., a mile northwest of Klondyke.

The bulk of the metal production from the district during the period 1952–57 (table 7) came from the Iron Cap and Head Center mines, principally the Head Center.

#### ARIZONA MINE

The Arizona mine is in the center W½ sec. 25 (unsurveyed) T. 5 S., R. 19 E., on the road from Aravaipa to the Abe Reed mine. It is one of the properties referred to by Ross (1925a, p. 95–96) as the Aravaipa Mining Co. group. No production definitely attributable to the mine is recorded. Horse Mountain Volcanics, including some "turkey-track" andesite, are cut by a fault zone that strikes a little west of north and dips 80°–85° W. At its south end the fault structure is 90 feet wide and has a core of fine-grained trachyte (?) dike rock (see p. 94) flanked by quartzose selvages stained by manganese oxide; the west selvage consists of 30 feet of interlayered finely laminated quartz and massive quartz containing a little copper stain and very sparse galena. In the vicinity of the Arizona shaft, the fault zone is 20 feet wide and is made up, from west to east, of 6–7 feet of laminated quartz containing a layer of massive quartz 1–2 feet wide, 6 feet of volcanic rock, and 6–7 feet of laminated quartz having a layer about 2 feet wide containing a little galena, anglesite, and copper stain. Ross noted argentite, sphalerite, pyrite, and chalcopyrite on the dump.

The Arizona vein is explored by a two-compartment shaft sunk to a depth of 580 feet by 1895 (Ross, 1925a, p. 98; Wilson, 1950, p. 60), an east-trending adit 600 feet long that crosses the vein about 200 feet from the portal, drifts along the vein 275 feet to the south and 400 feet to the north from the adit, and several short drifts off the shaft. The adit connects with the 83-level of the shaft. The shaft is said to be in limestone below the 500-foot level, and Wilson reports that diamond drilling carried out in 1942–43 revealed that pink limestone containing silicated limestone and iron oxide was found to extend to a depth of more than 100 feet below the 516-level of the shaft. Ross states that on the 83-level the vein has a maximum width of more than 10 feet and consists of quartz, galena, cerussite, and manganese oxide; he also reports an average assay along this level of 10–15 percent lead, 12–15 ounces of silver per ton, and a little gold. The shaft is reported to have been in barren rock to a depth of 560 feet where limestone containing a little sphalerite, pyrite, and chalcopyrite was found.

#### FAIRVIEW PROSPECT

A prospect shaft said to be on the Fairview claim is 4,000 feet northwest of Aravaipa, about on the line between secs. 25 and 26 (unsurveyed), T. 5 S., R. 19 E., and 1,500 feet north of the south edge of these sections. A 2-compartment shaft of unknown depth has been sunk on the south end of a fracture zone 3 feet wide that strikes about north and dips 80° E. The fracture extends 250 feet north of the shaft, beyond which point it is covered. Country rock is "turkey-track" andesite of the Horse Mountain Volcanics. In an opencut near the shaft is a vein 10–14 inches wide of amethyst, quartz, and a little specularite. Rock in the ore bin contains a little chrysocolla, anglesite, cerussite, and very scarce wulfenite.

#### GRAND CENTRAL MINE

The Grand Central mine is about 1,000 feet southeast of the Head Center mine near the center north edge of sec. 30, T. 5 S., R. 20 E. Production prior to 1925 was negligible, but during the period 1926–28, when the mine was operated by the Grand Central Mining Co., it may have been appreciable; according to Wilson (1950, p. 56), the mine produced during this period approximately 3,500,000 pounds of lead, 1,214,797 pounds of zinc, and $20,000 in silver. Nothing is known of the history of the mine subsequent to 1930.

A shaft inclined 32° N. 70° E. is sunk on an altered zone in Horquilla Limestone, which strikes N. 10° E. and dips 35° W. Galena, quartz, and a little copper stain can be seen in a small outcrop near the shaft.

A steep funicular railway connects the shaft to a loading bin on the Aravaipa-Head Center mine road.

#### HEAD CENTER MINE

The Head Center mine is on the east side of Williamson Canyon at the end of the road in the SE¼ SW¼ sec. 19, T. 5 S., R. 20 E. Production from the Head Center mine is lumped with that from the Iron Cap mine in the available statistics, so that its total output is unknown, but the mine was the principal source of ore of the company between 1950 and 1957 and probably has been the largest producer of the district. The Head Center vein is developed by an adit 210 feet long, an inclined shaft down the vein, and several closely spaced levels.

The Head Center vein is along a fault zone that strikes slightly north of east, dips 30°–45° N., and over most of its length brings Horse Mountain Volcanics in the hanging wall against Horquilla Limestone in the footwall. To the east of Williamson Canyon as far as the Iron Cap mine, and for nearly a thousand feet west of the canyon, the fault is intruded by a dike of porphyritic dacite or quartz porphyry. At the Head Center shaft, rocks along the fault are strongly shattered, and in the bottom of Williamson Canyon the vein is a breccia zone at least 20 feet wide and having sheared silicic Horse Mountain Volcanics in both walls.

In an opencut just east of the Head Center shaft, the vein consists mainly of quartz cut by veinlets of manganese oxide. Some of the quartz is finely laminated and contains thin layers of galena and anglesite.

According to Wilson (1950, p. 59) most of the vein was in rhyolite porphyry (dike rock?); in the eastern part of the adit level the vein was in part in the footwall limestone. Wilson reports that the ore shoot being mined in 1949 was about 350 feet long and trended east. He writes as follows:

> The vein ranges in thickness up to about 10 feet in the rhyolite and 14 feet in the limestone. The segment of the vein containing the ore shoot forms a low northward-plunging arch, within which both the strike and dip show local variations of several degrees.

Displacement of the vein by cross faults has not exceeded a few feet in the area explored.

Some residual sulfides occur near the surface, but in general oxidation has been thorough to a depth of about 30 feet below the adit and continues downward throughout all the workings; in general, from 70 to 80 percent of all the lead and zinc minerals occur in nonsulfide form. Sufficient water was encountered below the fourth level to require intermittent pumping.

Galena and sphalerite, together with minor pyrite and a little chalcopyrite, are the sulfide minerals. Some of the sphalerite is pale lemon yellow to colorless. Most of the ore has been sufficiently low in zinc to be shipped for lead smelting.

Samples taken in 1943 (Denton, 1947b, p. 8) from the Head Center vein along the adit and to a vertical depth of about 130 feet in the shaft assayed from traces to 38 percent lead, 1–29 percent zinc, traces to 6 percent copper, 1–8 ounces of silver per ton, and less than 0.1 ounce of gold per ton. Sample widths were 1.2–5.4 feet. A representative sample from the shaft assayed 11.7 percent lead, 17.4 percent zinc, 1.7 percent copper, and 1.72 ounces of silver per ton.

### IRON CAP MINE

The Iron Cap mine is at the end of the road half a mile north of Landsman Camp in the SE¼ sec. 19, T. 5 S., R. 20 E. Together with the Head Center mine, it was a principal source of ore of the company. The mine has been described briefly by Denton (1947b, p. 5–6) and Wilson (1950, p. 56–57). Mine workings consist of a lower adit more than 600 feet long, various stopes, and a sizable glory hole.

Production from the Iron Cap mine is believed to have been considerably less than that from the Head Center mine.

The lower adit is in sandstone of the Pinkard Formation at the portal, but at 475 feet from the portal it crosses a fault and enters Horquilla Limestone. The glory hole is entirely in Horquilla Limestone cut by a broad and rather vague fracture zone, probably related to the Head Center fault, that strikes N. 50°–70° E. and dips 40°–55° NW. Geology and mine workings are described by Wilson (1950, p. 58) as follows:

The lower adit shows several northwestward-trending reverse faults of steep northeastward dip. One of them, termed the Winze fault, at a distance of 410 feet from the portal intersects a fault which strikes westerly, dips 40°N., and brings Pennsylvanian [Horquilla] beds over Cretaceous [Pinkard]. This low-angle fault zone, now known as the East vein, proved to contain the most important ore shoot found in the mine. It might have escaped discovery if the adit had been a few feet farther southeast.

A considerable tonnage has been mined from the Upper Stope and West ore bodies, immediately south of the Upper Tunnel fault. They consist of veins, thin stringers, and irregular spotty replacements, associated with bedding slips and fractures in Pennsylvanian limestone.

Most of the ore shoots occur within broad, low anticlines that plunge down the dip.

The Iron Cap ores consist essentially of sphalerite and galena, together with a little pyrite and chalcopyrite. Small amounts of chalcocite and covellite are present locally, but in general the ores are not oxidized to any important extent.

Ore still in the bins consists of highly altered limestone(?) cut by veinlets of coarsely crystalline quartz containing irregular pods and lenses of yellowish-green sphalerite, galena, calcite, and sparse pyrite and chalcopyrite. Sphalerite also is disseminated locally in limestone around the glory hole.

Samples of the vein in the old upper adit, taken in 1943 (Denton, 1947b, p. 10), assayed 1–19 percent lead, 1–35 percent zinc, less than 1.7 ounces of silver per ton, and traces of copper and gold. Sample lengths ranged from 1.2 to 6.0 feet. The unweighted-average assay was 7.0 percent lead, 10.6 percent zinc, and less than 1 ounce of silver per ton. Samples from the East vein assayed 1–19 percent lead, 1–28 percent zinc, less than 3.2 ounces of silver per ton, and traces of copper and gold. Sample lengths were 2.0 to 8.0 feet. The unweighted-average assay was 5.7 percent lead, 14.0 percent zinc, and less than 1 ounce of silver per ton.

### NO. 1 MINE

The No. 1 mine is just west of Aravaipa in Arizona Gulch. The mine has been inaccessible for many years, and little is known about its geology or production. According to Denton (1947b, p. 4) the mine is reported to have yielded $90,000 in lead carbonate ore in 1916. Mine workings consist of a shaft inclined 55°–60° N., reported to have short drifts off the 60-, 126-, and 226-levels (Wilson, 1950, p. 60), and an opencut north of the shaft about 100 feet long.

Most of the shaft workings appear to be in a block of Escabrosa Limestone that is faulted against Horse Mountain Volcanics. Much of the limestone is replaced by rosettes of johannsenite, some having quartz cores. Contacts between altered and unaltered limestone along joints and bedding planes are very sharp. Small amounts of quartzite and fissile shale on the dump indicate that at depth, probably at the bottom, the shaft entered Bolsa Quartzite and the Martin Formation, both of which are exposed just west of the shaft in fault contact with Escabrosa Limestone.

The opencut north of the shaft and just west of the Williamson Canyon road is along a fault that at the north end of the cut strikes N. 30° W. and dips 70° E. and at the south end strikes S. 45° E. and is vertical. The fault is marked by about a foot of pink breccia. Horizontal Escabrosa Limestone in the southwest wall of the fault is replaced by johannsenite for as much as 5 feet from the fault, but no other evidence of mineralization was seen.

#### PANAMA MINE

The Panama mine is in the gulch just east of Aravaipa. Horquilla Limestone is brought against Bolsa Quartzite to the east along a northward-trending fault that dips steeply west. An outcrop of silicated limestone several hundred feet long has near its center a zone of alteration perhaps 50 feet long and 20 feet wide containing oxides of iron and manganese. A north-northeastward-trending adit about 100 feet long driven below this outcrop cut a mineralized zone 50 feet or so in length and containing a little sphalerite, galena, pyrite, and quartz. A second outcrop of altered rock, possibly volcanic, lies on the west side of the fault some 300 feet south of the first outcrop and is about 100 feet long by 20 feet wide. It is explored by a short eastward-trending adit. Near the fault a mineralized zone 20–25 feet wide contains perhaps 10–15 percent of combined galena and sphalerite.

Both outcrops were diamond drilled by the Athletic Mining Co. in 1948–49. The outcome of later exploration is unknown, but the prospect has been abandoned since at least 1957.

### OTHER MINES AND PROSPECTS

#### ABE REED MINE

The Abe Reed mine is near the center of sec. 23 (unsurveyed), T. 5 S., R. 19 E., near the top of the southeast wall of Old Deer Creek. It may be reached by a poor road from Aravaipa. The mine is on one of the claims referred to by Ross (1925a, p. 100) as the Rawhide group.

Silicic flow breccia, tuff, and agglomerate of the Horse Mountain Volcanics are cut by a fault trending north-northeast and dipping 50°–60° E. Along the fault, a narrow breccia zone contains a little quartz. The fault is explored by a south-trending adit and an inclined shaft 60 feet deep (fig. 31). In the adit near the shaft, the fault breccia contains small pods of galena and sparse chalcopyrite. The galena is partly altered to anglesite, and the chalcopyrite to chalcocite and chrysocolla. At the south end of the adit are two small stopes where the fault contained a little galena and copper stain. Elsewhere in the adit the breccia appears to be barren.

Total production is unknown but must have been very small. In 1950 the mine produced about 185 tons of lead ore, and in 1951, 121 tons; these amounts probably represent nearly the total output of the mine.

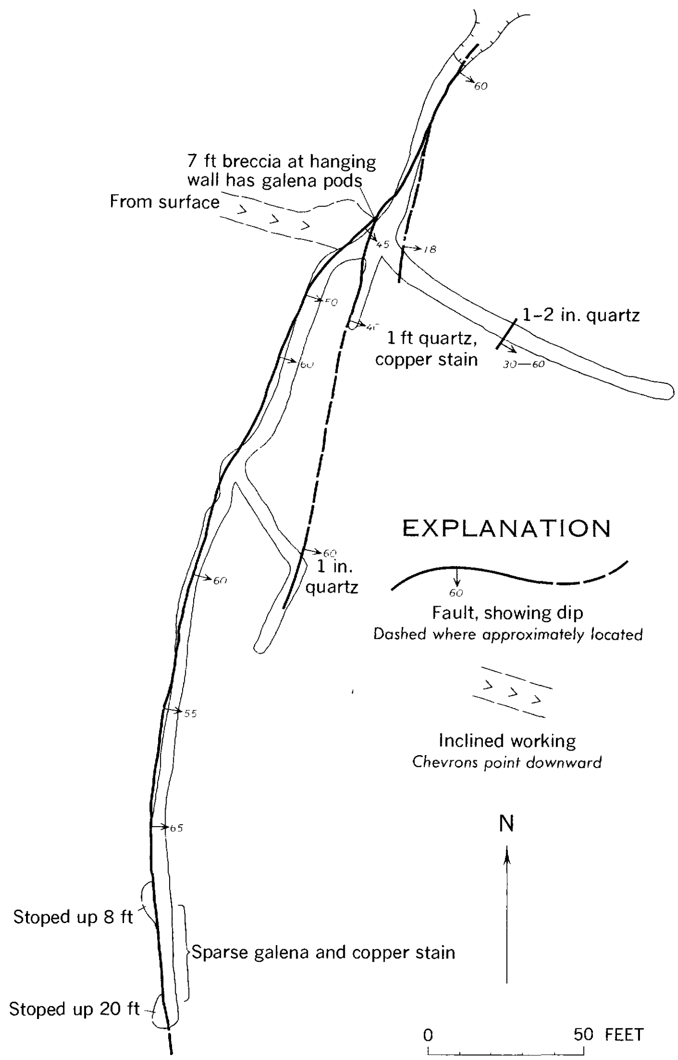


FIGURE 31.—Geologic map of the adit level of the Abe Reed mine.

#### BEN HUR MINE

The Ben Hur mine is in the SE¼ sec. 36 (unsurveyed), T. 5 S., R. 19 E., just north of the road to Aravaipa. Production prior to 1950 is reported to have been 30 tons of ore containing 30 percent lead. In 1950 the mine yielded 150 tons of ore assaying 12.5 percent lead, 2.4 percent zinc, 1.3 ounces of silver per ton, and 0.07 ounce of gold per ton (C. S. Bromfield, written communication, 1951). In 1951 the output was 107 tons of ore, and in 1952, 418 tons. Development consists of a shaft 100 feet deep, a caved shaft reported to be 115 feet deep, and short drifts. The mine was inaccessible at the time of this study.

The shafts explore a breccia along a steeply plunging trough at the intersection of two faults in Escabrosa (?) Limestone that is intruded by a rhyolite dike. Veinlets and irregular masses of galena in a gangue of quartz, fluorite, and specularite are enclosed in the breccia. The galena is largely oxidized to cerussite and anglesite.

#### COBRE GRANDE MINE

The Cobre Grande mine area is near the corner common to secs. 21, 22, 27, and 28, T. 5 S., R. 20 E., about seven-tenths of a mile north of Cobre Grande Mountain. The area may be reached from Landsman Camp over 2.5 miles of steep trail, or from Monkey Spring, Goodwin Canyon, and the valley of the Gila River over a rough and steep jeep road. Ross (1925a, p. 103) reports production of one carload of ore.

Mine workings are in a block of Escabrosa (and Horquilla?) Limestone that here and there is silicated or has irregular zones of iron oxide and sparse copper stain. Workings include an adit (the Cowboy tunnel of Ross), several other adits, one of which on the road to Monkey Spring is reported by Ross to have been 700 feet long, a shaft said to be 160 feet deep, and several bulldozer cuts made by Duval Sulphur and Potash Co. during exploration carried out in 1958–59.

The main adit trends S. 30° W., is mainly in limestone, and has about 250 feet of workings, a 30-foot winze, two 15-foot raises, and an irregular small stope, presumably along the bedding of the limestone, that dips 20° SE. A little chalcanthite coats the walls of the stope. Ross reports pyrite, chalcopyrite, a little galena, quartz, calcite, chlorite, epidote, garnet, specularite, and magnetite. The adit on the road to Monkey Spring trends N. 55° W. in Pinal Schist and is caved 180 feet from the portal, but probably reached the fault (the Cobre Grande fault, p. 112) between Pinal Schist and limestone, as Ross reports that the face was in limestone.

A bulldozer cut northwest of the main adit exposes dark-gray fetid crinoidal limestone that is irregularly and sporadically replaced near a quartz porphyry dike by chalcopyrite, iron oxide, johannsenite, chrysocolla, and malachite. A shaft south of the south end of the cut is sunk on an epidotized fault zone in limestone; the zone strikes north-northwest, dips 80°–90° W., and is about 8 feet wide. The footwall of the zone is marked by sparse copper stain. On the dump is a little massive fine-grained pyrite having a faint iridescent copper stain.

An adit at the end of the Cobre Grande mine road is driven S. 15° W. 60 feet along an irregular narrow copper-stained slip in epidotized limestone. The slip dips 45°–90° W. Malachite and chrysocolla form thin layers along the walls of the slip.

Just northwest of the main adit, a vague belt of silicated limestone 500–600 feet long and ranging in width from 10 to 70 feet has been prospected by bulldozer. The altered zone seems to trend about N. 70°–80° W. On one bulldozer terrace near the west end of the explored area, the north wall of the zone dips steeply south and the south wall more gently south, perhaps 20°–30°. Fine-grained gray limestone is irregularly replaced both along bedding and in zones that cut across bedding, by epidote, johannsenite, and locally, much yellow garnet. Some replaced beds are now solid epidote, others solid johannsenite. The altered limestone contains small amounts of chalcopyrite and its oxidation products malachite, chrysocolla, and tenorite. Chalcopyrite appears to be concentrated in narrow northwesterly-trending streaks. At its east end, across a gully from the main adit, the altered zone consists of about 10 feet of nearly solid epidote.

Altered limestone along a silicic dike has been explored by bulldozer on a low ridge west of the main adit. On the south side of the ridge the dike is 40–50 feet wide. Along its northeast side it is flanked by 15–20 feet of epidote-johannsenite rock which grades away from the dike into 20 feet or so of epidotized limestone and finally into more or less unaltered limestone. This entire area is closely faulted and the rocks are so strongly altered that the relations of dike, altered dike, and limestone are obscure.

#### COPPER BAR AND SAM JONES PROSPECTS

The Copper Bar shaft and adit are on the north side of Copper Canyon just south of the center of sec. 32, T. 5 S., R. 20 E., and the Sam Jones adit is directly opposite across the canyon (fig. 32). These workings were described by Ross (1925a, p. 92–95) as the Royal Tinto Mining and Smelting Co. group. He reports that 15 tons of picked chalcocite ore assaying 29.7 percent copper and several dollars in

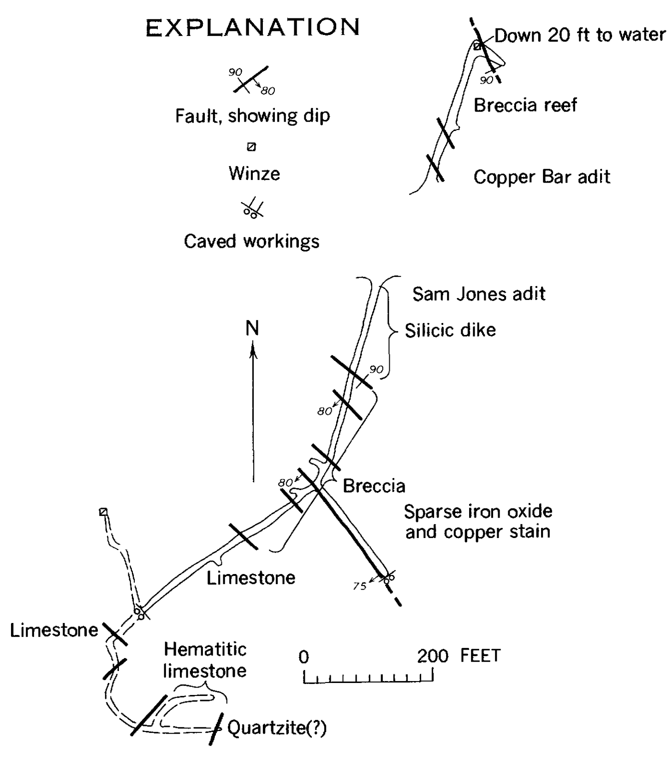


FIGURE 32.—Geologic sketch map of the Copper Bar and Sam Jones adits. Modified after Ross (1925a, fig. 8).

gold and silver was shipped in 1902. No further production is known, and both workings appear to have been abandoned for many years.

The Copper Bar workings are on a breccia reef 20–30 feet wide that cuts Pinal Schist. The reef originally may have been a rhyolite dike, as it now consists of brecciated rhyolite and Pinal Schist cemented by specularite. It contains a little pyrite and copper stain. The shaft, 6 by 8 feet in dimensions and reported to be 100 feet deep, is filled with water to within 10 feet of the surface; Ross reports that considerable chalcocite was found in the upper 25 feet of the shaft and that chalcopyrite appeared near the bottom.

What is possibly the same reef crosses a west-sloping tributary of Tule Canyon in the SE¼ sec. 29, T. 5 S., R. 20 E., where it has been prospected by a pit on the Raymond No. 1 claim.

The Sam Jones adit begins in silicic dike rock and after crossing a northwestward-trending fault enters Escabrosa Limestone and remains in limestone as far as the adit is accessible. Other than sparse iron oxide and a little copper stain, no evidence of mineralization was seen.

#### LAST CHANCE MINE

The Last Chance mine is in the SW. cor. sec. 23 (unsurveyed), T. 5 S., R. 19 E., probably on the Winthrop claim of Ross. The only recorded production is 100 tons of lead ore in 1944 and a few tons of ore in 1947. Country rock is interlayered silicic lava and tuff of the Horse Mountain Volcanics. The mine is on a breccia zone 2–3 feet wide along a fault that strikes N. 25° W. and dips 70° NE. Mine workings consist of an inclined shaft 115 feet deep and a level that starts at a depth of 90 feet and extends 190 feet to the southeast along the fault. At the collar the shaft is inclined 55°, but below a depth of 35 feet it steepens and at the bottom is inclined 70°. Along the level in the interval between 100 and 120 feet from the shaft, the fault breccia is 3 feet wide and is cut by veinlets of coarse-grained massive galena and anglesite 1–3 inches wide.

#### LEAD KING MINE

The Lead King mine is in the bottom of Stowe Gulch just above its confluence with Tule Canyon near the center of the north edge of sec. 6, T. 6 S., R. 20 E. According to the owner of the mine, Herb Hatter of Klondyke, nine carloads of ore were shipped in 1951.

The geology of the Lead King area is rather complicated, as is shown by the sketch map of figure 33. The mine itself is mostly in a small lens of Horquilla Limestone that is faulted against Pinal Schist along its northwest side and is intruded by dikes of porphyritic silicic rock and by an irregular mass of "turkey-track" andesite. The limestone is converted to garnet-epidote-johannsenite tactite at its northeast end and also to a lesser extent along contacts with dikes. Underground, some limestone is altered to highly fractured light-gray to white jasperoid that locally is a breccia. Mine workings, consisting of a short adit and a shallow winze, are shown in figure 34.

The principal ore mineral is brownish-yellow sphalerite, which veins and replaces the silicate minerals of the tactite, forms pods and veinlets with calcite in massive limestone, and to a small degree fills fractures and irregular open spaces in jasperoid. Sphalerite in tactite is accompanied by abundant specularite, whereas that in jasperoid is almost devoid of specularite. Galena is scarce except near the foot of the winze. Other minerals are a little lavender or green fluorite in fractures in jasperoid, and very sparse chalcopyrite. No clear idea could be obtained about the shape of the sphalerite bodies in the mine and the contacts with wallrocks are gradational assay walls. According to a report furnished by Herb Hatter, samples from various places on the level and in the winze assayed 5.3–10.2 percent zinc, 0.4–1.0 percent lead, and 0.2–1.4 ounces of silver per ton; the average assay was 7.7 percent zinc, 0.7 percent lead, and 0.8 ounce of silver per ton. The ore also averages 0.2 percent cadmium.

The specularite breccia reef east of the Lead King adit is about 20 feet wide and consists of sharply angular fragments of wallrock crisscrossed by a net of specularite veinlets and filmed by sparse malachite and azurite. Along its west wall the reef is flanked by an irregular body of quartz porphyry. The Aleman adit has been driven 220 feet southwest along the breccia-porphyry contact.

#### OREJANA MINE

The Orejana mine is about 1¼ miles northwest of Aravaipa in the center of sec. 26 (unsurveyed), T. 5 S., R. 19 E. No production is recorded, but a little ore may have been produced from a small stope near the end of the adit, possibly in the 1890's. Mine workings consist of a south-southeastward-trending adit nearly 700 feet long and a shaft (fig. 35). Country rock at the mine is silicic flow breccia, light-purple silicic tuff, and purple andesite of the Horse Mountain Volcanics. These rocks are cut by a steeply dipping north-northwestward-trending fault that has been traced with a fair degree of certainty for 2 miles. Slickensides on the fault surfaces at the head of the raise are nearly vertical. The Orejana vein is a breccia zone 1–4 feet wide along this fault. Most of the vein material is silicified

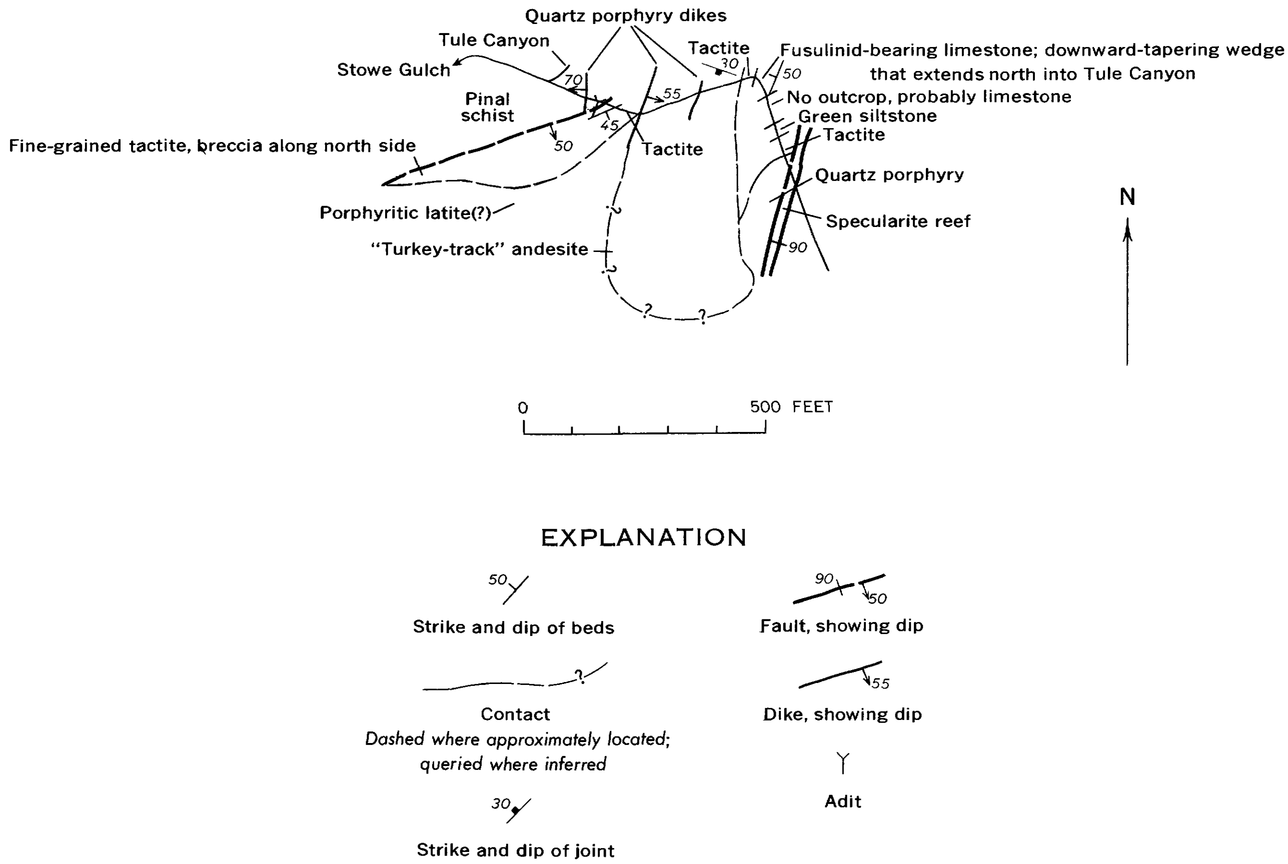


FIGURE 33.—Geologic sketch map of the Lead King mine area along Stowe Gulch.

breccia, laminated and comb quartz, amethystine quartz, chalcedony, and here and there a little galena, anglesite, chalcopyrite, malachite, and chrysocolla. On the dump of the raise, barren breccia contains a little fluorite.

#### PRINCESS PAT MINE

The Princess Pat mine is just north of Old Deer Creek in the NW¼ sec. 13 (unsurveyed), T. 5 S., R. 19 E., at the north edge of the Klondyke quadrangle. It may be reached by road from a point on old U.S. Highway 70 about 7 miles east of Coolidge Dam. The mine was described by Ross (1925a, p. 106–107), and little if any prospecting appears to have been done in the area since his examination. Ross reports that 1 ton of oxidized copper ore was shipped "from workings near the northwest corner of the property."

Rocks of the area are purple andesitic lava and tuff of the Williamson Canyon Volcanics. Lava flows just above the adit strike east and dip 25° N. The volcanic rocks are cut by a fracture zone trending about N. 20° W. and dipping steeply west, along which the Princess Pat adit has been driven. The fracture zone is as much as 6 feet wide and is stained by iron oxide and small amounts of azurite and malachite. Ross states that a little sphalerite, pyrite, chalcopyrite, and galena(?) were found along a zone 7 feet wide in a westerly-trending crosscut 320 feet from the portal of the adit.

Mine workings include a main adit, now flooded and inaccessible, reported by Ross to be 870 feet long and as having two crosscuts to the west each 120 feet long and a third crosscut to the east 70 feet long, and several small opencuts on the hillside above the adit. In addition to the underground workings, a concrete tank 60 feet long and 20 feet wide for leaching oxidized copper ore, a second tank 55 feet long and 3 feet wide for precipitation of cement copper using scrap iron, and a large concrete water storage tank were built, apparently fairly recently, near the portal of the adit; neither the leaching nor precipitation tank appears to have been used to any extent.

#### SINN FEIN MINE

The Sinn Fein mine is near and at the end of the Williamson Canyon road, on the line between secs. 19 and 30, T. 5 S., R. 20 E. It is a short distance west and southwest of the Head Center mine. According to

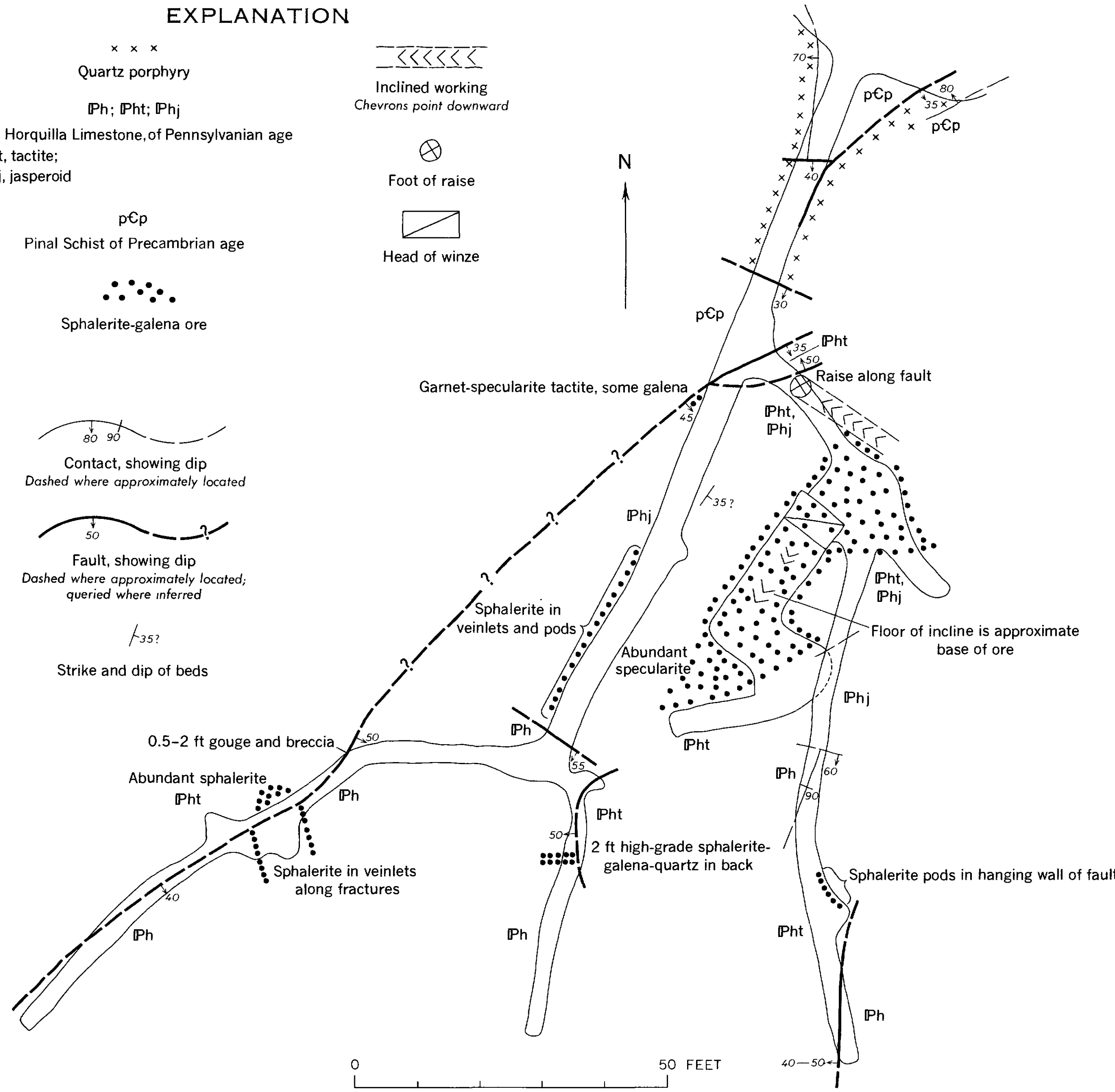


FIGURE 34.—Geologic map of the Lead King mine.

Ross (1925a, p. 100), three carloads of ore had been shipped prior to 1925. During the period 1947–53, the Sinn Fein mine produced the following amounts of lead ore: 1947, a few tons; 1948, 1,021 tons; 1949, 2,524 tons; 1950, 1,538 tons; 1951, 1,868 tons; 1952, 824 tons; 1953, 440 tons. Ore produced during the period 1950–52 assayed about 17 percent lead, 1.3 percent copper, 2.3 ounces of silver per ton, and 0.2 ounce of gold per ton.

Mine workings consist of two separate groups, an adit, winze, and winze level 50 feet below the adit that will be referred to as the old Sinn Fein mine, and the principal inclined shaft and levels of the new Sinn Fein mine, a few hundred feet north of the old mine. The new workings were extended in 1957 by the Balboa Mining and Development Co., of Grand Junction, Colo., but little ore was shipped. An inclined shaft 50 feet deep was sunk opposite the portal of the old workings in 1958–59.

The old workings are along a faulted contact between Horquilla Limestone to the east in the hanging wall and a latite(?) dike to the west (fig. 36). The fault

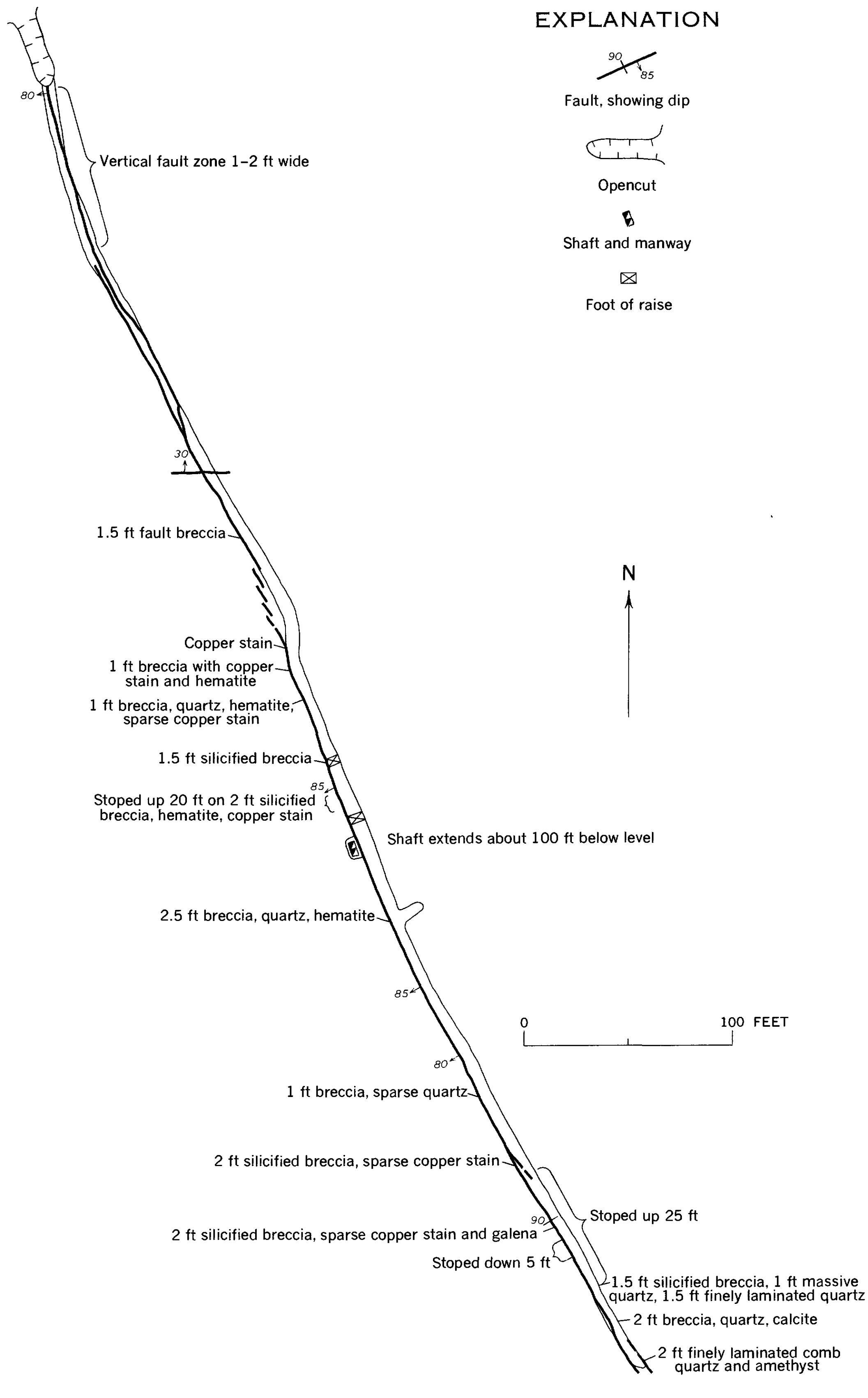


FIGURE 35.—Geologic map of the Orejana adit.

strikes slightly west of north and dips 45°–60° E. It is marked by a breccia vein 1–4 feet thick containing sparse quartz, iron oxide, and galena, and traces of chalcopyrite and purple fluorite. The breccia is cut off near the north end of the adit by a northwestward-trending steeply dipping fault, but appears to be repeated for a short distance on the lower level.

Minerals on the dump include, in addition to those already noted, abundant anglesite, some cerussite, and sparse azurite, malachite, and chrysocolla.

A little ore has been stoped between the adit and winze levels, but production must have been very small.

The incline across Williamson Canyon from the old workings is sunk 50 feet on a fracture zone in Horquilla Limestone just above the base of the formation. The fracture strikes north and dips 50°–65° E., about parallel to the fault in the old Sinn Fein workings, and has a little quartz along it.

The new or inclined shaft workings of the mine, on the main Sinn Fein vein, are shown in figure 37. The vein is along the Head Center fault, which in the mine strikes slightly north of west and dips 30°–45° N. throughout most of the mine; it flattens somewhat at the bottom of the shaft and swings to a more northerly strike. The fault is in general a contact between Horse Mountain Volcanics and Horquilla Limestone, but near the Head Center and Sinn Fein mines it is intruded by a dike of porphyritic dacite or quartz porphyry, and in the Sinn Fein mine the only rock recognized was either altered silicic dike rock or volcanic rock.

The main Sinn Fein vein consists of from a few inches to as much as 8 feet of gouge that near the hanging wall contains veinlets of galena, sphalerite, quartz, fluorite, specularite, and sparse pyrite and chalcopyrite. Locally the ore has vugs lined with quartz crystals. Much of the ore mined from the main stope appears to have been oxidized, and anglesite is abundant throughout the upper part of the mine. Wulfenite is fairly common as small crystals in open spaces in the upper parts of the mine.

#### TULE MINE

The mine workings referred to collectively in this report as the Tule mine are just east of Tule Spring in the SE¼ sec. 31, T. 5 S., R. 20 E. The area is at the junction of the Tule Spring and Tule Canyon faults and is one of intricate small-scale faulting involving quartz porphyry dikes, Horse Mountain Volcanics, Escabrosa(?) Limestone, and Pinal Schist. Although several prospect adits and shafts have been driven, the only working of consequence is an inclined shaft sunk in 1957 on the intersection of a fault striking east, dipping 55° N., and believed to be a branch of the Tule Spring fault, with a very slightly mineralized fault within the Tule Canyon breccia reef, striking N. 45° E. and dipping 70° NW. The incline was inaccessible at the time of this study, but traces of galena were found on the dump.

Other prospect workings in the vicinity appear to be barren. These include a shaft 30 feet deep on the Tule Canyon breccia reef 900 feet north-northeast of the incline, a 30-foot shaft 250 feet southeast of the incline in Laurel Canyon Granodiorite, an adit 80 feet long in altered limestone immediately east of Tule Spring, and a flooded adit in purplish-gray welded tuff of the Horse Mountain Volcanics in the Tule Canyon about 500 feet north of the spring.

#### MISCELLANEOUS PROSPECTS

A few small and for the most part nameless prospects near Aravaipa will be described briefly, in approximate geographic order from northwest to southeast.

Just south of Old Deer Creek and east of the north-trending fault in the center of sec. 18, T. 5 S., R. 20 E., a shallow pit in sandstone of the Pinkard Formation shows a little malachite and azurite derived from chalcopyrite. No structure is now exposed in the pit, which is mostly caved.

The Green Gem claim is on the ridge near the center of the line between secs. 17 and 20, T. 5 S., R. 20 E. The rock of the area is garnetite derived from Horquilla (and Escabrosa?) Limestone. The metal or metals believed to be present were not mentioned in the claim notice.

The fault contacts of the small outcrop of Horquilla Limestone in the SE. cor. sec. 23 (unsurveyed), T. 5 S., R. 19 E., have been prospected by three shafts 20–60 feet deep. No ore was found.

Several small prospects are in the NE¼ sec. 25 (unsurveyed), T. 5 S., R. 19 E. A conspicuous silicified zone shown on the geologic map as a fault in Horse Mountain Volcanics in the northeast corner of the section has been explored by an opencut and inclined shaft on the Silver Reef claim. The zone strikes N. 20° W. and dips steeply east. It is as much as 8 feet wide and consists mainly of rock fragments having crusts of quartz, and vugs lined with quartz crystals. In the shaft a vein 4 inches wide of crustified quartz-galena ore lies along the silicified zone. On the hill above the shaft, the silicified zone is 8 feet wide and has a vein of finely crustified quartz 4 feet wide in the footwall.

The fault along the east side of the small outcrop of Horquilla Limestone near the center of the NE¼ sec. 25 is explored by a shaft inclined 65° S. 80° W.

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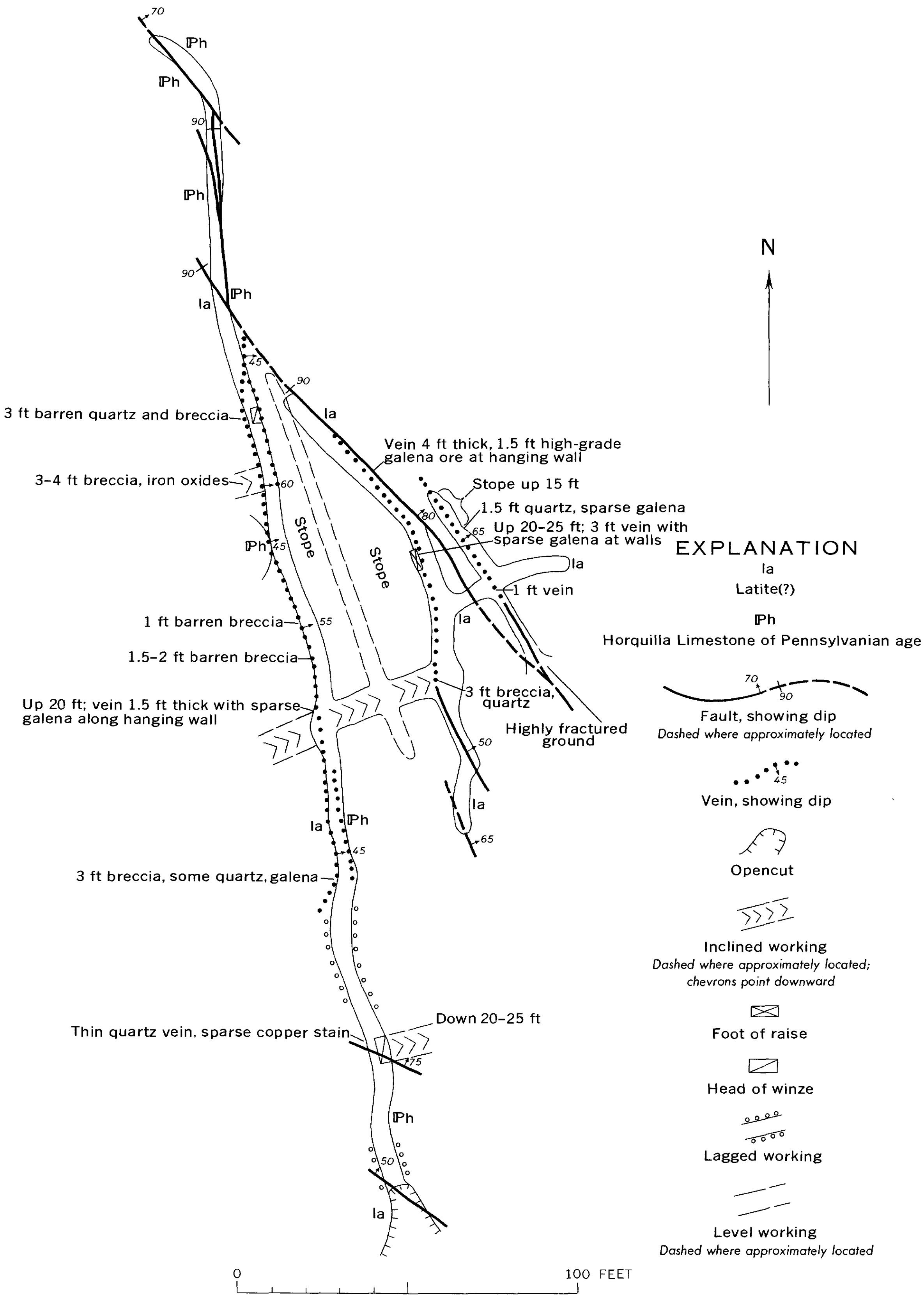


FIGURE 36.—Geologic map of the old Sinn Fein mine workings.

A little rusty quartz and galena were found. About 500 feet farther west, an inclined shaft and pit explore a quartz-amethyst vein 1–2 feet wide, striking N. 5° W. and dipping 75° W. The vein has a core of amethyst, flanked locally by thin layers of galena. The size of the dump indicates that the shaft and other possible workings are several hundred feet in extent.

A shaft 20 feet deep and a pit on the ridge just north and west of Williamson Canyon in the NW¼ sec. 30, T. 5 S., R. 20 E., are along a fracture in Horquilla Limestone. The fracture strikes N. 50° W., dips 80° SW., and has along it a little quartz, amethyst, galena, malachite, chrysocolla, and wulfenite. According to an old claim notice, the workings are on the Booker T. Washington claim.

A layer of brecciated jasperoid in Escabrosa Limestone in the center of the N½ sec. 30, T. 5. S., R. 20 E., 2,000 feet southeast of the Head Center mine, has been explored by an inclined shaft about 60 feet deep and an open stope 75 feet long. The breccia strikes N. 55° W., dips 65° NE., and has a strike length of

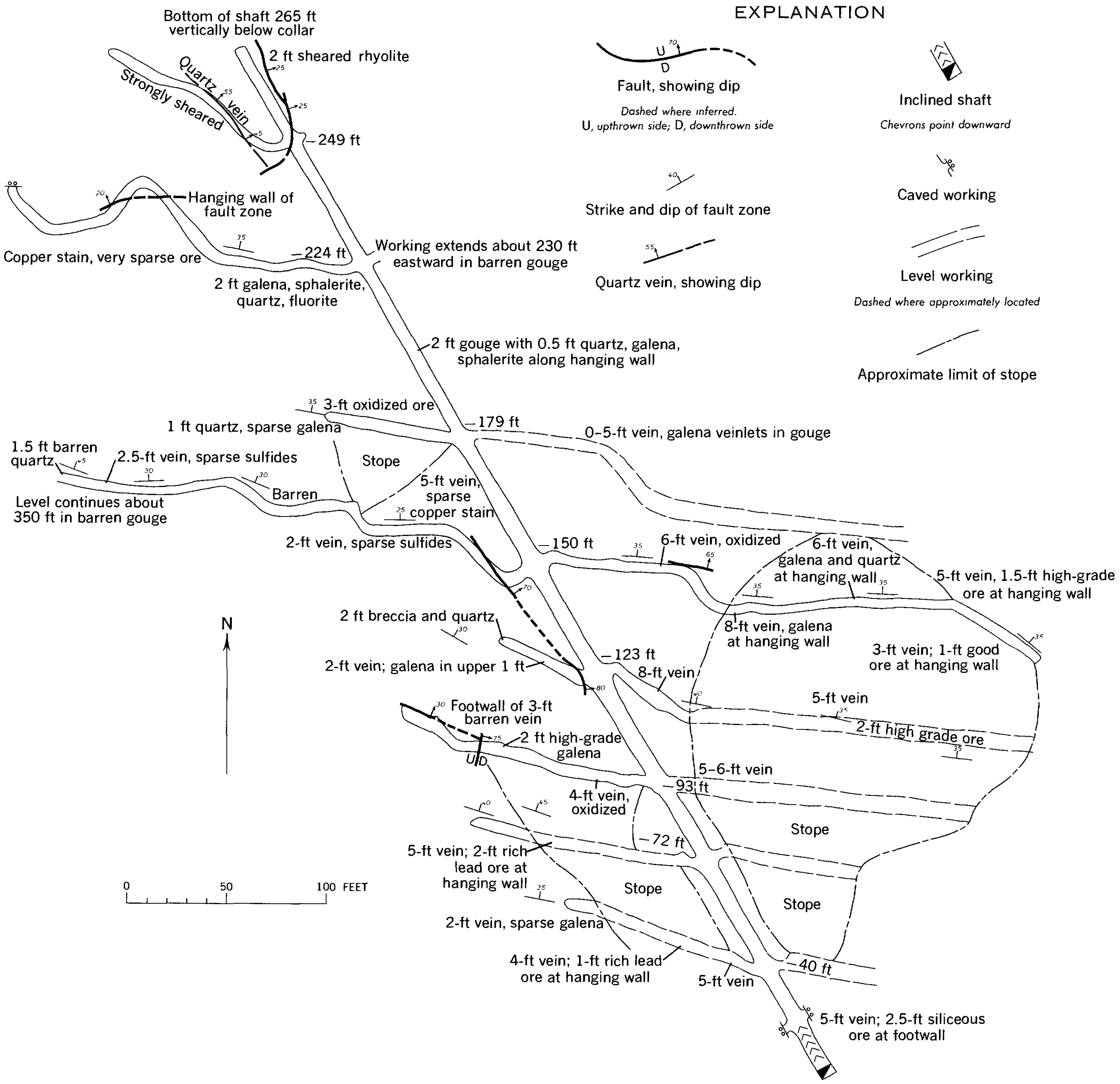


FIGURE 37.—Geologic map of the inclined shaft workings of the new Sinn Fein mine.

perhaps 500 feet. On the top of the ridge west of the prospect, the breccia is 10–12 feet wide, but to the west it narrows and at the shaft is 4 feet wide. Except for a little quartz in vugs, the breccia is made up entirely of fragments of jasperoid in a jasperoid matrix. At the prospect, open spaces in the breccia are filled with quartz, a little brownish-gray calcite and purple fluorite, and sparse galena, malachite, chrysocolla, chalcopyrite, and chalcocite. Tiny plates of wulfenite line vugs.

Several prospects are at or near the contact between Bolsa Quartzite and the Martin Formation or between Martin and Escabrosa Limestone on the crest and west side of the ridge south of the Iron Cap mine in the NE¼ sec. 30, T. 5 S., R. 20 E. These prospects may be on the Ionia claim. On the crest of the ridge, a shallow pit explores a small outcrop of limestone replaced in part by johannsenite. Just below the crest to the west, a little high-grade galena-anglesite-quartz ore is on the dump of a caved adit. This ore also contains a little wulfenite and copper stain. An adit farther below begins in the Martin Formation that strikes N. 80° E. and dips 50° N.; the adit trends S. 60° E. and is caved near the portal. The lowest adit, just above the bottom of the canyon west of the ridge, is partly caved. On the dump are altered limestone partly replaced by johannensite, sphalerite, chalcopyrite, a little pyrite, and sparse copper stain.

A body of massive specularite-garnet of unknown size, having a little copper stain, has been prospected at a place five-tenths of a mile north-northeast of Landsman Camp in the NW¼ sec. 29, T. 5 S., R. 20 E. Country rock is Escabrosa Limestone.

A vaguely defined zone of alteration in the small outcrop of oolitic Escabrosa Limestone along and north of the road between Aravaipa and Tule Spring in the SE¼ sec. 25 (unsurveyed), T. 5 S., R. 19 E., has been prospected by several pits. The zone trends about N. 75° E. and is 3–5 feet wide. Along it the limestone is replaced by a little galena, pale yellow-green sphalerite, amethystine quartz, and coarse-grained calcite.

Several pits have been dug along a fault between Escabrosa Limestone and Bolsa Quartzite in the NE¼ sec. 36 (unsurveyed), T. 5 S., R. 19 E. The fault seems to strike about N. 60°–70° E. and may dip to the northwest. Breccia along the fault has vugs containing quartz, a carbonate mineral that may be ankerite, a little galena, and pale greenish-yellow sphalerite, and probably some pyrite.

A prospect near the center of the south edge of sec. 32, T. 5 S., R. 20 E., consists of two shallow inclined shafts on a fault in Bolsa Quartzite. The fault strikes east and dips 50°–75° N. It is marked by sparse copper stain.

An adit 120 feet long and a crosscut 210 feet long have been driven into the steep hillside between Stowe Gulch and the point where the road to Landsman Camp joins the Klondyke-Aravaipa road (NW¼ sec. 6, T. 6 S., R. 20 E.). Wallrocks are metasedimentary rocks or metatuff of the Pinal Schist. The adit is along a gouge-filled fracture that strikes northwest and dips steeply southwest. No ore was seen in the adit, but a little copper stain appears in an opencut just above the adit.

### GRAND REEF GROUP

Most of the mines and prospects to be described in this section are along or near the Grand Reef fault between Imperial Mountain and Klondyke Wash. The Silver Coin mine is probably half a mile east of the fault, and a few insignificant prospects are well east of the fault in Pinal Schist. Mines will be described in geographical order, from north to south.

#### WINDSOR MINE

The Windsor mine is on the northeast flank of Imperial Mountain about halfway between Stowe Gulch and the summit of the mountain. The shaft collar is on the Imperial Mountain road. The mine was described by Ross (1925a, p. 89–91, fig. 7) as part of the Bullis group of claims. No production is recorded.

The mine is on the northwest branch of the Grand Reef fault, which here strikes northwest, dips steeply southwest, and has Horse Mountain Volcanics in the southwest wall and Bolsa Quartzite in the northeast wall. Mine workings explore a short segment of the breccia reef along the fault (fig. 38). The reef consists mainly of brecciated wallrock, quartz, and very sparse copper stain. Galena, anglesite, and a little fluorite, quartz, and malachite make up a small pod in the breccia just southeast of where the shaft penetrates the adit level. Galena may have selectively replaced certain breccia fragments. No other sulfide was seen. Quartz in part is late and veins galena. Ross reports cerargyrite, tenorite, covellite, and chalcocite from the shaft. He also reports results of an earlier sampling of reef material; in the shaft, the lead content ranged from a few tenths of 1 percent to more than 9 percent, the silver content averaged less than 15 ounces per ton, and the copper content was 0.14 percent, and in the drift southeast of the adit the silver content was 0.94–2.42 ounces per ton.

An audit about 1,000 feet northwest of the Windsor adit may be on the May Tustin claim. Mine workings are entirely in igneous rock, probably volcanic

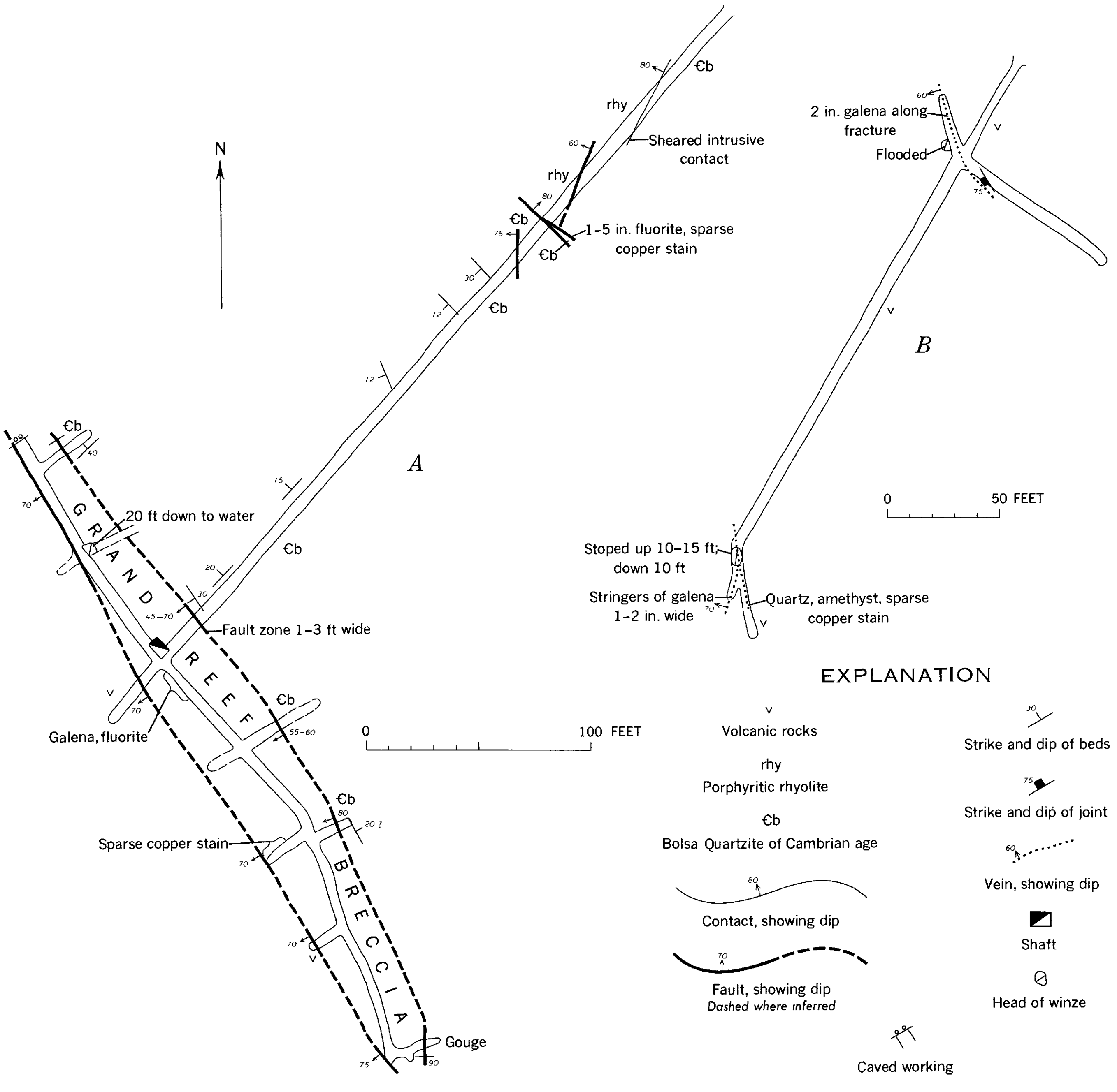


FIGURE 38.—Geologic maps of underground workings in the Windsor mine area. *A*, Adit level of the Windsor mine. *B*, Adit on the May Tustin(?) claim.

for the most part although some may be dike rock. Mine workings are shown in figure 47*B*. The veins are fracture zones having thin stringers of quartz, amethyst, and galena.

Several other shafts and adits penetrate Imperial Mountain; some along the Grand Reef were noted in the description of that structure (p. 109), and others are inaccessible or provide no evidence of mineralization.

#### PROSPECTS BETWEEN IMPERIAL MOUNTAIN AND THE TENSTRIKE MINE

Between Imperial Mountain and the Tenstrike mine, the Grand Reef has been prospected at several places.

In the SW. cor. sec. 8, T. 6 S., R. 20 E., a shaft now flooded is sunk on a breccia zone at least 20 feet wide.

Two prospects on the Grand Reef are in the SW¼ NW¼ sec. 17, half a mile northwest of the Tenstrike mine. At the northwestern prospect, the reef strikes N. 30° W., dips 75° SW., and is explored down the dip for 40 feet. The hanging wall is a dike of porphyritic rhyolite 25 feet wide, the footwall is dark-brown hematitic breccia containing fragments several inches across. A little chrysocolla is the only ore mineral seen. The southeastern prospect is a series of shallow pits on highly silicified hematitic breccia that has only very sparse copper stain.

#### TENSTRIKE MINE

The Tenstrike mine is in the SW¼ sec. 17, T. 6 S., R. 20 E. It may be reached from Aravaipa Valley over a rough truck road. Mine workings consist of several short adits, a shaft 120 feet deep, and an opencut south of the shaft. Ross (1925a, p. 88) says that probably a few carloads of ore had been shipped from this and contiguous claims. The only subsequent production reported is 311 tons of lead ore in 1942 and a few tons of ore in 1952; the workings now accessible give no evidence of appreciable production.

The Tenstrike shaft is sunk on a strong gougy fracture along the Grand Reef, striking N. 20°–25° W. and dipping 75° W. to 85° E. No ore was seen. In the canyon to the southeast of the shaft, an adit 120 feet long is driven S. 70° W. through the Grand Reef to the southwest wall, which is a fault striking N. 35°–45° W. and dipping 85°–90° SW. Along the fault is 1.5–2 feet of banded amethystine quartz and ground-up rock. The northeast wall of the Grand Reef has about 10 feet of gouge and breccia along it. No sulfide minerals were seen anywhere in the adit.

A second adit south of the first is driven N. 5° W. 45 feet along a barren fault in the Grand Reef breccia. The fault dips 70°–75° W.

The location of the Aravaipa shaft mentioned by Ross (1925a, p. 79) could not be ascertained definitely; it may be the caved shaft a short distance north of the Tenstrike shaft. Ross reports that the shaft was less than 100 feet deep and was connected to the Tenstrike mine by about 500 feet of drifts.

#### PROSPECTS BETWEEN THE TENSTRIKE AND GRAND REEF MINES

Between the Tenstrike and Grand Reef mines, the Grand Reef has been explored unsuccessfully at several places.

In the center of sec. 20, T. 6 S., R. 20 E., a shaft has been sunk on a fracture zone in Laurel Canyon Granodiorite 100 feet northeast of the Grand Reef fault. The fracture strikes N. 15° W., is vertical and has along it a little azurite, chrysocolla, and malachite. The shaft is filled with water to within 50 feet of the collar. Below the shaft, an adit has been driven in a N. 10° W. direction in granodiorite.

In the SW¼ sec. 20, another shaft 80–100 feet deep was sunk in greenish-gray altered Laurel Canyon Granodiorite near the Grand Reef fault. The shaft is probably on the Alto No. 3 claim, formerly the Copper Prince claim of the Tenstrike group (Ross, 1925a, p. 88). It is inclined 80°–85° in a S. 35° W. direction and apparently is entirely in barren granodiorite.

#### GRAND REEF MINE

The Grand Reef mine is in Laurel Canyon in the NE¼ sec. 29, T. 6 S., R. 20 E. It was formerly accessible by truck but the road is now in very bad condition above Waterfall Canyon. The mine has been described by Ross (1925a, p. 78–85) and Wilson (1950, p. 60–62). It was one of the largest producers of the Aravaipa district, probably second only to the Head Center mine.

The Grand Reef mine was developed in the 1890's but apparently no ore was shipped until 1915. For the period 1915–20, Ross reported that about 30,000 tons of ore was mined to yield 1,389 tons of crude shipping ore and 2,613 tons of concentrate. The crude ore had an average assay of 40.9 percent lead, 2.83 percent copper, 1.4 percent zinc, 20 ounces of silver per ton, and traces of gold. The mine appears to have been inactive from 1921–29. Most of the production shown for the period 1929–31 in table 7 came from the Grand Reef mine (Wilson, 1950, p. 56). According to the Minerals Yearbooks, most of the production from the Aravaipa district in 1939, 1940, and 1941 was also from the Grand Reef mine. No production has been recorded since 1941. In summary, the Grand Reef mine appears to have produced about 40,000 tons of ore that may have averaged about 8–9 percent lead, 1–2 percent copper, and 7 ounces of silver per ton (Ross, 1925a, p. 83).

The Grand Reef deposit is developed by an adit about 1,200 feet long (fig. 39), an interior shaft extending 300 feet below the adit level, and levels off the shaft at 100-foot intervals; Ross estimates the total length of workings at more than 4,000 feet. At present the shaft is flooded below a level (the 55-foot level of Ross?) some 70 feet below the adit level. The main ore shoot has been stoped for 200 feet above and at least 70 feet below the adit level, and other stopes, now backfilled or caved, are west of the main stope (the No. 3 stope of Ross) and 500–900 feet north of the main stope.

The Grand Reef at Laurel Canyon rises spectacularly above the canyon as a nearly vertical sheet of silicified breccia as much as 150 feet wide, striking just west of north. Laurel Canyon is a very narrow

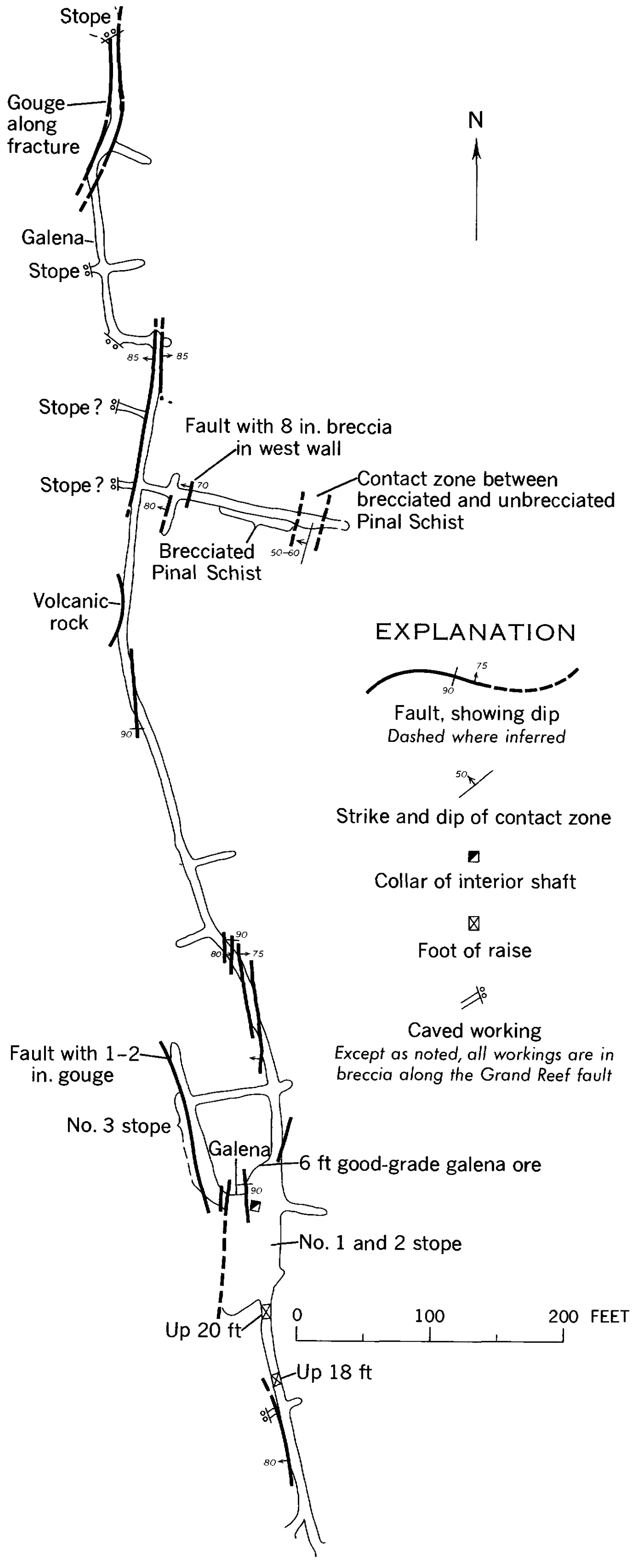


FIGURE 39.—Geologic map of the adit level of the Grand Reef mine.

notch where it crosses the Grand Reef. The Grand Reef mine workings are all north of the canyon.

The reef breccia consists of various-sized angular fragments of Pinal Schist in a matrix of silicic dike rock and quartz. So little ore is left in the accessible parts of the underground workings that not much is known about the occurrence of the ore minerals within the breccia, but apparently the breccia is replaced locally by massive galena. Specks of galena, sphalerite, and chalcopyrite also are disseminated in a granular quartz-fluorite breccia matrix. Pyrite appears to be scarce. Supergene minerals include considerable anglesite and minor cerussite, malachite, azurite, and chrysocolla. The only hypogene gangue minerals of consequence are quartz and fluorite.

The main ore shoot is reported by Ross to have a stope length of 120 feet and a width of 15–30 feet or more on the adit level. At a distance of 70 feet below the adit level, the main stope is 40–50 feet long and 10–15 feet wide and has a clearly defined north-striking vertical fracture along its west wall. The No. 3 stope extends from 30 feet below the adit level nearly to the surface and has a stope length of 60 feet and a width of 3 feet. Sizes of the other stopes are not known, but that near the north end of the adit may have been as much as 200 feet long. Wilson (1950, p. 62) also reports a stope on the 200-foot level south of the shaft.

### DOGWATER MINE

The Dogwater mine is in an east branch of Laurel Canyon in the NW. cor. sec. 33, T. 6 S., R. 20 E. It was described briefly by Ross (1925a, p. 79, 85, fig. 4). The only production reported is an unknown part of 117 tons of mixed ore from the Grand Reef, Aravaipa, and Dogwater mines in 1920, and the size of the workings indicates that only a small amount of ore could have been produced.

Mine workings consist of an adit 190 feet long, driven S. 10°–25° E. on a vein along a fault of the Grand Reef structure, and a stope to the surface in the interval between 110 and 160 feet from the portal. The vein dips 80°–90° SW. In the face of the adit, the vein structure is 4–5 feet wide, and the vein consists of silicified fault breccia containing galena concentrated in small bunches in a layer 6–8 inches wide along the southwest wall or disseminated in silicic gangue. Gangue minerals are quartz, chalcedony, and purple to white fluorite. Supergene minerals include anglesite, cerussite, and a little malachite, azurite, chrysocolla, and plumbojarosite. Wulfenite in veins as much as an inch thick and in vugs is sufficiently abundant to suggest that it may be a hypogene mineral; no source of the molybdenum is apparent, galena being the only sulfide mineral seen.

A second adit 250 feet north-northeast of the main adit and possibly on the Silver Cable claim is caved 50 feet from the portal. Ross (1925a, p. 79) stated that the adit is a few hundred feet long, and has stopes above. The adit trends southeast along a fault zone between Santa Teresa Granite and Pinal Schist; the fault zone dips steeply northeast. Near the fault, the Pinal is cut by several narrow fine-grained gray porphyritic dikes that trend about parallel to the fault. Over a width of as much as 3 feet the zone is marked by veinlets of quartz carrying a little copper stain, flecks of galena, and some anglesite and cerussite; the largest quartz vein is about a foot across, and a few anglesite veins are as much as an inch across.

### JUNCTION PROSPECT

A prospect on the Grand Reef fault north of Waterfall Canyon in the center of the N½ sec. 33, T. 6 S., R. 20 E., is believed to be on the Junction claim. Country rock includes Pinal Schist, silicic dikes, and breccia of the Grand Reef fault; a section along the south side of the gulch in which the prospect is located is shown on figure 40. A specimen of the more westerly vein consists mostly of finely crustified quartz and fluorite with a little carbonate, hematite, barite, and galena. These minerals are cut by late quartz veins.

### LACLEDE MINE

The Laclede mine is in a branch of Klondyke Wash just north of the center of sec. 10 (unsurveyed), T. 7 S., R. 20 E. It was described by Ross (1925a, p. 86), who said that a production of three carloads of ore (copper-silver?) had been reported.

The mine is in blue-green fine-grained amygdaloidal and scoriaceous andesite of the volcanic member of the Buford Canyon Formation; the volcanic rocks rest on the conglomerate member just northeast of the mine. The country rock is cut by many fractures that trend N. 10°–50° W., dip 55°–80° NE., and are filled with epidote. According to Ross, the mine is on a nearly vertical vein that strikes about east.

On the northwest side of the gulch, an adit 40 feet long trends N. 10° W. and connects to a shaft 30 feet deep; and on the southeast side of the gulch is a second, flooded shaft. A very small amount of chrysocolla is on the dump of the first shaft. Ross cites reports of native silver and of assays very high in silver.

### SILVER COIN MINE

The Silver Coin mine is in the south branch of Klondyke Wash in the SW¼ sec. 11 (unsurveyed), T. 7 S., R. 20 E. The mine was described by Ross (1925a, p. 87), who reported that small lots of ore had been shipped up to 1925. The only recorded production since then is an unknown tonnage in 1947.

The Silver Coin vein is along a fault between a small plug of biotite quartz latite(?) to the north and the volcanic member of the Buford Canyon Formation to the south. The fault strikes N. 70° E., dips steeply north, and has been traced along the strike for about 700 feet; it may be a southwesterly extension of the Quartz Hill fault (p. 106). Wallrock exposed along the south side of the vein on the adit level and also in both walls on the lower level is believed to be a fault sliver of Pinal Schist. At the portal of the adit, the latite has a dark chilled selvage 3 feet wide against Pinal Schist, indicating that the fault may be nearly along the original intrusive contact. The vein has been explored by a shaft 105 feet deep, an adit connecting with the shaft, and a level 40 feet below the adit level. Geologic maps of the two levels are shown on figure 41.

The vein consists mainly of silicified brecciated wallrock. The south wall of the vein commonly is well defined, whereas toward the north wall the breccia passes gradually into massive rock. Along the adit level, most of the vein is low grade or barren

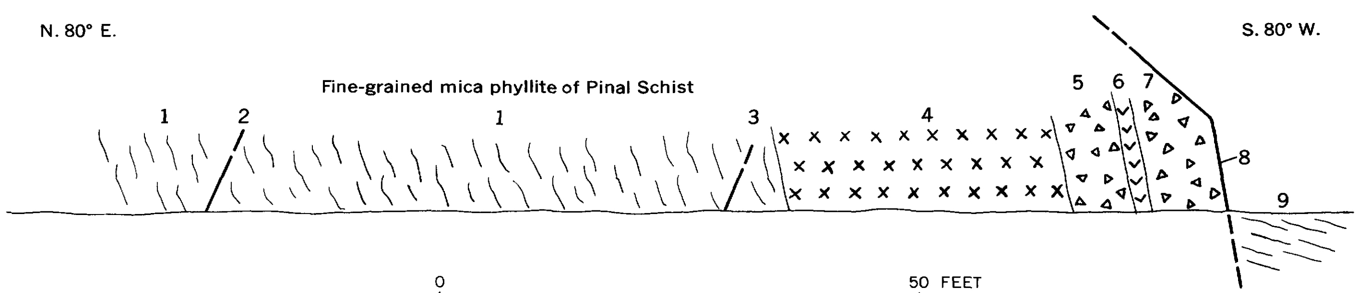


FIGURE 40.—Sketch of geologic section along south side of gulch, Junction prospect, looking about south. 1, Pinal Schist: fine-grained mica phyllite. 2, Vein; hard quartz-galena-anglesite 5–10 inches wide; very low grade. 3, Vein; finely banded quartz-fluorite-carbonate-galena 10–12 inches wide; very low grade. 4, Gray fine-grained porphyritic rhyolite dike. 5, Green fine-grained breccia; some rhyolite, some may be Pinal. 6, Light grayish-green altered porphyritic latite(?) breccia. 7, Red breccia; footwall has finely banded chalcedony or opal. 8, Hanging wall of Grand Reef fault. 9, Horse Mountain Volcanics; not exposed at gulch level.

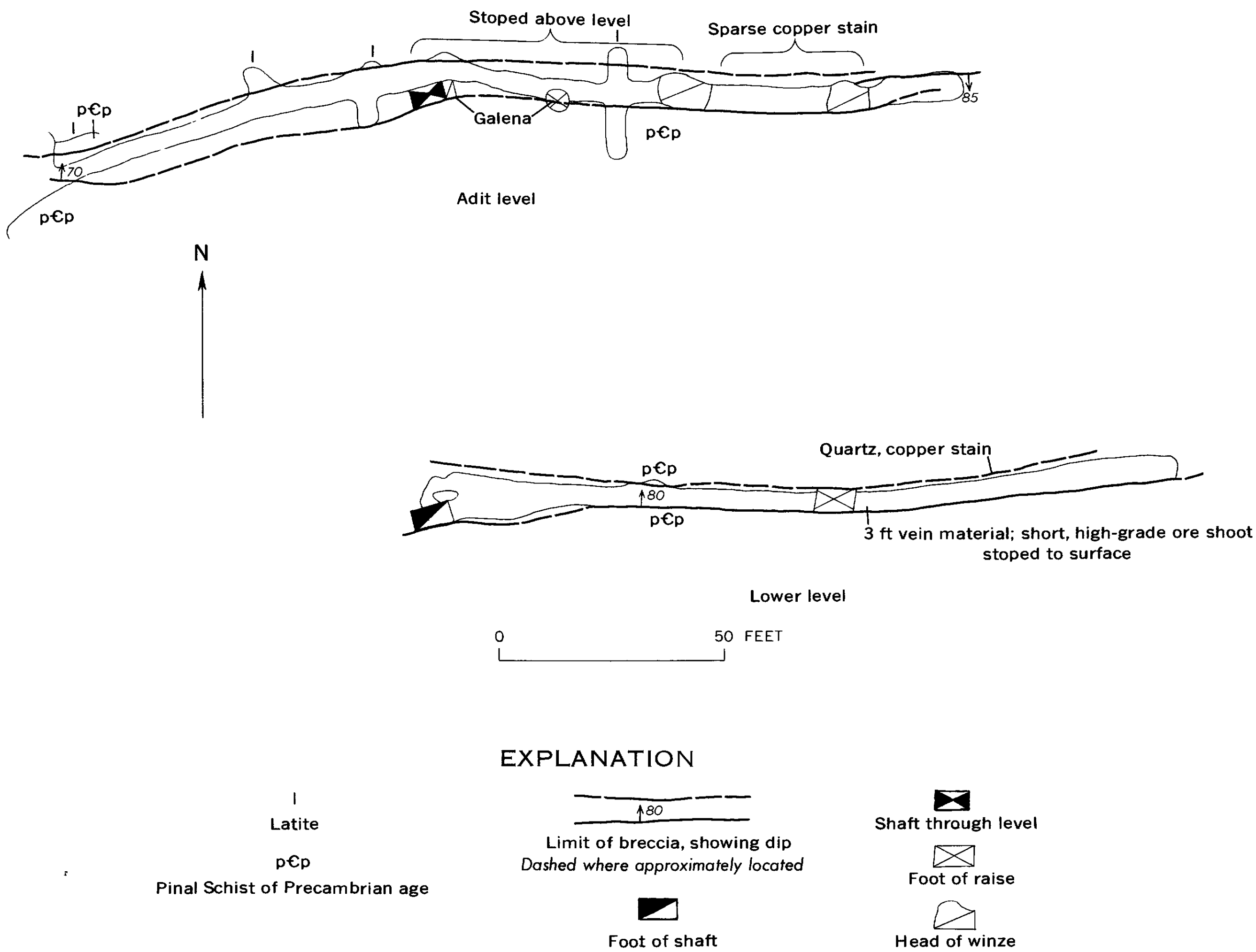


FIGURE 41.—Geologic maps of the adit and lower levels, Silver Coin mine.

except for streaks along the south wall a few inches wide that have considerable galena, the only sulfide mineral seen. Other minerals include anglesite, cerussite, plumbojarosite(?), wulfenite, and sparse copper stain.

A prospect 1,300 feet northeast of the Silver Coin mine explores a barren fault between volcanic rocks to the north and slightly silicified volcanic rocks to the south. The fault strikes N. 65° E., dips 85° NW., and may be a continuation of the Silver Coin fault.

### PROSPECTS IN PINAL SCHIST

Several small showings of supergene copper minerals have been prospected in the large outcrop area of Pinal Schist at the head of Spring Canyon and Klondyke Wash.

In the SW¼ sec. 34, T. 6 S., R. 20 E., three prospect pits 400 feet apart along a line trending about northeast expose small amounts of chrysocolla, calcite, and quartz. In the most southwesterly pit, these minerals seem to be in a pod trending about N. 60° E., roughly parallel to the regional trend of the Pinal; in the other pits no structure is visible.

In the SE¼ of the same section, sparse copper stain is exposed in a caved adit.

A shallow pit in the SW¼ sec. 2, (unsurveyed) T. 7 S., R. 20 E., has a little copper stain in chloritic Pinal Schist along a structure that seems to trend about N. 70° W.

A narrow fracture zone in quartzite schist of the Pinal has been prospected in the NE¼ sec. 13, (unsurveyed) T. 7 S., R. 20 E. The vertical fracture strikes N. 75° W., and has been explored by a crosscut adit 30 feet long that trends N. 30° E. along the vertical schistosity of the country rock, and by a winze 25–30 feet deep. About 40 feet west of the adit, the quartzite schist is intruded by diabase. Some rusty quartzite and a few pounds of chrysocolla and malachite are on the dump.

## TABLE MOUNTAIN-FOURMILE CREEK GROUP

Several small copper prospects and one old copper mine lie along a broad belt that extends southeast from the Table Mountain mine and Little Table Mountain to the Left Prong of Fourmile Creek and is underlain principally by the lower andesite unit of the Galiuro Volcanics. The division between this group of mines and prospects and those of the Copper Creek area is taken arbitrarily to be the southwestern limit of the andesite unit. Claim notices were found at a few prospects, but most are nameless. Mines and prospects will be described in geographical order from northwest to southeast.

### TABLE MOUNTAIN MINE

The Table Mountain mine is on the west side of Virgus Canyon in the SE¼ sec. 15 and the NE¼ sec. 22, T. 7 S., R. 18 E., about 1¼ miles north-northeast of Little Table Mountain. The mine may be reached over a fair truck or jeep road from the valley of the San Pedro River near the mouth of Aravaipa Creek, or by way of a very rough jeep road that branches off the Turkey Creek road in sec. 32, T. 6 S., R. 19 E. The mine area is covered by 12 patented claims, 11 of which are shown on figure 42. The Table Mountain No. 1–10 claims are owned by Mollie Morgan, Evelyn Sandstrom, and Mattie Young, of Mammoth, and the Grand Duke and Louisville claims by Marion Gillis, address unknown.

No description of the mine has been published, and the following historical data, as well as the claim map, are taken from several private reports kindly made available to me by Mrs. Young.

The Table Mountain ore deposits were first prospected in the late 1870's for gold. During 1898–1900, a road was built from Klondyke, a small crushing and smelting works constructed, and a little copper-gold ore smelted; the size of the slag pile suggests that only a few hundred tons could have been smelted, and the very high silica content of the ore together with the nearly total lack of sulfide minerals must have posed serious smelting problems. According to one report, development work of the period totaled 2,000 feet of adits and drifts from which about 100,000 tons of ore containing 7–9 percent copper and $4 per ton in gold was mined. Production prior to 1928 is estimated at 400–600 tons of crude ore assaying more than 14 percent copper. Ore on the dump at present assays 2–3 percent copper, 0.5–0.6 ounce of silver per ton, and 0.14–0.15 ounce of gold per ton. Sorted chrysocolla ore averages 20–25 percent copper. The slag assays 2.4 percent copper and 0.02 ounce of gold per ton.

At present the former main adit (No. 6, fig. 42) is caved at 200 feet from the portal but is reported to have been 700 feet long and to have had a winze 40 feet deep. At a distance of 450 feet from the portal, the adit is rumored to have cut a vein of vanadinite-wulfenite-quartz ore 10 feet wide; the vein assayed 3–4 percent lead, 1–2 percent vanadic oxide, 2–3 ounces of silver per ton, and $5–$18 in gold per ton. Caves found in this adit also are said to have been lined with wulfenite and vanadinite; one cave is reported to be 300 feet long and 50–60 feet wide.

Rocks of the Table Mountain mine area are cherty and dolomitic Escabrosa Limestone overlain unconformably by the lower andesite unit of the Galiuro Volcanics; the relations were described in the sections on Escabrosa Limestone (p. 26) and Galiuro Volcanics (p. 70). The north end of the eastern contact between limestone and volcanics is a fault, but the remaining contacts are depositional.

The principal ore-bearing rock at the mine is a layer of gray or mottled red, brown, and white massive jasperoid or jasperoid breccia that on the west side of the mine ridge may be as much as 100 feet thick. In the mine area the jasperoid layer seems to be 20–25 feet thick and is overlain directly by volcanic rocks. Over an area at least 1,000 feet long and 500 feet wide, the jasperoid and, to a lesser degree, the limestone contain sporadic and irregular concentrations of supergene copper minerals in pods, along fault and joint surfaces, and coating weathered surfaces. The jasperoid has been thoroughly prospected for about 500 feet north of the main opencuts, and at intervals for several hundred feet more.

Several copper minerals have been identified from the mine area; chrysocolla is by far the most abundant, but malachite and azurite are common; dioptase in vugs was formerly fairly abundant but has been so assiduously sought by mineral collectors that little remains, and conichalcite and planchéite are reported by Bideaux and others (1960). Other minerals reported are wulfenite, vanadinite, mimetite, austinite, and willemite. During the present study, only dioptase, wulfenite, and vanadinite among the rarer species were recognized. Vanadinite was seen only in dump material, where it forms small yellow to orange crystals in a matrix of rudely crustified granular quartz that fills open spaces in brecciated jasperoid. Other than jasperoid and quartz, the only common gangue mineral is barite, which forms large plates that evidently grew in open spaces and now have supergene copper minerals in their interstices.

No satisfactory evidence was found bearing on the age of the volcanic rocks relative to that of the cop-

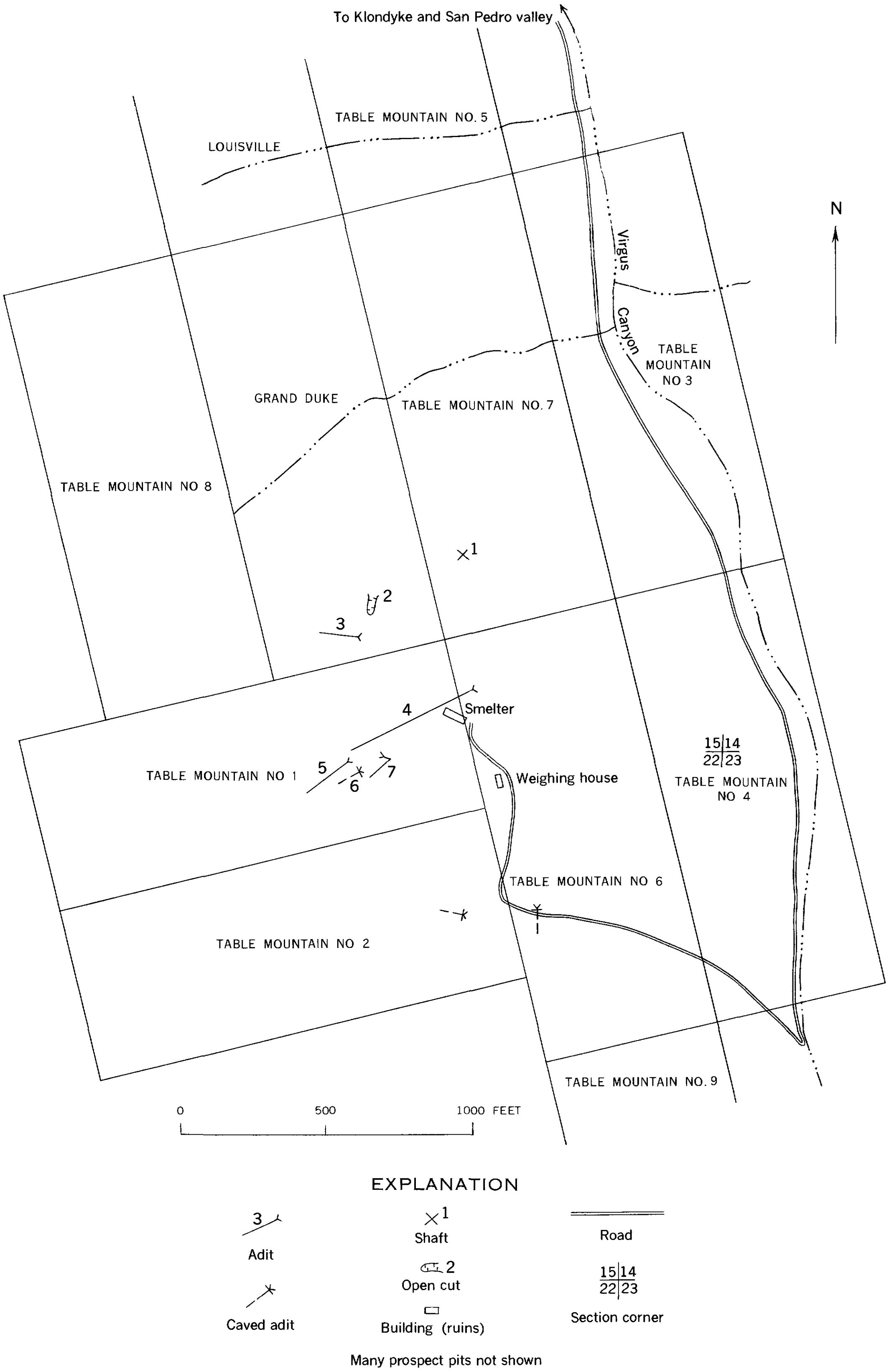


FIGURE 42.—Claim map of Table Mountain mine area. (Slightly modified after U.S. Mineral Survey No. 3313, April 1937.)

per mineralization. The fact that no sulfide minerals were seen or have been reported suggests however that oxidation has been thorough and may have occurred prior to the deposition of the volcanic rocks.

Inasmuch as the principal workings of the mine are inaccessible, no coherent account of the ore occurrences is possible. Instead, the various workings shown by number on figure 42 will be described briefly.

1. A shaft 25 feet deep explores a vertical fault zone in limestone. The fault strikes about N. 55° E. Limestone along the fault contains a little malachite, azurite, chrysocolla, and manganese oxide.
2. Pieces of barite-chrysocolla ore are on the dump of a caved opencut in jasperoid. No ore is exposed in the cut itself.
3. An adit 145 feet long trends N. 85° W. At the portal the adit is in jasperoid having sparse copper stains along joints, but at 100 feet from the portal it passes through a faulted wedge of limestone 15 feet wide. At 135 feet from the portal, the adit enters limestone below the jasperoid along a contact that dips 25° E. and is marked by several inches of gouge.
4. An adit 475 feet long having its portal about 50 feet below the slag pile and old smelter. The adit is entirely in light-gray fine-grained thick-bedded barren limestone striking N. 25° E. and dipping 15° NW. Underlying the limestone is 50 feet or more of interbedded pinkish-gray fine-grained cherty dolomitic limestone and dark-gray limestone.
5. An adit about 175 feet long trends S. 50°–55° W. in limestone just below the base of the jasperoid layer. In the southwesternmost 140–150 feet, the roof of the adit is rubbly jasperoid.
6. Former main adit, now caved at 200 feet from the portal. The accessible part of the adit is entirely in cherty limestone.
7. Adit in limestone that strikes east and dips 15°–20° N.; the portal is in rubble. This adit trends S. 70° E. for 15 feet, then turns abruptly S. 45° W. and continues 95 feet to a raise 20–25 feet high. No ore was seen.

### MISCELLANEOUS PROSPECTS

A small copper prospect is just south of the divide between Turkey Creek and the Right Prong of Fourmile Creek in the NW¼SE¼ sec. 28, T. 7 S., R. 19 E. A narrow fracture in coarse porphyritic "turkey-track" andesite strikes N. 45° W. and dips 75° SW. The fracture surfaces are filmed by chrysocolla and a little malachite.

Another small prospect is on the south side of the Right Prong of Fourmile Creek, on a ridge just north of the number 32, sec. 32, T. 7 S., R. 19 E. Dark-gray to dark-red porphyritic olivine andesite is cut by a vertical fracture zone striking N. 70° W. Fracture surfaces are coated by a little blue-green and green chrysocolla. The fracture zone is explored for 30 feet along an opencut. A second opencut 100 feet to the northwest and 25 feet long explores a vertical fault that strikes N. 60° W. Fault surfaces are polished and are filmed with a little chrysocolla and sparse malachite. A third prospect is 1,600 feet north and on the north side of the Right Prong in the NW¼ sec. 32. Purplish-gray pepper-and-salt textured olivine andesite is cut by a fracture zone that strikes N. 70° W. and dips 80°–90° SW. Fracture surfaces are coated by as much as a millimeter of blue-green chrysocolla and a little malachite. The fracture is explored by a vertical shaft about 60 feet deep and by an incline off the shaft at a depth of about 50 feet.

A prospect on the north side of the Right Prong of Fourmile Creek, in the center of the NW¼ sec. 33, T. 7 S., R. 19 E., is along a poorly defined fracture zone in the fine-grained basal part of a wedge of coarsely porphyritic "turkey-track" andesite just above the latite subunit of the Galiuro Volcanics. The fracture zone strikes N. 80° W. and dips 65° N. Fractures are filled with thin seams of malachite and chrysocolla. The prospect consists of two short inclines. Very little copper stain is apparent at a short distance below the surface.

Several small prospects are on or near the crest of the Galiuro Mountains in the SW. cor. sec. 32, T. 7 S., the NW. cor. sec. 5, and the NE. cor. sec. 6, T. 8 S., all R. 19 E. On the crest of the range in sec. 5, a partly timbered shaft 50–60 feet deep explores an east-striking vertical fracture in "turkey-track" andesite. Dump material includes andesite cut by irregular veinlets 2–3 mm thick of blue-green chrysocolla, a little malachite, and white chalcedony. One vug was lined with bright-green dioptase.

About 200 feet farther west and slightly below is an open stope 20 feet long and 25 feet deep along a fracture zone some 2 feet wide. Fracture surfaces are filmed by chalcedony, chrysocolla, and malachite.

The prospect in sec. 32 consists of two shafts 10–12 feet deep on a fracture zone less than a foot wide in coarse "turkey-track" pillow lava and flow breccia. The zone strikes east and dips 80° S. Fracture surfaces are coated with chrysocolla. Part of the wallrock at this prospect is a peculiar pale-red (10*R* 6/2) breccia consisting of fragments 1–10 mm across of dark volcanic rock, phenocrysts of alkali feldspar and biotite, and xenocrysts of quartz in a strongly eutaxitic mesostasis of colorless to buff devitrified glass. Field relations of this rock are obscure; it may be extrusive, but it also could be a breccia dike several tens of feet wide.

Three prospects are just southwest of the crest of the ridge in sec. 6. The first is a shallow pit in fractured dark purplish-gray fine-grained andesite. No structure is evident. Fracture surfaces are coated with a little blue-green chrysocolla. The second, 200 feet to the east and slightly higher, consists of a shaft 50–60 feet deep on a fracture zone 3–4 feet wide in dark-purple fine-grained vesicular porphyritic olivine andesite. The fracture strikes N. 70° W. and is vertical. Films of blue-green chrysocolla and a little coarse-bladed malachite coat fracture surfaces. The size of the dump suggests that some drifts may lead away from the shaft. According to a claim notice dated July 24, 1956, the claim is known as Wheelbarrow No. 5 (formerly Crown Point) and is owned by Eddie Lackner of Klondyke.

A third prospect is 200 feet S. 20° W. of the second and well below it. A fracture striking N. 65° E. and dipping 80°–90° SE. is explored by a shaft 50–60 feet deep. Country rock is purplish-red fine-grained vesicular porphyritic olivine andesite. The wallrock is brecciated, fracture surfaces are filmed with chrysocolla, malachite, and a little azurite and calcite, and open spaces also are filled with supergene copper minerals. A few quartz veins an inch or less wide cut the andesite.

The Copper Hill prospect is in the center of the S½ sec. 6, T. 8 S., R. 19 E. A claim notice dated February 10, 1957, is in the name of Leo L. Cook. Country rock is gently dipping purple fine-grained vesicular olivine andesite. A vaguely defined fracture zone striking N. 80° W. is explored by a shaft and an opencut. The fracture zone is 4–5 feet wide and contains sparse stringers of supergene copper minerals. A second intersecting fracture zone 2–3 feet wide that strikes N. 50° W. is explored by an adit 30 feet long and a small stope. About 100 feet below the shaft collar is an eastward-trending adit that probably connects to the shaft. The adit follows a fracture in the andesite. On the dump of the adit is a little andesite having films and small pods of chrysocolla, quartz, a little malachite, and sparse tenorite(?).

A prospect in the center of the SE¼ sec. 6, T. 8 S., R. 19 E., consists of a shaft at least 100 feet deep along a fracture zone 10–15 feet wide that strikes N. 40° W. and dips 80° SW. Country rock is fine-grained reddish-gray andesite. Fracture surfaces have thin films of chrysocolla. Below this prospect and just above Copper Creek is a long adit that presumably connects with the shaft. It trends S. 45° E. along a chrysocolla stringer that dips steeply southwest and at the portal is less than an inch wide. Wallrock is dark grayish-red vesicular andesite flow breccia. Dump material contains almost no copper minerals; in one piece of andesite, vesicles were filmed with chrysocolla.

In the SE. cor. sec. 6, T. 8 S., R. 19 E., grayish-purple vesicular porphyritic olivine andesite flow breccia is cut by a vertical fracture striking N. 70° W. Fracture surfaces are coated by as much as an inch of blue and blue-green chrysocolla and a little fine-grained malachite. The fracture is explored by an opencut 40 feet long and 15 feet or less in depth.

A few small copper prospects are in or near the fossil volcanic cone in the SW¼ sec. 5, T. 8 S., R. 19. E. The most southeasterly of these is on the northwest end of the knob marked by the closed 5,000-foot contour in the SE¼SW¼ sec. 5. A vertical fracture in red to dark-purple fine-grained fresh amygdaloidal andesite strikes N. 75° W. and is about 100 feet long. Fracture surfaces are filmed with blue-green chrysocolla and malachite. A shallow pit is the only exploratory working.

Nine hundred feet north, a fracture zone 3–4 feet wide in purple andesite has been explored by an opencut 75 feet long and 25 feet deep. Fracture surfaces are coated with malachite and some azurite and chrysocolla. Several tons of low grade ore is piled on the dump.

Six hundred feet farther northwest, near the closed 5,000-foot contour in the center of the SW¼ sec. 5, a fracture zone in agglomerate and breccia of the ash cone strikes N. 65°–70° E. and dips 80° SE. Grooves in fracture walls plunge 20° SW. The fracture has been explored for 200 feet along the strike and to a maximum depth of 25 feet. Films of blue-green chrysocolla, a little faded malachite, traces of azurite, and a black opaline material, perhaps chrysocolla also, coat fracture surfaces. Some chrysocolla has resulted from alteration of malachite.

Another prospect is 800 feet farther northwest, near the closed 4950 contour in the SW¼NW¼ sec. 5. A fracture in red to purple andesite flow breccia, tuff, and agglomerate strikes N. 70°–80° E., dips 80° S., and is at least 250 feet long. It is explored by two shafts that appear to be rather deep. Fracture surfaces are covered with as much as a few inches of chrysocolla and malachite; the thickest seams are near the east end of the fracture.

The Mission No. 1 claim is in the NW¼ sec. 7, T. 8 S., R. 19 E., just below the "4" of the 4750 contour number. It was claimed by Fred D. Coats and Leo L. Cook in February 1957. Andesite flows are cut by a fracture striking N. 70°–80° E. and dipping 85° N., which is explored by a trench 20 feet long and an adit 30 feet or more in length. Fracture surfaces are filmed by chrysocolla and quartz.

The Mission No. 4 prospect is in the center of the N½ sec. 7, T. 8 S., R. 19 E., just northeast of the "7" in the 4750 contour number. A claim notice dated February 1957 is signed by Fred Coats and Leo Cook. A fracture in andesite trends west-northwest and dips 75°–80° S. Fracture surfaces have films of chrysocolla and malachite, apparently after chalcocite. The prospect is just southwest of a biotite latite dike 8–10 feet wide.

Two prospects are on the Buena Suerte claim in the NE¼NE¼ sec. 7, T. 8 S., R. 19 E. The northeast prospect is a shaft about 6 feet deep on an east-striking vertical fracture in reddish-purple fine-grained amygdaloidal andesite. Fracture surfaces have thin films of chrysocolla. The second prospect, 300 feet southwest, is on an east-striking fracture zone that dips 80°–90° S. Country rock is purple fine-grained amygdaloidal andesite. The zone is about 3 feet wide and contains several thin seams of chrysocolla and specularite. Exploration workings consist of a shaft, now flooded, and an adit 50 feet below the shaft. The adit trends N. 60°–65° W. and is at least 100 feet long; it was aimed at the shaft but apparently did not connect with it.

## COPPER CREEK GROUP

The Copper Creek group embraces the copper-molybdenum breccia-pipe deposits for which the district is noted, the Bluebird lead-silver vein, and a few minor copper prospects. Several copper prospects in the Galiuro Volcanics at the head of Copper Creek were described in the previous section. Mines and prospects in the breccia pipes will be described first, and the section will conclude with brief notes on the Bluebird mine and minor prospects.

### AMERICAN EAGLE MINE

The American Eagle mine is in the SW¼ sec. 11, T. 8 S., R. 18 E., on the Copper Creek-Sombrero Butte road just south of the Klondyke quadrangle. According to Denton (1947a, p. 3), the mine was worked during 1914–19 by the Copper States Mining Co. Production is unknown, but the size of the underground workings still open indicates that an appreciable amount of ore was extracted. At present the adit level of the mine is flooded but still accessible and the stopes are partly caved and in bad condition.

The American Eagle deposit is in moderately brecciated Copper Creek Granodiorite. On the dump is some quartz-sericite rock containing abundant pyrite and rosettes of tourmaline. The deposit was studied by Weed (1913, p. 378), whose description follows:

> The American Eagle blow out, or chimney, is not formed of breccia like the others of the district, but consists mainly of cracked diorite, altered and sericitized with ore at the intersection of the joints, forming patches of breccia. Tourmaline is abundant and intergrown with the chalcopyrite. The rich streak occurs on the south side of the chimney.
>
> Although the chimney of copper-stained rock seen at the American Eagle is a large one and the amount of oxidized ore unusual, the development work now carried down to 300 feet below the outcrop shows that the deposit is not a typical pipe deposit, but a replacement plane or vein about 6 to 18 feet wide, of relatively rich ore that lies against fresh diorite. On the 200-level this vein is 30 to 49 feet wide, though only 18 feet of it is in ore of which 6 feet is shipping, running about 14% copper (as shown by smelter returns) and the remaining 12 feet is concentrating ore. On the 300-level the ledge is 50 feet wide, but only 6 feet carries commercial values. This rock is not leached, it is merely devoid of enough sulphides to pay.
>
> This streak of copper ore that has been mined out runs N. 60° E., or nearly parallel to the prevailing direction of rock sheeting and has a dip of 70° N., being traceable from the blow out down to the 300 level.

### CHILDS-ALDWINKLE MINE

The Childs-Aldwinkle mine is just north of Copper Creek near the center of the west edge of sec. 11, T. 8 S., R. 18 E. According to Denton (1947a, p. 3) the principal productive period of the mine was between 1933 and 1938, when 329,000 tons of ore was concentrated to yield nearly 7 million pounds of molybdenite and 6 million pounds of copper. From 1933 to 1935 the concentrator of the Old Reliable mine was used, and subsequently ore was treated in a 200-ton-per-day concentrator on the Childs-Aldwinkle property. Maximum production was in 1936, when 87,021 tons of ore was concentrated. At present, most of the underground workings of the mine are caved or otherwise inaccessible, but the main haulage level is still open and in good condition, and a second and higher adit gives access to one of the glory holes.

The mine was developed by two adit levels, a two-compartment winze extending about 530 feet below the haulage level, and five levels spaced at 100-foot intervals below the haulage level. The former outcrop of the Childs-Aldwinkle breccia pipe is now marked by two large glory holes (fig. 43). Figure 44 is a geologic map of the haulage level, and figure 45 is a section through the mine.

The mine has been described in detail by Kuhn (1941, 1951), and the reader is referred to his papers for descriptions of the now inaccessible parts of the mine and ore body. In this section only brief comments on rock alteration and mineralogy will be made.

The Childs-Aldwinkle pipe is enclosed in Copper Creek Granodiorite, and the breccia fragments consist entirely of this rock altered to varying degrees. The mode of the fresh wallrock appears in table 3, column 2. The breccia fragments are as much as 8 feet across, are angular to somewhat rounded in shape, and are embedded in a matrix of small fragments. The contact between brecciated and unbrecciated granodiorite is almost unmarked by signs of movement such as slickensides or gouge, is very sharp, and everywhere seems to dip steeply. Granodiorite of the walls may be slightly altered, contain milky feldspars, and be cut by a few copper-stained specularite veinlets.

Many fragments show a striking concentrically zoned pattern of alteration, having rinds 2–3 inches wide of greenish-gray fine-grained rock containing disseminated chalcopyrite, and cores of light greenish-gray rock having milky feldspar and abundant chlorite. Microscopically, the core of a breccia fragment from the haulage level near the shaft contains biotite having sagenitic webs of rutile(?), partly altered to pale-green chlorite. Plagioclase is partly replaced by sericite, and potassium feldspar by vermicular quartz. In the rind of the same fragment, plagioclase is entirely altered to sericite, no biotite survives, and even the chlorite that replaces it in the core rock is partly changed to sericite. Potassium feldspar is nearly completely replaced by quartz, which is more abundant than in the core rock. Finally, fresh chalcopyrite is disseminated through the rind. The contact between rind and core is very sharp, and chalcopyrite is confined entirely to the rind. In the core rock of another fragment, biotite has tiny inclusions of an unidentified mineral surrounded by faint pleochroic halos. Potassium feldspar is partly replaced by vermicular quartz; this partial replacement presages the nearly complete replacement shown in the rind rock described above.

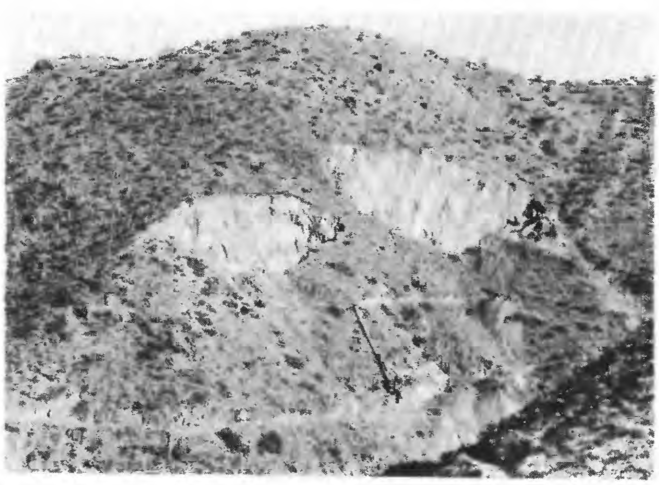

FIGURE 43.—Glory holes of the Childs-Aldwinkle mine, looking northwest. All rock in view is Copper Creek Granodiorite. On skyline at left is outcrop of a barren breccia pipe.

The principal ore minerals are chalcopyrite and molybdenite. Molybdenite is confined to open spaces and matrix between breccia fragments, and the bulk of the chalcopyrite is interstitial to the fragments. Plates of molybdenite a centimeter across are not uncommon. Both molybdenite and chalcopyrite are commonly interstitial to quartz or are perched on quartz. Very limited data suggest that molybdenite, pyrite, and specularite are concentrated in the outer part of the breccia pipe, peripheral to chalcopyrite. Kuhn (1941, p. 532) said that the molybdenite was in a fairly constant amount, 1–2 percent, throughout the mine, whereas the copper content increased from 1 percent at the surface to 6–8 percent at a depth of 800 feet, and then decreased to less than 2 percent at the bottom of the mine. Bornite in small amounts accompanies chalcopyrite near the south wall of the pipe on the haulage level but was not seen elsewhere; however, Kuhn reports that it was the principal copper mineral at a depth of 800 feet below the surface. Pyrite does not seem to be abundant. Tennantite is reported by Kuhn to have appeared at a depth of 200 feet below the surface and to have been an important ore mineral below a depth of 700 feet. He also noted small amounts of chalcocite, enargite, galena, and sphalerite.

The only abundant hypogene gangue mineral in the workings now accessible is quartz, which commonly forms crusts of stubby prisms in vugs. Kuhn reports orthoclase, calcite, and gypsum from the haulage level, and orthoclase, biotite, and apatite from deeper levels.

Two principal ore bodies, the Alamo and South, were mined; both are rudely funnel shaped, downward tapering, and nearly vertical in attitude. (See fig. 45; also Kuhn, 1951, fig. 39.) The outcrop of the South ore body was 220 by 100 feet in area, and that of the Alamo ore body was 270 by 150 feet. These ore bodies probably joined at a depth of about 700 feet, and they pinched out at a depth of 800 feet. A north branch of the Alamo ore body continued in depth for at least 50 feet below the bottom of the Alamo-South ore body. At the bottom of the mine this branch ore body is elongated along a north-trending fault.

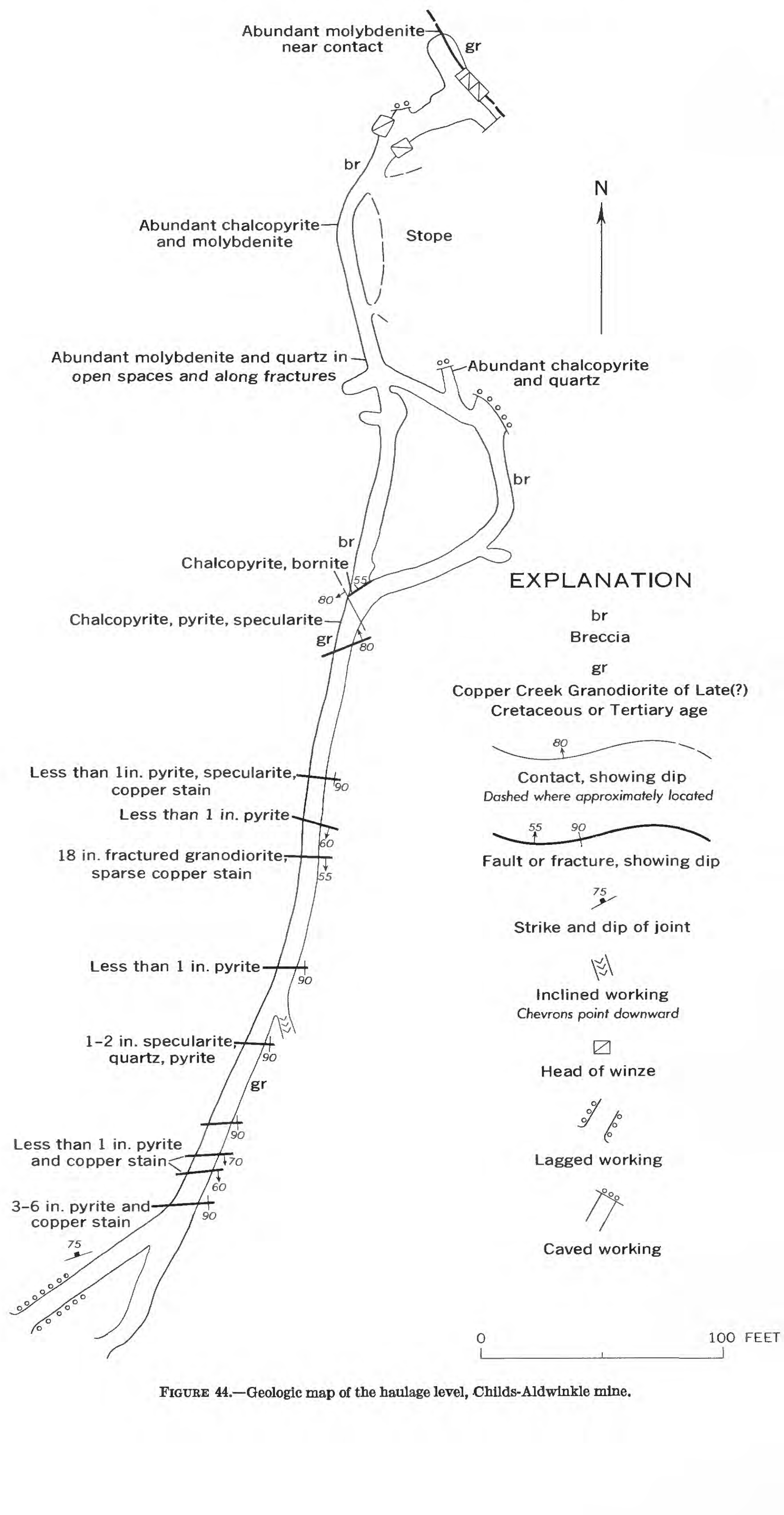


FIGURE 44.—Geologic map of the haulage level, Childs-Aldwinkle mine.

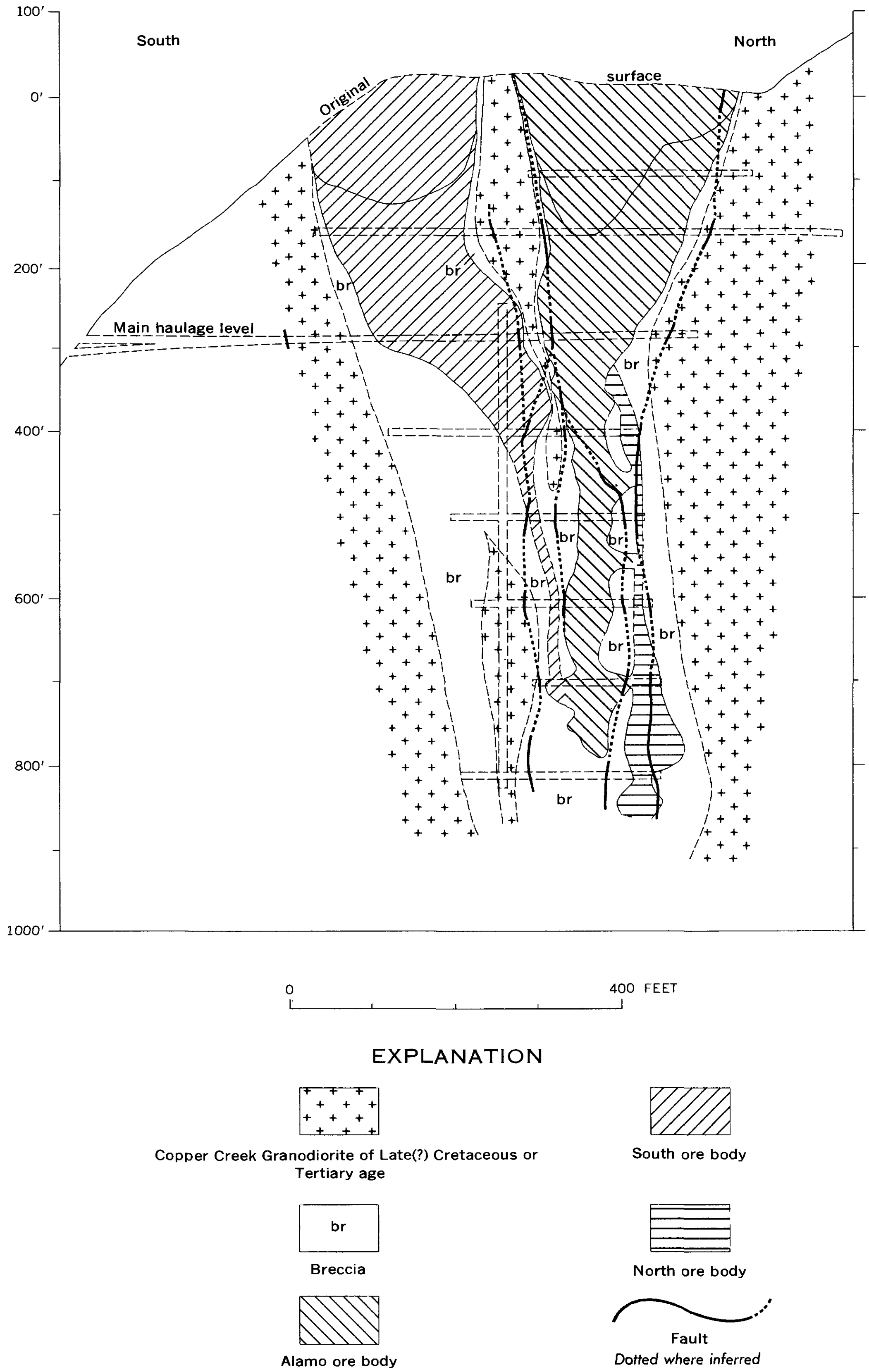


FIGURE 45.—Section through the Childs-Aldwinkle mine. After Kuhn (1941, fig. 7).

### COPPER GIANT MINE

The Copper Giant mine is in the SE¼ sec. 3, T. 8 S., R. 18 E., just north of the south edge of the section. It was noted by Weed (1913) but otherwise seems not to have been described. The mine explores one of the largest breccia pipes of the Copper Creek region. The outcrop of the pipe is rudely shaped like a boomerang, each wing is about 500 feet long and the apex points northeast. The southern wing is explored by two short adits and a winze (fig. 46).

The Copper Giant pipe is on the contact between granodiorite and hornfels derived from the Glory Hole Volcanics, and both rocks are represented in the fragments of the pipe. At the portal of the upper adit, the breccia is well exposed and consists of angular to rounded fragments, mostly 1–4 inches across, and a few blocks of granodiorite as much as 5 feet across. Perhaps 50–65 percent of the fragments are of hornfels. The breccia has very little fine-grained matrix and many open spaces. A strong platy structure, dipping 10°–20° SW., is evident in the breccia. Copper stain and a little pyrite are interstitial to or along fractures in the breccia fragments. No hypogene ore minerals were seen, but Weed reported chalcopyrite, cupriferous pyrite, and wolframite from "workings below the water level" (presumably in the winze).

### COPPER PRINCE MINE

The Copper Prince mine is in the NE¼ sec. 10, T. 8 S., R. 18 E., a short distance south of the Copper Giant mine. According to Kuhn (1941, p. 521–522), the Copper Prince breccia pipe was prospected by the Calumet and Arizona Mining Co. in 1907–09, and the upper levels were mined by the Arizona Molybdenum Corp. in 1937. The only production recorded is 1,227,667 pounds of copper in 1937. The mine is developed by an adit, a shaft reported by Weed (1913) to be 420 feet deep, and various stopes, most of which are now inaccessible. Figure 47 is a geologic map of the adit level.

On the adit level the Copper Prince breccia pipe is elliptical in plan, measuring about 150 feet across in an east-northeasterly direction by at least 280 feet in a north-northwesterly direction. The limits of the pipe are short curved peripheral faults or joints linked together as a boundary fracture that is continuous within the accessible part of the level. Breccia fragments range in size from a few inches to several feet across, and many appear to have undergone only very slight displacement from their original positions.

The wallrock of the Copper Prince pipe is a light olive-gray porphyritic biotite quartz monzonite facies of the Copper Creek Granodiorite; it was described on page 58, the mode is given in table 3, column 8, and photomicrographs of both fresh and altered rock appear on figure 48. A specimen collected about 7 feet from the wall of the pipe on the adit level resembles the fresh rock except that the plagioclase feldspar is strongly altered to sericite and hydromica;

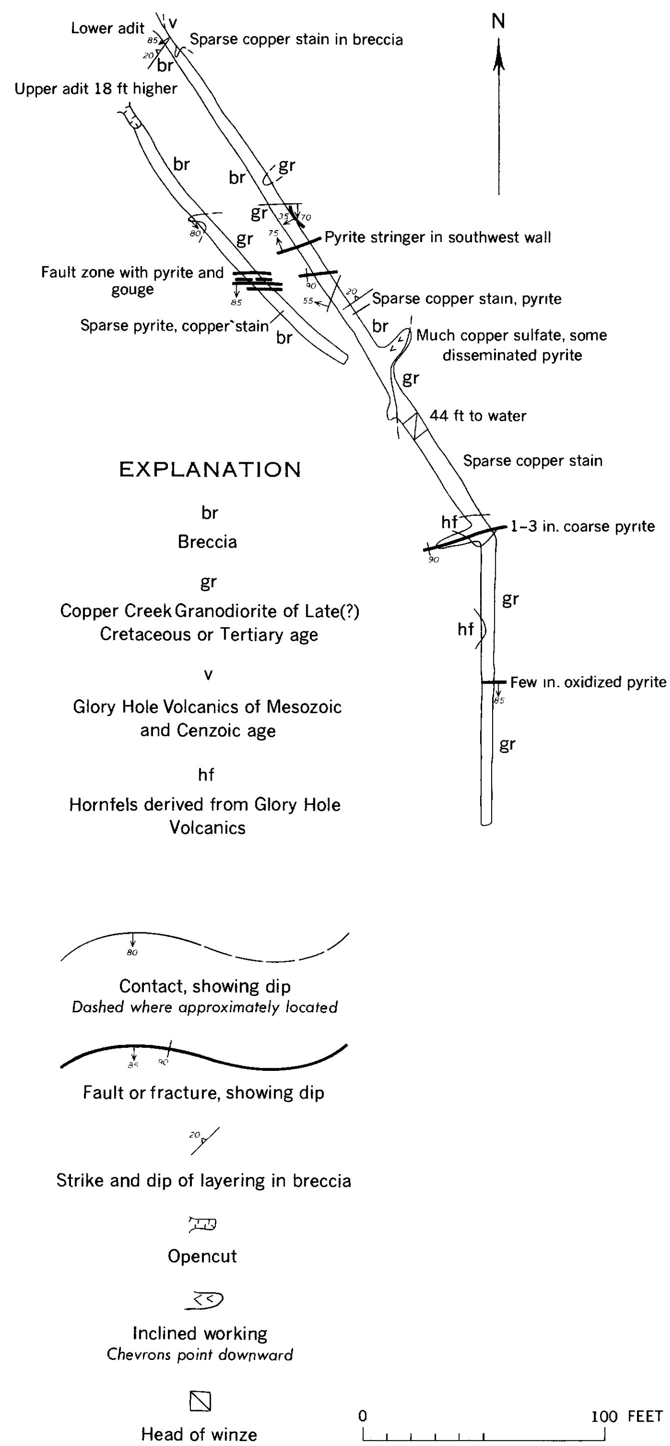


**FIGURE 46.—Geologic map of the Copper Giant adits.**

some of the sericite flakes are as much as 0.05 mm across. Biotite is partly altered to chlorite and iron ore. Potassium feldspar of the groundmass is fresh.

In a general way, the brecciated quartz monzonite of the pipe is altered to an orange color near the periphery of the pipe and to a whitish color in the center of the pipe. A fragment of grayish-orange rock from the northwest pillar (see fig. 48, bottom) differs from fresh rock in having biotite completely altered to chlorite and iron ore, orange plagioclase feldspar strongly altered to albite and having abundant inclusions of sericite 0.05–0.1 mm long, and considerably more coarse-grained quartz that suggests silicification; the modal percentage of coarse-grained quartz is 9, whereas in fresh rock it is only about 1.5. The groundmass is an aggregate of quartz and unaltered potassium feldspar. The orange of the plagioclase is due to abundant inclusions less than 0.005 mm across that presumably are some form of iron oxide. The fact that this coloration is restricted to the plagioclase feldspar suggests that the iron may have been an original constituent of the plagioclase, released as iron oxide only upon sericitization of the feldspar.

The only hypogene ore mineral of consequence is chalcopyrite, in veins and less commonly filling open spaces. Lenses and pods of massive pyrite are abundant; locally the pyrite is filmed or veined by chalcocite. Weed (1913) reports wolframite and scheelite, and Kuhn (1941, p. 529–530) noted molybdenite. Hypogene gangue minerals are very scarce; small quartz crystals fill open spaces here and there. Walls of the underground workings in the breccia pipe are heavily coated with copper sulfate. Galbraith and Brennan (1959, p. 4) report native copper in "twisted and wirelike masses in oxidized ore."

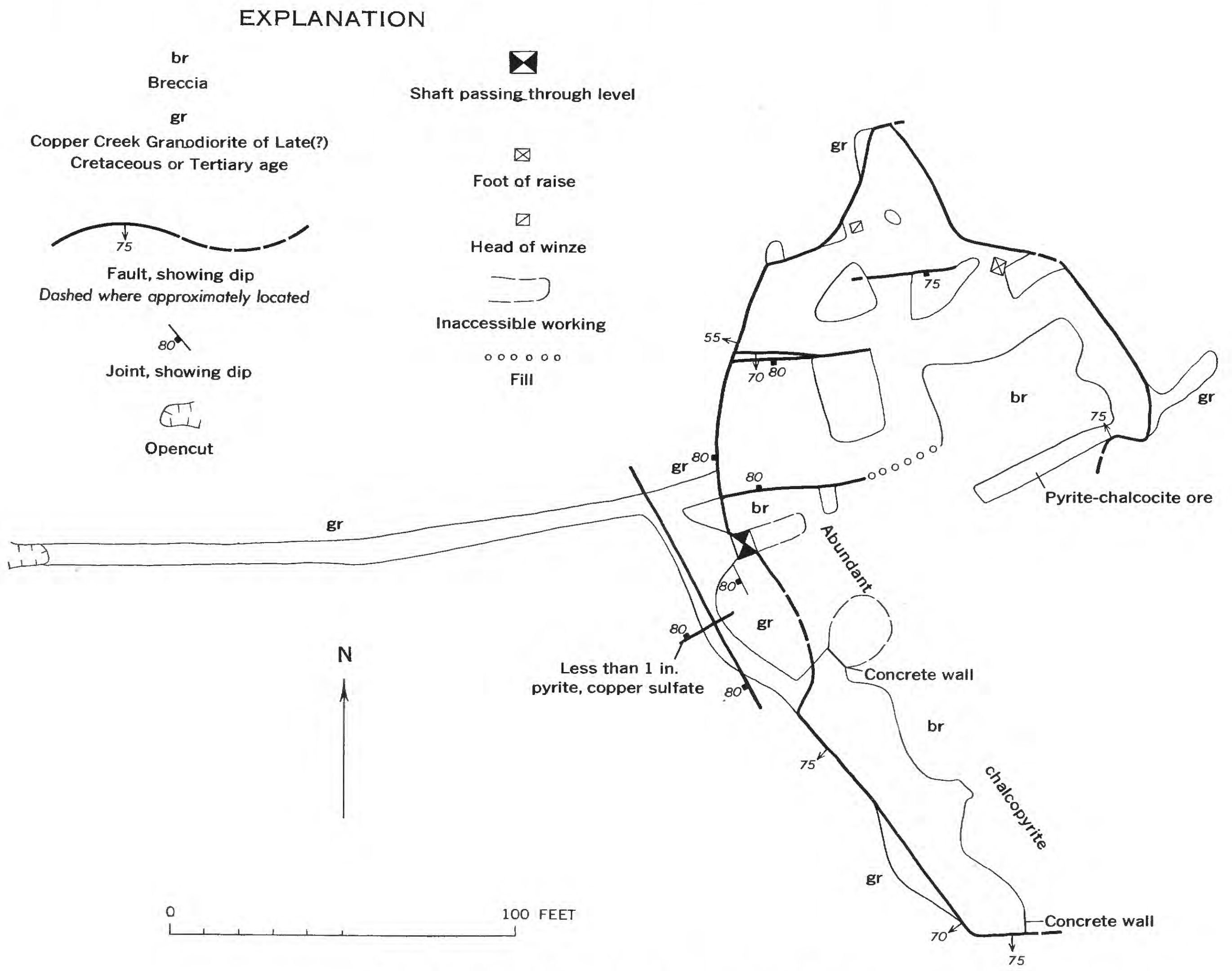


FIGURE 47.—Geologic map of the adit level, Copper Prince mine.

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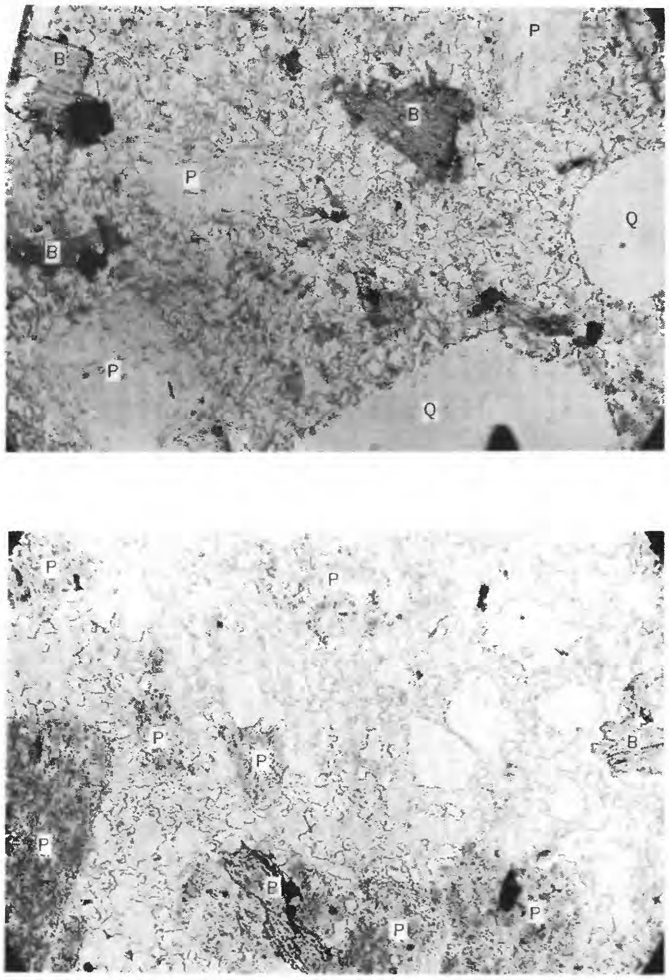


FIGURE 48.—Photomicrographs of porphyritic Copper Creek Granodiorite at the Copper Prince mine. Plane-polarized light, × 38. Slides are slightly below focus in both photomicrographs. Above, fresh wallrock of Copper Prince breccia pipe, adit level 20 feet west of pipe. Phenocrysts of quartz (Q) plagioclase feldspar (P), and biotite (B) are set in a fine-grained granular groundmass of quartz (light gray, outlined by Becke line) and potassium feldspar (light-gray mesostasis). Below, altered granodiorite, breccia block from northwest pillar of main stope. (See fig. 47.) Phenocrysts of strongly sericitized and cloudy plagioclase feldspar (P) and of biotite (B) completely converted to chlorite and iron ore in groundmass of quartz (light gray, outlined by Becke line) and potassium feldspar (light-gray mesostasis). Groundmass quartz is considerably more coarse grained than in the fresh rock.

According to Joralemon (1952, p. 254) a flat-lying lens cutting across otherwise low-grade breccia about 200 feet below the surface yielded several thousand tons of almost pure chalcopyrite. Two hundred feet deeper, the pipe was reduced to an open fissure in diorite, partly filled with pyrite and quartz.

### GLORY HOLE MINE

The Glory Hole mine (also known as the Globe mine) is just north of the center of the south edge of sec. 3, T. 8 S., R. 18 E. It has been described briefly by Weed (1913) and Kuhn (1941, p. 522). According to Weed, mine workings extend to a depth of 600–650 feet and comprise a shaft and several levels. At present only the adit level is accessible. No production is recorded, and no stopes are evident in the accessible part of the mine. A geologic map of the adit level is given on figure 49.

The mine explores two of a group of three closely spaced breccia pipes enclosed in hornfels derived from Glory Hole Volcanics. On the adit level the main or northwest pipe is oval in plan and measures about 110 feet in a northerly direction by 70 feet in an easterly direction. It forms a very prominent outcrop projecting conspicuously above the surrounding terrain (fig. 50). A second pipe southeast of the main pipe is 100 feet across where cut by the adit level. The third pipe, west of the main pipe, is much smaller.

The main pipe is a jumbled mass of unsorted angular to subrounded platy fragments mostly from 1–6 inches across. Many blocks are 1–5 feet across, and a few are as large as 10 feet across. The fragments show a vague layering dipping 25°–35° N. (fig. 51). Locally the outcrop is sparsely stained by supergene copper minerals.

The contact between breccia pipe and wallrock is well exposed in an opencut on the north-northwest side of the pipe. Fractured and copper-stained Glory Hole Volcanics are in sharp almost vertical but curved contact with iron- and copper-stained breccia. The breccia fragments are platy and are nearly flat lying right to the contact. The contact provides no evidence of movement.

On its east side the main pipe has a selvage a few inches wide of small platy fragments lying approximately parallel to the contact. The nearly vertical contact is smooth, as if at least a little movement had occurred along it.

The southeast pipe is made up of markedly platy fragments most of which are 1–3 inches across and $\frac{1}{8}$–1 inch thick. Layering imparted by these fragments dips 20°–25° eastward. The fragments either are in contact with each other or are separated by open spaces; there is no fine-grained matrix. Voids may be lined with small quartz crystals. Many angular fragments have rounded relatively hard cores enclosed in softer shells that are believed to have originated, at the time the pipes were formed, through the process of hypogene exfoliation. The breccia is stained by iron oxide but appears to be devoid of copper minerals.

The west pipe, not explored by the mine, consists of roughly equidimensional blocks of highly altered very light gray chalky rock 3–12 inches across. Only the texture of the parent rock is faintly preserved, the original minerals having been completely converted to fine-grained sericite and quartz. Most of

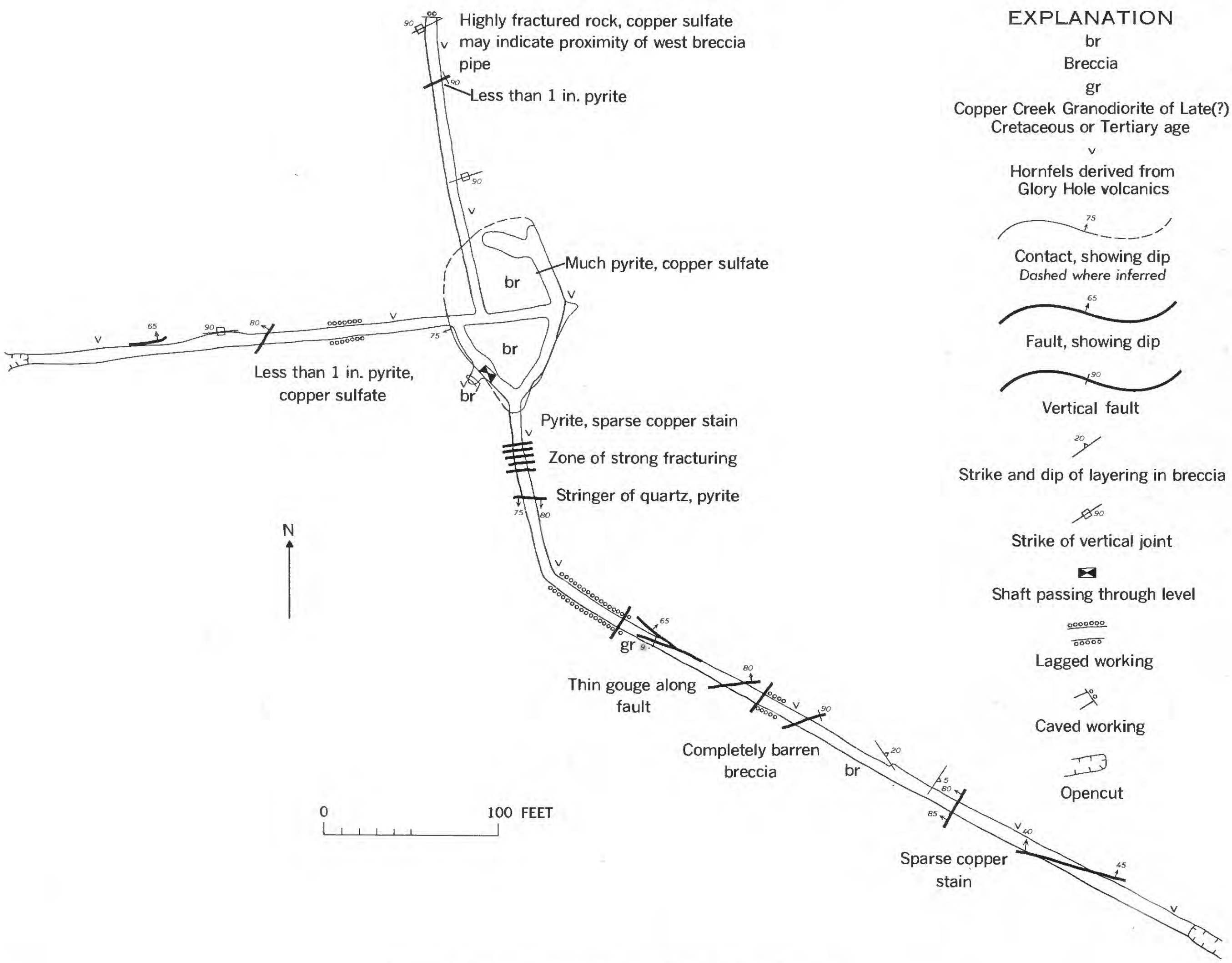


**Figure 49.**—Geologic map of the adit level, Glory Hole mine.

**Figure 50.**—Outcrop of the main breccia pipe of the Glory Hole mine, looking S. 80° E. Outcrop on skyline at right is of a small breccia pipe. All other rock in view is hornfels derived from Glory Hole Volcanics.

**Figure 51.**—Breccia on east side of main breccia pipe, Glory Hole mine, looking west. A vague layering dips about 25° to the right (north). The large block just to the right of and above the hammer shows hypogene exfoliation.

the sericite is in tiny shreds, but some plates are as much as 0.5 mm across; a few aggregates have outlines of feldspar. Quartz grains are generally less than 0.1 mm across. Minor minerals include jarosite probably after pyrite, and sparse tiny equant nearly opaque yellowish grains of rutile.

Specimens of hornfels of the Glory Hole Volcanics were collected along the adit level at distances of 20, 40, 60, and 80 feet from the southeast edge of the southeast pipe in order to determine whether any pervasive alteration of wallrocks had taken place near the pipe. Even in the rock nearest the pipe, no alteration that seemed to be related to the formation of the pipe could be recognized. The rocks are greenish gray to dark greenish gray and are cut by numerous fractures lightly stained by iron oxide and supergene copper minerals. Microscopically, they include biotite andesite or dacite lavas and pyroclastic rocks. All are characterized by very abundant, extremely fine grained yellow-brown biotite mainly interstitial to the coarser components, but also as inclusions in them (fig. 52). This biotite is clearly a metamorphic mineral, as in none of the unmetamorphosed Glory Hole Volcanics is it present in comparable amounts. Moreover, it is almost as clearly an original mineral of the hornfels, rather than a result of alteration attendant upon formation of the Glory Hole pipes; biotite-rich hornfels is found in areas remote from breccia pipes, and alteration at other breccia pipes is of the quartz-sericite type.

Granular pyrite was the only hypogene mineral seen underground; it is interstitial to breccia fragments and forms stringers cutting wallrock of the pipes. Weed (1913) reported that sulfide ore of good grade was found on the 200 level. He also reported a little chalcocite as films on earlier sulfide minerals. According to Weed, an extensive area of oxidized and leached ore-bearing breccia was found below the sulfide ore. The ore in general is said to have assayed less than 3 percent copper. Walls of the workings within the northwest or main pipe are heavily coated with copper sulfate.

### OLD RELIABLE MINE

The Old Reliable mine is in the center of sec. 10, T. 8 S., R. 18 E. It has been described briefly by Weed (1913) and Kuhn (1941, p. 521), and results of detailed sampling are presented by Denton (1947a). Production is unknown, but according to Denton the mine probably was operated intermittently between 1908 and 1919, yielding most of the 30,000 tons of ore concentrated and the 700,000 pounds of copper produced by the Copper States Mining Co. during that period.

Mine development consists of two adit levels 100 feet apart vertically, three connecting winzes, and a raise to the surface. Assay maps of all the workings are given by Denton. A geologic map of the upper (100) level is shown on figure 53.

At the surface, the Old Reliable breccia pipe is enclosed in altered Glory Hole Volcanics. The outcrop is a ragged mass of rock perhaps 600 feet long in a northwesterly direction by 200–300 feet wide; parts of the outcrop stand well above the enclosing rocks. At the outcrop the pipe is composed of a weakly coherent mass of angular to subangular blocks of volcanic rock ranging from a few inches to as much as 4 feet across. A small body of biotite latite porphyry is enclosed in the breccia; no contacts are exposed, but the porphyry presumably intrudes the breccia. Many fragments in the center of the pipe are well rounded, probably as a result of hypogene exfoliation. The contact between breccia and wallrock is irregular, steep dipping, and marked locally by prominent fractures. Breccia fragments have a rude parallel orientation; on the southeast side of the pipe the layering dips inward at an angle of about 35°. The outcrop is faintly stained by supergene minerals of copper and iron. Hypogene minerals interstitial to the breccia fragments are quartz and tourmaline.

On the upper level the pipe has divided into at least four pipes separated by from 25 to 80 feet of wallrock, which on this level includes biotite latite porphyry as well as Glory Hole Volcanics.

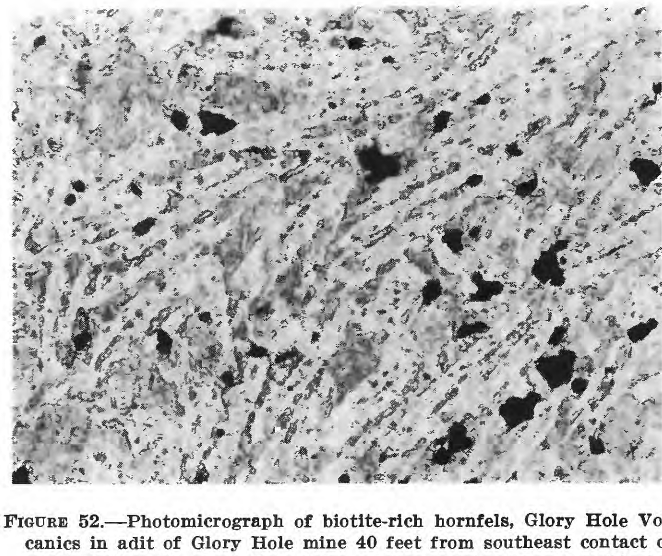

FIGURE 52.—Photomicrograph of biotite-rich hornfels, Glory Hole Volcanics in adit of Glory Hole mine 40 feet from southeast contact of southeast breccia pipe. Except for small amounts of iron ore (black), the rock consists entirely of plagioclase microlites and interstitial very fine grained granular biotite. Trachytic texture of original lava is well preserved. Feldspar has numerous inclusions of biotite but is essentially fresh and unaltered. Plane-polarized light, × 131.

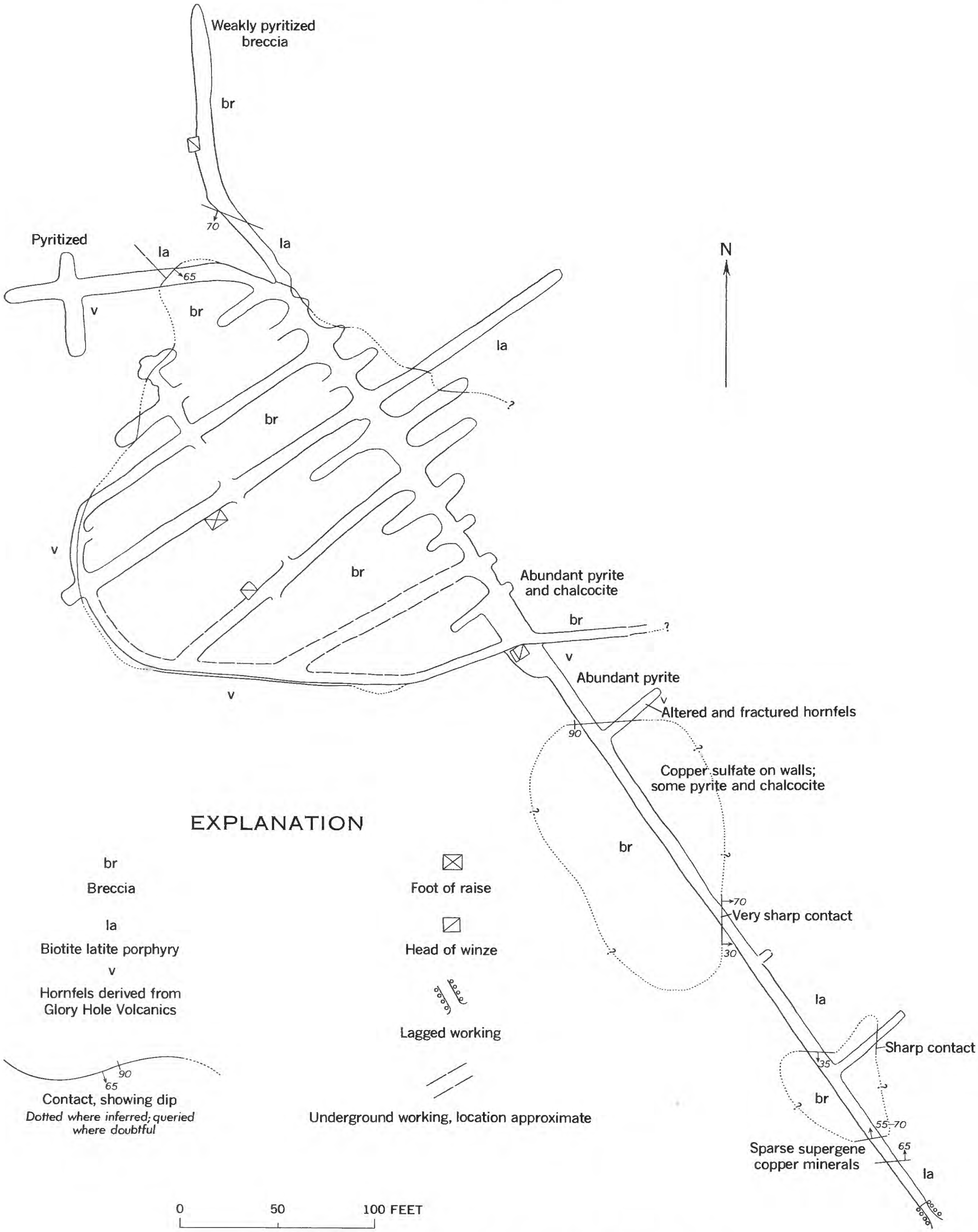


FIGURE 53.—Geologic map of the upper (100) level of the Old Reliable mine.

The subsidiary pipe southeast of the main pipe is 120 feet across where it is cut by the level. It consists of a chaotic assemblage of rounded fragments 1–3 inches across and contains a little disseminated malachite.

The main pipe is 250 feet across and is made up of small rounded rock fragments in which are scattered blocks as large as 5 feet across. The central part of the pipe is actually a mixture of rather fine grained and very coarse grained breccia or practically unbrecciated wallrock. The contact between breccia and wallrock is irregular in detail but very sharp. Interstitial to the breccia fragments are abundant sericite and pyrite, some of which is coated with chalcocite and very fine grained malachite or other supergene copper minerals. Chalcopyrite is scarce. Denton reports that covellite, bornite, and tetrahedrite also were found during a microscopic study of the ore. Galbraith and Brennan (1959) report atacamite (p. 45), barite (p. 57), and olivenite (p. 72).

Breccia fragments from two places within the pipe were examined microscopically. The fragments are of light-gray to light greenish-gray rather featureless rock containing sparse disseminated pyrite, chalcopyrite, and their oxidation products. In thin section the porphyritic texture of the original volcanic rock is preserved vaguely, although the rock has been pervasively altered to very fine grained quartz and sericite. Minor minerals include tiny aggregates of jarosite, scattered yellow-brown nearly opaque grains of rutile as much as 0.2 mm across, and wisps of pale-green chlorite.

According to Weed (1913), the copper content of the various ore blocks ranged from 2.13–4.06 percent, and the average was 2.71 percent. Concentrate from the mine at that time assayed 17.81 percent copper, 17.26 percent iron, 20.52 percent sulfur, and 42.10 insoluble material. Denton reports that mixed oxide-sulfide ore from the 100 level assayed 3.65 percent copper, and sulfide ore from the same level, 1.20 percent copper. Ore in the raise from the 100 level to the surface contained 0.22–2.17 percent copper and averaged 0.86 percent.

### SUPERIOR PROSPECT

The Superior breccia pipe is in the SE¼ sec. 3, T. 8 S., R. 18 E., about 1,000 feet north-northeast of the Glory Hole mine. It has been described very briefly by Kuhn (1941, p. 522) and was mentioned by Joralemon (1952, p. 254). A north-trending adit on the south side of the pipe, caved 60 feet from the portal, is the only exploratory working. No production is recorded.

The outcrop of the Superior pipe is one of the most conspicuous of the region (fig. 54). The pipe cuts hornfels of the Glory Hole Volcanics. The pipe itself is made up of flattish angular fragments of all sizes from flakes less than a inch across to slabs 4 feet across and 2 feet thick; most of the fragments are less than 1 foot across. Some blocks originally 5–6 feet across have been only slightly broken and give the impression that the breccia components have not moved very much. These platy fragments constitute locally a rather prominently layered breccia dipping gently eastward. The breccia is somewhat iron stained but appears to be devoid of copper minerals.

A breccia fragment from the north side of the pipe is a pinkish-gray to white fine-grained rock dotted with small rust-stained cavities. Quartz and abundant glistening scales of mica can be recognized with a hand lens. Microscopically the rock consists almost exclusively of quartz and sericite in grains 0.1–0.5 mm across. A few large grains of sericite appear to be pseudomorphs after biotite. Some of the quartz appears to be replacing sericite. Abundant equant or less commonly prismatic grains of a deep orange to yellow mineral 0.01–0.05 mm across are included in both sericite and quartz; the grains are too small for accurate identification but appear to be rutile, presumably residual from the alteration of biotite containing inclusions of sphene.

Pyritic rock from the adit it made up of a fine-grained aggregate of quartz, sericite, pyrite, and iron oxide. Millimeter-size rounded and corroded grains of quartz are probably original phenocrysts, and crudely rectangular aggregates of sericite are pseudomorphs of original feldspar phenocrysts. Biotite is converted to sericite and iron ore. Pyrite is dissemi-

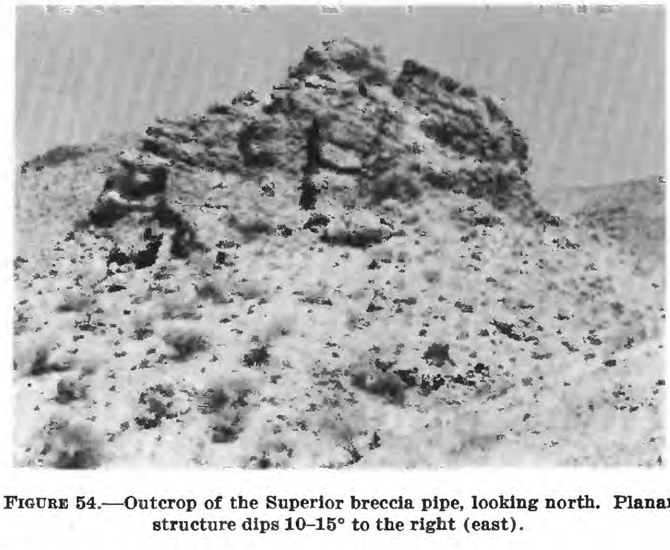

FIGURE 54.—Outcrop of the Superior breccia pipe, looking north. Planar structure dips 10–15° to the right (east).

nated through the rock in grains as much as several millimeters across.

The accessible part of the adit is entirely in granodiorite, and apparently all but the bottom part of the pipe has been eroded away. According to Joralemon (1952, p. 254), the adit "found only pyritic, partly sericitized diorite with no breccia and no copper, and no fractures or veins of any notable size."

### OTHER BRECCIA PIPE PROSPECTS

None of the other dozens of breccia pipes in that part of the Copper Creek region in the Klondyke quadrangle shows more than traces of copper. Only a few will be described separately.

A large breccia pipe forms the west summit of the hill west of the Childs-Aldwinkle mine in the NE¼ sec. 10, T. 8 S., R. 18 E. In plan, the pipe is oval, is elongated in a northerly direction, and is perhaps 150 feet in greatest dimension. The pipe is entirely in light brownish-gray Copper Creek Granodiorite. The mode of the fresh wallrock appears in table 3, column 1. Near the pipe the granodiorite here and there is cut by narrow chlorite zones that are filmed with copper stain. In the rock of these zones, biotite is considerably altered to chlorite, and pyroxene is completely altered to chlorite and iron ore.

In a short adit at the south end of the pipe, the breccia consists of various-sized granodiorite fragments altered to an aggregate of quartz, sericite, and tourmaline. Some sericite grains are more than a millimeter across. The most strongly silicified fragments are somewhat rounded. Both quartz and tourmaline are very abundant interstitial to the breccia fragments. The breccia is weakly stained with supergene copper minerals and is dotted with small iron-stained cavities.

Near the outer margin of the pipe, the breccia fragments are of a pale red-purple rock tinged with green. This rock consists almost entirely of an aggregate of ragged grains of quartz 0.2–1 mm across and interstitial potassium feldspar extensively replaced by coarse-grained sericite. Some potassium feldspar occurs as Carlsbad twins as much as 2 mm across. Crudely rectangular patches of sericite in cross-hatched orientation are probably pseudomorphs after feldspar. Sheaves of pale-green chlorite are scattered through the rock. No plagioclase feldspar was recognized. The sequence of alteration is potassium feldspar, sericite, quartz (fig. 55). A more strongly altered rock from near the center of the pipe is similar but also has a few peculiar grains that consist almost entirely of a sagenitic web of rutile needles embedded in a granular matrix most of which is quartz (fig. 55, bottom).

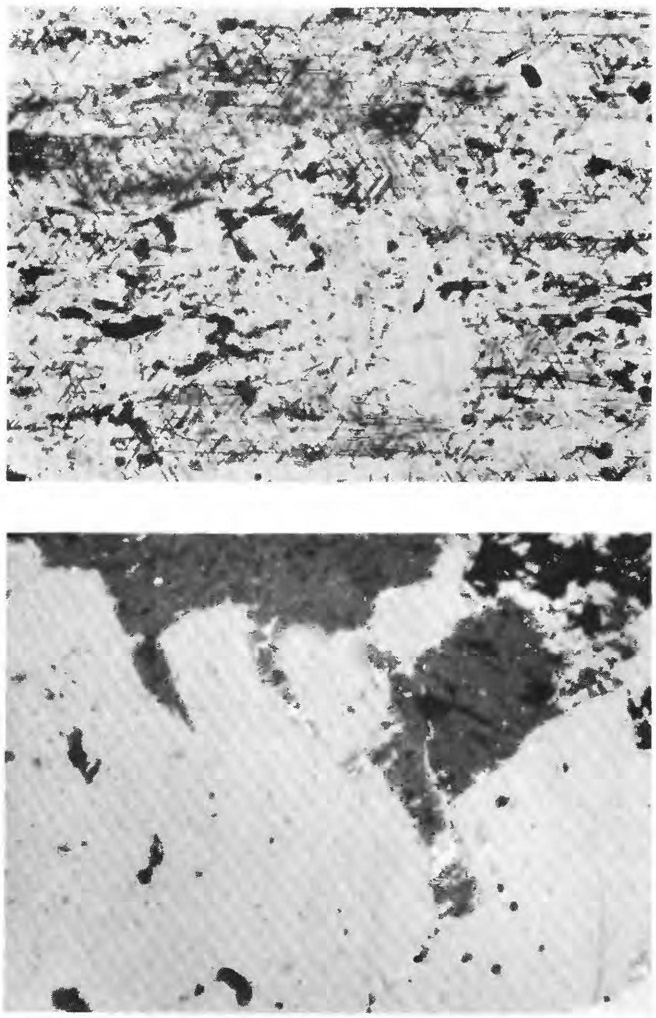

FIGURE 55.—Photomicrographs of altered Copper Creek Granodiorite from breccia pipe west of the Childs-Aldwinkle mine. Above, breccia fragment near outer edge of pipe. Orthoclase (dark gray) partly altered to sericite (white) is veined and replaced by quartz (light gray). Crossed nicols, × 44. Below, breccia fragment near center of pipe. A fine-grained sagenitic web of rutile needles is enclosed in a granular matrix most of which is quartz. Shapes of sagenitic areas suggest that they originally may have been biotite grains now so completely replaced that no trace of biotite remains. Plane-polarized light, × 122.

An adit in the west-sloping canyon in the NE¼ sec. 10 is driven south under the outcrop of this pipe and intersects it at a distance of about 600 feet from the portal. As revealed in the adit and two short drifts, the pipe is roughly circular in plan and about 25–30 feet in diameter. A little chalcopyrite and copper stain was seen in the adit north of the breccia pipe, but the breccia itself seems to be barren.

A breccia pipe in the NE¼ sec. 10, T. 8 S., R. 18 E., 1,250 feet south of the northeast corner of the section, is slightly stained by supergene copper minerals and has been explored by several pits and short adits. The pipe is in Copper Creek Granodiorite and is roughly circular, 75–100 feet across. Most of the breccia fragments are about 6 inches across, but some are several feet across. The pipe is surrounded by a zone about 10 feet thick of somewhat fractured granodiorite that grades outward into massive rock.

A small breccia pipe near the SE. cor. sec. 2, T. 8 S., R. 18 E., is of interest because the matrix consists of radiating aggregates of tourmaline needles and interstitial quartz. The pipe is in granodiorite, and the breccia fragments are of granodiorite thoroughly altered to quartz and sericite. The fragments are subrounded and as much as a foot across. Some of the tourmaline clearly has grown in open spaces, but much of it veins and replaces granodiorite. The pipe is sparsely stained with supergene copper minerals.

A breccia pipe near the corner common to sec. 2, 3, 10 and 11, T. 8 S., R. 18 E., and about 150–200 feet in diameter is characterized by abundant very large masses of radiating tourmaline prisms, accompanied by specularite and a little malachite. Breccia fragments are mostly less than 6 inches across and are strongly altered to quartz, sericite, chlorite, and iron oxide. The pipe is surrounded by a zone about 15 feet wide of fractured granodiorite.

The breccia pipes just south of the closed 4550 contour in the center of the E½ sec. 3, T. 8 S., R. 18 E. are made up of platy fragments of altered Glory Hole Volcanics. Individual fragments may be bent or broken (fig. 56). The flattish fragments impart a well-defined and commonly nearly horizontal layering to the breccia. Near contacts with wall rock, however, the layering may be inclined nearly to vertical, flattening abruptly within a short distance of the contact (fig. 57). The breccias are weakly stained by supergene copper minerals.

Near the west edge of the quadrangle in the NW¼ sec. 3, T. 8 S., R 18 E., dark-gray hornfels derived from coarse-grained welded(?) tuff of Glory Hole Volcanics is cut by a conspicuous breccia pipe and by east-trending zones of quartz-sericite alteration. The north contact of the pipe is vertical and the east contact dips 60° E. The breccia consists of angular to subrounded fragments as much as 3 feet across. Although most of the breccia fragments are extremely irregular in shape, the more platy among them impart to the breccia a rude layering that on the west side of the pipe strikes N. 20°–30° E. and dips 25° NW., and at the east end strikes northeast and dips 10° NW. The breccia fragments themselves are a light-gray rather chalky appearing fragmental rock. Microscopically, the rock has a faint suggestion of flow layering but is clearly fragmental and may be an altered welded tuff. It consists almost entirely of quartz and sericite; a few grains of quartz are as much as 0.2 mm across, but most are much smaller. Sericite forms scattered pseudomorphs after feldspar. The only other component is a few grains of an unidentified colorless uniaxial positive mineral of high refringence and low birefringence (0.012–0.015).

FIGURE 56.—Breccia from breccia pipe in center E½ sec. 3, T. 8 S., R. 18 E. Specimen is 6½ inches wide. Light rock is hornfels of the Glory Hole Volcanics, much altered to quartz and sericite; dark interstitial material is fine-grained aggregate of quartz, sericite, and chlorite. Note bending and disruption of indivdual platy fragments.

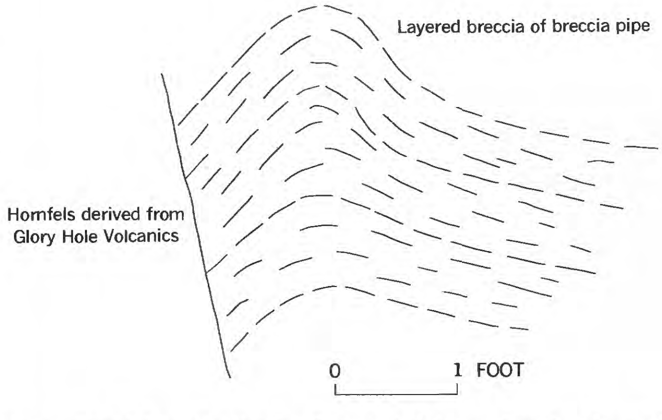


FIGURE 57.—Schematic sketch of contact between breccia pipe and wallrock in small pipe south of knob 4550, center E½ sec. 3, T. 8 S., R. 18 E. Looking S. 15° W. Attitude of layering suggests upward thrusting of entire pipe, with attendant drag along the walls, followed by slumping of the central part of the pipe. Neither displacement appears to have been great, as individual layers within the breccia are only slightly disrupted.

### BLUEBIRD MINE

The Bluebird mine is in the SE¼ sec. 2, T. 8 S., R. 18 E., in a south-sloping gulch tributary to Copper Creek. According to Kuhn (1951, p. 56–57), the mine was discovered in 1863 and was worked intermittently during 1914, 1918–30, 1939–40, and 1947–48. In the period 1939–40, ore was concentrated in a mill having a capacity of 25 tons per day, and in 1947–48 a concentrator having a capacity of 50 tons per day was in operation for a short time, and 598 tons of ore was treated. Production data are incomplete, but those available are given in table 8.

The mine is almost completely inaccessible at present and most of the data to follow are taken from Kuhn (1951, p. 63–65). Mine development consisted of a vertical shaft 535 feet deep and seven levels having aggregate length of nearly 5,000 feet.

The Bluebird vein is in Copper Creek Granodiorite. It strikes N. 55° E., dips 80°–90° SE., and has an outcrop length of about 700 feet. In the open stope on the west side of the gulch the vein is along the northwest wall of a fracture zone 2–3 feet wide and is only 1–2 inches wide. According to Kuhn, the vein ranged from 2–5 feet in width.

Wallrock of the vein is light brownish-gray medium-grained and slightly cataclastic granodiorite having a seriate porphyritic texture. It is somewhat fractured and slightly altered. Microscopically, a specimen taken 3 feet southeast of the vein consists of euhedral to subhedral phenocrysts of andesine ($An_{50-60}$), interstitial allotriomorphic quartz, potassium feldspar, and biotite, and accessory sphene, iron ore, zircon, and sparse apatite; the mode is given in table 3, column 5. In the rock adjoining the vein, plagioclase is almost completely altered to untwinned albite enclosing a felted mat of fine-grained sericite. Biotite is converted to an aggregate of sericite and iron ore. The potassium feldspar of the matrix is fresh, as are apatite and sphene. Calcium obviously has been removed from the rock, and potassium added.

Material on a small dump near the open stope indicates that the Bluebird vein consisted of finely layered quartz and sulfide minerals. The principal ore mineral is galena, some of which is intimately associated with tetrahedrite. Minor sulfide minerals include argentite, chalcopyrite, pyrite, sphalerite, and chalcocite. A little calcite, tourmaline, and chlorite are in the predominantly quartzose gangue. Kuhn also reports bornite and a long list of supergene minerals including cerargyrite, native silver, stromeyerite, wulfenite, and descloizite. Galbraith and Brennan (1959, p. 79) also report wolframite [wulfenite?].

The Bluebird vein is described by Kuhn (1951, p. 63, 65) as follows:

> The Bluebird vein * * * consists of numerous subparallel fissures en echelon. In many places it has been intruded by small andesite dikes.
>
> Two distinct mineralized bodies occur in the vein. The main ore body, containing sulfides of lead, silver, copper, and iron, has been followed from the surface to the 535 level and found to pitch 45° NE. The other body, containing wulfenite of subcommercial grade, apexes near the 335 level.
>
> The main ore zone consists of sulfide-filled fractures cutting quartz, altered granodiorite, and andesite. In many places, sulfides occur along the fault which forms the footwall of the vein, but commonly stringers of galena follow fractures crossing the vein. Along single fractures the sulfide zones are an inch or less in width, but, where several of the fractures meet, widths of 3 to 9 inches are common. The ore pinches and swells along the individual fractures, and within the ore body are barren areas. Crushing has occurred within the vein, and these areas are barren. Towards the horizontal limits of the ore body, the amount of sulfides diminishes, although the vein continues.
>
> In general, only slight oxidation of the iron and copper minerals is apparent in the main vein.
>
> The mineralized portion of the vein northeast of the sulfide body on the lower levels occurs within a breccia that has been followed on the 535 level for at least 200 feet. Angular to rounded, altered blocks of granodiorite, 4 to 8 inches across, surrounded and cemented by quartz, limonite, and psilomelane, occur within a zone 4 to 6 feet wide. It is similar in appearance to the initial stage of solution breccia at the Childs-Aldwinkle pipe. Small dikes have intruded the breccia. On the 335 and 435 levels, the breccia zone is adjacent to the sulfide body, but on the 535 level about 100 feet of fresh granodiorite separates the two bodies. A fault containing 2 to 4 inches of gouge, quartz, and limonite cuts the breccia zone and connects with the galena-bearing fissures of the sulfide body. The wulfenite on the 535 level occurs with limonite, partly filling open spaces within a quartz network. Psilomelane is present as stains on quartz and as stringers generally less than ¾ inch wide.

### OTHER PROSPECTS

Only a few of the many other prospects in the Copper Creek region merit individual description.

A shaft near the SW. cor. sec. 2, T. 8 S., R. 18 E., explores a rusty fracture in hard Copper Creek Granodiorite. The fracture strikes N. 65° W. and is vertical. Some pyrite was found at depth. The shaft is filled with water to within about 40 feet of the surface. Three prospects in the NW¼ sec. 11 are possibly on the same fracture. They include a short adit and a small cut opened along narrow copper-stained fractures in granodiorite.

An adit at the place where the road from the Old Reliable mine crosses Copper Creek (center sec. 10, T. 8 S., R. 18 E.) trends N. 50°–10° E. and is 400 feet long. The entire adit is in pyritic hornfels of the Glory Hole Volcanics.

Another adit on the south side of Copper Creek about 900 feet farther southeast is also in hornfels. This adit, known locally as the "Gamblers' Tunnel," trends S. 30° W. and is 280 feet long.

An adit on the west side of the deep south-sloping canyon in the W½ sec. 10, T. 8 S., R. 18 E., apparently was intended to explore a breccia pipe that crops out on the ridge above. The adit trends N. 51° W. and is caved 395 feet from the portal. It passes successively through 60 feet of heavily pyritized hard hornfels, 45 feet of fine-grained biotite diorite facies of the Copper Creek Granodiorite, and 290 feet of hornfels.

A malachite-stained shear zone in granodiorite near the center of the north edge of sec. 11, T. 8 S., R. 18 E., has been explored by several pits. The shear zone trends slightly north of west and dips steeply south. Along it, wall rock is strongly altered to quartz and sericite. Locally, the zone encloses a quartz vein that may attain a thickness of 3 feet. At the east end of the shear zone, a shaft 20–25 feet deep has been sunk on a narrow quartz vein containing various supergene copper minerals, specularite, pyrite, and a little galena and chalcopyrite. The vein strikes N. 50° E. and is vertical.

A small copper prospect is near the junction of two west-sloping gullies at the center of the line between secs. 11 and 12, T. 8 S., R. 18 E. A vertical fracture zone trending N. 70° E. is explored by two adits and a pit. Along the fracture are as much as 6–8 inches of quartz and iron oxide having sparse copper stain.

A narrow copper-stained fracture in granodiorite in the NW¼ sec. 12, T. 8 S., R. 18 E., near the southward-pointing sharp bend in Copper Creek, has been explored by two adits, a shaft, and a small stope. The fracture strikes N. 75° E., dips 75° N., and has been stoped from the upper adit along a length of 180 feet. It contains about 6 inches of quartz, chrysocolla, and tenorite. The lower adit trends S. 25° E., is 430 feet long, and has short drifts at distances of 90, 120, 200, and 340 feet from the portal; the drift at 90 feet extends 110 feet N. 65° E. and has a winze at a distance of 50 feet from the adit.

On the east side of Copper Creek about 700 feet farther northwest, several adits have been driven to intersect narrow stringers of supergene copper minerals trending about N. 70° E. Country rock is granodiorite containing chalky feldspar near the veins and locally a little disseminated pyrite.

Still farther northwest, the steep hillside north of Copper Creek is dotted with small pits on rusty fractures trending N. 70° E. and dipping steeply southeast. Some fractures have several feet of quartz-sericite rock along them.

A prospect 1,700 feet east-southeast of the number "12" in sec. 12, T. 8 S., R. 18 E. explores a copper-stained dike of coarse porphyritic ("turkey-track") andesite 4 feet wide that intrudes Copper Creek Granodiorite. The dike strikes N. 85° W. and is vertical.

A fault in the S½ sec. 12, T. 8 S., R. 18 E., approximately on the quadrangle boundary, is explored near its west end by 2 inclined shafts 45–50 feet deep and by an adit downhill from the shafts. In the prospect area the fault strikes N. 75°–90° E. and dips 55° SE. Wallrock is granodiorite. Rock on the dumps indicates that a vein or veins as much as 6 inches wide were found at depth; the vein material consists of pyrite, quartz, iron oxide, and a little copper stain.

A prospect in the SE¼ sec. 12, just south of the quadrangle boundary, consists of an adit about 50 feet in length along a quartz vein in soft whitish altered granodiorite. The vein is along a vertical shear zone that strikes N. 80° W. It attains a width of at least 6 inches and has stringers and pods of pyrite and a little copper stain.

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