Geology of the Christmas Quadrangle Gila and Pinal Counties Arizona

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Geology of the Christmas Quadrangle Gila and Pinal Counties Arizona

By RONALD WILLDEN

CONTRIBUTIONS TO GENERAL GEOLOGY

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A description of the rocks and structural features of an area containing some major copper deposits of southeastern Arizona

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GEOLOGY OF THE CHRISTMAS QUADRANGLE, GILA AND PINAL COUNTIES, ARIZONA

By Ronald Willden

ABSTRACT

The Christmas quadrangle, which covers an area of about 250 square miles in Pinal and Gila Counties, Ariz., contains rocks from older(?) Precambrian to Recent age.

The Precambrian is represented by 11 mappable units, 4 of which have been tentatively assigned to the older(?) Precambrian and 7 of which have been assigned to the younger(?) Precambrian. The older(?) Precambrian rocks include metavolcanic rocks and schist, which have been intruded by granite—compositionally alaskitic quartz monzonite—which has been intruded by granodiorite. The younger(?) Precambrian rocks consist of 4 subdivisions of the Apache Group (Pioneer Formation, Dripping Spring Quartzite, Mescal Formation, and basalt), the Troy Quartzite, diabase, and diorite, the last 2 of which intrude all the older rocks. The exposures of Precambrian rocks are mostly north of the crest of the Mescal Mountains, which trend about N. 60° W. through the center of the quadrangle.

Paleozoic rocks consist of undivided Cambrian rocks, the Martin Formation of Devonian age, the Escabrosa Limestone of Mississippian age, and the Naco Limestone of Pennsylvanian age. The Paleozoic rocks are found throughout the quadrangle but are most abundant in and north of the Mescal Mountains.

The layered rocks from the lowest formation of the Apache Group to the Naco Limestone are generally concordant, although there are important erosional intervals in the section below the Troy Quartzite, below the Cambrian rocks, and below the Martin Formation.

The Mesozoic is represented by coal-bearing sedimentary rocks of Late Cretaceous age and by andesitic volcanic rocks and interbedded sediments that overlie the coal-bearing sediments. Microdiorite, feldspar-mica porphyry, and hornblende andesite bodies that intrude the Cretaceous rocks and locally the Naco Limestone may also be of Cretaceous age or they may be early Tertiary.

The Tertiary is represented by conglomerate, older volcanic rocks, intrusive rhyolite, gravel, basalt and andesite, tuff and rhyolite, and rhyolite. The older volcanics, which are found only in the east-central part of the quadrangle, comprise from bottom to top the following four map units: an andesite and basalt unit, tuff, dacite, and welded tuff.

The Gila Conglomerate and basalt, which are widespread in the quadrangle, have been assigned a Tertiary and Quaternary age. Quaternary units consist of older alluvium, pediment gravels, younger alluvium, tufa, and talus.

The Deer Creek syncline is a large asymmetrical fold involving Cretaceous and Paleozoic rocks in the southern part of the quadrangle. The Reed Basin thrust, now represented by detached klippen along the north side of the Deer Creek syncline, overrode the syncline, probably from the south. Other thrust faults in Dicks Spring Canyon and northwest of Coolidge Dam may be contemporaneous with the Reed Basin thrust, although there is no compelling evidence to support this.

High-angle faults are abundant in the quadrangle, particularly in the Mescal and Hayes Mountains. Those faults, whose surfaces are exposed, are either vertical or normal faults, but some reverse faults probably exist. Six high-angle faults can be traced for distances of 5 to 19 miles. These are the Quartzite Mountain, Red Rooster, Dicks Spring, Mescal Creek, Hawk Canyon, and Bull Basin faults. The Quartzite Mountain fault, which is older than the Red Rooster fault, has displaced the north side up relative to the south side, but all the others have displaced the north side down relative to the south side. The major high-angle faults are younger than the thrust faults and are generally younger than at least part of the Gila Conglomerate.

Ore deposits in the quadrangle are virtually confined to the important copper deposit in the Christmas mine. Several small copper prospects are present in the southern part of the quadrangle east of the Gila River and one in the south part of the Hayes Mountains, but these have not been worked for many years. Coal in the lower part of the Cretaceous section has been explored in the past but is too thin and in too remote an area to be economically exploited. A small oolitic hematite deposit in the Martin Formation in the northwest corner of the quadrangle is probably unworkable at the present time because of its marginal grade and small size.

INTRODUCTION

The Christmas quadrangle is one of several heretofore unmapped critical areas in the heart of the Arizona copper belt. The mapping of these areas should aid materially in the understanding of the geology and ore controls of the important mining districts in the belt. To the west of the quadrangle is the important Ray district; to the north, the Globe-Miami district; to the south, the San Manuel district; and in the southwest part of the quadrangle, the Christmas mine of the Banner district. These districts have produced several billion pounds of copper, and the Christmas mine alone had produced 54,969,573 pounds of copper to the end of 1954 (Eastlick, 1958) and has a reserve of 660 million pounds of copper.[1] The individual districts have been the subject of considerable geologic study, but the mapping of the surrounding and intervening areas was begun relatively recently in the hope that a detailed geologic map of the copper belt would aid the search for new deposits.

[1] Annual Report, Inspiration Consolidated Copper Co., for year ended December 31, 1959.

The geologic mapping of the Christmas quadrangle has been conducted with less attention to detail than has been, or will be, the case for most of the other areas in the copper belt, because the topographic map of the Christmas quadrangle, which was first published in 1915, portrays certain local features inaccurately. The decision to use the existing base map for the geologic mapping was based on the hope that the salient geologic features of the quadrangle could be adequately portrayed on it in spite of the inaccuracies of detail.

LOCATION AND ACCESSIBILITY

The Christmas quadrangle is bounded by long 110°30′ W. and 110°45′ W. and lat 33° N. and 33°15′ N. The Gila County–Pinal County boundary follows the Gila River diagonally through the quadrangle—the north side of the river in Gila County and the south side in Pinal County. The northern one-third of the quadrangle is in the San Carlos Indian Reservation. The location of the quadrangle with respect to other geographic features in southeastern Arizona is shown on figure 1.

Much of the quadrangle is difficult of access by vehicles. A poorly maintained macadam road crosses the northeast corner of the quadrangle and connects Coolidge Dam, which forms San Carlos Reservoir, with U.S. Highway 70 at Cutter and just west of Bylas. A dirt road connects Smith's Ranch (shown on the map as Tuttles Ranch) with this paved road at Coolidge Dam, and a rough bulldozer road extends up Hawk Canyon from Smith's Ranch to beyond the east boundary of the quadrangle. State Highway 77, which crosses the southwest corner of the quadrangle, is an excellent modern road from its connection with U.S. 70, about 1 mile east of Globe, to Christmas. However, from Christmas to Winkelman, it is a winding, narrow road—too narrow for two cars to pass at several places. A bulldozer trail joins State Highway 77 near the point where the highway leaves Dripping Spring Valley and, in general, follows the trail shown on the map across the Mescal Mountains to Tulapai Creek, where it connects with a poor dirt road that extends by way of Gilson Wash to a connection with U.S. Highway 70 at Cutter. The northwest corner of the quadrangle is further accessible by several dirt roads that extend from the Gilson Wash road to stock tanks, wells, or springs in the vicinity. A dirt road connects the Brundrick Ranch in Reed Basin with State Highway 77 about 1 mile south of Winkelman. At times, it is possible to drive up Deer Creek from Brundrick's Ranch to about the east boundary of the quadrangle, but usually it is not possible to go beyond the ranch shown on the map as Mings Ranch.

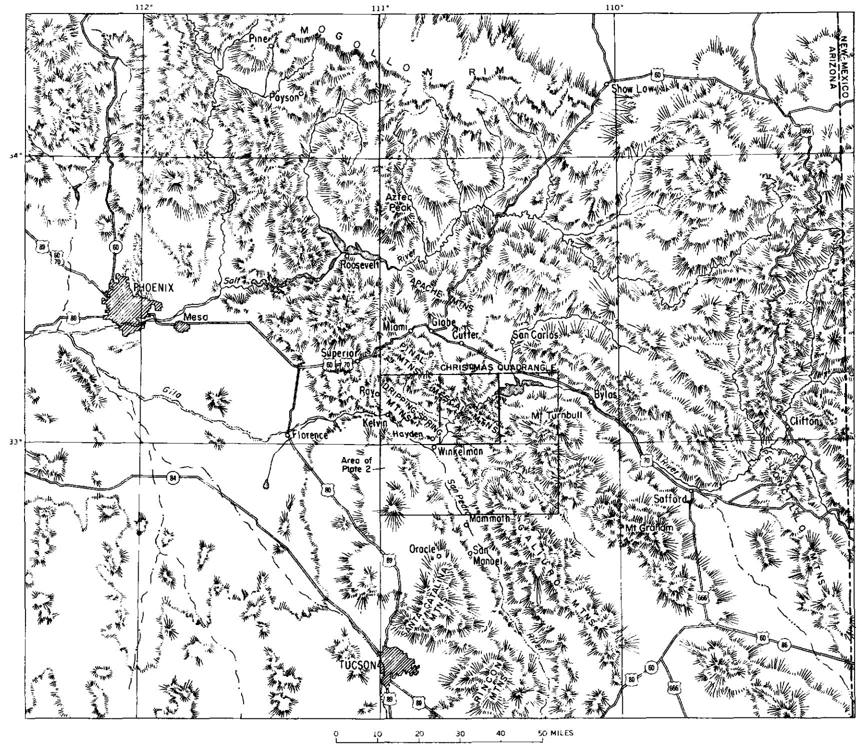

Figure 1.—Index map of southeastern Arizona showing location of the Christmas quadrangle.

PHYSICAL FEATURES

The Mescal Mountains extend northwestward diagonally through the central part of the quadrangle, and the south end of the Hayes Mountains extend into the north part of the quadrangle. Other prominent topographic features are Granite Basin on the southwest slope of the Mescal Mountains; the canyon of the Gila River, which cuts through the Mescal Mountains; and the plateau in the southeast corner of the quadrangle, which is dominated by a prominent peak shown on the map as Quartzite Mountain but known to local residents as Red Rooster.

The highest point in the quadrangle, which is somewhat above 6,250 feet, is at the west boundary on the crest of the Mescal Mountains; and the lowest point, which is about 1,950 feet, is on the Gila River, also at the west boundary; thus, the total relief in the quadrangle is about 4,300 feet. Where the Gila River cuts through the Mescal Mountains, relief of 2,000 feet in a horizontal distance of 1 mile is common.

The quadrangle has an integrated drainage network with lateral intermittent streams flowing southeastward and northwestward into the southwestward flowing Gila River, which is a perennial stream although the flow is controlled by Coolidge Dam and during part of the year virtually no water is allowed to flow out of San Carlos Reservoir. The intermittent streams have their courses on bedrock or on a shallow alluvial cover on bedrock, and in the larger of these streams, water can often be obtained, even in dry periods, by digging in the alluvial material. There are a few springs in the quadrangle and one of these, Mescal Warm Spring, which issues from limestone, has deposited an enormous tufa mound. The temperature of this spring was not determined, but the water was considerably below atmospheric temperature when I visited the spring.

The wide range in elevation in the quadrangle and the consequent variations in temperature and rainfall have resulted in the growth of a great many kinds of plants. Ponderosa pines grow high on the north-facing slopes of the Mescal and the Hayes Mountains. At successively lower elevations, plants which are progressively more drought and heat tolerant appear, until in the dry southern part of the quadrangle, the typical Sonoran Desert plants dominate the landscape. The brush on some of the higher north-facing slopes is so thick as to be virtually impenetrable for a man on foot or horseback; other vegetational hindrances are dense mesquite thickets along the Gila River and cholla "jungles" in the south part of the quadrangle. Such places are, fortunately, not abundant.

CLIMATE

The Christmas quadrangle can be said, in a general way, to have a semiarid climate, although the higher parts of the Mescal Mountains probably get 20 to 25 inches of precipitation a year.[2] The precipitation falls in two main stormy periods: one in the winter months of December through March, and the other in the summer thundershower season of July through mid-September. The summer thundershowers sometimes reach cloudburst proportions and flash floods result.

Midday temperatures in the summer in the area are unpleasantly warm, but the wide daily temperature range, with a daily minimum temperature as much as 30° lower than the maximum results in pleasant nights. Midday temperatures in the winters are generally pleasant but periods of cold weather occur. Outdoor work can best

[2] On the basis of a comparison with the Pinal Ranch climatological station, which is on U.S. Highway 60–70 about halfway between Miami and Superior, at an elevation of 4,520 feet.

be accomplished in the months of March through May, and October and November, although strong winds are common in the spring.

Some climatological data from stations in and near the Christmas quadrangle are given in the following tables.

Average precipitation (in inches) at points in and near the Christmas quadrangle

[Data from U.S. Weather Bureau, 1960]

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Elev. (ft)
Globe [1]	1.56	1.40	1.29	0.63	0.26	0.41	2.31	2.81	1.37	0.75	0.95	1.66	15.40	3,540
Kelvin [2]	.19	1.01	.00	.16	.00	Tr.	.39	2.84	.03	6.02	.61	3.64	14.89	1,814
Pinal Ranch [1]	2.83	2.97	2.71	1.15	.32	.36	2.57	3.59	1.84	1.34	1.81	3.48	24.97	4,520
San Carlos [2]	.13	1.29	.00	.05	.00	Tr.	2.97	1.18	Tr.	4.27	.52	3.13	13.54	2,643
San Carlos Reservoir [1]	1.51	1.38	1.36	.64	.21	.43	1.60	2.11	1.18	.66	1.01	1.68	13.77	2,532
Winkelman [2]	.12	1.14	.00	.42	.00	.03	1.59	4.99	.29	2.22	.38	3.32	14.50	2,120

[1] Long-term mean based on period 1931–55.
[2] Figures for 1959 only.

Temperature data for 1959 (in degrees Fahrenheit) at points in and near the Christmas quadrangle

[Data from: U.S. Weather Bureau, 1960]

	Annual average	Maximum		Minimum		Extreme Maximum		Extreme Minimum	
		Temp.	Month	Temp.	Month	Temp.	Date	Temp.	Date
Globe	63.5	85.2	July	46.1	Dec.	107	June 17	20	Jan. 21
San Carlos	63.8	85.8	July	45.3	Jan.	108	June 24	11	Jan. 1
San Carlos Reservoir	66.8	87.9	July	47.5	Dec.	109	June 18	24	Jan. 1
Winkelman	66.6	88.7	July	48.9	Dec.	112	June 17	18	Jan. 2

Temperature data not available for Kelvin and Pinal Ranch.

PREVIOUS WORK

The earliest geological observations in the Christmas quadrangle were made by Lieutenant William H. Emory, of the U.S. Corps of Topographical Engineers, who traversed the north part of the quadrangle and the southwest corner en route from Fort Leavenworth to San Diego in 1846, in company with a military force, "the Army of the West," under the command of Colonel Stephen W. Kearney (Emory, 1848, p. 71–76). This party, in general, followed the Gila River across Arizona, but the impenetrable canyon of the Gila through what is now the Christmas quadrangle forced a detour of some 60 miles. This detour took the party from the river at about where Coolidge Dam now stands, across the north end of the quadrangle, to the east end of the Pinal Mountains—called the Piñon Lanos by Emory—thence into Dripping Spring Valley and down the valley to its junction with the Gila (fig. 1). They followed the Gila

River for about 6 miles, but once more left the river, probably because of dense brush and abrupt canyon walls. This time they went up a dry wash on the south side of the river to near the base of Saddle Mountain [3]—referred to as Saddle-Back and illustrated by Emory (1848 facing p. 75)—and then by way of another dry wash down to San Pedro Valley and on to its junction with the Gila. On this traverse, Emory observed, in the Hayes Mountains, the various units that have come to be known as the Apache Group—the Barnes Conglomerate member, Mescal Limestone, and red sandstones of the Pioneer and Dripping Spring Formations—and the abundant red granite. He also noted Apache Group rocks on the west slope of the Pinal Mountains and remarked on dikes of trap rock along the Gila below its junction with Dripping Spring Valley, but he incorrectly reported that Saddle Mountain was red sandstone.

Lieut. A. W. Whipple, of the U.S. Corps of Topographical Engineers, was apparently the next trained observer to visit the area. While engaged in the boundary survey between Mexico and the United States in 1851, he visited the area of the confluence of the San Pedro and Gila Rivers and collected some fossils from the limestone exposed there (Marcou, 1858, p. 24).

The next penetration of the region by trained observers was in 1873 by members of the Wheeler Survey west of the 100th meridian, the railroad survey along the route near the 32d parallel having passed some distance to the south (Parke, 1855). A. R. Marvine crossed the Apache and the Pinal Mountains northwest of the Christmas quadrangle (Marvine, 1875, p. 218–225), and G. K. Gilbert crossed the mountains east of the quadrangle, noting the volcanics that, to the north, overlap the sedimentary rocks near Saddle Mountain (Gilbert, 1875, p. 509).

Detailed geologic investigations in the Christmas quadrangle were stimulated by the mining activity in the region. The first of these studies was of the coal in the Deer Creek coal field and several publications resulted (Devereaux, 1881; Walcott and Bannon, 1885; Campbell, 1904a, 1904b; and Ross, 1925a, p. 114–117). Ransome prepared the first exhaustive accounts of the geology of nearby areas as a result of his studies of the Globe, Miami, and Ray mining districts (Ransome, 1903; 1904; 1919; 1923). After the publication of the Ray folio (Ransome, 1923) depicting the geology of the Ray quadrangle, which adjoins the Christmas quadrangle on the west, it was possible to project rock units and structural features into the Christmas quadrangle. Darton's reconnaissances through the quad-

[3] The northern slope of Saddle Mountain extends into the Christmas quadrangle southwest of The Tablelands.

rangle—evidently originally intended for publication in the folio series (Ross, 1925b, footnote p. 2)—were published in an Arizona Bureau of Mines Bulletin in 1925 (Darton, 1925). This same year saw the publication of a report by Ross (1925b) on the Saddle Mountain and Banner mining districts. Schwenneson (1921) had, a few years before, briefly described some geologic features of the east part of the quadrangle. No further geologic work was published until 1956, when the results of the U.S. Geological Survey and Bureau of Mines explorations in the Christmas mine, late in the Second World War, were reported by Peterson and Swanson (1956). More recent exploration work at the mine has been reported by Eastlick (1958). Bromfield and Shride (1956) prepared a map of the San Carlos Indian Reservation, but detail for the part of the reservation that is in the Christmas quadrangle was taken from a map previously published by Darton (1925, pl. 72) and does not represent new information. The portions of the quadrangle shown on the geologic maps of Gila County (Wilson and others, 1959) and Pinal County (Wilson and Moore, 1959) likewise represent compilations of previously published data, except for the southeast corner of the quadrangle, which was taken from new reconnaissance mapping by Creasey, Jackson, and Gulbrandsen (1961). The two reports by Darton and Ross were the only geologic reports of an areal nature available on the quadrangle prior to the preparation of this report.

ACKNOWLEDGMENTS

The residents of the area have been, without exception, friendly and most helpful, and have freely given the information at their disposal. I feel indebted to all of them, but especially to Mr. and Mrs. Dick Van Winkle and Mr. and Mrs. A. O. Brundrick. The officials of Inspiration Copper Co. have contributed much helpful information, in particular John T. Eastlick, resident geologist at the Christmas mine, without whose help the report would have been sadly incomplete. W. D. Hurst and George Hervey provided capable assistance in the field, and many of my colleagues on the Geological Survey have, by their visits in the field and stimulating discussions in the office, contributed materially to my understanding of the geology of the quadrangle.

REGIONAL GEOLOGIC SETTING

The regional geologic setting of the Christmas quadrangle is shown on plate 2. The Mescal Mountains, which extend diagonally through the quadrangle, are part of the well-defined mountain system that extends from the Pinal Mountains to Mount Graham (fig. 1). This mountain system can be regarded in a general way as a southwestward tilted fault block, although the Deer Creek syncline on the south side of the Mescal Mountains shows that the structure is not so simple as a tilted fault block.

The most continuous structural features, other than the Deer Creek syncline, are the high-angle faults that extend through the Christmas quadrangle north of the Mescal Mountains. Some of these faults, such as the Mescal Creek fault (p. E47) and the Hawk Canyon fault (p. E48), have displacements of several thousand feet, but other no less continuous faults such as the Bull Basin fault (p. E49), have much smaller displacement.

Most of the rock units in the Christmas quadrangle have been named and described by workers in nearby areas. The units in the Christmas quadrangle do not differ markedly from their previously described counterparts in these adjacent areas. For these reasons, the formation descriptions that follow are generally brief with the emphasis on the local aspects of each unit.

PRECAMBRIAN ROCKS

Precambrian rocks are widely exposed in the north part of the Christmas quadrangle. Eleven units are distinguished on the map; four of these are assigned to the older(?) Precambrian, and seven to the younger(?) Precambrian, although the absolute age of none of them has been determined within the quadrangle.

OLDER(?) PRECAMBRIAN ROCKS

The older(?) Precambrian rocks include schist, metavolcanic rocks, granite, and granodiorite. None of these have been assigned formational names in the Christmas quadrangle, although in nearby areas various formational names have been used. Many kinds of metamorphic rock—in most places intruded by coarse-grained rocks and overlain by nonmetamorphosed sedimentary rocks—are included in the formation known as the Pinal Schist. The schist and metavolcanic rocks of the Christmas quadrangle undoubtedly correlate with Pinal Schist. To the south, the name Oracle Granite (Peterson, 1938) has been used for generally coarse grained granite, quartz monzonite, alaskite, and related rocks; whereas, to the north rocks of the same type have been called the Ruin Granite. The name Madera Diorite was used for a large intrusive mass in the Pinal Mountains that extends just inside the west part of the Christmas quadrangle, where it is mapped as granodiorite. For various reasons, none of these names are regarded as particularly appropriate to the rocks in the Christmas quadrangle. The relative ages of three of the four older Precambrian units are known but the age of the fourth, the metavolcanics, is not known; however, it is, believed to be older than the intrusive rocks by comparison with nearby areas where the so-called Pinal Schist includes many types of rocks, all of which predate the older Precambrian intrusives. In the following pages, the units will be discussed from oldest to youngest, so far as their relative ages are known, with the exception of the metavolcanics, which will be discussed after the schist.

SCHIST

Schist has very limited distribution in the quadrangle, being found at only two places on the north side of the Mescal Mountains. Schist is exposed on the north side of Mescal Creek in the northwest part of the quadrangle and on the south side of Hawk Canyon near the east boundary of the quadrangle.

The schist exposed on Mescal Creek is a red coarse-grained quartz-mica schist, which is nearly surrounded by granite and has somewhat gradational contacts with the granite. The gradational contacts, the absence of any other bodies of schist nearby, and the near encirclement of the schist by granite are regarded as evidence that the body of schist represents either a large inclusion in the granite or a roof pendant.

The body of schist on the south side of Hawk Canyon is also a quartz-mica schist, but the grain size is generally much smaller and the color ranges from gray to reddish gray. Part of the contact of the schist is an intrusive contact with granite and part is a fault contact with volcanic rocks of probable Tertiary age.

METAVOLCANIC ROCKS

Metavolcanic rocks are exposed on the east and west sides of Quartzite Mountain in the southeast corner of the quadrangle. On the east side of Quartzite Mountain the metavolcanic rocks are cut by a diabase dike, and on both sides of the mountain they are overlain by the Dripping Spring Quartzite. The bodies of metavolcanics are cut off on the north by a high-angle fault.

The metavolcanic rocks are principally silicic varieties, although their mineral composition can not be determined without the aid of a microscope or X-ray equipment.

The metavolcanic rocks are light brown, brownish gray, or dark gray on weathered surfaces, and fresh surfaces are generally dark gray, locally with reddish-brown spots. The rocks are cut by indistinct steeply dipping foliation but have no relict flow structure. Some rocks contain rounded embayed quartz crystals as well as aggregates of sericite and hematite set in a fine-grained matrix, which seems to be mostly sericite and which also contains small apatite and magnetite crystals. Other rocks contain magnetite, a small amount of biotite and chlorite, and aggregates of sericite, quartz, and clay set in a finer grained matrix of the same minerals plus potassium feldspar.

GRANITE

Granite is the most widely exposed unit, other than the Gila Conglomerate, on the north side of the Mescal Mountains in the Christmas quadrangle. It is exposed all along the northeast base of the Mescal Mountains, from the crest of the Hayes Mountains eastward for several miles, and along the northeast base of the ridge north of Coolidge Dam. The granite intrudes schist and is intruded by granodiorite, diabase, and diorite of Precambrian age, and by rhyolite dikes of probable Tertiary age. The granite is overlain by rocks of the Apache Group and by the Troy Quartzite.

Granite should be understood to be a formational name rather than a rock name, because most of the material included in the unit is actually alaskitic quartz monzonite. Granite is a particularly appropriate name, however, because in much of the area both the plagioclase and the potassium feldspar are red and, on casual examination, the rock appears to be a true granite or an alaskite. The mafic minerals, which consist almost entirely of at least partly chloritized biotite, rarely exceed 5 percent of the rock and at most places are considerably less, thus accounting for the designation alaskite. Thin aplite dikes are abundant in the granite and at some places quartz-microcline pegmatites are common.

The granite is generally coarse grained; the principal constituents range from about 1 mm to 1 cm in greatest dimension. At many places, the granite is coarsely porphyritic, containing microcline phenocrysts up to about 5 cm in greatest dimension. The average mineralogic composition is about 33 percent quartz, 30 percent plagioclase, 35.5 percent potassium feldspar, which is generally perthitic, and about 1.5 percent mica and accessory minerals. In some specimens, the quartz crystals are nearly equant grains with some crystal faces well developed; whereas in other specimens, the quartz is interstitial to the feldspars and lacks crystal faces. Potassium feldspar—including perthite—generally appears to have crystallized earlier than plagioclase. Large phenocrysts of perthite—up to 5 cm in greatest dimension—at many places are set in a matrix of 2 to 5 mm grains of quartz, plagioclase, and potassium feldspar. In some specimens, the potassium feldspar is partly surrounded by plagioclase resembling an incipient rapakivi texture. The plagioclase is extensively altered to clay and minute shreds of mica; the potassium feldspar is also altered but to a lesser extent.

In much of the granite, both the plagioclase and the potassium feldspar are red and at some places they are dark red; because the feldspars are so abundant, the entire rock is dark red. The red color is concentrated in microscopic fractures in the feldspars and can be destroyed on the surface by immersion in dilute hydrochloric acid for a few minutes.

GRANODIORITE

The granodiorite is exposed along the west boundary of the quadrangle on the north side of the Mescal Mountains, where border features indicate it intrudes the granite; elsewhere the granodiorite is intruded by diorite. The granodiorite is overlain by the Pioneer Formation. This granodiorite is part of a large intrusive mass, designated the Madera Diorite by Ransome (1903, 1923) and described as a quartz mica diorite.

The granodiorite is foliated and contains dark inclusions near its contact with the granite; the granodiorite is also finer grained at the contact than it is elsewhere. The grain size of the principal constituents away from the intrusive contact ranges from about 1 mm to 1 cm and averages about 4 mm.

The average composition of the granodiorite is 31 percent quartz, 45 percent plagioclase, 7 percent potassium feldspar, 14 percent biotite, and about 3 percent sphene, magnetite, apatite, and zircon. The plagioclase, which forms myrmekitic intergrowths with quartz along some grain boundaries, is zoned and has a composition range from An_{30} to An_{40}; it is also commonly partly altered to sericite. The potassium feldspar is generally perthitic but contains only a small amount of plagioclase. Sphene is present as large euhedral crystals; the other accessory minerals also occur as euhedral crystals but are generally enclosed in biotite.

APACHE GROUP

The Apache Group comprises, in ascending order, the Scanlan Conglomerate Bed, which is included with the overlying Pioneer Formation; the Dripping Spring Quartzite and its basal conglomerate, the Barnes Conglomerate Member; the Mescal Formation; and the basalt of the Apache Group, hereafter referred to as basalt or Apache basalt. All these units are exposed in the Christmas quadrangle but only four—the Pioneer Formation, the Dripping Spring Quartzite, the Mescal Formation, and the basalt—are shown on the map. The two conglomerates are too thin to show at the scale of the map.

The Apache Group has been assigned a younger Precambrian age by many workers, but that this is at best an imprecise assignment is shown by recent absolute age determinations by Silver (1960). He reported "a minimum age of 1,075±50 million years and a probable age of 1,200 million years or greater" for some uranium- and thorium-bearing minerals in granitic differentiates of diabase sills that intrude formations of the Apache Group in the Sierra Ancha Mountains. The Apache Group must be older than this because it is cut by the diabase.

PIONEER FORMATION

The Pioneer Formation is exposed in the Hayes Mountains and on the north side of the Mescal Mountain west of the Gila River. The Pioneer rests on granite and is conformably overlain by the Barnes Conglomerate Member, which forms a basal conglomerate of the Dripping Spring Quartzite. The Pioneer pinches out before reaching the Gila River when traced southeastward in both ranges, and this pinchout allows the Dripping Spring Quartzite and its basal conglomerate to rest directly on the granite.

The Pioneer Formation attains a maximum thickness of about 180 feet near the west boundary of the quadrangle in the Mescal Mountains. The formation consists of a basal conglomerate, the Scanlan Conglomerate Bed, somewhat slaty shale, siltstone, and sandy siltstone. The Scanlan, formerly of formational rank, is here reduced to the status of a bed. The shale is generally dusky red, whereas most of the coarser grained rocks are light yellowish brown to green. The red rocks frequently have ovoid green or greenish-gray spots, which are generally lacking in other red formations and which help to distinguish the red phases of the Pioneer from other units.

SCANLAN CONGLOMERATE BED

The Scanlan Conglomerate Bed—named Scanlan Conglomerate by Ransome (1903) for exposures near Scanlan Pass in the Globe quadrangle—forms a basal conglomerate of the Pioneer Formation in the Christmas quadrangle; it is too thin to show on the map but at most places where the Pioneer Formation overlies granite and the contact is exposed, the Scanlan was oberved resting on the granite.

The Scanlan in the Christmas quadrangle is everywhere a coarse arkose containing scattered large pebbles of quartzite and, at some places, white vein quartz. The quartzite and quartz pebbles are usually well rounded but some broken rounded pebbles (fig. 2) indicate that the rounding took place in an erosion cycle prior to that which produced the Scanlan.

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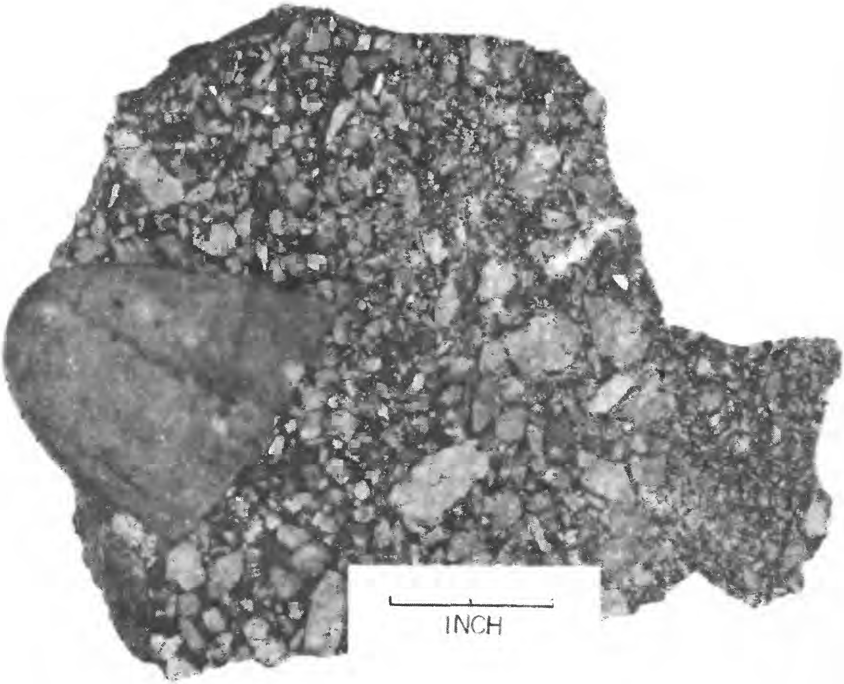

FIGURE 2.—Specimen of Scanlan Conglomerate Bed with large, broken quartzite pebble and angular feldspar and quartz grains set in jasper matrix.

DRIPPING SPRING QUARTZITE

The Dripping Spring Quartzite, which as used here includes the Barnes Conglomerate Member, is exposed in the Hayes Mountains, and along the north side of the Mescal Mountains from the west boundary of the quadrangle to within about 2½ miles of the east boundary. The formation is also exposed on Quartzite Mountain and in the hills on either side of Coolidge Dam.

The Dripping Spring Quartzite rests concordantly on the Pioneer Formation through most of the Hayes Mountains and the Mescal Mountains west of the Gila River. The Pioneer Formation pinches out just west of the Gila, and the Dripping Spring rests on the granite to the eastern limit of the Dripping Spring. On Quartzite Mountain, the Dripping Spring overlies metavolcanic rocks but the contact is not well exposed. The Dripping Spring Quartzite is overlain by the Mescal Formation in much of the quadrangle; but at places, particularly east of the Gila River, the Mescal is so thin it has not been shown on the map. At places, such as on Quartzite Mountain, the Troy Quartzite rests directly on the Dripping Spring Quartzite.

The Dripping Spring Quartzite, which attains a maximum thickness of about 550 feet in the Mescal Mountains west of the Gila River, can be divided into four units or members. These units consist of: (1) the Barnes Conglomerate Member at the base of the formation; (2) a cliff-forming quartzite unit above the Barnes; (3) a unit of interbedded red shale and quartzite that generally forms a slope; and (4) an upper thin-bedded, somewhat shaly quartzite that forms a stepped cliff.

BARNES CONGLOMERATE MEMBER

The Barnes Conglomerate Member has a maximum thickness in the quadrangle of about 45 feet but, generally, is 10 to 15 feet thick. In places there are two, and at other places three, conglomerate beds, separated by a feldspathic quartzite. The amount of feldspathic quartzite increases and the thickness of the conglomerate decreases when traced southeastward from just west of the Gila River until the Barnes is indistinguishable from the feldspathic quartzite that normally overlies it.

The Barnes Conglomerate Member is one of the most distinct and readily recognized units in the quadrangle. Well-rounded ellipsoidal pebbles of milky quartz and white, gray, buff, brown and red to reddish-gray quartzite and chert are set in a matrix of angular quartz, feldspar, and quartzite. The color of the matrix ranges from light yellowish gray or reddish gray to dark gray but is most commonly dark gray. The dark colors are generally due to a hematite coating on the quartz and quartzite grains, and to detrital hematite and magnetite grains; but at a locality on the north side of the Mescal Mountains in the northwest part of the quadrangle about 1½ miles northwest of Mud Spring, the matrix contains from 10 to 30 percent secondary tourmaline. At some places, the dark color is due to a large proportion of smoky quartz in the matrix. The feldspar content of the matrix ranges from trace amounts to 60 percent but is generally in the range of 10 to 30 percent. The highest percentages of feldspar are found where the conglomerate rests directly on the granite with no intervening Pioneer Formation.

UPPER MEMBERS OF DRIPPING SPRING QUARTZITE

The quartzite unit above the Barnes Conglomerate Member is buff to light gray, fine to medium grained, well sorted, and medium to thick bedded, and it generally contains several percent of feldspar. The quartzite is usually about 100 feet thick but increases to about 200 feet at places.

The lower quartzite grades upward into a unit of interbedded red shale and gray, buff, and reddish-brown quartzite. Ripple marks and mud-crack casts are commonly displayed on bedding surfaces. This unit, about 150 feet thick, is usually a slope former except for a buff quartzite bed from 15 to 30 feet thick which occurs at places in the upper half of the unit.

The interbedded shale-quartzite unit grades upward into a somewhat shaly thin-bedded quartzite that forms a bluff or stepped cliff. The quartzite is buff to yellowish gray (sometimes dark grayish red), fine grained, and feldspathic, although not so noticeably as the lower quartzite unit. This upper quartzite is about 75 feet thick except in the western part of the quadrangle, where it reaches a thickness of about 125 feet. It thins southeastward and was not observed on the east side of the Gila River.

MESCAL FORMATION

The Mescal Formation is exposed conformably overlying the Dripping Spring Quartzite in much of the northwest quarter of the quadrangle, but at places it is either too thin to show on the map or is absent. The Mescal is generally overlain by the Troy Quartzite, but south of Mud Spring and just west of the quadrangle it is overlain by a thin sheet of amygdaloidal basalt.

The Mescal reaches a maximum thickness of about 200 feet on the north side of the Mescal Mountains near the west boundary of the quadrangle, and in the Hayes Mountains at the north boundary of the quadrangle. Elsewhere, it is thinner owing to erosion prior to the deposition of the Troy Quartzite. This erosional interval also, at least in part, accounts for the limited extent of the Apache basalt.

The Mescal Formation forms a brushy slope on the north side of the Mescal Mountains, and for this reason its stratigraphy is poorly known. A variety of rock types have been observed in the formation. A sandy dolomite—highly contorted, thinly laminated, light red, reddish-gray to gray—is common. Chert, which in most places appears to be a relpacement of the carbonate rock, is abundant and is the only rock type present where the formation is only a few feet to a few tens of feet thick. The chert beds at such places consist of thin, discontinuous plates of chert cemented by a generally darker chert. The chert may be any color from light gray to black, but red and reddish-gray chert is abundant. Other common rocks are regularly laminated sandy dolomite, medium-bedded gray limestone, which is commonly cherty, and white or nearly white marble.

The Mescal Formation is an important host rock for asbestos deposits in the area to the north of the Christmas quadrangle. The asbestos deposits in the area north of the quadrangle seem to be related to the diabase intrusives that cut the Mescal. Asbestos is generally lacking in the Mescal in the Christmas quadrangle despite similar crosscutting relations of diabase to the Mescal although one small deposit of asbestos has been worked just north of the quadrangle (Bromfield and Shride, 1956, p. 676–679).

BASALT

Basalt was observed overlying the Mescal at one locality in the quadrangle, which is in the northwest part of the quadrangle on the west side of the canyon, south of Mud Spring. The basalt is extensively exposed, however, above the Mescal west of the Christmas quadrangle. As exposed in the Christmas quadrangle, the basalt is a dark-green to dark-gray aphanitic rock containing scattered light-gray to white flattened amygdules. The amygdules consist of sericite, and the groundmass now consists of sericite as pseudomorphs of plagioclase laths and chlorite, which probably represents altered mafic minerals. One layer about 15 feet thick consists of sericite pseudomorphing plagioclase laths and from 15 to 40 percent ilmenite filling the interstices between the laths. South of Mud Spring, the basalt is separated from the Dripping Spring Quartzite by only a few feet of chert, which indicates either an extensive period of erosion prior to the extrusion of the basalt, or extensive solution of the Mescal Formation and resulting collapse of the basalt prior to the erosion interval that separates the Troy Quartzite from rocks of the Apache group.

TROY QUARTZITE

The Troy Quartzite, which is widely exposed in the Christmas quadrangle, has been assigned both a Precambrian and Cambrian age in the past, and has recently been reassigned to the Precambrian by Krieger (1961), which usage is followed herein.

The Troy Quartzite is generally concordant with the underlying rocks but it rests on Apache basalt, the Mescal Formation, Dripping Spring Quartzite, and possibly granite. Progressively older rocks appear beneath the Troy southeastward along the north side of the Mescal Mountains. The Troy is shown to be in depositional contact with granite at one locality about 1 mile north of Bull Basin (pl. 1), but this contact is not exposed; because there are faults along the base of the Troy a short distance to the northwest, this contact may actually be a fault. This cutting out of strata beneath the Troy is largely due to removal by pre-Troy erosion, but some disapperance of strata is also due to original depositional thinning of the Pioneer and Dripping Spring Formations to the southeast.

The Troy Quartzite is overlain by undivided Cambrian rocks in the Mescal Mountains and at places in the north part of the Hayes Mountains. Elsewhere, the Troy is overlain by the Martin Formation of Devonian age. The contact between the Troy Quartzite and the Cambrian rocks or the Martin Formation is generally concordant but at places there is a small discordance.

The Troy Quartzite, which attains a maximum thickness in the Christmas quadrangle of about 900 feet, can be divided into two members that have not been mapped separately: a lower conglomeratic sandstone and quartzite 200 to 500 feet thick, and an upper quartzitic member with a maximum exposed thickness of about 400 feet.

The lower member consists of a lower part of pebble conglomerate, sandstone, and conglomeratic sandstone, and an upper part of sandstone and quartzite with scattered thin beds of pebble conglomerate (in places only one pebble thick). The top of the lower member is a 20- to 75-foot-thick bed of soft sandstone, with abundant prominent slump structures that give a highly contorted appearance to the bed. The base of the lower member is a chert pebble conglomerate at places where the underlying unit is chert of the Mescal Formation or Apache basalt. Where the Troy rests on limestone or dolomite of the Mescal, Dripping Spring Quartzite, or granite, the basal conglomerates are composed mostly of quartzite and quartz pebbles. The lower member is generally medium to thick-bedded, and crossbedding is common. The sandstone and conglomerate beds are white, light gray, buff, and red. The red color is due to hematite coating on sand grains and, in some beds, to discrete hematite grains. The quartzite beds are buff, light brown, and reddish-gray. The pebbles in the conglomerate beds in the upper part of the lower member are mainly milky quartz, although quartzite pebbles occur.

The change in thickness of the lower member can be ascribed to three causes: (1) nondeposition of the lower chert-pebble conglomerate through much of the area; (2) thinning in a southeast direction of the balance of the member; and (3) erosion in Precambrian as well as later time.

The upper member of the Troy is medium- to thick-bedded to massive quartzite. Crossbedding is common but not as common as in the lower member. The quartzite beds are light gray to white, buff, and reddish gray. The buff beds are generally nearly white on fresh surfaces. Individual quartzite beds in the upper member are not separated by beds of soft material, and so, the upper member forms high precipitous cliffs, such as the north face of the crest of the Mescal Mountains, near the west boundary of the Christmas quadrangle.

DIABASE AND DIORITE

Diabase and what appears to be closely related diorite intrude all the Precambrian rocks in the Christmas quadrangle. An erosional unconformity separates the diabase from the overlying Cambrian rocks and, at one place, the Martin Formation.

The diabase and diorite have been mapped separately because texturally, they are quite different (fig. 3); the diorite is resistant to weathering and forms prominent outcrops, whereas the diabase is generally deeply weathered and crops out in few places. Compositionally, however, the two rocks are much alike, and they seem to be the same age.

The diabase and diorite generally occur as tabular bodies, approximately parallel to the bedding of the sedimentary rocks or to a prominent set of joints in the granite. The joints in the granite are also generally parallel to the bedding of the sedimentary rocks. Transgressive bodies also occur and sections *A–A′* and *B–B′* illustrate the supposed manner of occurrence of some diabase and diorite bodies. Both the diabase and diorite have chilled contacts against the rocks they intrude, but their mutual contacts are not exposed well enough to determine their relative age from chilled border rela-

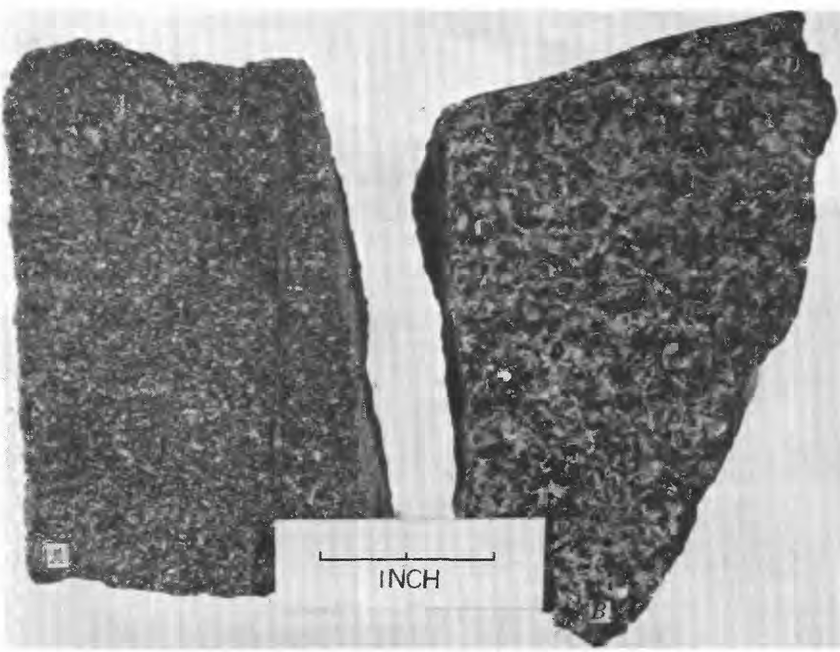

FIGURE 3.—Representative hand specimens of diorite (*A*) and diabase (*B*). Note prominent diabasic texture in *B* and its absence in *A*.

tions. Small pegmatites were observed in the diorite but were not observed in the diabase.

The diabase generally has a typical diabasic texture, in which the interstices between randomly oriented plagioclase laths are filled with pyroxenes and other mafic minerals; but at some places, the texture is ophitic and large pyroxene grains enclose several plagioclase laths. The rock is composed mostly of plagioclase, two pyroxenes, and black opaque grains, but some specimens also contain small amounts of biotite and apatite. The plagioclase is partly altered to sericite and in some specimens is completely altered. The pyroxenes are partly altered to chlorite; in some specimens no fresh pyroxene remains.

The diorite, in contrast to the diabase, has a hypautomorphic-granular texture and is nearly all fresh rock. The diorite is composed mainly of plagioclase, two pyroxenes, and black opaque minerals but also contains small amounts of olivine, biotite, and quartz. Some chlorite is developed around some of the mafic minerals, but otherwise the rock is unaltered.

CAMBRIAN ROCKS, UNDIVIDED

Cambrian rocks, consisting of quartzite, sandstone, shale, shaly sandstone, conglomerate, and carbonate rocks, are exposed on the north side of the Mescal Mountains, at a few places in the Hayes Mountains, and on the upper plate of the Reed Basin thrust.

These Cambrian rocks are generally concordant with the underlying units, but they rest on diabase, Troy Quartzite, Mescal Formation, and granite. Thus, a considerable erosional unconformity separates the Cambrian and older rocks. The Cambrian rocks are overlain by the Martin Formation.

The Cambrian rocks have a maximum exposed thickness of about 400 feet in the Mescal Mountains east of the Gila River. Elsewhere, the section is thinner and at places is only a few tens of feet thick. The changes in thickness from place to place are partly due to removal by pre-Devonian erosion and partly due to deposition of the Cambrian rocks on an irregular surface. Thinning of the Cambrian section due to pre-Devonian erosion is shown by the Martin Formation resting directly on diabase on the north side of the Mescal Mountains just south of where the San Carlos Indian Reservation boundary crosses the crest of the mountains.

Four subdivisions of the Cambrian section can be recognized at some places where the section is most complete. These four subdivisions, in ascending order, are (1) an angular boulder conglomerate, (2) medium-bedded gritty quartzite, (3) a sandstone and quartzitic sandstone unit with abundant burrow marks on bedding surfaces, and (4) a mudstone and shale unit that contains thin quartzite layers in the lower part and thin carbonate beds in the upper part.

A dark, reddish-brown to purplish-brown, poorly sorted, angular boulder conglomerate, 5 to 50 feet thick, commonly occurs at the base of the Cambrian section where the underlying rock is diabase; but where the underlying rock is the Troy Quartzite or the Mescal Formation, the conglomerate is not present. The presence or absence of conglomerate at the contact between the Cambrian rocks and granite was not determined because this contact is hidden by talus. The boulders in the conglomerate represent all the older sedimentary units, but boulders of the igneous rocks were not observed.

A medium-bedded, crossbedded gritty quartzite unit as much as 50 feet thick overlies the conglomerate at some places and at others rests directly on the Precambrian rocks. This quartzite is buff, light brown, and reddish gray. The coarse grains that produce the gritty appearance consist of quartz and quartzite.

The gritty quartzite is overlain at places by a white to light-gray to buff medium- to thick-bedded sandstone and quartzitic sandstone unit about 30 to 100 feet thick. At some places, the sandstone unit rests on the Precambrian rocks, and at one place, it rests on the angular boulder conglomerate that forms the lowermost unit of the Cambrian. Most of the bedding surfaces of the sandstone unit are marked with abundant low crossing ridges, which appear to be animal burrows. The individual sandstone beds are separated by mudstone and shaly sandstone, both of which become progressively more abundant upward until shaly material predominates. The predominance of shaly materal is the chief characteristic of the uppermost recognized unit of the Cambrian section.

The shaly unit at the top of the Cambrian section ranges from a few feet to as much as 300 feet thick. At places, it rests on the burrow-marked sandstone unit and at others, on Precambrian rocks. Quartzite beds from a few inches to 1 foot thick occur abundantly in the lower part. These quartzite beds commonly contain linguloid brachiopods that appear as short, sometimes curved, white streaks on weathered surfaces. Thin carbonate beds occur in the upper part of the shale unit. Collections of rather poorly preserved trilobites were obtained from the shale unit at two localities in the small canyon west of Poverty Flat about 1 mile south of the Gila River and at one locality below the 4767 peak in the prominent canyon east of the confluence of Gilson Wash and Tulapai Creek. A. R. Palmer (written communication, 1960) reported that scraps of trilobites in one collection from west of Poverty Flat "seem to represent a bolaspidellid and a marjumiid form. Associations of trilobites of this type are generally characteristic of the upper Middle Cambrian, and the appearance of the trilobites in the other two collections is compatible with this."

Krieger (1961) assigns what appear to be the same rocks to the Bolsa and Abrigo Formations. The crossbedded gritty quartzite in the lower part of the Cambrian section in the Christmas quadrangle resembles rocks assigned to the Bolsa by Krieger and by other workers farther to the south. The higher units resemble rocks that Krieger assigns to the Abrigo, although in southeastern Arizona the Abrigo is dominantly carbonate rock (Gilluly, 1956, p. 16–20).

DEVONIAN ROCKS

MARTIN FORMATION

The Martin Formation of Devonian age is exposed throughout the length of the Mescal and the Hayes Mountains, and on the hills on either side of Coolidge Dam, on Limestone Ridge, on Quartzite Mountain, near the center of the south boundary of the quadrangle, and on the upper plate of the Reed Basin thrust. The formation has a nearly uniform lithology and thickness of about 250 feet everywhere that it is exposed except on the Reed Basin thrust. The Martin rests on Cambrian rocks in the Mescal Mountains except at one locality, where it rests on diabase. It also rests on Cambrian rocks in the northern part of the Hayes Mountains and on the upper plate of the Reed Basin thrust. Elsewhere, the Martin Formation rests on Troy Quartzite. The different rock units beneath the Martin demonstrate an erosional unconformity of considerable magnitude, but wherever the contact could be observed in detail, the rocks above and below it are conformable. The Martin Formation is conformably overlain by the Escabrosa Limestone of Mississippian age.

Two well-defined subdivisions of the Martin Formation can be recognized throughout the quadrangle. The lower unit, which is about 200 feet thick, consists of dolomite, limestone, and sandy dolomite. The upper unit, 50 to 75 feet thick, consists of shale.

The lower unit is characterized by pale-yellowish-gray (light-reddish-gray on fresh surface) medium-bedded lithographic dolomite. Dark-gray to dark-brown crystalline dolomite occurs at the base of the unit at a few localities, and a buff to bright-yellowish-brown limy dolomite bed, 3 to 10 feet thick, consistently occurs at the top of the unit. Several light-gray, somewhat mottled, limestone beds are present in the upper part of the carbonate unit and a few others occur through the lower part. Sandy dolomite beds are most commonly found near the base of the carbonate unit, and at some places a carbonate-cemented quartz sandstone occurs in the lower part of the unit. On Limestone Ridge, an oolitic hematite bed or iron-formation (described in the section on ore deposits) as much as 7 feet thick separates the uppermost limy dolomite bed of the carbonate unit from the overlying shale unit. Elsewhere in the quadrangle, this horizon is marked by hematite nodules in the dolomite or by the presence of a poorly sorted sandstone with a hematitic cement. The lower 30 feet of the Martin Formation, known locally as the O'Carroll bed, is an important host rock for ore deposits in the Christmas mine and in the Dripping Spring Mountains to the west of the Christmas quadrangle. The new ore body being developed in the Christmas mine is in this bed.

The shale unit that forms the upper division of the Martin Formation invariably forms a debris-covered slope, and good outcrops are found in only a few gullies. The shale is green or light yellow green. It is generally overlain by a thin-bedded slope-forming limestone, 20 to 40 feet thick; this limestone is herein regarded as part of the Escabrosa Limestone.

The Martin Formation on the upper plate of the thrust in Reed Basin is only about 120 feet thick. It consists of about 40 feet of shale and 80 feet of reddish-gray dolomite, which is quite sandy and thinly laminated near the base.

MISSISSIPPIAN ROCKS

ESCABROSA LIMESTONE

The Escabrosa Limestone conformably overlies the Martin Formation and is found wherever the Martin crops out except on Quartzite Mountain. The Escabrosa, which is conformably overlain by the Naco Limestone, maintains a fairly uniform thickness of 500 to 600 feet throughout the quadrangle.

Most of the Escabrosa is made up of massive limestone, which forms prominent and, at places, spectacular cliffs. The limestone is light gray to dark gray (in most places weathers to light gray) and contains abundant brown chert nodules. Caverns and other solution features are common. The uppermost 50 to 100 feet of the formation consists of medium- to thick-bedded gray to brownish-gray limestone with abundant light-brown chert beds. The contact with the overlying Naco Limestone is somewhat arbitrarily placed at the base of the lowest, nearly white, limestone overlying the brownish-gray limestone. At some localities, this contact is marked by a deep-red shale a few feet thick, but generally the shale was not observed.

Dark-gray and brown dolomite beds much like the dark dolomite locally found at the base of the Martin Formation occur in the Escabrosa at some places on the north side of the Mescal Mountains east of the Gila River.

Large horn corals and crinoid stems are abundant in the formation, but other fossils were noted at only a few horizons.

PENNSYLVANIAN ROCKS

NACO LIMESTONE

The Naco Limestone is one of the most widespread formations in the Christmas quadrangle. The Naco forms the dip slope on the south side of the Mescal Mountains across the full width of the quadrangle and accounts for the wood-grainlike pattern observed on the mountainside from a distance. The Naco is also exposed in the Hayes Mountains, on Limestone Ridge, on the hills on either side of Coolidge Dam, on the north side of the plateau south of Deer Creek, on the upper part of Ash Creek at the south boundary of the quadrangle, and at the east end of the Dripping Spring Mountains in the vicinity of Christmas and Winkelman.

The Naco, which has a maximum thickness of 1,500 to 1,700 feet in the Christmas quadrangle, conformably overlies the Escabrosa Limestone. The contact is somewhat arbitrarily located on the lowermost, nearly white limestone bed. The Naco is overlain by Cretaceous rocks. This contact is apparently conformable, but at some places the Cretaceous rocks consist of an undivided sedimentary unit, and at others they consist of the next younger unit, an undivided volcanic and sedimentary unit.

The Naco consists mainly of light-gray, in many places nearly white, medium-bedded, fine-grained to nearly porcellaneous limesone with partings or thin beds of yellow to yellowish-gray shale between individial beds. Yellowish-gray limestone beds, which at most places are shaly, occur through the section and are particularly abundant in the upper part. The prominent ledges, generally only a few feet high, are made up of several thinner beds that lack shaly partings.

The Naco Limestone is generally richly fossiliferous and has abundant fusulinids distributed through much of the section. Fusulinids have not been found in the lowermost 30 feet of the formation, however, and are scarce in a zone from about 400 to 700 feet above the base of the formation. Of 6 collections from the Naco exposed on the north side of Mescal Creek about 1½ miles northwest of Mescal Warm Spring, 5 contained fusulinids, all of Pennsylvanian age (R. C. Douglass, written communication, 1960). The highest collection—1,500 feet above the base and only about 30 feet below the top of the formation—according to Douglass "contains a fauna dominated by *Triticites* and does not contain any *Schwagerina* or *Pseudoschwagerina*. The *Triticites* are of a kind found in the latest Pennsylvanian, but often extend into beds of Early Permian age. My best guess of the moment would be that the youngest sample represents Late Pennsylvanian rather than Early Permian age."

CRETACEOUS ROCKS

Two formations in the Christmas quadrangle have been assigned a Cretaceous age. The older one, an unnamed sedimentary unit, can be rather confidently assigned a Late Cretaceous age on the basis of fossils collected east of the Christmas quadrangle (Ross, 1925b, p. 14). The younger unit, unnamed volcanic and sedimentary rocks, is also considered to be of Cretaceous age for reasons to be discussed below.

UNNAMED SEDIMENTARY ROCKS

An unnamed sedimentary formation, consisting of sandstone, shale, and conglomerate, is exposed at places along the south base of the Mescal Mountains and the north flank of the lava plateau in the south part of the quadrangle. This sedimentary formation overlies the Naco Limestone with no apparent unconformity; indeed, at places there is some confusion as to where the contact should be placed, because the upper part of the Naco locally contains pale-yellow limy sandstone beds that look much like sandstone beds in the Cretaceous section. The unnamed sedimentary formation is overlain by an unnamed volcanic and sedimentary formation consisting mainly of andesitic volcanic rocks and volcanic-debris sedimentary rocks. The upper contact is conformable at some places and clearly unconformable at others. In some places, the overlying volcanic unit contains interbedded sedimentary material identical to that in the lower sedimentary formation.

The sedimentary formation has a maximum exposed thickness of about 500 feet, but is generally much thinner. What appears to be the same sedimentary formation is exposed along Hawk Canyon east of the Christmas quadrangle, and there it attains a much greater thickness.

The section of the sedimentary formation on the north side of Reed Basin is the most complete section in the quadrangle. The following description applies only to this one locality, although in a general way it also fits the section on the south side of Reed Basin. The lower 50 feet of the formation consists of gray and greenish-gray mudstone with a thin coal seam or carbonaceous shale near the top of the mudstone. Light-yellow-brown sandstone beds begin

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to appear interbedded with gray to buff mudstone and shale just above the coaly bed. Mudstone and shale are less abundant upward, and about 200 feet above the base of the formation they are scarce. Coarse cobble to boulder conglomerate beds a few feet to tens of feet thick are abundant in the middle part of the section. The cobbles and boulders consist mainly of Troy Quartzite and various hard units in the Apache Group, but granite and limestone (predominantly from the Naco) are locally abundant. The upper part of the section is mainly light-yellow-brown sandstone.

Fossil wood is commonly found in the sandstone beds just above the coal bed or the carbonaceous shale which is the lateral equivalent of the coal. Wood is abundant nowhere else, although it is found at places stratigraphically higher in the section.

These unnamed sedimentary rocks probably correlate with similar rocks in the Klondyke quadrangle, southeast of the Christmas quadrangle, that Simons (1961) has referred to the Pinkard Formation and correlated with rocks in the Clifton-Morenci area (Lindgren, 1905, p. 73–74).

UNNAMED VOLCANIC AND SEDIMENTARY ROCKS

An unnamed volcanic and sedimentary formation of Late Cretaceous age covers most of the southern quarter of the Christmas quadrangle. The unit is also exposed in a small area 1 to 1½ miles northwest of Mescal Warm Spring. The volcanic unit rests on both the unnamed sedimentary formation of Cretaceous age and on the Naco Limestone. The contact with the Naco Limestone is generally concordant when examined in detail but represents a widespread erosional unconformity with a small angular discordance at some places. The various Tertiary units that overlie the Cretaceous volcanic formation either dip gently to the south or are horizontal, and there is generally a considerable angular discordance between the Cretaceous rocks and younger units.

The maximum thickness of the volcanic formation is uncertain, but an exploration hole on the east side of Little Gold Gulch, sec. 2, T. 55., R. 16 E., penetrated nearly 3,000 feet of the unit. The section cut in the exploration hole, which bottomed in what is probably the Naco Limestone, corresponds in a general way to the section observed on the surface.

Four rather indistinct subdivisions of the volcanic-sedimentary formation can be recognized. These subdivisions can be best observed by traversing the major northeast-trending stream channels where the rocks are generally fresh and well exposed. The interstream areas are covered with rubble and the rocks are sufficiently weathered to be difficult to distinguish. The subdivisions from bottom to top are

(1) a unit several hundred feet thick consisting of agglomerate, mudflows, and some flow breccias; (2) a unit of variable thickness but in places as much as 300 feet thick, consisting of coarse cobble to boulder conglomerate, sandstone, mudstone, and waterworked tuff; (3) a unit at least 1,000 feet thick, consisting of agglomerate, mudflows, lapilli tuff, and some flow breccias; and (4) a unit at least 1,000 feet thick, consisting mostly of flow breccias with some agglomerates and mudflows. Numerous hornblende andesite sills have been injected into the section, as well as into the Cretaceous sedimentary formation and the Naco Limestone, and these sills are commonly so weathered as to be difficult to distinguish from the rocks they intrude. The presence of these sills increases the difficulty of estimating the thickness of the various units.

The volcanic rocks are principally andesite, but basalt was observed at a few places. Most of the andesite contains abundant plagioclase and scattered hornblende phenocrysts in a light-gray to gray groundmass. Some specimens contain pyroxene in place of hornblende and some contain both. The basalt is generally dark brownish gray and contains a few plagioclase and olivine phenocrysts in an aphanitic groundmass. The sedimentary subdivision generally contains a large proportion of volcanic debris, but at some places is nearly devoid of volcanic material and is difficult to distinguish from the Upper Cretaceous sediments below the volcanic unit. Water-worked sedimentary material occurs in all the subdivisions of the formation but is abundant at only the one horizon.

The volcanic-sedimentary formation is assigned a Late Cretaceous age because of its intertonguing and gradational contact with the underlying sedimentary unit. Further support for this age assignment is provided by fossil wood that has been found at a few places in the volcanic section, and which is identical in appearance to that in the sandstone just above the coal bed. At one place southeast of The Butte, fossil wood was found at about 2,000 feet above the inferred base of the volcanic unit.

CRETACEOUS(?) OR TERTIARY ROCKS

Three intrusive units in the Christmas quadrangle have been assigned a Cretaceous(?) or Tertiary age. These intrusive units are microdiorite, feldspar-mica porphyry, and hornblende andesite. Their age relations are not completely known; for this reason, they are shown to be the same age on the explanation of the geologic map (pl. 1), but a few crosscutting and chilled border relations were observed in the field. These relations suggest that the microdiorite is the oldest of the intrusive units and the hornblende andesite is the youngest.

Many more dikes and sills occur in the southwestern part of the quadrangle than are shown on the map. Many dikes and sills have not been shown because they are narrow and can be traced only short distances, and because the topographic base map does not show enough detail in this area to permit the accurate location of small bodies.

MICRODIORITE

Several microdiorite intrusive bodies cut the Cretaceous volcanic rocks in the southwest part of the quadrangle, and dike offshoots of one of these bodies cut the Naco Limestone in the extreme southwest corner of the quadrangle. The microdiorite intrusive bodies have a complex cross-sectional shape with a few to many dikes and sills extending out from a plug or broad dikelike core. An example of the complexites of shape presented by these bodies is the intrusive body northeast of the confluence of Little Rock Creek and Deer Creek (see section *C–C′*, pl. 1), which has a vertical southern contact and a nearly horizontal northern contact and has several narrow dikes and sills projecting westward from the parent body.

The microdiorite is generally light gray (very pale yellowish gray on weathered surfaces), fine grained, and holocrystalline. Some of the rocks mapped as microdiorite consist of plagioclase (sodic andesine), microscopically colorless monoclinic pyroxene, and black opaque minerals with a small amount of microcrystalline groundmass. Other rocks contain biotite in addition to the pyroxene and some contain hornblende instead of pyroxene. The feldspar generally shows strong oscillatory zoning and commonly appears unaltered. The larger mafic crystals commonly are altered to chlorite and magnetite but small grains remain unaltered. A small amount of quartz (1 or 2 percent) is visible in most specimens, and one specimen contains about 10 percent quartz. The principal characteristic that serves to distinguish the microdiorite from the other intrusive rocks is the nonporphyritic fine-grained texture. The color and the form of the bodies are also useful criteria.

FELDSPAR-MICA PORPHYRY

Feldspar-mica porphyry as used herein includes rocks that were mapped as quartz-mica diorite and quartz-hornblende diorite by Ross (1925b), and as quartz-mica diorite by Peterson and Swanson (1956). The quartz-mica diorite and the quartz-hornblende diorite of Ross are virtually identical rocks. The only difference is that the quartz-mica diorite at Christmas may contain slightly more quartz than the quartz-hornblende diorite, but other quartz-mica diorite bodies shown by Ross are not richer in quartz.

The feldspar-mica porphyry occurs as dikes, sills, plugs, one small stock, and a large laccolith exposed in Granite Basin. Most of the porphyry intrusive bodies cut the Cretaceous volcanic rocks at the surface. At Christmas, some of the porphyry bodies cut the Naco Limestone at the surface; and in the mine workings, they cut older Paleozoic rocks. The large laccolith in Granite Basin was intruded into the Naco Limestone. The lower contact of the laccolith is generally in the lowermost part of the Naco Limestone, but in places is along the contact between the Naco and Escabrosa Limestones. Some of the feldspar-mica porphyry intrusive bodies are in contact with the microdiorite, and at one place on Ash Creek, a chilled border of feldspar-mica porphyry against microdiorite was observed. This is the only evidence of the relative age of the two rocks.

The feldspar-mica porphyry intrusive bodies are important ore controls in the Christmas mine (Peterson and Swanson, 1956, p. 363–364; Eastlick, 1958), where the Paleozoic carbonate rocks have been extensively metamorphosed adjacent to the intrusives. A peculiar feature of the large laccolith in Granite Basin is the small metamorphic effect it has produced in the adjacent limestones. The limestone immediately above the laccolith has been converted to a nearly white marble for a thickness of about 50 feet, and limestone inclusions have been converted to marble, which commonly contain pale-green garnet. The only other metamorphic effect observed was baked shale at a few localities where the laccolith was intruded along the Naco-Escabrosa contact. Where the underlying rock is limestone, there has been no recrystallization, but the weathered surfaces of the limestone are of a deep-reddish-gray color which was observed nowhere else. This large laccolith has a chilled zone only a few inches thick (fig. 4), which is surprisingly thin for an intrusive body about 2,000 feet thick.

The feldspar-mica porphyry contains nearly equant plagioclase phenocrysts and prismatic books of biotite set in a light-gray aphanitic groundmass. Small hornblende crystals are commonly present, and a few rounded and embayed quartz phenocrysts can be identified in most specimens of the larger intrusive bodies. Quartz phenocrysts are generally lacking in the small intrusives. Phenocrysts make up from 40 to 70 percent of the rock. The groundmass material consists of potassium feldspar indicated to be sanidine by X-ray diffraction patterns, quartz, and a small amount of plagioclase. The minerals in most specimens are fresh but in some, especially those from intrusives near Christmas, the biotite is partially chloritized; sericite and clay are developed in the plagioclase.

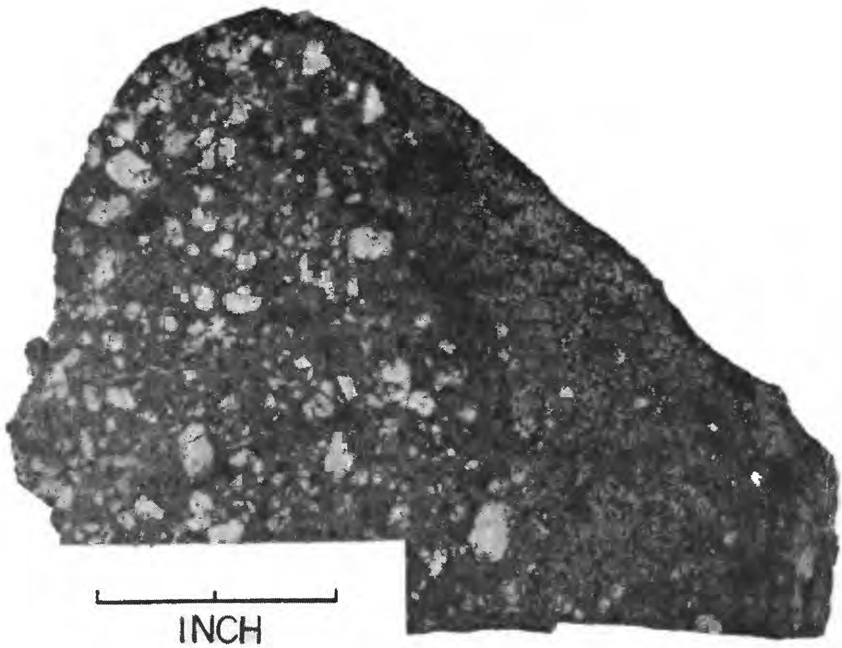

FIGURE 4.—Specimen of chilled zone of feldspar-mica porphyry laccolith in Granite Basin. Right side of specimen was at contact with Naco Limestone.

Since this study was completed, biotite in one of the feldspar-mica porphyry dikes in the Christmas mine has been dated as 62 million years old by the potassium-argon method (Creasey and Kistler, 1962). This date indicates an early Tertiary age for the feldspar-mica porphyry.

HORNBLENDE ANDESITE

Hornblende andesite dikes, sills, and plugs are widely distributed through the southern quarter of the Christmas quadrangle. In general, only the larger or laterally more continuous of these bodies have been shown on the map. Some dikes only a few feet thick can be traced for as much as 2 miles, and one sill from about 30 to 50 feet thick can be traced westward from the vicinity of Lime Spring for a distance of about 3 miles. These bodies cut the Cretaceous sedimentary and volcanic formations, other intrusive units, and Paleozoic rocks on the upper plate of the Reed Basin thrust. A chilled border of hornblende andesite against feldspar-mica porphyry was observed at one place, and this indicates that the hornblende andesite is the youngest of the three Cretaceous(?) or Tertiary intrusive units. Some crosscutting relations on the ridge south of Rock Creek and near the west boundary of the quadrangle south of Christmas suggest the feldspar-mica porphyry is younger than the hornblende andesite. At both localities, however, the porphyry is altered, and it is quite possible that the crosscutting relations have been confused by post-intrusive faulting along the porphyry dikes.

Three distinct rocks have been included in the hornblende andesite map unit. One type, which generally occurs as dikes and plugs, has small lathlike hornblende and plagioclase phenocrysts; the second variety, which has only been observed as sills, has large nearly equant hornblende phenocrysts as much as 2 inches in longest dimension (fig. 5); and the third variety, which occurs as small dikes and sills, lacks phenocrysts entirely. The three rocks are alike in having a gray aphanitic groundmass.

The possibility of a Tertiary age for at least this one intrusive unit is suggested by its intrusive relation to the Reed Basin thrust. The thrust overrides Upper Cretaceous rocks and the hornblende andesite was not intruded until after the thrusting took place.

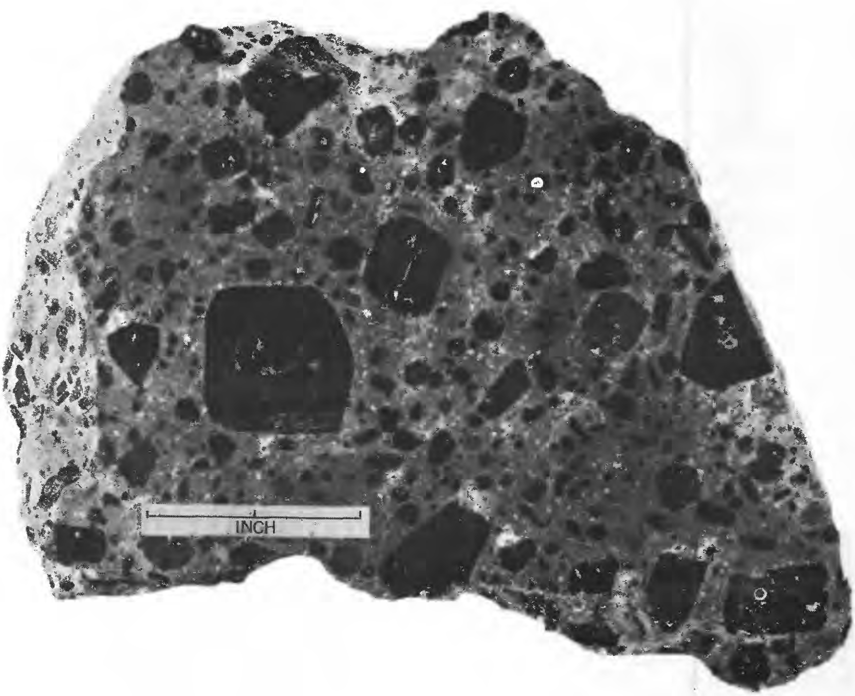

FIGURE 5.—Specimen of an unmapped hornblende andesite sill from southwest side of 3046 hill southwest of confluence of Deer Creek and Little Rock Creek.

TERTIARY ROCKS

Tertiary rocks are exposed along Rockhouse Canyon in the east part of the quadrangle, on Corral Mountain and the ridge crests to the west of it, on the high plateau at the south boundary of the quadrangle, and in a small area in the northeast corner of the quadrangle. The Tertiary rocks in the vicinity of Rockhouse Canyon from oldest to youngest are (1) conglomerate, (2) older volcanic rocks that have been further subdivided into 4 map units, and (3) intrusive rhyolite plug and dikes. Those in the south part of the quadrangle—including Corral Mountain—from oldest to youngest are (1) gravel, (2) basalt and andesite, and (3) a unit composed of interbedded tuff and rhyolite in which the larger areas of rhyolite have been shown with a separate pattern on the map. The Tertiary rocks in the northeast corner of the quadrangle are assigned to this tuff and rhyolite unit. All the Tertiary rocks exposed in the vicinity of Rockhouse Canyon, with the probable exception of the rhyolite plug and dikes, are older than Tertiary rocks exposed elsewhere in the quadrangle.

CONGLOMERATE

A conglomerate unit as thick as 300 feet rests on the Naco Limestone west of Coolidge Dam and is overlain by volcanic rocks. The conglomerate is thickest at the northwest end of its outcrop where it is cut off by a high-angle fault. The conglomerate thins to the southeast and was not mapped east of the Gila River, although it is generally present at the base of the volcanic section to the east boundary of the quadrangle.

The lower part of the conglomerate unit is composed of well-lithified limestone pebble-to-cobble conglomerate. The clasts are angular to subrounded and consist mainly of Naco Limestone. This lower limestone conglomerate thins southeastward and was not observed east of the Gila River; this thinning is responsible for most of the thinning of the entire unit. The upper part of the unit is composed of poorly consolidated, poorly sorted, volcanic-debris, pebble and cobble conglomerate. The volcanic clasts are much like the material in the overlying volcanic unit; perhaps the upper part of the conglomerate is reworked agglomerate.

OLDER VOLCANICS

A sequence of volcanic rocks several thousand feet thick is exposed in the east-central part of the quadrangle. These volcanic rocks rest on the conglomerate unit and are overlain by a younger conglomerate, which has been mapped as Gila Conglomerate.

The volcanic sequence has been subdivided into four units: (1) a lower basalt and andesite, (2) tuff, (3) dacite flows and tuffs, and (4) welded tuff at the top.

The basalt and andesite unit consists of interlayered, thin basalt flows, andesite flows, poorly consolidated basaltic agglomerates, and poorly consolidated volcanic-debris conglomerates. The basaltic rocks are generally dark reddish brown and contain small olivine phenocrysts and a few small lathlike plagioclase crystals in an aphanitic groundmass that is locally vesicular. Where vesicles are present, they are commonly filled with calcite. The andesites are light gray to gray and aphanitic, and contain scattered small plagioclase and hornblende phenocrysts. East of the Gila River, the basalt and andesite unit is cut by several dacite dikes and sills, some of which may have been feeders for the more silicic volcanics that overlie the basalt and andesite unit.

The tuff unit, which is well lithified in some places and is nearly unconsolidated in others, is nearly white to yellow brown and ranges from 50 to as much as 200 feet in thickness. The lower part contains abundant andesite, dacite, and pumice fragments in a matrix composed of shards that have in places been converted to clay; whereas the upper part is composed principally of shards and quartz, feldspar, and biotite crystals. East of the Christmas quadrangle, several prominent tuff beds are exposed in the volcanic section and at least one of them is lower in the section than the tuff shown on the map.

The dacitic unit consists mainly of flows and well-lithified tuffs but also includes some platy andesite and some basalt. The dacite flows contain quartz, plagioclase, and biotite phenocrysts. The groundmass is generally light gray or brown and aphanitic, but in some places, it consists of dark-gray glass; some glassy rocks lack phenocrysts. Some of these glassy rocks may actually be welded tuffs but definite criteria of their origin were not observed. The tuffs are generally light gray and are aphanitic with only a small percentage of phenocrysts consisting of quartz and plagioclase.

The uppermost unit, which is exposed only in a small area in the lower part of Rockhouse Canyon, is a welded tuff. The upper part of the section is a light-yellow-brown glassy rock about 25 percent of which consists of quartz, plagioclase, and biotite crystals. The glassy rock grades downward into a poorly consolidated tuff. In the glassy rocks, the plagioclase crystals are strongly zoned, the quartz crystals are rounded and embayed, and the groundmass, which has a very low porosity, contains many flattened shards.

INTRUSIVE RHYOLITE

A rhyolite plug with a northwestward-projecting dike is exposed in section 1, T. 4 S., R. 17 E., and a second dike is exposed on the north side of Hawk Canyon, about 1 mile southeast of the plug. These bodies cut Precambrian rocks and the northern dike is overlain by gravel assigned to the Gila Conglomerate. These bodies have been assigned a Tertiary age because dacitic or silicic extrusive rocks occur only in the Tertiary section. They are discussed here because of their proximity to the older volcanic unit, which contains abundant silicic rocks, and because rhyolitic intrusive rocks are absent near areas where rhyolitic extrusive rocks are exposed.

The intrusive rhyolite is light gray to pale buff and contains scattered plagioclase and biotite phenocrysts in an aphanitic groundmass. The groundmass, which amounts to 80 to 95 percent of the rock, consists mainly of potassium feldspar (possibly sanidine), quartz, minor amounts of plagioclase (andesine), and mica.

GRAVEL

A loosely consolidated gravel deposit is exposed beneath a nearly flat-lying series of basalt flows in the southern part of the Christmas quadrangle. The gravel deposit is exposed along the west end of the lava plateau at the south boundary of the quadrangle; a gravel deposit with the same relation to the basalt (and therefore included in the same map unit) but with a different composition is exposed on the north side of Corral Mountain and on the southeast side of Quartzite Mountain.

The gravel exposed at the west end of the lava plateau is composed of poorly rounded pebbles and cobbles, mainly of andesitic volcanic rock. The gravel is poorly sorted and is generally poorly consolidated, but at the south boundary of the quadrangle just north of Saddle Mountain, the gravel is sufficiently consolidated to produce steep bluffs. This material was mapped as Whitetail Conglomerate by Ross (1925b). The lower part of the gravel unit exposed on the north side of Corral Mountain is composed of debris from the Troy Quartzite, the Apache Group, and some limestone from the Paleozoic section; the upper part is composed of andesitic debris. The material mapped as gravel on the southeast side of Quartzite Mountain is actually a tuff containing scattered large pumice fragments and subangular quartzite clasts. This tuff was included in the gravel map unit because of its similar stratigraphic relations (that is, it overlies pre-Tertiary rocks and is overlain by a nearly horizontal basalt and andesite unit), but more probably correlates with some part of the Galiuro Mountains volcanic sequence.

BASALT AND ANDESITE

A series of nearly horizontal basalt and andesite flows is exposed around the edge of the lava plateau in the south part of the quadrangle, and in the area west of Corral Mountain. The basalt and andesite unit generally rests conformably on the Tertiary gravel unit, but in the area west of Corral Mountain, the gravel is only locally present and the basalt and andesite rest unconformably on the Cretaceous rocks. The basalt and andesite unit is conformably overlain by a tuff and rhyolite unit, which also has been assigned a Tertiary age.

Basalt is by far the most abundant rock in the unit; andesite was observed at only a few places on the north side of the lava plateau in the southern part of the quadrangle. The basalt occurs as flows from about 10 to 25 feet thick. The flows are vesicular to scoriaceous with the scoria weathering to dark red or dark reddish brown and the vesicular rock weathering to grayish brown. On fresh surfaces, which are dark brown, olivine phenocrysts and small, lath-like grains of what is probably plagioclase can be identified with a hand lens. Most of the vesicles are lined with opal and some are completely filled. The andesite is light gray or light grayish brown on weathered surfaces and a darker gray on fresh surfaces. The andesite is a dense aphanitic rock with no phenocrysts; its most distinctive feature is the great abundance of flat platelike chips wherever the rock crops out.

TUFF AND RHYOLITE

A unit composed of rhyolitic tuff and rhyolite flows caps the lava plateau in the south part of the quadrangle. It occurs on Corral Mountain, in the area west of it, and in a small area in the northeast part of the quadrangle. The unit rests conformably on the basalt and andesite in the lava plateau but rests unconformably on Cretaceous rocks and on basalt in the vicinity of Corral Mountain. The base of the tuff and rhyolite in the northeast part of the quadrangle is not exposed. The tuff and rhyolite unit is locally overlain by gravel or basalt, both of which have been assigned to the Gila.

The tuff and rhyolite unit is generally undivided, but at a few places the individual rhyolite flows are large enough to show separately. The unit contains some flow-banded vitrophyre in addition to the tuff and rhyolite.

Individual bodies of tuff are commonly well lithified, but evidence of welding of the tuff was not observed. The tuff weathers light brownish gray to light bluish gray but is nearly white on fresh surfaces. The tuff contains abundant pumice, rhyolite, and obsidian fragments set in a shard matrix which also contains some quartz, biotite, and feldspar crystals. Concretions and opal-filled cavities are abundant in some of the tuff bodies, and basalt fragments are present at some places.

The rhyolite, which is light brownish or reddish gray, commonly shows contorted flow banding, most of which is steeply inclined to vertical. Quartz phenocrysts can be identified in a glassy to aphanitic groundmass in some specimens of the rhyolite, but phenocrysts are lacking in most of the rhyolite.

TERTIARY AND QUATERNARY ROCKS

GILA CONGLOMERATE

Three map units have been used to depict the valley-fill sediments, commonly known as the Gila Conglomerate of Pliocene and Pleistocene age, and intercalated basalt flows in the Christmas quadrangle. These units are conglomerate or gravel, basalt, and undivided conglomerate and basalt. These units rest unconformably on all the older rocks in the quadrangle, and the three units collectively are among the most widespread rock units. They are overlain at places by younger gravel deposits.

An unconformity within the conglomerate can be recognized at a few places where streams have undercut steep banks. The conglomerate beneath the unconformity is generally steeply inclined, with dips from 25° to 50°, whereas the overlying conglomerate is horizontal or nearly so; the two conglomerates are not greatly different in composition. This unconformity was observed at a few places in Soda Springs Gulch, at one place along the Gila River north of Tuttles Ranch, and at a few places on the southwest side of Hawk Canyon. The steeply inclined conglomerate is shown separately on the map along the lower part of Hawk Canyon where the overlying horizontally bedded conglomerate is shown as undivided conglomerate and basalt. Elsewhere, no attempt has been made to show the two conglomerates separately. Intercalated basalt flows have not been observed in the steeply inclined conglomerate and it is possible their presence or absence could be used as a criterion for distinguishing two divisions of the Gila Conglomerate. This criterion would have to be used with some caution, however, because basalt is lacking at the surface in the rather gently inclined conglomerate in Dripping Spring Valley, but three water wells in the lower part of the valley penetrated about 40 to 50 feet of basalt interbedded with conglomerate at depths of about 200 feet.

The lower part of the Gila Conglomerate is generally composed mostly of the underlying rock; higher beds are more heterogeneous but are composed almost entirely of rocks exposed within a distance of a few miles. At some places, there is a crude stratification by type of source rock. In Hawk Canyon, the lowest exposed conglomerates are composed mainly of volcanic rocks like those in the older volcanic unit; the middle part of the section is composed mostly of limestone; and the upper part is composed of quartzite and granite.

The basalt flows are a few feet to a few tens of feet thick and are commonly vesicular throughout with large irregular cavities in the lower part of the flows. The rock is dark gray to dark brownish gray and aphanitic with only a few small phenocrysts of olivine and plagioclase. The basalt on The Tablelands has been assigned to this unit, principally because there is a small amount of unconsolidated gravel beneath the basalt and rounded quartzite pebbles on the upper surface of the basalt, indicating that the basalt was once intercalated in a section of loosely consolidated or unconsolidated gravels.

QUATERNARY DEPOSITS

Five map units have been used to show the distribution and variety of the Quaternary deposits in the Christmas quadrangle. The relative ages of these units are poorly known and on the map the five units are assigned to two age groups. Older alluvium and pediment gravels seem to be somewhat older than the younger alluvium, talus, and tufa.

OLDER ALLUVIUM

Older alluvium occurs at several places in the southern part of the quadrangle and in an area about 2 miles northwest of Coolidge Dam. The older alluvium includes material of diverse origin but all younger than the Gila Conglomerate and older than the alluvial material in the major stream channels.

Monolithologic breccias of Naco Limestone are included in the older alluvium unit on the south side of Deer Creek. These breccias appear to have formed by the breaking up of large blocks of limestone as the blocks slid down the steep slope north of the limestone outcrops.

The older alluvium on the north and south sides of Dripping Spring Valley are also essentially monolithologic breccias or gravels, but are not a product of landslides. Instead, they appear to be alluvial fan deposits. The deposits on the south side of the valley are composed of andesitic volcanic rock, and those on the north side are composed of Naco Limestone.

PEDIMENT GRAVELS

A dissected pediment surface in the northwest corner of the quadrangle is covered by gravels. The pediment slopes east-northeastward from the north base of the Mescal Mountains. The surface has an elevation of 4,800 feet about 1 mile east of the west boundary of the quadrangle and an elevation of about 4,150 feet just south of the confluence of Gilson Wash and Tulapai Creek.

The pediment gravel is composed almost entirely of material derived from resistant units in the Apache Group and Troy Quartzite. Boulders of the Barnes Conglomerate Member are particularly conspicuous. The pediment gravels rest on granite near the base of the Mescal Mountains, and on Gila Conglomerate near Tulapai Creek.

YOUNGER ALLUVIUM

Younger alluvium, which consists entirely of unconsolidated gravel, sand, and mud, is confined to the bottoms of the major stream channels in the quadrangle. It can be found through most of the length of these channels but only the larger areas of alluvium have been shown.

TALUS

Talus deposits have been mapped at the base or on some of the steeper slopes in the Mescal Mountains, and on the north side of Saddle Mountain. Only the largest talus deposits or those that obscure the bedrock geology are shown; many more talus deposits are present in the quadrangle. These talus deposits are essentially monolithologic and are composed of the rock immediately above them.

TUFA

Tufa, formed as spring deposits, is exposed as steep bluffs at several places along Mescal Creek and the Gila River upstream from its confluence with Mescal Creek. The largest of these spring deposits forms a broad terrace south of Mescal Warm Spring. All the tufa deposits have been formed by springs controlled by the Mescal Creek fault (p. E47).

The tufa is brownish gray, porous, vuggy and cavernous, and commonly it shows a horizontal banding. Small springs discharge from near the base of the larger tufa deposits, allowing the lower parts of such deposits to be thickly covered with vegetation.

STRUCTURE

Most of the structural features in the Christmas quadrangle are products of a long period of deformation that began sometime in the Late Cretaceous or early Tertiary and continued well into the

Tertiary and possibly into the Quaternary. Early phases of this long period of deformation produced folds and thrust faults, and later phases produced extensive high-angle, generally normal, faults.

The general concordance of strata from the base of the Apache Group into the Cretaceous rocks shows that the area was not subjected to strong compressive deformation from late Precambrian to latest Cretaceous time. Deformation in this interval was evidently confined to epeirogenic movement, and some inflation and faulting of the Apache Group and Troy Quartzite due to the intrusion of the diabase and diorite.

The predominant structural feature of the Christmas quadrangle is the prevalent southwestward dip of the rocks in each of the mountain blocks. This southwestward dip in some of the blocks is due to tilt of the mountain blocks along major high-angle faults which lie along the northeast side of the blocks. In the Mescal Mountains, however, at least part of the tilt is a result of folding that produced the Deer Creek syncline.

The principal structural features of the quadrangle can be seen on plate 2. These features will be described from oldest to youngest although the relative ages of some are poorly known. The folds will be described first because the largest fold in the quadrangle is older than at least one thrust fault, and the thrust faults will be described before the high-angle faults, some of which offset thrusts.

FOLDS

Well-defined folds are rare in the Christmas quadrangle. They are limited to a large syncline, the Deer Creek syncline, involving the Paleozoic and Cretaceous rocks, and two small synclines and two anticlines involving the Paleozoic rocks. The dip of the layered rocks is steepened or flattened near some high-angle faults and this results in a foldlike structure on the cross section, but such structures lack traceable axes.

DEER CREEK SYNCLINE

The Deer Creek syncline is the dominant structural feature in the south half of the quadrangle. The entire length of the Mescal Mountains in the Christmas quadrangle can be regarded as the north limb of the syncline, although the axis can be confidently projected only as far as the west side of Reed Basin. The syncline extends several miles east of the quadrangle.

No evidence of an anticlinal structure of similar magnitude can be found to the north of the Deer Creek syncline. To the south of the syncline, on Ash Creek at the south boundary of the quadrangle, the Paleozoic rocks strike northeastward and dip northwest; and as these beds are traced southward for about 2 miles, the strike becomes nearly north with a westward dip (Creasey, Jackson, and Gulbrandsen, 1961). An anticlinal axis that converges with the axis of the Deer Creek syncline thus can be postulated under the Tertiary volcanic rocks. This anticline is not a large structure because the dominant attitude of the Paleozoic rocks in the Holy Joe Peak quadrangle east of San Pedro Wash is a northwest strike and northeast dip (M. H. Krieger, oral communication, 1961).

The Naco Limestone and Cretaceous rocks on the north limb of the syncline dip southwestward at 15° to 30°, but on the south limb, particularly in the east part, these rocks are steeply inclined or, at some places, overturned. Some of the steepness of the south limb of the syncline may be due to later movement on two high-angle faults that generally parallel the south limb of the syncline at the front of the lava plateau just south of the syncline.

The folding that produced the Deer Creek syncline is probably the oldest phase of the Late Cretaceous or Tertiary period of deformation. This folding took place after the extrusion of the Cretaceous volcanic rocks but prior to the intrusion of at least some of the intrusive rocks, somewhat arbitrarily assigned a Cretaceous(?) or Tertiary age, which are so abundant within the area of exposure of the Cretaceous rocks. Hornblende andesite stocks and dikes cut a thrust plate which rests on the upturned Naco Limestone and Cretaceous rocks on the north limb of the Deer Creek syncline. The intrusive rocks cannot be closely dated, but their abundance within areas of exposure of the volcanic rocks and their compositional similarities to the Cretaceous volcanic rocks suggest that the intrusive rocks may be closely related to the extrusives.

DICKS SPRING CANYON SYNCLINE

The axis of a syncline can be traced along Dicks Spring Canyon for a distance of about 3 miles. This axis has a rather sinuous trace, and the syncline is asymmetrical in cross section and in longitudinal section. In the upper part of the canyon, there is a thick section of Naco Limestone on both limbs of the syncline, but at the south end, where the axial part of the syncline is covered by basalt interlayered in the Gila Conglomerate, there is only about 50 feet of Naco on the east limb. The beds on the west limb of the northern part of the syncline are more steeply inclined than those on the east limb, whereas in the southern part of the syncline, the eastern beds are the most steeply inclined.

The sinuosity of the axis and the asymmetry of the syncline may be due to the displacement of the thrust fault exposed on both sides of Dicks Spring Canyon; indeed, the syncline itself may be a product of the same forces that produced the thrust. If the thrust on the west side of the canyon is an uplifted part of the thrust exposed on the east side, then the syncline is in the upper plate of the thrust. The axis of the syncline and the trace of the thrust on both sides of the canyon are roughly parallel and trend about N. 35° W. This suggests compression in a N. 55° E. direction to produce the structures.

OTHER FOLDS

The axis of an anticline nearly parallel to the southern part of the axis of the Dicks Spring Canyon syncline can be traced in the Naco Limestone along the west side of Dicks Spring Canyon for nearly 1 mile. This anticline and the Dicks Spring Canyon syncline become less pronounced toward the south and probably die out entirely under the basalt of the Gila, because there are no reversals of dip in the Naco where it reappears south of the basalt.

A poorly defined anticline can be traced for a short distance on the upper plate of the thrust west of Dicks Spring Canyon. Beds on both limbs of the fold are gently inclined. Northeast of where a projection of the axis of the anticline would intersect the trace of the thrust, beds on the east side of the projected axis have been steepened by displacement on a high-angle fault. This fault prevents determining whether rocks in the lower plate of the thrust are also involved in the fold.

A small tightly compressed syncline is developed in the Paleozoic rocks north of Bull Basin. There are no anticlines or thrust faults associated with the syncline, and the syncline is in a down-dropped block between two high-angle faults. It is quite possible the fold was caused by drag on the two faults, but there has been at most only 300 feet of displacement on either fault, and several much larger faults in the quadrangle show little if any drag.

A large abrupt arch has been formed in the Naco Limestone by the intrusion of the Granite Basin laccolith (secs. *B–B′* and *C–C′*, pl. 1). The Naco Limestone on the south side of the arch and the Naco and Escabrosa on the north side—or floor of the laccolith—strike about N. 60° W. to N. 70° W. and dip 20° to 30° SW. On the east end of the arch, the attitude has changed to a strike of N. 15 E. to N. 30 E. and a dip of about 85° SE. The beds on the west end of the arch also strike northeastward but are not so steeply inclined. The laccolith has made room for itself almost entirely by forceful intrusion. A few small blocks of Naco Limestone are scattered through the porphyry, and for a short distance on the west end of the laccolith, the lowermost 50 feet or so of beds forming the roof appear to have foundered in the laccolith.

THRUST FAULTS

At least three and perhaps four thrust faults are present in the Christmas quadrangle. One of these, the Reed Basin thrust, is exposed as detached klippen along the south flank of the Mescal Mountains. A second is exposed on the northeast flank of the ridge northwest of Coolidge Dam; this thrust may connect, under the Gila Conglomerate, with a thrust mapped to the west boundary of Graham County by Wilson and others (1958). Thrust faults exposed on both sides of Dicks Spring Canyon may be parts of a third thrust, which was offset by later movement on a normal fault, but they may also be two separate thrusts.

The relative ages of these thrusts are not known, but two of them, the Reed Basin thrust and the thrust northwest of Coolidge Dam, appear to have been produced by forces acting in about the same direction and thus may be the same age, whereas the thrust in Dicks Spring Canyon appears to be a result of forces acting in a considerably more eastward direction.

REED BASIN THRUST

The Reed Basin thrust is here named for exposures of the thrust in the northeast part of Reed Basin. The upper plate consists of several detached klippen on the south flank of the Mescal Mountains between Reed Basin and the east side of the quadrangle. Paleozoic rocks on the upper plate of the thrust rest on the Cretaceous sedimentary and volcanic rocks, and on the Naco Limestone. The upper-plate rocks include the Naco Limestone, Escabrosa Limestone, Martin Formation, and undivided Cambrian rocks, although the Naco is by far the most abundant upper-plate unit.

The upper-plate rocks are considerably broken up and a normal stratigraphic succession—although even it is overturned—was observed at only one place, southeast of the Lower Coal Field mine.

The direction of displacement of the thrust is believed to have been from south or southwest to north or northeast. There are several reasons for this, none of which is conclusive, but in the aggregate, they support the interpretation. (1) The Martin Formation is thinner on the upper plate of the thrust than it is anywhere else in the quadrangle, and it is also quite thin in the Holy Joe Peak quadrangle to the south (M. H. Krieger, oral communication, 1960). However, in the Holy Joe Peak quadrangle, the Martin is almost entirely shale, whereas on the upper plate of the Reed Basin thrust it is only about one-third shale. (2) Cambrian rocks are on the upper plate of the thrust, but no Troy Quartzite is present on the upper plate. In the area to the south of the Christmas quadrangle, Cambrian rocks are widely exposed and the Troy Quartzite has a limited distribution (M. H. Krieger, oral communication, 1961), whereas in the north part of the quadrangle, the Troy Quartzite is more abundant than Cambrian rocks. (3) The asymmetry of the Deer Creek syncline and the trend of its axis suggest compression in a N. 20° to 30° E. direction as the cause of the folding. It seems to be most logical to assign the thrusting to this same period of deformation, although the possibility exists that the steepening of the south limb of the syncline was produced by the same forces that produced the Reed Basin thrust.

Several miles of displacement on the thrust seem to be required if the movement has been from the south.

The age of the Reed Basin thrust is not definitely known but is believed to be younger than the folding of the Deer Creek syncline and older than the intrusion of the hornblende andesite. The length of time between these two events is not known, but for reasons mentioned above, it is believed to be short.

THRUST NORTHWEST OF COOLIDGE DAM

A low-angle southwestward-dipping fault is exposed along the northeast side of the ridge northwest of Coolidge Dam (section C–C′, pl. 1). This fault, which has layered Precambrian rocks above it and crystalline Precambrian rocks below, disappears beneath the waters of San Carlos Reservoir and is presumably buried by the Gila Conglomerate southeast of the reservoir (section D–D′, pl. 1). To the north the low angle fault butts against a high-angle fault and is probably offset northward where any further continuation is covered by the Gila Conglomerate. A zone of imbricate faults with a trend approximately parallel to the low-angle fault has telescoped the Paleozoic and Precambrian strata on the ridge northwest of Coolidge Dam. Many more faults are present in this zone than are shown on the map (pl. 1).

This low-angle fault is herein regarded as a thrust fault largely because the imbricate faults just southwest of it seem best explained as slices off a sole thrust. Supporting evidence for this interpretation is provided by a thrust fault with similar structural relations that has been mapped on the northeast side of this same ridge in western Graham County about 6 miles southeast of Coolidge Dam (Wilson and others, 1958). It seems quite possible that the thrust at Coolidge Dam is a continuation of the same structure.

The amount of displacement and the direction of movement on this supposed thrust are unknown. However, the trend of its trace when connected with the thrust in Graham County is sufficiently close to the trend of the Deer Creek syncline to permit the assumption that the the thrust at Coolidge Dam is a late stage of the same period of deformation that produced the syncline, much as the Reed Basin thrust is believed to be a late stage of this period of deformation.

The fault relations shown at depth on section C–C′, plate 1, might require some modification if the assumption is correct that the thrust at Coolidge Dam is related to deformation that produced the Deer Creek syncline. The Tertiary rocks shown to be cut by the fault at depth rest with an angular unconformity on Cretaceous sedimentary and volcanic rocks just east of the Christmas quadrangle (Creasey, Jackson, and Gulbrandsen, 1961). The amount of time represented by this unconformity is unknown but the apparent short time intervals between tectonic events represented by the Deer Creek syncline, the Reed Basin thrust, and the hornblende andesite intrusives seem to require that the Tertiary rocks be younger than the thrusting.

The Tertiary, Paleozoic, and Precambrian rocks on the southwest side of this thrust probably have been tilted to their present steep attitude by displacement along one or more high-angle faults buried beneath the Gila Conglomerate to the northeast.

No great amount of displacement is required on the thrust in the Christmas quadrangle. Displacement on slices off the main thrust sufficient to cut out 200 feet to perhaps as much as 500 feet of strata is all that is required.

THRUST IN DICKS SPRING CANYON

The thrust faults exposed on both sides of Dicks Spring Canyon are believed to be parts of one thrust sheet that has been broken up by later displacement on high-angle faults, particularly on the Dicks Spring fault. At places, the thrust surface is well exposed and dips 10° to 15° W. or SW.; at such places, the structural relations are unmistakable; but at other places, projected segments of the thrust could not be recognized with certainty on the ground.

The upper plate rocks are generally Paleozoic and the Martin Formation is most commonly the lowest upper plate unit; however, Precambrian granite on the upper plate overrides the Dripping Spring Quartzite at the north end of the thrust trace on the east side of the canyon, and also along what is believed to be a southern projection of the thrust on the east side of the canyon (pl. 2). The lower plate rocks are generally Precambrian, but Cambrian rocks have been overridden at several places.

The trace of the thrust on both sides of the canyon crudely parallels the axis of the Dicks Spring Canyon syncline, which trends about N. 35° W. The syncline is believed to be in the upper plate of the thrust and may well be a product of the same forces that produced the thrust. If the two structures were produced by the same forces, these forces can be interpreted as acting in an approximately N. 55° E. direction.

The amount of displacement is probably not large. Troy Quartzite and Cambrian rocks on both the upper and lower plates on the west side of Dicks Spring Canyon indicate only a small amount of offset.

The age of the thrusting cannot be closely determined from the evidence in the Christmas quadrangle. The Cretaceous volcanic rocks that overlie the Naco Limestone along Mescal Creek may be on the upper plate of the thrust, or they may have been deposited after the thrusting took place and then tilted to their present steep attitude by displacement on high-angle faults. The thrusting is certainly younger than Pennsylvanian and older than the displacement on the Dicks Spring fault.

HIGH-ANGLE FAULTS

High-angle faults, which affect most of the map units, are abundant in the quadrangle. The exposed fault surfaces are either vertical or so inclined that the movement on the fault has been normal; but only a few fault surfaces are exposed and for most faults, particularly the smaller faults, the possibility of reverse movement cannot be eliminated. Indeed, reverse movement—or at least high-angle faulting accompanied by strong horizontal compression—on at least two faults, those on either side of the small syncline north of Bull Basin, would account better for the resulting structure than does normal displacement.

Six major high-angle faults, traceable for distances of 5 to 15 miles and with displacements of a few hundred to several thousand feet, and a great many smaller faults have been mapped in the Christmas quadrangle. The major faults trend from about N. 15° W. to N. 75° W. and are all steeply inclined to vertical with normal displacement; the smaller faults have a diverse orientation and a generally unknown dip. Dip-slip displacement is indicated for most of the faults, but at least one fault, which is probably a tear in the upper plate of a thrust exposed in the northern part of the Hayes Mountains, has had important strike-slip displacement.

The major faults are the Hawk Canyon, Dicks Spring, Mescal Creek, and Bull Basin faults in the north part of the quadrangle, and the Red Rooster and Quartzite Mountain faults near the south boundary. The first four of these faults involve the Gila Conglomerate of Tertiary and Quaternary age, and the last two involve rocks no younger than Tertiary. The Quartzite Mountain fault is older than the Red Rooster fault and both of these may be older than the four major faults to the north, although there is no real evidence to support this inference. The four major faults in the north part of the quadrangle may be roughly contemporaneous but the relative age of latest movement on them can be established. The Dicks Spring fault is the oldest of these four faults. It is cut off by the Mescal Creek fault, which can be projected under Gila Conglomerate and basalt to a point where it (the Mescal Creek fault) would be cut off by the Hawk Canyon fault. The Bull Basin fault cuts Gila Conglomerate and basalt that overlies the Hawk Canyon fault. Thus, the relative ages of the major faults are fairly well known, and all the major faults seem to be younger than the small faults, none of which offsets a major fault.

The six major faults will be described below in their probable age succession from oldest to youngest.

RED ROOSTER–QUARTZITE MOUNTAIN FAULT ZONE

The Quartzite Mountain fault, named for exposures on the south and west sides of Quartzite Mountain, extends along the north side of the lava plateau in the south part of the quadrangle. It is a steeply inclined to vertical fault, on which the south side is down with respect to the north side. The Paleozoic and Cretaceous rocks have been brought into contact with various Tertiary units by displacement along the fault. The amount of displacement is not well known and is difficult to determine because a somewhat younger fault, the Red Rooster fault on which the movement has been in the opposite direction, closely parallels or coincides with the Quartzite Mountain fault.

The Red Rooster fault is exposed on the north side of Quartzite Mountain and takes its name from this prominent topographic feature, which is known to residents of the area as Red Rooster. The fault extends east of Quartzite Mountain beyond the eastern end of the Deer Creek syncline; but to the west, it generally follows the Quartzite Mountain fault. The existence of the lava plateau as a topographic high is due to uplift on the Red Rooster fault.

The amount of displacement on the Red Rooster fault is difficult to determine because of its partial coincidence with the Quartzite Mountain fault, and because of complications introduced by older high-angle, quite possibly reverse, faulting along the same zone now occupied by the Red Rooster and Quartzite Mountain faults. The block south of the Red Rooster–Quartzite Mountain fault zone must have been uplifted and eroded enough to expose the Troy Quartzite prior to the deposition of the Tertiary rocks. Evidence for this is found in the extreme southeast corner of the quadrangle, where a pumice-lithic tuff and the overlying basalt rest on the Troy Quartzite. The steepness of the south limb of the Deer Creek syncline may be a result of this uplift, and if so, a reverse southward-dipping fault to produce the uplift seems most likely. After the extrusion of the Tertiary rocks, the south block of the Red Rooster–Quartzite Mountain fault zone was dropped down on the Quartzite Mountain fault, and the Tertiary rocks were eroded from the north block. The south block was then uplifted on the Red Rooster fault.

In the Red Rooster–Quartzite Mountain fault zone, at least three periods of faulting took place. The oldest of these took place after, or possibly as early as, the folding of the Deer Creek syncline and prior to the extrusion of the Tertiary volcanic rocks. The two later periods of faulting are both younger than the Tertiary volcanics.

DICKS SPRING FAULT

The Dicks Spring fault, named from Dicks Spring Canyon, can be traced a distance of about 5 miles from the west side of the upper part of Dicks Spring Canyon to the bottom of the canyon of the Gila River about 1½ miles southwest of Dicks Spring, where it terminates against a younger fault, the Mescal Creek fault. The Dicks Spring fault is a normal fault; the west side is up relative to the east side. The displacement on the fault amounts to a maximum of about 2,500 feet in the area of the window in the thrust plate on the west side of the canyon. To the north and south, the displacement on the fault is less, but if subparallel faults at both ends of the Dicks Spring fault represent bifurcations of the fault, the total displacement is about the same throughout the length of the structure. Gila Conglomerate on the east side of the fault ends abruptly against the fault and most of the movement on the fault has taken place since the accumulation of these deposits. Other gravel deposits, which are shown on the map (pl. 1) as Gila but which may be much younger, locally cover the fault. Therefore the fault is a late Tertiary or early Quaternary structure.

MESCAL CREEK FAULT

The Mescal Creek fault is well exposed for a distance of about 3½ miles along Mescal Creek (from which it gets its name) and on the hillside northeast of the creek and on the north side of the Gila River. The fault can be projected about 2½ miles eastward from where it disappears under Gila Conglomerate on the Gila River, to where it would terminate against a younger fault, the Hawk Canyon fault. The fault can also be projected northwestward a distance of about 7½ miles within the quadrangle. The total length, exposed and projected, is about 13½ miles. The fault is normal—dips are as low as 50°, although generally steeper—and the southwest side is up relative to the northeast side. Precambrian granite on the southwest side is faulted against Gila Conglomerate, Naco Limestone, and Escabrosa Limestone on the northeast side. Displacements of 4,500 to 8,000 feet can be measured on cross sections by projecting the layered rocks to the fault. Drag of the beds adjacent to the fault would decrease these figures, but probably not by more than a few hundred feet.

The Mescal Creek fault is younger than at least part of the Gila Conglomerate and is older than the pediment gravels which extend across the projection of the fault with no offset. The pediment gravels have been assigned a Quaternary age, and they are clearly older than the younger alluvium which occurs in stream channels that have incised the pediments. The incision of the pediments may not represent much time because most of the downcutting has taken place in the Gila Conglomerate.

HAWK CANYON FAULT

The Hawk Canyon fault, named for exposures in Hawk Canyon, is a major structure comparable in strike length—although with probably greater displacement—to the Mescal Creek fault. The Hawk Canyon fault has a combined exposed and projected length within the Christmas quadrangle of about 9½ miles, and can be traced about 7 miles to the east of the quadrangle (Creasey, Jackson, and Gulbrandsen, 1961). The Hawk Canyon fault is a normal fault; the southwest side is up relative to the northeast side. Precambrian granite has been faulted against Paleozoic rocks, older Tertiary volcanic rocks, and Gila Conglomerate.

The amount of displacement on the Hawk Canyon fault is difficult to determine because of the uncertainty as to the importance of the thrust fault northwest of Coolidge Dam. If the thrust fault is a minor structure that does not persist at depth and has only small dislocations of the strata at the surface, then the dip of the beds can be projected downward to the Hawk Canyon fault, and displacement amounting to 15,000 to 20,000 feet is required to account for the observed offsets on the Hawk Canyon fault. If, on the other hand, the thrust is a major structure underlying all the block southwest of Coolidge Dam to the Hawk Canyon fault, then the displacement on the Hawk Canyon fault is probably considerably less; but the displacement is almost impossible to determine because no offset surface can be projected to the fault from the south.

The Hawk Canyon fault cuts the steeply inclined gravels of the Gila Conglomerate and is covered by the horizontal deposits of the Gila. Neither of these units have yielded fossils, so the latest movement on the fault cannot be precisely dated.

BULL BASIN FAULT

The Bull Basin fault, which takes its name from Bull Basin on the south side of the Mescal Mountains, can be followed diagonally across the width of the Christmas quadrangle, a distance or more than 19 miles. This is a greater strike length than any other high-angle fault in the quadrangle, and yet the Bull Basin fault has the smallest displacement of the major high-angle faults. The fault surface is vertical where it is exposed in a small canyon southwest of Poverty Flat. Elsewhere the fault surface is not exposed, although at places the trace of the fault can be accurately located. The south side of the fault is up relative to the north side, which is true of all the major high-angle faults in the quadrangle except the Quartzite Mountain fault.

The displacement on the fault is greatest in the area from Poverty Flat to the Gila River, amounting to about 1,500 feet. The displacement decreases to about 200 feet at the west boundary of the quadrangle, and to about 400 feet where the contact between the Naco Limestone and Cretaceous rocks is offset near the east boundary of the quadrangle.

The horizontal deposits of the Gila Conglomerate are offset by the Bull Basin fault, and therefore it is the youngest datable structural feature in the quadrangle.

OTHER FAULTS

Many high-angle faults of short strike length and generally small displacement cut the Paleozoic and Precambrian rocks in the Hayes and the Mescal Mountains. A few other high-angle faults are exposed in the south part of the quadrangle. Most of these smaller faults have had dip-slip displacement, although whether in a normal or reverse sense is generally unknown. One northeast-trending high-angle fault, about 1½ miles long in the Hayes Mountains in north part of the quadrangle, appears to be a tear fault in the upper plate of the thrust on the east side of Dicks Spring Canyon. The trace of the thrust on the north side of the fault has been displaced northeastward about 1½ miles from the trace on the south side of the fault. Many of the high-angle faults in the Hayes Mountains may be due to fracturing of the strata on the upper plate of this thrust fault during the displacement of the thrust. Some of the high-angle faults probably represent inflation and dislocation of the Precambrian layered rocks by the intrusion of the diabase and diorite.

High-angle faults are abundant in the Christmas mine and some have displaced the ore bodies. One of the high-angle faults, the Christmas fault, has a dip-slip displacement amounting to about 1,200 feet (Eastlick, 1958). The ore bodies are on the footwall side of the Christmas fault.

ORE DEPOSITS

Ore deposits in the quadrangle are few in number and kind. One large copper deposit at the Christmas mine is being worked, and other smaller ore bodies in the mine and in the area east of the Gila River have been worked in the past. In addition, a thin seam of coal at the Lower Coal Field mine has been worked, a small deposit of oolitic hematite in the northwest corner of the quadrangle may someday be workable, and a small asbestos prospect is located near the north boundary of the quadrangle. In essence, however, the story of the ore deposits of the Christmas quadrangle is the story of a single mine, the Christmas mine.

The small mines east of the Gila River were visited and described by Ross (1925b); because they have generally remained inactive since that time, they will not be discussed here. A small copper prospect in the southern part of the Hayes Mountains, which has been inactive for many years, was described by Bromfield and Shride (1956, p. 631–632), who also described a small inactive asbestos prospect in the Hayes Mountains near the north boundary of the quadrangle.

The coal that occurs in the lower part of the Cretaceous section through much of the Deer Creek syncline has been prospected at several localities. An inclined shaft and a coke oven mark one of these localities at the Lower Coal Field mine northeast of Reed Basin. The activities in the coal fields up to 1922 have been summarized by Ross (1925a, p. 114–117). There have been no attempts to mine coal since that time, but according to the local ranchers, in the last few years the Lower Coal Field mine has been visited two or three times a year by various people interested in the possible exploration of the deposit.

CHRISTMAS MINE

The Christmas mine is near the west boundary of the Christmas quadrangle, about 1½ miles by road west of State Highway 77. The mine offices and the small community of Christmas are in a steep-sided canyon, which drains eastward into the Gila River. The principal working shaft of the mine, the McDonald shaft, which was completed in 1961, is on the crest of the ridge north of Christmas.

The mine has been briefly reported on by Ross (1925b) and in more detail by Peterson and Swanson (1956) as a result of exploration by the Geological Survey and the U.S. Bureau of Mines during World War II. The results of exploration by Inspiration Consolidated Copper Co. have been reported on by Eastlick (1958). These reports, particularly the last two, are sufficiently complete that I undertook no new work in the mine. The following statements on the mine have been taken from the last two reports and these reports should be referred to for a fuller discussion of the geology of the mine.

HISTORY

The history of the mine through 1943 has been summarized by Peterson and Swanson (1956) as follows:

The original mineral claims that include the Christmas deposit were located about 1880 by Dennis O'Brien and William Tweed, who sold or optioned them to Phelps-Dodge Co. The locations proved to be on the San Carlos Indian Reservation and were declared invalid. In December 1902, the portion of the reservation that includes the deposits was restored to the public domain by Executive Order, and the claims were relocated on Christmas Eve by G. B. Chittenden.

Phelps-Dodge Co. filed suit to recover the property without success, and the Saddle Mountain Mining Co. was organized to hold and operate the claims. A small copper smelter, erected in 1905, was operated until the Spring of 1907, when the company failed. The Gila Copper Sulphide Co. was organized in 1909 to take over the assets of the old company. Capital necessary to resume operation could not be raised until April 1915, when a contract was made with American Smelting and Refining Co. under which that company assumed management and advanced funds to develop the property. Production of copper ore began in February 1916; and by the end of the year, the loan had been repaid. American Smelting and Refining Co. continued to operate the property until January 1919. In the meantime, certain bonds fell due and were defaulted. A receiver was appointed, who operated the mine until it was shut down in April 1921.

In 1925, Mineral Products Co., a corporation controlled by the Iron Cap Copper Co., bought a controlling interest in the Gila Copper Sulphide Co. which was then reorganized as the Christmas Copper Co. The mine was reopened, and in 1925 a 500-ton concentrator was moved from the Iron Cap mine in the Globe-Miami district and erected at Christmas. To 1932 about 321,000 tons of ore had been treated by flotation. The Christmas Copper Co. became bankrupt and was reorganized as the Christmas Copper Corp. in 1936. The mine was reopened in 1937 but was closed again in March of the following year owing to the low price of copper.

Mining was resumed in 1939 and the property has been operated under lease since that date by the Sam Knight Mining Lease, Inc., producing high-lime fluxing ore. Shipments have been limited to the amount of flux required by the Hayden smelter for treating the copper concentrate from the mine at Ray. The ore shipped during 1942 averaged 2.16 percent copper and about 30 percent lime. No other metals were paid for by the smelter. The operation has been economically possible only because of low transportation costs and because the premium paid for lime more than offsets the treatment charge.

Inspiration Consolidated Copper Co. acquired the property in 1954 and started an aggressive exploration and development program. Eastlick (1958) reported that the development work consisted of deepening the No. 3 shaft 534 feet, cutting stations at the 1100, 1300, and 1400 levels, driving 16,800 feet of drifts and raises, and drilling 73,060 feet of diamond-drill holes. This work established "ore reserves of 20,061,625 tons of proven and probable ore averaging 1.83 percent copper, with a recoverable copper content of 66,000,000 pounds" (Bogert, 1960). A new shaft was necessary to exploit the ore body developed by this work, and sinking of the new shaft—the McDonald shaft—was begun in December 1959 and completed in 1961; production began in early 1962.

GEOLOGY

The rocks at the surface in the vicinity of the Christmas mine consist of the Naco Limestone and the overlying Cretaceous volcanic rocks, both of which are intruded by dikes and sills of feldspar-mica porphyry (quartz-mica diorite of previous workers) and by dikes of basalt and andesite. The Escabrosa Limestone, Martin Formation, and Troy Quartzite are exposed underground in the mine workings. The Troy Quartzite reported in the lower levels of the mine may also include Cambrian rocks or may be entirely Cambrian rocks.

The structural features have been summarized by Eastlick (1958), as follows:

> The Dripping Springs Range is indicated by Ransome (1919) to be a complexly faulted, anticlinal structure. The dominant structural features of the region are the generally east-west trending, quartz-mica-diorite dikes and the series of major northwest-trending faults. The orientation and distribution of the diorite dikes suggest that they were intruded along a system of steep, N. 70° W.-N. 70° E. trending fissures, approximately parallel to the axis of the regional deformation. The major faults are normal faults of the Basin and Range type with their hanging wall or down-thrown sides towards the valleys.
>
> At Christmas one of these major structures, the Christmas fault, separates the area into two geologic settings. To the west, Naco limestone, capped by andesite, forms the prominent outcrops along the steep ridges above the mine and on the east side, andesite comprises the predominant rock eastward to and across the Gila River. The surface outcrops of the quartz-mica-diorite, intruding the limestones to the west and the volcanics to the east, form an irregular elliptical outline with the long axis trending about N. 70° E. across the Christmas fault zone. Development work underground indicates the intrusive to consist, essentially, of two thick dikes, converging to the west towards No. 3 Shaft and to the east towards No. 4 Shaft, with numerous branching sills and interfingering smaller dikes. In the footwall of the Christmas fault, the greatest mass of quartz-mica-diorite is centered to the east of No. 3 Shaft between the 500 and 1100 levels where several, thick sills and numerous, irregular apophyses extend into the adjoining limestones.

The sediments surrounding the intrusive contacts have generally south to southeasterly dips of 10°–20°. Much of the original structure is obscured by later post-mineral faulting and by the intrusion of the quartz mica diorite; but it is apparent that some deformation preceded the intrusives. Along the south contact zone, the diorite cuts across the north limb of a small anticlinal fold, and the downward steepening of the sedimentary beds near the north contact suggests that the North dike intruded along the flank of a small flexure. Compressional stresses are also indicated by minor bedding-plane slips, small thrust faults, and local rolls along the bedding.

Pre-mineral fractures are evidenced by the numerous, steep-dipping sulphide and quartz stringers in the diorite and in the surrounding rocks. These occur along definite conjugate pre-mineral fracture systems, one set consisting of essentially parallel fractures along the intrusive contacts and the other * * * of fractures approximately at right angles to the contacts.

Underground, the Christmas fault is exposed on the 300, 400, and 800 levels on the north contact, and at the portal of the 400 level on the south contact. This fault, with a normal displacement of approximately 1200 feet down to the east, strikes generally N. 20°–25° W. and dips 65°–75° northeast. Movement occurs along a 10 to 20 foot crushed zone with brecciated blocks and fragments of diorite, andesite, and limestone between several fault strands. Another paralleling structure, the Joker fault, has been discovered on the 800 level, 900 feet to the east of the Christmas fault. It strikes N. 10°–25° W. and dips 75° northeast with a normal displacement down to the east of an unknown distance. Numerous smaller faults occur throughout the three major fault blocks. The majority, with normal movements of a few inches to 40 feet, have north to northwesterly strikes, trending obliquely to or parallel to the major structures. In the footwall area of the Christmas fault, two prominent east-west structures form the borders of a * * * graben. On the north side, the 1301 fault strikes generally N. 70°–75° W. and dips 55°–60° southwest with movement down 60 feet to the south. The No. 3 Shaft fault along the south border strikes approximately N. 85° W. and dips 60°–70° northeast with a displacement of about 150 feet down to the north.

The age of faulting, particularly that of the major structures, has been the subject of much discussion. There can be no argument that at least part of the displacements along the Christmas and Joker faults are post-mineral, and evidence points strongly, both on a regional and a local scale, to the fact that probably the major part, if not all, the movement was later. Displacements along the 1301 and the No. 3 Shaft faults appear to be post-ore, but may reflect later post-mineral movement along pre-mineral fault or shear zones. The smaller northeasterly to northwesterly striking faults are definitely post-ore in age, cutting and displacing the sedimentary strata, the mineralized beds and stringers, the post-mineral basic dikes, and the diorite intrusive dikes and sills.

ORE BODIES

The ore bodies in the upper part of the mine have been described in some detail by Peterson and Swanson (1956) and the new ore body in the lower part of the Martin Formation has been described by Eastlick (1958). The following general remarks about the ore bodies are taken from Eastlick's report (1958).

The known ore bodies of the Christmas mine are classified as pyrometasomatic in type, occurring as replacements in metamorphosed limestones of the Naco, Escabrosa, and Martin formations. The relationship of the ore deposits to the intrusive is almost diagrammatic. The type and intensity of mineralization varies with distance from the intrusive contacts, with the degree of metamorphism, with the physical and chemical properties of the sedimentary rocks, and with the intensity of pre-mineral fracturing and shearing.

The sedimentary rocks near the intrusive contacts are highly altered and metamorphosed. In the Naco and Escabrosa limestones, garnet and marble are the principal contact-metamorphic products along with lesser amounts of epidote, wollastonite, idocrase, chlorite, and serpentine. In the Martin limestone, the lower beds are highly altered to serpentine, diopside, tremolite, and chlorite with garnet sparingly present. Shale beds like the upper member of the Devonian are altered to fine-grained, banded hornfels and, in some of the thin-bedded limestones, silicification is almost complete. The numerous steep stringers and seams of sulphides which cut the ore deposits attest the fact that much of the metallization took place after development of the lime silicate minerals. Mineralizing solutions, undoubtedly traveling along the pre-mineral fracture zones near the limestone-diorite contacts, formed the extensive replacement ore bodies at intersections with favorable horizons in the metamorphosed limestones.

The principal metallic minerals are chalcopyrite, bornite, magnetite, pyrite, sphalerite, and pyrrhotite. Small amounts of galena and specular hematite are commonly present near the outer margins of the mineralized zones. Some minor molybdenite occurs sparsely in the mineralized beds, generally localized in the siliceous and silicified zones. Magnetite increases with depth, becoming a predominant constituent in ores in the Escabrosa and Martin limestones. Oxidation was almost complete above the 300 level, and extends locally to below the 800 level. Supergene ore minerals include chalcocite, native copper, copper oxides, and copper carbonates.

The ore body presently being mined by Inspiration, which has been explored and developed since 1954, is in the lower 30 to 60 feet of the Martin Formation. This zone, known as the O'Carroll bed, is mineralized over a wide area to the west of Christmas. The ore body in the Martin Formation has been described by Eastlick (1958) as follows:

The most extensive of the replacement ore bodies is found in the lower part of the Devonian limestones. Mineralization in this horizon, extending north and south from the main intrusive dikes, occurs as a flatly-dipping, massive tabular deposit. These lower limestones, developed to the north on the 1300 level * * * and to the south on the 1400 level * * * have proved to be consistently mineralized over an area 2700 feet in width across the intrusives, and 1400 feet in length along the intrusive contacts. Diamond drilling to the east and west of the developed area indicate extensions to 3000 feet along the south contact and to 2000 feet along the north contact. The lower 30 feet of the Martin limestone, consisting of thin-bedded dolomitic and shaly limestones, is the most favorable zone for replacement. However, adjacent to the intrusives, where the intensity of metamorphism and mineralization was greatest, the ore replaces up into the lower part of the massive limestones of the middle member.

Along the south contact, the deposit lies along the south limb of a small anticlinal fold which plunges gently to the west. Mineralization extends throughout a thickness of 65–80 feet for at least 1300 feet along the strike and for 600 to 850 feet down-dip, thinning abruptly to the south and to the west. Adjacent to the north dike, the thicker mineralization extends with a thickness of 55–75 feet for 1600 feet parallel to the intrusive contact, and for 200–400 feet up-dip along the bedding, becoming thinner to the northwest. Between the dikes the more favorable, thin-bedded, impure limestones are replaced, but mineralization above is spotty.

Magnetite forms the predominant metallic mineral throughout the deposit, comprising from 15 to 25 percent of the total content. Steep-dipping seams of anhydrite and gypsum are common, and local occurrences of fluorite are noted. The sulphide minerals commonly show both a vertical and lateral zonal arrangement. Laterally the mineralization grades from a pyrite-chalcopyrite zone near the intrusive borders, to a chalcopyrite-bornite intermediate zone, and to a pyrrhotite-pyrite-sphalerite-chalcopyrite outer zone. Vertically in the thicker sections, pyrite, chalcopyrite, sphalerite, and sometimes galena generally border a chalcopyrite-bornite central zone.

GEOLOGIC CONTROLS OF THE MINERALIZATION

The principal factors controlling the localization of ore bodies have been discussed at some length by Peterson and Swanson (1956, p. 363–365), and their report is quoted below:

There are four prerequisites for the localization of ore bodies in the Christmas mine. The first and most important of these is proximity to the limestone-quartz diorite contact; the second is the favorable character of certain limestone beds; the third is garnetization of the favorable beds; and the fourth is faulting and fracturing that followed garnetization.

The main channels of the mineralizing solutions appear to have been along the contacts between the limestone and the quartz diorite, and most of the ore bodies are in the limestone close to the borders of the main quartz diorite mass or along the walls of dikes that extend outward from the main mass. In some places, * * * the mineralizing solutions followed minor faults and fractures and replaced beds that are a considerable distance from the contact. The distance to which metallization extends depends largely on the extent of garnetization and the presence of post-garnetization fractures. In some places, especially along the walls of dikes, ore may lie directly against the quartz diorite, but along the main contacts there is generally a zone of low-grade material between the ore bodies and the quartz diorite. Since the contact is not usually exposed in the stopes, the width of this zone is uncertain, but probably it rarely exceeds 25 feet.

Precisely what characteristic of the limestone beds determines the difference in susceptibility to replacement is not clear, but the selection of certain definite beds by the mineralizing solutions is very consistent. Originally, most of the ore-bearing beds were relatively pure limestone, but many of the unmineralized beds are pure also. A few of the consistently mineralized beds are impure and cherty, but generally the ore in them is not as good as that in the purer beds. The outstanding characteristic of the ore beds is that they are relatively thin units which occur in a series of alternating shale and limestone.

Garnetization of the limestone is an important prerequisite of metallization. Garnetized beds are not always ore-bearing, but beds that have not been garnetized are nowhere sufficiently metallized to constitute ore. The ore bodies occur only where the contact alteration was sufficiently intense to produce abundant garnet in the limestone beds, and the size of the ore bodies is limited by the width of the altered zone.

The width of the garnet zone differs considerably from place to place. Its extent was influenced by faults and fractures that preceded or accompanied the intrusion of the quartz diorite. Where fracturing occurred, the solutions or gases that caused the alteration were able to permeate to greater distances from the contact. The fractures that preceded the garnetization have been largely obscured and healed by alteration and recrystallization of the limestone but in places can still be recognized.

Fracturing that followed garnetization had a far greater influence on the localization of ore bodies than the earlier fractures. In some places, garnetized rock has been mineralized where no fracturing is apparent, but in most stopes it is quite apparent that the shape of the ore bodies was governed by the fracture pattern. Irregularities in the outlines of the stopes occur as the result of fractures that have permitted mineralizing solutions to permeate farther into the garnetized limestone than elsewhere. Similar irregularities may have been caused, however, by the garnetization pattern, which in turn was governed by the pregarnetization fractures. The ore does not extend beyond the limits of the garnet rock regardless of the pattern of subsequent fracturing. The effect of fracturing on the thickness of the ore is not so marked, because most of the ore bodies are bounded top and bottom by shale beds which appear to have been nearly impermeable to the copper-bearing solutions.

IRON DEPOSIT

The contact between the shale and carbonate units of the Martin Formation on Limestone Ridge (northwest corner of the Christmas quadrangle) is marked by an oolitic hematite bed (Willden, 1960). The oolitic bed can be traced for about 2,500 feet and is from 5 to 7 feet thick over a length of 2,150 feet. This iron-formation consists of ooliths of hematite and glauconite in a matrix of calcite, dolomite, and quartz silt. The average composition of the iron-formation from four weighted chemical analyses (Willden, 1961) is 52.43 percent Fe_2O_3, 0.23 percent FeO, 8.62 percent CaO, 1.88 percent MgO, 6.48 percent CO_2, 16.90 percent SiO_2, 5.49 percent Al_2O_3, 1.75 percent P_2O_5, 0.16 percent MnO, 0.23 percent TiO_2, 0.08 percent Na_2O, 1.37 percent K_2O, 4.00 percent H_2O, and 0.03 percent S. Assuming that the iron-formation maintains its surface dimensions downdip, and that it has an average specific gravity of 3.19 (average from three measurements of hand specimens), there are about 1,250 tons of iron-formation per foot of depth. This deposit probably will not be worked for many years because of its small size and marginal grade but its existence allows hope that other and perhaps larger deposits may be discovered elsewhere in the Martin Formation.

GEOLOGIC HISTORY

The earliest known event in the area now known as the Christmas quadrangle was the deposition of the rocks which were later metamorphosed to become the Precambrian schist and metavolcanic rocks. These deposits were intruded by the widespread granite, which was in turn intruded by granodiorite—all in probable early Precambrian time.

The area was then uplifted and so deeply eroded that any near-surface phases of these intrusive rocks and large amounts of the older schist and metavolcanic rocks were completely removed before the deposition of the Apache Group rocks in younger(?) Precambrian time. The pinching out of the Pioneer Formation and the southeastward thinning of the lower members of the Dripping Spring Quartzite through the quadrangle indicate that the lower Precambrian rocks had not been entirely leveled when the Apache sea invaded the area.

Another period of uplift and erosion followed the deposition of the Apache Group rocks. The depth of erosion was greatest in the eastern part of the area where, at one place, the granite may have been exposed prior to the deposition of the Troy Quartzite. The Troy was deposited on a surface that exposed Apache basalt, Mescal Formation, Dripping Spring Quartzite, and possibly granite, but that apparently had not been folded or much tilted.

Some time after the deposition of the Troy Quartzite but prior to the long erosion interval that separates the Cambrian strata from the Precambrian, thick sills and dikes of diabase and diorite were intruded into the Precambrian rocks. The intrusion of the diabase and diorite inflated the section and doubtless produced many faults, but apparently was unaccompanied by any compressional deformation.

The Cambrian rocks were deposited on a deeply eroded and irregular surface that exposed diabase, Troy Quartzite, Mescal Formation, and granite. The relief on the surface of the Precambrian rocks is poorly known but in some places amounted to as much as about 100 feet in a horizontal distance of only a few hundred feet. The slight angular discordance between the Cambrian and Precambrian rocks observed at a few places is most likely due to some initial dip of the Cambrian strata off the highs of Precambrian rock.

The absence of Ordovician and Silurian strata is due to nondeposition or possibly to erosion in pre-Devonian time. At places, pre-Devonian erosion cut deeply enough to completely remove the Cambrian rocks, thus allowing the Martin Formation to rest on the Troy Quartzite and at one place, on diabase. Conditions were quite stable from the beginning of sedimentation in Devonian time through the Pennsylvanian, during which time about 2,500 feet of principally carbonate rocks were deposited.

The Permian, Triassic, Jurassic, and lower part of the Cretaceous are unrepresented in the Christmas quadrangle. The Upper Cretaceous sediments were deposited on a surface that exposed progressively older parts of the Naco Limestone in an eastward and southward direction from the vicinity of the Lower Coal Field mine, although the two units are generally concordant when examined in detail. Andesitic volcanic rocks began to accumulate in the southern part of the quadrangle while the Cretaceous sedimentary rocks were still being deposited. These volcanic rocks may have been extruded from vents in the southwest corner of the quadrangle where intrusive material is most abundant in the volcanic section. The sedimentary terrane was finally buried beneath the volcanics, which accumulated to at least a local thickness in excess of 3,000 feet. Some of the stocks, plugs, dikes, and sills that intrude the Cretaceous rocks, and locally the Paleozoic rocks, may represent exhumed feeders of the volcanic rocks, but others are clearly younger because they cut a thrust plate that overrides the volcanic rocks and that was thrust into the area after the folding of the Cretaceous and Paleozoic rocks in the Deer Creek syncline.

The folding of the Deer Creek syncline took place after the accumulation of the andesitic volcanic rocks and probably also after the intrusion of the Granite Basin laccolith. It seems unlikely that the laccolith would have domed its roof as it did had the Naco Limestone been tilted to its present attitude when the intrusion took place. The Reed Basin thrust was probably a late phase of the compressive deformation that produced the Deer Creek syncline. The steep south limb of the syncline could thus be accounted for as a result of the overriding plate. The thrust fault northwest of Coolidge Dam, which seems to have originated by compressive deformation acting in about the same direction as that which produced the Deer Creek syncline, may also represent a late phase of this deformation or it might be a younger, relatively minor structure.

The thrust fault and syncline in Dicks Spring Canyon appear to have been produced by compressive deformation acting in a more easterly direction than that which produced the Deer Creek syncline and the other two thrust faults. The age of this deformation is not well known but is likely post-Cretaceous.

The older Tertiary volcanic rocks may have accumulated prior to the displacement of the thrust fault northwest of Coolidge Dam but the evidence for this is inconclusive. These volcanics and those in the south part of the quadrangle certainly accumulated prior to the final movement of the major high-angle faults. The major high-angle faults cut the Tertiary rocks and the steeply inclined members of the Gila Conglomerate, and some offset the horizontal members of the Gila. Much of the displacement, if not all, on the high-angle faults in the Christmas mine (in particular on the Christmas fault) is younger than the ore bodies.

The Gila Conglomerate accumulated in basins that may have been produced by early displacement on some of the high-angle faults but which may also have been produced by folding. The patches of Gila Conglomerate along Rock Creek east of the Gila River indicate that the Deer Creek syncline was once at least partially filled by the Gila Conglomerate.

Patches of basalt and conglomerate at elevations of 4,000 to 5,000 feet indicate that much of the area was probably once buried by the Gila Conglomerate and basalt, which have largely been removed since the development of through-going drainage. The pediment in the northwest part of the quadrangle probably predates the development of through-going drainage.

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