Geology of the Prescott and Paulden Quadrangles, Arizona

By MEDORA H. KRIEGER

A detailed discussion of the stratigraphy and structure and a brief description of the geography, physiography, and mineral and water resources

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ABSTRACT

The Prescott and Paulden 15-minute quadrangles in north-central Arizona were mapped as part of a program to determine the regional setting of the massive sulfide deposits at Jerome and Humboldt. The structure and stratigraphy of the older Precambrian, Paleozoic, and Cenozoic rocks were studied, and data on the mineral and water resources of the area were collected. The approximate thickness of the Paleozoic and Cenozoic cover above the Precambrian rocks and the probable extent of the Precambrian Mazatzal Quartzite beneath this cover were determined. Both are important economically, as known ore deposits of the area are Precambrian in age, but the Mazatzal Quartzite is not mineralized.

The older Precambrian consists of volcanic rocks of the Alder Group, the Mazatzal Quartzite, and intrusive rocks that range from gabbro to granite. The volcanic and intrusive rocks are extensively exposed along the southern border and in the east-central part of the area. The Mazatzal Quartzite crops out in a few places in the northern half.

The Alder Group is part of the Yavapai Series. It consists largely of basaltic, andesitic, and rhyolitic flows and tuffaceous rocks. The group has been separated into five named formations and into isolated masses of unnamed basaltic flows and tuffaceous rocks, probably of the Alder Group. The named formations are (1) the Texas Gulch Formation, composed largely of rhyolitic tuff, (2) the Indian Hills Volcanics, composed largely of rhyolitic and basaltic or andesitic flows, (3) the Spud Mountain Volcanics, composed of andesitic breccia and tuff, (4) the Chaparral Volcanics, composed of rhyolitic and andesitic tuffs, and (5) the Green Gulch Volcanics, composed of tuffaceous rocks and basaltic flows. The first three are arranged in probable order of decreasing age. The stratigraphic position of the other formations is unknown. Original textures and structural features have been preserved in places. These include (1) pillow and flow structures, amygdules, vesicles, and phenocrysts in the flows, (2) crystal, lithic, and vitric fragments, (3) relict bedding, and (4) abrupt changes in composition across the strike in tuffaceous rocks. Textures and structural features indicating original form were lacking or later destroyed by deformation or metamorphism in some rocks, but these rocks can in places be traced along the strike into rocks that contain diagnostic features. As the bedded deposits contain no limestone or sandstone and very little slate, they are probably largely volcanic in origin. The formations have been metamorphosed largely to the green schist facies but locally to a higher grade of metamorphism. The thicknesses of individual formations are not known, but the total thickness of the group is probably at least 20,000 feet.

The Mazatzal Quartzite consists of about 4,000 feet of quartzite, conglomerate, and very little argillite. It is in fault contact with the Alder Group, and neither the top nor the bottom is exposed. In central Arizona the quartzite is considered older Precambrian in age because it is older than the deformation and igneous intrusions that separate older from younger Precambrian rocks in that area. In the Prescott-Paulden area the quartzite seems younger than the intrusive rocks and the major deformation that affected both the Alder Group and the intrusive rocks. The grade of metamorphism is very low; the rocks are not foliated, and the argillite is composed principally of (1) quartz and pyrophyllite, (2) kaolinite, or (3) quartz and mixed-layered mica-montmorillonite. No quartz veins or granite dikes cut the formation, and the conglomeratic portion contains abundant pebbles and cobbles of vein quartz that must have come from a granitic terrane.

The intrusive rocks, part of what has been called the Bradshaw Granite, include gabbro, Government Canyon Granodiorite, Prescott Granodiorite, alaskite, and Dells Granite, listed in probable decreasing order of age. The relations are obscure because (1) mafic intrusions include lithologically inseparable gabbro and diabase, some of which is older and some younger than the quartzose intrusive rocks, (2) most of the intrusions have been cut by dikes of granodioritic to aplitic composition whose correlations with a certain intrusive body is uncertain, (3) many contacts are mechanical owing to intense distributive shear, and (4) the various masses mapped as Prescott Granodiorite may not be consanguineous, although their modal, chemical, and normative compositions are so similar as to suggest this conclusion. All the intrusive rocks probably belong to the Precambrian. A Precambrian age is assumed for those that are not overlain by Paleozoic rocks because of (1) similarity to intrusive rocks of known Precambrian age, (2) the intense deformation they have undergone, and (3) the lead-alpha determination of Precambrian age of zircon in one of the relatively undeformed granodiorites.

The Paleozoic rocks, which are separated from the Precambrian rocks by a major unconformity, are the Tapeats Sandstone, Martin and Redwall Limestones, Supai Formation, and Coconino Sandstone. The basal Paleozoic sandstone has, in the past, been considered either Cambrian or Devonian in age. Although basal sandstone of Devonian age occurs locally, it is not the same as an older sandstone that, on the basis of present evidence, is the Tapeats of Cambrian age. The Tapeats is 0–150 feet thick and consists of a lower unit of sandstone and an upper unit of shale. The Martin Limestone of Middle(?) and Late Devonian age overlies the Tapeats with apparent conformity. Its thickness ranges from less than 50 feet, where it cuts out around the topographic high of Mazatzal Quartzite, to about 440 feet. The formation consists largely of dolomitic limestone and can be subdivided into four units. The Redwall Limestone of Early Mississippian age is about 220 feet thick and consists of four units, all of which are quite pure limestone, except for one unit that is cherty. Minor disconformities sepa-

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rate the Redwall from the underlying and overlying formations. The Supai Formation of Pennsylvanian and Permian age is largely a red-bed deposit; it consists of three members—lower, middle, and upper—that total about 1,600 feet in thickness. The formation is conformably overlain by the eolian Coconino Sandstone of Early Permian age; it has been eroded from all but the northeastern corner of the area, where less than 400 feet of its original thickness of more than 500 feet remains. The three members of the Supai Formation have been mapped. The units into which the other formations can be subdivided have not been mapped but were helpful in recognizing stratigraphic separations on small faults and monoclines. Erosion since the close of the Paleozoic Era has stripped all the Paleozoic rocks from the southern half of the area and much of the younger Paleozoic formations from the northern half. The youngest Permian formations, the Toroweap Formation and Kaibab Limestone, have been completed removed.

Cenozoic rocks consist of Tertiary(?) andesite dikes, volcanic and sedimentary rocks of late Tertiary(?) age, and Quaternary gravel and alluvium. The andesite dikes cut Precambrian rocks in the southern part of the area; they are probably older than the upper Tertiary(?) rocks. The upper Tertiary(?) rocks consist of (1) fanglomerate and channel gravels, sand, silt, and clay of fluviatile and lacustrine origin, (2) basalt flows and cinder cones, and (3) andesitic flows, plugs, breccias, tuffs, mud flows, and gravels. Locally andesite separates older from younger gravel and basalt. Elsewhere relative ages of the various rocks are uncertain. The rocks of late Tertiary(?) age are westward continuations of rocks mapped as the Hickey and Perkinsville Formations in the Clarkdale-Jerome area. These two formations were separated largely on the basis of relation to structure: the Hickey Formation of Pliocene(?) age, being older and the Perkinsville Formation of Pliocene(?) to Pleistocene(?) age, younger than the major post-Paleozoic deformation. In the Prescott-Paulden area all the rocks of late Tertiary(?) age appear to be younger than the major post-Paleozoic structure, and no clear-cut separation into two formations could be made. The Quaternary rocks are Pleistocene pediment and terrace gravels and Recent gravel and alluvium, which conceal large areas of the upper Tertiary(?) rocks in Chino-Lonesome Valley.

Structually, many rocks of the Alder Group and later intrusive rocks have been intensely deformed, but the Mazatzal Quartzite and younger rocks have been only mildly deformed. The Precambrian deformation produced isoclinal folds, foliation parallel to bedding, and strike faults in rocks of the Alder Group and foliation and shear planes in intrusive rocks. The rocks of the Alder Group have been separated into isolated blocks by faults and igneous rocks, and the stratigraphic relations and the broad structural pattern are uncertain. Lithologic trends of intrusive rocks, in general, parallel those in volcanic rocks. Structural features trend northward, except for a northeast-trending discordant fault zone that is characterized by distributive shear. Deformation of the Mazatzal Quartzite produced open folds and local zones of small, tight folds and small-scale thrusts but no foliation. The major structure consists of two northeast-trending anticlines that plunge gently southward and are separated by a fault. The western anticline has apparently been folded so that on the south end it plunges north and its limbs diverge abruptly. The gentle regional north and northeast dip of the Paleozoic rocks in the general area is interrupted in the Paulden quad-

rangle by sharp monoclines and by two anticlines, having opposing northwest and southeast plunges, that meet in the central part of the quadrangle. The Paleozoic rocks are also cut by high-angle faults. Structural relief caused by the regional dip is about 3,200 feet; that caused by monoclines, anticlines, and faults is in some places 1,000–2,700 feet. Most of the deformation apparently preceded deposition of the volcanic and sedimentary rocks of late Tertiary(?) age, but faults having small displacement locally cut these rocks. East of the Paulden area the major post-Paleozoic deformation occurred after deposition of the Hickey Formation.

The major physiographic feature is Chino-Lonesome Valley, which extends from the southeastern part of the area for 60 miles to the northwest. The valley is an erosional and structural basin that was filled with upper Tertiary(?) rocks. Exterior drainage commenced when the basin was filled sufficiently for water to spill over a low point into the Verde River drainage. This point is near the center of the northeastern boundary, not at one end as in a normal valley. A temporary base level along the Verde River resulted in a gravel-strewn pediment that covered much of the valley. The northward drainage of the southern part of the valley was captured by headward erosion of the south-flowing Agua Fria River, and much of the pediment is dissected. Granite Creek, the major tributary to the Verde River, is a superimposed stream and has been let down onto resistant Precambrian rocks from the overlying upper Tertiary(?) rocks or pediment gravels. The surface forms are largely erosional. The mountains and hills are of several types, depending on the rocks and structure involved. Erosion of the schistose volcanic and intrusive rocks of the Bradshaw Mountains along the south border produced long sharp ridges separated by north-trending gulches. The topographic form of the isolated Dells Granite is controlled by nearly vertical joints. Flat-topped mesas and buttes are remnants of pediments or of nearly horizontal Paleozoic rocks or basalt flows. Hogbacks formed locally on steeply dipping Paleozoic rocks and the Mazatzal Quartzite. A few remnants of volcanic cones and plugs or domes dot the landscape. Except for the southwest-facing escarpment of Black Mesa in the northwest corner and the escarpment of the Colorado Plateau in the extreme northeast corner, much of the area northeast of Chino-Lonesome Valley has low relief and is deeply dissected only along the Verde River and its tributaries.

The Iron King lead-zinc massive sulfide deposit in the southeast corner of the area near Humboldt is the only operating mine in the area. The mine was studied by S. C. Creasey, and a detailed report is included in a 1958 report on the Jerome area by C. A. Anderson and S. C. Creasey. Many of the rocks of the Alder Group and the intrusive rocks have been mineralized slightly or are cut by mineralized veins, but except for the Iron King mine, no important deposits have been found. The Lynx Creek placers have contributed a considerable part of the placer gold of the State; the principal production was before 1900, but the deposits have been operated intermittently since then. Rocks of the Prescott Granodiorite and Mazatzal Quartzite and some upper Tertiary(?) tuffs have been used for building stone. The Coconino Sandstone and part of the upper member of the Supai Formation are quarried for flagstone. The pure units of the Redwall Limestone have been used for cement and lime. The Chino artesian basin supplies water to the city of Prescott and for irrigation near the village of Chino Valley.

INTRODUCTION

The study of the Prescott and Paulden quadrangles was made as part of a program of the U.S. Geological Survey to determine the regional geological setting of two important copper mines: the United Verde and United Verde Extension at Jerome, Ariz., and the Iron King lead-zinc mine at Humboldt, Ariz. Anderson and Creasey (1958) mapped the Jerome area, which included the Mingus Mountain quadrangle, a small part of the Clarkdale quadrangle north of the United Verde mine, and small parts of the Mayer and Mount Union quadrangles near Humboldt (fig. 1). The geologic map of the southeast corner of the Prescott quadrangle was also included in their report. Creasey (1950 and 1952; Anderson and Creasey, 1958, p. 155–169) mapped the surface and underground geology of the Iron King mine. Lehner (1958) mapped the Clarkdale quadrangle. The Clarkdale, Paulden, Prescott, and Mingus Mountain quadrangles compose the old Jerome 30-minute quadrangle.

Geologic mapping of the Prescott-Paulden area furnished information on the older Precambrian sedimentary, volcanic, and intrusive rocks, on Paleozoic stratigraphy, on the upper Tertiary(?) sedimentary and volcanic rocks, and on structural features that affected these rocks. Information was also obtained on the mineral deposits and on the approximate thickness of the Paleozoic and Cenozoic cover over the Precambrian rocks, which are the principal host rocks for ore deposits in the area. Data on ground-water resources supplied by personnel of the Water Resources Division of the U.S. Geological Survey are incorporated into this report.

ACKNOWLEDGMENTS

Fieldwork in the Prescott quadrangle was carried on during the summers of 1947–49 with the assistance of W. E. Bergquist and during the summer of 1950 with the assistance of R. L. Kupfer. It was completed during 1951 and 1952. About 12 months were spent in fieldwork in the Paulden quadrangle during the summers of 1953–55; I was assisted by the following persons for varying periods: J. H. Wallace, E. L. Markward, Virginia Remy, M. J. Ebner, Kathleen McQueen, N. C. Pearre, M. H. Miller, Dorothy McKenney, June Waterman, and Rosina Yoder.

Mr. S. F. Turner of the Geological Survey supplied data on the ground-water resources of the city of Prescott. Well-log data for the area were obtained from Mr. Turner, from Dr. H. C. Schwaller of the Irrigation Department, State Land Department, University of Arizona, Tucson, from the Museum of Northern Arizona, and from ranchers and well drillers. E. D. Wilson kindly loaned his unpublished geologic map of the Jerome 30-minute quadrangle.

PREVIOUS WORK

No detailed reports on the geology of the area have been published execept for stratigraphic studies of the Redwall Limestone. The discovery and early workings of gold placer deposits on Lynx Creek are mentioned in several reports on the resources of the southwest, especially in those by Raymond (1874) and Hamilton (1883). The earliest mention of the geology is by Blandy (1883), who published a map showing granitic rocks, schist, and slate along the southern boundary of the area. He made specific mention of the scarcity and unimportance of the quartz veins in granite near Prescott.

The geology and ore deposits of Jerome were described by Reber (1922, 1938), who subdivided the Precambrian rocks. His map extends into the eastern part of the Prescott quadrangle. Wilson (1922, 1939) reported on and published maps of the area underlain by the Mazatzal Quartzite in the Paulden quadrangle.

The first published map to show the general distribution of formations in the two quadrangles is the "Geologic Map of the State of Arizona" (Darton and others, 1924). This part of the map was compiled largely from an unpublished map of the Jerome 30-minute quadrangle prepared for the State by L. F. Reber, Jr., and Olaf Jenkins and from later reconnaissance by Wilson. The map by Reber and Jenkins was later published in Lindgren's report (1926, pl. 1) on the ore deposits of the Jerome and Bradshaw Mountains quadrangles. Lindgren's report contains information on mines and prospects of the area but only briefly discusses the regional geology.

Tenney (1928, p. 109) mentioned limestone quarries near Cedar Glade (now Drake). Descriptions of the Lynx Creek placer deposits and operations were summarized by Wilson and Tenney (1932) and Wilson (1937, 1952). Mills (1941) first briefly described the Iron King mine and later (1947) published an excellent short account of the geology of the mine, especially of the character of the ore shoots.

Gutschick (1943) and Easton and Gutschick (1953) made stratigraphic and faunal studies of the Redwall Limestone in the area. McNair (1951) presented evidence which he believed indicated that the basal sandstone near Jerome is Devonian and not Cambrian. A preliminary statement on Precambrian stratigraphy and structure in the Jerome-Prescott area was given by Anderson (1951).

ECONOMIC AND PHYSICAL GEOGRAPHY

Location.—The Prescott-Paulden area includes about 490 square miles and is bounded by the meridians 112°-15′ and 112°30′ W., and the parallels 34°30′ and 35°00′ N. (pls. 1, 2). Most of the area is in Yavapai County, central Arizona (fig. 1); about 8 square miles of the northeast corner is in Coconino County.

Population and industry.—The city of Prescott, which now includes Forbing Park and Miller Valley, is the county seat and the largest settlement in Yavapai County; in 1956 its population was estimated at more than 11,000. Prescott is the shopping center for ranching and mining in the county and contains a few small light industries; together with the higher pine-clad hills to the south and west, it is a resort area during the summer months. The Veterans Hospital at Whipple and a small Indian settlement, Yavapai Indian Reservation, are adjacent to the city. The village of Chino Valley, west of Granite Creek, lies on the boundary between the quadrangles and is a farming and ranching settlement. Drake, a railroad junction in the northern part of the area, is the cutting and shipping center of the local flagstone industry; the quarries and camps of the quarrymen lie to the northeast, mostly outside the study area. Except for these settlements and for dwellings at Granite Dells, Prescott Municipal Airport, Paulden, and a few ranches, a large part of the area is uninhabited.

Indian ruins.—Small Indian ruins, pictographs, and Apache forts are scattered throughout the area; some of them are listed in table 1. The site of the ruin on the west side of Granite Creek, where the creek enters the Mazatzal Quartzite (pl. 2, 1,380,000 N., 359,800 E.[1]), was undoubtedly chosen because of its proximity to outcrops of argillite used for artifacts.

TABLE 1.—*Location of some Indian ruins and pictographs in the Prescott-Paulden area*

Older Indian ruins (mostly Pueblo type):	Indian pictographs:
Prescott quadrangle:	Prescott quadrangle:
1,276,600 N., 325,500 E.	1,283,300 N., 358,800 E.
1,279,300 N., 384,600 E.	1,285,600 N., 361,300 E.
1,286,800 N., 358,500 E.	1,303,600 N., 343,700 E.
1,300,200 N., 370,300 E.	Paulden quadrangle:
1,301,200 N., 348,200 E.	1,388,400 N., 352,800 E.
1,309,700 N., 343,500 E.	Apache forts:
Paulden quadrangle:	Prescott quadrangle:
1,380,300 N., 359,800 E.	1,280,500 N., 333,600 E.
1,411,500 N., 378,900 E.	1,310,200 N., 327,500 E.
1,402,200 N., 340,200 E.	
1,412,100 N., 369,200 E.	

Mining and quarrying.—Base and precious metals and some nonmetallic materials have been mined or quarried in the area. The only operating mine, and

[1] The 10,000-foot grid of the Arizona (Central) rectangular coordinate system has been placed on the maps, and many references to this coordinate system are made in the discussions of specific localities and geologic features.

the only important one developed, is the Iron King lead-zinc mine in the extreme southeast corner of the area. Gold has been recovered from placer deposits, principally along Lynx Creek in the south-central part. The Precambrian rocks, except the Mazatzal Quartzite, have been widely prospected and have yielded minor amounts of metals, mostly gold. Some prospecting has been done in slightly mineralized Paleozoic rocks near the Verde River at the east edge of the area (pl. 2). The Supai and Coconino Formations are quarried for flagstone; several formations are used locally for building and construction. The Redwall Limestone has been quarried for cement and lime. Four unproductive wildcat oil wells were drilled north of Paulden. The Chino-artesian basin supplies water for irrigation near the village of Chino Valley; Prescott obtains much of its water supply from this source.

Accessibility.—Prescott and Drake are served by a branch of the Santa Fe Railroad, which runs from the main line at Ashfolk, 50 miles north, to Phoenix, the State capitol, 100 miles south of Prescott. Branch lines from Drake and from north of Prescott serve Clarkdale (Jerome) and the Iron King mine (fig. 1).

Many roads traverse the area (fig. 1). Route 89 crosses the western part from north to south, passing through Drake, Paulden, and Chino Valley, and connecting Prescott with east-west highways to the north and south. Route 89 Alternate leaves Route 89 about 6 miles northeast of Prescott and joins Prescott with Jerome, the Verde Valley, and Flagstaff to the northeast. State Route 69, the Black Canyon Highway, connects Prescott with the Iron King mine and Phoenix. County roads to ranch, mine, and resort areas, and other roads and trails provide access to all parts of the area; no outcrop is more than 1 or 2 miles from a road passable by truck or jeep.

Physical features.—The Prescott-Paulden area lies mostly in the mountain region of Arizona (Ransome, 1903, p. 15), a zone of north- and northwest-trending ranges and broad valleys. To the northeast lies the plateau region; to the southwest, the desert region (fig. 1, inset).

The scenery is varied. More than half the area is occupied by the intermontane Chino-Lonesome Valley (figs. 22, 23, 29, 30), which extends to the northwest for 60 miles from the southeast corner. It was filled with fluviatile and lacustrine deposits that were eroded into a broad gravel-strewn pediment, which has since been dissected. The northern part of the rugged Bradshaw Mountains extends for a few miles into the area (fig. 1). From the northeast side of Chino-Lonesome Valley to the Colorado Plateau margin, which lies mostly north of the Paulden quadrangle, the area is relatively low-
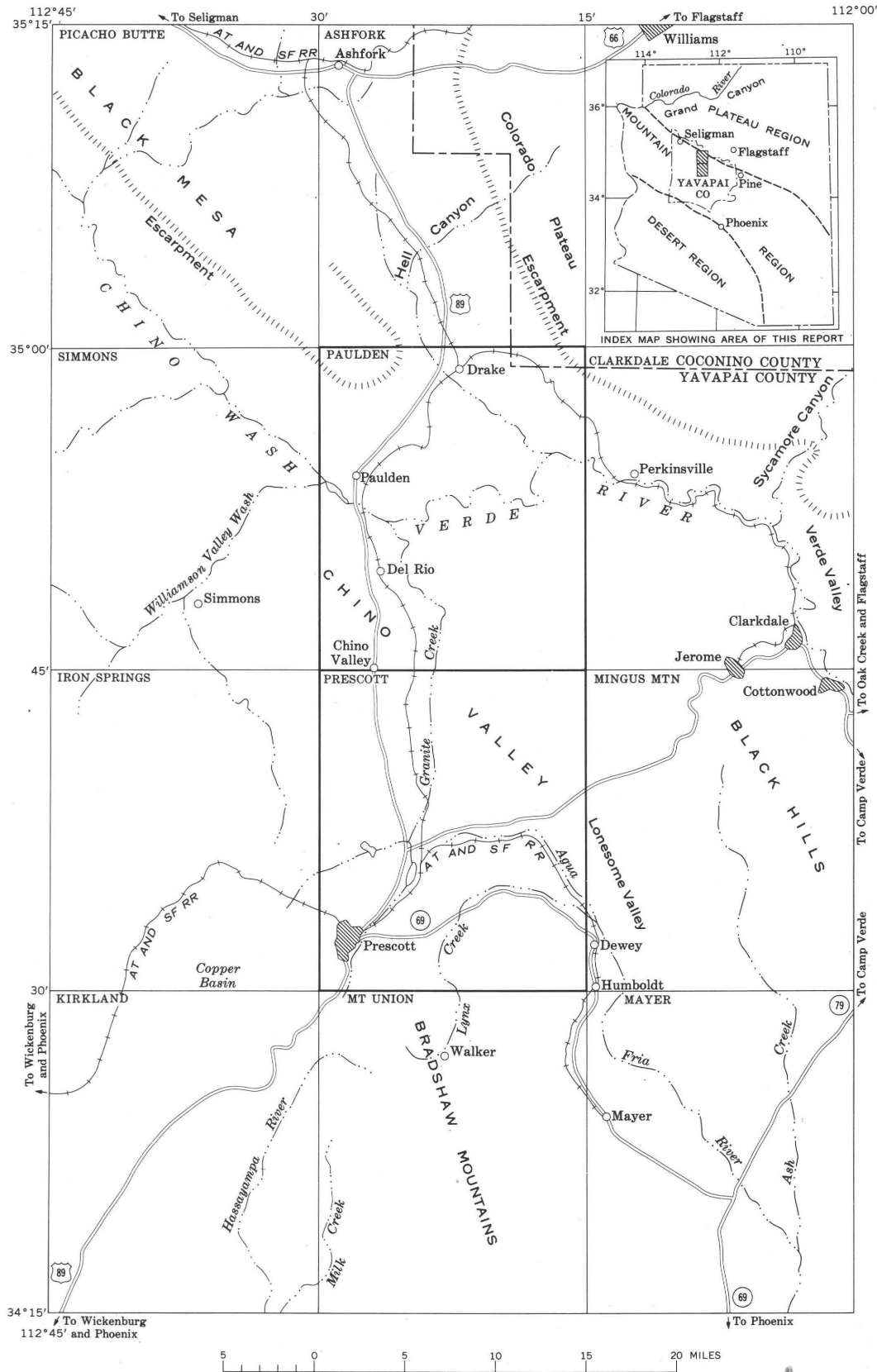
FIGURE 1.—The study area. Inset shows location of the two quadrangles in relation to Yavapai County and the State and the approximate position of the three topographic regions.

lying but is related to the plateau by its flat-lying Paleozoic rocks. The southwest-facing escarpment of Black Mesa, largely northwest of the area, is part of, but not continuous with, the plateau margin to the east. Granite Creek has been deeply incised into the resistant Mazatzal Quartzite (pl. 2), and gorges have been cut in Paleozoic rocks and overlying basalt flows by the Verde River (fig. 2) and its tributaries. An isolated block of granite northeast of Prescott has been eroded into rectangular and picturesque forms owing to strong joint control (fig. 14). Other forms include volcanic cones, andesitic plugs (fig. 19), buttes and mesas, which are remnants of once more extensive basalt flows of Paleozoic rocks, and a few narrow hogback ridges formed by erosion of monoclinally folded sedimentary rocks.

FIGURE 2.—The view is to the east-northeast along the Verde River, Paulden quadrangle, from near 1,410,500 N., 384,300 E. The following units are exposed: Precambrian quartz diorite (qd), Tapeats Sandstone (€t), Martin Limestone (Dm, units A–D), and Redwall Limestone (Mr). Note figure (arrow) for scale.

Altitudes range from 6,968 feet near the south margin of the area (pl. 1) to about 3,875 feet along the Verde River in the northeastern part (pl. 2). Much of the area is between 4,500 and 5,500 feet in altitude. Highest altitudes in surrounding areas are between 7,500 and 8,000 feet.

Drainage.—The Verde River and parts of two of its tributaries are the only perennial streams. The principal tributaries of the river (fig. 30) are Granite Creek, which flows northward across the area, and the washes in Hell Canyon and Big Chino and Williamson Valleys. The southeastern part is drained by the Agua Fria River and its major tributary, Lynx Creek. Dams impound water to form Sullivan Lake—the headwaters of the Verde River (pl. 2)—and Watson Lake and Willow Creek Reservoir in the Granite Dells north of Prescott (pl. 1).

Climate.—Arizona has a wide range in climatic conditions owing to a wide range in surface altitudes. The Prescott-Paulden area lies between the extremes of both altitude and climate. Only rarely does the temperature reach 100°F in Prescott, where below-zero temperatures are not common. Incomplete weather reports are available for Prescott since 1872 and for the Prescott Municipal Airport, 8 miles north of Prescott, since 1942. These data are summarized in table 2. Summer and winter are the periods of greatest precipitation.

TABLE 2.—*Temperature, humidity, and precipitation in the Prescott area*

[Unless otherwise noted, length of record is as follows: For temperature and humidity: Prescott, 40 years; Prescott Municipal Airport, 10 years. For precipitation: Prescott, 28 years; airport, 10 years]

	Prescott	Airport
Temperature, in degrees Fahrenheit:		
January average	35	35.6
July average	72.5	75
Annual average	[1] 54	57
Maximum	[1] 105	102
Minimum	[1] −21	−5
Summer average	70	--------
Winter average	36	--------
Humidity, in percent:		
Annual average	--------	47
December average	--------	66
June average	--------	26
Average precipitation, in inches:		
January	1.80	1.19
February	2.20	.69
March	1.56	.88
April	1.20	.71
May	.44	.19
June	.34	.11
July	2.62	2.69
August	3.39	2.81
September	1.98	1.20
October	.99	.64
November	1.08	.60
December	2.38	1.31
Annual	19.98	13.02
Snowfall	--------	20

[1] Length of record: 80 years.

July and August are generally the wettest months of the year, most of the precipitation falling during local thunderstorms. Snowfall is common above an altitude of 5,000 feet but rarely accumulates at this altitude. The average winter snowfall at the airport is 20 inches. Compared with lower altitudes, higher altitudes have cooler summer and colder winter temperatures and greater accumulations of snow and

somewhat greater rainfall. Recorded precipitation at the airport is lower than at Prescott because of the airport's lower altitude and greater distance from the mountains and also because the airport records were taken during a period of drought.

Vegetation.—Pine forests, pinyon-juniper woodland, grassland, and chaparral constitute the four types of vegetation in the area. Pine forests are limited to the southern part of the area, mostly above an alitude of 5,500 feet. Sparse pinyon-juniper woodland (fig. 2) covers a large part of the northern half and a little of the southern half. The chaparral areas (southwestern brush- or shrub-type vegetation) occur principally in the southern part along the margin of Chino-Lonesome Valley. Most of Chino-Lonesome Valley (figs. 19, 28) and the area east and south of Drake is in grassland. For a more detailed account of the vegetation of adjacent areas, see Anderson and Creasey (1958, p. 5–6) and Lehner (1958, p. 518–519).

GENERAL GEOLOGY

Rock formation in the Prescott and Paulden quadrangles belong to the Precambrian, Paleozoic, and Cenozoic Eras. The distribution and structure of these formations are shown on plates 1 and 2. The formations are shown diagrammatically in figure 3. The older Precambrian formations consist of volcanic, sedimentary, and intrusive rocks. Volcanic rocks belong to the Alder Group of the Yavapai Series; the sedimentary rocks belong to the Mazatzal Quartzite. The Mazatzal Quartzite is in fault contact with the Alder Group. Precambrian igneous rocks intrude the Alder Group but not the Mazatzal Quartzite. The intrusive rocks consist of gabbro, granodiorite, granite, and alaskite of Precambrian age and are probably closely related in time.

Paleozoic rocks of Cambrian and Devonian through Permian ages presumably overlay the Precambrian rocks throughout the area but have been stripped from the southern half. Mesozoic rocks, with the possible exception of the Moenkopi Formation of Triassic age, were not deposited here. The Cenozoic rocks consist of andesite dikes of Tertiary(?) age, volcanic and sedimentary rocks of late Tertiary(?) age, and Quaternary gravel and alluvium. The sedimentary rocks of late Tertiary(?) age consist of gravel, sand, silt, clay, and thin beds of rhyolite tuff and freshwater limestone of fluviatile and lacustrine origin. The interbedded volcanic rocks are basaltic flows, tuffs, and cinder cones and andesitic plugs, domes, flows, breccias, mud flows, tuffs, and gravels. The sedimentary and volcanic rocks filled Chino-Lonesome Basin and covered much of the area northeast of the basin. These rocks are westward extensions of Pliocene(?)-Pleistocene(?) rocks, which

are separated to the east into the older Hickey and younger Perkinsville Formations on the basis of relation to structure (Anderson and Creasey, 1958; Lehner, 1958). Locally in the Prescott-Paulden area andesite separates older from younger gravel and basalt, but elsewhere no clear-cut division of an older and a younger formation could be made. '

Rocks of the Alder Group have been intensely deformed; in most places bedding and foliation are about parallel, and the formations dip steeply. Many of the Precambrian intrusive rocks have also been intensely deformed. Distributive shear characterizes much of the older Precambrian deformation. The Mazatzal quartzite, however, although folded, has not been intensely deformed in this area. Paleozoic and late Cenozoic rocks, most of which are nearly horizontal, have locally been displaced by high-angle faults, and the Paleozoic rocks have been folded into sharp monoclines.

OLDER PRECAMBRIAN ROCKS

The Precambrian rocks of Arizona have been divided into older and younger Precambrian (Butler and Wilson, 1938, p. 11) on the basis of a major unconformity. The older Precambrian rocks include the Pinal Schist in southeastern Arizona, the Yavapai Schist and the Mazatzal Quartzite and associated formations in central Arizona, the Vishnu Schist in the Grand Canyon region, and the granitic rocks that intrude the schist and quartzite. Wilson (1939, p. 1153) correlated the quartzite in the Paulden area with the Mazatzal and recognized only one period of deformation and intrusion, which occurred after the deposition of the Mazatzal. In the Paulden quadrangle, evidence suggests that the quartzite is younger than deformation of both schist and granitic rocks; the quartzite was not intruded by granitic rocks or deformed to the extent that the schist and granite were. Younger Precambrian rocks— the Grand Canyon Series to the north and the Apache Group to the southeast—are not present in the Prescott-Paulden area. The regional correlation of the Precambrian rocks was discussed by Anderson and Creasey (1958, p. 44–45).

YAVAPAI SERIES—ALDER GROUP

In the Jerome area Anderson and Creasey (1958, p. 9) recognized two groups (Alder and Ash Creek) in rocks previously called the Yavapai Schist. They therefore redefined the Yavapai as a series. Only the Alder Group is represented in the Prescott-Paulden area.

Rocks of the Alder Group were described by Anderson and Creasey (1958, p. 20–32), who redefined strata previously called the Alder Sreies (Wilson, 1939,

	SYSTEM	SERIES	FORMATION AND MEMBERS		THICKNESS (FEET)	
	QUATERNARY	Pleistocene and Recent	Pediment and terrace gravels and alluvium, Qg		0–50+ of each type of deposit	1
			— UNCONFORMITY —			
	TERTIARY(?)	Upper Tertiary(?)	Sedimentary rocks, Ts Volcanic rocks: Andesite, Ta Basalt, Tb Basaltic cinder cone, Tc		0–1700+	2
			— UNCONFORMITY —			
	PERMIAN	Lower Permian	Coconino Sandstone, Pc		400+	3
			Supai Formation	Upper member, Psu	700±	4
				Middle member, Psm	250±	5
				Lower member, PⲒPsl	600±	6
	CARBONIFEROUS	PENNSYLVANIAN		— UNCONFORMITY —		
		MISSISSIPPIAN / Lower Mississippian	Redwall Limestone, Mr		219±	7
			— UNCONFORMITY —			
	DEVONIAN	Middle(?) and Upper Devonian	Martin limestone, Dm		>50–439	8
			— UNCONFORMITY —			
	CAMBRIAN		Tapeats Sandstone, Ƈt		0–154	9
			— ANGULAR UNCONFORMITY —			
	OLDER PRECAMBRIAN		Mazatzal Quartzite mq, ma₁, ma₂ mc₁, mc₂ Intrusive rocks dg, al, pg, gg, gb Alder Group of Yavapai Series av, gv, cv, ik, sv, iu, tu Fault contact, Mazatzal may be unconformable above Alder Group and intrusive rocks		Mazatzal Quartzite 4000+ Alder Group 30,000±	10

FIGURE 3.—GENERALIZED STRATIGRAPHIC SECTION,

GENERAL DESCRIPTION AND REMARKS
1   Gravel veneer on pediment surfaces; gravel, sand, and silt on terraces; alluvial and colluvial material on slopes and valley bottoms; sand and coarse gravel in stream channels. Unconsolidated except where locally cemented by caliche
2   Sedimentary rocks: fanglomerate, coarse to fine gravel, sand, silt, clay of fluviatile and lacustrine origin, thin beds of fresh-water limestone, and minor amounts of interbedded rhyolitic tuff, Ts; volcanic rocks: andesite flow, plug, breccia, mud flow, tuff, and gravel composed largely of andesite fragments, Ta; basalt flow, Tb; basaltic cinder cone, Tc. In places andesite separates older from younger sedimentary and basaltic rocks
3   Massive pale-orange to grayish-orange sandstone characterized by crossbedding on a large scale. In most places forms a sheer cliff
4   Chiefly strongly crossbedded reddish-orange sandstone separated by horizontally bedded and thinly laminated fine-grained pale-reddish-brown sandstone and siltstone; forms cliffs, buttresses, and pinnacles
5   Chiefly pale-red to grayish-red somewhat calcareous siltstone interbedded with conglomerate and cross-laminated sandstone; very irregularly and thinly bedded; forms a subdued topography
6   Thin-bedded reddish-orange shale, siltstone, sandstone, and some gray limestone; chert and limestone breccia at base; thicker bedded and contains less shale upward; pink crossbedded sandstone at top; forms steplike slope
7   Comprises four units: unit 1 consists of 0 – 35 feet of thin-bedded reworked Devonian material and 23 feet of bluish-gray oolitic limestone; unit 2 consists of 80 feet of fine-grained cherty limestone; unit 3 consists of 81 feet of coarsely crystalline limestone; and unit 4 consists of 35 feet of bluish-gray micro-oolitic to pellety limestone, locally underlain by crystalline and cherty limestone and by a solution breccia. Formation forms a cliff in most places
8   Comprises four units: unit A is 0 – 21 feet of cliff-forming crossbedded impure clastic dark-gray dolomitic limestone; unit B is 0 – 97 feet of slope-forming light-gray thin-bedded lithographic limestone with shale partings; unit C is 0 – 75 feet of thicker bedded mottled cliff-forming dark-gray dolomitic limestone; unit D is less than 50 to 255 feet of alternate thin beds similar to units A, B, and C, with some siltstone, shale, and sandstone; forms a steep, steplike slope
9   Comprises two units: a lower unit of cliff-forming dark-reddish-brown and buff crossbedded sandstone 0 – 142 feet thick that averages at least two-thirds of the total thickness, and an upper unit of slope-forming reddish- to yellowish-gray mudstone, siltstone, and shale, and locally conglomerate, 0 – 22 feet thick

10   Intrusive rocks: (from oldest to youngest) gabbro, gb; Government Canyon Granodiorite, gg; Prescott Granodiorite, pg; alaskite, al; and Dells Granite, dg; (not shown are coarse-grained granite, fine – grained granite, and younger diabase and fine-grained gabbro-diorite).
    Mazatzal Quartzite: includes lavender, reddish, and grayish massive to crossbedded fine- to coarse-grained quartzite and minor granule conglomerate, mq; interbedded lower and upper red argillite, ma_1 and ma_2; and lower and upper conglomerate containing quartz and jasper pebbles, cobbles, and small boulders, interbedded with quartzite, mc_1 and mc_2
    Alder Group rocks: unnamed basaltic flows and tuffaceous rocks of the Alder(?) Group, av; Green Gulch Volcanics, basaltic flows, breccias and tuffs, and rhyolitic and basaltic tuffs and flows, gv; Chaparral Volcanics, andesitic and rhyolitic tuffs, cv; Iron King Volcanics (not exposed), andesitic tuffs and andesitic or basaltic flows, ik; Spud Mountain Volcanics, andesitic breccia and andesitic tuffs, sv; Indian Hills Volcanics, rhyolitic and andesitic or basaltic flows, a few tuffaceous rocks, iu; Texas Gulch Formation, largely rhyolitic tuffaceous sedimentary rocks, some rhyolite flows or massive tuffs, andesitic flows and tuffs, and minor amounts of conglomerate and jasper-magnetite beds, tu

PRESCOTT-PAULDEN AREA, ARIZONA.

p. 1121, 1159). In general the group consists of basaltic, andesitic, and rhyolitic flows and tuffaceous sedimentary rocks. Of the six formations described by Anderson and Creasey, five were recognized in the Prescott-Paulden area; these are the Texas Gulch Formation and the Indian Hills, Spud Mountain, Chaparral, and Green Gulch Volcanics. The sixth formation, the Iron King Volcanics, is beneath Cenozoic deposits in the extreme southeast corner of the area (pl. 1, sec. E–E′). In addition, isolated masses of basaltic flows and tuffaceous rocks probably belong to the Alder Group but are not given formation names or assigned to one of the previously named formations.

The Alder Group has been regionally metamorphosed, and many of the textures, structural features, and mineral assemblages are typical of rocks of the green schist facies; some are the result of higher grade metamorphism. The principal metamorphic minerals are chlorite, actinolitic hornblende, epidote, clinozoisite (zoisite), albite, sericite,[2] and quartz. Microcline is a common stable relict mineral in the rhyolitic rocks. Biotite, muscovite, hornblende, oligoclase-andesine, garnet, and staurolite(?) indicate local higher grade metamorphism.

Although the Alder Group has been metamorphosed, unravelling its stratigraphy and structure was of greater importance in the search for clues to ore deposits in the Precambrian rocks than was the study of metamorphic features. A careful search was therefore made for relict textures and structural features.

If relict amygdules or pillow structures can be recognized in chlorite or hornblende schist, the rocks are classed as andesite or basalt. Rocks of the same general composition that show relict bedding are called andesitic or basaltic tuffs or tuffaceous sedimentary rocks; those containing abundant phenocrysts or crystal fragments of plagioclase are called andesite. Sericitic schists or fine-grained rocks composed of quartz and alkalic feldspar and containing flow structures and phenocrysts of quartz and feldspar are classed as rhyolite; similar rocks having relict bedded structures are classed as rhyolitic tuff or tuffaceous sedimentary rocks. Siliceous-looking flows containing a greater amount of mafic minerals and calcic plagioclase than normal rhyolites are called dacites. Some fine-grained rocks originally lacked features indicating that they were a volcanic flow, massive tuff, or a fine-grained intrusive rock. The original textures and structures in other rocks have been obliterated by intense deformation, higher

grade metamorphism, or later retrograde metamorphism. Fortunately, many of the rocks in which original diagnostic features were lacking or were later destroyed can be traced along the strike into rocks in which relict textures and structural features indicate the original character of the rock.

Because of the almost complete absence of sedimentary rocks such as limestone, sandstone, and shale and because of the abundance of volcanic material in the Precambrian rocks in this area, much of the bedded material has been interpreted as of tuffaceous, rather than terrigenous, origin. Bedded tuffs and a few pillow lavas indicate deposition in water, probably in a marine environment.

Attempts to work out the stratigraphy and structure of the Alder Group in the area met with little success. The rocks have been isoclinally folded and foliated. They are separated into isolated masses by faults and intrusive igneous rocks or are exposed only in windows in Paleozoic and Cenozoic rocks. Some masses may lack internal continuity; a displacement may not have been recognized because it paralleled lithologic trends and brought similar rocks of different formations into apparent continuity, or because it had been injected by igneous rocks.

Little evidence was found to indicate the direction in which tops of beds face. In many places where the orientation of a bed could be determined, only the local rather than the regional structure was indicated because of known or inferred isoclinal folding.

Rocks of the Alder Group were injected by and caught up in intrusive igneous rocks. Where mixing of volcanic and intrusive rocks is difficult to show on the map (pls. 1, 2), a stippled pattern has been placed over the pattern used for the principal rock type in the area. Data on these complex areas are given in sections on the principal rock type involved.

The formations of the Alder Group dip so steeply that outcrop widths would approximate stratigraphic thickness except for several complications: (1) Isoclinal folds and small unmapped masses of igneous rocks cause outcrop widths to be greater than stratigraphic thickness, and (2) flowage, shearing out of beds, and unmeasured amounts of rocks of the Alder Group in adjacent intrusive rocks cause outcrop widths to be less than stratigraphic thickness.

Because of these complications and because neither the top nor the bottom of the Alder Group is exposed, the thickness of the group is not known; however, it is probably at least 20,000 feet. In the Jerome area Anderson and Creasey (1958, p. 20) estimated the Alder Group to be 20,000–30,000 feet thick. Their figures include thicknesses of the Spud Mountain, Chaparral,

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[2] Although muscovite and sericite are the same mineral, in this report the term "sericite" is used for fine-grained metamorphic or secondary muscovite; the term "muscovite" is used for the primary igneous mineral and also for the larger (generally more than 2 mm) crystals formed by higher grade metamorphism.

and most of the Green Gulch Volcanics in the southeastern part of the Prescott quadrangle but not thicknesses of the unnamed volcanic rocks that are probably in the Alder Group and thicknesses of additional units in the Texas Gulch Formation and Green Gulch and Indian Hills Volcanics.

TEXAS GULCH FORMATION
DISTRIBUTION

The Texas Gulch Formation was named and described by Anderson and Creasey (1958, p. 28–30) for exposures in Texas Gulch in the southwestern part of the Jerome area. The principal exposure of the Texas Gulch Formation in the Prescott-Paulden area is in the south-central part (pl. 1). Three small exposures are in the northern part along Granite Creek about 1 mile south of its junction with the Verde River (pl. 2; fig. 5). Lithologic units have not been mapped, except for four units in the largest exposure (pl. 1). They are units containing respectively, jasper-magnetite beds, andesite flows and tuffs, rhyolite crystal tuffs, and rhyolitic flow or massive tuff. The andesitic rocks have been mapped in three places; the other units, in only one area each.

THICKNESS, STRATIGRAPHIC RELATIONS, AND CORRELATION

The thickness and stratigraphic relations of the Texas Gulch Formation are not known. Structural and stratigraphic features suggest that the main mass occupies a south-plunging syncline within which are small folds, the top and the bottom are both absent, the oldest beds are on the east and west sides, and the youngest part is the rhyolitic flow or massive tuff unit near the center of the outcrop. This interpretation is based on jasper-magnetite float and beds of rhyolite tuff, slate, and conglomerate in the western part of the mass that may be correlative with similar beds on the east; on generally west-facing beds in the eastern part; and on south-plunging lineation, interpreted as the b axis of the structural coordinate system.

The greater outcrop width of the formation (about 12,000 ft) along the southern border of the quadrangle, in contrast with a narrower width (less than 5,000 ft) about 2 miles to the north, is probably due to duplication of beds by folding and to the southward plunge of the syncline. The formation must be 3,000–4,000 feet thick in this area.

No normal stratigraphic contacts of the Texas Gulch Formation with other Precambrian formations are exposed. Its western contact with unnamed basaltic flows of the Alder(?) Group appears to be a fault or shear zone (pl. 1). To the north and east the Texas Gulch Formation is intruded by igneous rocks. The eastern contact is sharp, but the granite adjacent to it contains abundant inclusions of volcanic rocks, which probably

are part of the formation. One small outcrop is in fault contact with the Mazatzal Quartzite (pl. 2).

Anderson and Creasey's interpretation (1958, p. 28) of the regional structure of the Alder Group in the Jerome area is that the Texas Gulch Formation is the oldest formation in the group. Whether it directly underlies the Indian Hills volcanics or is separated from it by other formations is not known, as the two are not in contact.

In the Jerome area Anderson and Creasey (1958, p. 28) applied the name Texas Gulch Formation to rocks formerly referred to as quartz-sericite schist, conglomerate, and slate by Lausen (1930) and as arkosic sandstone, squeezed conglomerate, and slate by Wilson (1939, p. 1157–1158). Wilson correlated these rocks with his Alder Series in the Mazatzal Mountains. In the southern part of the Prescott-Paulden area, many of the rocks mapped as Texas Gulch Formation are lithologically similar to those in the type locality. Similarities include the abundance of fine- to coarse-grained rhyolite tuff that locally grades into lithic tuff, the considerable amounts of slate, and a distinctive conglomerate. Not all the lithologic types are found in both areas. Thin beds or layers of marble occur in the Jerome area; none occur in the Prescott area. Thin beds of jasper-magnetite and scattered jasper-magnetite pebbles in conglomerate occur in the Prescott area but not in the Jerome area. In the Prescott area the slate is gray; in the Jerome area it is chiefly purple or maroon and only locally gray or green. Another difference is the presence of dacite(?) and andesite in the Prescott area but not in the Jerome area. If rocks in the Prescott and Jerome areas are correctly correlated, these differences may be because neither area contains a complete section. Near Granite Creek (pl. 2) the abundance of quartz-sericite schist that may represent metamorphosed slate and rhyolitic tuff suggests a correlation with the Texas Gulch Formation to the south. Also, Wilson (1939, p. 1153) termed these rocks "phyllite and argillaceous sandstone of Alder type." Inclusion of rocks here called Texas Gulch Formation in the Alder Group and their correlation with the Texas Gulch Formation in the Jerome area are both tentative but the best that can be done on the basis of present knowledge.

LITHOLOGY AND INTERNAL STRUCTURE

The Texas Gulch Formation is composed largely of rhyolitic tuff but it includes rhyolite flows(?), andesite tuffs and flows, slate, conglomerate, dacite(?) flows and tuffs, and jasper-magnetite beds. Much of the descriptive material in the section on undifferentiated rocks applies to rocks in differentiated units; some rocks are described only under an individual unit.

The rocks are variably foliated; the finer grained ones have a smoother, more regular foliation than the coarser grained ones; conglomerates have a hackly foliation. Lineation, which is widespread, results from elongation of sericite or chlorite flakes, elongation of pebbles, and intersection of cleavage and bedding. Except for mineral streaking, which is parallel to the a axis, most lineation is parallel to the plunge of minor drag folds and to the b axis of the structural coordinate system. Thickening on crests and thinning on limbs of small drag folds is characteristic of the jasper-magnetite beds. Some pebbles in conglomerates are attenuated to lengths as much as 10 times widths.

The rhyolite tuffs are various shades of gray. Many of them are very fine grained and finely laminated, especially in the area extending 1,500 feet west of the unit containing jasper-magnetite beds. Relict bedding is preserved in places. Some tuffs are coarse grained or contain sparse to abundant crystal or lithic fragments. Lithic fragments range from about 1 mm to 15 cm in length. In some beds, crystal or lithic fragments are massed almost without matrix. The tuffs grade into slate and into sandstone and conglomerate of questionable tuffaceous origin. The matrix of the tuff consists of quartz, sericite, alkalic feldspar, and lesser amounts of biotite, chlorite, muscovite, epidote, and sparse actinolite. Magnetite is a fairly abundant accessory mineral in some tuff. Most fragments in the lithic tuffs have the same composition as the matrix—mainly rhyolite—but some are composed of quartz, chalcedony, or andesite. Except for a distinctive conglomerate, discussed in the next paragraph, the lithic tuffs are most abundant west of the rhyolite flow or massive tuff unit.

A distinctive conglomerate lies east and west of the unit containing jasper-magnetite beds (fig. 4). Similar conglomerate is exposed near the western edge of the largest exposure (1,285,400 N., 352,600 E.). West of the unit containing jasper-magnetite beds, the conglomerate is a maximum of 50 feet thick; east of this unit the conglomerate is mostly less than 10 feet thick. The conglomerate is similar to rhyolitic lithic tuffs except for the presence of pebbles and cobbles of red chalcedony and jasper-magnetite; the conglomerate also contains a few fragments of andesite and of graphic intergrowths of quartz and alkalic feldspar.

Gray slate, which may be a normal terrigenous sediment,[3] is associated with the jasper-magnetite beds and with conglomerate and tuffaceous rocks for about 1,500

feet west of the jasper-magnetite beds. Quartz-sericite schist, associated with lithic tuffs (pl. 1; near 353,500 E., north of 1,281,500 N.) and with micaceous quartzite in the two western outcrops near Granite Creek (pl. 2), may be metamorphosed gray slate. Some of these schists are spotted. In the southern exposures the spots, as much as 2 cm by 0.6 cm, are pseudomorphs after staurolite(?) and now consist of sericite, magnetite, and chlorite in a matrix of quartz, sericite, chlorite, magnetite, and some alkalic feldspar. In the northern exposures the spots are biotite metacrysts as much as 3 mm in diameter that poikilitically enclose quartz grains.

Dacite(?) rocks, probably flows and tuffs, occur west of the rhyolite flow or massive tuff unit (south of 1,281,000 N.). They interfinger with rhyolitic lithic tuff and with rocks of uncertain origin. The dacite(?) is medium dark gray and well foliated. Some contain large amygdularlike areas of granular quartz; others contain fragments of a slightly different composition; some are bedded. The very fine grained matrix or groundmass consists of sericite, quartz, alkalic feldspar, chlorite, minerals of the epidote group, and abundant magnetite. Altered plagioclase grains are mostly less than 2 mm long; many are less than 0.5 mm long.

Rocks of uncertain origin are characterized by sparse to abundant flattened white fragments of feldspar(?) or rhyolite. The fragments are angular and are randomly oriented in the plane of foliation, but they are somewhat augenshaped at right angles to foliation. Many of them are as large as 1.5 cm by 0.4 cm; some are much larger. They consist of a mixture of zoisite, epidote, sericite, alkalic feldspar, quartz, and a little chlorite. The matrix is composed of alkalic feldspar, quartz, chlorite, epidote-zoisite, and magnetite.

Unit containing jasper-magnetite beds.—The unit that contains thin beds of jasper-magnetite consists of tuffaceous sedimentary rocks composed of rhyolite, some andesite, and a little gray slate; jasper-magnetite beds form a very minor part of the unit. Thin interbeds of jasper-magnetite are concentrated in layers 25–50 feet thick, which are separated by at least 100 feet of tuffaceous rocks free of jasper-magnetite. Individual jasper-magnetite beds range from paper thin to about an inch in thickness. They are dark gray to blackish red—except for iron-poor, silica-rich interbeds, which are a lighter gray. A few beds have been traced along the strike for as much as 1,000 feet. The jasper-magnetite beds are composed of very fine grained magnetite—locally of hematite or the specular variety of hematite—in a matrix of microcrystalline quartz and variable amounts of quartz, sericite, albite, chlorite, and minerals of the epidote group. These beds resemble the Precambrian iron formation of the Lake Superior region

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[3] Anderson and Creasey (1958, p. 29–30) considered purple slate in the Jerome area to be terrigenous on the basis of a higher alumina content and a higher ratio of potash to soda as compared with rhyolite tuffs of the area.

(Leith and others, 1935, p. 21) and probably had a similar origin. James (1954) concluded that the high iron content of the iron formation is the product of iron-rich sedimentation in marine waters.

Andesite flows and tuffs.—The eastern mass of andesite is largely tuff; the middle one is largely flow, and the western one is largely a porphyritic rock of uncer-

tain origin. Much of the andesite, in both differentiated and undifferentiated areas, is very fine grained and well bedded; some is medium grained and massive. The andesite is medium dark to medium greenish gray. Some is porphyritic or contains clusters of large flattened plates of saussuritized plagioclase. A few of the coarser grained rocks are vesicular or contain quartz

EXPLANATION

Younger rocks

Texas Gulch Formation

tu, *undifferentiated Texas Gulch Formation*
tj, *unit containing jasper-magnetite beds*
tc, *conglomerate beds in undifferentiated Texas Gulch Formation and unit containing jasper-magnetite beds*

Contact
Dashed where approximately located; dotted where concealed

Fault

Strike and dip of beds
Direction in which top of bed faces, based on graded bedding, channelling, bedding-foliation relations, or pattern of drag folds
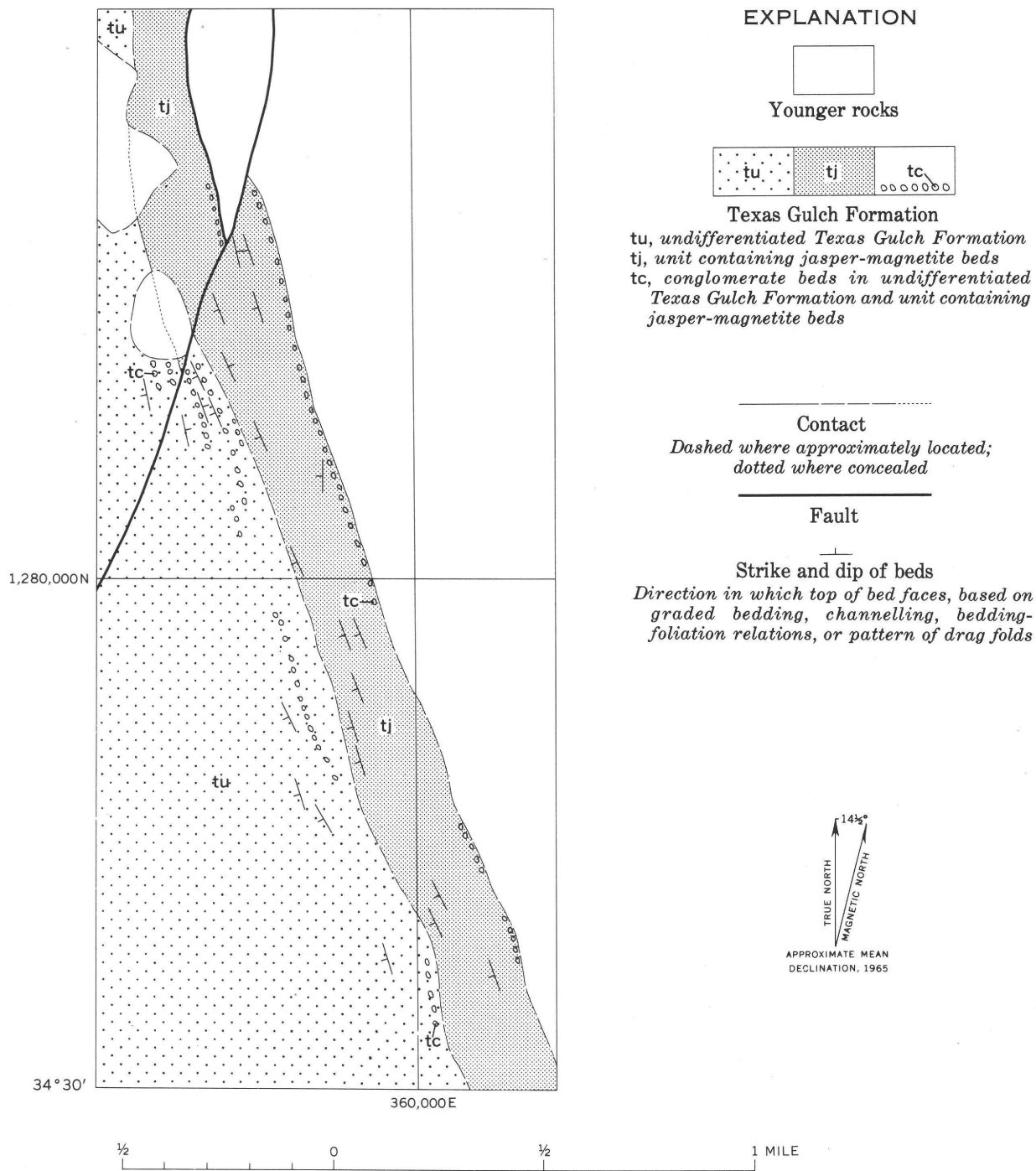
FIGURE 4.—Distribution of conglomerate in the Texas Gulch Formation, Prescott quadrangle.

or calcite amygdules. Small crystal fragments or phenocrysts of saussuritized plagioclase are erratically distributed through some of the rock. The andesite consists of chlorite, albite, and variable amounts of sericite, epidote, actinolite, calcite, quartz, magnetite, and ilmenite. Chlorite and sericite (from rhyolitic detritus) are abundant in the finer grained fissile rocks; actinolite, in the coarser grained ones. Hornblende (actinolitic) forms some metacrysts. The porphyritic rock contains plagioclase, actinolitic hornblende, epidote, magnetite, and sphene.

Rhyolite crystal tuff.—Rhyolite crystal tuff is fine to coarse grained. Quartz and feldspar crystal fragments, as much as 2 mm in diameter, are sparse to abundant; either mineral may predominate; locally they are absent. Lithic fragments are composed of rhyolite and chalcedony. The matrix consists of quartz, sericite, alkalic feldspar, and a little chlorite and epidote.

Rhyolite flow or massive tuff.—The rhyolite flow or massive tuff is dark to medium gray or pale red to pinkish gray; it weathers pinkish gray to light brownish gray. The dark-gray rocks are very fine grained and dense, almost flinty in appearance. Massive rhyolite grades into and interfingers with foliated rhyolite, but the micaceous minerals have a preferred orientation, even in massive-appearing rhyolite. Most of the rock lacks features that might indicate whether it is a flow or massive tuff; its length does not support a flow origin. The tiny phenocrysts or fragments of quartz and albite and a few of orthoclase are not conspicuous or abundant; they are mostly less than 1 mm in diameter. The matrix consists of quartz, alkalic feldspar, and sericite. Green biotite, magnetite, pyrite, epidote, or irregular aggregates of biotite, calcite, and magnetite were observed in some of the rhyolite. Muscovite forms metacrysts in some of the coarser textured rock.

INDIAN HILLS VOLCANICS

DISTRIBUTION

The Indian Hills Volcanics, named by Anderson and Creasey (1958, p. 20) for exposures in the Indian Hills in the western part of the Jerome area, extend into the east-central part of the Prescott-Paulden area, where they crop out north of Route 89A (pl. 1) and in four places south of 1,381,000 N. and east of 395,000 E. (pl. 2). The formation consists of interbedded andesitic and rhyolitic flows. The two units are differentiated on plate 1 but not on plate 2. Tuffaceous material, in areas mapped as contaminated Indian Hills Volcanics and in adjacent contaminated intrusive rocks, is included in the formation; tuffaceous rocks are not part of the formation in the type section.

THICKNESS AND STRATIGRAPHIC RELATIONS

The maximum outcrop width of the Indian Hills Volcanics within the area is about 4,000 feet. The thickness is probably less than outcrop width because the formation is probably folded and because the outcrop includes a considerable amount of granodiorite and gabbro too small or too poorly exposed to map. In places sheets and pods of gabbro compose as much as one-third of an area mapped as rhyolite. Gabbro may be as abundant as andesite in some areas mapped only as andesite, but it is not as apparent as in the rhyolite. In areas mapped as contaminated Indian Hills Volcanics, the volcanic rocks appear to make up about half of the outcrops. Granodiorite and some alaskite and gabbro, however, may be more abundant but are not apparent because the volcanic rocks crop out better. The volcanic rocks occur as angular to lenticular xenoliths in the intrusive rocks and as large masses into which the intrusive rocks were intimately injected.

In the Prescott-Paulden area the Indian Hills Volcanics are not in contact with other formations of the Alder Group. In the Jerome area (Anderson and Creasey, 1958, p. 21) the Indian Hills and Spud Mountain Volcanics appear conformable, but the direction in which tops of beds face was not determined. Because the Iron King Volcanics probably overlie the Spud Mountain Volcanics, the Indian Hills Volcanics were interpreted as underlying the Spud Mountain Volcanics. Although the base of the Indian Hills Volcanics is not exposed, Anderson and Creasey interpreted the volcanic rocks as presumably overlying the Texas Gulch Formation.

LITHOLOGY AND INTERNAL STRUCTURE

Interbedded andesitic and rhyolitic flows and some tuffaceous sedimentary rocks make up the Indian Hills Volcanics. The main exposures of the flows are in the Jerome area; they are described in detail by Anderson and Creasey (1958, p. 21).

The rocks are foliated but less so than other formations of the Alder Group. Foliation is absent in some outcrops in the Jerome area; it is more pronounced to the west, especially in the areas of fine-grained bedded tuffs. Some contacts between rhyolite and andesite flows are shear zones.

Rhyolitic flows.—The rhyolitic flows are grayish orange pink to light gray or greenish gray, except for dense siliceous, almost flinty rhyolite, which is medium gray to medium dark gray. Textures and structural features typical of rhyolite flows—such as flow banding, flow breccia, amygdules, and vesicles—occur locally but are generally inconspicuous. Phenocrysts consist of quartz, albite, and a little potassium feldspar; few of

them are conspicuous. Most phenocrysts are less than 1.0 mm long; where abundant, they may be more than 2 mm long. The groundmass is composed of microcrystalline aggregates of alkalic feldspar, quartz, and a little sericite; accessory minerals are chlorite, minerals of the epidote group, and magnetite. Sericite is abundant in the more sheared rocks. In some northern outcrops (pl. 2), biotite is concentrated in widely scattered thin layers and lenses, and quartz phenocrysts are recrystallized.

Andesitic and basaltic flows.—The andesitic and basaltic flows are greenish black. The flows are blocky, except where they are somewhat fissile owing to foliation or shearing. Amygdules, composed of minerals of the epidote group, and vesicles are widely distributed. Phenocrysts of altered plagioclase and less commonly of hornblende are widespread and are as much as 2 cm long. The holocrystalline commonly fine-grained groundmass consists of granular albite and minerals of the epidote group, small flakes of chlorite, and some biotite, magnetite, and calcite. Most chlorite has a slight preferred orientation; some is well oriented.

Tuffaceous sedimentary rocks.—Most of the andesitic and rhyolitic tuffaceous sedimentary rocks are fine-grained fissile foliates of light to dark color. Graded bedding and drag folds were observed in a few places. Mafic minerals are more abundant in some siliceous tuffs than in the rhyolite flows. Quartz, alkalic feldpar, and variable amounts of sericite make up the rhyolitic tuffs. Albite, minerals of the epidote group, chlorite, and some actinolitic hornblende compose the andesitic tuffs. Epidote is conspicuous in many of the rocks, even those composed largely of rhyolitic detritus.

SPUD MOUNTAIN VOLCANICS

DISTRIBUTION

The Spud Mountain Volcanics (Anderson and Creasey, 1958, p. 21–26) were named for excellent exposures on Spud Mountain, in the extreme southeast corner of the area (pl. 1), where they crop out as one large and several smaller masses. An outcrop of breccia, mapped with the Indian Hills Volcanics but probably part of the Spud Mountain Volcanics is in the east-central part of the area (pl. 2, 1,367,500 N., 398,100 E.). The breccia is faulted against Indian Hills Volcanics and Martin Limestone. In the type locality the formation consists of two units: (1) andesitic tuff lying east of (2) andesitic breccia. Elsewhere in the Jerome area, some rhyolitic tuff and andesite flows are intercalated in the andesitic tuff and breccia units.

THICKNESS AND STRATIGRAPHIC RELATIONS

The thickness and stratigraphic relations of the Spud Mountain Volcanics are uncertain because the formation is cut off on the west by the Spud fault and buried to the north and east by Cenozoic rocks. It has an outcrop width within the area of about 5,500 feet, of which about 4,000 feet is the breccia unit and 1,500 feet, the tuff unit. The tuff unit may be approximately 1,500 feet thick in this area; the breccia unit may not be more than 2,000 feet thick, as the structure of the unit may be anticlincal (pl. 1, sec. E–E′), as interpreted by Anderson and Creasey (1958, p. 72).

To the southeast the volcanics appear to be conformably and gradationally overlain by the Iron King Volcanics (pl. 1, sec. E–E′) (Anderson and Creasey, 1958, p. 23). The andesitic breccia is interpreted as occupying the lower part and the andesite tuff, the upper part of the formation.

LITHOLOGY AND INTERNAL STRUCTURE

The Spud Mountain Volcanics are various shades of grayish green to greenish gray; actinolitic hornblende produces the darker shades. Lighter shades are due to sericite from admixed rhyolitic detritus. The rocks weather brown or reddish brown to yellowish gray.

Most of the breccia within the map area is foliated, but it does not readily break parallel to this foliation because of abundant fibrous actinolitic hornblende. Fine-grained tuffs in any one locality are more intensely foliated than coarser grained crystal tuffs or breccia beds. Some fragments in the breccia facies show little or no evidence of stretching; others, even in adjacent beds, have been attenuated to lengths as much as 12 times the widths.

Relict bedding is preserved in some tuffaceous beds. Graded bedding, brought out by the distribution and size of plagioclase grains, can be recognized in places.

The principal constituents of both breccia and tuff are chlorite, albite and albite-oligoclase, minerals of the epidote group, some carbonate, and accessory magnetite, sphene or leucoxene, and apatite. Clinozoisite (or zoisite) is more abundant than epidote; actinolitic hornblende is found only in the andesitic breccias. The distribution of quartz is very erratic. Except in saussuritized plagioclase, sericite is largely confined to finer grained tuffs and was derived probably from admixed rhyolitic detritus.

Andesitic breccia.—Included within the breccia facies of the Spud Mountain Volcanics are beds of breccia, granular crystal tuff, and fine-grained tuffaceous sedimentary rocks. The unit is predominantly andesitic in composition. Breccia beds, which range from less than 1 foot to possibly 500 feet in thickness, are more abundant than the tuffs in the breccia facies.

The fragments, from less than 1 inch to 18 inches long, are sparsely to abundantly distributed throughout the breccia beds. Within individual beds most of

them are rather uniform in size. Their shape, which is generally subrounded, is due, in some places, to the original form or, in other places, to later deformation.

Fragments in the breccia are composed largely of porphyritic andesite. A few andesite fragments are amygdaloidal or vesicular. Other fragments consist of rhyolite, fine-grained dark rocks of undetermined origin, and mixtures of quartz and epidote of probable metamorphic origin. Rhyolitic fragments are locally abundant on the west side of Spud Mountain. Phenocrysts in the andesite fragments occur as individual crystals and clusters of crystals. They consist principally of equant saussuritized plagioclase and have a maximum size of 1 cm. The character, size, and distribution of the phenocrysts are identical in many places with those of the crystal fragments in andesitic crystal tuff, which forms the matrix of some of the breccia. Elsewhere the matrix is fine-grained andesitic tuff. Fine-grained tuff and crystal tuff similar to the matrix occur as interbeds in the breccia and are identical with andesitic tuff described in the following paragraphs.

Andesitic tuff.—The contact between the tuff and breccia is gradational and is arbitrarily located. Away from the contact, breccia or conglomerate and coarse crystal tuff beds are thin and less abundant, the fragments are smaller, and finer grained tuff beds are more prevalent. Conglomerate beds as much as 10 feet thick are common in the part of the tuff within the Prescott quadrangle; however, to the east and presumably higher in the section, coarse-grained crystal tuff beds and associated conglomerates are much less abundant, and more of the unit is fine grained (Anderson and Creasey, 1958, p. 24–25).

The andesitic tuff is a sedimentary rock composed largely of andesitic volcanic detritus. Most individual beds are not more than a few inches thick; grain size varies from bed to bed. The particles range from clay to cobbles, but most of them are between silt and coarse sand in size. Some variation in grain size is due to differential shearing, but most of it is probably a primary sedimentary feature.

Visible minerals in the tuff are chlorite, saussuritized plagioclase, and variable amounts of quartz and sericite; saussuritized plagioclase is the most conspicuous mineral. The plagioclase grains give the rock a porphyritic appearance or bring out its bedding depending on their distribution.

The finer grained facies are phyllites or slates. Chlorite and some sericite produce a sheen on cleavage surface that is characteristic of these rocks. Small grains of quartz or saussuritized plagioclase can be seen with a hand lens in some of these beds. Fissility is more pronounced and regular than in the coarser grained tuffs.

CHAPARRAL VOLCANICS

DISTRIBUTION

The Chaparral Volcanics (Anderson and Creasey, 1958, p. 30–31), named for exposures in Chaparral Gulch (1,277,000 N., 392,000 E.), trend northeastward for about 3 miles across the southeast corner of the area (pl. 1).

The volcanics consist of two lithologic units: rhyolitic tuff and andesitic tuff. Most of the andesitic tuff lies east of the rhyolitic tuff. A narrow layer of rhyolitic tuff occurs in andesitic tuff (pl. 1), and a narrow layer of andesitic tuff that tapers to a point from a width of about 50 feet occurs in rhyolitic tuff (shown only on pl. 1 of the Jerome report, Anderson and Creasey, 1958).

At the north, the outcrop of the rhyolitic tuff is split into three parts by the south-tapering masses of Prescot Granodiorite and alaskite. South of the tongues of intrusive rocks, the separate belts of rhyolite join to form a single belt. At the many places where quartz-sericite schist was formed at the contact between rhyolitic tuff and intrusive granitic rocks, the location of the contact is indefinite because the schist that was produced by intense distributive shear could have originated from either the tuff or the granitic rocks.

THICKNESS AND STRATIGRAPHIC RELATIONS

No estimate of the thickness of the Chaparral Volcanics can be made, and its stratigraphic relations to other formations are unknown. The formation is separated from adjacent formations by major faults that are occupied by intrusive igneous rocks (pl. 1). The Chaparral fault separates it from the Green Gulch Volcanics on the northwest, and the Spud fault separates it from the Spud Mountain Volcanics on the southeast. Structural complications—isoclinal folding, strong phyllonitization (Knopf and Ingerson, 1938, p. 190), and shearing out of beds—make an attempt to estimate original thickness hopeless.

The formation has an outcrop width of 1,500–2,600 feet. At the north end the distance between the two bounding faults is about 3,800 feet, but approximately 1,500 feet of this distance is occupied by intrusive rocks. The outcrop width of the rhyolitic tuff is much greater than that of the andesitic tuff at the north but less than that of the andesitic tuff to the south. The stratigraphic relation of andesitic tuff to rhyolitic tuff is not known, as the direction in which tops of beds face was not determined.

Although lithologically some of the Chaparral Volcanics resemble parts of other formations of the Alder Group, evidence currently available is insufficient to justify any correlation. The faults and shears in the area suggest that the Chaparral Volcanics may have

been moved for a long distance and may not even be part of the Alder Group.

LITHOLOGY AND INTERNAL STRUCTURE

Rhyolitic tuff.—The rhyolitic tuff is a fine-grained predominantly sedimentary rock that ranges from fissile, finely laminated foliates to more massive rocks. The rocks included in the rhyolitic tuff grade from compartively pure rhyolite to those containing added andesitic material. On a broad scale the rhyolite tuff consists of three types; each variety predominates in a separate area, but some interbedding of and gradation between the types occur. The eastern belt consists mostly of white fissile quartz-sericite schist; the western belt, of massive pink rhyolite; and the middle belt, of finely laminated greenish-gray tuff having contorted bedding. A single belt composed largely of white tuff occurs south of the tongues of intrusive rocks.

Rhyolitic tuff of the eastern belt is very light gray to yellowish gray, very fine grained, and finely laminated. Scattered tiny grains of quartz and a few of feldspar are the only visible minerals, although the sheen of the rock attests to the presence of sericite and a green tinge indicates admixed chlorite. Most of the feldspar grains are albite; a few are orthoclase. The matrix is composed of quartz, sericite, and variable amounts of alkalic feldspar.

Much of the rhyolitic tuff in the middle belt is a finely laminated greenish-gray to dark greenish-gray rock. Fissility is less well formed than in the rocks of the eastern belt. Contorted beds and small drag folds are common. The rock contains some epidote, actinolite, and biotite or chlorite; sericite is less abundant than in rocks of the eastern belt.

Rhyolitic tuff of the western belt is largely a massive pale-red rock; some is yellowish gray. Some grains of quartz and feldspar are a little larger and more abundant than those in the tuffs of the east. The matrix is mainly quartz and feldspar; a little epidote occurs locally. In much of this belt, no textures or structural features resembling primary flow or bedded features were found. The massive rhyolite is interpreted as a massive tuff on the basis of its extremely long strike length in contrast to its width; most rhyolitic flows are lenticular.

Andesitic tuff.—The andesitic tuff is fine grained, well foliated, and fissile, except for interbeds of more massive, coarser grained tuff. The finer grained tuff is commonly greenish gray to olive green; some is blotched and streaked with variegations of light yellowish green. Much of the lighter color is due to admixed rhyolitic material; where crosscutting, it is due to alteration. The matrix is composed of chlorite, sericite, albite, epidote, and quartz. The coarser tuff, in beds 1–50 feet thick, is more plentiful in the eastern than in the western part of this unit. It is grayish green and less well and more irregularly foliated than the finer grained tuff. Its principal constituents are chlorite, albite, and epidote. Feldspar grains are saussuritized.

GREEN GULCH VOLCANICS

DISTRIBUTION

The Green Gulch Volcanics (Anderson and Creasey, 1958, p. 31–32) were named for excellent but incomplete exposures along Green Gulch (between 1,282,000 N., 393,500 E. and 1,281,900 N., 386,500 E.). The formation crops out in the southeast part of the area (pl. 1) west of the Chaparral fault. Scattered outcrops protrude above the Cenozoic cover north of the main exposures. The formation is cut out near the south border of the area by the fault and by gabbro. It is not exposed elsewhere in the Prescott-Paulden area or the Jerome area. The formation has been divided into a basaltic flow unit and a tuffaceous unit; the basaltic flow unit lies east of the tuffaceous unit, which is split into two parts by intrusive rocks.

THICKNESS AND STRATIGRAPHIC RELATIONS

If outcrop widths approximate thickness, the formation must be more than 5,000 feet thick; the outcrop width of the basaltic flow unit is 7,000 feet, and that of the tuffaceous unit is 4,500 feet.

The stratigraphic relations could not be determined as the Green Gulch is not in normal contact with other formations of the Alder Group. Except locally, the lithology of the Green Gulch Volcanics is not sufficiently like that of any other formation in the group to permit a correlation.

Although beds face east and west in the basaltic flow unit, west-facing beds are more prevalent than east-facing ones. For this reason, the tuffaceous unit is believed to overlie the basaltic flow unit.

LITHOLOGY AND INTERNAL STRUCTURE

Basaltic flow unit.—The basaltic flow unit consists of flow, breccia, tuff, and conglomeratic tuff. Most of these rocks are medium to dark gray and have a green cast. Rocks rich in metamorphic hornblende are dark bluish gray; those rich in chlorite are grayish green.

Relict pillow and breccia structures, amygdules, vesicles, and bedding are preserved here and there and are well exposed in the water-polished exposures in the larger gulches. Pillows were recognized only in Green Gulch and the next gulch to the south (indicated by symbol on pl. 1). Many of the pillows are attenuated to as much as 15–20 times the width. Amygdules, composed of quartz and quartz-epidote, and vesicles are more widespread than the pillows. Relict bedding and drag folds are preserved in tuffaceous interbeds separat-

ing flows and breccias. Bedding symobls in the basaltic flow unit on plate 1 indicate the location of some of these interbeds. Fragments in the breccia and conglomeratic tuff are composed of rhyolite and more abundant andesite or basalt and of crystal fragments from these rocks. The fragments range from less than 1 mm to about 15 cm. Some are attenuated; lengths in places exceed widths by as much as 10 times. Some fragments are angular to subangular.

Small saussuritized plagioclase phenocrysts and porphyroblasts or aggregates of hornblende are the most abundant megascopic minerals. Some phenocrysts (or fragments in the tuffs) are clustered. Chlorite is visible locally. Relict felty texture was recognized in one place, but metamorphism has obliterated many original textures.

The principal constituents are actinolitic hornblende, albite, and epidote; chlorite and carbonate are abundant where the rocks were highly sheared. Higher grade metamorphism in the northeasternmost exposures produced hornblende, oligoclase, and some brown biotite, sphene, and apatite. Here narrow veinlets that resemble ptygmatic folds consists of minerals of the epidote group and some quartz, chlorite, plagioclase, sphene, and muscovite, all of which were probably formed by metamorphic diffusion.

The predominance of mafic constituents and the lack of abundant plagioclase phenocrysts suggest that this unit is basaltic rather than andesitic. The presence of pillows likewise suggests a basaltic composition; Satterly (1941) pointed out that most of the analyzed pillow lavas of Canada are basalts, and an analysis of the Iron King Volcanics (Anderson and Creasey, 1958, p. 27), which contains pillow lavas, indicates a basaltic composition.

Tuffaceous unit.—The tuffaceous unit consists of tuffs and breccias and very minor rhyolitic flows. The clastic rocks are principally rhyolitic and admixed rhyolitic and andesitic in composition, but a few are mafic. The mafic tuffs and breccias are identical to the tuff and breccia in the basaltic unit and predominate for about 1,000 feet west of the arbitrarily located contact between the two units.

Most of the rhyolitic rocks are dark gray; some have a green, olive, or pink cast; they weather olive gray or pinkish gray. A few are light-gray porcelaneous slates. In the eastern exposures those that weather olive gray have a characteristic sheen due to abundant sericite and a little chlorite. Here the rhyolitic tuffs are fine grained and range from finely laminated fissile foliates to more massive locally coarser grained rocks. Relict bedding and drag folds are apparent in water-worn outcrops along Green Gulch. An additional indication of

the sedimentary origin of at least the eastern part of the unit is the abrupt variation in composition and texture across the trend of the unit. No relict bedding was observed in the western outcrops; flow banding was observed in one place (1,280,800 N., 382,200 E.).

Phenocrysts and crystal fragments are visible in many places, but few of them are more than 1 mm long. They consist mostly of clear albite-oligoclase, quartz, and magnetite. Some plagioclase has saussuritized centers; larger ones are completely saussuritized. The groundmass or matrix is composed of quartz, orthoclase, albite, sericite, minerals of the epidote group, magnetite, sphene, and sporadic chlorite and actinolite or actinolitic hornblende. Saussuritized plagioclase, epidotegroup minerals, and magnetite are locally abundant. The plagioclase and epidote minerals together with chlorite and actinolite probably represent admixed andesitic or basaltic detritus. The rhyolitic tuffs in the eastern outcrops are composed largely of quartz and sericite. In the western outcrops quartz and alkalic feldspar are the principal constituents.

The unit contains a few rhyolitic breccias. Fragments are composed of rhyolite and andesite or basalt; some are angular, others are rounded. They range from a fraction of an inch to 10 inches in length.

UNNAMED VOLCANIC ROCKS OF THE ALDER(?) GROUP

DISTRIBUTION

Volcanic rocks that may belong to the Alder Group, but which could not be correlated with known formations in the group, are mapped as two lithologic units; basaltic flows and tuffaceous rocks. These rocks crop out in four places along the southern border of the area (pl. 1) and in two places in the northern part (pl. 2). They are referred to as (1) the southwestern basaltic flows and tuffaceous rocks, (2) the south-central basaltic flows, (3) the south-central tuffaceous rocks, (4) the southeastern basaltic flows and tuffaceous rocks, (5) the northern tuffaceous rocks, which extend south-southeastward from upper King Canyon (1,392,500 N., 381,000 E.), and (6) the northern basaltic flows, which form six small outcrops (fig. 5) east and southeast of the Pinnacle (1,400,000 N., 353,000 E.). Small unmapped amounts of these lithologic units occur in adjacent intrusive rocks.

THICKNESS AND STRATIGRAPHIC RELATIONS

On the basis of outcrop widths, individual masses of these unnamed volcanic rocks are estimated to be 1,000–3,000 feet thick, but the relations are unknown. No correlation of individual masses with one another has been made. Lithologically some or all of the masses of tuffaceous rocks could be stratigraphic equivalents, as could some of the basaltic flows.

Where mapped, the individual masses are surrounded by younger rocks. Many of them occur only as roof pendants or lenses in intrusive rocks (pl. 1, sec. B–B′ and E–E′). Only the south-central basaltic flows are adjacent to another formation of the Alder Group, but a fault or shear zone separates the two. The southwestern basaltic flows and tuffaceous rocks interfinger or are repeated by folds along the contacts between the two units. The relations of the southeastern basaltic flows and tuffaceous rocks is not known; on the east, along, and west of Charcoal Gulch, a fault or shear zone probably separates the two units.

LITHOLOGY AND INTERNAL STRUCTURE

Basaltic flows.—Rocks mapped as unnamed basaltic flows comprise basaltic flow, breccia, tuff, and some interbedded rhyolitic tuff. The basaltic rocks are medium to dark gray with a slightly green or blue cast.

Foliation except in some sedimentary breccia and tuff, is variable but generally less well defined than in most of the formations of the Alder Group. Intense shear has produced zones of retrograde metamorphism and abundant chlorite. The northern basaltic flows and some of the southeastern and southwestern ones are poorly foliated to nonfoliated.

Amygdules, vesicles, agglomeratic structures, and pillows(?) indicate a flow origin for some rocks. Bedding, a fragmental character, and abrupt changes in lithology indicate or suggest a sedimentary origin for others. Amygdules are composed of quartz, epidote, or calcite. Pillows(?) were noted in the southwestern basaltic flows (especially near 1,276,100 N., 337,900 E.). The closely packed rounded, ellipsoidal, or irregularly shaped pillow(?), mostly less than 1 foot long, have thin fine-grained dark selvages, which are probably chilled borders. The irregular shape and small size are suggestive of bombs, lapilli, and other agglomeratic fragments, but triangular chalcedonic fillings are reminiscent of the chalcedonic fillings between most pillows in the area. The enclosing matrix is rich in zoisite (or clinozoisite). The northern basaltic flows consist largely of closely packed fragments having the same composition as the enclosing matrix. Some of these fragments resemble the small lapilli and bombs of an agglutinate (Tyrrell, 1931, p. 66).

Sedimentary breccias are largely confined to the south-central basaltic flow. Fragments in the breccias are 1 mm to 15 cm long and consist of saussuritized plagioclase, basalt, and a little rhyolite. The fragments are angular, rounded, or attenuated. Recognizable tuff interbeds are confined to the south-central and

to the western parts of both the southeastern and southwestern basaltic flows.

Much of the rock is massive, fine grained, and nondescript; it has no features that indicate a flow, tuff, or intrusive origin. Scattered saussuritized plagioclase phenocrysts, crystals fragments, or clusters of them, are generally visible and may be abundant. Many of them are about 1 mm in size; some are as much as 7 mm. Most of them are equant to lath-shaped. In distribution and abundance the phenocrysts in fragments are similar to, or contrast with, those in the matrix.

Saussuritized plagioclase and magnetite are generally the only relict primary minerals, but a little relict pyroxene was observed in the northern and southeastern basaltic flows. Some unaltered zoned plagioclase laths occur as phenocrysts and in the groundmass in the northern and south-central basaltic flows. The felty to diabasic texture and subparallel orientation of plagioclase laths are interpreted as primary.

Most minerals and textures are metamorphic. The rock is composed of a granular assemblage of albite or oligoclase, actinolite or actinolitic hornblende, minerals of the epidote group, and some quartz, chlorite, calcite, sericite, and accessory magnetite, sphene, and apatite. Hornblende or actinolitic hornblende forms sparse to abundant large porphyroblasts, poikiloblasts, or aggregates. Hornblende, brown biotite, and muscovite are common in areas of higher grade metamorphism. A subparallel dimensional orientation of actinolitic hornblende and variations in the relative proportions of hornblende and plagioclase in thin layers are probably metamorphic features.

Tuffaceous rocks.—The unnamed tuffaceous rocks are principally a sedimentary series composed of volcanic detritus of basaltic (or andesitic) and rhyolitic composition; some may be terrigenous siliceous sediments. A few small unmapped basaltic flows and questionable flows are included with the tuffs. The tuffs are mostly fine grained, finely laminated, and well foliated; where micaceous minerals are abundant, the tuffs cleave readily. Mineral streaking, plunge of drag folds, and intersection of cleavage and bedding give some of the rock a pronounced lineation. Some pebble- to cobble-sized fragments have the same composition as the enclosing matrix; the composition of other fragments contrasts with the matrix.

The basaltic or andesitic tuffs are medium dark to dark gray and have a green or blue cast; some layers are light yellowish or greenish gray. Some tuffs contain visible crystal fragments of saussuritized plagioclase; others contain poikiloblastic or porphyroblastic actino-

litic hornblende as much as 1 cm long. The matrix is composed of metamorphic albite or oligoclase-andesine, actinolitic hornblende, and minerals of the epidote group. Accessory minerals are magnetite, apatite, sphene, and pyrite. Quartz, potassium feldspar, biotite, chlorite, muscovite, or sericite sporadically occur. Zoisite or clinozoisite is more abundant than epidote. Much of the quartz and feldspar represent admixed rhyolitic detritus, but some may have been derived from granitic veinlets that cut the tuff. Except for sericite formed from alteration of plagioclase, micaceous minerals are generally absent unless the rocks contain rhyolitic detritus or have been sheared. The typical finely laminated rocks are composed of layers of different combinations and proportions of the principal minerals; hornblende is especially abundant in the dark layers; and zoisite, or clinozoisite, in the light-colored layers. Some light-colored layers contain abundant tremolite-actinolite.

Many rhyolitic tuffs are medium-dark to light shades of bluish, greenish, or yellowish gray; some are nearly white; others are pale or grayish red to grayish orange pink. They are composed of quartz, variable amounts of alkalic feldspar, muscovite, sericite, biotite, chlorite, minerals of the epidote group, and accessory magnetite, pyrite, and sphene. The tiny angular to subrounded crystal fragments, some visible in hand specimen, are composed of quartz, potassium feldspar, and albite; a few are composed of saussuritized plagioclase. Many of the rocks are quartz-sericite schists, but higher grade metamorphism of the southwestern tuffaceous rocks has formed some quartz-biotite and quartz-muscovite schists. In the southeastern exposures some tuffaceous rocks are composed of quartz and alkalic feldspar but contain little or no sericite. In one place along Bannon Creek (near 1,274,200 N., 336,200 E.), pseudomorphs after poikilitic tremolite(?) are now composed of biotite, chlorite, epidote, sphene, and a little relict amphibole. They are as much as 1 cm long and enclose many quartz and feldspar grains. Tremolite(?) metacrysts are unusual in a rock composed largely of quartz and calcitic albite. Some schists contain magnetite metacrysts as much as 4 mm in diameter; others (near 1,290,500 N., 375,800 E.) contain tiny red garnets.

Garnet-epidote-quartz alteration zones and quartz-magnetite veins or alteration zones are common in the southwestern and south-central areas of tuffaceous rocks; some occur in the southeastern areas. The quartz-magnetite veins are discussed under veins and silicified and alteration zones in the section on older Precambrian intrusive rocks (p. 48).

The garnet-epidote-quartz alteration formed largely in the mafic tuffs as concordant and crosscutting thin layers and lenses and locally, as knots and ptygmatic-like veinlets. The minerals formed during the alteration are epidote, grayish-red garnet, and quartz in varying proportions. Sparse to abundant zoisite, tremolite, sericite, sodic plagioclase, magnetite, and sphene occur in various combinations in the alteration zones.

MAZATZAL QUARTZITE

DISTRIBUTION

The Mazatzal Quartzite, named by Wilson (1922, p. 299; 1939, p. 1124) for exposures in the Mazatzal Mountains (southeast of Pine, inset, fig. 1), crops out south of the Verde River in the central part of the Paulden quadrangle (pl. 2), where it is referred to as the Del Rio area. Within an area of about 23 square miles, the quartzite forms 1 large and 21 small outcrops (fig. 5), which total about 3 square miles in area.

THICKNESS AND STRATIGRAPHIC RELATIONS

About 4,000 feet of Mazatzal Quartzite was measured in the Del Rio area, but the total thickness is not known, as neither the top nor the bottom of the formation is exposed. Wilson (1939, p. 1155) measured only 1,780 feet, but he believed the formation to be cut by a thrust fault.

The stratigraphic position of the Mazatzal is not known. The quartzite is in fault contact (fig. 5) with the Texas Gulch Formation (1,402,500 N., 347,000 E.) and with basaltic flows of the Alder(?) Group (near 1,393,500 N., 353,300 E.). Quartzite apparently surrounds the basaltic flows to the north, but contacts are covered. The probable stratigraphic position of some of the small outcrops of the formation is shown in figure 5.

The Mazatzal Quartzite is unconformably overlain by the Tapeats Sandstone, or Martin Limestone, of Paleozoic age or by Cenozoic rocks.

LITHOLOGY AND INTERNAL STRUCTURES

The Mazatzal Quartzite comprises a series of fine- to coarse-grained quartzite, granule to boulder conglomerate, and a little argillite. In ascending order the formation consists of quartzite, 260 feet (0–1); lower conglomerate, 440 feet (2–5); lower argillite, 50 feet (6); quartzite and minor conglomerate, 940–1,100 feet (7–11); upper argillite, 60 feet (12); quartzite and minor conglomerate, 835 feet (13–17); upper conglomerate, 1,150 feet (18–26); and quartzite, 325 feet (27–28). (Figures in parentheses refer to units described in the measured section.) The formation is described
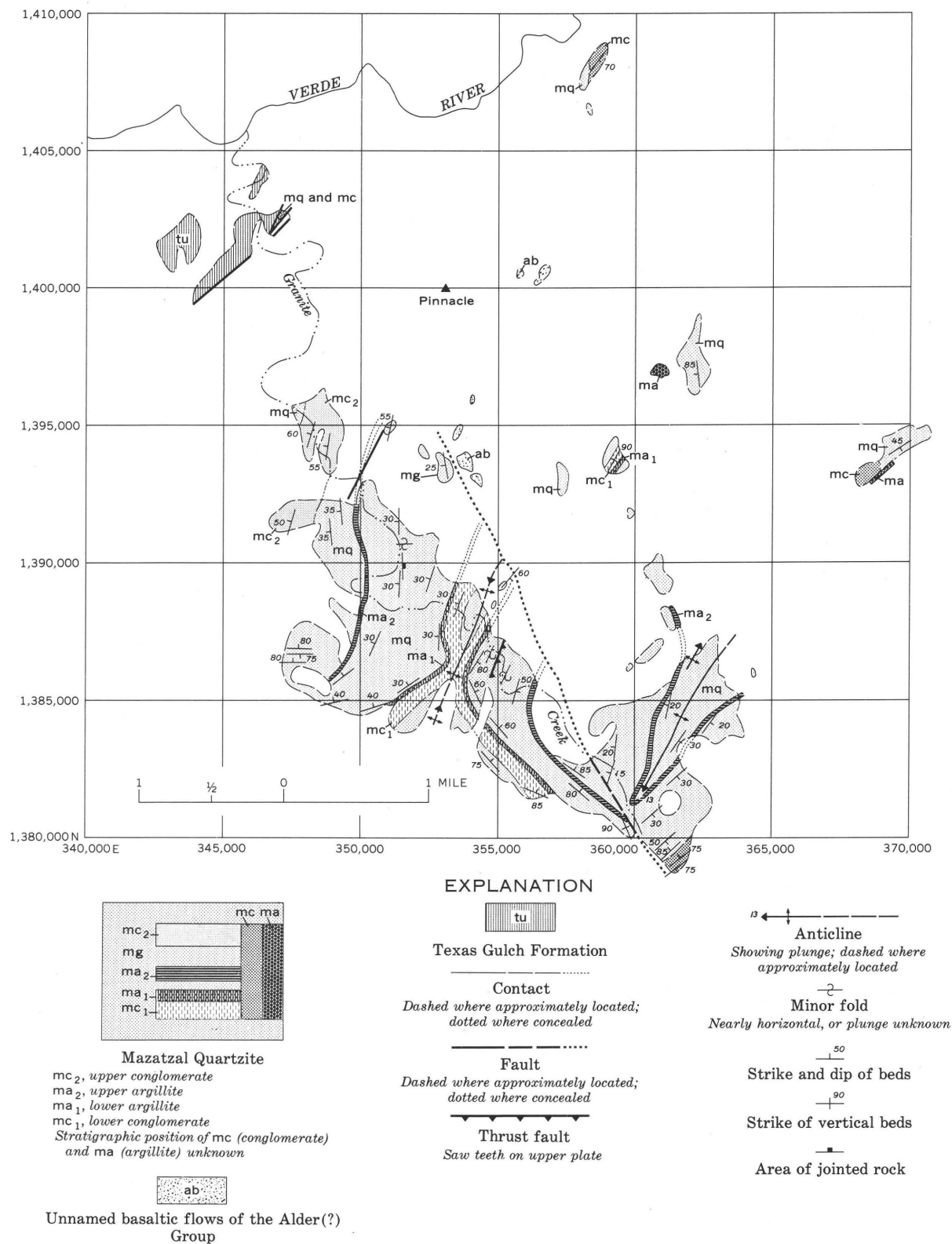
FIGURE 5.—Outcrops of the Mazatzal Quartzite and of Precambrian rocks adjacent to the Mazatzal in the Paulden quadrangle. The structure and probable correlation of isolated outcrops to the main mass of the Mazatzal are shown.

EXPLANATION

tu

Texas Gulch Formation

Contact
*Dashed where approximately located;
dotted where concealed*

Fault
*Dashed where approximately located;
dotted where concealed*

Thrust fault
Saw teeth on upper plate

Mazatzal Quartzite

mc₂, *upper conglomerate*
ma₂, *upper argillite*
ma₁, *lower argillite*
mc₁, *lower conglomerate*
Stratigraphic position of mc *(conglomerate)
and* ma *(argillite) unknown*

ab

Unnamed basaltic flows of the Alder(?)
Group

Anticline
*Showing plunge; dashed where
approximately located*

Minor fold
Nearly horizontal, or plunge unknown

Strike and dip of beds

Strike of vertical beds

Area of jointed rock

in detail in the following sections (note that two different figures, sections 1 and 1a, were obtained for units 7–11):

Mazatzal Quartzite, Del Rio area, Arizona

[Color terms and numerical designations are those used in the "Rock Color Chart," National Research Council, 1948]

Section 3

[Top located at 1,395,600 N., 347,600 E.]

	Thickness (feet)
Top eroded and covered by Cenozoic deposits.	
Quartzite (27–28):	
28. Quartzite and a little granule conglomerate, pale red-purple (5RP 6/2), medium-grained, thin bedded (beds are about 6 in. thick), cross-laminated, well-indurated (quartz cement); conglomerate contains subrounded to subangular granules of quartz and a few of red chalcedony_____	50
27. Quartzite and a little granule to small-pebble conglomerate, grayish-red (5R 4.5/2), rarely pale-red (7R 5/2); weathers dusky red to very dark red (5R 3/4–2/6); medium-grained, thin-bedded (6 in. to 1 ft), cross-laminated, well-indurated (quartz cement); contains a few very thin partings of red argillite and micaceous sandstone, granules and small pebbles of quartz, a little red chalcedony, and, locally, red argillite 1½ in. across__	275
Total thickness of exposed quartzite (27–28) ------------------------------------	325
Upper conglomerate (18–26):	
26. Conglomerate and medium- to coarse-grained quartzite, grayish red-purple to grayish-red (5RP 4/2–5R 5/2); unit weathers very dusky red (10R 2/2); very thin to thin bedded, well-indurated; subrounded granules and pebbles (as large as 3½ by 2 in.) of quartz, red and dark-gray chalcedony, grayish and reddish quartzite, and quartz porphyry; some angular red chalcedony pebbles; conglomerate beds 6 in. to 2 ft thick; pebbles at least as abundant as matrix in one 15-ft interval------------------	30
25. Quartzite, medium- to coarse-grained, less abundant granule to pebble conglomerate; light brownish-gray, very pale brown to brownish-gray (5YR 6/1–6/2–4/1), mostly thin-bedded (1 ft to rarely 7 ft), cross-laminae accentuated by black hematite; quartzite contains scattered pebbles (½–¼ in. in size) of quartz and a few of red chalcedony; most pebbles in conglomerate are of quartz and less than 1 in. in diameter; a few cobbles (as much as 1 ft in diameter) occur near base in a very coarse grained matrix------------	230

Mazatzal Quartzite, Del Rio area, Arizona—Continued

Section 3—Continued

	Thickness (feet)
Upper conglomerate (18–26)—Continued	
24. Sandstone, sandy and micaceous, and shale, grayish-red (10RP 5/3–5R 4.5/3), fine-grained to silty, weakly cemented, locally ripple-marked, slope-forming; estimated thickness, less than_____	5

The same conglomerate bed (23) that forms the top of section 2 forms the bottom of section 3.

[Bottom of section located at 1,395,000 N., 348,100 E.]

Section 2

[Top located at 1,391,500 N., 347,200 E.]

	Thickness (feet)
23. Conglomerate and a few reddish-brown quartzite interbeds as much as 1 ft thick, light brownish-gray (5YR 6/1)—locally light olive-gray (5Y 6/1) and pale red (7R 5/2)—grayish red-purple (5RP 4/2) near base; weathers blackish red to dusky-red (5R 2/2–3/2); some black hematite grains concentrated in laminae; medium to very coarse grained, thin (6 in.) to thick-bedded; pebbles of subrounded to subangular quartz, and a few of quartzite, quartz porphyry, and angular red chalcedony; red and dark-gray chalcedony more abundant toward base; pebbles, generally as abundant as matrix, mostly less than 1 in. in size near top, mostly about 2 in. near base; largest pebbles (3–4 in. in size) in middle; a few triangular fragments of blackish-red (5R 2/2) chalcedony and grayish quartzite are 6 by 4 in. in size_____	140
22. Quartzite, medium-grained, and granule to small-pebble conglomerate; weathers dark, like base of unit 23; thin layers (as much as 1 ft thick) of coarser conglomerate like lower part of unit 23____	50
21. Pebble conglomerate and a little quartzite; weathers very dusky red to grayish brown (10R 2/2–5YR 3/2); pebbles of red chalcedony and quartz about equally abundant; a few of quartzite, quartz porphyry, and gray chalcedony and some angular fragments of grayish-red (5R 4/2) argillite (as much as 1 ft in size)__	25
20. Conglomerate, chiefly quartz pebbles and small cobbles generally 2 in. in size; a few as much as 8 in. across_____	5
19. Conglomerate and some quartzite; weathers light brownish gray to light olive gray (5YR 6/1–5Y 6/1) near base; some finer grained beds weather dusky red (5R 3/4–3.5/5); pebbles composed of quartz, red chalcedony, or a little quartzite and quartz porphyry; pebbles are mostly less than 2 in. in diameter but range from granules to cobbles, smaller ones near base; some finer grained beds are cross laminated_____	448

Mazatzal Quartzite, Del Rio area, Arizona—Continued

Section 2—Continued

	Thickness (feet)
18. Quartzite, granule conglomerate, and some thin beds of small-pebble conglomerate; unit weathers dusky red; some beds in the middle of the unit weather to a lighter color_____	220
Total thickness of the upper conglomerate (18–26) _____	1,153

A saddle near the middle of the ridge separates the predominantly conglomerate beds (above) on the west from the predominantly quartzite beds (below) on the east.

Quartzite (13–17):

17. Quartzite and granule conglomerate, largely grayish-red (5R 4/2–5/2) to slightly red-purple; finer and more even grained beds are dark reddish-brown (5R 3/5); cross-laminated; quartz grains in a reddish matrix_____	35
16. Quartzite and granule conglomerate, very pale red-purple (5RP 7/2), grayish orange-pink (5YR 7/2), and pale-red (10R 6/2), cross-laminated_____	95
15. Conglomerate; pebbles (as much as 2 in. in size) of quartz and some red chalcedony; a few other rock fragments_____	25
14. Quartzite, pale-red (10R 6/2), fine to very coarse grained, crossbedded; a few somewhat friable medium-grained beds; some interbeds as much as 5 ft thick contain quartz pebbles (less than 1 in. in diameter)_____	602
13. Quartzite and sandstone, pale reddish-brown (10R 5/4), moderate-red (5R 5/4–4/6), grayish-orange-pink (10R 7/3–5YR 7/2), thin-bedded (less than 6 in.), cross-laminated, medium- to coarse-grained; basal beds contain angular pieces of red argillite. Approximate thickness_____	75
Total thickness of quartzite (13–17)_____	832

Upper argillite (12):

12. Argillite (very fine grained mudstone), some micaceous shale and sandstone; various shades of red (mostly 6R 4/6–7R 4/6; some 5R 4.5/5–3.5/3–4.5/3); weathers lighter shades, numerous light spots due to leaching of iron oxide; massive to very thinly laminated. Estimated thickness of argillite (12)_____	25–60

NOTE.—Bottom of section located at 1,391,800 N., 349,600 E.

Mazatzal Quartzite, Del Rio area, Arizona—Continued

Section 1a

[Top located at 1,386,500 N., 349,700 E.]

	Thickness (feet)
Top overlain by upper argillite (unit 12).	
Quartzite (7–11):	
11. Quartzite (the typical lavender quartzite of the Mazatzal) and well-indurated sandstone, pale-red (5R 6/2–5.5/3–5/2), very pale red-purple (5RP 7/2), to light brownish-gray (5YR 6/1); weathers light brownish gray, light olive gray, yellowish gray, to very pale yellowish brown (5YR 6/1–5Y 6/1–5Y 7/2–10YR 7/2); medium- to fine- and even-grained, locally cross-laminated; composed almost entirely of quartz; redder quartzite is fine to medium grained and well sorted; lavender quartzite is slightly coarser and less well sorted. Thickness approximate, it grades down into unit 10_____	408
10. Quartzite and a few beds (as much as 1 ft thick) of granule and pebble (as much as half an inch in size) conglomerate, light brownish-gray (5YR 6/1–7/1); weathers pale yellowish brown with a rough surface, locally, pale red (10R 6/2–7/1); medium to very coarse grained, cross-laminated; grades upward into medium- to fine-grained lavender quartzite (pale-red, 5R 7/2, to very pale red-purple, 5RP 7/2)_____	330
9. Conglomerate, light olive-gray (5Y 6/1) to light brownish-gray (5YR 6/1); rounded to subangular pebbles as much as half an inch in diameter_____	4
8. Sandstone, well-cemented; some quartzite and a few thin beds of granule and small-pebble (as much as 1 in. in size) conglomerate; pale-red (5R 6/2) to light brownish-gray (5YR 6/1); weathers pale red (10R 6/2); cross-laminated (less so than is unit 7C); dark-gray hematite grains in some cross laminae__	67
7C. Quartzite; weathers medium gray to brownish gray (5N–5YR 4/1–3/1), locally grayish red (7R 5/4); medium- to coarse-grained; scattered (locally abundant) granules and small pebbles (as much as 1 in. in size) of quartz and a few of red chalcedony; prominently cross-laminated; cross laminae accentuated by abundant grains of dark-gray hematite _____	27
7B. Conglomerate and some quartzite lenses as much as 6 in. in thickness; pebbles and cobbles (as much as 3½ in. in size) of subrounded quartz, subrounded to subangular red and dark-gray chalcedony, and, a few of quartzite and quartz porphyry_____	4

Mazatzal Quartzite, Del Rio area, Arizona—Continued

Section 1a—Continued

	Thickness (feet)
Quartzite (7–11)—Continued	
7A. Quartzite, light brownish-gray to pale grayish-red (5YR 6/1–5/1–5R 6/1); weathers pale brown (5YR 5/2) with a rough surface; weathers darker brownish-gray near top; coarse to very coarse grained; scattered granules and very small pebbles; cross-laminated____	265
Total thickness of quartzite (7–11), as measured in section 1a_____	1,105

[Bottom of section is located at 1,384,700 N., 350,800 E. and is underlain by lower argillite (6)]

Section 1

[Top located at 1,383,900 N., 356,200 E.]

Top overlain by upper argillite (unit 12).

	Thickness (feet)
Quartzite (7–11):	
11. Quartzite (same as unit 11, section 1a), lavender, becoming reddish at top; crossbedded, even-grained_____	480
10. Quartzite and some granule to small-pebble conglomerate; weathers light brownish gray (5YR 6/1)_____	230
9. Conglomerate, same as unit 9 of section 1a_	4
8. Quartzite and some small-pebble (as much as a quarter of an inch in size) conglomerate, pale-red (5R 6/2–5/3), coarse-grained, cross-laminated; some laminae accentuated by hematite grains_	40
7. Quartzite, poorly exposed; some is like unit 7C of section 1a_____	188
Total thickness of quartzite (7–11), as measured in section 1_____	942
Lower argillite (6):	
6. Sandstone, micaceous, sandy micaceous shale, and a little argillite; grayish-red (5R 4/2–5/2) to pale reddish-brown (8R 5/4), white or light-colored spots due to leaching of iron oxide, medium- to fine-grained; angular to subrounded closely packed grains of quartz and some muscovite in a reddish matrix.	
Thickness of lower argillite, estimated_____	25–50
Lower conglomerate (2–5):	
5. Conglomerate and quartzite; weathers brownish gray (5YR 4/1) at top; pebbles are smaller, and beds of quartzite are thicker and more abundant than in unit 4_____	305
4. Conglomerate; lighter colored than unit 3; contains abundant cobbles and small boulders (as much as 12 in. in size) of quartz and a few of red chalcedony____	15

Mazatzal Quartzite, Del Rio area, Arizona—Continued

Section 1—Continued

	Thickness (feet)
Lower conglomerate (2–5)—Continued	
3. Conglomerate; red and gray chalcedony fragments are more abundant than in unit 2; weathers dusky red (5R 3/4)___	100
2. Conglomerate and a little quartzite, pale-red (5R 6/2) to grayish orange-pink (5YR 7/2); rounded to angular quartz and some angular red chalcedony, ranging in size from granules to cobbles 6 in. long_____	20
Total thickness of lower conglomerate (2–5)_____	440
Quartzite (0–1):	
1. Quartzite, grayish orange-pink (5YR 7/2) to very pale red (5R 7/2); weathers yellowish gray, light brownish gray, light olive gray, to pale yellowish brown (5YR 8/1–5YR 6/1–5Y 6/1–10YR 6/2); medium- to coarse-grained and very coarse grained, mostly well-indurated; massive, bedding is indistinct_____	208
0. Quartzite, weathers dark reddish brown at base; unit was not measured, but is exposed below unit 1; approximate thickness_____	50
Total exposed thickness of quartzite (0–1), approximate_____	258

Base concealed by Cenozoic deposits.

[Bottom of section located at 1,382,700 N., 354,900 E.]

Total thickness exposed, approximate_____ 4,000–4,200

Section 1a was measured as a check on the correlation of the western and eastern outcrops of upper argillite and on the stratigraphy of the rocks between the upper and lower argillite in the two areas. The difference in measured thickness (about 160 ft out of a total of about 1,000 ft) could be due to several factors: (1) errors in measuring caused in part by the gentler dip of the rocks in section 1a; (2) original differences in thickness; and (3) the fact that upper and lower contacts of the two argillites in section 1a were covered and may actually have been farther west and therefore higher up in the section than estimated.

QUARTZITE AND CONGLOMERATE

Most of the quartzite and conglomerate are hard vitreous rocks that form cliffs and rugged topography, but some beds are less resistant. The fresh rock is various shades of red, grayish pink, and brown to pale red purple; much of it has a lavender tint. The rock weathers dark to light shades of gray, red, and brown. From a distance the outcrops are dark colored.

Bedding ranges from thin to thick or massive and from indistinct to conspicuous. Crossbedding is common in much of the finer grained rocks and is sporadic in conglomerate. Most lamination planes are 1 foot or less in length; some are as much as 3 feet long. In places grains of dark-gray hematite accentuate cross laminae and some bedding planes. Some laminae, composed principally of hematite, are more than 5 mm thick. The hematite grains, which are subrounded and mostly less than 0.5 mm in diameter, represent original concentrations, not later replacement.

Textures range from fine grains to boulders 12 inches in diameter (fig. 6). Most of the lavender quartzite below the upper argillite (unit 11, measured sections) is even grained, but elsewhere much of the material is poorly sorted. Pebbles are very sparsely distributed to closely packed. Many of them are subrounded, but some large pieces of argillite and red chalcedony are subangular to angular. The pebbles are milky quartz, variable amounts of red, reddish-black, and dark- and light-gray chalcedony, a little grayish and reddish quartz porphyry and quartzite, schistose and more massive dark volcanic rocks, and argillite. Argillite fragments are common immediately above the upper argillite. No granitic pebbles were seen. The quartzite and matrix of the conglomerate are composed of quartz and a little chalcedony, black hematite, argillite, and muscovite. Grains of magnetite and ilmenite, observed in most thin sections, are rounded to angular; smaller grains are more angular.
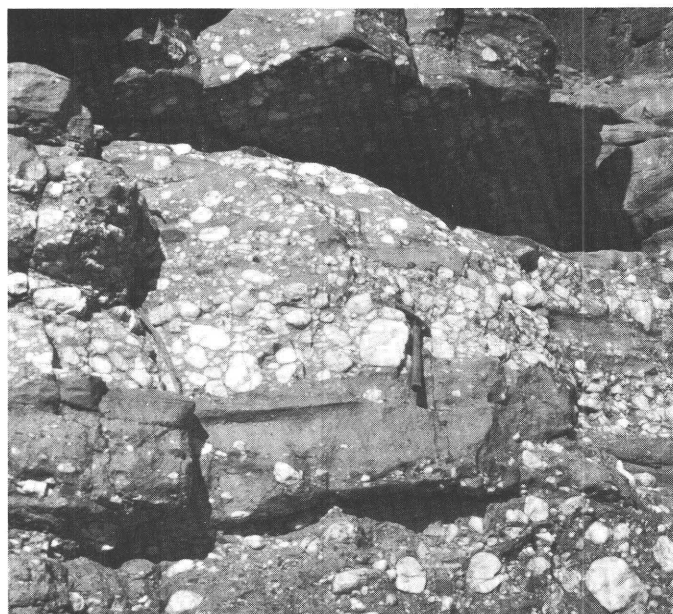
FIGURE 6.—Lower conglomerate in the Mazatzal Quartzite, Granite Creek (near 1,388,200 N., 353,600 E.)

Argillite forms thin partings in the Mazatzal Quartzite and two thicker beds—lower (unit 6) and upper (unit 12) argillite. The lower argillite, consisting of micaceous sandstone, sandy micaceous shale, and a little argillite, forms two narrow bands in the central part of the main mass of the formation. The upper argillite, consisting of argillite, micaceous sandstone, and sandy micaceous shale, forms three bands in the main mass— a western, a central, and an eastern one.

The argillites crop out poorly and form grassy slopes and flats over which small chips of the material are scattered. The upper argillite was first noted and mapped because of small pits dug on it by Indians, who used the material for pendants. Most of the pits are on the two eastern outcrops; only one was noted on the western outcrop. The argillite is similar to the pipestone or catlinite used by Minnesota Indians for pipes of peace and other artifacts.[4]

The argillite is shades of grayish red, reddish brown, and red purple. It weathers moderate orange pink; much of it contains numerous spheroidal-, ellipsoidal-, and disk-shaped spots that are the same color as the weathered surface or very light gray. The spots range from less than 1 to 10 mm in diameter; they are formed by leaching of iron oxide from the matrix. Scattered small white grains are also visible.

The argillite ranges from a very fine grained, dense rock to one composed of rounded and ellipsoidal grains as much as 1.5 mm in diameter. Much of the argillite is massive, but some is thinly laminated; the slightly darker laminae are about 1 mm thick, and the lighter colored ones are 3–10 mm thick. The laminated rock tends to break parallel to the bedding, but it does not split readily. The massive rock has a very irregular fracture, except where cut by numerous closely spaced joints. Slickensides have formed where the rock has been shattered, but the argillite shows no internal evidence of having been deformed.

Micaceous sandstone and sandy micaceous shale grade into argillite and into quartzite. These rocks are medium to fine grained, thinly bedded (2–3 cm), and in places ripple marked. The color is similar to that of the argillite. The rock is composed of grains consisting of quartz, residual muscovite, aggregates of fine sericite, and minor amounts of chalcedony, tourmaline, magnetite, and ilmenite in a fine-grained reddish matrix that is composed principally of sericite and iron oxide. Many quartz grains are angular, and most of them are less than 0.2 mm long; a few are as much as 1 mm long.

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[4] According to Laudermilk (1944), the source of all red pipestone was believed to be in Minnesota until the Del Rio locality was discovered.

Although quantitatively unimportant, the argillite is discussed in some detail because of its interesting mineralogical composition and the light its composition may throw on its probable origin and on the age of the Mazatzal Quartzite.

The mineralogy of five specimens of argillite was determined by use of X-rays (table 3). Specimens from the central outcrop (Nos. 1, 4, and 5, table 3) are composed of quartz, pyrophyllite, and minor amounts or traces of mica, chlorite, and hematite. One specimen (No. 3, table 3) from the western outcrop consists of kaolinite and minor pyrophyllite and hematite; the other (No. 2, table 3) consists of quartz, mixed layered mica-montmorillonite, and traces of hematite.

The fine-grained finely laminated argillite (No. 4, table 3) from the central outcrop contains angular to rounded colorless grains and aggregates of a mineral having a moderately high birefringence. The grains, as much as 0.1 mm in diameter, are enclosed in a fine-grained ferruginous matrix that, where iron oxide has been leached, has birefringence similar to that of the larger grains; both probably are pyrophyllite. The elongated grains in the argillite from the western outcrop (No. 3, table 3) are composed of cryptocrystalline material of very low birefringence, presumably kaolinite. No quartz was recognized in thin sections of either specimen.

TABLE 3.—*Mineralogy of argillite from the Mazatzal Quartzite, Paulden quadrangle*

[Analyses based on X-ray studies. Analysts: J. C. Hathaway, H. C. Starkey, and P. D. Blackmon, U.S. Geol. Survey. Tr., trace]

Specimen	1		2		3		4		5	
Fraction after grinding	Clay	Silt	Clay	Silt	Clay	Silt	Clay	Silt	Clay	Silt
Percent of sample	24	76	20	80	21	79	28	72	21	78
Estimated amount of minerals present, in parts in ten:										
Pyrophyllite	6	4	----	----	Tr.	Tr.	6	5	6	6
Quartz	3	5	2	6	----	----	2	5	2	4
Mica	Tr.	----	----	----	----	----	1	Tr.	1	Tr.
Hematite	Tr.	Tr.	Tr.	Tr.	1	1	Tr.	Tr.	Tr.	Tr.
Mixed layered mica-montmorillonite [1]	----	----	8	3	----	----	----	----	----	----
Kaolinite	----	----	----	----	8	9	----	----	----	----
Chlorite	----	----	----	----	----	----	Tr.	----	Tr.	----

[1] About 20 percent montmorillonite layers.

1. Massive fine-grained argillite, central outcrops (1,381,000 N., 359, 400 E.). Lab. No. 266397.
2. Massive fine-grained purplish argillite, western outcrops (1,388,200 N., 350,000 E.). Lab. No. 266396.
3. Massive granular argillite, western outcrops (1,388,200 N., 350,000 E.). Lab. No. 266395.
4. Finely laminated fine-grained argillite, central outcrops (1,381,000 N., 359,400 E.). Lab. No. 266394.
5. Massive fine-grained argillite, central outcrops (1,381,000 N., 359, 400 E.). Lab. No. 266393.

The chemical composition of one specimen (No. 1, table 3) is given in table 4 and compared with the chemical composition of other argillaceous rocks; the minor elements in specimen 1 are given in table 5.

TABLE 4.—*Chemical analysis of argillite from Mazatzal Quartzite, Paulden quadrangle, compared with analysis of other argillaceous rocks*

Sample	1	2	3	4	5
SiO_2	77.5	62.2	60.96	60.15	61.54
Al_2O_3	15.3	19.4	16.15	16.45	16.95
TiO_2	.27	.75	.86	.76	.82
Fe_2O_3	1.2	7.5	5.16	4.04	2.56
FeO	.06	.30	2.54	2.90	3.90
MnO	.01	.02	.07	Trace	----
MgO	.26	1.6	3.06	2.32	2.52
CaO	.15	.08	.71	1.41	1.76
Na_2O	.13	1.3	1.5	1.01	1.84
K_2O	1.3	3.6	5.01	3.60	3.45
P_2O_5	.04	.20	.23	.15	----
Ignition	----	3.3	----	----	----
H_2O-	} 3	{ ----	.17	.89	} 3.47
H_2O+		{ ----	3.08	3.82	
BaO			.04	.04	
SO_3				.58	
NH_3			.01		
CO_2	<.05	----	.68	1.46	1.67
C				.88	
S	<.01				
Total	99	100.25	100.23	100.46	100.48

1. Rapid analysis of argillite from Mazatzal Quartzite, Paulden quadrangle (1,381,000 N., 359,400 E.). Analysts: P. L. D. Elmore, S. D. Botts, K. E. White, U.S. Geol. Survey. Lab. No. 148371.
2. Rapid analysis of purple slate, south of Shylock mine (1,312,900 N., 418,500 E.), Mingus Mountain quadrangle. Analysts: S. M. Berthold and E. A. Nygaard From Anderson and Creasey (1958, table 10).
3. Purple slate, Castleton, Vt. From Clarke (1924, p. 554).
4. Composite analysis of 51 Paleozoic shales by H. N. Stokes. From Clarke (1924, p. 552).
5. Average composition of pelitic rocks. From Shaw (1956, table 10).

TABLE 5.—*Semiquantitative analysis for minor elements in argillite from Mazatzal Quartzite, Paulden quadrangle*

[Analyst, H. J. Rose, Jr., U.S. Geol. Survey. Lab. No. 148371]

Element	Percent	Element	Percent
Cu	0.001	La	0.003
Pb	.001	Ti	.1
Mn	.01	Zr	.01
Co	.001	Nb	0
Ni	.003	Be	.0003
Fe	1.0	Mg	.3
Cr	.001	Ca	.1
V	.001	Sr	.003
Al	10.0	Ba	.01
Ga	.003	Na	.1
Sc	.001	B	.003
Y	.003		

Looked for but not found: Ag, Au, Hg, Ru, Rh, Pd, Os, Ir, Pt, Mo, W, Re, Ge, Sn, As, Sb, Bi, Zn, Cd, Tl, In, Ce, Nd, Hf, Th, Ta, U, P.

The silica content is higher (about 17 percent) in the argillite than in other argillaceous rocks. This higher content makes the other components of the argillite seem lower, but they generally retain the same relative proportions as the other argillaceous rocks. The alkali ratios of the five specimens are given in table 6.

All have a high ratio of potassium oxide to sodium oxide. The amount of sodium oxide varies only slightly (0.04–0.18 percent) and is lowest in the kaolinite-rich sample (No. 3, table 6). The amount of potassium oxide is more variable; it ranges from 0.96 to 1.6 percent in the specimens composed of quartz and pyrophyllite (Nos. 1, 4, and 5, table 6); it is lowest (0.11 percent) in the kaolinite-rich sample (No. 3, table 6) and highest

(2.9 percent) in the specimen containing the mixed-layered (mica-montmorillonite) clay mineral component (No. 2, table 6), where it is contained mostly in the mica mineral structure.

TABLE 6.—*Alkali ratio in five specimens of argillite from Mazatzal Quartzite, Paulden quadrangle*

[Specimens 2–5.—Rapid analyses for Na_2O and K_2O only. Analyst, I. H. Barlow, U.S. Geol. Survey]

Specimen	Na_2O (percent)	K_2O (percent)
1	0. 13	1. 3
2	. 14	2. 9
3	. 04	. 11
4	. 18	1. 6
5	. 15	. 96

1. Massive fine-grained argillite, central outcrops (1,381,000 N., 359,400 E.). From chemical analysis 1, table 4.
2. Massive fine-grained, argillite, western outcrops (1,388,200 N., 350,000 E.). Lab. No. 15337.
3. Massive granular argillite, western outcrops (1,388,200 N., 350,000 E.). Lab. No. 15336.
4. Finely laminated fine-grained argillite, central outcrops (1,381,000 N., 359,400 E.). Lab. No. 15335.
5. Massive fine-grained argillite, central outcrops (1,381,000 N., 359,400 E.). Lab. No. 15334.

Kaolinite, montmorillonite, and pyrophyllite are unexpected constituents in older Precambrian rocks. Grim (1953, p. 356), pointed out that montmorillonite is generally absent in sedimentary rocks older than the Mesozoic, whereas it is abundant in many Mesozoic and Cenozoic rocks, in Recent marine sediments, and in present-day weathering products; kaolinite is less abundant in rocks older than the Devonian than in younger ones. Montmorillonite and kaolinite are generally not formed under the same conditions (Grim, 1953, p. 355–356). All three minerals are common products of mild hydrothermal alteration in nature. Pyrophyllite forms at higher temperatures (above 350° C) than does kaolinite, according to laboratory experiments by Hemley (1959); at a low pH it forms at a lower temperature than does mica. The significance of these minerals is not understood. There is no evidence that they formed under hydrothermal conditions, though possibly the higher temperature represented by pyrophyllite may be related to late Tertiary(?) andesite plugs; kaolinite and montmorillonite may represent products of weathering. The relation of temperature of formation or degreee of metamorphism indicated by pyrophyllite to that of the formation of the green schist facies common in rocks of the Alder Group is not known.

The high K_2O to Na_2O ratio of the argillite may indicate derivation from normal terrigenous clay, as this ratio is typical of normal clays (table 4, Nos. 2–5); Precambrian rhyolite tuffs of the area have a high Na_2O to K_2O ratio. On the other hand, montmorillonite is common in bentonitic clays derived from volcanic ash. Extensive leaching of the argillite is indicated by the high silica content, but it must have occurred under different weathering conditions than exist today.

Laudermilk (1944) stated that specimens of argillite from the Del Rio locality had the same general chemical composition as the pipestone from Minnesota: SiO_2, Al_2O_3, $Fe_2O_3 \cdot FeO$, and minor amounts of CaO, MgO, Na_2O, K_2O, and rare elements. However, he stated that a different alkali ratio (high K_2O to Na_2O in the Minnesota material; a reverse ratio in the Del Rio material) and different amounts of certain other elements (copper, silver, calcium, strontium, and barium) distinguish the material from which Minnesota and Arizona artifacts were made. Laudermilk's conclusions were based on spectrographic and petrographic studies by Howell (1940, p. 51), who stated: "Potassium, a constant constituent of the northern material, is either extremely minute or entirely missing in the southern samples examined. Sodium and lithium show a similar decrease between specimens from these two sources." Howell stated further (p. 55) that the Minnesota material is "composed predominantly of pyrophyllite, hematite, and a sericite-like mineral as against a predominance of kaolinite for the Arizona shales." The present X-ray and chemical studies of Del Rio material (tables 3–6) do not agree with Howell's results. His material may have come from the eastern outcrop, which was not examined chemically or by X-ray during the present study, or from variations that may occur across or along the strike of an outcrop band.

AGE AND CORRELATIONS

The Mazatzal Quartzite in the Del Rio area is older than the Tapeats Sandstone. It may be younger than the metamorphism of the Alder Group and than the granitic intrusions that cut the Alder Group.

The composition of the argillite, the absence of foliation, and the unstrained character of quartz grains in folded quartzite indicate that the Mazatzal in this area was at most only slightly metamorphosed. In contrast, rocks of the Alder Group have been foliated and metamorphosed to green schist and higher grade facies. A granitic terrane older than the Mazatzal is indicated by the abundance of pebbles, cobbles, and small boulders of vein quartz in the conglomerate and by the absence of quartz veins or granitic rocks intruding the Mazatzal; quartz veins and granitic rocks are abundant in the Alder Group. Although lack of granitic pebbles and feldspar grains in the quartzite might indicate deposition prior to the granitic intrusions, their absence may be attributed to vigorous and long-continued erosion that removed particles of earlier granite or reduced them to clay-sized particles, now represented by thin argillaceous partings in the quartzite.

Southeast of Pine (fig. 1, inset) the Mazatzal Quartzite is assigned to the older Precambrian because it was folded, intruded by granite, and eroded prior to depo-

sition of the younger Precambrian Apache Group. This deformation and granitic intrusion mark the Mazatzal Revolution (Wilson, 1939, p. 1134), which separates older from younger (Apache Group and Grand Canyon Series) Precambrian rocks (Butler and Wilson, 1938, p. 11).

Wilson (1922, p. 299) first correlated the quartzite in the Del Rio area with the Mazatzal Quartzite in the Mazatzal Mountains and adjacent areas. Although a correlation from Pine Creek to the Del Rio area, a distance of more than 60 miles, may be open to question, the lithology of the thick quartzites and conglomerates in the areas mapped as Mazatzal is similar, and the correlation does have merit. According to E. D. McKee (oral commun., 1957), the quartzite in the Del Rio area resembles the Shinumo Quartzite of the Unkar Group, which is the older of the two groups that make up the younger Precambrian Grand Canyon Series in the Grand Canyon, more than 90 miles north of the Del Rio area. The fact that younger Precambrian rocks overlie the Mazatzal to the southeast does not preclude the possibility that the Mazatzal is equivalent to the Shinumo Quartzite, as the relative ages of the younger Precambrian rocks north and southeast of the Del Rio area are unknown.

Because of the possibility that the Mazatzal Quartzite in the Del Rio area has been moved along faults from an area of very low grade metamorphism that was not intruded by granitic rocks, the formation has been left in the older Precambrian. The quartz cobbles and pebbles in the Del Rio area may have been derived from a terrane older than the Alder Group, such as is now known to have existed (see footnote 7, p. 49), and the granitic intrusions that cut the Mazatzal to the southeast may be younger than the granitic intrusions in the Prescott-Paulden area. Age determinations made by analysis of enclosed zircon grains in granitic rocks, in quartzite in the Grand Canyon, Del Rio, and Mazatzal Mountain areas, and in rhyolitic tuff in the Alder Group may eventually help to solve this problem of age relations.

INTRUSIVE ROCKS

Jaggar and Palache (1905) proposed the name Bradshaw Granite for most of the quartzose intrusive rocks south of the Prescott-Jerome area, and Lindgren (1926, p. 16, pl. 2) extended the term Bradshaw Granite to rocks in the Prescott-Jerome area. Lindgren considered the "diorite" and some quartz diorite or granodiorite to be younger than the Bradshaw Granite and believed that younger quartz-bearing intrusive rocks were possibly Laramide in age. Studies in the Jerome and Prescott-Paulden areas show that (1) the so-called

Bradshaw Granite consists of several different intrusives ranging from granodiorite, which is the most abundant, to granite and alaskite, (2) much of the "diorite," now called gabbro, is older than the Bradshaw Granite, and (3) one of the "younger quartz diorite or granodiorite stocks" is Precambrian in age and older than at least some of the Bradshaw Granite.

In this report the name Bradshaw Granite is abandoned and new names are assigned to some of the intrusive rocks that formerly were part of the "Bradshaw Granite." The major intrusives in the Prescott-Paulden area, and their probable age relations from oldest to youngest, based largely on field evidence, are: (1) gabbro and quartz diorite, (2) Government Canyon Granodiorite, (3) Prescott Granodiorite, (4) quartz monzonite and alaskite, (5) coarse-grained granite, (6) Dells Granite, and (7) fine-grained granite.

The relationships of the various intrusive masses are obscure for the following reasons:

1. The gabbro includes diabase and fine-grained gabbroic to dioritic rocks, some of which are younger than quartzose intrusive rocks but cannot be distinguished from the older gabbroic rocks petrographically or in the field in most places.

2. Mafic volcanic rocks of the Alder(?) Group may have been misidentified as fine-grained gabbro older than the quartzose intrusive rocks.

3. Dikes of granodiorite, granite, alaskite, and aplite cut the intrusive rocks, but correlation of these dikes with a given intrusive mass is doubtful or impossible in some places; in addition, the aplites are of more than one age.

4. Compositional and textural features of the quartzose intrusive rocks differ from place to place, some of the differences being due to contamination of the magma by the intruded rocks; therefore, a mass may be erroneously assigned to a different intrusion.

5. Intense shearing masked and destroyed primary features of some rocks and resulted in mechanical rather than normal intrusive contacts; most of the north-trending contacts are zones of shear, and many contacts were located arbitrarily because of mechanical mixing of adjacent rocks.

6. The various masses mapped as the Prescott Granodiorite are not contiguous, and their relationships to one another could not be determined exactly in the field; they are considered consanguineous because of similarities in modal, chemical, and normative compositions.

7. Some of the quartzose intrusive rocks may possibly be pre-Alder Group in age (see footnote 7 on p. 49).

The available modal, chemical, and normative data on the intrusive rocks are given in tables 7–10. Variation diagrams show the modal and normative quartz-orthoclase-plagioclase composition of the different groups of intrusive rocks. Figure 9 represents the Government Canyon Granodiorite; figure 11, the various masses of Prescott Granodiorite; and figure 13, the granitic rocks. Modes, norms, and average mode are plotted. Figure 7 shows (A) the quartz-orthoclase-plagioclase norm and average mode of all the rocks, (B) modal and normative quartz-feldspar-mafic and accessory minerals, (C) plots of oxides on SiO_2-K_2O·Na_2O-FeO·Fe_2O_3·MgO·CaO diagrams, and (D) oxides plotted against SiO_2. The distribution of the various masses is shown in figures 8, 10, and 12. Included in these tables and figures are data on gabbro from the Mingus Mountain quadrangle and north-central part of the Mayer quadrangle, on granodiorite of the Walker area (Lindgren, 1926, p. 21) in the north-central part of the Mount Union quadrangle, and on the quartz diorite of the Jerome area (Anderson and Creasey, 1958, p. 40, table 13). The quartz diorite is considered part of the Prescott Granodiorite and is referred to as the Yarber Wash, Big Bug Creek, and Chaparral masses (fig. 10). The Big Bug Creek mass (McCabe area of Lindgren, 1926, p. 21, pl. 2) and the granodiorite of the Walker area are among the "younger granodiorites" of Lindgren. Modes and norms agree fairly well. Most average modes, however, are lower in orthoclase than are the norms, because in the norm all potash has

been assigned to orthoclase whereas in the mode some potash is tied up in the micas.

GABBRO AND RELATED ROCKS

DISTRIBUTION

Gabbro and related rocks are widely distributed throughout the Precambrian rock outcrops of the Prescott-Paulden area. They form two large and several smaller bodies. Innumerable lenticular to dikelike masses, many of them too small to show on the geologic maps, intrude the Alder Group and quartzose intrusive rocks.

The largest mass extends from the southern border of the area (pl. 1, west of 370,000 E.) northward for nearly 5 miles. The second largest mass forms the high ridge east of Prescott and extends from the southern border of the area (pl. 1, near 344,000 E.) northward for 3¾ miles.

Scattered gabbro masses, the largest occupying not more than 1 square mile, are in the southeastern (pl. 1) and east-central (pls. 1, 2) parts of the area. Dikelike masses occur in the Chaparral and Spud faults (pl. 1). A small mass of quartz diorite, probably a facies of gabbro, crops out along the Verde River (pl. 2, between 375,500 E. and 390,000 E.) and is the northernmost exposure of Precambrian rocks in the area.

Diabase dikes cut the Alder Group and some of the intrusive rocks but have not been mapped. They are abundant in the alaskite porphyry near Charcoal Gulch (pl. 1, between 377,000 E. and 378,000 E.) and in the

TABLE 7.—*Modal composition of quartzose intrusive rocks in the Prescott-Paulden-Jerome area*

[See figs. 8, 10, and 12 for locations; figs. 9, 11, and 13 for plots of norms and modes on Qu-Or-Pl diagrams; fig. 7 for other triangular and variation diagrams; table 8 for chemical and table 10 for normative composition]

Map symbol	1 qd	2 gg	3A pgy–1	3B pgy–2	3C pgy–3	4 pgs	5 pgc	6 pgl	7 pgp	8 pgm	9 qm	10 al	11 cg	12 dg
Quartz	17	16	27	26	27	32.0	29.0	28	28.0	22	23	35.0	33.0	36
Orthoclase	5	14	9	4	7	5.0	8.0	10	10.0	9	28	26.0	19.0	28
Plagioclase	54	52	56	61	58	52.0	56.0	52	54.0	56	[1] 37	38.0	39.0	25
Hornblende	16	8	2	4	3	-----	-----	-----	-----	3	-----	-----	-----	-----
Mica [2]	5	7	5	4	4	10.0	4.0	7	6.0	7	7	1.0	9.0	9
Epidote [3]	2	2	-----	-----	-----	1.0	3.0	2	2.0	2	4	-----	-----	-----
Accessory minerals	1	1	1	1	1	<.5	<.5	1	<.5	1	1	<.5	<.5	2
Total	100	100	100	100	100	100.0	100.0	100	100.0	100	100	100.0	100.0	100
Percent of feldspar that is orthoclase	8	21	14	6	10	9	12	16	16	14	43	40	33	53

[1] Approximate composition based on X-ray diffraction, $An_{15±5}$.
[2] Largely white mica; includes primary and metamorphic biotite, chlorite, and muscovite-sericite.
[3] Mostly secondary epidote derived from mafic minerals; includes some derived from plagioclase.

1. Quartz diorite, Verde River, Paulden quadrangle, average of two thin sections (not shown in figs. 8, 10, or 12).
2. Government Canyon Granodiorite, average of 14 thin sections.
3. Yarber Wash mass, Prescott Granodiorite: 3A, western facies, average of four thin sections; 3B, eastern facies, average of five thin sections; 3C, average of western and eastern facies (Anderson and Creasey, 1958, table 13).
4. Salida Gulch mass, Prescott Granodiorite, average of 11 thin sections.
5. Chaparral mass, Prescott Granodiorite, average of six thin sections.
6. Lynx Creek mass, Prescott Granodiorite, average of eight thin sections.
7. Prescott mass, Prescott Granodiorite, average of seven thin sections.
8. Mineral Point mass, Prescott Granodiorite, average of four thin sections.
9. Quartz monzonite, average of two thin sections.
10. Alaskite, average of four thin sections.
11. Coarse-grained granite, average of seven thin sections.
12. Dells Granite, average of four thin sections.

TABLE 8.—*Chemical analyses of quartzose intrusive rocks and gabbro of the Prescott-Jerome area*

[See figs. 8, 10, and 12 for location, figs. 9, 11, and 13 for plots of norms and modes on Qu-Or-Pl diagrams, fig. 7 for other triangular and variation diagrams, table 7 for modal; and table 10 for normative composition. Analyst: W. W. Brannock and others, U.S. Geol. Survey, rapid rock analyses, except for granodiorite of Walker area (from Lindgren, 1926, p. 21, No. 3) and gabbro (from Anderson and Creasey, 1958, p. 38, table 12, No. 8)]

Map symbol Lab. No.	1 gb	2 gg 148366	3 wg	4 pgy 148361	5 pgs 148362	6 pgl 148363	7 pgp 148364	8 pgm 148365	9 al 148369	10 cg 148368	11 dg 148370	12 fg 148367
SiO_2	48.57	61.4	65.74	65.6	69.5	70.1	67.7	64.5	77.9	76.3	76.2	78.2
Al_2O_3	20.32	16.7	16.76	16.2	16.0	16.6	15.8	17.4	13.2	13.4	13.7	13.0
Fe_2O_3		2.6	3.99	2.5	1.3	1.2	2.0	1.6	.61	.8	.69	.6
FeO	8.87	2.7		2.3	1.5	.81	1.6	2.2	.06	.48	.17	.35
MgO	4.87	2.8	1.70	1.7	1.1	.72	1.5	2.1	.05	.26	.10	.10
CaO	9.15	4.7	3.78	4.6	3.2	2.9	3.3	4.5	.22	.49	.50	.74
Na_2O	2.66	4.2	3.37	3.6	4.3	4.7	4.0	4.4	4.1	3.9	4.2	4.4
K_2O	.34	3.4	3.55	2.1	2.1	2.0	2.6	1.9	4.5	3.7	4.5	1.9
TiO_2	.64	.69		.38	.23	.20	.41	.36	.11	.10	.04	.06
P_2O_5		.35		.14	.09	.05	.13	.15	.00	.02	.00	.00
MnO	.12	.08		.08	.04	.05	.06	.06	.00	.01	.03	.01
H_2O	4.02	.62	.99	.84	.70	.67	.64	1.0	.30	.50	.56	.39
CO_2		.06		.07	.34	.24	.28	.16	.08	.32	.13	.36
Total Sulfur as S		<.01		<.01	<.01	<.01	.04	<.01	<.01	<.01	<.01	.02
Total	99.56	100	99.88	100	100	100	100	100	101	100	101	100

1. Gabbro, composite of five specimens from loc. 49 and one from loc. 50 (fig. 10).
2. Government Canyon Granodiorite (loc. 5, fig. 8).
3. Granodiorite of Walker area (loc. 48, fig. 10).
4. Yarber Wash mass (western facies), Prescott Granodiorite (loc. 47, fig. 10).
5. Salida Gulch mass, Prescott Granodiorite (loc. 23, fig. 10).
6. Lynx Creek mass, Prescott Granodiorite (loc. 12, fig. 10).

7. Prescott mass, Prescott Granodiorite (loc. 7, fig. 10).
8. Mineral Point mass, Prescott Granodiorite (loc. 36, fig. 10).
9. Alaskite (loc. 16, fig. 12).
10. Coarse-grained granite (loc. 13, fig. 12).
11. Dells Granite (loc. 1, fig. 12).
12. Fine-grained granite (loc. 6, fig. 12).

TABLE 9.—*Semiquantitative analyses for minor elements in quartzose intrusive rocks of the Prescott-Jerome area*

[See table 8 for explanation of map symbols. Analyst: H. J. Rose, Jr., U.S. Geol. Survey]

	Government Canyon Grano- diorite	Prescott Granodiorite						Alaskite	Coarse- grained granite	Dells Granite	Fine- grained granite
		Yarber Wash mass	Salida Gulch mass	Lynx Creek mass	Prescott mass	Mineral Point mass					
Map symbol Lab. No.	gg 148366	pgy 148361	pgs 148362	pgl 148363	pgp 148364	pgm 148365	al 148369	cg 148368	dg 148370	fg 148367
Cu	0.003	0.003	0.001	0.0003	0.003	0.001	0	0.001	0.0001	0.001
Pb	.001	.001	.001	.001	.003	.001	.001	.001	.003	.001
Mn	.03	.03	.03	.03	.03	.03	.01	.01	.03	.01
Co	.001	.001	.0003	.0003	.001	.001	0	0	0	0
Ni	.003	.001	.001	.001	.001	.003	0	0	0	0
Fe	3	3	3	3	3	3	.3	.3	.3	.3
Cr	.001	.001	.0003	.0003	.001	.001	0	.001	0	.0003
V	.01	.01	.003	.003	.003	.003	.001	.001	.003	.001
Al	10	10	10	10	10	10	10	10	10	10
Ga	.003	.001	.001	.001	.003	.003	.003	.003	.003	.001
Sc	.001	.001	.0003	.0003	.001	.001	0	.001	0	.0003
Y	.003	.001	.001	.001	.003	.001	.003	.003	.01	.001
La	.003	.001	.003	.001	.003	.001	.001	.003	.001	.003
Ti	.3	.3	.1	.1	.1	.1	.03	.03	.01	.03
Zr	.01	.003	.001	.001	.003	.001	.001	.003	.003	.01
Nb	0	0	0	0	0	0	0	0	.01	0
Be	.0003	.0001	.0001	.0001	.0001	.0001	.0003	.0003	.0003	.0001
Mg	3	1	1	1	1	1	.03	.1	.1	.1
Ca	3	3	1	1	1	3	.1	.3	.3	.3
Sr	.1	.03	.03	.03	.1	.1	.001	.01	.001	.01
Ba	.03	.03	.03	.03	.03	.03	.003	.03	.003	.03
Na	3	3	3	3	3	3	3	3	3	3
B	0	0	0	0	0	0	0	0	.003	.001

Looked for but not found: Ag, Au, Hg, Ru, Rh, Pd, Os, Ir, Pt, Mo, W, Re, Ge, Sn, As, Sb, Bi, Zn, Cd, Tl, In, Ce, Nd, Hf, Th, Ta, U, P.

TABLE 10.—*Normative composition of quartzose intrusive rocks and gabbro of the Prescott-Jerome area*

[See figs. 8, 10, and 12 for locations; figs. 9, 11, and 13 for plots of norms and modes on Qu-Or-Pl diagrams; fig. 7 for other triangular and variation diagrams; table 7 for modal composition and table 8 for chemical composition]

Map symbol	1 gb	2 gg	3 wg	4 pgy	5 pgs	6 pgl	7 pgp	8 pgm	9 al	10 eg	11 dg	12 fg
Quartz	5.64	10.68	21.96	24.00	27.90	28.14	24.96	18.36	36.30	38.10	33.24	43.74
Orthoclase	1.67	20.02	21.13	12.23	12.23	11.68	15.57	11.12	26.69	21.68	26.69	11.12
Albite	22.53	35.63	28.30	30.39	36.15	39.82	34.06	37.20	34.58	33.01	35.63	37.20
Anorthite	42.53	16.68	18.90	21.96	15.01	13.62	15.57	21.41	1.11	2.50	2.50	3.61
Hypersthene	11.50	7.05	[1]4.20	5.88	4.25	1.93	4.36	7.44	[1].10	.73	[1].20	[1].20
Diopside	2.38	3.77	------									
Magnetite	8.12	3.71	------	3.71	1.86	1.86	3.02	2.32	------	1.16	.46	.93
Ilmenite	1.22	1.37	------	.76	.46	.46	.76	.76	.15	.15	------	.15
Apatite	------	.67	------	.34	.34	.34	.34	.34	------	------	------	------
Corundum	------	------	.51	------	1.22	1.73	.61	.31	1.12	2.04	.92	2.35
Hematite	------	------	4.00	------	------	------	------	------		.64	------	.32
Total	95.59	99.58	99.00	99.27	99.42	99.58	99.25	99.26	100.69	99.37	99.96	99.30
Percent of feldspar that is orthoclase	2.5	28	31	19	19	21	24	16	43	38	41	21
Plagioclase composition	[2]An$_{65}$	[3]An$_{32}$	[4]An$_{40}$	[4]An$_{42}$	[3]An$_{29}$	[3]An$_{25}$	[3]An$_{31}$	[4]An$_{37}$	[5]An$_{3}$	[5]An$_{7}$	[5]An$_{7}$	[5]An$_{9}$

[1] Iron free (enstatite).
[2] Labradorite-bytownite.
[3] Oligoclase-andesine.
[4] Andesine.
[5] Albite.

1. Gabbro, composite of 5 specimens from United Verde mine at Jerome and 1 from Yarber Wash (locs. 49 and 50, fig. 10). In the chemical analysis, iron is reported as FeO; in calculating norm ratio of Fe$_2$O$_3$, FeO is arbitrarily taken as 5:3.
2. Government Canyon Granodiorite.
3. Granodiorite of Walker area.
4. Yarber Wash mass (western facies), Prescott Granodiorite.
5. Salida Gulch mass, Prescott Granodiorite.

6. Lynx Creek mass, Prescott Granodiorite.
7. Prescott mass, Prescott Granodiorite.
8. Mineral Point mass, Prescott Granodiorite.
9. Alaskite.
10. Coarse-grained granite.
11. Dells Granite.
12. Fine-grained granite.

Prescott Granodiorite west of the largest mass of gabbro, but they are sparse in the Government Canyon Granodiorite and in the mass of Prescott Granodiorite that is north of the largest mass of gabbro (one was noted near 1,279,800 N., 333,700 E., and another near 1,300,000 N., 268,000 E.). Diabase dikes are probably abundant in gabbro but are not as obvious as in the granitic rocks, where they contrast in color. Larger masses of diabasic rock are included with gabbro because of the difficulty in distinguishing diabase from gabbro and because of the uncertainty as to age relationships between the rock types.

GENERAL CHARACTER

Gabbro.—The gabbro is a variable generally dark-colored granular rock. Where fresh, much of it is medium dark to medium gray, but the color ranges from nearly black to light gray, greenish gray, and grayish green. Much altered gabbro is green tinted. Weathered outcrops are various shades of brown.

Grain size ranges from coarse to fine. Most of the gabbro is medium grained, the crystals ranging from 2 to 5 mm. Crystals in coarse-grained rocks are 5–10 mm long; some euhedral pyroxene crystals are several inches across. Rocks that may have been coarse grained are now finer grained because of cataclastic deformation. Some are now coarse grained because of the development of more or less equant porphyroblastic or poikiloblastic hornblende several inches across.

Textures include the ophitic (or poikilophitic), hypidiomorphic-granular, diabasic, and porphyritic textures of intrusive rocks and the foliated, cataclastic, granularly recrystallized, or porphyroblastic to poikiloblastic textures of metamorphic rocks. Most of the younger diabase has well-defined diabasic texture and chilled margins. Some is porphyritic or contains large saussuritized plagioclase xenocrysts.

The gabbro in some parts of the two largest masses is layered. Many of the pyroxene-rich, plagioclase-rich, and locally olivine-rich and magnetite-rich layers range from ¼ inch to 3 inches in thickness. Some layers probably resulted from crystal settling. Where alternating layers are now composed of metamorphic minerals—dark-colored hornblende and light-colored zoisite (or clinozoisite) and tremolite (or anthophyllite)—the origin of the layering is in doubt.

Original minerals in the gabbro were plagioclase and monoclinic pyroxene (augite?); accessory magnetite, ilmenite, apatite, and zircon; and some pyrite and allanite. Olivine and quartz are erratically distributed. Metamorphism has saussuritized the plagioclase, replaced pyroxene by amphibole, and serpentinized the olivine.

A, Plots of norms (▲) and average modes (■) on quartz-orthoclase-plagioclase diagram

B, Plots of norms (▲) and average modes (■) on quartz-feldspar-mafic and accessory mineral diagram (included with the mafic minerals in the mode are white mica and epidote)

C, Plots of oxides on SiO₂–Na₂O, K₂O–FeO, Fe₂O₃, MgO, CaO diagram

D, Plots of oxides against silica

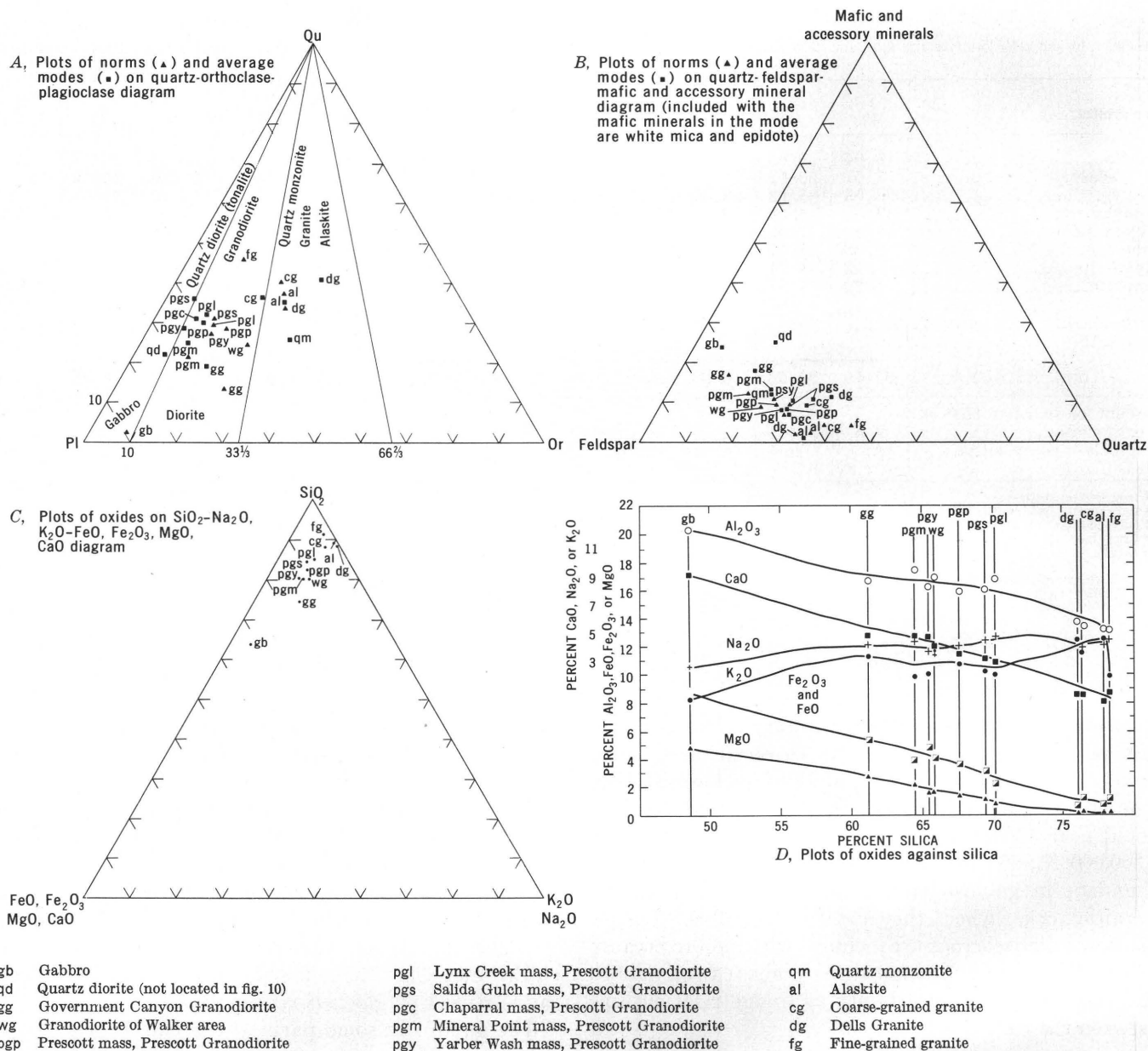| gb	Gabbro	pgl	Lynx Creek mass, Prescott Granodiorite	qm	Quartz monzonite
qd	Quartz diorite (not located in fig. 10)	pgs	Salida Gulch mass, Prescott Granodiorite	al	Alaskite
gg	Government Canyon Granodiorite	pgc	Chaparral mass, Prescott Granodiorite	cg	Coarse-grained granite
wg	Granodiorite of Walker area	pgm	Mineral Point mass, Prescott Granodiorite	dg	Dells Granite
pgp	Prescott mass, Prescott Granodiorite	pgy	Yarber Wash mass, Prescott Granodiorite	fg	Fine-grained granite

FIGURE 7.—Variation diagrams of quartz-bearing intrusive rocks and gabbro in the Prescott-Paulden-Jerome area. See figures 8, 10, and 12 for location of masses; figures 9, 11, and 13 for quartz-orthoclase-plagioclase plots of individual thin sections; and tables 7, 8, and 10 for modal, chemical, and normative analyses.

Plagioclase in parts of the two largest masses forms euhedral to anhedral clear unaltered crystals that range in composition from andesine to labradorite or more calcic plagioclase. Some of it is packed with minute unidentified inclusions (probably magnetite, spinel, and others). In fresh diabase the plagioclase is zoned. Much of the plagioclase has been partially to completely altered to a granular aggregate of clinozoisite and zoisite associated with albitic plagioclase and sericite; some has recrystallized to clear granular oligoclase-andesine.

Pyroxene is preserved in diabase dikes and in a few places in the two largest masses of gabbro. Most of it is partly to completely replaced by amphibole. The amphibole ranges from actinolite to hornblende; most of it is actinolitic hornblende. Actinolite forms fibrous masses and needles; hornblende forms fine to coarse equant crystals or grains.

Olivine, much of it altered to serpentine, occurs in the northern part of the second largest mass (mostly north of 1,285,000 N.) and in small amounts elsewhere. Some rocks that may have had the composition of

periodotite are now composed largely of either antigorite and narrow chrysotile veinlets or of talc, serpentine, and a few unaltered olivine remnants.

Interstitial quartz and potassium feldspar occur as original, minor constituents, but some quartz and microcline were derived probably from granitic emanations that locally permeated the gabbro. Quartz appears to be much less common as an original constituent in the largest masses than in some of the smaller ones, but its source in the more sheared rocks is problematic.

A little primary (?) biotite was noted in some of the least altered gabbro; much of the biotite is metamorphic and intergrown with magnetite. Chlorite replaces pyroxene, amphibole, or biotite, commonly forming rims around these minerals or forming aggregates with epidote, quartz, and other minerals. It is most abundant along shear zones.

Locally, more or less feathery masses of tremolite, anthophyllite, and zoisite, or clinozoisite) have partly to almost completely replaced plagioclase and pyroxene in the two largest masses of gabbro. The thermal metamorphism that formed these minerals was caused by adjacent quartzose intrusive rocks.

Some gabbro has been extensively epidotized, and some of it in the southwestern part of the second largest mass contains piedmontite as veinlets and disseminations (see p. 105).

Iron-rich gabbro occurs in parts of the two largest masses and in small masses (near 1,288,700 N., 374,000 E., especially the one near 1,290,500 N., 374,500 E.). Locally, layers are composed almost entirely of magnetite and ilmenite. Plagioclase is the principal silicate mineral, almost to the exclusion of pyroxene or hornblende in some of these rocks. Apatite is generally abundant. Although euhedral magnetite crystals are common in the gabbro, in the iron-rich rock most magnetite and ilmenite occupy interstitial positions between and are molded on plagioclase and pyroxene. The granular intergrowths of magnetite and ilmenite are of secondary or late-stage origin and replace pyroxene and hornblende. Magnetite appears to be later than ilmenite in iron-rich rocks but earlier than ilmenite in the more normal gabbro.[5]

Chemical analyses of gabbroic rocks from the area have not been made. The average silica content (Anderson and Creasey, 1958, table 12, No. 8, p. 38) of

[5] The magnetic susceptibility of several specimens of gabbro from the Prescott quadrangle was tested in the Physical Properties Laboratory of Newmont Exploration, Ltd. The susceptibility of most of the specimens ranges from $4,200 \times 10^{-6cgs}$ to $7,100 \times 10^{-6cgs}$ (1,680–2,840 gammas). The susceptibility of some specimens of light-colored altered gabbro and of serpentine ranges from 19×10^{-6} to 200×10^{-6cgs} (7.6–80 gammas). A specimen rich in magnetite and ilmenite gave a reading of $13,000 \times 10^{-6cgs}$ (5,200 gammas). The susceptibility of the gabbro is sufficiently high to give rise to magnetic anomalies (U.S. Geol. Survey, 1950) over gabbro areas.

five specimens from the United Verde mine at Jerome and one from southeast of the Prescott quadrangle (see fig. 10, table 8, and also fig. 7 and table 10) is 48.57 percent compared with a silica content of 48.24 percent for average gabbro and 56.77 percent for average diorite (Daly, 1933, p. 16–17). Much of the least metamorphosed parts of the two largest masses appears to be a saturated gabbro in which the plagioclase is at least as calcic as labradorite; it is likely that most of the smaller more metamorphosed masses had a similar composition. The presence of olivine in some and quartz in others indicates a range from undersaturated to oversaturated rocks. Quartz gabbroic to quartz dioritic facies occur, but only the quartz diorite along the Verde River is large enough to map and describe separately.

Quartz diorite.—Quartz diorite along the Verde River is a medium- to coarse-grained rock composed principally of light pinkish-gray feldspar and greenish-black to dark olive-gray hornblende and some biotite. Grain size of much of the rock is 4–5 mm, but some hornblende crystals are as large as 5 by 10 mm. The rock varies slightly in relative proportions of dark and light minerals and in the amount of quartz and potassium feldspar (largely microcline). The plagioclase is sericitized or saussuritized. Chlorite replaces hornblende and biotite. The rock contains some coarse epidote and accessory magnetite, apatite, zircon, sphene, and allanite. Because the quartz content is greater than 10 percent (table 7; fig. 7A), the rock is classed as quartz diorite. The higher content of hornblende, biotite, and epidote suggests correlation with gabbro rather than with one of the granodiorites.

RELATIONS TO OTHER ROCKS

Gabbroic rocks are younger than the Alder Group, as they clearly intrude the volcanic rocks and contain xenoliths of them. The large-scale intrusive relations are illustrated on the geologic map (see pl. 1, near 1,283,000 N., 350,000 E.). Most of the gabbroic rocks are older than the quartzose intrusive rock, but some are younger.

Gabbro is cut out by Prescott Granodiorite (for example, at the northern end of the largest mass of gabbro). It is brecciated, and fractures are filled with granitic to aplitic material, especially along the sides of some of the masses and in some areas of contaminated gabbro and Prescott Granodiorite. In the east-central part (northeast part, pl. 1) intrusive breccia, formed by the invading Prescott Granodiorite and aplite, are common. The east side of the largest mass and the southwest part of the second largest mass of gabbro have been contact metamorphosed, and zoisite (or clinozoisite) and tremolite (or anthophyllite) extensively replace primary plagioclase and pyroxene.

Mainly because of spatial relations, the intrusive rocks that probably produced both the alteration and the veinlets are thought to be alaskite, quartz monzonite, and Government Canyon Granodiorite.

Some gabbroic rocks, mostly diabase, have intruded gabbro, alaskite porphyry, and some masses of Prescott Granodiorite. The dikes in gabbro fill clean fractures and have chilled borders. Larger masses of fine-grained mafic rocks, especially in areas mapped as contaminated gabbro and Prescott Granodiorite in the south-central part of the area, contain xenoliths or xenocrysts of granodiorite. These xenoliths, however, could have come from a pre-Alder Group intrusive rock (see footnote 7, p. 49). Much of what is shown as contaminated gabbro in the westernmost lenses in this area may be volcanic in origin.

GOVERNMENT CANYON GRANODIORITE

DISTRIBUTION

The Government Canyon Granodiorite, herein named for good exposures along Government Canyon (1,280,-000 N., 341,000 E.), forms two masses in the southwestern part of the area (pl. 1; fig. 8). The western mass, which is separated into two parts by Cenozoic rocks, must end somewhere between its northernmost exposures and the Dells Granite, less than 2 miles to the north. Minor amounts of granodiorite, too small to show on the geologic map, occur in the southern part of the adjacent unnamed volcanic rocks of the Alder(?) Group.

GENERAL CHARACTER

The Government Canyon Granodiorite forms topographic lows, many of which are covered with pine forest. The rock weathers light yellowish brown to light brown. It disintegrates to a sandy soil, through which protrude scattered more or less spheroidal boulders of relatively fresh rock. The fresh rock is medium to medium light gray and has a salt and pepper appearance.

The granodiorite ranges from a massive rock to one having a fairly pronounced planar and linear structure. Primary planar and linear flow structures are brought out by alinement of xenoliths, of plagioclase, hornblende, and biotite crystals, and in places of porphyritic and nonporphyritic layers. A secondary foliation locally cuts the western mass.

Xenoliths of various sizes are abundant in the western mass. In the eastern mass xenoliths, mostly less than 6 inches long, are rather sparsely but uniformly distributed, except near the contacts with the volcanic rocks, where they are abundant and of many sizes. The xenoliths are composed largely of mafic volcanic rocks and of fine-grained gabbro(?).

Government Canyon Granodiorite
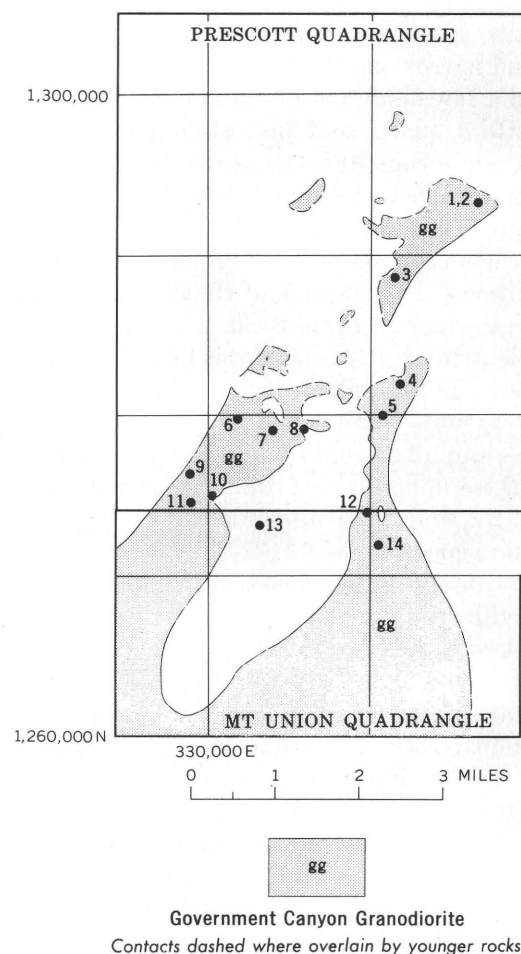Contacts dashed where overlain by younger rocks

FIGURE 8.—Distribution of the Government Canyon Granodiorite in the Prescott and Mount Union quadrangles, showing location of specimens used for modal, chemical, and normative analyses. No. 13 is from a small mass in schist.

Typical granodiorite is a medium-grained rock having a seriate texture. Some of it is porphyritic. The maximum length of plagioclase, hornblende, and biotite crystals is about 1.5 cm. In addition to these minerals the rock contains orthoclase, quartz, epidote, and accessory minerals (see tables 7, 8, 9, and 10, and figs. 7 and 9 for modal, chemical, and normative composition).

Plagioclase is somewhat zoned and has an average composition of sodic andesine; normative plagioclase is An_{32}. The plagioclase forms euhedral to anhedral grains. The centers of most crystals are slightly sericitized or saussuritized; a few are highly altered. Microcline and perthite fill interstices and locally form poikilitic grains 3 mm in diameter. Quartz is interstitial to plagioclase and mafic minerals. Most of it shows wavy extinction, but little of it is granulated. Green hornblende and greenish-brown biotite are in euhedral crystals and in very ragged grains and aggregates.

EXPLANATION

•
Mode of individual thin section

▪
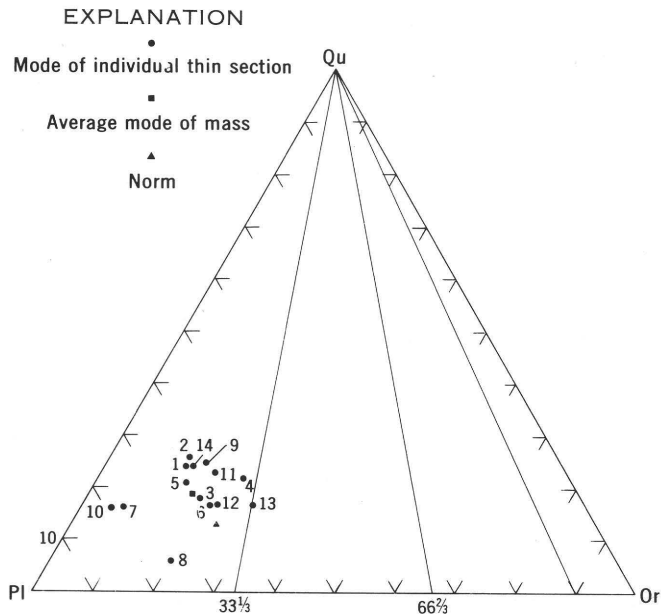Average mode of mass

▲
Norm

FIGURE 9.—Government Canyon Granodiorite. Plots of modes and norms on quartz-orthoclase-plagioclase diagram. Numbers refer to individual thin sections or to chemically analyzed specimens; location of numbers is shown in figure 8. See also figure 7 and tables 7, 8, and 10.

Some are intergrown with other mafic and accessory minerals or altered to chlorite. Some hornblende is poikilitic. Sphene is commonly conspicuous as well-formed crystals as much as 1.7 mm long and as ragged and poikilitic grains. Apatite and magnetite form euhedral crystals less than 0.4 mm in size. Biotite contains tiny zircons. A few euhedral epidote crystals were observed; much of the epidote is secondary and forms intergrowths with mafic and accessory minerals. Veins and disseminations of piedmontite occur locally (see p. 105).

RELATIONS TO OTHER ROCKS

The Government Canyon Granodiorite is younger than unnamed volcanic rocks of the Alder(?) Group; the intrusive relations are manifested by the very irregular contact between the two rocks (south of 1,284,000 N.), by widespread intrusive breccias, and by granodiorite injected along bedding, fracture, and foliation planes in the volcanic rocks. Erratically and conformably oriented volcanic xenoliths from a few feet to 3,500 feet long are abundant in the southern part of the western body of granodiorite. The granodiorite is probably younger than gabbro (see the discussion in the preceding section).

The western mass of Government Canyon Granodiorite is cut by many dikes of Prescott Granodiorite and occurs as xenoliths in the Prescott Granodiorite; however, no dikes of Prescott Granodiorite were noted in the eastern mass of Government Canyon Grano-

diorite. The possibility that the eastern and western masses are not part of the same intrusion or that the western mass contains two granodiorites has been considered, but no supporting field evidence was observed. The eastern mass is the northern part of what Lindgren (1926, p. 21–22 and pl. 2) called the Groom Creek area of granodiorite, which he considered probably Late Cretaceous to early Tertiary in age. The lead/alpha age of zircon in the granodiorite, however, is Precambrian (see p. 50).
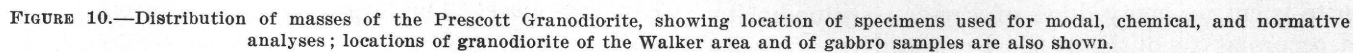
PRESCOTT GRANODIORITE

DISTRIBUTION

The Prescott Granodiorite, herein named for extensive exposures in the western part of the city of Prescott, forms isolated masses in the southern and east-central parts of the Prescott-Paulden area. For ease in discussion, the various masses are given locality names: the Prescott, Salida Gulch, Lynx Creek, Chaparral, and Mineral Point masses (fig. 10). Small outcrops, dikes, and lenses and much granodiorite in areas of contaminated rocks are part of the Prescott Granodiorite. The quartz diorite of the Jerome area (Anderson and Creasey, 1958, p. 38–41) is considered to be part of the Prescott Granodiorite and is referred to as the Yarber Wash and Big Bug Creek masses. The Chaparral mass was also called quartz diorite by Anderson and Creasey. In the present report, a rock is considered to be a granodiorite if more than 10 percent of the feldspar is orthoclase. On this basis, only the eastern facies of the Yarber Wash mass is a quartz diorite; the Salida Gulch mass is on the dividing line between quartz diorite and granodiorite (fig. 7, 11). As the Prescott mass, which gives its name to these rocks, is a granodiorite and as the norms of all the rocks fall within the granodiorite field, the term granodiorite is used.

The Prescott mass forms a triangular-shaped outcrop in the southwest corner of the area. The Salida Gulch mass is a long, narrow north-trending body in the south-central part. The Lynx Creek mass lies at the north end of the largest body of gabbro. All of these masses are buried to the north or northeast by Cenozoic deposits, and their extent beneath these deposits is unknown, except that the Prescott mass cannot extend for more than 2 miles to the northeast before it is cut out by or faulted against the Dells Granite (pl. 1, secs. *C–C′* and *F–F′*). Two narrow north-northeast-trending bodies of granodiorite in the Chaparral zone form the Chaparral mass. The larger one, whose extent to the northeast is unknown, is in the Chaparral Volcanics; the smaller one occurs along the Spud fault. The Mineral Point mass is in the east-central part of the area

FIGURE 10.—Distribution of masses of the Prescott Granodiorite, showing location of specimens used for modal, chemical, and normative analyses; locations of granodiorite of the Walker area and of gabbro samples are also shown.

(pls. 1, 2) and is exposed intermittently for about 10 miles. Its extent to the south and southwest beneath Cenozic deposits is unknown.

The various masses of Prescott Granodiorite have been correlated on the basis of similarity in modal, chemical, and normative composition (figs. 7, 11; tables 7, 8, 9, 10). The Prescott mass is the least altered and deformed and is described in detail; brief mention of differences in the other masses are also given.

Weathering of the Prescott mass characteristically results in large erosional mounds of relatively fresh rock surrounded by sand flats formed by accumulation of angular fragments, some of crystal-grain size. Disintegration along joints results in piles of rounded boulders, some balanced, whose form depends largely on the spacing and attitude of joints.

The Prescott mass is a fine- to medium-grained massive slightly altered rock, having a poikilitic, hypidiomorphic-granular texture. Fresh granodiorite is medium gray, light gray, or greenish gray. Slightly darker or lighter shades are principally a function of grain size, but lighter shades in places are due to less abundant biotite or to the opaque character of the more altered plagioclase. The weathered surface is grayish orange pink to grayish orange; some is reddish brown owing to baking by basalt or is light brown owing to weathering of introduced pyrite.

The granodiorite contains plagioclase, quartz, potassium feldspar, biotite, epidote, and accessory minerals. Most plagioclase is translucent to greasy; some is glassy, and some is chalky or greenish. Individual grains are hard to distinguish in hand specimen. The plagioclase forms zoned subhedral laths and anhedral grains, mostly less than 1 mm long. A few euhedral laths are 2 mm long; sparse phenocrysts are larger. Some plagioclase encloses other mineral grains; the margins of some are intergrown with quartz and microcline. Cloudy sodic plagioclase surrounds microcline in places. The centers of the plagoiclase, which is about andesine in composition, are cloudy because of slight argillization, sericitization, or saussuritization. The margins are clear albite (An_{5-10}). Normative plagioclase in this mass is An_{31}; it ranges from An_{37} to An_{25} in the other masses.

Quartz occurs as glassy colorless to light-gray slightly strained anhedral grains, mostly less than 1 mm in diameter. Some of it forms myrmekitic or graphic intergrowths with plagioclase. Where microcline is not abundant, quartz is interstitial to plagioclase.

Most of the potassium feldspar is microcline, but some occurs as orthoclase and as perthitic or microperthitic intergrowths. Microcline forms clear, colorless square to rectangular, poikilitic crystals having irregular margins. The crystals average about a quarter of an inch long; some are as much as 1½ inches across. The poikilitic microline is scattered sparsely to abundantly throughout the rock and encloses the other minerals. Commonly, the inclusions are distributed rather evenly through the microcline; some are so abundant that the enclosing microcline is easily overlooked. Locally the inclusions are concentrated around the margins of the microcline.

Biotite forms greenish-black flakes, books, and granular aggregates, which average about 0.5 mm in diameter; a few are as much as 1–2 mm. Pleochroic halos around zircon are common. Some biotite is replaced by magnetite (or ilmenite), epidote, or chlorite.

Epidote is widely distributed, from minor quantities to amounts nearly as abundant as biotite. Some grains are euhedral, but epidote is probably metamorphic; it also occurs in veinlets. Veinlets and disseminated grains of piedmontite (see p. 105) are abundant in the granodiorite northwest and west of Prescott.

Accessory minerals are sphene, magnetite, ilmenite(?), apatite, and zircon. Sphene forms euhedral crystals as much as 0.6 mm long and granular rims around magnetite. Leucoxene has formed from sphene and from ilmenite or titaniferous magnetite.

Although most of the Prescott mass is uniform, some of it is spotted, layered, or altered. Contamination from mafic rocks produced sparse to abundant rounded, irregular, or angular spots (especially near 1,295,500 N., 340,500 E.; and 1,294,000 N., 336,000 E.). Most of the spots are about a quarter of an inch in diameter. They are composed of green biotite and minor amounts of epidote, sphene, magnetite, apatite, and leucoxene.

Parallel dikes of aplite and pegmatite produced layered rocks in a few places (1,296,400 N., 334,500 E.; 1,295,500 N., 340,800 E.; and 1,308,000 N., 327,300 E.). The layers strike north-northeast and dip about vertically. Individual layers average 1–3 feet wide, but range from 1 inch to more than 10 feet. Some can be traced along the strike for several hundred feet. Some layers consists of compound dikes, the centers being aplitic and the margins pegmatitic, or vice versa; others are made up of irregular aplitic and pegmatitic zones. The layers are cut by younger pegmatite and aplite dikes.

Most of the Prescott mass has been altered by mild regional metamorphism. For about 3 miles north of the southern border of the area, a more intense alteration is probably the result of hydrothermal solutions associated with quartz, quartz-tourmaline, and tourmaline veins. It formed a mafic-poor aplitic-looking rock containing dark specks composed of granular mixtures
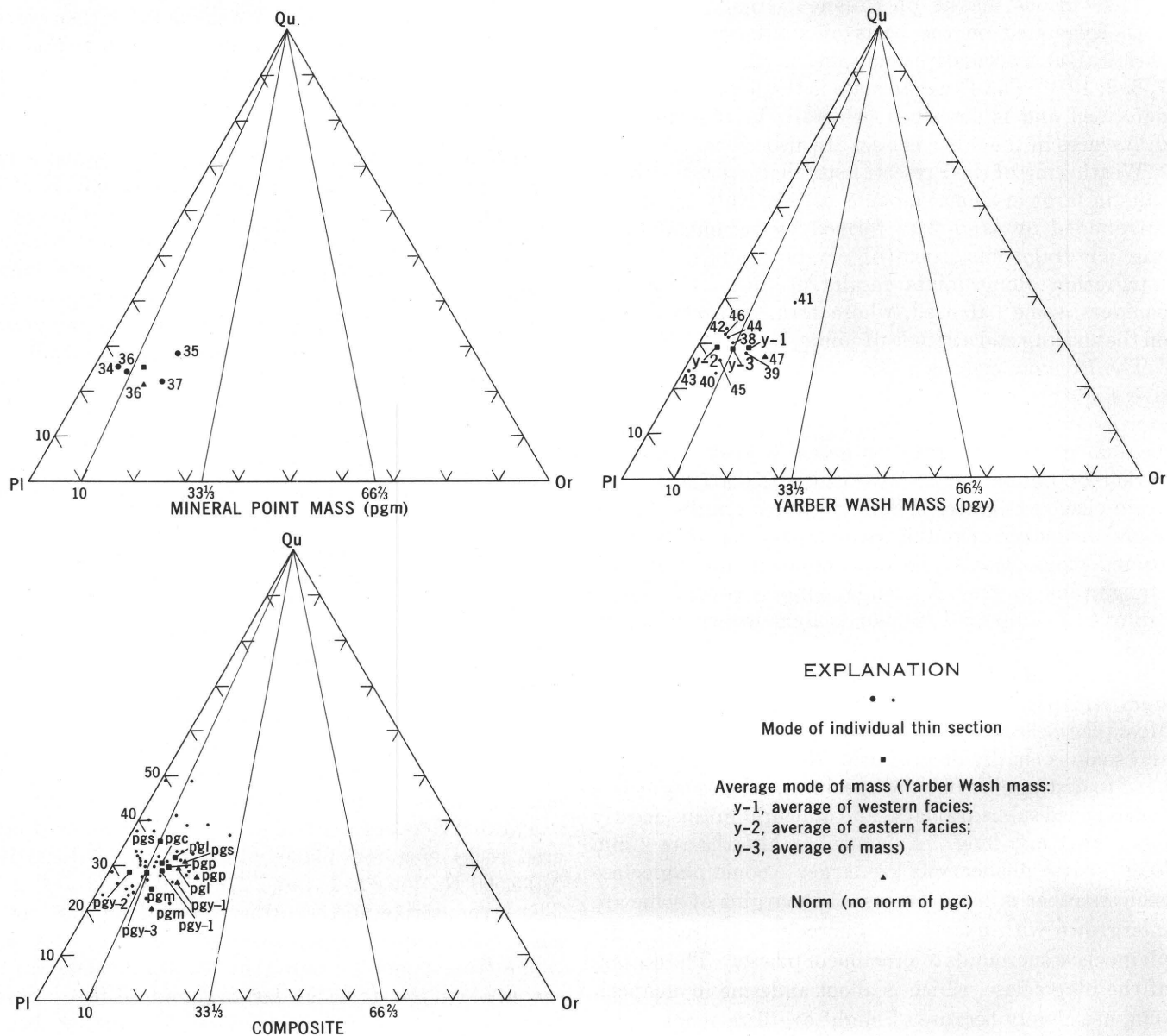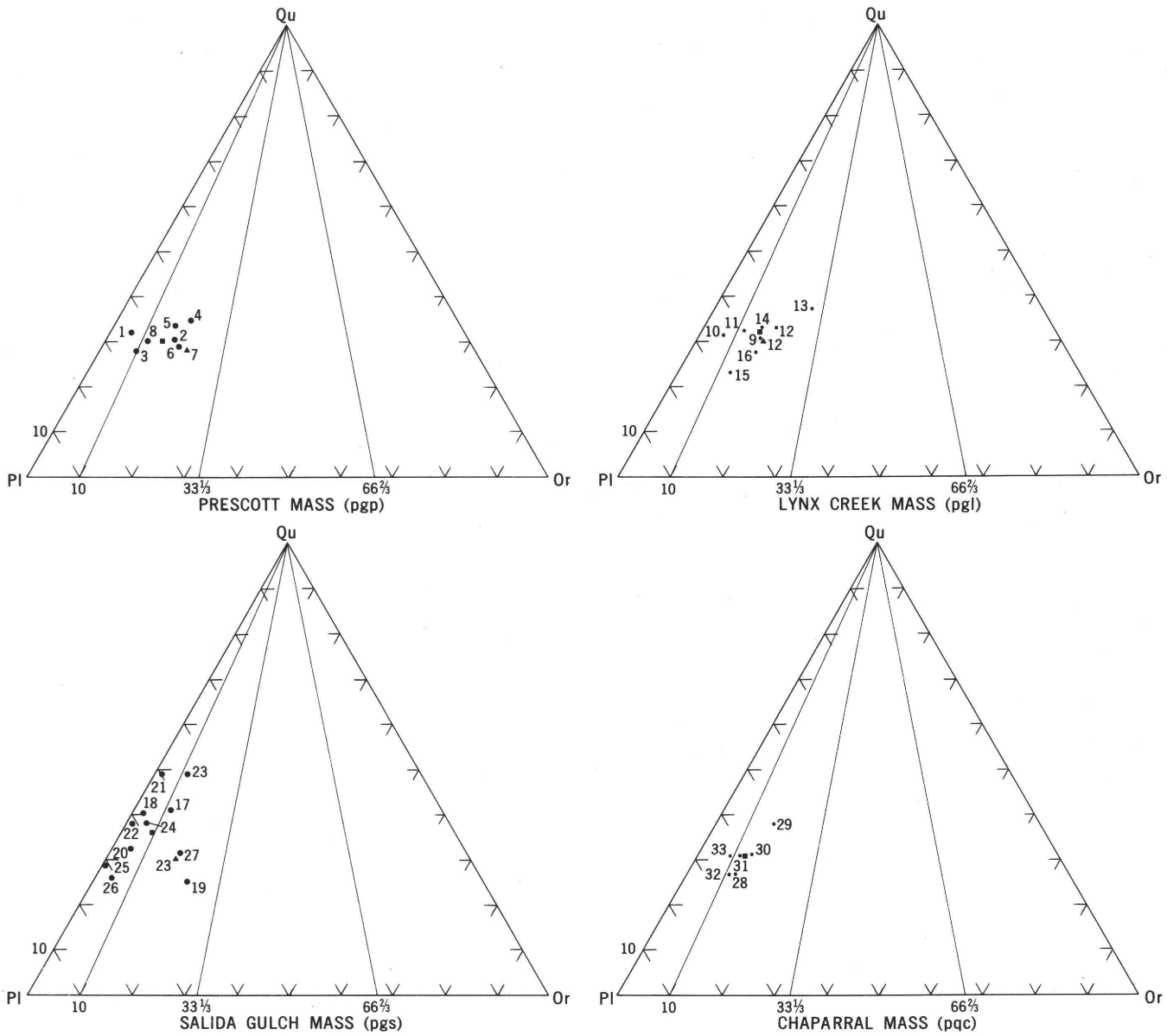
FIGURE 11.—PRESCOTT GRANODIORITE. PLOTS OF MODES AND NORMS ARE ON QUARTZ-ORTHOCLASE-PLAGIOCLASE
OF NUMBERS AND EXPLANATION OF LETTER SYMBOLS ARE

DIAGRAMS. NUMBERS REFER TO INDIVIDUAL THIN SECTIONS OR TO CHEMICALLY ANALYZED SPECIMENS: LOCATION SHOWN IN FIGURE 10. See also figure 7 and tables 7, 8, and 10.

of magnetite, specular hematite, and leucoxene that are pseudomorphic after magnetite, pyrite, or original mafic minerals. The saussuritized centers of plagioclase have been replaced by coarse sericite. Microcline is somewhat mottled owing to intergrowth or replacement by sodic plagioclase or myrmekitic quartz. Specular hematite occurs as veinlets, and coarse sericite coats fractures in places.

Except for small parts of the Lynx Creek and Mineral Point masses, the other masses do not resemble the Prescott mass. They are more deformed and altered, lack poikilitic microcline, and are generally coarser grained. The northern part of the Salida Gulch mass is intensely foliated quartz-feldspar-biotite schist and augen gneiss. Much of the Chaparral mass is a cataclastically deformed mafic-poor rock. Grain size in undeformed parts of these masses ranges from 1 to 5 mm, but the size of some of the feldspar augen suggests an original coarse-grained or porphyritic rock containing feldspar crystals more than 8 mm long. The calcic cores of plagioclase are highly saussuritized. Quartz occurs as granular aggregates or is drawn out into long thin plates. Potassium feldspar forms fine intergrowths or granular mixtures with quartz and albite. Hornblende was observed only in the Mineral Point mass; allanite, in the Salida Gulch, Chaparral, and Mineral Point masses.

No primary mafic minerals are preserved in the Salida Gulch and Chaparral masses, with the possible exception of a few large biotite flakes. Most boitite and chlorite occur as granular aggregates associated with epidote and accessory minerals. In the intensely foliated rock in the northern part of the Salida Gulch mass, metamorphic brown or greenish-brown biotite is concentrated in plates or thin lenses. In the less foliated rock to the south, the biotite is green or brownish green. This part of the Salida Gulch mass contains more chlorite than the more schistose rock to the north. In the Chaparral mass mafic minerals have been largely sheared out and completely altered to chlorite, epidote, calcite, and leucoxene.

RELATIONS TO OTHER ROCKS

The conclusion that the rocks mapped as the Prescott Granodiorite are part of the same intrusion is based primarily on similarities in modal, chemical, and normative composition, but this correlation is open to question. Refinements in age determinations may prove or disprove this conclusion. On the basis of the amount of deformation the rocks have undergone, the Prescott, Yarber Wash, Big Bug Creek, Mineral Point, and Lynx Creek masses could be interpreted as younger than the Salida Gulch and Chaparral masses.

Field relations prove that most of the masses of Prescott Granodiorite intrude the Alder Group or contain xenoliths of the Alder Group, but because of intense deformation and mechanical mixing, relations are obscure in some places. The Lynx Creek mass clearly intrudes tuffaceous rocks of the Alder(?) Group and gabbro. The Mineral Point and Yarber Wash masses also intrude gabbro; most of the other masses contain xenoliths of gabbroic(?) rocks. The Prescott mass intrudes the western mass of Government Canyon Granodiorite. Pink aplite dikes, some spatially related to alaskite, cut all the masses; coarse-grained alaskite cuts the Mineral Point mass. The Salida Gulch mass is cut by coarse-grained granite, fine-grained granite, and fine-grained gabbroic to diabasic rocks. A few diabase dikes also cut the Lynx Creek mass, but none cut the other masses. The Dells Granite and Prescott Granodiorite are not in contact, but the Prescott mass is cut by dikes of aplite and pegamatite and veins of quartz, quartz-tourmaline, and tourmaline that are probably related to the granite; the granite contains xenoliths that resemble the granodiorite.

The fine-grained granite rather thoroughly permeated some of the Salida Gulch mass. This mass contains numerous dikelike bodies, too small to map, and larger irregularly shaped bodies of mafic rocks that are mapped as gabbro. Some of the bodies may be older volcanic or gabbroic rocks; others have a diabasic texture, cut the granodiorite, contain xenoliths of granodiorite, or have chilled margins against the granodiorite.

The granodiorite bodies in the Chaparral-Spud fault zone parallel the regional foliation within the zone. The bodies were intruded prior to final deformation within the zone or, more probably, were dragged into it. Postintrusive deformation produced augen gneiss and mylonite in the granodiorite and obscured the original relations of granodiorite to Chaparral Volcanics and to gabbro. The contacts are gradational, and the granodiorite may nowhere be in contact with rocks that it originally intruded.

ALASKITE AND RELATED ROCKS

DISTRIBUTION

Alaskite and related rocks crop out in the southeastern and east-central parts of the Prescott-Paulden area (pls. 1, 2; fig. 12). These rocks are mapped as quartz monzonite, alaskite, and alaskite porphyry; the alaskite porphyry includes aplitic alaskite and aplite.

Quartz monzonite lies west of the eastern mass of the Green Gulch tuffaceous unit. It is separated into two parts and buried to the north by Cenozoic deposits.
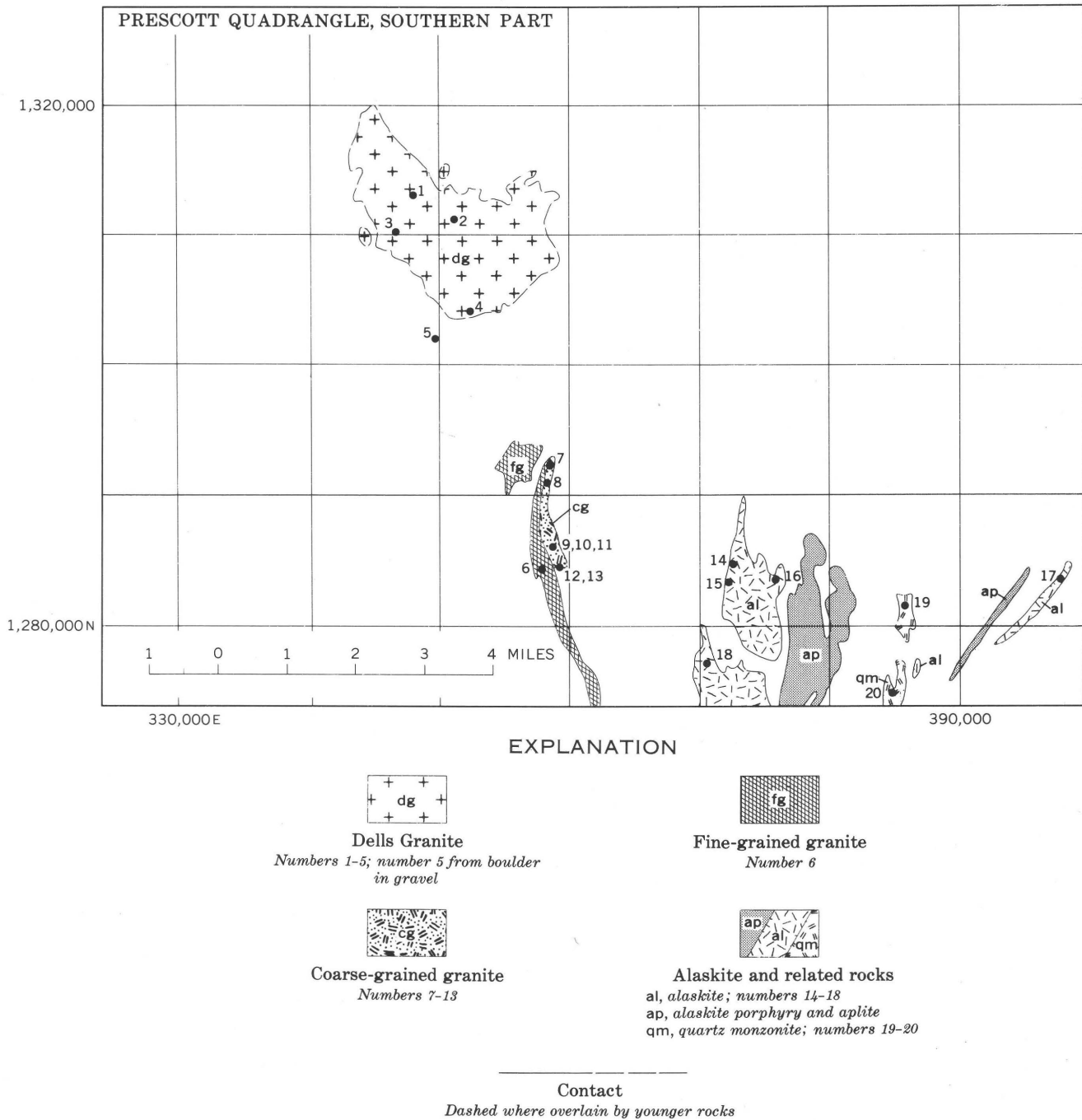
FIGURE 12.—Distribution of granitic rocks, showing location of specimens used for modal, chemical, and normative analyses.

Alaskite forms two large and several small discrete bodies in the southeastern part of the area, all of them east of the largest mass of gabbro. Five small lenses and pods, one of them occurring largely south of the map area, are in the southwestern part of the tuffaceous rocks of the Green Gulch Volcanics; a long, narrow body of alaskite is in the Chaparral Volcanics. Eight small bodies of alaskite extend south-southeast from Upper King Canyon (pl. 2, 1,396,500 N., 379,100 E.). Un-

mapped sheets, pods, and irregular dikes of alaskite are found in the Prescott Granodiorite and gabbro south of these exposures.

Alaskite porphyry forms one large mass in the southeastern part of the area. Two narrow masses of aplitic alaskite occur in the northern part of the Green Gulch tuffaceous unit, and an elongated lens lies immediately east of Chaparral fault. Unmapped aplite dikes, probably related to alaskitic rocks, are common in the

Mineral Point and Lynx Creek masses of the Prescott Granodiorite (fig. 10) and cut other intrusive rocks.

GENERAL CHARACTER

Alaskite and alaskite porphyry are resistant rocks. In the southern part of the area the largest masses form high ridges having local steep to precipitous slopes. The crests of the ridges that extend northward from the wider parts of the larger alaskite masses are occupied by narrow dikelike masses of alaskite augen gneiss. A subdued topography, formed on alaskite in the east-central part of the area and on the quartz monzonite, is the result of proximity to old erosion surfaces—pre-late Tertiary on the quartz monzonite and pre-Paleozoic on the alaskite.

Quartz monzonite.—Quartz monzonite is medium grained, locally coarse grained or porphyritic, and has a massive to foliated structure. The rock is mottled olive gray and light brownish gray and is composed of microcline, plagioclase, quartz, and mafic and accessory minerals. The modal composition is given in table 7. The Plagioclase is a somewhat zoned oligoclase (An$_{15\pm5}$ as determined by X-ray diffraction). The cores are partially sericitized and saussuritized. Chlorite, less abundant biotite, epidote, and muscovite, and a few relics of hornblende form irregularly shaped aggregates. Accessory minerals are magnetite, apatite, zircon, and allanite.

Alaskite and alaskite porphyry.—The alaskitic rocks are similar in color and composition. They differ in degree of deformation and amount of contamination but principally in texture. Textural gradations between alaskite and alaskite porphyry occur in a few places.

Most alaskitic rocks are pale red to grayish orange pink, some are moderate red, and some are nearly white because of alteration. The rocks weather light shades of brown; exceptions are the northern part of alaskite in the Chaparral Volcanics and some of the aplitic alaskite east of Chaparral fault, which weather dark to moderate reddish brown.

Alaskite ranges from a massive rock through augen gneiss to mylonite. Augen gneiss is characteristic of many of the narrow dikelike masses, some unmapped, in gabbro and volcanic rocks; it forms only narrow zones in the large masses. Alaskite in the Chaparral Volcanics is mostly equigranular at its northern end and augen gneiss in the middle; its southernmost 1,000 feet is a tail of mylonite less than 50 feet wide. Much of the granitic-textured alaskite is medium grained. In augen gneiss, however, the size of some feldspar augen suggests that some of the original rock was coarse grained or porphyritic.

Most alaskite porphyry is massive and fine grained. Its sparse to abundant phenocrysts, 2–6 mm in diameter,

consist of feldspar and quartz. Aplite and aplitic alaskite are fine grained and have a sugary texture. Slight recrystallization of mylonite may also have formed a sugary texture. Some aplitic alaskite, especially on the eastern edge of the large mass of alaskite porphyry, contains phenocrysts of quartz and feldspar, generally less than 1 mm and rarely as much as 2 mm in diameter.

Modal, chemical, and normative compositions of medium-grained equigranular alaskite are given in tables 7, 8, 9, and 10, and figures 7 and 13. The rock consists of potassium feldspar, albite, quartz, a little mica, and accessory minerals.

The feldspar is albite, microcline, orthoclase, and perthite. Some potassium feldspar has been partly replaced by late albite. Most of the augen are potassium feldspar. Albite, in many places, is slightly sericitized; most potassium feldspar is fresh. Normative albite is An$_3$.

Quartz is strained, crushed, or granulated in most alaskite but is only slightly strained in the finer grained rocks. In augen gneiss it forms lenticular or plate-like aggregates or granular mixtures with feldspar.

In unsheared and uncontaminated alaskitic rocks poor in mafic minerals, primary biotite, muscovite, magnetite (or ilmenite), zircon, and sphene are sparse. In some of the sheared rocks, aggregates of fine flakes of biotite, chlorite, or sericite are concentrated in thin plates or lenses. In some intensely deformed alaskite in the Chaparral zone, mafic minerals have been completely sheared out.

Contaminated alaskitic rocks contain sparse to abundant biotite, chlorite, amphibole, and epidote, which were derived from mafic volcanic rocks and gabbro that have been sheared into the alaskite or were picked up by it from the intruded rocks. The aggregates of chlorite, sericite, epidote, leucoxene, and some calcite were derived from original or xenolithic biotite or other mafic minerals. Biotite has altered to chlorite. Tiny pyrite cubes are abundant in some alaskitic rocks and appear to be related to mild sericitization.

RELATIONS TO OTHER ROCKS

Alaskite, alaskite porphyry, and quartz monzonite are probably consanguineous; the alaskite porphyry is slightly younger, and the quartz monzonite is slightly older than the alaskite. If consanguineous, then alaskite and related rocks are all younger than the gabbro and the granodiorites but older than some diabase.

Quartz monzonite.—Quartz monzonite probably intrudes gabbro. Many pink aplite dikes in quartz monzonite suggests that is a slightly older facies of the alaskite and alaskite porphyry.
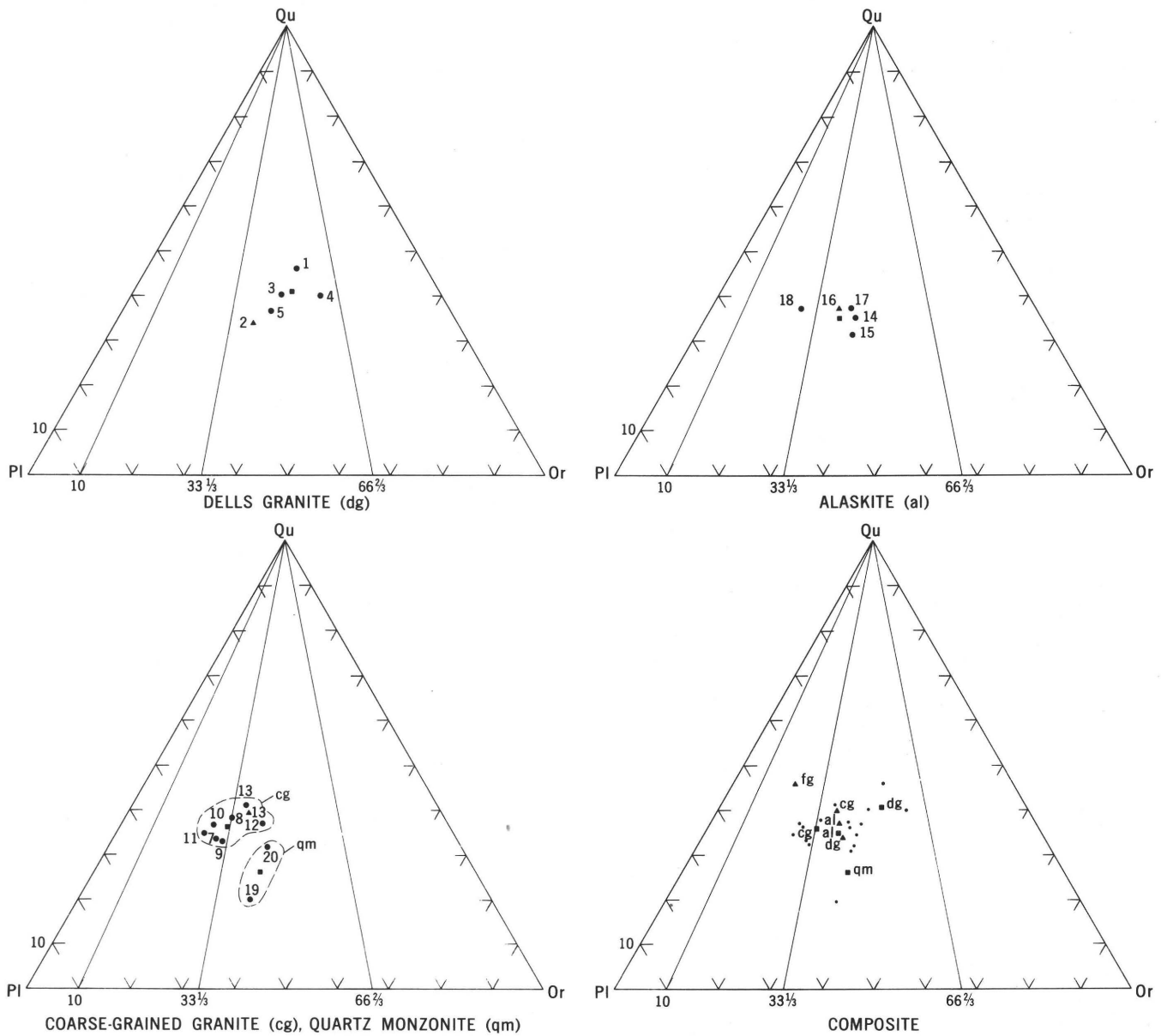
FIGURE 13.—Granitic rocks. Plots of modes and norms are on quartz-orthoclase-plagioclase diagrams. Numbers refer to individual thin sections or to chemically analyzed specimens; location of numbers and explanation of letter symbols are shown in figure 12. See also figure 7 and tables 7, 8, and 10.

Alaskite.—The larger masses of alaskite intrude the unnamed volcanic rocks of the Alder(?) Group. Although the actual contacts are poorly exposed, the outcrop pattern of the basaltic flows that separate the two largest bodies of alaskite indicates intrusion by alaskite, an indication strongly supported by the many aplite dikes in the basaltic flows. Part of the outcrop pattern of the tuffaceous rocks northeast of these alaskite masses is due to intrusion of the alaskite. In upper King Canyon (pl. 2) alaskite is clearly intrusive into the tuffaceous rocks.

Unmapped masses of alaskite in gabbro north of the largest masses of alaskite and alaskite porphyry have dikelike form. They are 1–50 feet wide and as much as half a mile long. The margins are zones of shear, and the alaskite is an augen gneiss, but much of the adjacent gabbro is relatively massive. Presumably shearing was taken up in alaskite rather than in gabbro.

Alaskite porphyry.—Alaskite porphyry and aplite clearly intrude unnamed basaltic flows of the Alder(?) Group and form distinctive intrusive breccias, especially along Green Gulch (near 1,284,500 N., 378,300 E.; and 1,284,400 N., 381,100 E.) and along Charcoal Gulch (near 1,283,200 N., 377,700 E.; and 1,277,800 N., 377,400 E.). The elongated subrounded to angular xenoliths are alined roughly parallel to the regional trend of the foliation and range from individual biotite or hornblende crystals or aggregates a fraction of an inch long to masses measured in tens of feet. Some xenoliths are dikelike in form. Xenoliths make up about 40 percent of some outcrops, and in these places many of them are about 3 feet long. Narrow diabase dikes in alaskite porphyry along Charcoal Gulch are also parallel to the regional north-trending foliation.

Narrow dikes of aplite intrude gabbro and the Lynx Creek and Mineral Point masses of Prescott Granodiorite in the southeastern and east-central parts of the area. Although most of the alaskite and alaskite porphyry masses parallel the regional formation, some aplite dikes are crosscutting.

COARSE-GRAINED GRANITE

DISTRIBUTION

Coarse-grained granite forms a long narrow north-trending mass in the south-central part of the area (pl. 1,284,500 N., 359,500 E., and fig. 12). Adjacent areas mapped as contaminated Prescott Granodiorite and contaminated fine-grained granite contain some coarse-grained granite.

GENERAL CHARACTER

Coarse-grained granite is a medium-light-gray to light-gray rock. Where intensely foliated it has a silvery sheen due to abundant sericite. The rock is medium to coarse grained and locally porphyritic, containing phenocrysts as much as 1 cm long. Most of the massive rock has an equigranular granitic texture. Some of the foliated rock is augen gneiss. The granite is composed of plagioclase, quartz, microcline, biotite, sericite, chlorite, and accessory minerals (see tables 7, 8, 9, and 10, and figs. 7 and 13 for chemical, modal, and normative compositions).

Quartz is strained, granulated, or drawn out into thin, platelike, fine granular masses. Microcline and mircrocline-perthite are subordinate to albite, which shows slight replacement by or alteration to coarse-grained sericite. Normative plagioclase is An_7. Some of the rock contains a few large altered plagioclase (oligoclase-andesine) crystals. Epidote is generally lacking. Metamorphic biotite occurs as aggregates of small flakes or is concentrated in lenticular areas or as thin plates. In most places it is not abundant and is generally subordinate to the white mica, most of which is also of secondary origin. Accessory minerals are zircon, magnetite, apatite, and sphene(?), which is now largely altered to leucoxene.

RELATIONS TO OTHER ROCKS

In a few places coarse-grained granite clearly intrudes the Salida Gulch mass of Prescott Granodiorite and is intruded by fine-grained granite. Most contact between coarse-grained granite and granodiorite, however, are gradational and arbitrary. Because biotite, epidote, and saussuritized plagioclase gradually increase in abundance toward the granodiorite contact, it was difficult in the field to distinguish the granite from the granodiorite. Prescott granodiorite may occupy more of the area mapped as coarse-grained granite, or coarse-grained granite may occupy more of the areas mapped as contaminated granodiorite. Modal, chemical, and normative analyses of the granite resemble those of both alaskite and the Dell Granite, but the coarse-grained granite has been mapped separately because it does not resemble either rock megascopically and because the analyses do not clearly indicate that it belongs to either the alaskite or the Dells Granite.

DELLS GRANITE

DISTRIBUTION

The Dells Granite, herein named for the Granite Dells, lies about 5 miles northeast of Prescott (pl. 1; fig. 12). It forms a somewhat triangular-shaped mass about 5 square miles in area. Its extent beneath the surrounding Cenozoic cover is probably limited by faults on the southeast and southwest to a mile or less (pl. 1, secs. B–B', C–C', D–D', and F–F'); its extent to other directions is unknown.

FIGURE 14.—Aerial photograph (Cou–8–73) of Granite Dells and Glassford Hill, showing joint pattern in the Dells Granite (dg) and the overlying rocks of late Tertiary (?) age: basalt flows (Tbl, lower; Tbm, middle; Tbu, upper); sedimentary and tuffaceous rocks (Ts); cinder cone (Tc); branching dike (Td); and andesite flow (Ta). Light areas east and north of Glassford Hill are caliche.

GENERAL CHARACTER

The form of the bold outcrops of the Dells Granite is controlled by joints and shows up well in aerial photographs (fig. 14) and on the topographic map, where contour lines make right-angle bends. In two places, northeast of Storm Ranch (1,308,800 N., 354,300 E.) and between Entro (1,312,000 N., 353,500 E.) and Route 89, N. 15°–40° W. joints have exerted more control on the topography than the principal set, which is N. 25° E. and N. 70° W. (fig. 26). Where the rocks are more disintegrated, especially northwest of Storm Ranch, bold hills and pronounced valleys are absent, and the area is more extensively covered by trees and brush.

Weathering along joints has formed large and small rounded boulders, some balanced boulders, and other unusual forms. It has also produced a checkerboard appearance (fig. 15) where iron oxide has migrated inward from horizontal, vertical, and sloping joint surfaces. Successive migrations of iron oxide resulted in concentric envelopes that become more spherical inward. The weathered surface is rough owing to rounded knobs or pits. The knobs consist of masses or individual large

FIGURE 15.—Checkerboard appearance formed in the Dells Granite due to weathering along joint planes; southwest of Willow Creek Reservoir (1,310,000 N., 343,900 E.).

crystals of pegmatitic minerals or of xenoliths of schist or gneiss. The pits, 3–6 inches deep and 1–2 feet in diameter, noted northwest of Watson Lake, are formed by weathering along joints or by removal of pegmatitic minerals or of xenoliths. Much of the granite is crumbly because its present surface is near an old erosion surface. A green claylike material coats joints and is disseminated through the rock near the surface in some places.

The Dells Granite is a fairly uniform massive medium- to coarse-grained rock having a granitic (seriate), locally porphyritic, texture. The principal minerals generally range from 2 to 5 mm in diameter. Phenocrysts of feldspar are erratically distributed and are almost completely absent in some areas. The phenocrysts have a maximum size of about 2 inches and average from $\frac{1}{4}$ to 1 inch in length. Most of them, and the larger ones, are microcline; some are albite. Fresh surfaces of the granite are very light gray to almost white, and weathered surfaces are various shades of orange pink and light brown. The granite is composed of white feldspar, light smoky-gray quartz, and variable amounts of biotite. Black tourmaline, purple fluorite, magnetite, specular hematite, and a little apatite occur either as accessory minerals or as introduced hydrothermal minerals. The modal, chemical, and normative compositions are given in tables 7, 8, 9, and 10, and in figures 7 and 13.

Quartz occurs as rounded, anhedral, slightly strained grains, many containing inclusions of other minerals. Microcline is the principal potassium feldspar. It

forms interstitial anhedral grains; some of it poikilitically encloses albite, quartz, and biotite; some phenocrysts have poikilitic margins. Perthite forms irregular areas in the microcline. Albite occurs as subhedral crystals, perthitic intergrowths, and a few phenocrysts. Some of it encloses other minerals, especially around the margins. It ranges from about An_{15} to An_4; normative plagioclase is An_7. A few phenocrysts show slight zoning. Much of the albite is slightly cloudy because of minor sericitic or argillic alteration.

Locally in the northeastern part of the mass, dark-green biotite forms books ranging from 1 to 4 mm in size, but in much of the rock, biotite is bleached and forms smaller flakes that have a ragged outline and a pale-olive color. Under the microscope this mica is nearly colorless and nonpleochroic or slightly pleochroic. Darker pleochroic halos occur around some of the tiny zircons. The index of refraction on cleavage flakes is slightly less than 1.61,[6] in contrast to the index of the fresh mica, which is nearly 1.64. The 2V of this colorless mica is too small for muscovite. Alternate platelike areas of iron oxides (magnetite, specular hematite, ilmenite, and leucoxene) occur in some of the bleached biotite. The bleaching appears to be associated with the introduction of deuteric or hydrothermal fluorite. Most of the specimens used for modal analyses contain bleached biotite; the chemically analyzed specimen contained fresh biotite. Alteration of the rock might account for the poor agreement between the norm and average mode of the granite (figs. 7, 13).

Accessory minerals are magnetite, specular hematite, and some leucoxene. Veinlets and granular masses of individual crystals generally less than 1 mm in diameter of purple to colorless fluorite can be seen in most thin sections and in many hand specimens. Crystals of black tourmaline range from less than 0.1 mm to more than 5 cm in length; some are concentrated in irregular areas as graphic intergrowths with quartz and feldspar. Tiny red garnets are present in some places but are more abundant in some aplites that cut the granite. A few diamond-shaped reddish areas, now largely altered to hematite(?) and leucoxene(?), probably represent original sphene.

LATE-STAGE PRODUCTS OF CRYSTALLIZATION

Deuteric and hydrothermal alteration slightly sericitized albite, bleached biotite, and introduced pegmatitic and aplitic minerals and quartz, quartz-tourmaline, and tourmaline veins. The abundance of these minerals, together with fluorite, suggests that the

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[6] The index checks reasonably well with partly altered biotite from Santa Rita (Kerr and others, 1950, p. 321).

granite was rich in water and mineralizers. These minerals are erratically distributed and do not appear to be as abundant in the northeastern part and along the northwestern border as elsewhere.

Pegmatitic material permeated the granite and formed dikes, irregular veins, pods, and individual crystals. Many of the dikes are only a few feet wide; individual microcline crystals are as long as 12 inches; pods of quartz and tourmaline and individual tourmaline crystals are several inches long. The dikes are composed of coarse quartz and microcline, some finer grained graphic or platelike intergrowths of quartz and albite (about An_6), dark-green biotite, muscovite, and tourmaline. Some dikes contain alternating layers of pegmatite and aplite; the aplite is fine grained, sugary, and white to grayish orange pink.

RELATIONS TO OTHER ROCKS

The Dells Granite is surrounded and unconformably overlain by Cenozoic rocks (fig. 14). The concealed contact between the granite and the Precambrian volcanic and intrusive rocks southeast of the Granite Dells is thought to be a fault trending north-northeast that passes beneath Glassford Hill (pl. 1, secs. $B-B'$, $D-D'$). The concealed contact between the granite and the Government Canyon and Prescott Granodiorites southwest of the Granite Dells may be a fault trending west-northwest close to the southwestern outcrops of the granite— that is, between the granite outcrops and a 1,000-foot well in late Tertiary(?) deposits (pl. 1, secs. $C-C'$, $D-D'$, $F-F'$). The granite is probably younger than the Prescott Granodiorite, as discussed on page 40.

FINE-GRAINED GRANITE

DISTRIBUTION

Two areas of fine-grained granite are found in the south-central part of the area (pl. 1, fig. 12). One is east of the Texas Gulch Formation and extends north from the southern border of the area for about 4 miles. The other is north of the Texas Gulch Formation and west of the unit containing jasper-magnetite beds. It is separated into two parts by a surficial cover of Cenozoic rocks.

GENERAL CHARACTER

Fine-grained granite is greatly contaminated with older rocks. The granite is massive, light, slightly pinkish, yellowish, or greenish gray. Individual grains are mostly less than 1 mm long. The granite is composed of plagioclase, orthoclase, quartz, and traces of mafic and accessory minerals. Chemical and normative compositions of what appeared to be a relatively uncontaminated sample from the eastern area are given in tables 8, 9, and 10, and in figures 7 and 13. The composition falls in the granodiorite field (fig. 7), but the plagioclase is albite; therefore the rock is a granite. The following petrographic data were obtained from study of thin sections of specimens from the eastern mass. Much of the quartz occurs as graphic or myrmekitic intergrowths, in places having a radial arrangement; some quartz encloses plagioclase. The irregular margins of the plagioclase are sodic albite, but the more or less euhedral centers of some are more calcic and slightly sericitized. Normative plagioclase is An_9. Large quartz grains as much as 5 mm in diameter, large saussuritized and sericitized plagioclase, and erratically distributed lenticular aggregates of mafic and accessory minerals probably were picked up from intruded quartz porphyry, the Prescott Granodiorite, gabbro, and the Alder Group. The mafic and accessory minerals are biotite, chlorite, epidote (zoisite), magnetite, apatite, sphene, leucoxene, actinolitic hornblende, zircon, calcite, and pyrite. Same granite in the western area resembles the aplitic alaskite or aplite in texture and in the almost complete absence of mafic and accessory minerals.

RELATIONS TO OTHER ROCKS

Fine-grained granite intrudes the Texas Gulch Formation, quartz porphyry, gabbro, the Salida Gulch mass of the Prescott Granodiorite, and coarse-grained granite. In places it thoroughly permeates older rocks. The aplitic material in the western outcrops may not be related to the fine-grained granite of the eastern area; it may be older, as indicated by local foliation. The eastern mass may not be consanguineous with the other quartzose intrusive rocks; its chemical and normative composition (tables 8, 10; figs. 7, 13) differs from that of the other rocks.

OTHER INTRUSIVE ROCKS

Quartz porphyry and rhyolite dikes, too small to show on the geologic map, occur in the south-central part of the Prescott-Paulden area, mostly in areas mapped as contaminated Prescott Granodiorite and contaminated fine-grained granite.

QUARTZ PORPHYRY

Quartz porphyry intrudes the Alder Group and is intruded by the Prescott Granodiorite, coarse-grained granite, and fine-grained granite. It is a light gray porphyritic rock; some of it has a primary flow structure and embayed pheonocrysts, but much of it has been intensely foliated. It is composed of quartz and albite phenocrysts as much as 10 mm long in a groundmass composed of quartz, alkalic feldspar, variable amounts of sericite, a little biotite or chlorite, a little epidote or zoisite, and accessory magnetite and apatite.

Some intensely foliated quartz porphyry consists of alternating layers of sericite and quartz-sericite; but some of the augen of quartz in the layers show little strain or granulation.

RHYOLITE DIKES

Rhyolite dikes are confined largely to the southern part of the area of fine-grained granite east of the Texas Gulch Formation. The dikes intrude the Alder Group and fine-grained granite. The rhyolite is fine grained, massive and light to medium light bluish to greenish gray; it weathers white. Quartz and albite phenocrysts are as much as 3 mm in size. Quartz is euhedral or resorbed. Some albite crystals are clustered. Large areas of epidote are scattered erratically through the rock. The groundmass is quartz, alkalic feldspar, and very minor amounts of epidote, sericite, and chlorite.

VEINS, SILICIFIED ZONES, AND ALTERATION ZONES

Veins, silicified zones, and alteration zones include quartz, quartz-tourmaline, and tourmaline veins (identified on pl. 1 by the letter q), quartz-magnetite veins or replacements (identified on pl. 1 by the symbol m), and to avoid the use of a separate symbol, silicified and alteration zones (identified on pl. 1 by the symbol si). The silicified and alteration zones include silicified breccia zones and economically important mineralized and alteration zones; many quartz veins have been mineralized. Mineralized veins and zones are discussed in the section on "Economic geology," page 104.

Quartz veins are widely distributed in the Precambrian rocks, except in the Mazatzal Quartzite. They are especially abundant in the east-central and southeastern parts of the area. Quartz-tourmaline and tourmaline veins cut principally the Dells Granite, Government Canyon Granodiorite, Prescott and Lynx Creek masses of Prescott Granodiorite, and the aplite and pegmatite dikes in these rocks.

The veins fill shear zones and a few joints. Some are parallel to and others are at an angle to the foliation in the host rock. The veins, pods, and lenses of quartz range in width from a few inches to, rarely, 50 feet. They are generally discontinuous within a shear zone. The longest quartz vein, about 1,000 feet, is in quartz diorite north of the Verde River (pl. 2, 1,413,500 N., 382,300 E.); other large veins and pods are found in the extreme southwest corner of the area and in alaskite in the Chaparral zone (pl. 1, 1,284,000 N., 398,000 E.). The largest tourmaline vein seen is 5 feet by about 100 feet. Some tourmaline veins form thin coatings on joints.

The quartz veins consist principally of milky or white quartz. Some contain appreciable amounts of tourmaline and grade into veins composed principally of tourmaline. Others contain minor amounts of gold, and many of them contain sufficient pyrite, chalcopyrite, or other metallic minerals to have induced prospectors to dig many shallow pits and adits. Few of the quartz-tourmaline and tourmaline veins contain enough metallic minerals to encourage exploration. The tourmaline ranges from hairlike needles to thicker crystals 2 mm long. The crystals form a network or mesh containing minor amounts of quartz.

Quartz-magnetite veins, pods, and lenses are most abundant in the southwesternmost and south-central masses of unnamed tuffaceous rocks of the Alder Group(?), but they occur also in the Spud Mountain Volcanics and the basaltic flow unit of the Green Gulch Volcanics. Those in intrusive rocks are probably part of a xenolith of volcanic rocks. The veins are parallel to foliation or bedding in the host rock and do not appear to have any stratigraphic significance. Some are en echelon, an eastern one lying to the north of an adjacent western one. They range from a few inches to 20 feet in width; a few fill all but a minor part of a 50-foot zone. Some have been traced as much as 1,500 feet.

The quartz-magnetite is medium gray to medium dark gray and has a purple or blue cast. Most of it is finely laminated; some is massive. Laminae range from paper thin to several feet in width and are formed by variations in amount and grain size of quartz and magnetite. Minute magnetite grains, 0.01–0.4 mm in diameter, are scattered or occur in ramifying streaks and bands, some of them more than 1 mm long. Most quartz grains are elongate and range from 0.01–0.8 mm in length, except in magnetite-free layers, where the individual grains are as much as 4 mm long. Small to large variations in the proportions of quartz and magnetite are common; the layers range from pure quartz to almost pure magnetite. Some veins enclose minerals characteristic of the host rock. The quartz-magnetite zones may represent recrystallized sedimentary jasper-magnetite beds or, more probably, a replacement of the tuff by hydrothermal quartz and magnetite. In the Prescott quadrangle portion of the Jerome area, these veins are referred to as jasper veins by Anderson and Creasey (1958, p. 43), but the veins here are more crystalline than the jasper veins farther east.

Silicified breccia zones occur in the Dells Granite west and northwest of Storm Ranch and in the Prescott and Lynx Creek masses of Prescott Granodiorite (pl. 1). Most zones are narrow, ranging from less than an inch to a few inches or feet wide. A number of narrow zones may be concentrated to form a wider zone, such as the

one in the Prescott mass (1,301,000 N., 329,000 E., to 1,305,300 N., 327,800 E.). The widest breccia zone has a maximum width of 50 feet and was traced intermittently for about half a mile (from 1,295,800 N., 370,700 E., to 1,297,700 N., 369,000 E.). This zone contains fragments of Precambrian volcanic and intrusive rocks, some of which are more than a foot long, and smaller ones of quartz, feldspar, tourmaline, and other minerals. The fragments are cemented by chert and other forms of silica. Limonitic areas suggest alteration of introduced pyrite or other iron oxide or sulfide-bearing minerals.

CONCLUSIONS

AGE

The Precambrian quartzose intrusive rocks in Arizona have generally been thought to belong to one period of orogeny that occurred before the deposition of the Mazatzal Quartzite, although Hinds (1936, p. 100) suggested two periods, one prior to and one after deposition of the Mazatzal. Until the recent discovery of a granodiorite older than the Texas Gulch Formation,[7] all the intrusive rocks of the Prescott-Paulden area were considered younger than the Alder Group. As relations are obscure in many places, the possibility exists that locally pre-Alder Group rocks may have been included in the Government Canyon or Prescott Granodiorites. No evidence, however, of intrusion of any granitic rocks into the Mazatzal Quartzite was found in the area.

Gabbro and the Yarber Wash mass of Prescott Granodiorite in the Jerome area, quartz diorite in the northern part (pl. 2), and alaskite and the Mineral Point mass of the Prescott Granodiorite in the east-central part (pls. 1, 2) of the Prescott-Paulden area are unconformably overlain by lower Paleozoic rocks. Elsewhere Paleozoic rocks are absent, and the Precambrian age of the intrusives is less certain. The lead/alpha age of zircon in the Government Canyon Granodiorite (see p. 50), however, is Precambrian. The intense deformation of some intrusive rocks in the southern part of the area—especially alaskite, coarse-grained granite, and the Chaparral and Salida Gulch masses of the Prescott Granodiorite—likewise indicates a Precambrian age for these rocks. If the correlation of the Yarber Wash and Mineral Point masses with the Prescott mass is correct, then the Prescott mass also is Precambrian, even though it has undergone only mild regional metamorphism. Also the Prescott mass

[7] Mapping in the Mount Union quadrangle about 10 miles south-southwest of the southeast corner of the Prescott quadrangle by P. M. Blacet of the U.S. Geological Survey in the summer of 1961 has shown that the Texas Gulch Formation rests unconformably on an older granodiorite (quartz diorite) (C. A. Anderson, oral commun., 1962). This is the first known occurrence of granitic rocks older than the Alder Group.

resembles granodiorite that is overlain by Tapeats Sandstone in the southeastern part of the Simons quadrangle (fig. 1). The age of the massive Dells granite is less certain, but it is considered Precambrian because it is cut by quartz and tourmaline veins, which have not been found cutting Paleozoic rocks to the north, and because it resembles granite that is overlain by Cambrian rocks in the Camp Wood quadrangle (see fig. 16) about 25 miles to the northwest. Fine-grained granite is considered Precambrian only because it is cut by diabase dikes, which have not been observed cutting Paleozoic rocks; its massive unaltered character suggests that it may be younger. The massive rhyolite dikes were intruded after regional deformation; they may be related to upper Tertiary rhyolite tuff, but because they are more altered than the rhyolite lapilli in the tuff, they are included in the Precambrian intrusive rocks. Quartz, tourmaline, and quartz-magnetite veins are presumably Precambrian; none were observed cutting Paleozoic rocks. They were formed probably after the major Precambrian deformation, as they are fractured but otherwise undeformed. The fragmental character of the breccia zones implies that brecciation occurred close to the surface in very late Precambrian or, possibly, in post-Precambrian times.

RELATIONS

The various masses of the Prescott Granodiorite are correlated on the basis of modal, chemical, and normative compositions (tables 7–10, figs. 7, 9, 11, 13, 15). The similarity in hand specimen between some of the masses is less striking. The Prescott mass is finer grained than all the other masses except parts of the Lynx Creek mass; it is characterized by large poikilitic microcline; the others are not. The Lynx Creek mass consists of finer and coarser grained rocks that are considered to be facies but conceivably represent different intrusions. The Yarber Wash and Mineral Point masses both have hornblende; no hornblende was observed in the Prescott and Lynx Creek masses, and if originally present in the Salida Gulch and Chaparral masses, it was destroyed during shearing.

The composition of most of the Prescott Granodiorite is sufficiently different from that of the Government Canyon Granodiorite—lower in modal and normative quartz and in total silica, higher in modal and normative mafic and accessory minerals (fig. 7)—to conclude that the two granodiorites are not part of the same intrusion. The presence of hornblende in the Yarber Wash and Mineral Point masses suggests a possible correlation with the Government Canyon Granodiorite, as does the somewhat lower quartz content of the Mineral Point mass compared with that of the other masses

of Prescott Granodiorite. The amount of contamination of the Mineral Point mass, however, makes inadvisable any firm conclusion that it is consanguineous with either the Prescott or the Government Canyon Granodiorite or that more than one granodiorite is present.

The lead/alpha age of zircon in the Government Canyon Granodiorite is 930 million years and that of the Yarber Wash mass is 1,045 million years. These ages were determined by H. W. Jaffe of the U.S. Geological Survey in 1954. The age of the Government Canyon Granodiorite was reported as 910 and that of the Yarber Wash mass as 1,050 million years by Anderson and Creasey (1958, p. 39). The change in age is due to slight revision in the constants used in the calculations (Jaffe, written commun., 1957). The results indicate only that these rocks are Precambrian; they should not be considered as indicative of the relative ages. If the Yarber Wash mass is a facies of the Prescott Granodiorite and if both areas mapped as Government Canyon Granodiorite are the same age, then the Government Canyon Granodiorite is older than the Yarber Wash mass. Because alaskite and some masses of Prescott Granodiorite were intensely deformed, they appear to be older than Government Canyon Granodiorite and the Prescott mass of Prescott Granodiorite.

Alaskite, coarse-grained granite, and the Dells Granite are similar in modal, chemical, and normative composition, but megascopically alaskite is too different from the two granites to be considered correlative; the amount of deformation and metamorphism of coarse-grained granite compared with that of the Dells Granite appears to preclude a correlation of the two granites.

All or most of the intrusive rocks of the area may have been derived from the same parent magma. The gradual shift of points from the plagioclase corner of the field towards the center of the field in figure 7A conforms to experimental data on silicate melts. The curves of oxides plotted against silica in figure 7D are relatively smooth and likewise conform to curves that would be expected from differentiation of a magma. Both are in general agreement with relations established in the field. As the point representing the potassium oxide content of fine-grained granite does not fall on the curve, this granite may have had a different source.

New and additional age determinations using the potassium/argon and strontium/rubidium methods to be made on Government Canyon Granodiorite, the Yarber Wash and Prescott masses of Prescott Granodiorite, and the Dells Granite may resolve some of the uncertainties.

UNCONFORMITY AT THE BASE OF THE PALEOZOIC ROCKS

The older Precambrian rocks of north-central Arizona are separated from Paleozoic formations by a major angular unconformity. Paleozoic rocks were laid down on the eroded edges of the older Precambrian volcanic, sedimentary, and intrusive rocks. Where local hills or monadnocks stood above this surface, the basal Paleozoic formations were deposited around them. In most places these hills rise to heights of little more than 50 feet above the general level, but part of the area underlain by the Mazatzal Quartzite (southwest-central part, pl. 2) was so high that about 500 feet of lower Paleozoic beds (Cambrian and most of the Devonian) are absent (fig. 17).

PALEOZOIC SEDIMENTARY ROCKS

GENERAL FEATURES

Paleozoic rocks are largely limited to the area northeast of Chino-Lonesome Valley, where they are widely exposed but are concealed in many places by Cenozoic rocks. Their presence beneath these deposits in Chino-Lonesome Valley is uncertain.

The southernmost exposures of the Paleozoic rocks (northeast corner, pl. 1) consist of the Tapeats Sandstone of Cambrian age and the basal beds of the Martin Limestone of Devonian age. Successively younger formations appear to the north. They are the upper beds of the Martin Limestone, the Redwall Limestone of Mississippian age, the Supai Formation of Pennsylvanian and Permian age, and the Coconino Sandstone of Permian age. The youngest Permian formations, the Toroweap Formation and the Kaibab Limestone, crop out northeast of the area.

The present distribution of Paleozoic rocks is due to uplift of the area to the southwest, which resulted in gentle titling of the rocks to the northeast, in local modifications of the northeast structure by faults and sharp warps, in burial by upper Tertiary (?) rocks; and in erosion prior to and after accumulation of the upper Tertiary(?) rocks. Northeast of the basin this distribution is illustrated in part by the maps showing the structure contours of the base of the Redwall Limestone (pl. 5) and the map showing the present thickness of Paleozoic and Cenozoic rocks (fig. 31).

The Tapeats Sandstone can be divided into two units; and the Martin and Redwall Limestones, into four units each. These units have not been mapped, but their recognition is helpful in working out offsets along monoclinal structures and faults of small displacement. The three members of the Supai Formation, a red-bed deposit, have been mapped (pl. 2). The Paleozoic rocks are probably about 2,800 feet thick in the northeast

corner of the area. The thicknesses of the formations and their units in north-central Arizona are shown in table 11.

TAPEATS SANDSTONE

DISTRIBUTION

Outcrops of the Tapeats Sandstone are limited to the extreme northeast corner of the Prescott quadrangle and to the southern part of the Paulden quadrangle (fig. 16). Northeast of the outcrops, the formation probably lies beneath younger Paleozoic rocks; it was not deposited in much of the area that is underlain by the Mazatzal Quartzite (fig. 17).

The southernmost exposures of the Tapeats Sandstone are on the hill near 1,364,000 N., 392,500 E. (pl. 1), and near the eastern margin of the quadrangle between 1,357,900 N. and 1,361,100 E. An outcrop, too small to show on the geologic map, occurs beneath basalt near 1,358,000 N., 398,500 E.

The most continuous exposures of the Tapeats (see pl. 2) are along the Verde River east-southeastward from Hubbel Ranch (1,417,500 N., 374,500 E.), in the headwaters of King Canyon (1,390,000 N., 383,000 E.), and north and northwest of St. Mathews Mountain (1,370,000 N., 399,000 E.). The sandstone forms isolated exposures along the Verde River west of Hubbel Ranch, near the mouth of Granite Creek (1,403,000 N., 346,000 E.), in upper and lower Bull Basin Canyon (south of Hubbel Ranch), in the headwaters of Gold Basin Canyon (1,398,000 N., 382,000 E.), and 3–3½ miles south-southwest of Paulden (near 1,398,000 N., 330,000 E.). The last occurrence is the only outcrop within the area that is not northeast of Chino-Lonesome Valley. About 100 feet of mudstone, siltstone, and sandstone of the Tapeats was penetrated about 1,150 below the surface in a wildcat oil well (No. 1, sec. 20, T. 18 N., R. 2 W.; pl. 1, secs. B–B', C–C') about 3½ miles northwest of Paulden.

TABLE 11.—*Thickness, in feet, of Paleozoic formations in north-central Arizona*

[Inc., incomplete; Abs., absent because of nondeposition or erosion; U, undifferentiated or unrecognizable. Figures given in parentheses are approximate range of thickness in the quadrangles involved; they are listed because the thickness of the formation or unit at the indicated section is not given. See figs. 16 and 17 for approximate locations. The sections in Paulden quadrangle were measured by Krieger]

Section	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Coconino Sandstone									(500–650)	(500–650)				1,000
Supai Formation:														
Uper			1,005						(650–750)	758				1,140
Middle									(250–300)	329				390
Lower			¹150						(580–625)	²578				²670
Total Supai Formation			1,155					Inc.	1,550	1,665				2,200
Redwall Limestone:														
Unit 4			51					35	(40)	(40)		} 151 (Inc.)	140	{-------
Unit 3			100					81	(100)	(100)				{
Unit 2			103					80	(55–80)	(55–80)		74	54	{
Unit 1			21					23	(25–55)	(25–55)		30	92	
Total Redwall Limestone	Inc.	Inc.	275	Inc.	Inc.	Inc.	Inc.	219	252	241	Inc.	256 (Inc.)	286	30
Martin Limestone:														
Unit D	U	U	U	U	} ³315	{ <50	} ³325	{ 218	(260–270)	(260–270)	255	260	250	-------
Unit C	U	U	U	U		0		65	(65–80)	(65–80)	75	63	78	
Unit B	U	U	U	U	55	0	90	97	(80–110)	(80–110)	88	89	79	
Unit A	U	U	U	U	20	0	20	15	(20–50)	(20–50)	21	53	34	
Total Martin limestone	332	324	385	381	350	<50	435	395	444	480	439	465	441	⁴390
Cambrian formations:														
Muav Limestone	297	50	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.
Bright Angel Shale	112	135	Abs.	Abs.	⁵⁶12	Abs.	⁶18	⁶21	⁶(0–20)	⁶(0–20)	⁶20	⁶(0–20)	⁶(0–20)	U
Tapeats Sandstone	317	223	⁷279	⁷114	⁷142	Abs.	53 (Inc.)	125	(0–40)	(0–40)	29 (Inc.)	(0–40)	(0–40)	U
Total Cambrian	726	408	279	114	154	Abs.	71 (Inc.)	146	50	50	49 (Inc.)	55	50	⁴40

¹ Part of all of the lower unit is correlated with the Callville Limestone of Pennsylvanian age.
² Part or all of the lower unit is correlated with the Naco Formation of Pennsylvanian age.
³ Contact between the C and D units is gradational.

⁴ The formation locally cuts out against hills composed of Precambrian rocks, as in section 6.
⁵ Pebble to boulder conglomerate.
⁶ May be equivalent to the Bright Angel Shale.
⁷ Contains pebbles of limestone and sandstone.

1. Fort Rock, about 25 miles northwest of section 2. McNair (1951, p. 510–511, 517).
2. Juniper Mountains (Walnut Creek), Camp Wood quadrangle. McNair (1951 p. 507, 511, 515).
3. Black Mesa. Supai Formation: Hughes (1949; 1952; 1950, The stratigraphy of the Supai formation, Chino Valley area, Yavapai County, Arizona: Arizona Univ. M. S. thesis); northeast corner of Turkey Canyon quadrangle. Redwall Limestone: Gutschick (1943); northeast corner of Simmons quadrangle. Martin and Tapeats Formations: Hughes (1950 [see above]); southeast quarter of Picacho Butte quadrangle.
4. Simmons, southeastern part of Simmons quadrangle. McNair (1951, p. 507, 515, 517–518).
5. Verde River–Granite Creek, Paulden quadrangle, between 1,407,700 N., 351,500 E., and 1,403,000 N., 347,000 E.
6. Granite Creek, Paulden quadrangle, near 1,385,000 N., 356,500 E.
7. Verde River, south of Bald Hill, Paulden quadrangle, between 1,416,100 N., 368,200 E., and 1,414,700 N., 368,000 E.

8. Verde River, south of the mouth of Hell Canyon, Paulden quadrangle, near 1,415,700 N., 368,200 E. The Redwall Limestone was measured about 1 mile to the north; the Tapeats Sandstone, about halfway between sections 7 and 8.
9. Verde River–Mormon Pocket–Henderson Flat, Clarkdale quadrangle. Lehner (1958).
10. Verde River–Packard Ranch–Sycamore Canyon, Clarkdale quadrangle. Supai Formation: McKee (oral commun., 1953). Redwall, Martin, and Tapeats Formations: Lehner (1958).
11. Upper King Canyon, Paulden quadrangle, near 1,392,500 N., 385,000 E.
12. Little Coyote Canyon, northwestern part of Mingus Mountain quadrangle. Anderson and Creasey (1958, p. 49, 51; unpub. data).
13. Haynes Gulch, south-central part of Clarkdale quadrangle. Anderson and Creasey (1958, p. 49, 51; unpub. data).
14. Pine area, 30–45 miles southeast of Jerome. Coconino Sandstone: McKee (1933, p. 82). Supai, Redwall, Martin, and Tapeats Formations: Huddle and Dobrovolny (1945).

THICKNESS AND STRATIGRAPHIC RELATIONS

The Tapeats Sandstone ranges from zero to about 150 feet in thickness. The thickest sections are in the central part of the Paulden quadrangle. To the east (Clarkdale and Mingus Mountain quadrangles), the Tapeats has a maximum thickness of about 100 feet and in a few places is more than 60 feet thick. The thickness of the formation and of its two units in north-central Arizona is given in table 11 (see also figs. 16, 17). In the Paulden-Jerome area—as used in the discussion of the Paleozoic rocks, the Paulden-Jerome area refers to the Clarkdale, Paulden, Prescott, and Mingus Mountain quadrangles—the lower unit generally makes up about two-thirds of the total thickness, except where it is cut out against topographic highs on the Precambrian surface. Along the Verde River (pl. 2) the lower unit makes up more than four-fifths of the total thickness.

The Tapeats Sandstone rests unconformably on Precambrian rocks. Where the underlying rocks are composed of older Precambrian intrusive or volcanic rocks, the surface on which the sandstone was deposited is one of low relief but has rounded hills protruding into or through the sandstone for little more than 100 feet. Where the underlying rocks are composed of the resistant Mazatzal Quartzite, sharp ridges and hills as much as 500 feet high protrude through the sandstone and into or nearly through the Martin Limestone (fig. 17).

The Tapeats Sandstone is overlain with apparent conformity by the Martin Limestone. The contact between the two formations has been arbitrarily placed at the base of the first massive limestone bed that overlies the limy siltstone and marl of the upper part of the normally shaly upper unit. Near the junction of Granite Creek and the Verde River, the lower unit, which is sandstone, grades up into and interfingers with a pebble to boulder conglomerate (fig. 18) that is equivalent to the shale unit to the east. The conglomerate has a maximum thickness of about 12 feet. A thin bed of reworked(?) sandstone (well exposed near 1,404,700 N., 344,800 E.) locally overlies the conglomerate. This sandstone is probably basal Devonian.

LITHOLOGY

Two lithologic units comprise the Tapeats Sandstone in the Paulden-Jerome area: a lower cliff-forming unit of sandstone and an upper slope-forming unit of shale and mudstone and, locally, of conglomerate.

The lower unit consists of medium- to coarse-grained sandstone, lenses of granule to pebble conglomerate, and a little siltstone, which forms shaly partings. Most of the pebbles are less than one-half inch long, but some, chiefly near the base, are as much as 2 inches long. Individual beds range from 1 inch to 15 feet. Small-scale cross-laminations are well formed in many beds, and cut-and-fill channels are common, especially in poorly sorted beds. The crossbedding is typical of the Tapeats of the Grand Canyon area. As described by McKee (1945, p. 125–126), it "consists of repeated layers or beds each containing series of short, uniformly sloping laminae truncated by flat surfaces above and below * * *. [The laminae] vary in length according to the thickness of the bed * * * but rarely * * * exceed 3 or 4 feet and in places are only a matter of inches." Current ripple marks are widespread. Grain size is rather uniform in some medium-grained beds, but in most beds it is variable. Alternation of well-sorted and poorly sorted material, abrupt changes in grain size, and changes in the amount of ferruginous cement give the unit a heterogeneous appearance. Grains and pebbles range from angular to rounded, but most of them are subrounded to subangular. Most of the bonding material is siliceous-ferruginous cement, but some is calcareous. Where ferruginous cement is abundant, the rock is friable. Much of the basal part of the unit, as well as most of the unit in thinner sections, is dusky red or grayish red to dark reddish brown because of the high iron content of the cement, but much of the upper part in thicker sections is buff (very pale orange to moderate orange pink or grayish orange pink). Spherical, lenticular, and irregular dusky-red areas are scattered throughout the buff sandstone, and similarly shaped buff areas occur in the red sandstone, a fact suggesting that the light color is due to leaching of iron oxide. According to McKee (1945, p. 129), however, basal beds of the Tapeats in the Grand Canyon area that were deposited in protected areas (depressions or "island embayments") are redder in color than those in unprotected areas. Quartz makes up all but a small proportion of the mineral grains and many of the pebbles in much of this unit. Minor constituents are chalcedonic quartz, feldspar, quartz porphyry, rocks of the Alder Group, granitic rocks, and, in the Granite Creek area, sandstone and limestone pebbles of unknown derivation. Pebbles of the Mazatzal Quartzite were not observed in this unit.

The upper, slope-forming unit of the Tapeats is poorly exposed and consists principally of mudstone and siltstone. Where observed it can be divided into two parts: the lower is a dusky-red to dark reddish-brown locally slightly fissile mudstone; the upper part is greenish shale that is intercalated with buff to greenish or reddish mudstone, siltstone, and marl. Some of the siltstone is highly micaceous. Marl and dolomitic limestone weather shades of red, are more abundant near the top, and in places are intercalated with sandstone. Except for the basal red mudstone in which beds

may be thicker, beds are less than 6 inches thick; shaly partings are common in the upper part of the unit. The conglomerate (fig. 18) that overlies the lower unit near the mouth of Granite Creek (within an area bounded by 1,400,000–1,410,000 N. and 340,000–350,000 E.) consists of subrounded to subangular pebbles to small boulders, composed of quartzite and conglomerate from the Mazatzal, in a sandy, calcareous matrix. Pebbles of Mazatzal Quartzite in a sandy matrix near the base of the shaly unit farther east (in King Canyon, near 1,936,500 N., 379,200 E.) and the stratigraphic position and slope-forming character of the conglomerate suggest that the conglomerate is a local facies of the upper unit. Sandstone that interfingers with the conglomerate lacks the typical crossbedding of the lower unit; this sandstone and conglomerate may represent a continental deposit formed during a temporary withdrawal of the sea.

AGE AND CORRELATION

Northwest of the area, the basal Paleozoic rocks are the Tapeats Sandstone, Bright Angel Shale, and Muav Limestone, all Cambrian in age (McKee, 1945, p. 11–36). Within the Paulden-Jerome area and for more than 100 miles to the southeast, the age and correlation of the basal Paleozoic sandstones are in doubt. Fearing (1926, p. 757–759) and McNair (1951) concluded that the basal sandstone at Jerome is Devonian in age and equivalent to the basal Devonian sandstone in the Pine area (fig. 1, inset) (Stoyanow, 1926, p. 311–313; 1936, p. 499–500; 1942, p. 1268–1269). Reber (1922), Ransome (1932), Stoyanow (1936, p. 462), and McKee (1951) interpreted it as probably equivalent to the Tapeats Sandstone in the Grand Canyon. The principal arguments in support of a Devonian age are the apparent conformity and lithologic gradation from the sandstone unit through the shale unit to the basal Martin and the thinning of the Cambrian formations and their overlap by the Martin as one goes from the Grand Canyon towards Jerome (figs. 16, 17; table 11). Evidence in favor of a Cambrian age are the stratigraphic position and lithologic similarities, especially the type of crossbedding. Although Anderson and Creasey (1958, p. 48–49) and Lehner (1958, p. 522, 523, 525) found little supporting evidence other than local sandstone beds in the upper part of the shale unit and a discontinuous sandstone bed at the base of the Martin, they favored a Cambrian age for most of the basal sandstone but referred to it as Tapeats(?). Additional evidence from the Paulden quadrangle supports a Cambrian age for most of the basal sandstone.[8]

Some basal Paleozoic sandstone and conglomerate beds in the Paulden quadrangle and where I have observed it to the southeast in the Pine area are of known Devonian age (Stoyanow, 1936, p. 497–498), but in these areas they are distinct from other basal Paleozoic sandstone whose Cambrian age has been questioned. In the following discussion these Cambrian sandstones will be referred to as Tapeats(?) to distinguish them from unquestioned Tapeats to the northwest. The basal Devonian sandstone and conglomerate interfinger with known Devonian limestone; they abut against and surround topographic highs of the Mazatzal Quartzite, in contrast to the sheetlike form of the known and the questionable Tapeats. They differ from known and questionable Tapeats by lacking typical crossbedding, by lacking the dusky-red color characteristic of basal Tapeats, and by being more flaggy and thin bedded. The Tapeats(?) Sandstone always underlies the lowest (A) unit of the Martin Limestone, and the sandstone unit is generally separated from the Martin by the shale unit. The shale unit resembles and may be equivalent to the Bright Angel Shale to the northwest.

McNair (1951, p. 516) considered the sandstone at Simmons to be the Cambrian Tapeats and that at Jerome to be basal Devonian—he stated that the clastic beds at Jerome "do not resemble the Tapeats excepting in their stratigraphic position." Sandstone in the many outcrops (fig. 16) between Simmons and Jerome, however, belong to the same formation; the buff sandstone near the mouth of Granite Creek is identical with that at Simmons, and dusky-red sandstone, similar to that at Jerome, underlies the buff sandstone at both the Simmons and Granite Creek localities. Furthermore, the Tapeats at Simmons and the Tapeats(?) at Granite Creek underlie identical beds of reworked(?) sandstone that McNair (1951, p. 516–518) considered to be basal Devonian at Simmons.

A Cambrian age for the sandstone at Simmons has not been proved, owing to the absence of fossils or of overlying Bright Angel Shale or Muav Limestone; however, the presence of worm-borings in the sandstone suggests a Cambrian age. According to E. D. McKee (written commun., 1957), this type of marking is extremely common in the known Tapeats. McKee stated that although any fossil as universal in character as a worm-boring cannot be restricted to any geologic age, this particular type is extremely common in the Cambrian of northern Arizona and has not been found in younger rocks in the region.

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[8] In the basal Paleozoic sandstone on Mingus Mountain (Jerome area), Curt Teichert found a bed crowded with U-shaped burrows of the Corophioides type. This evidence supports the Cambrian age of the rocks formerly called questionable Tapeats, as these burrows are abundant in the undoubted Tapeats of Juniper Mountains and are probably indicative of marine conditions. Teichert did not observe these burrows in the basal Devonian sandstone, which he considered fluviatile or at least nonmarine, in the Salt River Canyon area (Teichert, written commun., June 1961; Averitt, 1961, p. A33).

EXPLANATION

Fort Rock

Exposures of Cambrian formations
with locality name

(1)

Cambrian fossils reported

(2)

Includes Bright Angel Shale and
(or) Muav Limestone

(3)

Continuous outcrops from here to
Grand Canyon, increasing to over
1000 feet in thickness

(4)

Cambrian and basal Devonian
sandstones both present
*Locally no Cambrian and little
Devonian was deposited*

317 ft

Thickness of Tapeats Sandstone
*Dashed line encloses areas within
which thickness averages 50 or
150 feet*

(409 ft)

Thickness of overlying Cambrian
formations

See table 11 for sources of data.
Compiled from geologic maps of
the Paulden-Jerome area; recon-
naissance by the author from
near Seligman to Camp Verde;
the geologic map of Arizona
(Darton and others, 1924); and
the geologic map of Yavapai
County (Wilson and others, 1958)

FIGURE 16.—Approximate distribution and thickness of Cambrian formation in central Arizona.
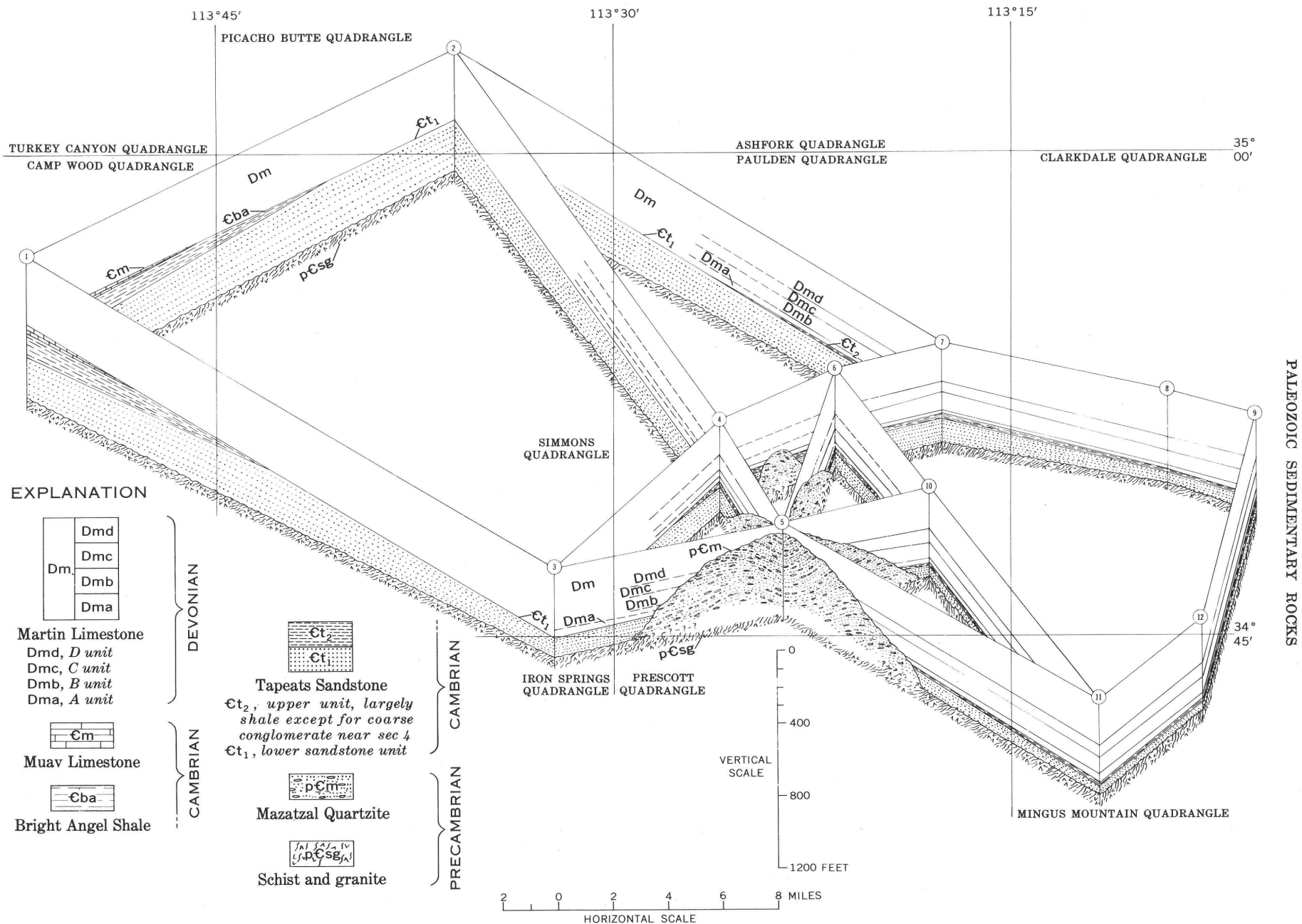
FIGURE 17.—Precambrian and lower Paleozoic formations in the Paulden quadrangle and adjacent areas: the topographic high formed by the Mazatzal Quartzite is shown. Sections 3 and 11 cannot be connected, as no Paleozoic rocks crop out along or south of this line except in the extreme northeast corner of the Prescott quadrangle. (See table 11 for location of sections, thicknesses of formations and units, and sources of data.)

Evidence of a break in deposition between the Tapeats(?) Sandstone and the Martin Limestone can be seen near the mouth of Granite Creek. The contact between the conglomeratic facies of the shale unit and the overlying A unit of the Martin is sharp and indicates an abrupt change in conditions of deposition. The surface on which the A unit—that is, the discontinuous bed of reworked(?) sandstone—was deposited locally bevels slightly the underlying conglomerate. The surface is relatively smooth and even, but small irregularities protrude a few inches to a foot above it (fig. 18). The overlying limestone abuts against and dips away from these protruding masses; the dips are probably due to a combination of compaction and initial dip.
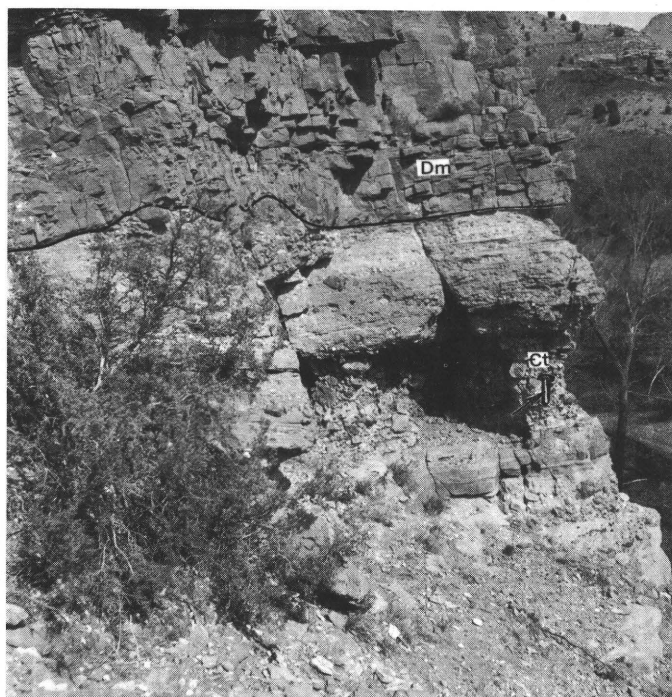
FIGURE 18.—Conglomerate at the top of the Tapeats Sandstone (€t), and the overlying Martin Limestone (Dm) (1,403,500 N., 345,000 E.). Note the abrupt change from conglomerate to limestone, the relatively flat surface cut on the conglomerate, the local irregularities where cobbles in the conglomerate protrude into the overlying limestone, and the compaction and initial dip of the limestone around the irregularities. See hammer for scale (arrow).

About four-tenths of a mile (near 1,402,800 N., 347,000 E.) east-southeast of the exposures of conglomerate shown in figure 18, the Tapeats(?) Sandstone rests on the Texas Gulch Formation of the Alder Group. The basal 20 feet of dusky-red sandstone grades upward into buff sandstone about 127 feet thick. Except in color and the presence of some calcareous cement, the buff sandstone differs little from the underlying sandstone. Pebbles of limestone and sandstone, in addition to the pebbles normally found in the sandstone, occur

near the base of the buff sandstone; however, no pebbles derived from the Mazatzal were observed in the section, although a topographic high of Mazatzal cuts out the sandstone less than 500 feet to the east. The upper 4 feet of sandstone at the Simmons section immediately below the reworked sandstone contains similar limestone and sandstone pebbles, as does the upper 50 feet of sandstone in the Black Mesa section.

The origin of these pebbles is an enigma. If the pebbles were derived from Cambrian formations (Tapeats and Muav to the northwest), then the sandstone that contains them must be Devonian, and probably all the sandstone in the area is also Devonian. However, a Devonian age is not necessary and is not considered likely, because the limestone pebbles do not resemble the Muav and because a thickness of sandstone, such as occurs at Black Mesa (279 ft) has not been reported elsewhere in the Devonian in northern Arizona. The limestone pebbles do not resemble thin beds of marble in the Texas Gulch Formation of the Jerome area—the only other known pre-Devonian carbonate rock nearby. The limestone and sandstone pebbles may have been derived from the younger Precambrian Grand Canyon Series or Apache Group. Limestone and sandstone form part of these younger Precambrian rocks, and, according to E. D. McKee (oral commun., 1957), a thick sequence of limestone has been reported in a drill hole underlying the Tapeats in the Grand Canyon. Because the area from the Grand Canyon to Paulden is covered by younger deposits, the southwestward extent of the Grand Canyon Series is unknown. Likewise, because of deep erosion of the Precambrian rocks in pre- and post-Paleozoic times south of here, the former extent of the younger Precambrian rocks is unknown.

Immediately east of the thick section of sandstone just described, the Texas Gulch Formation is in fault contact with the Mazatzal Quartzite, and the Mazatzal and adjacent schist form a topographic high. The sandstone is absent east of the fault, and the conglomerate that overlies 140 feet of sandstone west of the fault rests directly on the Mazatzal Quartzite east of the fault. The area near the fault is largely talus covered, so the relation of the Tapeats(?) to the Mazatzal is not obvious, but one small exposure proved that the sandstone is in depositional contact with a small sliver of the quartzite that lies just west of the main fault between the two Precambrian formations. The sandstone, therefore, is not older than the fault, as might be assumed from its absence east of the fault and from the absence of Mazatzal pebbles in the sandstone immediately west of the fault. According to E. D. McKee (oral commun., 1957) this deposition of Tapeats Sand-

stone against a quartzite high is typical of the situation in the Grand Canyon, where the Shinumo Quartzite of the Grand Canyon Series forms sharp peaks surrounded and buried by Tapeats Sandstone; the sandstone may contain a few angular fragments of quartzite close to the contact but contains none within a short distance of it. The outcrops of Mazatzal that supplied the rounded pebbles and cobbles in the overlying conglomerate may not have been exposed at the time the sandstone was deposited. The amount of rounding of the resistant pebbles and cobbles of quartzite and conglomerate from the Mazatzal indicates that this material was derived from some distance away and not from the nearby outcrop of the Mazatzal. The similarity between the relation of the Tapeats(?) Sandstone to the Mazatzal and of Tapeats to the Shinumo Quartzite in the Grand Canyon area contrasts with the relation of known Devonian sandstone to the Mazatzal Quartzite in the Paulden quadrangle; this contrast also suggests that the questionable sandstone in the Paulden-Jerome area is Cambrian.

In view of the foregoing evidence, the Cambrian age of the basal Paleozoic sandstone in the Paulden-Jerome area is no longer questioned.

MARTIN LIMESTONE

DISTRIBUTION

Outcrops of the Martin Limestone are found mostly northeast of the Tapeats Sandstone and are more extensive than those of the Tapeats. Northeast of Chino-Lonesome Valley, the formation is widely distributed across the northern part of the area (pl. 2) along a northwest-trending strip that has a maximum width of about 9 miles. The formation is exposed almost continuously (1) along the Verde River from Stewart Ranch Headquarters (1,406,000 N., 341,500 E.) nearly to the mouth of Hell Canyon, (2) from the southeast corner to the Verde River, principally east of King Canyon (1,397,000 N., 378,000 E.), and (3) along the southwest side of Black Mesa for 5 miles from the northwest corner of the study area. The Martin is buried by younger rocks northeast of a line running parallel to but at least a mile southwest of Hell Canyon. It is not exposed in or west of Chino Valley, except for two small outcrops south-southwest of Paulden (near 1,397,000 N., 330,000 E.). A wildcat oil well (No. 1, sec. 20, T. 18 N., R. 2 W.) northwest of Paulden cuts more than 400 feet of the Martin beneath about 700 feet of Cenozoic deposits. The southernmost exposures of the formation are in the same area as those of the Tapeats; a small outcrop, too small to show on plate 1, occurs near 1,359,000 N., 397,200 E.

THICKNESS AND STRATIGRAPHIC RELATIONS

The Martin Limestone thins to less than 50 feet over the topographic high of the Mazatzal Quartzite (fig. 17). Elsewhere in the Paulden-Jerome area the formation has a relatively uniform thickness of 390–479 feet, as it does for many miles to the northwest and southeast (table 11). Four units, from botton to top the A, B, C, and D units, [9] are recognizable in the southeast of the Paulden-Jerome area; they are less distinct northwest of the area. The units thin and are successively cut out around the topographic high of Mazatzal Quartzite. Away from the topographic high, the A unit is 15–21 feet thick, and the B unit is 55–97 feet thick. The C and D units are 65–75 feet and 218–255 feet thick, respectively, in the eastern part of the area, but to the west the position of the contact between the two units is uncertain.

Except where topographic highs on the Precambrian surface cut out the Tapeats, the Martin Limestone rests on the Tapeats, as described on page 52. The aMrtin is overlain disconformably by the Redwall Limestone of Mississippian age; the maximum relief on the Martin surface is about 35 feet and averages 10–15 feet.

LITHOLOGY

The Martin Limestone comprises dolomite, dolomitic limestone, limestone, disseminated argillaceous and arenaceous material, and minor amounts of limy siltstone and sandstone. The dark color, thinly and evenly bedded character, and steplike slopes to which the formation weathers serve to distinguish it from the overlying Redwall Limestone.

Some beds in the C and D units are fossiliferous, and fish plates have been reported from sandstone beds near the top of the B unit near Jerome. The fauna of the Martin at Jerome was described by Stoyanow (1936, p. 495–500).

A UNIT

The A unit is largely dolomitic limestone, but near Granite Creek (1,402,800 N., 347,000 E.), it contains interbedded sandy and conglomeratic layers and is underlain by a 2-foot bed of reworked(?) sandstone. Lehner (1958, p. 525) reported a similar, nonpersistent basal sandstone in the Clarkdale quadrangle. The well sorted medium to coarse grained sandstone is composed principally of well-rounded frosted grains of quartz. It is light gray or light olive gray to nearly white and has local limonitic spots.

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[9] The units were so designated by Lehner (1958, p. 525) but were called lower, lithographic, middle, and upper units by Anderson and Creasey (1958, p. 50).

The A unit is a very impure quite uniform clastic cliff-forming dolomite and dolomitic limestone that emits a strong fetid (petroliferouslike) odor when freshly broken. According to Curt Teichert (written commun., 1956), the rock contains no hydrocarbons, and the odor may be due to ammoniacal salts. The rock is light brownish gray to light olive gray and weathers to slightly darker shades. Coarser beds are, in general, darker than the finer grained beds. Impurities—largely clay and silt—impart a pink or yellow cast. Most beds are medium to coarse grained, but some are fine grained. Dolomite forms larger grains than does calcite. The weathered surface is pitted because of the weathering out of scattered coarse calcite grains, as much as 1 cm in diameter, whose origin is uncertain. The beds range from $\frac{1}{8}$ inch to 4 feet in thickness. The clastic character of the unit can be observed where etching has revealed crossbedding, channels, or fragments. Massive beds are coarse grained, possibly owing to recrystallization. The upper part of the A unit near Granite Creek (especially near 1,403,000 N., 347,000 E.) is coarser grained and lighter colored. In places it is a breccia abundantly and irregularly replaced by dark-brown chert—the chert may be related to late Tertiary(?) basalt flows. At this place the basal 4 feet of the unit is the typical dark dolomitic limestone, but it contains many sand grains and small pebbles derived from the Mazatzal Quartzite. East of the fault that separates the Texas Gulch Formation from the Mazatzal, the coarse-grained light-colored limestone rests directly on the conglomerate bed at the top of the Tapeats.

B UNIT

The B unit (fig. 2) contrasts sharply with the olive-gray A and C units. It is an aphanitic evenly and thinly bedded light-colored slope-forming dolomitic limestone containing shale partings.

The limestone beds are pinkish gray, locally darker gray or lavender, and weather light gray to white. Beds range from 3 inches to 3 feet and average about 8 inches in thickness. Few of them show internal stratification. The beds are separated by shaly partings—from thin films to 3 inches thick—which are exposed only in road cuts and cliffs. The shale is dark gray to grayish yellow green and pale yellowish green. The unit, which is more calcite than dolomitic, is very fine grained; it is virtually a lithographic limestone. The weathered surface is smooth, except where disseminated grains of sand project above the surface and where it has a wrinkled appearance because of solution along joints. Light-yellow and dark-gray chert, as nodules, lenses, and thin layers parallel to the bedding, is fairly abundant in some of the beds.

A persistent sandstone, locally called the red marker bed, lies within a few feet of the top of the unit. Even though in places it is represented by only thin sandy lenses in the limestone, this horizon marker was recognized wherever the upper part of the unit is exposed in the Paulden-Jerome area. It ranges from a few inches to about $6\frac{1}{2}$ feet in thickness. Locally it consists of several beds of sandstone, of scattered sand grains, or of lenses of sandstone interbedded in aphanitic limestone through an interval of more than 10 feet. In places the rock is more nearly an orthoquartzite. Ripple marks and crossbedding are locally conspicuous. The sandstone is generally various shades of light reddish brown to pale red; some is buff to light gray. At one place in the southeastern part of the Paulden quadrangle the sandstone contains fragments of aphanitic limestone as much as 8 inches in maximum size. Near the mouth of Granite Creek and in an exposure as far east as Bull Basin Canyon (1,401,500 N., 373,700 E.), small pebbles as much as $2\frac{1}{2}$ inches in diameter of Mazatzal Quartzite occur in the sandstone or in limestone immediately below the sandstone.

Much of the upper part of the B unit beneath the red marker bed in the Granite Creek area is a yellowish-brown chert that weathers very light gray to white. The origin of this chert is in doubt, but in the southeastern part of the quadrangle, the local association of similar chert beds in the unit which late Tertiary(?) basalt flows suggests that the chert is a replacement associated with volcanism. West of Hubbel Ranch (1,417,700 N., 374,500 E.) the upper part of the B unit, below the red marker bed, contains beds of a very light gray massive friable medium-grained sugary limestone or dolomite that weathers light yellowish or reddish. Some beds are as much as 8 feet thick and lack internal stratification, except for a few greenish sandy, shaly partings.

C UNIT

The C unit (fig. 2) is darker colored, coarser grained, and thicker bedded than the B unit; it forms weak cliffs. The typical rock of the unit is light to moderate olive-gray dolomitic limestone mottled by fine-grained light-pinkish-gray areas. The mottled areas, which are due to recrystallization, are irregular in size and shape but, in general, are several inches long. Beds range from less than 1 inch to 4 feet in thickness; few of them show internal stratification. Beds that resemble those of the A unit and have the same fetid odor occur in the C unit, especially near the base. A bed of light-weathering aphanitic limestone, similar to beds in the B unit, commonly lies 7–12 feet above the base of the C unit. In the southeastern part of the Paulden quadrangle, the contact between the C and D units is placed below the first bed of aphanitic white-weathering dolomitic lime-

stone (B-unit type) at the top of the typical beds of the C unit. West of Hubbel Ranch the contact between the C and D units occurs either about 35 or 65 feet above the base of the C unit—about 30 feet of mottled limestone (C-unit type) overlie one or more beds of aphanitic light-weathering limestone (B-unit type), which are about 35 feet above the base of the C unit.

D UNIT

The D unit is characterized by diverse lithology. It comprises alternating beds typical of the three lower units and some interbedded calcareous shaly siltstone, mudstone, and sandstone.

Much of the lower part of the D unit consists of interbedded rocks of A, B, and C lithologies. The bottom 50 feet or so of the unit in upper King Canyon contains beds, as much as 5 feet thick, of A and C lithologies and a few beds of B lithology. Above this part of the D unit, the beds are thinner (ranging from a few inches to 2 ft.) and contain more abundant aphanitic beds that weather light gray, bluish gray, lavender, and purple. The upper part of the unit contains some shaly mudstone, platy siltstone, and a few thin beds of sandstone. Some beds contain chert. In places, the top of the unit is a grayish-orange-pink medium-grained dolomitic limestone.

Where the uppermost beds of the unit overlap the Mazatzal Quartzite (near 1,382,500 N., 358,000 E.), numerous beds of sandstone and conglomerate derived from the Mazatzal interfinger with beds typical of the D unit. The beds dip gently to steeply away from the Mazatzal because of initial dip or compaction. In places only the sandstone and conglomerate are exposed—as on the east side of the largest mass of Mazatzal Quartzite and the two small outcrops near the south side of this mass (northeast of 1,380,000 N., 362,500 E. and at 1,382,300 N., 357,200 E. and 1,384,000 N., 353,700 E.)—but these beds can be distinguished from the Tapeats(?) by their thin-bedded, flaggy character and darker, but not red, color.

Several distinctive beds can be used as key or marker horizons, at least for short distances. One is a massive bed, generally about 2 feet thick, which is olive gray mottled with conspicuous yellow to orange colorations on weathered surfaces.

AGE AND CORRELATION

The Devonian limestone at Jerome was originally named the Jerome Formation by Stoyanow (1930) and later described by him in detail (1936, p. 495–500). Stoyanow (1936, p. 503) considered the Temple Butte Limestone (named by Walcott, 1890, p. 50) of the Grand Canyon as correlative with his Jerome Formation. In the southeastern part of the state, the Devonian lime-

stone was named the Martin Limestone by Ransome (1904, p. 33). According to Stoyanow the Devonian rocks thin towards and are largely absent from the area between Pine (fig. 1, inset) and Theodore Roosevelt Lake (60 miles southeast of Pine). Because of certain differences in lithology and in sequence, Stoyanow (1936, p. 495) postulated a land mass—Mazatzal Land— to separate the Devonian seas northwest of Mazatzal Land from those southeast of it. He considered the upper part of his Jerome Formation to be equivalent in age to the Martin Limestone.

Huddle and Dobrovolny (1945) found that in spite of local thinning the Martin Limestone could be traced from Globe into the Pine area, even though it is locally only 30 feet thick in the areas Stoyanow called Mazatzal Land. They pointed out that the lithologic similarities and the indication of original continuity of the Devonian rocks are sufficient to justify the extension of the name Martin Limestone into the Pine area. They believed that the Martin can be traced into the Temple Butte Limestone of the Grand Canyon region.

Because the Martin Limestone in the Pine area, as described by Huddle and Dobrovolny, is without doubt the same as the Devonian rocks in the Jerome area, Anderson and Creasey (1958, p. 51) applied the name Martin to these rocks at Jerome.

McNair (1951, p. 516) correlated the Devonian rocks of Jerome with those at Hurricane Cliffs in the western part of the Grand Canyon and called them all Martin Limestone. Huddle and Dobrovolny (1945; 1952, p. 73) subdivided the Martin Limestone in the Pine area into three members. Their lower member apparently includes the A and B units and a basal sandstone. Their upper members differ from the C and D units in containing greater amounts of sandstone and shale. Where I have observed the formation in the Pine area, the four units can be recognized in sections where the formation is not adjacent to or partly cut out by topographic highs of the Mazatzal Quartzite. According to Curt Teichert (oral commun., 1956), the four units can be recognized as far as Theodore Roosevelt Lake, although they become less distinct southeast of Pine. Northwest of the Paulden quadrangle, the A unit was recognized during reconnaissance, but the other units were not recognized much beyond the western boundary of the quadrangle. At Fort Rock and farther northwest, the formation consists entirely of cyclothems, each of which comprises one or more of six broadly defined lithologic types and phases, according to W. H. Wood.[10]

Huddle and Dobrovolny (1952, p. 67 and 86) placed the Martin Limestone of central Arizona in the Upper Devonian, except for the lower part, which may be

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[10] Wood, W. H., 1956, The Cambrian and Devonian carbonate rocks at Yampai Cliffs, Mohave County, Arizona: Arizona Univ. Ph. D. thesis.

equivalent to the lower part of the Devils Gate Limestone (Middle and Upper Devonian) of Merriam (1940, p. 16–17) in central Nevada. The Martin in the Prescott and Paulden area, therefore, is assigned a Middle(?) and Late Devonian age.

REDWALL LIMESTONE

DISTRIBUTION

The distribution of the Redwall Limestone is about the same as that of the Martin Limestone, except that its outcrops extend farther to the northeast. Its most extensive exposures in the Paulden quadrangle are in the northwestern part, the east-central part, and along the Verde River in the central part. Its most northeasterly exposures are along Hell Canyon and along the Verde River east of its junction with Hell Canyon.

THICKNESS AND STRATIGRAPHIC RELATIONS

The Redwall Limestone is about 220 feet thick where measured in the Paulden quadrangle and somewhat thicker in the Clarkdale and Mingus Mountain quadrangles (table 11). To the northwest towards the Grand Canyon, it thickens to 500 feet (McNair, 1951, p. 515, 519). To the southeast it thins locally to about 30 feet in the Pine area (Huddle and Dobrovolny, 1945).

The Redwall Limestone lies unconformably between the Martin Limestone of Devonian age and the Supai Formation of Pennsylvanian and Permian age. The relief on the Martin surface is low and gently undulatory; the Martin and Redwall therefore appear conformable. Depressions on the Martin surface are filled with material derived from the Martin and not readily separable from the Martin. For mapping purposes, the base of a massive light bluish-gray oolitic limestone that overlies the Martin or the reworked Martin was used as the contact between the Martin and Redwall. In many places the relief on the Redwall surface is more than 50 feet in a horizontal distance of little more than 100 feet.

LITHOLOGY

The Redwall Limestone is a cliff-forming massive, thick- to thin-bedded, white to light-gray coarsely crystalline to aphanitic limestone. Solution channels and caverns, in places collapsed or filled, are common. The filling consists of fragments of limestone or chert, or both, cemented with a bright red claylike sediment or with silica. In several places large blocks of the Supai Formation rest on the lower part of the Redwall or even on the upper part of the Martin. Some of these blocks may have been let down along faults, but some probably were let down as a result of solution and collapse within the Redwall. Much of the limestone is fossiliferous, but local zones are barren.

In the Jerome area Wooddell (Stoyanow, 1936, p. 512–513) divided the Redwall Limestone into six members. Gutschick (1943; see also Easton and Gutschick, 1953), who studied the Redwall from the Pine area northwestward to beyond Seligman (fig. 1, inset), subdivided it into four members designated, from oldest to youngest, members I, II, III, and IV. His members II and III are about the same as Wooddell's members 3 and 4. Gutschick's four members have been recognized in the Paulden and Clarkdale (Lehner, 1958, p. 530–531) quadrangles and are called units 1, 2, 3, and 4. In the Jerome area Anderson and Creasey (1958, p. 52) did not distinguish between units 3 and 4.

UNIT 1

Unit 1 consists of two parts: reworked Martin Limestone and oolitic limestone. The lower part, 0–40 feet thick according to Gutschick (1943), consists of thin-bedded clastic dolomitic limestone, arenaceous limestone, and calcareous sandstone that resembles the Martin. The beds are finely crystalline and light to very light brownish gray and olive gray, locally tinged with pink or lavender because of impurities.

Much of the upper part of the unit is a conspicuous, massive aphanitic very light bluish-gray oolitic limestone. In most places in the Paulden quadrangle it forms a slope or bench between the weak cliff-forming lower part of unit 1 (or the upper part of the Martin Limestone) and the cliff-forming unit 2; it is 23 feet thick where measured. Locally the bed grades laterally into crystalline limestone. A bed of finely crystalline darker limestone or dolomitic limestone that resembles the Martin lies 2–5 feet above the base of the oolitic limestone in many places. The top of the unit is a coarsely crystalline fossiliferous limestone, generally only a few feet thick. Fossils include cup corals, brachiopods, and gastropods.

UNIT 2

Unit 2 is 80 feet thick where measured and is a fine- to medium-grained porous limestone containing abundant chert nodules, lenses, and layers. The limestone ranges from nearly white or very light gray to yellowish gray. The chert is white, grayish yellow, and locally dark gray; it weathers reddish brown. Beds are 2–5 feet thick. Fossils are scarce and consist of corals, crinoids, and brachiopods. Solution and collapse have produced widespread breccias, especially in the southeastern part of the area. The breccia consists of fragments of chert and a few of limestone that are cemented by silica or by a red claylike sediment. Some of these breccias resemble fault breccias, except in their blanketlike distribution.

Unit 3 is 81 feet thick where measured and is a thick-bedded coarsely crystalline massive fossiliferous pure limestone of uniform character. It is yellowish gray to very light gray and weathers yellowish gray; the weathered surface is rough owing to the unit's coarse grain size and to the abundance of crinoid discs. Corals are relatively abundant; other fossils include bryozoa, blastoids, gastropods, trilobites, and fish (Gutschick, 1943).

A solution breccia and overlying light-gray limestone compose unit 4, which forms weak cliffs. The solution breccia consists of irregular cobble- to boulder-sized limestone fragments surrounded by red silty material. Most of the limestone resembles that of the upper part of unit 1, except that much of it is micro-oolitic to pellety. In the northwestern part of the area, the limestone is partly crystalline in the lower part and partly cherty in the middle part. Local fossil zones contain corals, gastropods, cephalopods, pelecypods, fish teeth, formanifera, and ostracodes (Gutschick, 1943, written commun. to Lehner, 1955; Easton and Gutschick, 1953). Gutschick interpreted the solution breccia to be a residual deposit representing an unconformity. I am not sure of its significance. Lehner did not observe the breccia or the crystalline and cherty beds and placed the contact between units 3 and 4 at the base of the oolitic limestone. The oolitic limestone is better exposed in the Paulden quadrangle than are the underlying beds of the unit. Where measured, the breccia is 15 feet thick, and the oolitic limestone is 20 feet thick.

AGE AND CORRELATION

Mississipian rocks in the Jerome area were called Redwall by Ransome (1916, p. 162), Lindgren (1926, p. 9), Stoyanow (1936, p. 512–514), and Gutschick (1943). The name Redwall was first applied to Mississippian limestone in northern Arizona by Gilbert (1875, p. 162, 177–186), who included rocks older and younger than Mississippian. Later, Noble (1922, p. 54) restricted the name Redwall to rocks of Mississippian age. In southeastern Arizona, limestone of Mississippian age was called Escabrosa Limestone by Ransome (1904, p. 42), and this term has been widely used in that part of the state. According to Stoyanow (1936, p. 505), the Escabrosa and Redwall "are not exactly taxonomic equivalents * * * but, rather, overlap each other." He stated that the deposition of the Redwall began somewhat later than that of the Escabrosa. In central Arizona, Huddle and Dobrovolny (1952, p. 86) found that the two formations are prob-

ably a continuous, mappable unit, which they called the Redwall Limestone.

Fossils collected by Ransome (1916, p. 162) indicate an early Burlington age (lower Osage series), and those collected by Wooddell (Stoyanow, 1936, p. 514) indicate a late Kinderhook to Keokuk age (largely late Kinderhook and Burlington). Gutshick (written commun. to Lehner, 1955) placed unit 1 in the Kinderhook and the other members in the Osage. He correlated unit 2 with the top of the Alamogordo and base of the Nunn Members of the Lake Valley Formation of Laudon and Bowsher (1941, 1949) of New Mexico. He correlated unit 3 with the Burlington Limestone of the Mississippi Valley. He tentatively placed unit 4 in the uppermost Osage (Keokuk affinity) but stated that it may be Meramec, especially if the "conspicuous solution bouldery zone" between units 3 and 4 does represent a break in the sedimentary sequence. The Redwall Limestone in this area is considered to be Early Mississipian in age.

SUPAI FORMATION

DISTRIBUTION

The Supai Formation, principally a red-bed deposit, is confined to the northeastern half of the Paulden quadrangle. The southeasternmost exposure lies about 4.3 miles north of the southeast corner of the quadrangle. The most extensive exposures are in the northeastern part, north of Limestone Canyon in the northwestern part, and north and south of the Verde River in the central part. The formation comprises three members (pl. 2); the middle and upper members have been eroded from all but the northeastern corner of the area.

THICKNESS AND STRATIGRAPHIC RELATIONS

The thickness of the Supai Formation is not known, as faults cut out some of the upper member and a continuous section of the middle member is not exposed, although most of this member is probably exposed in Red Butte. In the northeast part, the formation is presumably about as thick as in the east part of the Clarkdale quadrangle, where it is 1,550–1,665 feet thick (Lehner, 1958, p. 533; E. D. McKee, oral commun., 1953). It probably thins to the northwest, as Hughes (1949, p. 33; 1952, p. 643) measured about 1,100 feet in Black Mesa about 20 miles northwest of the Paulden quadrangle. The formation thickens to the southeast (table 11).

The three members into which the Supai Formation can be subdivided have been recognized to the east and southeast. In the Clarkdale quadrangle (Lehner, 1958, p. 535–537), the lower member is 580–625 feet thick; the middle member, 250–300 feet; and the upper member, 650–750 feet. In Black Mesa, Hughes (1949, p.

33; 1952, p. 643) recognized only two members; the lower is about 150 feet thick, and the upper, about 1,000 feet. In the northwestern part of the Paulden quadrangle, the exposures include the lower part of his upper member and probably his lower member.

The Supai Formation unconformably overlies the Redwall Limestone, as described on page 60. The contact is generally marked by a basal limestone or a chert breccia or conglomerate in a red-purple to grayish-red mudstone and silty shale. In the northwestern part of the area, however, the contact between the Redwall and Supai, because of poor exposures, was arbitrarily considered to be at the base of a light-gray to lavender limestone that has been partly to completely replaced by chert. At least 25 feet of the formation probably underlies the cherty limestone. Along Limestone Canyon about 3 miles northwest of the quadrangle boundary (Ashfork quadrangle, NW¼ sec. 17, T. 19 N., R. 2 W.), the sequence between the top of the Redwall and the cherty limestone is (1) chert breccia, (2) olive-gray fetid limestone, (3) light-bluish-gray to lavender non-cherty limestone, and (4) a thin zone of red beds. The cherty limestone and underlying beds probably correspond to the lower unit of Hughes (1952, p. 643), which comprises interbedded limestone, red siltstone, and basal conglomerate.

The contact of the Supai Formation with the overlying Permian Coconino Sandstone is gradational and intertonguing. In the upper part of the Supai, torrential-type and some eolian-type cross-laminae occur in thick sandstone beds. These cross-laminae are beveled and covered by thinly laminated horizontally bedded siltstone and fine-grained sandstone. The Coconino Sandstone has large-scale eolian-type cross-bedding and lacks the horizontal silty layers. Because where examined at close range the crossbedding in the sandstone of the upper member of the Supai resembles that in the Coconino, it may be impossible to determine to which formation isolated outcrops belong. The contact can locally be determined by color, as most of the Coconino is buff and the Supai is reddish. Some Coconino, however, has the same color as the Supai, and vice versa. Hughes (1952, p. 642), like Huddle and Dobrovolny (1945), considered the contact to be "* * * at the base of the lowest massive sandstone with well-developed Coconino-type crossbedding." McKee (oral commun., 1953), on the other hand, arbitrarily placed the upper limits of the Supai at the top of the uppermost flat-bedded siltstone or sandstone. McKee's criterion was used to map the contact in the Paulden and Clarkdale quadrangles. In the Grand Canyon area the Hermit Shale separates the Coconino Sandstone from the Supai; there the contact between the Hermit Shale and the Supai Formation is an erosional unconformity (Noble, 1922, p. 63–64).

LITHOLOGY

The Supai Formation, largely a red-bed deposit, consists of sandstone, siltstone, shaly mudstone, and minor amounts of limestone and chert near the base. The limestones are marine in origin, as northwest of the area they contain a brachiopod-pelecypod fauna (Hughes, 1952, p. 639, 652–656). The detrital material is deltaic or flood-plain in origin, according to McKee (1940, p. 822). McNair (1951, p. 532) suggested a marine mud-flat environment.

LOWER MEMBER

The lower member comprises sandstone, siltstone, minor amounts of shaly mudstone, some limestone beds—especially in the lower part—and basal chert breccia or limestone conglomerate. It forms a steplike topography, except for a cliff of sandstone at the top.

The basal chert breccia is almost universally present. It consists of angular to subangular fragments of chert and some of limestone as much as several inches across. The chert is gray, black, and red; it occurs in a very dusky purple, dusky-red, or black shaly, silty, or sandy matrix, some of which is hematitic. Limestone conglomerate occurs locally at the base and is also interbedded with red beds higher in the section. It contains chert, limestone, and siltstone pebbles as much as 4 inches in diameter in a light-gray to brownish-gray limestone that weathers pale reddish brown. Chert in siltstone and sandstone occurs as nodules and more or less spherical concretionary masses. These masses reach dimensions of 3½ by 2 feet and are composed of alternating concentric bands of white chert and red silt. The limestone, which occurs in beds 1–6 feet thick, is mostly fine grained to aphanitic and olive gray, light gray, or light bluish, yellowish, or brownish gray.

In the northwestern part of the area, especially south and east of Rock Butte (1,453,000 N., 342,500 E.) and about 4½ miles east-northeast of Paulden (near 1,424,000 N., 356,500 E.), some light-gray and lavender limestone has been partially to completely replaced by chert. Some of the chert is banded white, lavender, purple, and red. The chert forms thin layers and irregular stringers parallel to the bedding. Veinlets of red and white chert cut the bedded chert.

Most of the member in the eastern part of the area and the beds that overlie the cherty limestone in the northwestern part consists of alternating siltstone, very fine grained sandstone, some mudstone, and some silty and cherty limestone. Sandstone is more abundant in the upper part. These rocks are pale to dark reddish brown and have a somewhat orange cast.

MIDDLE MEMBER

The middle member remains only in the northeastern part of the area (north of 1,435,000 N., and east of 392,000 E.). This member contrasts with the underlying and overlying members, especially in topography and color. It forms slopes having a few subdued rounded ledges and some rounded hills—such as Red Butte (1,436,500 N., 394,500 E.). The color is generally grayish red to reddish brown; the weathered surface has a purple cast that contrasts with the more orange red color of the other members.

The principal constituent is siltstone; minor constituents are conglomerate, sandstone, and a very little limestone. Beds range from less than 1 inch to about 3 feet in thickness. Some siltstone is calcareous or contains calcareous nodules and grades laterally into limestone. Conglomerates are composed of a pale-red to reddish-brown siltstone and pebbles as much as 5 inches long composed of pale-brown to pale-red siltstone and some light brownish-gray to medium-gray limestone. The beds are typical "intraformational conglomerates." The few sandstone beds are 5–10 feet thick, light brown to pale reddish brown, and fine grained. They form rounded ledges. Some are calcareous and prominently cross-laminated. The limestones are very light brownish gray, cross-laminated to structureless, aphanitic, and sandy or silty.

UPPER MEMBER

The upper member of the Supai Formation crops out in the extreme northeast corner of the area. It contrasts sharply with the middle member in topography, lithology, and color and consists of sandstone and a little siltstone that form cliffs, buttresses, and pinnacles. The sandstone is medium to coarse grained; some is finer grained. Current cross-lamination is conspicuous in the sandstone beds; the cross-laminae are generally larger than those in the middle member. Near the top some of the cross-laminae are eolian. A reddish-orange color characterizes this member, but some of it is light brown or moderate reddish brown. It weathers to slabs and plates or to a sandy soil. Some sandstone is calcareous. Bedding is massive; some sets of beds, according to Lehner (1958, p. 538), are 150 or more feet thick.

Siltstone beds are a few feet to 30 feet thick but average 6–8 feet. The siltstone is pale reddish brown and has irregular wavy laminae. Some is cross-laminated on a small scale. It weathers to smoothly rounded ledges that, together with its horizontal beds, contrast markedly with the large-scale crossbedding of the sandstone.

AGE AND CORRELATION

The name Supai Formation was applied by Darton (1910, p. 25–27) to red sandstone and shale occurring between the Redwall Limestone and overlying Coconino Sandstone in the Grand Canyon area. Noble (1922, p. 59) redefined the Supai by removing from the top about 300 feet of red shale and sandstone of Permian age, which he called the Hermit Shale, and by adding about 250 feet of red shale, purple and gray limestone, and calcareous sandstone to the bottom. These lower beds are Pennsylvanian in age and had previously been included in the Redwall Limestone. Noble (1922, p. 62) regarded the Supai as probably Pennsylvanian in age. Darton (1925, p. 72, 89) believed that most if not all of the red beds are Permian in age, except for the lower beds that Noble had included in the formation.

Much of the Supai Formation outside the Grand Canyon area includes beds of known or inferred Pennsylvanian age as well as those of Permian age. Wherever possible in recent years, these Pennsylvanian beds have been separated from the Supai or have had their probable Pennsylvanian age pointed out. In the Paulden-Jerome area, lack of fossils and of a distinctive lithology makes this separation impossible, although it is probable that the lowest beds are Pennsylvanian.

In northwestern Arizona the Supai Formation is underlain by and interfingers with the Callville Limestone, named by Longwell (1921, p. 46–47) for limestone lying between Mississippian rocks and Permian red beds in the Muddy Mountains of Nevada. Longwell placed the Callville in the Pennsylvanian but later stated (1949, p. 930) that the Callville contains some Permian strata. McNair (1951, p. 520) restricted the name Callville in northwestern Arizona to Pennsylvanian limestones and removed from the Callville the overlying dolomitic limestones of Permian age. The basal member of the Supai in Black Mesa northwest of the Paulden quadrangle (Hughes, 1952, p. 654–656) contains brachiopods, pelecypods, and trilobites; these fossils indicate marine conditions this far to the southeast. The fossils are not diagnostic as to age, but the beds containing them may be equivalent to the upper part of the Callville (Upper Pennsylvanian) or to lower part (Lower Pennsylvanian), depending on whether the seas were transgressive (McNair, 1951, p. 520), or regressive (Hughes, 1952, p. 656, fig. 10).

In southeastern Arizona the name Naco Limestone was applied by Ransome (1904, p. 44) to Pennsylvanian rocks. In central Cochise County the Naco has been assigned to a group and subdivided into several formations of Pennsylvanian and Permian age (Gilluly, Cooper, and Williams, 1954, p. 15–42). Beds of Naco Limestone interfinger with Supai red beds to the north

and northwest of the type locality. Huddle and Dobrovolny (1945) extended the name Naco to beds at Fossil Creek and at Fort Apache (40 and 140 miles, respectively, southeast of Jerome). In these two areas, R. L. Jackson[11] (1951) and Winters (1951) likewise applied the name Naco to beds of Pennsylvanian age that had been included in the Supai. E. D. McKee (oral commun., 1953) correlated the bottom 332 feet of the lower member of the Supai in Sycamore Canyon (Clarkdale quadrangle) with the Naco and placed the boundary between it and the overlying Supai Formation along an arbitrary plane.

Huddle and Dobrovolny (1945) stated that the Supai transgresses time lines and probably varies in age from Des Moines (Middle Pennsylvanian) through Leonard (Early Permian) and that the lower member in southeastern Arizona differs in age from place to place and probably ranges from Des Moines through Wolfcamp (Early Permian). Huddle and Dobrovolny assigned the middle member to the Wolfcamp(?) and Leonard and correlated it with the Abo Formation of New Mexico. It may represent the main part of the Supai Formation and the Hermit Shale of the Grand Canyon. They stated that the upper member is Leonard in age and is about equivalent in age to the Yeso Formation in New Mexico.

The Supai Formation of the Paulden quadrangle is assigned a Pennsylvanian and Early Permian age to conform to usage immediately to the east and northwest, although the basal part contains no diagnostic fossils and cannot be definitely correlated with either the Callville or the Naco Formations.

COCONINO SANDSTONE

DISTRIBUTION

The Coconino Sandstone is found only in the extreme northeastern corner of the Paulden quadrangle. These exposures are its southwesternmost limit in this area; the formation underlies much of the Colorado Plateau in northern Arizona. In the Paulden quadrangle about half the area underlain by the sandstone is covered by basalt of late Tertiary(?) age.

THICKNESS AND STRATIGRAPHIC RELATIONS

Less than 400 feet of Coconino Sandstone is exposed because of faulting and because of removal of the upper part of the formation prior to its burial by late Tertiary(?) basalt. In the Clarkdale quadrangle the formation is 500–650 feet thick (Lehner, 1958, p. 541). It thickens to the southeast (table 11) and thins and

pinches out to the north and northwest (McNair, 1951, p. 532–534; Noble, 1922, p. 67).

The Coconino Sandstone conformably overlies the Supai Formation and intertongues with it as described on page 62. Northeast of the quadrangle the sandstone is beveled by the Toroweap Formation along a sharp, remarkably smooth contact. McKee (1938, p. 15) concluded: "Extensive truncation of sloping Coconino laminae to a perfectly flat surface can be accounted for only by beveling of the sediments while still unconsolidated."

LITHOLOGY

The Coconino Sandstone is a homogeneous massive fine-grained sandstone having conspicuous large-scale crossbedding. Most of it is very pale orange to grayish orange or grayish orange pink. Quartz is the major constituent; clay and iron oxides and traces of feldspar and heavy minerals are very minor constituents. The quartz grains are rounded to subangular. Many of them are frosted and pitted; some are stained with iron oxide; a few are clear. Silica forms the cement. Some beds are nearly as resistant as quartzite; some are friable, but many of them are moderately firm. The crossbedding is eolian and individual laminae are as much as 50 feet long. The sandstone weathers to slabs and blocks; it splits readily along bedding planes. Ripple marks and tracks are common.

AGE AND CORRELATION

The Coconino Sandstone was named by Darton (1910, p. 21 and 27) for exposures in the Grand Canyon, where it is underlain by the Hermit Shale of late Early Permian age (White, 1929). To the southeast the Coconino is underlain by the upper member of the Supai Formation which is Leonard in age. As the Kaibab Limestone (as redefined by McKee, 1938, p. 12) is likewise Leonard in age, the underlying Toroweap and Coconino Formations are also considered to be Leonard (Early Permian) in age.

UNCONFORMITY AT THE BASE OF THE CENOZOIC ROCKS

A major unconformity and long period of erosion separate the Paleozoic rocks from the Cenozoic rocks in north-central Arizona. Although the thickness (about 300 feet) of the Triassic Moenkopi Formation in Sycamore Canyon (Price,[12] 1949), about 17 miles east-northeast of the Paulden quadrangle, indicates that the formation extended farther south and west, no other formations are known to have been deposited in this part of Arizona until late Tertiary; the oldest known

[11] Also see Jackson, R. L., 1951, The Stratigraphy of the Supai formation along the Mogollon Rim, Central Arizona: Arizona Univ. M.S. thesis.

[12] See also Price, W. E., Jr., 1948, Rim rocks of Sycamore Canyon, Arizona: Arizona Univ. M.S. thesis, 92 p.

Cenozoic rocks reported from this area are early Pliocene (20 miles south of Prescott, J. F. Lance, oral commun., 1950). During this period more than 3,000 feet of Paleozoic rocks and an unknown amount of Precambrian rocks were eroded from the southern part of the Prescott-Paulden area, and lesser amounts were eroded from the northern part.

Recurrent uplift and erosion probably occurred in Late Triassic, Late Cretaceous to early Tertiary, and possibly other times. McKee (1937) cited the Shinarump Conglomerate of Late Triassic age and the gravel deposits of Pliocene(?) age beneath the basalt flows on the Colorado Plateau as evidence of extensive uplift in central Arizona prior to these times. Both contain pebbles and cobbles ranging from Precambrian to Permian in age that could only have come from the southwest.

The uplift tilted the Paleozoic rocks northward a few degrees and erosion beveled them; so, successively older Paleozoic rocks and finally Precambrian rocks are found beneath basalt of late Tertiary(?) age as one goes southward across the Prescott-Paulden area.

CENOZOIC ROCKS

Cenozoic rocks in the Prescott-Paulden area consist of andesite dikes of Tertiary(?) age, sedimentary and volcanic rocks of late Tertiary(?) age, and gravel and alluvium of Quaternary age.

ANDESITE DIKES

DISTRIBUTION

Andesite dikes cut the Precambrian rocks in the southern part of the area (pl. 1). They range from a few inches to more than 50 feet in width; some were traced for more than 2 miles. The dikes trend mostly northward or east-northeastward. The longest ones trend (1) northward in the Texas Gulch Formation, (2) east-northeastward across the largest mass of gabbro, alaskite, and alaskite porphyry, and (3) northward in the eastern mass of unnamed tuffaceous rocks of the Alder(?) Group.

LITHOLOGY

The dike rocks are distinctive in appearance. They are light gray to medium light gray or, rarely, very light or medium dark gray. Fairly fresh outcrops are characteristically light brownish gray; brown, yellow, or red shades are typical of weathered surfaces. Mafic minerals may weather out leaving well-defined molds or may alter to limonite. Plagioclase is chalky on weathered surface.

Phenocrysts are conspicuous and range from about 1 to 10 mm in length, averaging a little less than 5 mm. plagioclase phenocrysts are generally more abundant and larger than mafic phenocrysts. Most plagioclase is zoned; some has been resorbed. It ranges from about An_{50} to An_{20}. Locally phenocrysts of hornblende and biotite are more abundant than those of plagioclase; some dikes contain only hornblende phenocrysts. Tiny magnetite and apatite crystals are generally present.

The groundmass is aphanitic and consists of plagioclase microlites and tiny laths in a cryptocrystalline base. The texture is felty. Flow structure, where present, is brought out by the arrangement of microlites. Some dikes have been slightly altered—the groundmass to calcite, the plagioclase to sericite, and the mafic minerals to chlorite, calcite, and magnetite or to limonite.

Part of the north-trending dike in the eastern mass of the unnamed tuffaceous rocks of the Alder(?) Group is a pebble dike locally packed with fragments of Precambrian rocks ranging from less than 1 to more than 60 mm in length.

AGE

The andesite dikes are younger than the Precambrian and older than the upper Tertiary(?) rocks. They have been intruded along faults, shear zones, and joints in Precambrian rocks, but none were observed cutting the upper Tertiary(?) rocks. Other evidence in support of a pre-late Tertiary(?) age are (1) the pebbles of dike material in fanglomerate beneath basalt south of Glassford Hill (near 1,294,400 N., 358,200 E.) and south of Willow Creek (near 1,304,250 N., 335,400 N.), (2) the apparent cutting off of a dike by the andesite plug south of Glassford Hill, (3) the lithologic dissimilarity between dikes and andesite plugs and flows—most of the dikes contain large plagioclase and hornblende or biotite phenocrysts, whereas the plugs and flows lack plagioclase phenocrysts and have generally small mafic phenocrysts—and (4) the slight propylitic alteration of some dikes in contrast to the general lack of alteration of the flows and plugs.

The andesite dikes intrude faults which may have immediately preceded the accumulation of the upper Tertiary(?) rocks. On the other hand, uplift and faulting probably occurred intermittently between Late Triassic and late Tertiary(?) times, and the dikes may have been intruded at one of these times. A late Precambrian age is unlikely because of the relatively fresh, unrecrystallized character of the groundmass. On the other hand, they have not been reported cutting Paleozoic rocks to the north and east. The andesitic dikes are tentatively assigned a Tertiary(?) age.

UPPER TERTIARY(?) ROCKS

The rocks of late Tertiary(?) age in the Prescott-Paulden area are westward extensions of rocks mapped as the Hickey Formation in the Jerome area (Anderson

and Creasey, 1958, p. 56–61, 79–83) and the Hickey and Perkinsville Formations in the Clarkdale quadrangle (Lehner, 1958, p. 549–557, 563–566, 571–579). The terms Hickey and Perkinsville, however, are not used in this report because of uncertainties as to correlation. East of the Prescott-Paulden area the Hickey and Perkinsville Formations were distinguished largely by structural and physiographic evidence, the Hickey Formation being older and the Perkinsville Formation younger than the last major post-Paleozoic deformation. No such distinction was possible in the Prescott-Paulden area, where all the rocks appear to be younger than the major post-Paleozoic deformation.

The upper Tertiary (?) rocks filled Chino-Lonesome basin and covered most if not all of the area northeast of the basin. They consist of (1) fanglomerate and channel gravel, (2) sand, silt, and clay of fluviatile and lacustrine origin, (3) basaltic flows, dikes, and cinder cones, (4) andesitic flows, plugs, breccias, tuffs, and gravels, and (5) some rhyolitic tuff. Andesite locally separates older gravel and basalt from younger gravel and basalt. Elsewhere, relations of the various lithologic types, as well as the significance of the andesite and its relation to the Hickey and Perkinsville Formations, are uncertain. Plates 1 and 2 show only the lithology of the upper Tertiary(?) rocks. Some stratigraphic relations and possible correlations with rocks to the east are shown on plate 4.

DISTRIBUTION

Upper Tertiary(?) rocks at one time covered most of the Prescott-Paulden area and now occupy about three-fourths of it, although they are largely concealed throughout much of Chino-Lonesome Valley by thin Quaternary deposits.

BASALT

The most extensive exposures of basalt flows are in the northeastern part of the area, in the north-central part from Paulden southeastward to St. Mathews Mountain, and in the southwestern part. One cinder cone is in the northern part west of the Pinnacle (1,401,000 N., 351,000 E.); two cones are in the southern part—the cone that makes up the central part of Glassford Hill (fig. 14) and an older cone to the south-southwest. One basalt dike has been mapped in the north-central part (near the center of pl. 2); and four in the southwestern part (two a short distance southwest of Granite Dells and one cutting each of the cinder cones, pl. 1).

ANDESITE

Andesite is widely distributed in the northern part of the Prescott-Paulden area, especially in a belt that extends northwestward from St. Mathews Mountain, a volcanic cone, in the southeast corner (pl. 2). The isolated peaks (fig. 19) east of Granite Creek on the northeast side of Chino Valley are plugs or plug domes. Thick accumulations of andesitic gravels, tuffs, mud flows, breccias, massive flows, and plugs or domes extend northwest then west from these peaks. Small plugs and remnants of flows, mud flows, tuffs, and andesitic gravels are found north and south of the main exposures. The northernmost outcrops are on and east of Red Butte (1,436,500 N., 394,500 E.).

Five isolated masses of andesite are in the Prescott quadrangle—three in the southern part and two in the northern part. A small plug is found south of Glassford Hill, and a flow remnant (fig. 14) is found on the northeast side of the Granite Dells; the form of the other masses is unknown.

The various forms of andesite are not differentiated on the geologic maps, although the location of some mud flows and gravels are shown (pl. 2). The best exposures of the fragmental rocks are west (fig. 21), east, and south of the Pinnacle (1,400,000 N., 353,000 E.).

SEDIMENTARY ROCKS

The sedimentary rocks that filled Chino-Lonesome basin (pls. 1, 2) are best exposed in the southern part.

FIGURE 19.—Andesite plug or dome remnants, north side of Chino Valley. The view is to the north-northeast from east of Granite Creek (near 1,368,500 N., 370,000 E.). The dark rocks at the left are the southernmost exposures of Mazatzal Quartzite. The rocks at the extreme right are Precambrian and Paleozoic formations. Photograph by Museum of Northern Arizona.

Northeast of the basin they are well exposed from near Puro (1,391,000 N., 342,500 E.) northeastward to Hell Canyon but are generally less well exposed elsewhere. They are more abundant than the volcanic rocks at the surface, except locally in the southwestern part, in the northeastern corner, and in a northwest-trending belt immediately northeast of the basin. Available data from deep wells (table 12) indicate that sedimentary material is also more abundant than volcanic material, except in the Chino artesian area near the village of Chino Valley.

Unmapped remnants of thin but widespread rhyolitic tuffs occur mainly in the southwestern part of the basin. These tuffs are more widespread than would appear from outcrops, as they are easily masked by pediment gravel and alluvium. They are best exposed in small gullies, prospect pits, and roadcuts—notably the cut at the top of the hill on the new alinement of State Route 69 (pl. 1, 1,292,100 N., 352,100 E.).

Thin unmapped beds of fresh-water limestone are rather widely distributed in gravels northeast of the basin, especially (1) south and locally north of the Verde River eastward from its junction with Hell Canyon, (2) along Hell Canyon for about 4 miles southeast of Drake, where the limestone forms a very thin bed above gravel and below basalt, and (3) south of Granite Creek (1,386,200 N., 353,600 E.) and about 1.2 miles to the northeast (1,390,500 N., 358,000 E.). In the southwestern part of the basin a little fresh-water limestone is below the uppermost basalt flow on the ridge south of Willow Creek (near 1,305,500 N., 339,700 E.) and beneath basalt on the south side of Glassford Hill (near 1,300,800 N., 360,500 E.).

LITHOLOGY

BASALT

Flows and dikes.—Basalt flows in and northeast of the basin are similar; those in the southwestern part were studied and are described in more detail than the flows elsewhere. The basalt spread out as sheets, 10–20 feet but locally 50 feet or more thick. Most flows are nearly horizontal and maintain a fairly uniform thickness for considerable distances. Many individual flows stand out clearly, but in some places no evidence of individual flows or their attitude can be observed. Remnants of a thick sequence of many thin flows can be seen on Glassford Hill (pl. 1; fig. 14), on the north side of St. Mathews Mountain (southeast corner of pl. 2), and elsewhere; but in many places only a few thin flows accumulated between sedimentary rocks, or the overlying sequence of flows has been eroded. Few source areas were observed; most of the basalt probably came from dikes. Much of the basalt in the northern part flowed from the Colorado Plateau rim north of the area along drainage lines into the Hell Canyon–Verde River lowland. Some flowed into this lowland from Black Mesa, northwest of the area. Some of it may have flowed northward towards the Verde River.

The basalt is typical of plateau basalts. Most of it is medium dark to dark gray; some is lighter or darker gray or shades of red. The weathered surface is dark gray or brownish black to very light gray, brown, or olive.

Most of the flows have massive interiors and blocky, brecciated tops and bottoms that may be vesicular to scoriaceous or agglomeratic. Thicker, more massive flows generally form steep-walled cliffs along canyons. A few inches of basaltic tuff underlie many flows. Vesicles range from microscopic openings to almond-shaped ones more than 3 inches long; they are rounded, elongated, flattened, and irregular. Many vesicles are filled with calcite; others, with quartz, opal, chalcedony, cristobalite, zeolites, and (or) epidote. Cristobalite spherules are generally about 0.2 mm in diameter; a few are 1 mm. Flow structure is brought out in places by alinement of vesicles and by alternating layers of vesicular and nonvesicular basalt; it indicates only local flow direction but not the direction from which a flow came.

Splatter cone type of accumulations are associated with some flows. On the east end of the ridge south of Willow Creek (pl. 1, 1,306,500 N., 341,000 E.), vesicular basalt grades upward into brecciated and ropy lava that contains abundant lava fragments and bombs. The largest bomb seen was 3 feet long. The bombs may have been carried for some distance on the surface of a flow, possibly from the Glassford cinder cone, as there is no evidence of explosive activity at this place sufficient to eject bombs of this size.

Columnar, platy, and spheroidal joints occur in many places in the basalt. Prominent columnar joints are in basalt on the north side of the tilted flow remnant or plug(?) south of Prescott (pl. 1, 1,281,000 N., 333,700 E.), along Hell Canyon, and along the Verde River west of Stewart Ranch (pl. 2); crude columnar joints are widespread. Platy and spherical joints are especially abundant in the thicker finely vesicular or nonvesicular portions. Gently dipping platy joints in the basal part of some flows are replaced upward by columnar joints. Linear striations on some platy joints, especially along the gulch east of the east-trending ridge south of Willow Creek, resemble grooves on slickensides. Spheroids in this gulch are as much as 6 feet long.

The basalt contains phenocrysts of olivine, magnetite, augite, and plagioclase (listed in general order of decreasing abundance). Phenocrysts make up 5 to rarely

25 percent of the rock. Except for those of magnetite, which are generally smaller, the phenocrysts average about 1 mm in size, but some are as long as 7 mm. Along Hell Canyon, especially near King Spring (near Gila and Salt River Meridian), large augite and olivine phenocrysts and clusters of phenocrysts measure as much as 4 cm across. The large augites are black and have a vitreous luster. In thin section they are light brownish gray, whereas the augite of most of the basalt is colorless to light greenish gray. Some basalt northeast of the basin contains elongated black pyroxene phenocrysts that in hand specimen resemble hornblende. In other places, especially west of the Pinnacle and beneath the andesite 2,000 and 3,000 feet northeast of St. Mathews Mountain, the basalt contains phenocrysts of light-green pyroxene. These elongated and green pyroxene phenocrysts and a few phenocrysts of biotite make distinguishing basalt from basaltic andesite difficult in places. Much of the olivine is fresh, yellowish or greenish, transparent to irridescent; some is partly altered to iddingsite or less commonly to serpentine and magnetite. Much of it is euhedral, some is resorbed or skeletal, and some is zoned. Plagioclase phenocrysts are zoned; the centers are calcic labradorite, and the margins are sodic labradorite.

The groundmass, which is fine grained or microcrystalline, is felty; some is intergranular or trachytic. It is composed of plagioclase needles in a base of mafic material, which, where it can be resolved, consists of augite, olivine, magnetite, and a little apatite.

The volcanic rock penetrated in water wells is reported as basalt or "malapais" ("malpais"), a term used for mafic volcanic rocks. It may be basalt, or some or all of it may be andesite. Most of this volcanic rock is described as red or black and as "coarse" or "porous"—water in the Chino artesian basin comes from "porous malapais." The volcanic material is interbedded with clastic material, some of which is undoubtedly pyroclastic in origin; some pyroclastic material probably was reported as sand and gravel, and some as "malapais." The well-log data suggest that the upper surface of the basalt(?) is fairly even and slopes gently upward from the northeast side of the basin to southwest of the village of Chino Valley (fig. 20). This surface should merge near where basalt masses protrude above the Quaternary cover. The buried volcanic rocks, however, may not be part of the outcropping basalt, and the upper surface of the buried volcanic rocks may not have been formed completely by related rocks.

Basaltic dikes are lithologically similar to the flows. Platy joints and flattened vesicles occur parallel to their chilled margins. The interior of the branching dike or neck that cuts the Glassford cinder cone is coarser grained than most flows and dikes and has a diabastic texture.

Cinder cones and tuffs.—The cinder cone west of the Pinnacle (1,401,000 N., 351,000 E.) is well exposed in the west-flowing gulch that partially dissects the cone. Beds dip 15°–55° away from its probable center. The rock is moderate brown, moderately dark reddish brown, or very dusky red. It is composed principally of fragments of porphyritic, vesicular to scoriaceous basalt. The phenocrysts of greenish pyroxene and brownish altered olivine, as much as 2 mm in diameter, are enclosed in a finely vesicular, frothy dark-colored unresolved groundmass.

The cinder cone which forms the center of Glassford Hill (1,307,000 N., 362,000 E.) is exposed only around the craterlike depression at the top of the hill and along the northeast-trending gulch that has cut through the overlying basalt and partially dissected the cone (pl. 1, sec. *D–D'*; fig. 14). Beds dip away on all sides from the dike or neck that is exposed in the depression. No interbedded flows or sills of basalt were observed. This cone was probably built up to a height of about 700 feet and then completely buried by basalt flows, some of which issued from the T-shaped dike or neck near the top. The basalt is conformable to the underlying cinder cone where exposed. Elsewhere around the hill the eroded edges of flows are exposed, and where their attitude could be determined, they are nearly horizontal. On the south side (near 1,301,400 N., 359,500 E.) the flows dip gently northward. The thick sequence of nearly horizontal to gently northward-dipping flows on the south side of the hill were at one time continuous with the thick sequence on the ridge to the south. The northward dip of the flows and the surface on which they are deposited (fig. 24 *A* and *B*) appears to be a normal feature related to basin filling. This surface sloped gently away from the southern margin of the basin. If the cinder cone was nearly buried by basalt from the south, as appears likely, then the present shape of Glassford Hill is due largely to erosion. The material that makes up the cinder cone is pale to dark reddish brown, grayish red, or pale red. It is well indurated, generally well bedded, and composed of crystal, lithic, and vitric fragments derived from basalt. The basaltic particles are fine ash (shards and pumice), lapilli, bombs, and blocks; large blocks and bombs are common.

A tilted and eroded cinder cone (1,300,000 N., 357,000 E.) southwest of Glassford Hill is largely concealed by float from overlying basalt, but it is well exposed through a vertical distance of about 150 feet in a few gullies. Beds in the lower part dip steeply northward or are nearly vertical; beds in the upper part dip 25°–40°—about normal for cinder cones. The cinder cone
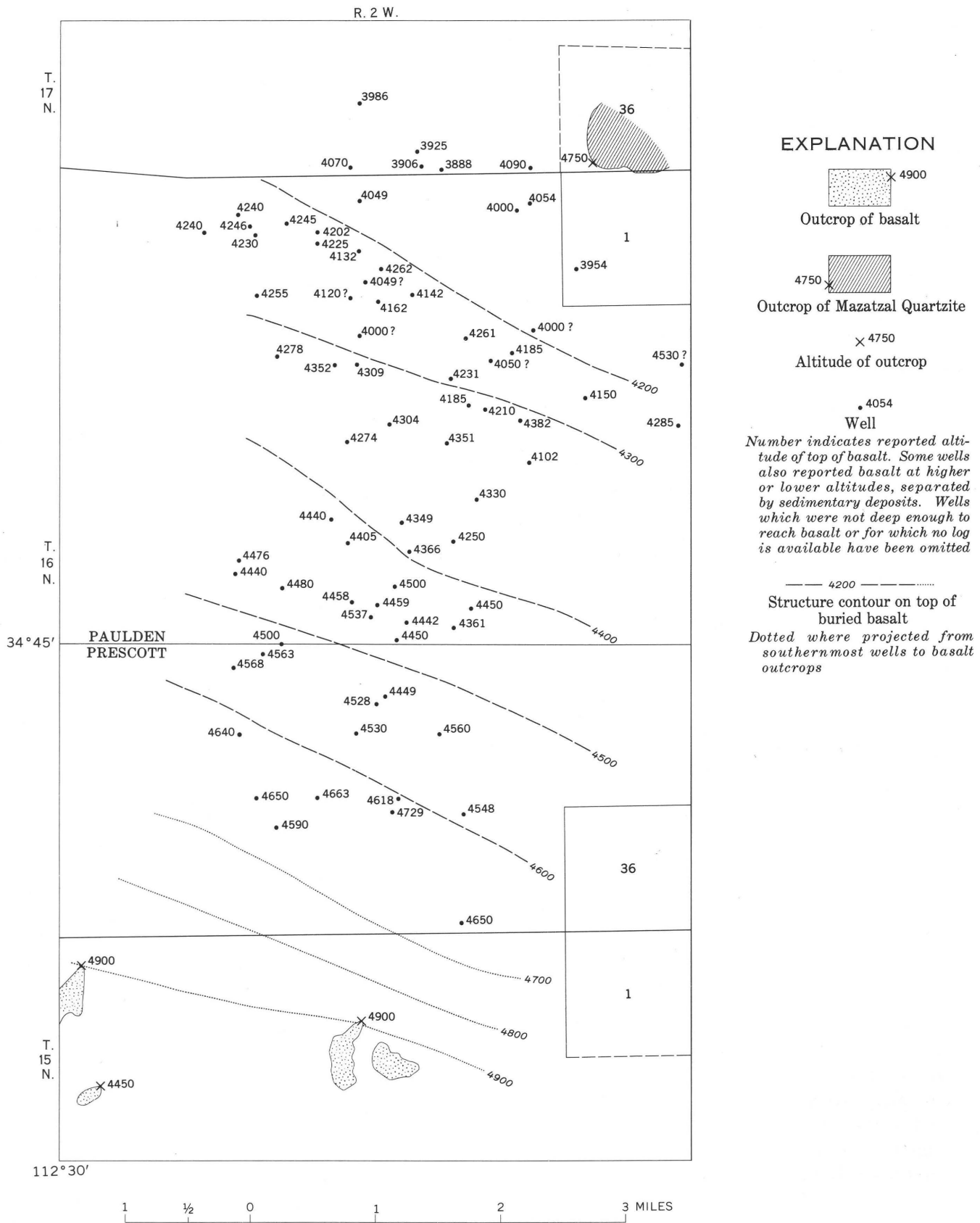
FIGURE 20.—Structure-contour map of the top of buried basalt in Chino artesian basin.

material ranges from well to poorly sorted and from friable to fairly well indurated. The lower part is soft, probably because of thermal alteration. In contrast to the Glassford cone, the material that makes up this cone ranges from yellowish gray through yellowish brown to pale or light brown and has a somewhat mottled appearance. It consists of well-bedded basaltic ash, lapilli, blocks, and small bombs. The fragments range from less than 1 to more than 60 mm long and are of two types: (1) yellowish or brownish lapilli and shards of basaltic pumice and (2) medium-gray to medium-dark-gray lapilli of scoriaceous, vesicular, and some nonvesicular basalt. Some beds are cemented by calcite; others contain tiny cristobalite spherules. The cinder cone is older than the surrounding basalt and gravel, a fact proved by its more altered character and by its steep dip in contrast to the nearly horizontal attitude of the basalt and gravel that bury it. The cone is not part of the Glassford cone, as it dips steeply north. Its relation to the nearby andesite plug is unknown.

Some basaltic tuffs are similar to the material that composes the cinder cones, but they are generally finer grained. These tuffs are gray, brown, reddish brown, or red, depending on the color of basaltic lapilli, scoria, and pumice or on the abundance of calcite cement.

ANDESITE

The topographic expression of the andesitic rocks varies from a subdued rubble-covered surface to sharp peaks, such as the Pinnacle and the peaks east of Granite Creek (fig. 19). The rubble-covered surface formed from fragmental andesite—gravel, mud flow, breccia, and agglomerate—and may make recognition of the form of an andesite mass difficult or impossible. The sharp peaks are composed of massive to flow-banded or platy-jointed andesite or of consolidated flow breccia or agglomerate. Some weathered surfaces are lumpy due to abundant inclusions or to autobrecciation.

Prominent columnar joints were observed only in the flow remnant northeast of the Granite Dells—one of the few recognizable flows in the area. Flow bands and platy joints, mostly steeply dipping and parallel, but in places fan shaped, are common in much of the nonfragmental andesite; flow bands are visible in some blocks in fragmental rock. Phenocrysts, plagioclase microlites, and some basic inclusions are parallel to the flow or platy structure but may have random orientation within the plane of flow.

Fragments in mud flows are angular to rounded; most of those in breccia and agglomerate are subangular. They range from little larger than groundmass particles to several feet or even tens of feet in size; many rounded ones in mud flows are about 2 feet in diameter.

Angular to subrounded basic inclusions are abundant in and near source or probable source areas. They are as much as 5 inches long and consist of (1) granular aggregates of light-green pyroxene (diopside?) containing or lacking reddish garnet, (2) aggregates of biotite containing minor plagioclase, (3) large crystals of dark-colored pyroxene, mostly altered to aggregates of coarse hornblende, (4) greenish-brown hornblende, (5) basaltic(?) hornblende containing or lacking magnetite, and (6) various mixtures of the foregoing minerals.

The andesite consists of hornblende andesite, biotite andesite, and basaltic andesite. Gradations are common between biotite and basaltic andesite; most contacts between basaltic and hornblende andesite are abrupt. Lithologic types have not been separated on the maps. Biotite andesite is most abundant, especially on St. Mathews Mountain and on some of the peaks east of Granite Creek. The most extensive biotite-andesite mud flow is east of the Pinnacle and underlies hornblende andesite mud flow near the base of the section. Hornblende andesite is confined principally to the area south of the Verde River for about 5 miles east of Route 89 (pl. 2) and to the andesite (pl. 1) northeast of the Granite Dells and west of Granite Creek (near 1,359,000 N.). As many as three hornblende andesite mud flows interfinger with andesitic gravel and tuffaceous deposits beneath andesite breccia and massive andesite in the southwest-trending gulch south of the Pinnacle. The principal areas of basaltic andesite are west of the headquarters of King Canyon and about 1½ miles east-southeast of the Pinnacle (pl. 2, near 1,384,000 N., 380,000 E., and 1,397,900 N., 360,300 E.), each area occupying about half a square mile.

The scarcity of mafic minerals (low color index) suggests that the hornblende andesite may be a dacite rather than an andesite. The index of refraction of obsidian and of some white pumice tuff associated with andesitic gravel is about 1.50; it indicates andesite or dacite (George, 1924, p. 368).

Hornblende andesite.—The hornblende andesite is a medium light gray to medium dark gray dense siliceous-looking rock containing phenocrysts of hornblende. Some glassy rocks are nearly black and have tiny hornblende needles; others have light grayish-brown zones, probably caused by slight devitrification, that gives a brecciated appearance.

Vesicles are generally lacking. The flow on the northeast side of the Granite Dells (pl. 1), however, contains miarolitic cavities with small transparent light olive-gray hornblende prisms about 1 mm long associated with orthoclase and spherules of cristobalite.

Hornblende is the only megascopic mineral, except

for minerals in basic inclusions and for scattered light-green pyroxene crystals. The hornblende crystals are 0.1–5 mm and rarely 1 cm long. Some crystals are clustered. Most hornblende is fresh, but some is partly to completely altered to aggregates of granular magnetite. Some is resorbed or skeletal. Most of it is pleochroic in shades of green to brown, but some is reddish brown to yellow.

Microscopic phenocrysts are of unzoned plagioclase 0.1 to 0.3 mm long and minor amounts of magnetite or ilmenite, apatite, sphene, pyroxene, and, in a few places, quartz, possibly as xenocrysts. Pyroxene is colorless or slightly green in plain polarized light. The groundmass is cryptocrystalline to glassy and contains microlites and small laths of plagioclase, mostly less than 0.01 mm long.

Biotite andesite.—Included in the discussion of biotite andesite—more properly biotite-pyroxene andesite—is much andesite that contains little or no biotite but that otherwise resembles biotite andesite. Biotite andesite is various shades of gray to nearly black. Much of it has a brownish or olive cast; some is reddish. Some biotite andesite mud flow is light brown to yellowish orange. A mottled appearance is due to alteration or devitrification of glassy groundmass or to differences in abundance of small vesicles. Vesicles are flattened and alined parallel to flow banding or to platy joints. Calcite, chalcedony, cristobalite, opal, quartz, tridymite, or zeolites (or combinations of these minerals) line or fill the cavities.

Phenocrysts are of pyroxene, which is generally the most abundant, biotite, magnetite, apatite, and, very rarely, plagioclase. Pyroxene phenocrysts are 0.1–1 mm or, rarely, 1 cm in maximum dimension. Larger crystals and glomeroporphyritic aggregates are probably inclusions or basic segregations, not phenocrysts. Most pyroxene is light green, glassy, and granular.

Few biotite crystals are larger than 1 mm in diameter by 0.1 mm thick, but some are twice that size. Most biotite is pleochroic, ranging from greenish brown to light yellow; some is reddish brown. Biotite is fresh, altered around the margins, or completely altered to aggregates of granular magnetite. Tiny needles and plates composed of granular magnetite are common in some andesite that contains no unaltered biotite. Some of these aggregates have the shape of hornblende. Magnetite phenocrysts are rarely as much as 0.5 mm in diameter.

The groundmass is aphanitic to glassy and composed of glass, devitrified glass, or an unresolved cryptocrystalline base containing plagioclase microlites or laths. The laths are mostly less than 0.1 by 0.11 mm in size; many are less than 0.02 mm long. Pyroxene and magnetite can be recognized in the groundmass in

a few thin sections. The texture is hyalophitic or felty and locally trachytic. Some groundmass has been partially replaced by calcite.

Basaltic andesite.—The mineralogy of the basaltic andesite is for the most part similar to that of the biotite andesite, but both light-green pyroxene and biotite may be absent from some of the rock. The basaltic andesite is darker than much of the biotite andesite. Olivine phenocrysts are common in rock that may or may not contain needlelike or platelike aggregates of granular magnetite, light-green pyroxene, or basic inclusions. Some olivine is partly to completely altered to iddingsite or to iddingsite having centers of antigorite(?). Some is unaltered or only slightly altered, even in rocks that contain the aggregates of granular magnetite. Altered olivine, biotite, hornblende(?), and, rarely, pyroxene are reddish or orange in these rocks. Some basaltic andesite has a speckled appearance caused by abundant phenocrysts as much as 1 cm across composed of light-green pyroxene and other mafic minerals.

Origin of the andesite.—The andesite was probably extruded and spread out from volcanic domes—endogenous and exogenous domes and plug domes (Williams, 1932). Evidence for this conclusion includes the steep to vertical flow planes and platy joints—some fan-shaped—the abundance of basic inclusions in andesite close to source and probable-source areas, and the abundance of fragmental material that in many places grades upward through andesitic gravel, tuff, and breccia to massive andesite (fig. 21). Basic inclusions probably represent early segregations from the magma and not xenoliths, as they are similar over widely scattered areas. Forceful intrusion of andesite is suggested in several places; an example is the plug east of the Pinnacle that is partly surrounded by steeply dipping Paleozoic rocks (pl. 2, sec. *F–F'*). The attitude of a steeply dipping zone of tuff and glassy welded or fused tuff that is conformable to the north side of a hill of Paleozoic rocks (near 1,378,800 N., 377,800 E.) is probably due to flow of a mass of the nuée-ardente type against the limestone hill. Fragments of limestone in the tuff are bleached and altered owing to the high temperature of the tuff.

SEDIMENTARY ROCKS

The exposed sedimentary rocks in the southern part of Chino-Lonesome basin consist of fanglomerate, mud flows, and some interbedded rhyolitic and basaltic tuffaceous material around the margins; in the interior of the basin these sedimentary rocks include channel gravel, sand, silt, clay, and marl and some rhyolite tuff. From the exposed Precambrian rocks to the south, the fanglomerate grades outward and upward into finer
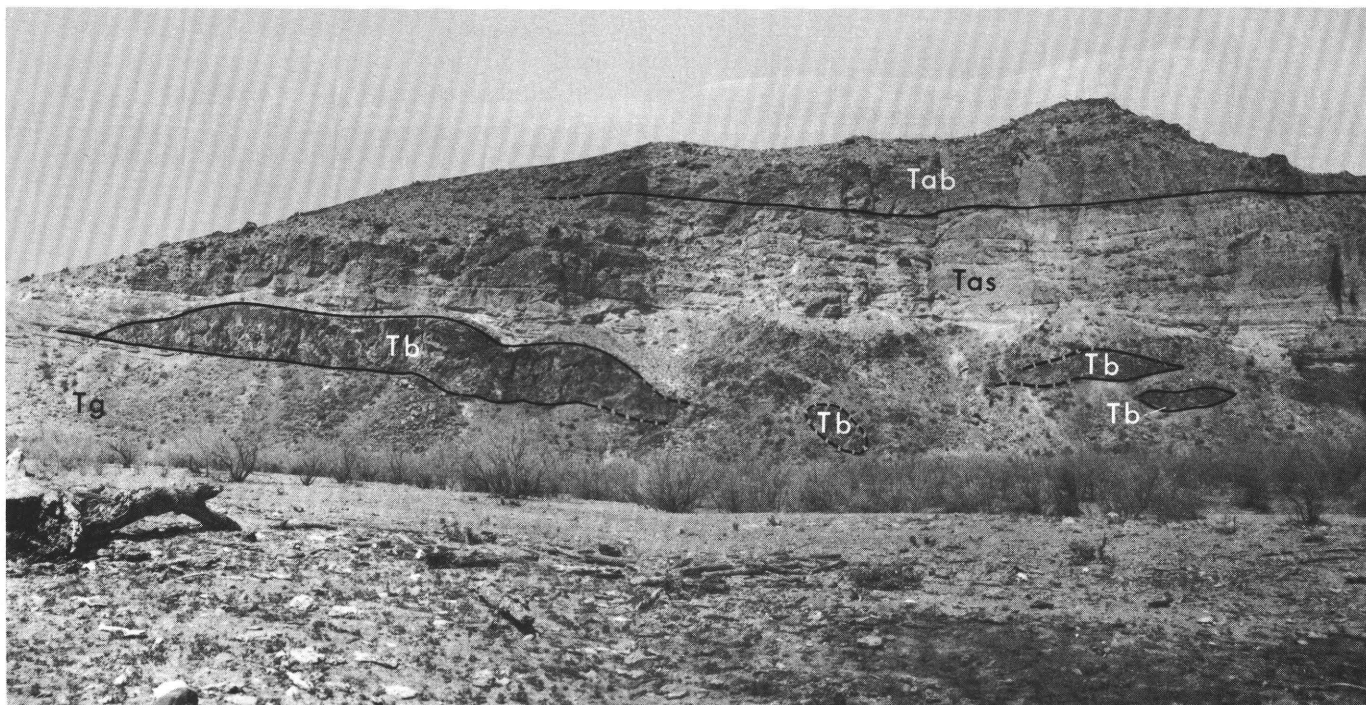
FIGURE 21.—Volcanic and sedimentary rocks of late Tertiary(?) age near Granite Creek (1,401,500 N., 348,300 E.). Tab, massive andesite breccia; Tas, lighter colored bedded tuff, breccia, and andesitic gravel; Tb, basalt flow; and Tg, gravel.

particles; some interfingering of coarse and fine material occurs. Most of the material that is 1–2 miles away from the Precambrian rocks is fine sand, silt, clay, and marl. The coarse and fine materials are not shown separately on the geologic map (pl. 1), but their approximate distribution is indicated on plate 4. Logs of wells in Chino Valley show a large amount of fine material, either "clay" or "volcanic ash." In the northwestern part of the area (pl. 2), the sedimentary material is so poorly exposed that little about its character is known with certainty. Both coarse and fine material is exposed locally. Northeast of the basin most of the sedimentary material is coarse grained and accumulated in channels; some (southwest of Drake) resembles the finer grained beds in the interior of the basin.

The sedimentary rocks have a wide range of color. Many gravels are various shades of greenish or yellowish gray, but in the northeastern part of the area, many of them are shades of red owing to abundant material derived from the Supai Formation; others are gray owing to abundant basalt fragments. Mud flows are generally pale red to yellowish brown (buff); the rhyolitic tuffs are white, buff, pale red, or shades of orange pink, reddish orange, and reddish brown. The clay, silt, and fine sand of the interior of the basin are pale orange to moderate or grayish orange pink; the interbedded marly layers are very pale orange to nearly white.

Gravels in the southern part of the area are composed of Precambrian fragments, generally a heterogeneous mixture, except close to a source area, where the fragments may be largely of one kind. Where granitic rocks were deeply weathered, the overlying gravel contains little granite. Northeast of the basin many gravels, especially south of the Verde River, are composed of about equal amounts of fragments of Precambrian and Paleozoic rocks, but locally, rocks of one era may predominate almost to the exclusion of rocks of the other era. The Precambrian fragments in this area are largely from the Alder Group but include intrusive rocks and Mazatzal Quartzite; the Paleozoic rock fragments are largely from the Martin and Redwall. In the northeastern part of the area the Paleozoic fragments are largely from the Supai and Coconino Formations. Scattered basalt fragments, composing generally less than 1 percent of the gravels at any one locality, are widely distributed in the coarser sedimentary rocks, especially in the southern part of the basin. Basalt fragments, however, may be very abundant in some gravels that are interbedded with or overlie basalt flows, and some of these were derived from penecontemporaneous flows. In the northeastern part of the area, much of the gravel is composed largely of basalt. Basaltic gravels have been reported in deep wells.

The fragments are angular to subrounded; many are subangular, but channel gravels are generally more

rounded. Those composed of schistose Precambrian rocks are platy; many of those from the Coconino Sandstone are slabby. The degree of sorting varies from bed to bed and from one locality to another. Some beds or lenses, especially along Hell Canyon, consist of closely packed pebbles or cobbles and a minimum amount of fine-grained material; others consist largely of sand or silt and only a few scattered pebbles, cobbles, or boulders. Some of the material, especially in the southwestern part, accumulated as mud flow on alluvial fans. Some mud flows are composed largely of tuffaceous material. Accumulation as mud flows is suggested by the local chaotic jumbling of cobbles and by scattered boulders, some more than 6 feet long, in nonbedded and nonsorted fine sand, silt, or clay. A good example of fine-grained mud flow is exposed in the gulch east of the road to Williamson Valley and Simmons (pl. 1; 1,313,500 N., 326,000 E.).

Away from the margins of the basin the nearly horizontal well-bedded fine-grained character of much of the sedimentary material (fig. 25), the intercalated crossbedded sands, and the sand- and pebble-filled channels indicate a lacustrine origin, possibly in playa lakes. This material is well exposed along lower Lynx Creek and the Agua Fria River and in roadcuts along the new alinement of State Route 69 near Fain Ranch (pl. 1; 1,298,000 N., 397,000 E.).

The sedimentary rocks are variably cemented, some sufficiently enough to form cliffs; others are almost completely unconsolidated. Consolidated and unconsolidated material is interbedded in places. Along Hell Canyon the gravel is virtually a conglomerate and is so firmly cemented that it breaks across pebbles. Chalcedony, opal, or zeolites, probably formed by hot springs associated with volcanism, cement some gravels and tuffs. Much of the cement in gravels is calcium carbonate, but little or no calcium carbonate, silica, or zeolites cements the clay, silt, and many of the rhyolitic tuffs. Some rhyolitic tuffs, however, have a calcareous cement, and calcite crystals that poikilitically enclose grains of tuff are as much as 1 cm in diameter. Spherical concretions in sandy tuff a short distance south of the Granite Dells (1,306,400 N., 347,300 E.) are 8–10 cm in diameter and consist of an exterior shell of sandy tuff in which the calcite cement has a radial arrangement. The centers (about 4 cm in diameter) of the concretions consist solely of coarsely crystalline calcite.

Tuffaceous rocks—Relatively pure tuffs that are rhyolitic in composition and mixed tuffaceous sedimentary rocks form part of the sedimentary sequence; most of them are associated with the basin deposits. The pure tuffs are much less abundant than the mixed tuffaceous rocks, which may contain basaltic material. Some silt and clay in the southeastern part of the area and probably some so-called clay and volcanic ash reported from deep wells in the Chino Valley area is rhyolitic tuff. The tuffs and tuffaceous rocks are variable in texture, composition, color, degree of sorting, bedding, consolidation, and type of cement. Interbedding with and gradations into nontuffaceous rocks are common. The tuffaceous rocks range from clay to gravel and locally contain scattered cobbles and boulders. Most tuffaceous deposits observed are 1–2 feet thick; some are as much as 25 feet thick.

Most pure rhyolitic tuffs are white, except where they are shades of red owing to baking by overlying basalt; some are buff. They are massive to thinly bedded, locally crossbedded, well to poorly sorted, and fine to coarse grained; they contain lapilli as much as 5 cm long. Most particles are angular, but some quartz grains (original phenocrysts?) are rounded. The tuffs are composed of vitric, crystal, and lithic fragments. The vitric fragments are shards, grains, and pumice lapilli; the lithic fragments are gray rhyolite lapilli; the crystal fragments are quartz, orthoclase, plagioclase, and a little biotite and magnetite. These same minerals occur as phenocrysts in pumice and rhyolite lapilli. The plagioclase is about An_{10}; some is zoned. The groundmass of the rhyolite is cryptocrystalline to glassy; some has been devitrified. The index of refraction of the shards is about 1.485 and suggests a rhyolite (George, 1924, p. 368). A prominent 10-foot thick bed of gray tuff, used for building stone, is well bedded, locally crossbedded, or massive. The medium-grained, coarse- to fine-sand particles consist of round gray vitric grains (index of refraction of 1.495) and sparse to abundant shards, dust, and tiny pumice lapilli. Some thin layers resemble sandstone and are composed of well-sorted pumice and rounded vitric grains; the vitric grains appear to be molded on each other and on scattered crystal grains. The best exposures of this rock are near 1,305,000 N., 331,800 E. (pl. 1).

An orange-colored tuffaceous sedimentary rock from a few inches to about 10 feet thick generally underlies the "middle" basalt flows north and northeast of Prescott (fig. 24A). It grades downward into pure white rhyolite tuff or into fanglomerate and upward into basaltic tuff. The "orange tuff" contains fragments common to these rocks. Its color is due in part to altered mafic, lithic, and crystal fragments, to basaltic scoria, pumice, lapilli, and shard, and, in part, to limonitic and hematitic staining of the matrix caused by baking.

Fresh-water limestone.—The fresh-water limestone, which ranges in thickness from a few inches to about 10 feet, is thinnest along Hell Canyon and near Granite Creek and thickest along the Verde River, where more than one bed occurs in gravel. Some of the limestone

is more resistant to erosion than is the gravel; it forms weak cliffs and breaks into very angular chunks. Clastic grains and pebbles of quartz and other mineral and rock fragments are common and abundant where the limestone grades into gravel. The rock weathers rough, owing to exposed pebbles and grains or to holes left by their removal. The dense limestone has a very low siliceous content and contains microfossils, gastropods, and stem molds(?). Much of the limestone is massive, but some is finely laminated. It ranges from white to shades of gray and very pale yellowish brown; some is mottled. The dark-gray color, characteristic of some limestone along Hell Canyon, is due to amorphous organic material. The fossils indicate deposition in shallow temperate to cold fresh to brackish or saline water (see p. 80).

THICKNESS

The thickness of the upper Tertiary(?) rocks in Chino-Lonesome basin was probably at least 2,000 feet in the deepest portion before the top was removed by erosion. Gravel-strewn pediment remnants and the superposition of Granite Creek across the Dells Granite and Mazatzal Quartzite (pls. 1, 2; figs. 29, 30) prove that the upper surface of the upper Tertiary(?) rocks is one of erosion; the creek was let down from the overlying upper Tertiary(?) rocks or from pediment gravels cut on them. That some of the local thick accumulations of basalt originally were more extensive is indicated by the eroded edges of thin nearly horizontal flows. The greatest known thickness of sedimentary material is about 1,000 feet, and the thickest uninterrupted basalts are about 500 feet. Much of the information on the thickness of the basin fill has been obtained from logs of wells. Deep wells near the center of the basin have not penetrated bedrock; the basin apparently becomes deeper towards the northwest at least as far as the headwaters of the Verde River. The distribution of the wells is shown on plate 3; the probable configuration of the basin, in figure 22; and the present minimum thickness of deposits, in figure 23. The well-log data are summarized in table 12.

About half a mile southwest of the Granite Dells, well 1 in sec. 14, T. 14 N., R. 2 W. (1,306,200 N., 345,000 E.), penetrated 1,013 feet of sedimentary material but did not reach bedrock. Above the collar of the well, about 325 feet of interbedded basalt flows and sedimentary rocks are exposed to the top of the east-trending ridge (1,305,500 N., 336,500 E.). Thus a total of at least 1,338 feet is indicated in this area. The uppermost flow on this ridge was at one time continuous with the uppermost flow (1,301,500 N., 350,000 E.) east of Granite Creek (pl. 1, sec. B–B'). More than 300 feet of basalt may have overlain this uppermost flow if the

EXPLANATION

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Contact between Precambrian and Paleozoic basement rocks (lined pattern) and upper Tertiary(?) volcanic and sedimentary rocks

———4500———

Contour showing probable configuration of Chino-Lonesome basin as extrapolated from outcrops and well data
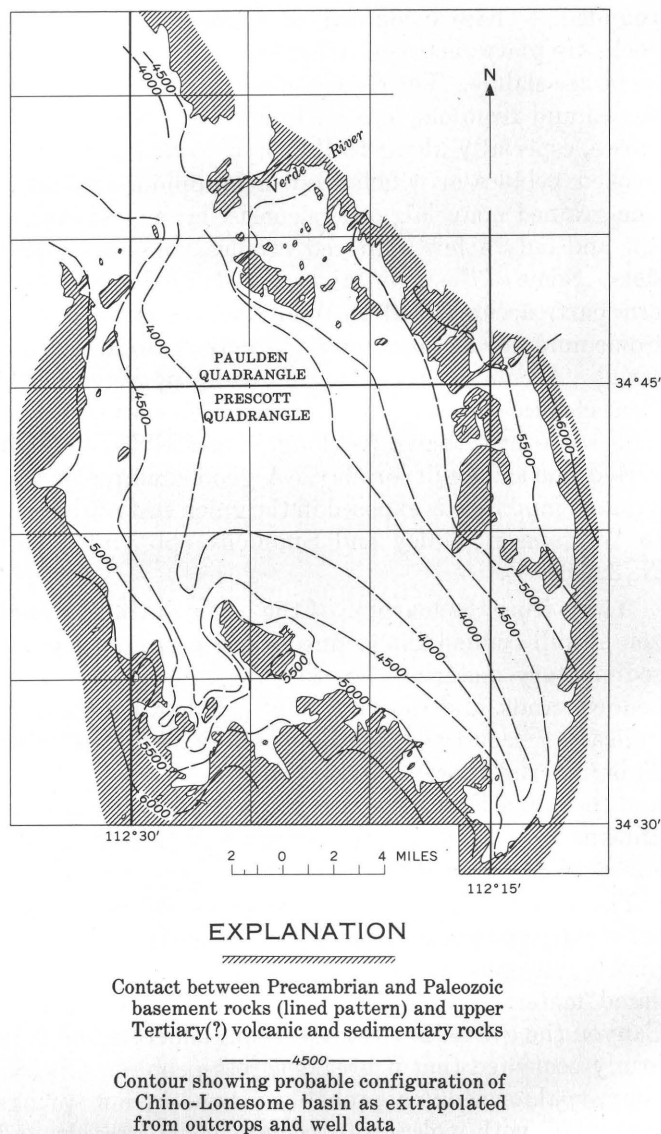
FIGURE 22.—Probable configuration of Chino-Lonesome basin in which volcanic and sedimentary rocks were deposited.

nearly horizontal basalt flows that form the ridge south-southwest of Glassford Hill extended westward.

In the southeastern part of the area, about 800 feet of nearly horizontal sedimentary material is exposed intermittently from near the point where Clipper Wash leaves the quadrangle (1,291,300 N.) to the base of the basalt flow on the south side of Glassford Hill. East of the southern part of the map area, a well (No. 1, sec. 11, T. 13 N., R. 11 E.; 1,282,300 N., 405,500 E.) entered Precambrian bedrock about 740 feet below the lowest exposures on Clipper Wash; the total amount of sedimentary material, therefore, may be 1,600 feet.

Near the village of Chino Valley, many wells that tap the Chino artesian area bottom in upper Tertiary(?) rocks as much as 768 feet below the surface; some of

EXPLANATION

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Contact between Precambrian and Paleozoic
basement rocks (lined pattern) and upper
Tertiary(?) volcanic and sedimentary rocks

0–500

500–1000

More than 1000
Present minimum thickness, in feet, based
on well data
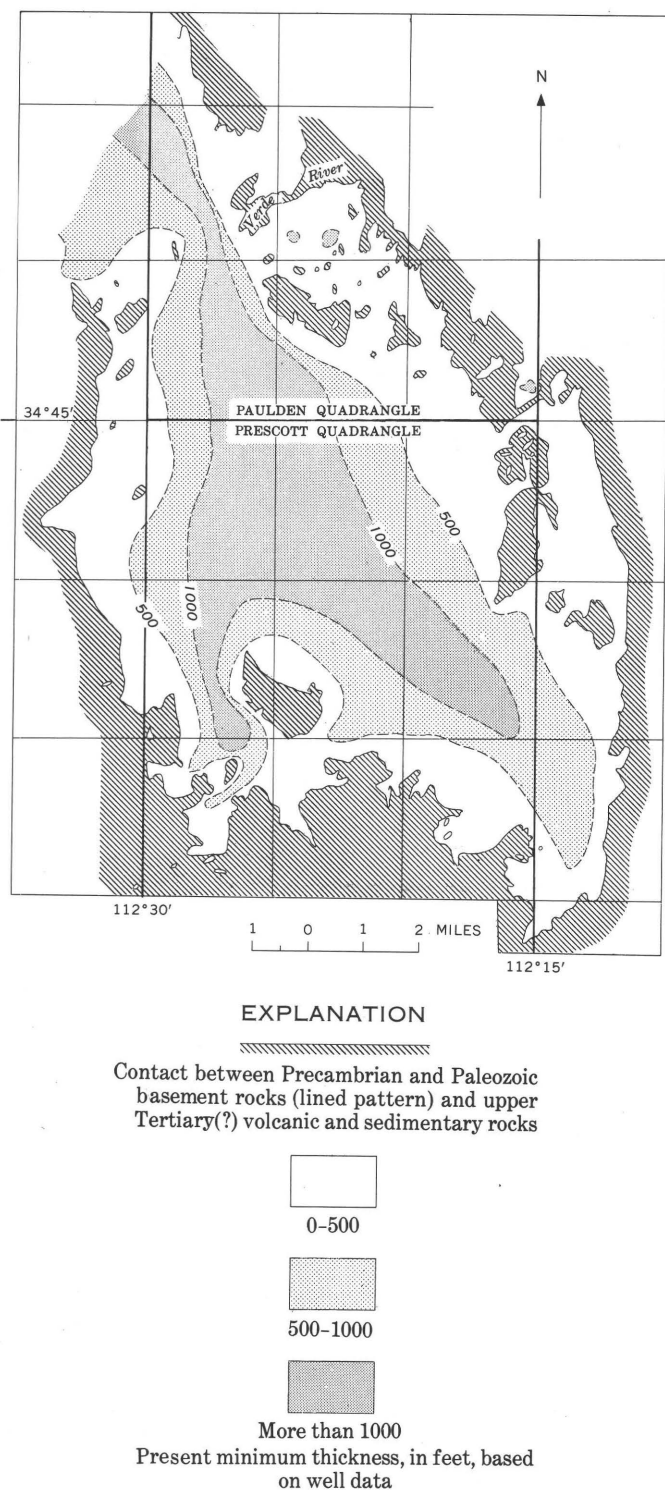
FIGURE 23.—Approximate present minimum thickness of volcanic and
sedimentary rocks of late Tertiary(?) age in and adjacent to Chino-
Lonesome basin.

them cut as much as 500 feet of "malpais." One well
(No. 1, sec. 17, T. 16 N., R. 1 W.) is reported to have
bottomed in basalt 1,085 feet below the surface. A
wildcat oil well (No. 1, sec. 32, T. 18 N., R. 2 W.) re-

portedly entered bedrock about 1,000 feet below the
surface. Another wildcat oil well (No. 1, sec. 20, T. 18
N., R. 2 W.) closer to the margin of the basin entered
bedrock 600 feet below the surface. An additional 200
feet or more of sedimentary material remains above the
collars of some of these wells and below the pediment
gravels that cap nearby hills. Erosion has been greater
in this area, which is the headwaters of the Verde River,
and at the southeast end of the basin than elsewhere.
Northwest of the Prescott-Paulden area, the deepest well
for which I have a record is 700 feet.

Northeast of the basin, the upper Tertiary (?) rocks
are thinner, except for thick accumulations of volcanic
rocks, probably around vents. Basalt ranges from 10
to more than 500 feet in thickness (at the north side of
St. Mathews Mountain); accumulations of 200–300 feet
are on the mesa about 3 miles northwest of St. Mathews
Mountain, near the headwaters of Muldoon Canyon
(1,395,000 N., 366,500 E.), and south of Stewart Ranch
(1,407,300 N., 354,500 E.). The maximum known thick-
ness of andesite is 850–1,000 feet on the Pinnacle, St.
Mathews Mountain, and the two peaks between them;
some thick accumulations may represent plug or domal
material intrusive into earlier andesite. About 300 feet
of massive andesite breccia underlain by breccia, tuff,
and andesitic gravel is exposed (fig. 21) along Granite
Creek south of the Verde River. Gravel in the central
part of the area northeast of the basin filled shallow de-
pressions and local channels and is mostly less than 200
feet thick. It is thickest near the lowland along the
Verde River, where it may have been downwarped when
the structural low was formed rather than have accu-
mulated in the lowland. The top of the gravel, which
is a relatively level surface beneath basalt or andesite,
may be erosional. Northeast of Hell Canyon the max-
imum thickness of combined basalt and gravel is about
300 feet, but in many places, especially along Hell
Canyon, it is less than 150 feet thick. Basalt generally
makes up most of the known thickness. The gravel
portion is very thin; some gravel along Hell Canyon
forms a sheetlike deposit less than 50 feet thick.
Thicker sections of gravel are in the general area where
the gravel is most extensively exposed—in the neighbor-
hood of Bar Heart Ranch and Schwanbeck Tank.

AGE

During Cenozoic times volcanic and sedimentary
rocks accumulated throughout Arizona. Volcanic ac-
tivity was dominant at various times and places, depo-
sition of clastic material was dominant at others, and
at still other times volcanic and sedimentary material
were deposited in nearly equal amounts. Discovery of
diagnostic fossils or physiographic and structural re-
lations locally indicate that many of these rocks are

TABLE 12.—*Summary of well-log data in Chino-Lonesome Valley, Arizona*

[Compiled from data supplied by H. C. Schwallen, State Land Office, University of Arizona, Tucson, Ariz., and by drillers and ranch owners and from data on file with the U.S. Geological Survey. Not all data are reliable, and the table reflects the author's interpretation of the available data. Some well altitudes are approximate. Basalt refers to volcanic rocks reported in logs as "malapais (malpais)," "lava," and "basalt"—some may be andesite; where more than one figure is given for altitudes of the top and bottom of basalt, the lavas are separated by clastic deposits; figures for some thin beds of clastic deposits have been omitted from the calculations. Where the figure for the bottom altitude of a well is underlined and followed by the symbol "br," the well entered bedrock at the given altitude]

Section and well	Well			Basalt			Thickness, in feet, of overlying (a), intervening, and underlying (b), sedimentary deposits
	Altitude (feet above sea level)		Depth (feet)	Altitude (feet above sea level)		Thickness (feet)	
	Top	Bottom		Top	Bottom		
T. 18 N., R. 3 W.							
Sec. 9, well 1	4,450	3,750	700				700
22, well 1	4,417	3,917	500				500
T. 18 N., R. 2 W.							
Sec. 20, well 1	4,500	2,440 3,900br?	2,600				600
32, well 1	4,385	3,385br	1,000				(?)
T. 17 N., R. 2 W.							
Sec. 26, well 1	4,446	4,171	275	4,441 4,416 4,396	4,429 4,408 4,388	12 8 8	5a 13 12 217b
2	4,489	3,986 4,188br?	503	4,486 4,457 4,427	4,469 4,447 4,417	17 10 10	3a 12 20 229 or 431b
34, well 1	4,500	3,925	575	4,325 3,986	4,314 3,925	11 61	175a 328
2	4,500	4,115	385				
3	4,500	3,913	587	4,290 4,070?	(?) (?)	377?	
4	4,514	3,792	722	4,291 3,906	4,229 3,792	62 114	223a 323
5	4,515	3,795	720	3,925?	3,904?	21?	590?a 109?b
35, well 1	4,508	3,778	730	4,446 3,888 3,801	4,108 3,808 3,778?	338 80 11?	62a 220 7 12?b
2	4,525	3,808	717	4,090 4,060?	4,075 3,815?	15? 245?	435a 15? 7?b
3	4,510	4,190	320				320
T. 16 N., R. 2 W.							
Sec. 1, well 1	4,591	3,891	700	3,954	3,891	63	637a
2, well 1	4,550	3,988	562	4,054	4,048	6	496a 60b
2	4,550	3,830	720	(?)	(?)	(?)	550a (?)
3, well 1	4,532	4,016	516	4,049	4,016	33	483a
2	4,574	4,045	529				
3	4,575	4,075	500	4,202 4,099	4,185 4,075	17 24	373a 86
4	4,575	4,075	500	4,225	4,075?	150?	350a
5	4,582	4,050	532	4,262? 4,095?	4,259? 4,059?	3? 36?	320?a 164? 9?b
6	4,584	3,918	666	4,049?	3,918	131?	535a
7	4,592	4,010	582	4,142	4,010?	132?	450a
8	4,575	4,034	541	4,132	4,034	98	443a
9	4,597	4,010	587	4,162	4,010	152	435a
10	4,602	4,013	589	4,120?	4,013?	107?	482?a

TABLE 12.—*Summary of well-log data in Chino-Lonesome Valley, Arizona*—Continued

Section and well	Well — Altitude (feet above sea level) Top	Well — Altitude (feet above sea level) Bottom	Depth (feet)	Basalt — Altitude (feet above sea level) Top	Basalt — Altitude (feet above sea level) Bottom	Thickness (feet)	Thickness, in feet, of overlying (a), intervening, and underlying (b), sedimentary deposits
T. 16 N., R. 2 W.—Continued							
Sec. 4, well 1	4,568	3,948	620	4,068	4,038	30	500a
				3,993?	3,948	45?	45?
2	4,600	4,100	500	4,110?	4,100	10	490?a
3	4,600	4,115	485	4,240	4,210	30	360a
				4,150	4,115	35	60
4	4,600	3,900	700	4,436	4,420	16	164a
				4,246	3,900	346	174
5	4,600	4,040	560	4,230	4,200	30	370a
				4,140	4,115	25	60
							75b
6	4,600	3,988	612	------	------	------	------
7	4,600	4,020	580	4,240	4,210	30	360a
							190?b
8	4,600	4,080	520	4,240	4,220	20	360a
				4,150	4,080	70	70
9	4,650	3,882	768	4,340	4,320	20	310a
				4,255	4,140	115	65
				3,985	3,915	70	155
							33b
5, well 1	4,567	3,870	697?	------	------	------	697?
9, well 1	4,650	3,885	765?	4,278	3,885	393	372a
10, well 1	4,650	4,050	600	4,352?	4,064	288?	298a
							14b
2	4,600	3,919	681	4,000	3,919	81	600?a
3	4,654	3,954	700	4,304	4,204	100?	350a
							250?b
4	4,633	4,037	596	4,309	4,037	272	324a
11, well 1	4,621	3,921	700	4,231	3,921?	310?	390a
2	4,560	4,000	560	------	------	------	560
3	4,611	4,111	500	4,261	4,111	150?	350?a
4	4,600	3,956	644	4,050?	3,986	64	550?a
							30?b
5	4,628	3,989	639	------	------	------	------
6	4,600	4,065	535	4,210	4,138	72	390a
				4,135	4,065	70	3
7	4,600	3,980	620	4,185	3,980	205	415a
8	4,582	4,042	540	4,382	4,042	340?	200a
9	4,600	4,020	580	4,185	4,020	165	415a
10	4,600	3,900	700	4,000?	3,900	100?	600a
12, well 1	4,600	3,956	644	4,150	3,970	180	450a
							14b
2	4,600	3,856	744	4,285	3,856?	429	315a
3	4,700	3,740?	960?	4,530	3,740?	790?	170a
14, well 1	4,600	4,100	500	------	------	------	------
2	4,602	4,052	550	4,102	4,052	50	500?a
3	4,650	4,063	587	4,250	4,063	187?	400?a
4	4,650	3,953	697	4,330	3,953	377	320a
5	4,656	4,016	640	4,351	4,029	322	305a
				4,018	4,016	2	11
15, well 1	4,700	4,134	566	4,405	4,155	250	295a
							21b
2	4,664	4,059	605	4,274	4,059	215	390a
3	4,700	4,200	500	4,366	4,200	166	334a
4	4,689	4,169	520	4,349	4,169	180	340a
5	4,699	4,389	310	------	------	------	310
6	4,700	4,109	591	4,440	4,109	331	260a
21, well 1	4,750	4,347	403	4,480	4,347	133	270a
2	4,750	4,337	413	4,476	4,337	139	274a
3	4,700	4,300	400	4,440	4,300	140	260a
4	4,775	4,348	427	4,568	4,348	220	207a
5	4,775	4,368	407	4,563	4,385	178	212a
							17b
6	4,750	4,350	400	4,500	4,350	150	250a
22, well 1	4,735	4,134	601	4,459?	(?)	(?)	276?a
							(?b)
2	4,737	4,136	601	4,537	4,242	295	200a
				4,232	4,136	96	10

TABLE 12.—*Summary of well-log data in Chino-Lonesome Valley, Arizona*—Continued

Section and well	Well Altitude (feet above sea level) Top	Bottom	Depth (feet)	Basalt Altitude (feet above sea level) Top	Bottom	Thickness (feet)	Thickness, in feet, of overlying (a), intervening, and underlying (b), sedimentary deposits
T. 16 N., R. 2 W.—Continued							
Sec. 22, well 3	4,725	4,125	600	4,458	4,230	228	267a
				4,210	4,125	85	20
4	4,700	4,270	430	4,500?	4,270	230?	200?a
5	4,750	4,550	200	--------	--------		200
6	4,725	4,025	700	4,450	4,102	348	275a 77b
7	4,725	4,177	548	4,442	4,177	265	283a
23, well 1	4,703	4,403	300	--------	--------		300
2	4,650	4,132	518	4,361	4,132	229?	289a
3	4,650	4,315	335	4,450	4,315?	135?	200?a
26, well 1	4,750	4,300	450	4,560	4,300?	260?	190?a
27, well 1	4,763	4,345	418	4,449	4,345?	104?	314a
2	4,764	4,311	453	4,528	4,404	124	236a
				4,368	4,345	23	36 34b
3	4,725	4,525	200	4,530?	--------	5?	195?a
4	4,800	4,610	190	4,618	4,610	8	182a
5	4,820	4,153	667	4,663	4,346	329	145a 185?b
		4,161br?		--------		--------	
28, well 1	4,850	4,600	250?	4,650	4,600	50	200a
2	4,820	4,420	400	4,640	4,420	220	180a
33, well 1	4,850	4,530	320	4,590	4,530	60	260a
34, well 1	4,799	4,529	270	4,729	4,529	200	70a
2	4,829	4,590	239				
35, well 1	4,778	4,543	235	4,548	4,543	5	230?a
2	4,800	4,258	542	4,650	4,258?	392?	150a
T. 15 N., R. 2 W.							
Sec. 17, well 1	5,057	4,627	430				
19, well 1	5,150	4,772	378	5,070?	4,900?	170?	80a 128b
21, well 1	5,069	4,709	360	--------	--------		
23, well 1	5,076	4,498	578	--------	--------		578?
25, well 1	5,010	4,171	839	4,360	4,213	147	650a
		4,213br?		--------			42b or br?
2	5,014	4,202	812	4,364	4,222	142	650a 20b
26, well 1	5,025	4,663	362	--------	--------		362
30, well 1	5,185	5,035	150	--------	--------		150
2	5,199	5,019	180	5,049?	5,019	30?	150?a
32, well 1	5,300	5,168	132				
36, well 1	5,050	4,680	370	--------	--------		370
T. 14 N., R. 2 W.							
Sec. 1, well 1	5,025	4,854	171	--------	--------		171
10, well 10	5,220	4,326	894	4,620?	4,580	40?	600?a 254b
14, well 1	5,196	4,973	223	--------	--------		223
2	5,200	4,920	280	--------	--------		280
3	5,200	4,187	1,013	5,200	5,190	10	1,003b
21, well 1	5,350	5,060	290	--------	--------		120
		5,230br		--------			
2	5,565	5,261	304	5,465?	5,413?	52?	100a 152b
3	5,525	5,250	275	--------			230?
		5,295br?		--------			
4	5,550	5,230	·320	5,380	5,360	20	170a 130b
22, well 1	5,340	4,764	576	5,340	5,290	50?	25?
				5,265	5,140	125?	376?b
2	5,453	4,603	850	--------	--------		850
23, well 1	5,197	4,718	479	--------	--------		479

TABLE 12.—*Summary of well-log data in Chino-Lonesome Valley, Arizona*—Continued

Section and well	Well			Basalt			Thickness, in feet, of overlying (a), intervening, and underlying (b), sedimentary deposits
	Altitude (feet above sea level)		Depth (feet)	Altitude (feet above sea level)		Thickness (feet)	
	Top	Bottom		Top	Bottom		
T. 14 N., R. 2 W.—Continued							
Sec. 26, well 1	5,200	4,690	510				510
2	5,214	5,065	149				147
		5,067br					
27, well 1	5,273	4,860	413				243
		5,029br					
28, well 1	5,377	5,125	252				252
33, well 1	5,350	5,137	213	5,300	5,288	12	50a
							151b
2	5,350	4,980br?	370	5,340	5,330	10	10a
							350b
3	5,400	5,282br	118				118
34, well 1	5,350	4,878	472			(¹?)	?
2	5,350	5,085	265				265
3	5,425	5,169	256				
4	5,400	5,040	360	5,400	5,040	360	
T. 13 N., R. 2 W.							
Sec. 4, well 1	5,350	5,050	300				300
T. 16 N., R. 1 W.							
Sec. 5, well 1	4,717	4,567	150	4,577?	4,567	10?	140?a
7, well 1	4,750	3,665	1,085?			(²)	
8, well 1	4,725	4,415	310	4,429	4,415	14	296a
14, well 1	4,830	4,560	270				270?
17, well 1	4,770	4,258	512			(²?)	512?
18, well 1	4,764	4,459	305				305
20, well 1	4,775	4,365	410				410
22, well 1	4,804	4,444	360				
23, well 1	4,840	4,447	393				393
34, well 1	4,810	4,508	302			(²)	302?
T. 15 N., R. 1 W.							
Sec. 5, well 1	4,820	4,520	300				300
6, well 1	4,820	4,555	265				265
24, well 1	4,914	4,596	318				
31, well 1	5,000	4,585	415				415
2	4,783	4,283	500				
T. 14 N., R. 1 W.							
Sec. 2, well 1	4,950	4,600	350				350
6, well 1	5,045	4,702	343				340
		4,705br?					
T. 15 N., R. 1 E.							
Sec. 26, well 1	5,325	5,175	150				150
28, well 1	5,060	4,660	400				400

[1] Basalt penetrated at top of well.
[2] Basalt penetrated at bottom of well.

TABLE 12.—*Summary of well-log data in Chino-Lonesome Valley, Arizona*—Continued

Section and well	Well			Basalt			Thickness, in feet, of overlying (a), intervening, and underlying (b), sedimentary deposits
	Altitude (feet above sea level)		Depth (feet)	Altitude (feet above sea level)		Thickness (feet)	
	Top	Bottom		Top	Bottom		
T. 14 N., R. 1 E.							
Sec. 11, well 1	4,875	4,525	350				350
16, well 1	4,817	4,217	600				600
28, well 1	4,675	3,845	830				830
2	4,725	4,325	400				400
T. 13 N., R. 1 E.							
Sec. 2, well 1	4,550	3,911	639	3,964	3,934	30	586a 23b
11, well 1	4,540	3,690 3,795br	850				745

probably Pliocene or Pleistocene, but in many places such evidence is lacking or inconclusive.

In 1946 K. K. Kendall of the Water Resources Division of the U.S. Geological Survey found fragmentary antelope and llamalike camel bones in the basin deposits north of Prescott. C. L. Gazin of the National Museum stated: "The llama-like camel * * * may represent a small species of *Pliauchenia*, * * *" possibly of Pliocene age (written commun. to C. A. Anderson, 1947). These bones were found along the Williamson Valley road (near 1,313,500 N., 326,000 E.), in a roadcut on the west side of Route 89 (near 1,301,200 N., 344,200 E.), about a mile south of Willow Creek (near 1,302,900 N., 340,500 E.), and in the NW¼ sec. 23, T. 14 N., R. 2 W., probably due east of the preceding location. During the present investigation, an unidentifiable bone fragment was found south-southwest of Glassford Hill (near 1,297,500 N., 355,000 E.). All these bones came from about the same stratigraphic horizon—below the middle basalt flows (fig. 24A) in orange-colored tuff or in the immediately underlying gravel.

The Williamson Valley road area is the most promising locality for fossils and contains fairly abundant bone fragments. J. F. Lance (oral commun., 1956) found an antelope leg bone that he thought is not younger than middle Pliocene and may well be the same age as a vertebrate fauna 20 miles south of Prescott. These fossils (Reed, 1950; Bryant, 1951) were discovered along Milk Creek (fig. 1) in the Mount Union quadrangle; they are early Pliocene in age according to Lance. The bones occur in sedimentary rocks that resemble the rocks north of Prescott except for having been tilted slightly. The similarity is increased by identical white rhyolite tuff beds in both.

Specimens of fossiliferous fresh-water limestone northeast of the basin were studied by E. B. Leopold (1955 and 1957), by D. W. Taylor, R. W. Brown, and R. Rezak (1955), and by K. E. Lohman (1957) of the U.S. Geological Survey. The limestone is reported to be moderately organic—the organic material is in an amorphous or macerated condition. Fossils include a medium-sized gastropod—probably a *Lymnaea*—fragments of dicot wood, rootlets, corroded conifer grains—probably *Juniperus*—fungal hyphae, filamentous green algae, spores, an undetermined Silicoflagellate-like or Heliodiscoaster-like form, diatoms, corroded sponge spicules, concretionary laminated algal deposits around pebbles—similar to water biscuits of modern fresh-water lakes—and crisscrossing tubes of undetermined origin, possibly stem molds or worm burrows. None of the material is diagnostic as to age, but it does indicate a subaqueous shallow dominantly fresh-water environment.

According to Lohman, the diatoms consist of fresh-water and brackish- or saline-water forms (table 13). The largest number of species are fresh-water forms, whereas the largest number of individuals are brackish- or saline-water forms. The identification of *Hyalodiscus radiatus* and its variety *articus*, the most abundant diatom, is uncertain. The badly leached or corroded condition of all specimens of both, in contrast to good preservation of delicate structures of most other diatoms, suggests reworking of an older deposit or transportation from a different habitat. *Hyalodiscus* cf. *H. radiatus* var. *artica* was originally described from Franz-Josef Land associated with marine and some brackish- and fresh-water species; this association suggests a tidal estuary. The diatoms have known geologic ranges of Miocene or Pliocene to Recent, except for

Navicula bituminosa, which has been found previously only in late Tertiary (Miocene or Pliocene) beds in Hungary. Two forms, *Gomphonema bohemicum* and *Hyalodiscus* cf. *H. radiatus* var. *artica*, live today only in cold water. The others, except the extinct *Navicula bituminosa*, are temperate-water species. Because of the foregoing associations, Lohman suggested that the limestone was deposited in a shallow somewhat saline lake fed by streams of temperate water and by streams originating in higher, colder country (such as the Colorado Plateau and its volcanic peaks).

TABLE 13.—*Diatoms from fossiliferous limestone of late Tertiary(?) age. Limestone underlines basalt and overlies andesitic gravel, 5 miles northeast of the village of Chino Valley (1,386,200 N., 353,600 E.)*

[Report by Kenneth E. Lohman, August 30, 1957. Occurrence: A, abundant; C, common; F, fairly common; and R, rare.]

Cymbella ehrenbergii Kützing (F)
   parva (Wm. Smith) Cleve (F)
Fragilaria cf. *F. pinnata* Ehrenberg (R)
Gomphonema angustatum (Kützing) Rabenhorst (F)
   bohemicum Reichelt and Fricke (F)
   intricatum Kützing (F)
   lanceolatum Ehrenberg (R)
Hyalodiscus cf. *H. radiatus* (O'Meara) Grunow (C)
   cf. *H. radiatus* var. *arctica* Grunow (A)
   sp. (F)
Navicula bituminosa Pantocsek (F)
   lucidula Grunow (R)
Nitzschia commutata Grunow (A)
   cf. *N. commutata* Grunow (F)
   palea (Kützing) Wm. Smith (R)
Pinnularia gibba var. *parva* (Ehrenberg) Grunow (F)
   interrupta Wm. Smith (R)
   microstauron var. *biundulata* Muller (F)
   microstauron var. *brebissonii* (Kützing) Hustedt (R)

Some of the white rhyolite tuff above the vertebrate fossil locality east of Williamson Valley road contains abundant pollen; pollen studies of this material are now being made at the Geochronology Laboratories of the University of Arizona (Jane Gray, written commun., 1959).

The Colorado Plateau northeast of the Prescott-Paulden area is covered by volcanic rocks that, according to Robinson (1913, p. 38), were erupted in three stages: (1) widespread eruption of basalt from small cones, (2) eruption of lava of andesitic to rhyolitic composition from isolated large cones and a large number of small ones, and (3) eruption of basalt from many small cones. The last period of eruption continued until Recent times; it was widespread, but not as widespread as the basalt eruptions of the first stage. Although not based on stratigraphic and fossil evidence, Robinson's assumption (1913, p. 91–92) that the first stage of eruption occurred in the late Pliocene has been widely quoted. Gravels beneath the plateau basalts were deposited as a result of uplift to the south that probably occurred in late Miocene or early Pliocene, according to Longwell (1946, p. 832).

Although fossils are lacking, the Hickey Formation of the Jerome area and Clarkdale quadrangle is considered to be Pliocene(?), and the younger formations, Pliocene(?) to Pleistocene(?) (Anderson and Creasey, 1958, p. 58, 61; Lehner, 1958, p. 554, 561–562, 565–566).

STRATIGRAPHIC RELATIONS AND CORRELATIONS

The upper Tertiary(?) rocks rest on Precambrian rocks in the southern half of the area (pl. 1) and on successively younger rocks to the northeast across the northern half of the area (pl. 2, sec. *L–L'*). This is illustrated in part by the map showing the approximate present thickness of Paleozoic and Cenozoic rocks (fig. 31), as northeast of Chino-Lonesome basin the thickness is due largely to Paleozoic rocks. The surface on which the upper Tertiary(?) rocks were deposited had considerable relief. The rocks are overlain by Quaternary pediment gravel and Recent gravel and alluvium.

Attempts to correlate the upper Tertiary(?) rocks in the Prescott-Paulden area with the Hickey and Perkinsville Formations to the east have so far proved futile. The volcanic and sedimentary rocks in the Prescott-Paulden area are obviously westward continuations of rocks mapped as Hickey and Perkinsville to the east, but the criteria used to distinguish the two formations do not apply in the Prescott-Paulden area.

The distribution and possible relations of the upper Tertiary(?) formations in the Prescott-Paulden-Jerome-Clarkdale area are shown on plate 4. As shown on this plate, the Hickey Formation consists of upper Tertiary(?) basalt and sedimentary rocks in the southwestern part of the Jerome area and of older (pre-andesite) basalt and gravel, andesite, and younger (post-andesite) basalt in the southwestern part of the Clarkdale quadrangle. (See Anderson and Creasey, 1958, p. 56–59, pl. 1, also p. 78–83, figs. 5, 6; Lehner, 1958, p. 549–556, pl. 45, also p. 568–576, for descriptions of the Hickey Formation and its distribution, as mapped by them, in these areas; the volcanic rocks of the Hickey Formation according to them consist largely of basalt.) On plate 4 the name Perkinsville Formation (Lehner, 1958, p. 563–566, pl. 45, also p. 556–563) has been applied to the upper Tertiary(?) rocks in the northeast corner of the Paulden quadrangle.

In the Jerome-Clarkdale area the Hickey Formation was distinguished from the younger formations on the basis of relation to deformation and erosion. The Verde Formation is east of the Black Hills and east of the Verde fault; the older Quaternary gravels—called older Quaternary gravels in the text but braced as Pliocene (?) to Pleistocene on the map explanation and correlated with the Verde Formation by Anderson and

Creasey (1958, p. 61, pl. 1)—are west of the Black Hills and west of Coyote fault; the Perkinsville Formation is north of the Black Hills. The Hickey Formation forms a thick sequence of basalt flows on top of the Black Hills, downfaulted flows east and west of the two bounding faults, and downwarped flows north and south of the Black Hills. The flows are underlain locally by gravel that is limited to northward-draining channels, except in the southern part of the Jerome area where sedimentary material is more abundant and generally predominates over basalt. East of the Verde fault the Verde Formation unconformably overlies the Hickey Formation. Except where downfaulted or downwarped, the Hickey Formation is confined to topographic highs, where it occurs as erosion remnants. Erosion, initiated by post-Hickey deformation, resulted in about 1,300 feet of relief and in the present southward drainage, according to Lehner (1958, p. 555). The younger formations are more closely related to present topography. They accumulated mainly in topographic lows.

The stratigraphic relations within the upper Tertiary(?) rocks in the Prescott-Paulden area are not clearly understood. The sequence, as worked out in the central part of the Paulden quadrangle, consists of gravel and a little basalt—referred to here as older gravel and older basalt—overlain by andesite that in turn is overlain by basalt and gravel. During reconnaissance in much of Yavapai County, andesite (or dacite) was observed in many places above gravel and below basalt. To conclude that all the andesite (or dacite) is contemporaneous and is important as a stratigraphic marker is tempting, but such conclusions have not been proved. The andesite may be older than, an early facies of, or younger than basalt of the Hickey Formation, or it may be of several ages. The presence of basaltic-looking rocks related to andesite and of andesitic-looking rocks related to basalt have complicated the picture. The upper Tertiary(?) rocks all appear to have been deposited after the last major deformation in the area.

The older basalt, which is quantitatively unimportant and may possibly be an early basaltic facies of andesite, occurs in four areas: (1) west of the Pinnacle (1,400,000 N., 353,000 E.), (2) on the eastern edge of the area, 2,000 and 3,000 feet northeast of St. Mathews Mountain, (3) 1,000 and 2,000 feet southeast of Stewart Ranch (1,407,-500 N., 354,500 E.), and (4) in the headwaters of Bull Basin Canyon (1,396,000 N., 372,500 E.). It consists of flows, except at the first locality, where it includes a cinder cone (pl. 2).

The older gravel extends from northeast of Chino-Lonesome basin nearly to Hell Canyon. Included with the older gravel are the gravels along the western margin of the area, which are probably older than andesite and which extend for about 4 miles north of the latitude of the village of Chino Valley; a small patch of gravels in the northeast corner of the area (1,453,000 N., 397,000 E.) is also included. The gravel beneath basalt along Hell Canyon, some of which is too thin to show on plate 4, and that beneath basalt north and south of the Verde River near the eastern edge of the area may also be part of the older gravel. Fragments of Precambrian volcanic and intrusive rocks are characteristic of the older gravels. These Precambrian fragments must have been derived from rocks south or southwest of Chino-Lonesome basin, probably prior to the formation of the basin. The small patch of gravel in the northeast corner is probably older gravel because it contains Mazatzal Quartzite pebbles that must have come from rocks south of the Verde River lowland. The pebbles of Mazatzal Quartzite and some of the Precambrian fragments along Hell Canyon and the Verde River may have been derived from older gravels.

The older gravel is intruded by andesite plugs and overlain by andesite flows, breccias, mud flows, and gravels composed largely of andesite fragments. The contact between older gravel and overlying andesitic gravel, tuff, and mud flow is well exposed on the sides of the gulches west (fig. 21), east, and south of the Pinnacle (1,400,000 N., 353,000 E.) and appears to be conformable and gradational. At only one place was a possible disconformity observed.

Most of the basalt northeast of the basin rests on andesite or on older gravel that generally contains andesite fragments at the top. In places these andesitic gravels are only a few inches thick. Most, if not all, of the thin andesitic gravels are related to the andesitic period of volcanism and not to a period of erosion following eruption of andesite; they are lateral extensions of andesitic gravel and mud flows that underlie andesite breccia and massive andesite (fig. 21). Erosion prior to eruption of the basalt, however, may have removed overlying andesite breccia, massive andesite, and much of the andesitic gravel.

The Hickey Formation (as mapped by Lehner) in the southwest corner of the Clarkdale quadrangle consists of the same sequence: older gravel and a little basalt, andesite, and post-andesite basalt (pl. 4). Lehner (1958, p. 553) recognized andesite in the area but included it with and considered it a facies of the basalt of the Hickey formation.

Basalt and overlying gravel in the northeast corner of the Paulden quadrangle are part of the Perkinsville Formation. The basalt flowed from the Colorado Plateau rim southward into the Verde River lowland.

Basalt of the Perkinsville Formation has been arbitrarily distinguished (pl. 4) from the basalt south of Hell Canyon and the Verde River. As the base of some of this basalt slopes northward toward the Verde River lowland, the basalt may have been erupted after formation of the lowland and at nearly the same time as the Perkinsville basalt. On the other hand, the base of some of this basalt and of some of what is shown as Perkinsville basalt along Hell Canyon upstream from King Spring (west of 376,500 E.) has the same attitude as the underlying Paleozoic rocks (pl. 4, sec. A–A'); it may have been downwarped into the lowland. Nearly all the basalt in the Paulden quadrangle, including Perkinsville basalt just north of the area (near 384,000 E.), overlies andesite; andesite, therefore, cannot be used as evidence for distinguishing basalts of different ages, except for the small amounts of basalt beneath andesite.

Gravel and interbedded fresh-water limestone beneath the lowest basalt (Perkinsville) in the northwest corner of the Clarkdale quadrangle is continuous with the gravel and limestone beneath basalt immediately to the west. Lehner mapped them as Perkinsville; I found it impossible to distinguish the gravel from the older gravel to the southwest. It is lithologically similar and contains Paleozoic and a few Precambrian fragments, whereas gravel of the Perkinsville in most places, according to Lehner (1958, p. 563–564), is composed largely of basalt derived from older basalts. The limestone along Hell Canyon southeast of Drake is between underlying gravel and overlying basalt. Limestone south of Granite Creek (1,386,200 N., 353,600 E.) underlies basalt and overlies older gravel, which contains andesite fragments at the top. The limestone north of Granite Creek (1,390,500 N., 358,000 E.) probably occupies the same position, but it may underlie the andesite.

The sequence as far as known in the southern part of the basin consists of sedimentary material and a few interbedded basalt flows. North and northeast of Prescott, the sedimentary material is overlain by three basalt flows or flow series that are separated by as much as 100 feet of gravel and rhyolitic tuffaceous rocks. Figure 14 (southwest corner) shows lower, middle, and upper basalt flows and the gravel and tuff beneath these flows. The middle and upper flows rest on relatively gently northward-dipping surfaces (fig. 24). The middle basalt flows rest on Precambrian rocks in places and on increasingly thicker basin deposits to the north.

In the exposed part of the basin, fanglomerate and coarse fluviatile deposits grade into and interfinger with the finer grained lacustrine deposits of the interior of the basin. Rhyolite tuff deposits east and west of Glassford Hill suggest correlation of the underlying deposits. The tuff on the west side is above gravel and below the middle basalt flows. The tuff east of Glassford (near 1,299,500 N., 384,700 E.) is above gravel that to the west underlies the upper basalt flows.

Where exposed in the central part of the basin, the fine-grained lacustrine deposits are similar to those exposed to the southeast. East of Granite Creek (pl. 1, 1,345,000 N., 360,000 E.) these deposits are overlain by basalt that is probably about contemporaneous with the basalt north of Prescott and with basalt to the east (pl. 1, northeast corner). The eroded edges of thin nearly horizontal flows in the northeast corner suggest that these flows spread out westward on a relatively level surface (pl. 1, sec. A–A') after the basin was largely filled. At one place (1,354,600 N., 394,000 E.) a tuff bed beneath basalt contains large white rhyolite pumice lapilli; the tuff is identical lithologically with tuff that underlies the upper basalt flows on the south side of Glassford Hill. The contemporaneity of the rhyolite tuffs, however, has not been proved.

Basalt at the headwaters of the Verde River (Sullivan Lake, pl. 2) also appears to rest on basin deposits. The continuity of the basin and its deposits northwest and southeast of Sullivan Lake, however, cannot be proved because of absence of subsurface data. Certainly the basin is much narrower south of Sullivan Lake than elsewhere, if the small exposures of Paleozoic rocks east and west of Del Rio Ranch represent the margins of the basin; the Paleozoic rocks could be xenoliths in andesite. Basalt near Sullivan Lake is part of the basalt northeast of the basin, which to the east is underlain by older gravel that contains andesite fragments at the top.

The relationships of the upper Tertiary(?) rocks of the basin to older gravel and to andesite are uncertain. The andesite plug south of Glassford Hill and the flow on the northeast side of the Dells Granite, however, are considered contemporaneous and are interpreted as probably older than the upper basalt flows of Glassford Hill.

The deposits in Chino-Lonesome basin appear to be the result of continuous and contemporaneous deposition in a single basin, but this cannot be proved or disproved because of the extensive cover of Quaternary pediment gravel and alluvium. This cover masks possible structural discordances or erosional unconformities within various parts of the basin.

The sedimentary rocks mapped as part of the Hickey Formation in the southwestern part of the Jerome area are unquestionably the same as the sedimentary rocks in the southeastern part of the Prescott quadrangle and probably the same as those in the basin as a whole. The sedimentary record for the most part indicates drainage into the basin—the coarser material is near the

EXPLANATION

Base of the middle basalt flows (shaded);
solid line where underlain by orange tuff
(lined pattern) (outcrop width greatly
exaggerated)

Fault
*Dashed where approximately located;
queried where doubtful; U, upthrown
side; D, downthrown side*

Structure contour
*Drawn on base of the middle
basalt flows*

• 5300
Altitude of base of the middle(?) basalt
flows in down-faulted block

EXPLANATION

Base of the upper basalt flows (shaded);
underlain by tuff and gravel

Structure contour
*Drawn on base of the upper
basalt flows*

Outline of base of basalt of Glassford Hill
• 5850
Altitude of basalt-granite contact
• 5500
Altitude of basalt-alluvium contact, base
concealed
• 5500
Altitude of contact of basalt with under-
lying cinder cone

FIGURE 24.—Structure contour of the base of basalt flows of late Tertiary(?) age north of Prescott. Upper map: base of the middle
basalt flows, showing outcrops of underlying orange tuff; lower map: base of the upper basalt flows.

margins—but other drainage directions east of the Prescott area may mean that the sediments do not all belong to the same period. In Tex Canyon (pl. 4, 1,304,000 N., 435,000 E.) the gravel is composed chiefly of Paleozoic rocks, which must have come from the north, possibly when drainage was southwestward into Chino-Lonesome basin. On the other hand, along the eastern margin of Lonesome Valley (roughly between 1,295,000 N. and 1,300,000 N. and between 410,000 E. and 420,000 E.) and farther east, the gravel contains fragments of alaskite that must have come from the southwest, possibly after the basin had been filled sufficiently for them to be carried across. A northward drainage, possibly before formation of the basin, is indicated by gravel beneath basalt on Kendall Peak (pl. 4, 1,330,000 N., 430,000 E.); this gravel is composed solely of Precambrian fragments, although Paleozoic rocks lie a short distance to the north. In the Jerome-Clarkdale area north of Kendall Peak, gravel beneath basalt of the Hickey Formation filled northward-draining channels (Anderson and Creasey, 1958, p. 57, 58). Lehner (1958, p. 554) considered it to be possibly correlative with scattered remnants of once extensive gravel deposits beneath basalt on the Colorado Plateau (Koons, 1948; Price, 1950); if so, this gravel may be considerably older than the gravel in the southern part of Chino-Lonesome Valley.

It is tempting to correlate the thick sequence of volcanic rocks in the Chino artesian basin (pl. 1, secs. A–A', F–F'; pl. 2, secs. H–H', J–J'; table 12) with the thick sequence of basalt of the Hickey Formation on top of the Black Hills. If it is downfaulted Hickey, then the overlying basin deposits may have accumulated after post-Hickey faulting. The basalt mapped as Hickey west of Coyote fault apparently is the same as the basalt in the east-central part of the area (pl. 4, sec. B–B'), which is tentatively correlated with the basalt that overlies sedimentary rocks of the basin to the west and southwest (pl. 1, sec. A–A'). If basalts of two ages are present, they have not been distinguished.

The many similarities between Chino-Lonesome basin and Verde basin and their deposits suggest a correlation. Arching of the Black Hills and major movement on the two bounding faults undoubtedly occurred at the same time and may have resulted in simultaneous formation of the two basins. Both basins were filled with fanglomerate and finer fluviatile and lacustrine deposits interbedded with basalt flows. The basin deposits have since been cut by pediments, and the pediments themselves have been dissected during a more recent cycle of erosion. The Verde Formation contains Silicoflagellate- or Heliodiscoster-like forms (E. B. Leopold, written commun., 1958) similar to those in fresh-water lime-

stone in the Paulden quadrangle (see p. 80, this report), but it contains an abundance of limestone and a paucity of rhyolite tuff compared with the deposits in Chino-Lonesome basin. Paleozoic limestones surround much of the Verde basin but are absent around much of Chino-Lonesome basin; this difference may account for the difference in carbonate content in the two basins. Although rhyolite tuff had not been previously reported from the Verde Formation, some was recovered from three drill holes (A. R. Still, oral commun., 1956).

The occurence of rhyolite tuff in the Hickey Formation (Lehner, 1958, p. 553–554; Anderson and Creasey, 1958, p. 56) also suggests a correlation of the Hickey with the deposits in Chino-Lonesome basin. On the one hand, contemporaneity of rhyolite tuffs has not been proved, and on the other hand, the rhyolite tuff in the Hickey is located in places where its inclusion in the Hickey might be questioned (pl. 4, 1,376,000 N., 407,500 E. and 1,305,000 N., 436,800 E.).

No definite conclusions as to stratigraphic relations and correlations of the upper Tertiary(?) rocks have been made as a result of the present study. The foregoing discussion is an attempt to point out some of the difficulties in correlating these rocks with formations to the east. Some of the problems will undoubtedly be solved by more fossil finds, by determinations of the potassium-argon age of biotite in volcanic rocks, and by other methods of study now being developed. The situation may be more complex than is suggested by the two formations now recognized to the east.

QUATERNARY DEPOSITS

The Quaternary deposits include Pleistocene pediment and younger terrace gravels and Recent gravel and alluvium. In Chino Valley, both east and west of Granite Creek, and in many other places, pediment and terrace gravels and the Recent material grade imperceptibly into one another. The Recent material has been mapped separately only along larger gulches and washes.

PLEISTOCENE GRAVELS

DISTRIBUTION

Pediment gravels at one time covered much of the Prescott-Paulden area. The largest remnant (figs. 28, 29) lies east of Glassford Hill; smaller patches remain, mainly around the margins of the basin. Gravels cap flat-topped hills—remnants of the main pediment—that form a row on each side of Granite Creek from the Granite Dells northward to the north side of Chino Valley. In the relatively flat country southwest and east of Drake (northern part of pl. 2), pediment or terrace gravels are difficult to differentiate from gravels of late Tertiary(?) age. Younger terrace gravels are

widely distributed along most of the gulches that cross the upper Tertiary(?) sedimentary rocks, especially along Lynx Creek and the Agua Fria River valleys (pl. 1).

THICKNESS AND STRATIGRAPHIC RELATIONS

The Pleistocene gravels are veneers on pediment and terrace surfaces. They are generally 0–25 feet thick but locally are as much as 50 feet thick.

The pediment gravels are about conformable to the nearly horizontal upper Tertiary(?) rocks but in a few places overlie them with an angular unconformity of 2°–3°. The pediment gravels overlap the upper Tertiary(?) rocks onto the Precambrian and Paleozoic rocks in a few places on the north and northeast sides of the basin and, locally, in the southern part—for example, north of Green Gulch and west of Lynx Creek (pl. 1, between 1,285,000 N. and 1,291,000 N.; near 380,500–381,000 E.; and near 1,292,000 N., 361,000 E.). They are overlain by Recent gravel and alluvium only near hills, such as Glassford Hill.

The younger terrace gravels overlie the upper Tertiary(?) deposits but at altitudes lower than the pediment gravels in any one area. They are locally overlain by Recent gravel and alluvial and colluvial material.

LITHOLOGY

The Pleistocene gravels are a heterogeneous mixture of boulders, cobbles, pebbles, and finer grained material derived from Precambrian, Paleozoic, and upper Tertiary(?) rocks. Cobbles and boulders of alaskite and gabbro as much as 8 feet long are not uncommon in the southern part of the area, where other Precambrian rock fragments are pebble to cobble sized. Away from the southern margin of the area, few fragments are larger than cobbles, and on the terraces few are larger than pebbles and small cobbles. Sorting is characteristically poor, but some material is sorted. The color ranges from dusky red and grayish brown through lighter shades of brown and gray. Most pediment gravels are dark red or brown, but some pediment gravels and many terrace gravels are lighter colored. On aerial photographs the pediment gravels on the hills that parallel Granite Creek and on the large pediment remnant east of Glassford Hill resemble, in their dark color, basalt-capped hills. The dark color is due to iron oxide coating on quartz and other grains of the matrix. These dark pediment gravels contrast markedly with the underlying light-colored silt, clay, and marl of the upper Tertiary(?) deposits. Other dark-colored gravels are aprons of basalt or andesite around many volcanic hills—for example the apron on the northeast side of Glassford Hill (fig. 14). Some of these aprons are pediment gravels, but many are more recent deposits.

In the southern part of the area most of the gravels are composed of Precambrian rocks that were derived from the south or west or from reworking of the upper Tertiary(?) rocks. Along the eastern margin (pl. 1) the gravels contain Precambrian and Paleozoic rocks that were derived from the east. In the northern part of the area (pl. 2) the gravels are composed of Paleozoic and less abundant Precambrian rocks or of upper Tertiary(?) volcanic rocks. Near basalt or andesite masses, volcanic fragments are very abundant but generally become scarce away from the volcanic rock outcrops. The gravels contain fragments of Mazatzal Quartzite near outcrops of this formation and for some distance to the northeast of these outcrops, where they have in part been derived from upper Tertiary(?) gravels that contained fragments of the quartzite.

In the southern part the terrace gravels are subangular to subrounded. Lack of rounding is due in part to the strongly foliated or jointed character of the Precambrian rocks. Angular cobbles and boulders in gravels near the southern margin of the basin probably represent upper Teritary(?) material that accumulated on steep alluvial fans and that was let down during erosion of the fanglomerate without being moved far. The large boulders of alaskite and gabbro on flat pediment surfaces several miles from higher Precambrian hills probably attained their present positions in this way, although they could have been carried there during flash floods.

RECENT ALLUVIUM

DISTRIBUTION

The distribution of the larger areas of Recent alluvium is shown on plates 1 and 2. In addition narrow ribbons occur along most of the smaller gulches and washes, especially where they cross the upper Tertiary(?) or some areas mapped as Pleistocene gravels. Finer grained alluvium covers the flats bordering drainage lines; coarser material is in the stream beds, and both coarse and fine colluvial material covers slopes between pediment or terrace surfaces and the valley bottom. Andesitic and basaltic alluvium surrounds hills of upper Tertiary(?) volcanic rocks, effectively conceals underlying rocks, and merges with pediment and younger gravels.

THICKNESS AND STRATIGRAPHIC RELATIONS

The thickness of the alluvium varies, and its maximum thickness is unknown. Presumably the deposits are thin, as most streams are degrading, but where there is an abrupt decrease in gradient, small alluvial fans are being built up. This is especially true east of Glassford Hill, where small gullies descend abruptly from the

pediment surface to the alluvial flat along the Agua Fria River and its tributaries. Where gullies dissect the alluvial flats, 5 to 10 or, locally, 20 feet of fine-grained alluvium is exposed. The alluvium is separated from the underlying upper Tertiary (?) lacustrine deposits by a few inches to a few feet of reddish-brown gravel. Along Coyote Wash (pl. 1, 1,317,000 N., 391,500 E.) a gully 25 feet deep in the lacustrine deposits has exposed an older gravel-lined channel that is filled with fine-grained alluvium (fig. 25). River gravels where placered along Lynx Creek, are as much as 25 feet thick.
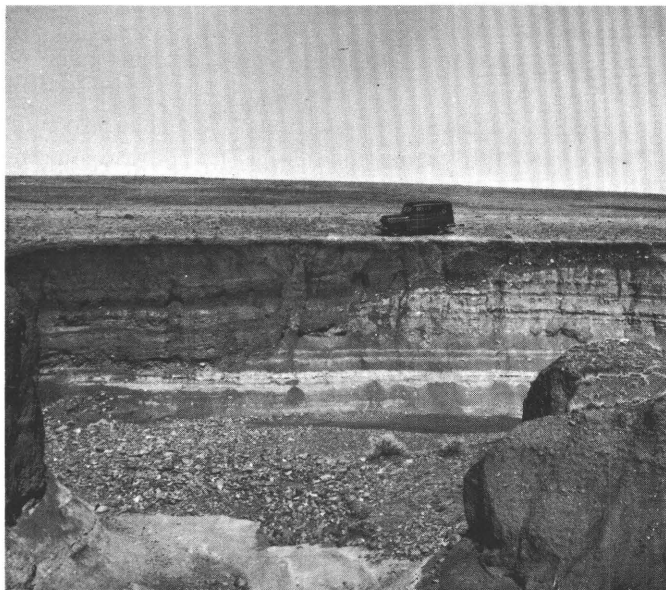
FIGURE 25.—Recent alluvium in channel cut in fine-grained sedimentary rocks of late Tertiary(?) age and exposed in a recent gully along Coyote Wash (pl. 1, 1,317,000 N., 391,500 E.). To the left, the channel extends nearly to the bottom of the gully. Rounded cobbles line the bottom of the channel, but much of the overlying material is fine-grained alluvium—largely clay. Note the light-colored well-bedded character of the older deposits, which consist of sand, silt, clay, and marl; some marly layers are nearly white.

LITHOLOGY

The fine-grained alluvium is gray or yellowish brown to brownish black. The darker color is characteristic of alluvium derived from upper Tertiary (?) basalt or from some of the mafic Precambrian rocks. Light yellowish-brown colors are common along the Agua Fria River and its tributaries, where the alluvium has been derived from fine-grained sedimentary rocks of late Tertiary (?) age. Much of the alluvium is composed of clay, silt, and fine sand, and locally it contains abundant plant material. Coarser material forms thin layers or fills channels.

The coarser material, which is concentrated along drainage channels, is composed of sand, pebbles, cobbles, some silt and clay, and scattered boulders several feet in diameter. Many fragments are subrounded.

Sorting and stratification are generally absent. Coarse colluvial gravels cover some slopes below pediments and may largely conceal underlying fine-grained sedimentary rocks of late Tertiary (?) age (fig. 28).

AGE

The pediment gravels were laid down after the upper Tertiary (?) rocks were deposited and the upper part removed by erosion. They were probably deposited after the last faults that cut the younger of the upper Tertiary (?) rocks, although a fault scarp probably of Recent age can be traced on aerial photographs along the north side of Big Chino Wash for more than 20 miles from the northwestern part of the area (pl. 2, 1,437,200 N., 330,000 E.). On the basis of the amount of dissection that the pediments have undergone, of the amount of downcutting through Precambrian rocks below the pediment surface, and of the presence of mammoth teeth in younger terrace deposits, the pediment gravels are considered Pleistocene in age.

The terrace gravels are younger than the pediment gravels, and some of the lowest ones may be of very recent age. A mammoth tooth, found by G. H. Hazen, Water Resources Division, U.S. Geological Survey, in terrace gravels 50–100 feet above Granite Creek (pl. 1, near 1,301,200 N., 344,200 E.) was identified by C. L. Gazin of the National Museum as *Mammuthus* sp.; it indicates a Pleistocene or possibly a late Pleistocene age. A mammoth tooth (?) was found in clay in the southeastern part of the area (pl. 1, 1,309,400 N., 399,300 E.) during the present investigation. A Pleistocene horse (genus *Equus*) was reported by Hay (1927, p. 55) from Lynx Creek (location not given) probably from alluvium deposited during erosion of the upper Tertiary (?) rocks.

Some alluvium is Recent in age. Small nonpetrified mammal bones, associated with the remains of bugs, twigs, droppings, and carbonized wood fragments, occur in silt and clay in the bottom of valleys tributary to the west side of the Agua Fria River (southeast part of pl. 1) and in coarser gravel underlying the alluvium 5–10 feet below the top of the gullies.

STRUCTURE

The major structural features in the Prescott-Paulden area are tight folds, shear zones, and strike faults produced by major deformation in Precambrian time; normal faults, sharp monoclines, and gentle folds were produced by less severe disturbances during the period since the close of the Paleozoic Era.

STRUCTURE OF OLDER PRECAMBRIAN ROCKS

Precambrian deformation in the Prescott-Paulden area may have been the result of one period of orogeny

which included intrusion of igneous rocks, preceded and followed by deformation. It produced isoclinal folds, foliation parallel to bedding, and strike faults in many of the Alder Group rocks and foliation and shear planes in intrusive rocks (S-tectonites). In the Mazatzal Quartzite, deformation produced open folds (B-tectonites) and no foliation.

The structure of the Precambrian rocks of Arizona has been summarized by Anderson (1951) and by Anderson and Creasey (1958, p. 45 and 62). They stated that the degree and type of metamorphism of the older Precambrian rocks varies from place to place and ranges from thermal metamorphism related to granitic intrusions to mild or intense dynamic metamorphism but that the structures are similar in a broad way. The folds trend north, northwest, and northeast and indicate an east-west compression that may have occurred during a single period of orogeny.

Until the recent proof of a pre-Alder granitic intrusion (see footnote 7, p. 49), only one major orogeny in Arizona during the Precambrian had been proved; it separated older Precambrian rocks from younger Precambrian rocks in northwestern and southeastern Arizona. In central Arizona, where younger Precambrian rocks are absent, it separated older Precambrian rocks from Paleozoic rocks. Wilson (1939) called it the Mazatzal revolution, because it involved the Mazatzal Quartzite. He stated that no pre-Mazatzal deformation or granite has been recognized, although a minor unconformity separated the quartzite from older rocks. Hinds (1936, p. 100), on the other hand, suggested two periods of orogeny and accompanying granitic intrusion: one prior to and the other after the accumulation of the Mazatzal Quartzite.

It is unlikely that only one period of major orogeny occurred in the tremendous length of time represented by the Precambrian, but little evidence for more than one has been found. In the Paulden quadrangle the abundance and size of the quartz pebbles in the conglomeratic facies of the Mazatzal Quartzite, the very low grade of metamorphism of the quartzite, and the absence of granitic rocks or quartz veins intruding the quartzite suggest that the Mazatzal was deposited after the major deformation and granitic intrusions in this area. Because the quartzite is in fault contact with the Alder Group, the difference in degree and type of deformation and metamorphism does not prove a pre-Mazatzal orogeny.

STRUCTURE OF THE ALDER GROUP

Alder Group rocks occur in small windows in younger rocks or are so isolated by intrusive rocks or separated by faults or zones of intense shear that stratigraphic relations are uncertain. Consequently, the broad structural pattern has not been unraveled, although structural continuity apparently exists within individual "blocks."

Northeast-trending structures occur in the discordant Chaparral fault zone, a zone characterized by distributive shear and bounded by Spud and Chaparral faults (pl. 1, southeast corner). Elsewhere, Precambrian deformation produced generally north-trending steeply dipping structures: (1) isoclinal folds, strike faults, and foliation parallel to bedding in the Alder Group and (2) foliation and shear planes in intrusive rocks. Most postintrusion structures are about parallel to preintrusion ones. The probable large displacement on the Chaparral fault zone makes any correlation of the stratigraphic units and of the structure on the two sides of the zone highly questionable. For this reason, the structures within and west of the shear zone are discussed separately.

Deformation, which may have been part of a single orogeny, probably preceded and followed intrusion of igneous rocks. Xenoliths of foliated volcanic rocks in unfoliated Government Canyon Granodiorite prove that some structures are preintrusive. The preintrusion structures in the Alder Group are isoclinal folds and foliation that, except in the noses of folds, are about parallel to bedding. Postintrusion structures are foliation, distributive shear, and strike faults. The north-trending structures may have been produced during successive surges, and the northeast-trending structures in the Chaparral zone may have formed slightly later. West of the Chaparral zone postintrusion structures in intrusive rocks are parallel to structures in the volcanic rocks that are presumed to antedate the intrusive rocks. Northeast-trending foliation and shear planes in volcanic and intrusive rocks in the Chaparral zone are discordant to the north-trending structures both east and west of the shear zone. A few minor zones of northeast-trending shear cut north-trending structures in volcanic rocks east and west of this zone; none were observed cutting north-trending structures in intrusive rocks outside the zone. The relation of north- to northeast-trending postintrusion structures, therefore, is uncertain.

STRUCTURE EAST OF THE CHAPARRAL ZONE

The Alder Group east of the Chaparral zone includes the Spud Mountain Volcanics in the southeastern corner (pl. 1), the Indian Hills Volcanics in the east-central part (pls. 1, 2), and probably the unnamed tuffaceous rocks of the Alder(?) Group farther north (pl. 2). The Spud Mountain and Indian Hills Volcanics are part of a large structural block in the western part of

the Jerome area (Anderson and Creasey, 1958, p. 71–74). The unnamed tuffaceous rocks of the Alder(?) Group are separated from these volcanics by intrusive rocks.

Spud Mountain Volcanics.—The Spud Mountain Volcanics were isoclinally folded prior to the formation of the northeast-trending Chaparral zone. Near Spud Mountain the strike of bedding and early foliation ranges from N. 20° E. to N. 45° W., but the general strike is about north. On Spud Mountain the strike swings from north to N. 45° W., and close to the Spud fault it swings back to the northeast. As bedding and foliation both make the swing, they were probably folded by drag on the major fault zone. Narrow zones of foliation, zones of breccia, or single planes of shear that strike N. 45° E. to N. 65° E. near Spud Mountain are clearly at an angle to early foliation. The structure near Spud Mountain is probably an anticline; a syncline may lie to the east (pl. 1, sec. *E–E'*); both probably plunge gently southward. No evidence of the direction that tops of beds face was found near Spud Mountain, but Anderson and Creasey (1958, p. 72) found sufficient evidence nearby to propose this interpretation of the structure.

Indian Hills Volcanics and unnamed tuffaceous rocks of the Alder(?) Group.—In the east-central part of the Prescott-Paulden area, lithologic units trend north and northwest, as do sparse bedding in the volcanics and foliation in volcanic and intrusive rocks. Dips are vertical to steeply east or west. Small drag folds in the tuff unit of the Indian Hills Volcanics plunge north 25°–35°, but drag folds in the unnamed tuffaceous rocks plunge south 45°–60°. Although foliation and drag folds in the volcanics are for the most part parallel to foliation and mineral streaking in the adjacent intrusive rocks, the drag folds and some foliation are considered preintrusion because foliation and drag folds in the unnamed tuffaceous rocks in upper King Canyon (1,389,500 N., 382,400 E.) are cut at a slight angle by an alaskite dike.

STRUCTURE WEST OF THE CHAPARRAL ZONE

Green Gulch Volcanics.—Lithologic units and structures in the Green Gulch Volcanics trend northward except next to the Chaparral fault. Here gabbro (mostly south of the map area) and the volcanics have been dragged into the fault, and northeast foliation cuts the earlier structures in the volcanics. West of the fault, bedding and foliation are steep and, with few exceptions, dip west. Scattered determinations of the directions in which tops of beds face suggest that, except for minor reversals, the beds face west. Sparse *b* lineation, formed by intersection of foliation and bedding, plunges north 10°–25°, parallel to the plunge of minor drag folds. The

a lineation was observed in a few places. Steeply north-plunging crenulations in foliation and bedding are probably related to later cross fractures. Based on the few determinations, the formation (at least east of 386,000 E.) is interpreted as the east limb of a north-plunging tightly folded syncline. Lineation in the western outcrops of the formation (near and east of 380,000 E.) plunges south or southwest 40°–75°. Some of it is streaking on a plane of shear that is postintrusion in age; it is parallel to sparse lineation in associated intrusive rocks. Lenticular and dikelike masses of alaskite, aplite, and gabbro, many too small to show on the geologic map, trend northward, parallel to the structural and lithologic trends in the tuffaceous rocks. Some of these intrusive rocks have a north-trending foliation.

Texas Gulch Formation.—The largest structural unit within the Prescott-Paulden area is the Texas Gulch Formation in the south-central part. The formation is bounded on the east by intrusive rocks and apparently separated on the west by a sheer zone from the unnamed basaltic flows of the Alder(?) Group. Data suggest a south-plunging syncline, within which are numerous smaller isoclinal or near isoclinal folds. Reasons for assuming a major syncline are as follows: (1) Lineation, believed to be the *b* direction of the structural coordinate system and related to deformation that produced the folds, plunges southward; (2) the outcrop of the formation progressively widens to the south; (3) tops of beds on the east generally face west (fig. 4); and (4) unmapped beds of gray staurolite(?) schist and conglomerate and float of jasper-magnetite are present on the west (near 1,285,400 N., 353,000 E.). Jasper-magnetite and some of the conglomerate are identical to the eastern beds of jasper-magnetite and conglomerate; the schist may represent metamorphosed gray slate such as is associated with the eastern beds of conglomerate.

Lineation consists of plunge of minor drag folds, intersection of cleavage and bedding, and elongation of pebbles. The pattern of drag folds, graded bedding, channeling, and cleavage bedding relations give consistent information on the direction in which tops of beds face, especially in the southern part of and immediately west of the unit containing jasper-magnetite beds. North of 1,285,000 N. the pattern of drag folds indicates numerous reversals of dip. Identical beds of conglomerate on both sides of the unit containing jasper-magnetite beds complicate the picture of a south-plunging syncline. The conglomerate bed west of this unit has been repeated by folding. Along the southern border of the area (near 1,274,000 N., 358,000 E.), rhyolite crystal tuff caps small hills, and its contact with the underlying andesitic rocks plunges south as do minor

folds in the tuff. Foliation, lineation, and boudinage structure in a few lenticular and dikelike masses of intrusive rocks, too small to map, indicate postintrusion deformation.

Because outcrops of the Texas Gulch Formation along Granite Creek south of the Verde River (pl. 2) are too small, its structure or relations to the formation in the southern part of the area cannot be determined. Beds in the western outcrops strike east and dip south, whereas foliation trends north. In the eastern outcrops, drag folds plunge 50°–70° S. Intense north-northeast foliation parallels the fault that brought the formation in contact with the Mazatzal Quartzite, but the Mazatzal is not foliated.

Unnamed volcanic rocks of the Alder(?) Group.— The unnamed basaltic flows near 350,000 E. in the southern part of the area (pl. 1) are separated from the Texas Gulch Formation by a shear zone. All the other masses of unnamed volcanic rocks in the southern part of the area are separated from one another by intrusive rocks. Foliation and zones of distributive shear in igneous rocks that intrude the volcanic rocks are about parallel to foliation in the volcanics.

Between the largest mass of gabbro on the west and alaskite porphyry on the east, deformation of volcanic and intrusive rocks was erratic. The unnamed basaltic flows and much of the alaskite are nonfoliated, except along the east and west margins and along narrow zones within them. Distributive shear was more intensive in and adjacent to the unnamed tuffaceous rocks, especially in the northwestern part, where deformation resulted in mechanical mixing of the rocks and in the formation of narrow dikelike masses of alaskite augen gneiss and, locally, of mylonite. Except in one area near 1,291,000 N., 376,000 E., where trends are north-northwest, bedding, lithologic units, and foliation in volcanic and intrusive rocks trend northward and are vertical or dip 65° or more west. A few small north-plunging drag folds in tuff may be related to earlier deformation. Most lineation is postintrusion, it plunges south 35°–60° and consists of mineral streaking and intersection of two cleavages or of bedding and foliation.

In the unnamed tuffaceous rocks along 364,000 E., bedding and foliation strike northward and dip steeply west or are vertical. The pattern of a few north-plunging drag folds indicate east-facing beds. North of 1,292,000 N., steeply south-plunging lineation of postintrusion origin parallels lineation in the Prescott Granodiorite to the west. East and west contacts with intrusive rocks are largely narrow zones of shear.

Bedding, flow-banding, and foliation in the unnamed basaltic flows near 350,000 E. trend northward and are vertical or dip more than 80° west. The direction that tops of beds face was determined in only one place where graded bedding in a tuffaceous bed indicated that the bed faces east. Breccia fragments have been stretched in some beds, but considerable areas of the rock are massive. Deformation may have been preintrusion, as most of the gabbro is massive.

The northern part of the westernmost mass of unnamed volcanic rocks trends northward, except at its northern end, where its trend is northeast at an angle to foliation in the volcanics. The northeast trend is probably due to a fault or shear zone. A pronounced lineation plunges gently south in places; and elsewhere a faint lineation plunges steeply north or south; the structural significance of the lineation is unknown. In the southern part of the volcanic rocks, foliation and bedding trend northeast; the trend becomes more easterly to the south. Less intense postintrusion deformation in the area may account for the more easterly strikes. Lit-par-lit injection of granodiorite along straight and contorted beds and inclusions of schistose and folded volcanics in the granodiorite prove deformation occurred prior to intrusion of the granodiorite.

The unnamed basaltic flows north of the large outcrop of Mazatzal Quartzite (pl. 2) are mostly massive but are locally cut by a very faint foliation. The volcanics are probably separated from the quartzite by a fault.

STRUCTURE IN THE CHAPARRAL ZONE—THE CHAPARRAL VOLCANICS AND CHAPARRAL AND SPUD FAULTS

Rocks of the Chaparral Volcanics are separated from other formations by faults, and their stratigraphic position in the Alder Group is not known. The volcanics and associated intrusive rocks probably occupy a wide fault zone that is characterized by distributive shear. The bounding faults, foliation, and lithologic units trend northeast at an angle to the earlier northward trends in adjacent rocks. Deformation within the zone was so intense that some alaskite was reduced to augen gneiss or to a dense mylonite. Most contacts are mechanical, and volcanic and intrusive rocks grade into one another owing to mechanical mixing.

The volcanic rocks were probably folded during an earlier period of deformation that produced north-trending structures in adjacent rocks. This early period is suggested by a faint north-trending foliation in the northwest part of the volcanics, and by contorted bedding and bedding at an angle to the northeast foliation locally found in tuff that lies between alaskite and the Prescott Granodiorite.

Northeast-trending foliation is the dominant structural feature within the zone. It dips 65° W. to 80° E., the dips to the west predominating. Lineation in

both volcanic and intrusive rocks is related to the deformation that produced the northeast structure. It plunges southward 10°–35° and consists largely of mineral streaking, but some of it consists of the plunge of minor drag folds. A few north-plunging axes of folds in crenulated foliation are due to later cleavage. In the eastern andesitic tuff, a gentle north-plunging pencil structure was formed by the intersection of northeast foliation and later cleavage.

The Chaparral and Spud faults (pl. 1, secs. *B–B'*, *E–E'*) bound the Chaparral zone. This zone strikes about N. 30° E. within the map area, but to the southwest the trend is about N. 50° E. In detail within the map area, the Chaparral fault trends about N. 25° E. and the Spud fault trends about N. 35° E. The faults may dip steeply west if their dips are parallel to the dip of foliation in volcanic and intrusive rocks within the zone. The northwest side of the zone moved northeastward relative to the southeast side, and in detail similar drag is found along all the narrow zones of late foliation within and adjacent to the Chaparral zone. Displacement may be as much as several miles.

To the northeast the fault zone is buried and does not reappear near Indian Hills (Mingus Mountain quadrangle, 1,324,000 N., 410,000 E.) along its strike extension. A fault zone of this magnitude would be unlikely to die out in this short distance; unless offset by a fault, its strike must continue to change to a more northerly and then a northwesterly direction These changes would bring the fault zone west of the low hills in the east-central part of the area, where the structures trending north-northwest in the volcanic and intrusive rocks may be related to the zone.

STRUCTURE OF THE MAZATZAL QUARTZITE

Precambrian deformation of the Mazatzal Quartzite (pl. 2) produced open folds and local zones of small tight folds and small-scale thrusts but no foliation. As the formation is separated from Alder Group rocks by faults (1,402,300 N., 346,700 E.; and 1,393,300 N., 353,500 E.), its stratigraphic position and the relation of its structure to that of the Alder Group are unknown.

The major structures in the Mazatzal Quartzite (fig. 5; pl. 2, sec. *G–G'*) are two northeast-trending anticlines that plunge gently southward. The anticlines are separated by a fault. The fault is not exposed, but its trend and approximate location are determined by structural discontinuity of the rocks on the two sides of the fault and by the close proximity of discordant outcrops of the upper argillite. The fault presumably continues northwest and separates the Mazatzal from the unnamed basaltic flows of the Alder(?) Group (1,393,300 N., 353,500 E.).

A conspicuous feature of the western anticline is that

it plunges to the north on the south end of the exposure and that its eastern limb in this area swings abruptly to the southeast and has nearly vertical dips. Similarly, the western limb swings away from the axis toward the southwest. These features suggest that the original structure, formed by northwest-southeast compression, was later deformed by forces acting at right angles to the earlier forces. Wilson (1939, p. 1156) explained the steeply upturned structure as caused presumably by a northwest-trending fault to the south whose trace is concealed by alluvium.

The eastern limb of both anticlines is somewhat steeper than the western limb. Dips of the western limbs average about 20° in the eastern anticline and 30° in the western anticline, except in the northwestern exposures, where dips average about 55°.

East of the crest of the western anticline, a small thrust fault (Wilson, 1939, pl. 3, fig. 1, p. 1156) cuts the quartzite along Granite Creek (1,386,600 N., 355,000 E.; indicated by symbol, fig. 5). Slickensides and some breccia formed, and small drag folds lie above the plane of the thrust to the east (1,386,000 N., 355,300 E.) and beneath the plane of the thrust to the west (1,386,700 N., 354,700 E.); displacement is probably minor.

Along the north-trending part of Granite Creek (1,389,600 N., 351,300 E. to 1,391,200 N., 351,000 E.) and for several hundred feet to the east, the rocks are shattered (the area is indicated by joint symbol on fig. 5). Slickensides formed on small thrust faults that parallel, or nearly parallel, bedding planes; breccia occurs along steeply dipping joints. Except in one place the beds dip consistently about 30° W. and can be traced across brecciated joints. This shattered area may be the place where Wilson (1939, p. 1155) believed that his measured section was ended by a fault. It is doubtful, however, that major displacement occurred; the upper argillite a short distance to the west has not been displaced, and the beds exposed to the south in the west-flowing part of Granite Creek are not affected. The shattering is too irregular in pattern to have been caused by a fault; it may be due to intrusion of an underlying andesite plug of late Tertiary(?) age or to collapse following withdrawal of andesitic magma.

Steep reversals of dip occur at several places—in the extreme southeastern part, in the southwestern part (near 1,387,000 N., 348,000 E.), and on the east side of Granite Creek at the north end of the shattered zone. Some of these may be due to intrusion of andesite. The one east of Granite Creek is a tight east-trending fold about 200 feet wide. Along the south edge of the fold, beds are vertical and are marked by slickensides, by breccia, and by gouge containing ellipsoidal "pebbles"

of quartzite. The east-trending fold does not continue to the west side of the creek.

The Mazatzal Quartzite formed topographic highs during several periods since the Precambrian; during Cambrian and Devonian times, when both the Tapeats Sandstone and Martin Limestone cut out against it, and during Late Tertiary(?) times, as proved by the presence of pebbles of the quartzite in gravels near Hell Canyon and beneath basalt in the extreme northeast corner of the quadrangle. Much of the quartzite today stands above the surrounding younger formations. Whether it has remained as a monadnock, been exhumed at various times, or been successively uplifted is not known. In places it now stands at least 150 feet above outcrops of the Redwall Limestone. As pebbles of the Mazatzal have not been observed in adjacent Redwall Limestone and as the Redwall does not obviously cut out against the Mazatzal, it seems likely that the area underlain by the quartzite was relatively uplifted in post-Paleozoic times. This conclusion is supported by the steep dips of the upper Martin where it abuts against the Mazatzal south of Granite Creek; these dips may be due partly to compaction and initial dip.

STRUCTURE IN THE INTRUSIVE ROCKS

Most of the structures in the intrusive rocks in the area have been mentioned in the discussion of the structure of the Alder Group. Brief summaries and additional data are given here.

Many of the intrusive rocks have been foliated, in places intensely so; lithologic trends and structures are about concordant to north-trending structures in the volcanic rocks, to northeast-trending structures in the southwestern part, or to the discordant northeast-trending structures in the Chaparral zone. Many intrusive masses form narrow lenticular sill-like or tonguelike masses within the volcanic rocks. Small lenses or tongues of gabbro are about as abundant as basaltic flows for about 1,000 feet west of the tongue of gabbro that partially splits the volcanic rocks near 350,000 E. in the southern part of the area. Discordant-appearing contacts—for example, north and south of the gabbro near 1,289,000 N., 374,000 E.—may be more apparent than real, as narrow prongs of volcanic rocks extend into the gabbro and vice versa owing to injection or to later distributive shear.

Where the intrusive rocks are relatively undeformed, intrusive breccias are widely preserved and indicate magmatic stoping. Good examples can be seen in alaskite porphyry along Charcoal Gulch and along Green Gulch near its junction with Charcoal Gulch in the southeastern part, in the Government Canyon Granodiorite in the southwestern part, and in the Prescott Granodiorite in the east-central part (pl. 1).

Aerial photographs reveal a north-trending lineation in the largest mass of alaskite porphyry and, to a lesser extent, in the largest body of alaskite. This lineation is not particularly evident on the ground; it is probably caused by a greater density of vegetation along faults, joints, or shears because of more abundant soil and water where the rocks are broken. A few north-trending zones of sheared or foliated alaskite separating massive alaskite support this conclusion.

Most gabbro bodies, particularly along their east and west margins, are foliated, and the foliation parallels their northward trends. The two largest masses, however, also have a northeast- to east-trending planar structure, which may be partly caused by crystal settling. Faint foliation, joints, shear zones, and quartz veins parallel to the layering suggest that some of the layering is due to postintrusion deformation and metamorphism. Some postinstrusion structures may be tension and thrust fractures related to deformation that produced the north-trending distributive shear.

Gabbro, Prescott Granodiorite, and alaskite masses within the Chaparral zone were probably dragged into the shear zone and rotated to their present position, although preexisting northeast-trending structures could have guided the intrusions.

Post-Precambrian faults cut the older Precambrian rocks, but where Paleozoic or younger rocks are absent, they are difficult to recognize. Gouge along fault or shear zones is interpreted as indicative of post-Precambrian movement, as gouge apparently was not produced during or before the deformation that formed the Chaparral zone. Gouge, breccia, and shears, some along lineaments that shows up on aerial photographs, were observed between the Government Canyon Granodiorite and the second largest mass of gabbro (north end), in the Prescott Granodiorite in Miller Valley (near 1,292,600 N., 333,000 E.) and about half a mile north (near 1,303,000 N., 324,500 E.) and half a mile west (west of quadrangle) of Forbing Park, and in the Dells Granite near the junction of Routes 89 and 89A. These zones cut some quartz and tourmaline veins; they also parallel north-northeast joints in the Prescott Granodiorite and Dells Granite (fig. 14). The joints may have formed at the same time as the gouge-filled shears, or recurrent movement may have occurred along them. Parallelism of the north-northeast and west-northwest joints in Paleozoic rocks to the north to the major joints in the Dells Granite suggest a common age, but the parallelism may be fortuitous; the joints may be related to cooling and crystallization of the granite. The steeply dipping major system of joints—those trending north-northeast and west-northwest—in the Dells Granite is illustrated on figure 26, which also shows a N. 25° W. nearly ver-

EXPLANATION

0–1 percent   1–2 percent   2–3 percent   3–4 percent   4–6 percent

6–8 percent   8–10 percent   10–12 percent   12–14 percent
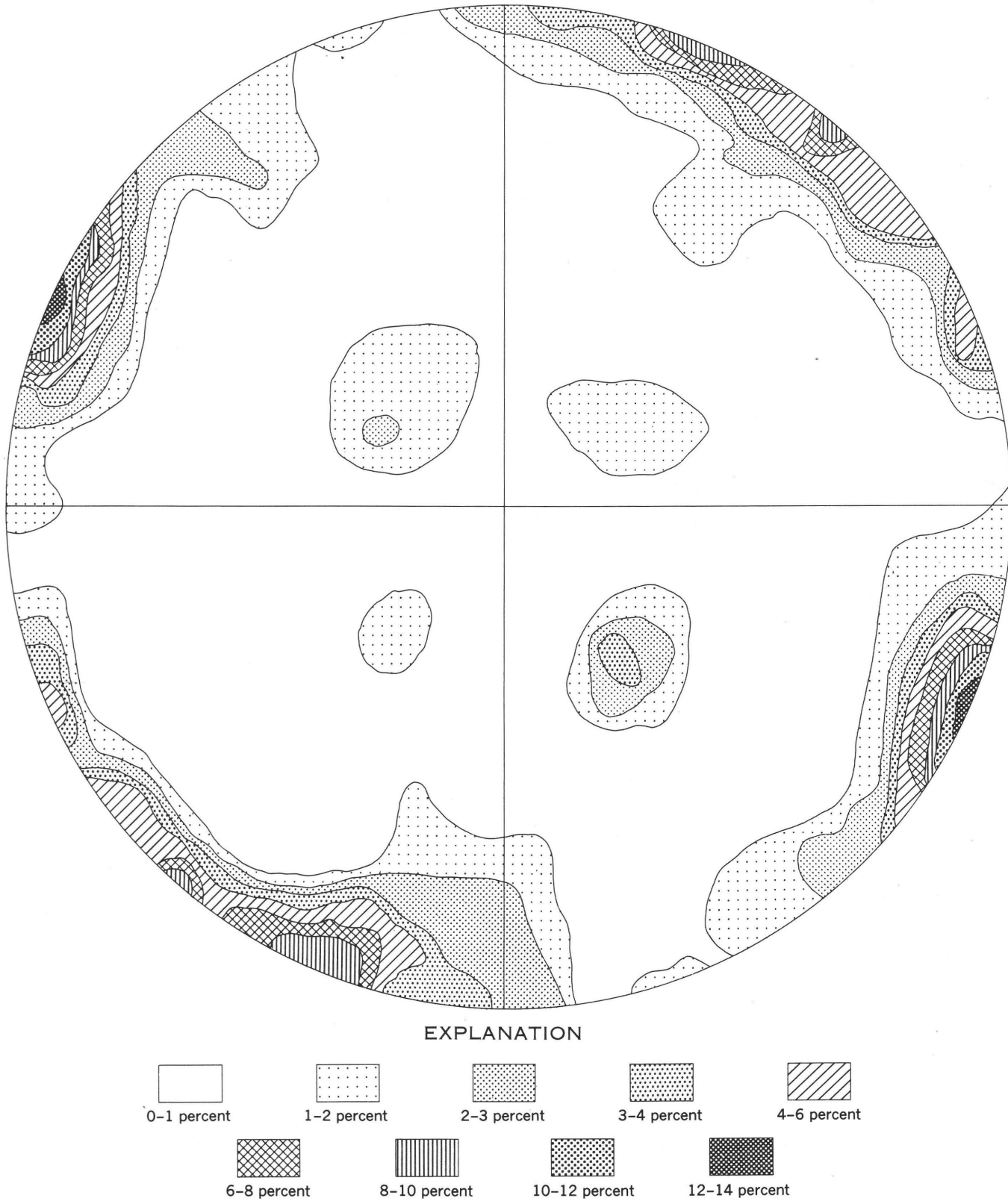
FIGURE 26.—Contour diagram of 274 joints in the Dells Granite; the poles are plotted on the lower hemisphere.

tical set and a few gently dipping (0°–50°) joints that strike about parallel to the major system. The gently dipping joints may be more abundant than appears, because little attention was paid to them in the field.

STRUCTURE OF PALEOZOIC AND CENOZOIC ROCKS

Major post-Paleozoic structural features are shown on the structure contour map of the Paulden, Clarkdale, and Mingus Mountain quadrangles (pl. 5). Structures in the Prescott quadrangle are not shown, because Paleozoic rocks have been eroded from all but the extreme northeast corner. Structures in the Clarkdale and Mingus Mountain quadrangles are included to illustrate the regional setting. The contour of the base of the Redwall Limestone eliminates the effect of the topographic high of Mazatzal Quartzite (pl. 2) that resulted in nondeposition of the Tapeats Sandstone and most of the Martin Limestone. Within the area underlain by the Mazatzal, some irregularities may be due to forcible intrusion of andesite (notably near 1,400,-000 N., 356,500 E.) or to subsidence due to withdrawal of andesitic magma.

Although the Paulden quadrangle lies largely south of the Mogollon Rim, the present boundary of the Colorado Plateau, and most of the younger Paleozoic rocks have been stripped from it, structurally this area belongs to the Plateau province; the rocks are generally flat lying, having a gentle north to northeast dip [13] interrupted by shallow folds, sharp monoclines, and faults.

The general north to northeast regional dip of the Paleozoic rocks of north-central Arizona is interrupted in the Paulden quadrangle (pl. 5). Interruption of the regional dip by west-facing Bull Basin monocline resulted in a northwest-plunging anticline that meets southwest-plunging Black Mesa anticline near the center of the quadrangle. Black Mesa anticline is bounded on the northeast by Limestone Canyon monocline and on the southwest by Big Chino fault or monocline. From Black Mesa anticline the rocks dip gently eastward across the northern part of the quadrangle. The rocks are also deformed along other monoclines and disrupted by faults. Structural relief along the eastern margin is about 3,250 feet; along the northern edge, 2,750 feet; along the southeastern anticline, 1,500 feet; and along Black Mesa anticline, 1,000 feet. Structural relief along the southwest side of this anticline is at least 1,400 feet; and south of here along the western margin of the quadrangle, 1,500 feet.

For purposes of description the headings "Older structure" and "Younger structure" are used. Only

[13] The absence of dip and strike symbols on the map (pl. 2) generally indicates that dips are less than 10°.

those structures that clearly deform the rocks of late Tertiary(?) age are called younger structures.

OLDER STRUCTURE

MONOCLINES

Although smaller in size, monoclines in the Paulden quadrangle exhibit many of the features characteristic of the monoclines of the Colorado Plateau. Many of the terms used by Kelly (1955) in his discussion of monoclines are used in this report; some types of monoclines are illustrated in figure 27.
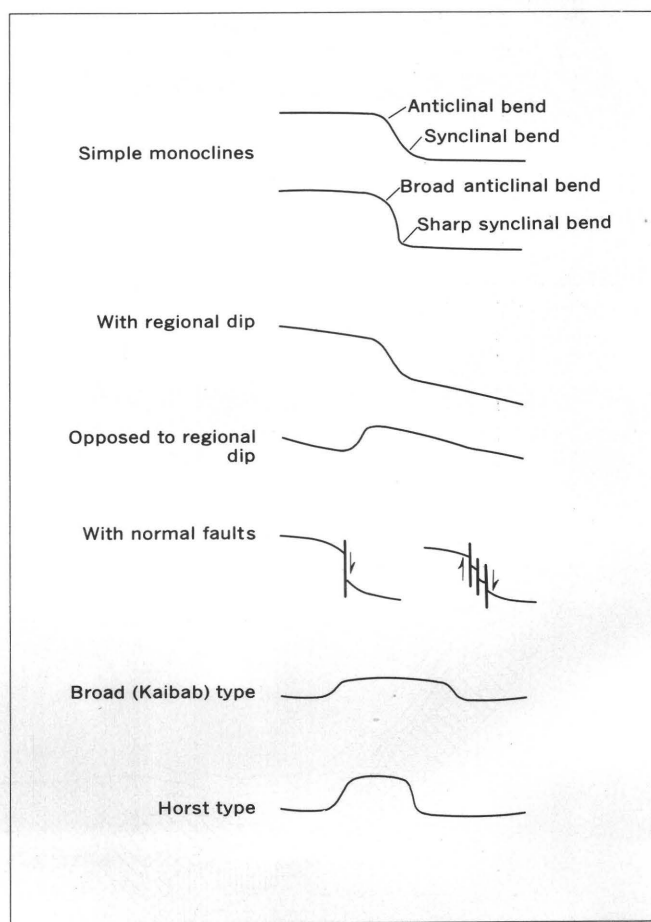
After Kelley, (1955, figure 2)

FIGURE 27.—Variations of monoclines in cross sections.

Monoclines are characterized by great ratio of length to width; the length may be measured in miles, the width in a few hundred feet. Most of the monoclines in the area are exposed for less than 2 miles. The longest one is more than 6 miles long; one has been traced for more than 17 miles, largely northwest of the quadrangle. Most of the monoclines are tight and where poorly exposed may be confused with drag along a fault. Sharpness of flexure, especially of synclinal bend, is characteristic; a bed may change from nearly

horizontal to vertical within a few inches. Anticlinal bends are generally broader. The monoclines are straight, curved, or branching and include double monoclines—broad (Kaibab) or horst types (fig. 27). Most of them trend northwest or north; a few small ones trend northeast to east; they face northeast, southwest, or south. Many are associated with faults. They cannot be traced across Precambrian rocks, and small ones are difficult to trace in massive rocks such as the Redwall Limestone. The Verde monocline is a horst type of structure; Black Mesa anticline might be described as a broad (Kaibab) type of structure.

Limestone Canyon monocline.—Limestone Canyon monocline (pl. 2, secs. *B–B′*, *C–C′*, *H–H′*; pl. 5) lies on what appears to be the northeast side of Black Mesa within the Paulden quadrangle, although to the northwest it actually runs approximately through the middle of the mesa. The monocline faces northeast and has been traced from about half a mile southeast of Lower Limestone Tank (1,452,700 N., 337,300 E.) for more than 17 miles to the northwest. At its northwest end (north of the center of Piccacho Butte quadrangle, fig. 1), it is buried by basalt of late Tertiary(?) age. At its southeast end it is buried by gravel and apparently dies out. Throughout its exposed length the zone of deformation is less than 1,000 feet wide. Martin, Redwall, and Supai beds are exposed along the structure. Dips range from about 30° to vertical; the strata northeast of the monocline are about horizontal or dip gently eastward; those southwest of it are nearly horizontal except south of the southeast end of the monocline, where dips are gently southeast. Structural relief across the monocline is between 300 and 500 feet near and northwest of the quadrangle boundary and decreases to the southeast. The exact amount of structural relief was not estimated, as a known stratigraphic horizon is not exposed in the synclinal bend.

Big Chino monocline or fault.—A major structure, Big Chino monocline or fault, forms the boundary between Black Mesa and the northwestern part of Chino-Lonesome basin; it extends from north of Paulden for at least 26 miles to the northwest. For more than 4 miles northwest of Route 89, the Martin and Redwall strata dip southwest 10°–40°. Many small northwest-trending faults (pl. 2, sec. *C–C′*), most having the northeast side downdropped, however, displace the beds. Northwest of the quadrangle the exposed Paleozoic beds are about horizontal; southwest of here they are buried by upper Tertiary(?) rocks. Conclusive proof of major displacement was obtained from a wildcat oil well (No. 1, sec. 20, T. 18 N., R. 2 E.; 1,430,800 N., 326,200 E.) that penetrated the Tapeats-Martin contact about 1,400 feet below the estimated altitude of

this contact about 2 miles northeast of the well. Whether this structural relief is due largely to faulting or to warping is unknown.

Verde monocline.—The Verde monocline (pl. 2, secs. *J–J′* and *M–M′* to *T–T′*) is a complex branching horst-type (fig. 27) structure that extends from the east edge of the Paulden quadrangle (near 1,403,000 N.) for about 4 miles to the west-northwest. It becomes a fault in the Clarkdale quadrangle, where it is exposed for about 1 mile.

The monocline forming the south side of the horst-type structure faces south and is opposed to the regional dip; that on the north side faces north in the direction of the regional dip. Structural relief is at least 300 feet on the south-facing monocline and is probably less on the north-facing one. Southeast of the Verde River, the south-facing monocline forms a narrow hogback in which the average dip of the beds is 30°–50°. The anticlinal bend involving Precambrian quartz diorite, Tapeats Sandstone, and basal Martin Limestone is well exposed half a mile southeast of the Verde River; the quartz diorite-Tapeats contact in places is almost vertical. The synclinal bend, involving Redwall and Supai beds, is well exposed about 1¼ miles southeast of the Verde River. Near the Verde River (1,410,500 N., 388,000 E.) the monocline splits into two branches, one trending slightly south of west, the other continuing northwest for about 2,000 feet, then swinging more nearly due west. Here the contact between quartz diorite and Tapeats is vertical or slightly overturned. Paleozoic rocks on the anticlinal bend have been removed by erosion. The synclinal bend, involving beds in the B unit of the Martin, is well exposed on the north side of the Verde River (1,411,500 N., 386,500 E.), where the beds make an abrupt turn from nearly horizontal to vertical.

The north-facing monocline on the north side of the horst-type structure lies only 200–300 feet northeast of the south-facing monocline near the east edge of the quadrangle; but some 3,000 feet from the quadrangle boundary, it swings northwest until it is about 2,000 feet from the south-facing monocline, where it resumes its west-northwest trend for about 1 mile. Here it is offset to the north a few hundred feet by a north-trending fault. West of here displacement is largely along a fault, which dies out abruptly.

A north-facing monocline branches off the south-facing monocline a short distance northwest of the Verde River (1,412,000 N., 386,000 E.) and extends northwest for about 3,000 feet, where it horsetails out into at least five north-trending faults or faulted monoclines. Cumulative vertical separation on the branches is close to 500 feet.

Bull Basin monocline.—The west-facing Bull Basin monocline (pl. 2 secs. *A–A′, E–E′, J–J′, K–K′;* pl. 5) on the west side of the southeastern anticline lies near and largely west of Bull Basin Canyon and trends north-northwest and then north from 1,390,000 N., 379,000 E. for about 4 miles. Faults mark its trend over some of this distance. South of about 1,400,000 N. the monocline appears to branch, the west branch trending nearly south. Total structural relief is 600–700 feet. The monoclines and faults may continue to the southeast for at least another 4 miles (pl. 5); the southernmost outcrop of the contact between the Martin and Redwall Limestones (1,372,600 N., 378,000 E.) is about 800 feet below the contact's altitude about 2 miles to the east, and only one fault, which has a stratigraphic throw of about 250 feet, was found (1,372,000 N., 387,500 E.). South of the Verde River, the monocline is buried by gravel, beneath which it is offset about half a mile to the southeast by a northwest-trending fault; it reappears near Hubbel Ranch (1,418,000 N., 373,700 E.), where it has been mapped as a fault; poorly exposed, steeply dipping beds, however, suggest a monocline (pl. 2, sec. *D–D′*). Structural relief here is about 700 feet.

Other monoclinal structures.—Other monoclinal structures occur in the area:

1. A south-facing arcuate monocline is north of St. Mathews Mountain. A younger fault has down-dropped the Tapeats on the north giving the effect of anomalous (reverse) drag (pl. 2, sec. *L–L′*).

2. A south-facing monocline (pl. 2, sec. *A–A′*) trends east-northeast from 1,377,000 N., 387,000 E., and is exposed for a little more than 1 mile. Structural relief appears to be about 500 feet and to decrease to the east, where the monocline may pass into a fault.

3. A northwest-facing monocline trends northeast from 1,414,500 N., 365,700 E., for about 4,000 feet and dies out abruptly to the southwest; structural relief at the northeast end is about 300 feet and appears to be due entirely to a fault.

4. A southeast-facing monocline trends northeast from 1,400,000 N., 344,800 E., for about 4,000 feet. East-dipping beds exposed to the south-southwest suggest that it has a length of at least 1½ miles. At the southwest end of the main exposures, the structure is narrow; at the northeast, it becomes broader.

FAULTS

Vertical to high-angle faults trend northwest to north and northeast to east. Most of them are shown as vertical in structure sections, as the amount and direction of dip on fault planes was determined only locally. Few are exposed for more than 2 miles. Some die out; others pass into monoclines. Stratigraphic throw ranges from less than 100 feet to at least 750 feet; some of the larger displacements represent vertical separation across several faults or across faults and monoclines. The amount of displacement on minor faults in the Paleozoic rocks can be determined only where the contact between formations or a thin unit within a formation is cut. In the massive Redwall Limestone, faults are difficult to trace. One low-angle thrust was observed; it displaced unit 1 of the Redwall Limestone and had an apparent dip slip of about 8 feet, as exposed in a cut near 1,425,600 N., 344,000 E.

Faults with vertical displacements of 250–700 feet are exposed for short distances in the northeast corner of the area (pl. 2). Most trend eastward, although a few trend northward. The north side of most east-trending faults is downthrown; the accumulated vertical separation (pl. 2, sec. *L–L′*) is about 1,200 feet. An eastward-trending fault (pl. 5), probably part of this group, is exposed for a short distance in Bear Canyon about a mile east of the Paulden quadrangle (Lehner, 1958, p. 570; pl. 45); it has a stratigraphic throw of about 600 feet, the north side being downthrown.

The major north-trending fault in the northeast corner of the area (near 1,450,000 N., 398,200 E.) has a vertical separation of at least 700 feet, the east side being downthrown (pl. 2b, sec. *L–L′*). Farther west a buried fault trending north-northeast is indicated on plates 2 and 5. Its trace is suggested by topographic expression and by slight displacement of basalt and gravel in Hell Canyon. Just north of the quadrangle boundary (near 385,000 E.), the fault brought the Supai Formation on the west up into contact with the Coconino Sandstone on the east. Four miles farther north the vertical separation of the contact between the Coconino Sandstone and Kaibab Limestone is an estimated 400–500 feet, and this movement was largely pre-Perkinsville in age.

Several faults in the southeastern part of the Paulden quadrangle are westward extensions of faults in the Clarkdale quadrangle (Lehner, 1958, pl. 45). The southernmost one trends northeast from 1,380,000 N., 395,000 E. The north side is downthrown, and the vertical separation is about 300 feet (pl. 2, sec. *L–L′*). East of the quadrangle boundary the fault curves north then north-northwest and re-enters the quadrangle near 1,393,500 N., where the west side is downthrown. A fault trending east-northeast having the south side downthrown about 300 feet extends for about 1½ miles from 1,386,500 N., 392,500 E. (pl. 2, sec. *L–L′*) and

continues for 1½ miles into the Clarkdale quadrangle, where it is buried by gravel. It offsets slightly the fault just described, whereas most of the east-trending faults in the Paulden area are offset by north-trending faults.

Near the northeast side of Chino Valley, east of Granite Creek, northwest-trending displacements have resulted in a total vertical separation estimated at about 800 feet (pl. 2, sec. *G–G'*). A fault, in which the west side is downthrown about 250 feet, is indicated by a small outcrop of Tapeats Sandstone (near 1,372,000 N., 387,500 E.) and by a sliver of probable Tapeats a mile to the northwest. Another fault or monocline about 2 miles to the west is indicated by the altitude of the contact between the Martin and Redwall Limestones, as mentioned in the discussion of Bull Basin monocline (p. 96).

A fault near the headwaters of King Canyon (1,387,900 N., 385,000 E.) trends eastward. The north side is upthrown; the stratigraphic separation is about 150 feet near where the fault swings to the northeast and decreases west and northeast of here. The Tapeats Sandstone on the south side is steeply upturned.

The northwest-trending fault that probably offsets Bull Basin monocline south of the Verde River is exposed for about half a mile. Near the Verde River (1,416,000 N., 368,000 E.) the stratigraphic throw is about 400 feet, the east side being downthrown. The fault is buried by gravel and basalt (near 1,415,000 N., 370,000 E.). About 1,300 feet northwest of the Verde River, the fault meets a northeast-trending fault or monocline; the fault was not recognized to the northwest.

West of Bull Basin monocline the top of the Redwall Limestone is about 150 feet lower than the base of this same limestone 1,500 feet to the southwest (near 1,395,000 N., 370,000 E.); the structural relief, therefore, is about 400 feet (pl. 2, secs. *J–J'* and *K–K'*). Although buried, this structure probably trends northwest (from near 1,391,500 N., 374,000 E.), but whether the displacement is due to a fault or a monocline is unknown. The 20° NE. dip of the Redwall south of the structure suggests a flexure. The structure marks the probable northeast side of the topographic high of Mazatzal Quartzite.

The irregular southwestern margin of Chino-Lonesome basin suggests an erosional valley, but the rather straight trends of parts of the eastern and northeastern boundary suggest structural displacement, as does the depth of wells in basin fill close to Precambrian or Paleozoic bedrock outcrops (figs. 20, 22, 23). Except for Coyote fault in the western part of the Mingus Mountain quadrangle and the structure on the south-

west side of Black Mesa (see "Monoclines") structures that may have partly outlined the basin have been completely obscured by basin fill, by subsequent pedimentation, and by wearing back of fault scarps by erosion during and after deposition of the upper Tertiary (?) rocks.

Faults may in part outline the Dells Granite (pl. 1). The fault on the southwest side is suggested by the known minimum depth of the basin a short distance southwest of granite outcrops (pl. 1, sec. *F–F'*). The one on the southeast side is suggested by the change, beneath basalt, from intensely foliated north-trending rocks to massive granite on what may be an extension of the fault that separates gabbro from Government Canyon Granodiorite to the southwest; it may have localized the Glassford cinder cone.

In the southern part of the area, a few high-angle north- and northeast-trending faults offset lithologic units of Precambrian rocks and have horizontal displacements of 100–1,000 feet. The faults are intruded by Tertiary (?) andesite dikes.

JOINTS

In many places the Paleozoic rocks are well jointed, especially in the Martin Limestone and to a lesser extent the Tapeats Sandstone. In general these joints strike N. 30° E. and N. 60° W. Their origin is unknown, but the two directions are about the same as those of the major joints in the Dells Granite and as those of some faults. In the northeastern part of the Clarkdale quadrangle, Lehner (1958, p. 542, 571) reported well-defined joints especially in the Coconino Sandstone, that trend N. 50° W. and N. 45° E. and are about parallel to nearby high-angle faults.

YOUNGER STRUCTURE

STRUCTURE FORMED BY INTRUSION OF ANDESITE PLUGS

Some steep dips in Paleozoic rocks are interpreted as due to forceful intrusion of andesite plugs, but the possibility of deformation associated with a fault or a monocline at an earlier time cannot be eliminated. The best example of structure probably formed by intrusion of andesite is found about three-fourth mile east of the Pinnacle (pl. 2, near 1,400,400 N., 356,500 E.). The Paleozoic rocks east of the plug dip steeply (65°) east; those southwest of the plug dip steeply southwest (pl. 2, sec. *F–F'*). A short distance west of the plug the unnamed basaltic flows of the Alder (?) Group are about 100 feet above the Redwall Limestone on the southwest side of the plug, an occurrence suggesting that the basaltic rocks were uplifted by an underlying plug.

Small outcrops of Tapeats Sandstone and Martin

Limestone at the north end of the large area of andesite west of Route 89 (pl. 2) may have been dragged up by the andesite. If not, and if the Paleozoic-Precambrian basement is close to the surface here, then Chino-Lonesome basin is relatively narrow at this place (figs. 22, 23) or is separated into two parts.

FAULTS

Faults having displacements as much as 2,800 feet cut Hickey basalt in the Jerome area (pl. 5), but no faults of this magnitude were observed cutting the upper Tertiary(?) rocks in the Prescott-Paulden area. Four faults cut these rocks in the area between Prescott and the Granite Dells and Glassford Hill (pl. 1). Orange tuff underlies the basalt on both sides of the northeast-trending fault southwest of the Granite Dells (fig. 24A) and the basalt south of fault near Prescott. If the orange tuff in each place represents the bed beneath the middle basalt flows, then vertical displacement may have been about 200 feet in the first locality and 300–400 feet in the second.

In the southern part of the Paulden quadrangle, a few faults cut basalt and have displacements of not more than 100 feet. Actual displacement is hard to prove because of the difficulty in tracing faults through basalt. In a few places where apparently faulted, the basalt flowed against fault scarps, or slight movement along an older fault disrupted the basalt.

Faults trending north-northeast cut basalt and older rocks about 1,500 feet above the junction of Rattlesnake Wash with Hell Canyon and in two places along Hell Canyon—one just east and one about half a mile west of King Spring. Vertical displacement of the base of the basalt is 50–100 feet. Post-basalt movement on the westernmost structure probably was largely in the form of a flexure; fine sand beneath basalt on the south side of the canyon dips steeply (35°) east and the basalt is downwarped. One basalt flow overlies a thin bed of fresh-water limestone above sand and gravel west of the flexure; four flows overlie the limestone east of it. Three flows lie west of the fault east of King Spring, and at least four flows are east of it.

A low fault scarp cuts upper Tertiary(?) gravel along the northeast side of Big Chino Wash (southwest side of Black Mesa), largely northwest of the Paulden quadrangle. It shows up well on aerial photographs for a distance of about 26 miles. Its course is somewhat sinuous, and it locally branches; in places a grabenlike depression was probably carved out by a stream that temporarily followed the fault. The scarp probably formed during renewed movement along an older structure—Big Chino monocline or fault.

AGE OF THE STRUCTURES

Structural disturbances are known to have occurred intermittently since the close of the Paleozoic Era, but the sedimentary record in this area yields little information as to when they occurred. Price (1949) reported a conspicuous disconformity between the Kaibab (Permian) and the Moenkopi (Early Triassic). McKee (1951, p. 494) stated that the first major uplift in central Arizona after the Precambrian probably occurred in the Late Triassic. Monoclines on the Colorado Plateau are Late Cretaceous to early Tertiary in age (Babenroth and Strahler, 1945, p. 148–149; Kelley, 1955, p. 797). Remnants of once extensive gravel deposits beneath basalts on the Plateau and in north- and northeast-trending channels beneath basalt south of the Plateau margin indicate uplift to the south probably in the late Miocene or early Pliocene (McKee, 1951, p. 498). East of the Prescott-Paulden area, Anderson and Creasey (1958, p. 78–83) and Lehner (1958, p. 568–579) recognized two major periods of deformation. One affected only Paleozoic and older rocks; the other, the stronger, followed accumulation of the Hickey formation but continued in milder form during and after accumulation of the Verde and Perkinsville Formations. It is characterized chiefly by normal faults trending north and north-northwest.

None of the major structures in the Paulden quadrangle are clearly younger than the upper Tertiary(?) rocks, and because of uncertainties as to the relations of the basalt to Hickey and Perkinsville basalts, the relations of these structures to post-Hickey deformation are uncertain. The terms "older and younger structures" do not imply deformation in pre- or post-Hickey times.

MONOCLINES

The possibility of a Late Cretaceous-early Eocene age for monoclines in the Paulden quadrangle is appealing because of the similarity of the monoclines to those on the Colorado Plateau that are of this age. However, a monocline in the southeastern part of the Clarkdale quadrangle has tilted Pliocene(?) basalt of the Hickey Formation (Lehner, 1958, p. 579); the Verde fault of post-Hickey age passes northward abruptly into a monocline (Anderson and Creasey, 1958, p. 80). The youngest beds involved in monoclines in the Paulden quadrangle are those of the Supai Formation, but younger Permian beds, since removed by erosion, undoubtedly also were folded. The monoclines were probably formed after the Paleozoic rocks were regionally tilted to the northeast (pl. 5), and they are older than at least some of the north- and northwest-trending faults. No involvement of any upper Tertiary(?) rocks in the monoclinal structures was observed; some monoclines are buried by upper Tertiary(?) rocks.

Bull Basin monocline is older than the gravel east of it. This gravel was probably deposited in a valley carved into the uplifted side of the block. Limestone Canyon monocline is older than the gravel northeast of the monocline, as is indicated by the presence in the gravel of pebbles of Martin Limestone derived from the uplifted block to the southwest. Limestone Canyon monocline northwest of the quadrangle and the fault extension of the Verde monocline east of the quadrangle are buried by basalt, but these basalts may both be Perkinsville in age. The monocline north of St. Mathews Mountain is older than basalt that buries it at the east edge of the quadrangle. To the east this basalt is called Hickey by Lehner (1958). Bull Basin and Verde monoclines are older than the Verde River; the intervening uplifted area (pl. 2, sec. *D–D'*; pl. 5) was worn down before the river took its present course.

FAULTS

Lehner (1958, pl. 45) mapped many faults in the Clarkdale quadrangle that cut basalt of the Hickey Formation (pl. 4). Most of the faults are east of Coyote fault. Of those that extend into the Paulden quadrangle, none clearly displaces the upper Tertiary(?) basalt more than a minor amount, although displacement of Paleozoic rocks may be 300 feet or more. The fault that curves northward east of the area and reenters it near 1,393,500 N. does not obviously disturb the older gravel. The northwest-trending fault that offsets Bull Basin monocline south of the Verde River does not disturb the older gravel or the overlying (post-andesite) basalt that conceals the probable trend of the fault.

The faults that cut Precambrian rocks in the southern part of the area (pl. 1) are probably younger than the Precambrian, but older than the upper Tertiary(?) rocks; the faults are intruded by andesite dikes that also probably have the same age limits. The principal movement on the faults, however, may have taken place at a much earlier period than the intrusion of the dikes. Quartz veins and zones of mild silification, presumably of Precambrian age, occupy or parallel some of the faults; the first movement, therefore, may have been in the Precambrian.

In the southwestern part of the area, movement on some faults occurring after basalt deposition may have been as much as 400 feet, if the orange tuff bed on which the displacement was measured is everywhere correlative. Only small faults cut the basalt (Perkinsville?) in the northeast part of the area.

Recurrent movement probably occurred along the structure on the southwest side of Black Mesa (largely northwest of the area); the most recent movement forming the low fault scarp in upper Tertiary(?) gravel.

CONCLUSIONS

The structural low in which the Verde River flows eastward from Chino-Lonesome basin may have formed at the same time that deformation arched the Black Hills, faulted and downwarped basalt of the Hickey Formation north of the Black Hills, and produced the major movement on Coyote and Verde faults. However, the underlying structure does not appear to have controlled the course of the Verde River to any extent (pl. 5), except where the Verde leaves the basin and for a short distance south of its junction with Hell Canyon. The structure was probably buried by upper Tertiary(?) rocks when the river's course was determined. The covering rocks would be considered Perkinsville were it not for the fact that they include older gravel that probably antedates the formation of Chino-Lonesome basin.

Until the relation of the upper Tertiary(?) rocks to the Hickey and Perkinsville Formations in the type areas is known, the age of the major deformation cannot be determined. If basalt in the southeastern part of the Paulden quadrangle is Hickey, then most of the structure there is pre-Hickey in age; if these rocks or some of them, however, are Perkinsville in age, then some of the structure may also be post-Hickey in age. Similarly, some or all of the rocks mapped as Hickey west of Coyote fault in the Jerome-Clarkdale area may be Perkinsville in age and may have accumulated after Chino-Lonesome basin was formed.

PHYSIOGRAPHY
GENERAL FEATURES

The major physiographic feature of the Prescott-Paulden area is the broad Chino-Lonesome Valley, which extends from a short distance southeast of the area for 60 miles to the northwest (figs. 1, 30). The southwestern boundary of the valley is quite irregular and consists of a series of mountain ranges, of which only the northern part of the Bradshaw Mountains extends into the area. The southeastern part of the valley is bounded on the east by the uplifted Black Hills block (Mingus Mountain quadrangle); the northwestern part is bounded by the uplifted Black Mesa block (mostly northwest of the area). Between these two blocks is a low relatively flat but locally dissected area that extends northeastward to the southwestern boundary of the Colorado Plateau (the Mogollon Rim).

Chino-Lonesome Valley is an erosional and structural basin filled with upper Tertiary(?) rocks. Exterior drainage commenced when the basin was filled sufficiently for water to spill over a low point into the Verde River drainage. This point is located near the

center of the northeastern boundary (near 1,406,000 N., 337,000 E.), not at one end, as in normal valleys.

The existence of temporary base levels allowed formation of gravel-strewn pediments and terraces. Drainage in the southern half of the valley was northward until the Lonesome Valley portion was captured by headward erosion of the Agua Fria River. Rapid dissection of the pediment followed the stream capture. The Verde River (fig. 2) and its tributaries northeast of the basin have cut steep-walled canyons in the generally horizontal Paleozoic and Cenozoic rocks. The surface forms are largely erosional, except for some formed by alluviation along valley bottoms.

MOUNTAINS

The mountains and hills are of several types, each type depending primarily on the rocks and structure involved but locally on the erosional history of the area. In the southern part, erosion of schistose rocks having nearly vertical structures produced long sharp ridges separated by north-trending gulches. Higher ridges and peaks reflect a greater resistance to erosion. In the southwestern part of the area, some subdued, rounded hills, generally composed of massive granite, represent a weathered erosion surface that was buried during late Tertiary (?) time and later exhumed.

The topographic form of the isolated Dells Granite is controlled by nearly vertical joints (fig. 14). Square to rectangular hills, locally having precipitous sides, rise 50–200 feet above the valleys. The major valleys in the granite trend approximately N. 25° E. and N. 70° W., parallel to the major joints. The valleys are 200–1,000 feet apart and as much as half a mile long.

In the southwestern part of the area (pl. 1), flat-topped mesas and buttes are part of a maturely dissected lava plateau or plain. Flat-topped hills in Chino-Lonesome Valley are remnants of once extensive pediments (figs. 28, 29). Northeast of the basin, flat-topped hills are capped by nearly horizontal Paleozoic rocks or basalt flows of late Tertiary (?) age.

Hogbacks were formed by erosion of steep monoclines. Flatiron-shaped slopes (dissected dip slopes) are fairly common in folded Mazatzal Quartzite.

Glassford Hill (fig. 14) in the southwestern part of the area is a cinder cone; the cone was partly buried by nearly horizontal basalt flows that were eroded to form a roughly circular hill. St. Mathews Mountain in the east-central part (pl. 2) is a dissected cone of andesitic flow, breccia, and intrusive-plug material and was also partly buried by basalt. Dissected andesitic plugs or domes form isolated hills (fig. 19) on the north side of the Chino-Lonesome Valley east of Granite Creek. Erosion of andesite that is cut by steeply dipping joints and flow planes produced sharp peaks such as the Pinnacle (pl. 2, 1,400,000 N., 353,000 E.). Erosion of andesitic gravel and breccia produced rounded hills covered with andesitic rubble.

PEDIMENTS

A broad pediment, strewn with sand and gravel, covered much of Chino-Lonesome Valley. The pediment sloped from the margins toward the center and then along the axis of the valley to the Verde River. It probably formed at the time that a temporary base level occurred along the river; much of it was subsequently destroyed by erosion. Lower pediments or terraces formed during shorter periods when temporary base levels had occurred along Granite Creek and the Verde and Agua Fria Rivers.

FIGURE 28.—Pediment east of Glassford Hill. The view is to the southwest from the east edge of the area (pl. 1, 1,310,000 N., 398,000 E.). The eroded edge of the pediment is across the Yaeger-Agua Fria alluvial flat. The Bradshaw Mountains are in the background, and Glassford Hill is on the extreme right. Coarse gravel in foreground is largely colluvial material from pediment gravel to the east. It conceals fine-grained sedimentary rocks of late Tertiary (?) age such as are shown in figure 25.
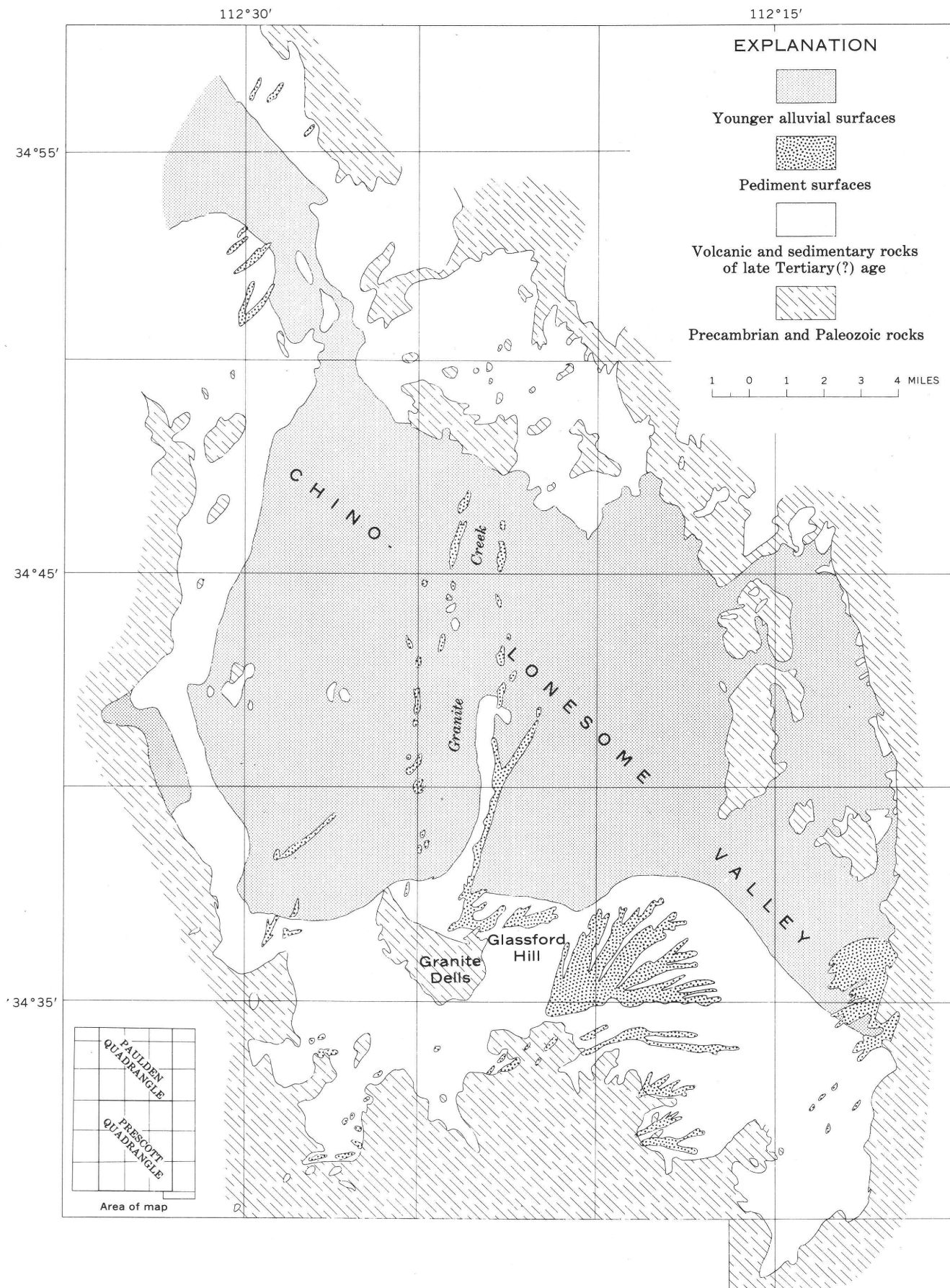
FIGURE 29.—Distribution of pediment remnants in Chino-Lonesome Valley, Ariz.

The pediment is cut largely on basin fill, but in a few places it can be traced onto Precambrian and Paleozoic rocks around the margin. It is easy to recognize where its gravels are underlain by fine-grained lacustrine deposits, but it is difficult to recognize where cut on fanglomerate or on basalt if the pediment gravels are composed largely of basalt fragments.

The major pediment remnant is east of Glassford Hill (figs. 28, 29). Smaller remnants occur on both sides of Granite Creek and around the margins of the basin. The east side of the pediment remnant east of Granite Creek slopes imperceptibly into lower terraces and into alluvium of the valley floor. In other places, where erosion has been rapid, the pediment remnants end abruptly.

DRAINAGE

CHINO-LONESOME VALLEY

One of the interesting physiographic features of the area is the drainage pattern in Chino-Lonesome Valley; the pattern records the history of drainage changes (fig. 30). Unlike a normal valley, which has an outlet at one end, the major outlet, the Verde River, of the 60-mile long valley is near the center of the northeast side. Northwest and west of the headwaters (Sullivan Lake), of the Verde River, drainage is southeastward (Big Chino Wash) and eastward (Williamson Valley Wash). South of Sullivan Lake drainage was entirely to the north and northwest until its southern part was captured by headward erosion of the south-flowing Agua Fria River because of its steeper gradient. Route 89A follows the inconspicuous present divide between north- and south-flowing drainage for most of its distance across the valley. Water falling north of the highway (pl. 1, near the Gila and Salt River meridian; fig. 1) travels, via Granite Creek and the Verde and Salt Rivers, almost twice as far to the Gila River near Phoenix, as does water falling south of the highway, which reaches the same point in the Gila River via the Agua Fria River.

The capture resulted in deep dissection of the pediment. The existence of temporary base levels along the Agua Fria and its tributaries, especially along Lynx Creek, resulted in the formation of lower pediments or terraces and may account for some of the slight alluviation that occurred along the river and its tributaries. Recent rapid erosion due to lowering of base level or to climatic changes has cut gullies 5–25 feet deep into alluvium and basin deposits (fig. 25).

The northward drainage of the valley consists of three parts. About 40 percent of the area is drained by Granite Creek and its tributaries. The remainder is almost equally divided between the washes east and west of Granite Creek, which were formerly the principal northward drainage lines. After capture of its headwaters by the Agua Fria River, the wash east of the creek could no longer remain a major drainage line; some stagnation and alluviation has occurred along it. The wash west of Granite Creek at one time drained all the area west of Granite Creek (west of the dotted line that extends northward from the Granite Dells, fig. 30) and possibly the area southwest of the Granite Dells. This drainage was captured by headward erosion of tributaries on the west side of Granite Creek, two north of and one south of the airport.

Granite Creek is a superimposed stream. It was let down onto resistant Dells Granite and Mazatzal Quartzite from overlying upper Tertiary(?) rocks or from a pediment cut on the upper Tertiary(?) or Precambrian rocks. Had its course been a short distance to the west, the creek would now be on softer basin deposits. At the time the course was determined, however, the softer rocks may have been concealed by resistant volcanic rocks. From the Dells Granite to the Mazatzal Quartzite, a distance of about 12 miles, the Granite Creek drainage was confined to a strip 1–2½ miles wide (fig. 30, east of the dotted line) that is bounded by flat-topped hills, which are pediment remnants. The creek bottom within this strip is a quarter to more than half a mile wide. The wide valley flat probably formed because the creek had a very low gradient caused by the temporary base level formed by the resistant Precambrian rocks. The creek could widen its valley upstream from the resistant rocks but could do little downcutting. The reason why the creek was originally confined to this narrow strip is obscure. Granite Creek now drains a large mountainous area that received more rainfall than do the areas drained by the washes to the east and west since their headwaters were captured. Granite Creek enters the Verde River about 100 feet lower than does the wash to the west. This lower base level may explain why the creek captured the headwaters of the drainage system to the west. This wash may now be cutting back more rapidly because it is on softer material and also because of permanent stream flow below Del Rio Springs, which taps the Chino-Artesian basin.

NORTHEAST OF CHINO-LONESOME VALLEY

The area northeast of Chino-Lonesome Valley as far as the Verde River is quite deeply dissected, but north of the river it is largely a flat land. The low relief appears to be due mainly to smoothing out of irregularities by basalt that flowed south from the Colorado Plateau. It could, however, be an extension of the pediment in Chino Valley. The lowland extends northward from the north-central part of the area and forms a break in the escarpment of the plateau (fig. 1). The
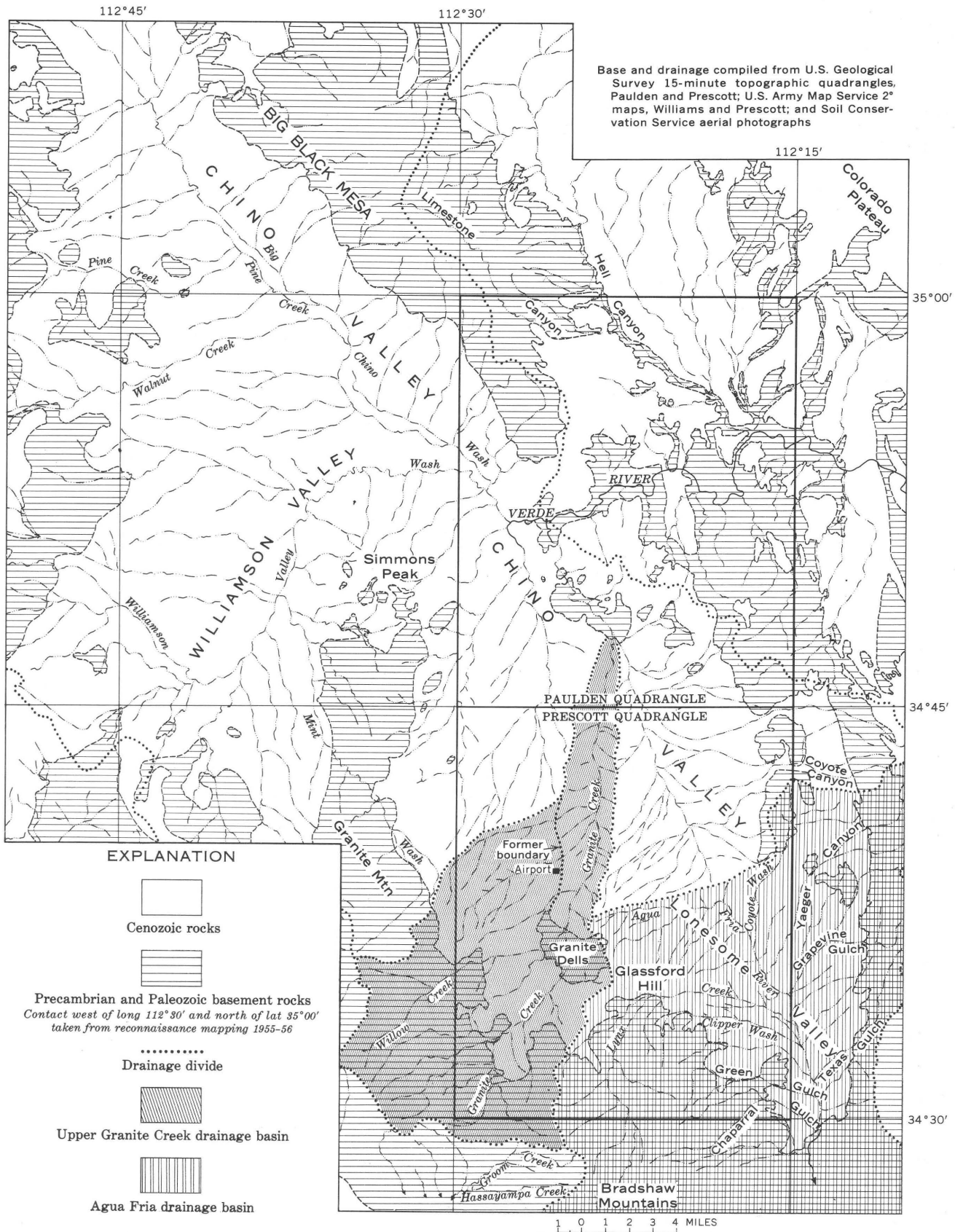
FIGURE 30.—Drainage pattern in Lonesome, Chino, and Williamson Valleys, Prescott-Paulden area, Arizona.

southwest-facing Black Mesa escarpment, mostly west of the area, appears to be an offset part of the Mogollon Rim. The Verde River and its tributaries have cut steep-walled gorges as much as 300 feet deep into the relatively flat basalt and gravel plane and into the underlying Paleozoic and Precambrian rocks. Structure in the Paleozoic rocks apparently had little control on the course of these streams, except that the Verde River leaves Chino-Lonesome Valley near a structural low. The faults and monoclines were probably buried by upper Tertiary(?) rocks or by pediment gravels at the time that the stream courses were determined.

ECONOMIC GEOLOGY

ORE DEPOSITS

HISTORY

Mining in the Jerome-Prescott area prior to the exploration of Arizona and New Mexico by the Spaniards was carried on by Indians. The presence of hammers and other stone implements in ancient workings at the site of the Silver Belt mine, a short distance southwest of the Iron King mine, indicates mining in the Prescott area during prehistoric time (Galbraith, 1947, p. 42). The first recorded discovery of an economic deposit was made in 1863, when Joe Walker and a party of prospectors found gold in Hassayampa River and Lynx Creek in the Prescott region (Hamilton, 1883, p. 47). The Lynx Creek placers have contributed a considerable part of the placer gold of the state and county. A little placer mining has been done on other creeks in the area. Lode mining during historic time close to the Prescott area commenced with the rediscovery of the ore deposits at the site of the Silver Belt mine in 1870 (Lindgren, 1926, p. 128). Rich silver ore was mined at this mine until 1880.

The Iron King lead-zinc mine (southeast corner of pl. 1) is the only important lode deposit discovered within the Prescott-Paulden area. It has been the leading mine in the Prescott-Jerome area since the closing of the United Verde mine at Jerome in 1953. Mining was begun at the site of the present Iron King mine probably about 1880. Production was sporadic and minor until 1937, when the present operation was started.

Except for the Mazatzal Quartzite, the Precambrian rocks in the Prescott and Paulden quadrangles are riddled with prospect pits, tunnels, and shallow shafts, largely dug on quartz veins. A small amount of ore, mostly gold, has been produced from some of them. Many of these veins were prospected during the early days of mining, but prospecting and small-scale development work have continued intermittently since then.

MINERALOGY

Brief descriptions of the minerals directly related to the ore deposits are given in this section. The list includes hypogene ore and gangue minerals—formed by ascending ore-forming solutions—and supergene ore minerals—formed by descending waters—but not the common rock-forming minerals. Some hypogene and supergene ore minerals are of no economic importance. The data on mineralogy have been obtained from brief examination of material on dumps of small prospects and from the following sources: Anderson and Creasey (1958, p. 91–95), Galbraith (1947), Wilson and others (1934), and Lindgren (1926, p. 24–31).

HYPOGENE MINERALS

ORE MINERALS

Arsenopyrite (FeAsS).—Small crystals of arsenopyrite are scattered throughout the massive sulfide ore body at the Iron King mine. It was also noted in specimens on some of the dumps of small prospects (near 1,274,600 N., 390,500 E. and 1,282,700 N., 393,800 E.).

Chalcopyrite ($CuFeS_2$).—Small quantities of chalcopyrite occur in many of the fissure vein deposits and in the copper vein a short distance west of the Iron King mine.

Galena (PbS).—Galena, as scattered medium to large crystals, is common in many of the fissure veins in the area. In the Iron King massive sulfide ore it is an important constituent, where it occurs as very fine to microscopic grains. It is present in the Gold Coin group (1,293,600 N., 368,300 E.) and was noted in small prospects in the following areas: 1,287,200 N., 371,500 E.; 1,274,600 N., 390,500 E.; 1,282,700 N., 393,800 E.; and along 393,300 E., between 1,282,100 N. and 1,283,400 N. Near the east edge of the Paulden quadrangle south of the Verde River (1,422,400 N., 396,000 E.), cubes of galena, more than 1 inch square, occur in calcite veins in the Mississippian Redwall Limestone. Galena was also reported by Lindgren (1926, p. 102) in a quartz vein (the "Peters silver mine") in the southeastern part of the Paulden quadrangle, probably in sec. 7, T. 16 N., R. 1 E.

Gold (Au).—Gold is economically important in the Iron King mine, in many of the small quartz veins in the area, and in the placer deposits along Lynx Creek. The gold at the Iron King mine is free-milling and occurs in galena, sphalerite, and pyrite, as indicated by metallurgical tests and assays. Chiefly because it is most abundant, pyrite carries most of the gold. Visible gold has been reported from some of the quartz veins, notably the Gold Coin group (1,293,600 N., 368,300 E.), the White Horse prospect (1,285,500 N., 370,500 E.), a prospect near 1,274,000 N., 369,200 E., and in Precam-

brian rocks north and south of the boundary between the Prescott and Paulden quadrangles. Placer gravels along Lynx Creek near Walker (about 3 miles south of the Prescott quadrangle) have yielded nuggets of about 5 ounces, whereas the gold from lower Lynx Creek ranges from finely divided material to nuggets of about three-tenths of an ounce (Wilson, 1952, p. 43).

Hematite (Fe_2O_3).—Specular hematite is widespread as veinlets in Precambrian rocks. Hematite is an abundant constituent in some of the beds of jasper-magnetite in the Texas Gulch Formation. It is concentrated along cross laminae and bedding planes in some of the Mazatzal Quartzite.

Magnetite (Fe_3O_4).—Although of no economic importance at present, magnetite is a major constituent in the narrow beds of jasper-magnetite in the Texas Gulch Formation and in some of the quartz-magnetite veins in Alder Group rocks, especially in the unnamed tuffaceous rocks. Magnetite-rich zones occur in gabbro, especially in and east of the largest mass (near 1,289,000 N., 371,600 E.; 1,288,700 N., 374,000 E.; and 1,290,500 N., 374,500 E.) and in some of the western part of the westernmost mass. Magnetite in the gabbro is associated with ilmenite. Magnetite is also present in black sands in an area locally called the Nugget Patch (1,290,000 N., 370,000 E.) and in gulches that drain areas of gabbro and late Tertiary(?) basalt.

Molybdenite (MoS_2).—Scattered flakes of molybdenite were observed in large quartz veins in the extreme southwestern corner of the Prescott quadrangle. Molybdenite also occurs in Copper Basin (Kirkland–Iron Springs quadrangles) about 7 miles west-southwest of the city of Prescott.

Platinum (Pt).—Platinum has been reported from the black sands near Prescott (Galbraith, 1947, p. 10).

Pyrite (FeS_2).—Pyrite is the principal ore mineral in most of the fissure veins in the area and is a major constituent in the massive sulfide deposit at the Iron King mine. Scattered pyrite crystals are widespread wherever there has been even minor hydrothermal alteration. It is sparsely disseminated as tiny cubes in some areas of alaskite, Prescott Granodiorite, and Alder Group rocks. Pyrite is recovered in the concentrator at the Iron King mine largely for its gold content but partly because of the demand for its use as a smelter flux.

Scheelite ($CaWO_4$).—Scheelite occurs in quartz veins in the Gold Coin group (1,293,600 N., 368,300 E.) and has been reported from quartz veins in the Prescott Granodiorite south of Prescott.

Serpentine minerals (antigorite and chrysotile, $H_4Mg_3Si_2O_9$).—Serpentine minerals, of no economic importance, occur in some gabbro, especially in the northern part of the western mass.

Sphalerite (ZnS).—Sphalerite, as minute grains forming streaks and aggregates in the pyritic massive sulfide and as grains interstitial to the pyrite, is the most abundant ore mineral in the Iron King mine. Many of the fissure veins in the area contain scattered crystals of sphalerite. It was noted at the New Strike prospect (1,276,200 N., 357,200 E.) and at a small prospect at the southern edge of the Prescott quadrangle (near 384,700 E.); it was also reported by Lindgren (1926, p. 102) in a quartz vein (the "Peters silver mine") in the southeastern part of the Paulden quadrangle.

Stibnite (Sb_2S_3).—Stibnite has been reported from the Malley Hill mine (Galbraith, 1947, p. 22) on Lynx Creek (the exact location is unknown; it may be south of the map area).

Tennantite [$(Cu, Fe)_{12}As_4S_{13}$].—Silver-bearing tennantite in the Iron King mine adds to the silver content of the ore.

GANGUE MINERALS

Barite ($BaSO_4$).—Barite is reported (Lindgren, 1926, p. 25) in the Silver Belt vein, southwest of the Iron King mine.

Carbonate minerals.—Several varieties of carbonate minerals occur in the ore deposits. Ankerite [$CaCO_3 \cdot (Mg, Fe, Mn) CO_3$] is the principal carbonate mineral at the Iron King mine. Calcite ($CaCO_3$) is found in many of the fissure veins in the area, as are ankerite and dolomite [$(Ca, Mg) CO_3$]. Brown carbonate, possibly siderite ($FeCO_3$), was noted in a few of the fissure veins.

Chlorite (*complex silicate of* Fe, Mg, Al_2O_3).—Alteration zones associated with some of the fissure vein deposits contain chlorite.

Piedmontite (*manganese-bearing epidote*).—Although of no economic importance and probably not related to any ore-bearing solutions, piedmontite is described here because it is a relatively rare mineral and is widely distributed in the southwestern part of the Prescott quadrangle. It forms small veinlets and disseminated grains in the southwestern part of the westernmost mass of gabbro, in the Government Canyon Granodiorite, and in Prescott Granodiorite north-northwest of Prescott. It is pink, but as seen under the microscope, the color is not evenly distributed; it grades on the edges into a yellow mineral having yellow absorption but the same indices of refraction. The indices of refraction of the piedmontite are: α, 1.738; β, 1.753; γ, 1.773 and X, yellow; Y, purple; and Z, purple (as determined by Marie L. Lindburg of the U.S. Geological Survey in 1949).

Quartz (SiO_2).—Quartz is the principal gangue mineral in most of the ore deposits of the Prescott quad-

rangle and is the most abundant one in the fissure veins of both quadrangles. At the Iron King mine it occurs as rather pure masses associated with the massive sulfide or is interstitial to the sulfide grains. It is the main constituent in the quartz-magnetite veins in some Precambrian volcanic rocks. Quartz has been mined for flux from a quartz vein (1,284,000 N., 398,000 E.) about 2 miles north of the Iron King mine. Considerable amounts are in the large quartz veins on the hill in the extreme southwestern corner of the Prescott quadrangle and in a large quartz vein in quartz diorite along the Verde River (1,413,500 N., 382,300 E.).

Sericite [$H_2KAl_3(SiO_4)_3$].—Sericite is a fine-grained variety of muscovite that is widespread in the alteration zone associated with the Iron King massive sulfide ore bodies and occurs in many of the narrow alteration zones associated with the fissure veins.

Tourmaline (*complex silicate of* B, Al, Fe, Mg).—Black tourmaline occurs in some of the fissure veins. Tourmaline-quartz and tourmaline veins are abundant in the Dells Granite and the westernmost mass of Prescott Granodiorite, where much of the tourmaline occurs as fine hair-like needles. Some of it forms dikelike or podlike masses as much as 5 feet wide. Tourmaline veins may be younger than some of the quartz veins.

SUPERGENE ORE MINERALS

Anglesite ($PbSO_4$) *and cerussite* ($PbCO_3$).—Anglesite and cerussite occur in the oxidized parts of the Iron King mine and may be present at the surface of some of the fissure veins that carry galena.

Cerargyrite ($AgCl$).—Cerargyrite has been reported from the Silver Belt mine, southwest of the Iron King mine, where it was found associated with cerussite in ancient workings (Galbraith, 1947, p. 42).

Chalcocite (Cu_2S).—Small quantities of chalcocite are found in many of the fissure veins that contain primary chalcopyrite. It was noted specifically in a prospect near 1,274,000 N., 369,200 E.

Chrysocolla ($CuSiO_3 \cdot 2H_2O$).—Films of chrysocolla are common at the surface of the fissure veins that carry chalcopyrite and at the United States mine (1,423,900 N., 399,300 E.).

Limonite (*hydrated iron oxide*).—Limonite gossan developed at the surface over the Iron King massive sulfide deposit and in minor amounts over most of the fissure deposits. Some limonite (gossan) was mined at the Iron King mine for its precious metal content in the early days of mining.

Malachite [$CuCo_3 \cdot Cu(OH)_2$] *and azurite* [$2CuCO_3 \cdot Cu(OH)_2$].—The green and blue copper carbonates malachite and azurite occur as scattered films at the surface of many of the fissure veins, in Tapeats Sandstone, and in calcite veins and disseminations in the Supai Formation at and south of the United States mine.

Manganese oxides.—Minor amounts of manganese oxides are associated with many of the fissure veins.

Vanadinite [$PbCl \cdot Pb_4(VO_4)_3$].—Vanadinite occurs as yellow to yellowish-green and light-brown needles and crusts in galena-bearing calcite veins in Redwall Limestone south of the United States mine (1,422,400 N., 396,000 E.).

Wulfenite ($PbMoO_4$.)—Wulfenite occurs with vanadinite as thin orange wedges south of the United States mine.

GENERAL CHARACTERISTICS

The ores deposits of the Prescott-Paulden area consist of Precambrian massive sulfide deposits, Precambrian and possibly younger fissure veins, a few noneconomic post-Paleozoic fissure veins and disseminated deposits, and Quaternary gold placer deposits. Practically all the base metal production and much of the precious metal production has come from the Iron King lead-zinc mine in the southeastern corner, the only known massive sulfide deposit within the area. Fissure veins have been mined largely for their precious metal content, principally gold; production from them has been small, but the amount is unknown. Placer deposits have probably supplied less than one-sixth of the gold produced in the area.

As most ore deposits in north-central Arizona are Precambrian in age, a knowledge of the thickness of the overlying Paleozoic and Cenozoic rocks is important in exploring for ore deposits in Precambrian rocks. For this reason a map (fig. 31) showing the approximate thickness of Paleozoic and Cenozoic rocks in the Paulden quadrangle has been compiled. The approximate minimum thickness of Cenozoic rocks in Chino-Lonesome basin is shown on figure 23.

The configuration of the Precambrian surface is illustrated in the structure contour map of the Paulden, Clarkdale, and Mingus Mountain quadrangles (pl. 5). As the contours are drawn on the base of the Redwall Limestone, the Precambrian surface is about 500 feet below the altitudes shown on plate 5, except in an area of about 23 square miles that is probably underlain by the Mazatzal Quartzite. Within this area the Precambrian surface may be as little as 10 feet below the base of the Redwall. The area that is underlain by the Mazatzal is economically unimportant, as no ore deposits occur in exposed portions of the Mazatzal and the quartzite has not been intruded by granitic rocks or by quartz veins.

MASSIVE SULFIDE DEPOSITS

Deposits composed of granular aggregates of sulfide minerals and little or no gangue minerals are referred to

as massive sulfide deposits. The Iron King mine at Humboldt, the only massive sulfide deposit in the Prescott-Paulden area, and the United Verde and United Verde Extension mines at Jerome are examples of this type of deposit. Pyrite is the dominant mineral, but variable amounts of other sulfides, especially chalcopyrite, sphalerite, and galena are present. Where appreciable amounts of these minerals (other than pyrite) occur, the ore is generally banded. Most massive sulfide deposits exhibit sharp contacts with host rock, but locally they grade into disseminated deposits. Silification and sericitization of the host rocks are common. Minable ore shoots are formed where the pyrite-rich facies was fractured and base or precious metals were added. This type of deposit was formed probably by hydrothermal mineralizing solutions that replaced schistose rocks.

FISSURE-VEIN DEPOSITS

The fissure veins were formed principally by fissure filling, but replacement of the wall rock occurred along some of them. They occupy shear zones, some of which are parallel to the foliation in the enclosing rocks.

Lindgren (1926, p. 37–48) described two types of fissure-vein deposits in the Jerome and Bradshaw Mountains quadrangles: gold-quartz veins of undoubted Precambrian age and gold and silver veins that he considered younger than the gold-quartz veins and possibly late Mesozoic or early Tertiary in age. The gold-quartz veins are widely distributed throughout the Precambrian rocks of these two quadrangles; the younger veins are confined apparently to the southern part and south of the Prescott quadrangle.

The gold-quartz veins are massive or have a crude banding. The quartz, which is glassy to milky, occurs as pods or lenses in shear zones, which strike parallel or at an angle to the foliation in the country rock. Few of the veins can be traced for as much as 1,000 feet. Calcite, ankerite, or siderite may be present. Tourmaline occurs in many of them. The sulfides, which are not abundant, consist of pyrite, chalcopyrite, sphalerite, and galena. Gold, some of it in visible particles, is present in many of the veins. Scheelite has been noted in some of them. In the eastern part of the Prescott and Paulden quadrangles, north and south of the boundary between them, unmineralized Paleozoic rocks overlie Precambrian rocks that contain quartz veins, an occurrence suggesting that the mineralization is Precambrian in age. Locally, as in the headwaters of King Canyon (1,385,400 N., 385,100 E.), copper carbonate occurs in the Tapeats Sandstone. The copper was probably dissolved out of quartz veins in adjacent alaskite and redeposited in the sandstone by ground water. Quartz,

quartz-tourmaline, and tourmaline veins are abundant in the Dells Granite and in the southwestern mass of Prescott Granodiorite, but gold and sulfide minerals are generally absent from or very sparsely distributed in these veins; few of these veins have been prospected.

Most younger fissure veins are straight and narrow and have well-defined walls. The quartz gangue is milky and has a drusy structure. Carbonate accompanies quartz in many of the veins, which also have minor and variable amounts of arsenopyrite, sphalerite, chalcopyrite, galena, and some tetrahedrite and tennantite. Gold and some native silver occur in the oxidized zone; gold is not visible in the primary ore. According to Lindgren (1926, p. 42) many of the veins are associated with rhyolite porphyry dikes, which are younger than the regional metamorphism and deformation that involved the Precambrian rocks. Other veins, according to Lindgren, are apparently related to stocks of quartz diorite or granodiorite that he considered possibly post-Precambrian in age. One of these stocks has been proved to be Precambrian in age (see p. 96, 35, 50).

POST-PALEOZOIC MINERALIZATION

Most of the ore deposits in Yavapai County are Precambrian in age or are probably Precambrian, as are the quartz-bearing intrusive rocks from which mineralizing solutions were probably derived. A few are considered Late Cretaceous to early Tertiary in age, partly because of similarities to the porphyry copper deposits of this age. In the Copper Basin copper-molybdenum deposits (W. P. Johnston [14]; Johnston and Lowell, 1961) about 7 miles west-southwest of Prescott (Iron Springs and Kirkland quadrangles, fig. 1), pyrite, chalcopyrite, bornite, and molybdenum occur in breccia pipes in the Copper Basin stock (predominantly quartz monzonitic). Surrounding the central copper-molybdenum zone are zinc-lead-silver deposits in which galena occurs as cubes as much as 2 inches on a side. The Bagdad porphyry copper deposit (about 40 miles west of Prescott) is likewise considered to be Late Cretaceous or early Tertiary in age (Anderson, Scholz, and Strobell, 1955, p. 79–80). Lack of overlying Paleozoic rocks in these areas makes a positive age assignment impossible.

In the eastern part of the Paulden quadrangle, the Supai Formation of Pennsylvanian and Permian age has been mineralized, a fact thus proving the existence of mineralizing solutions of post-Paleozoic age. Near the Verde River from a short distance east to about eight-tenths of a mile west of the quadrangle boundary, much of the fine-grained red Supai sandstone has been

[14] Johnston, W. P., 1955, Geology and ore deposits of the Copper Basin mining district, Yavapai County, Arizona: Utah Univ. Ph. D. thesis, p. 96–98.
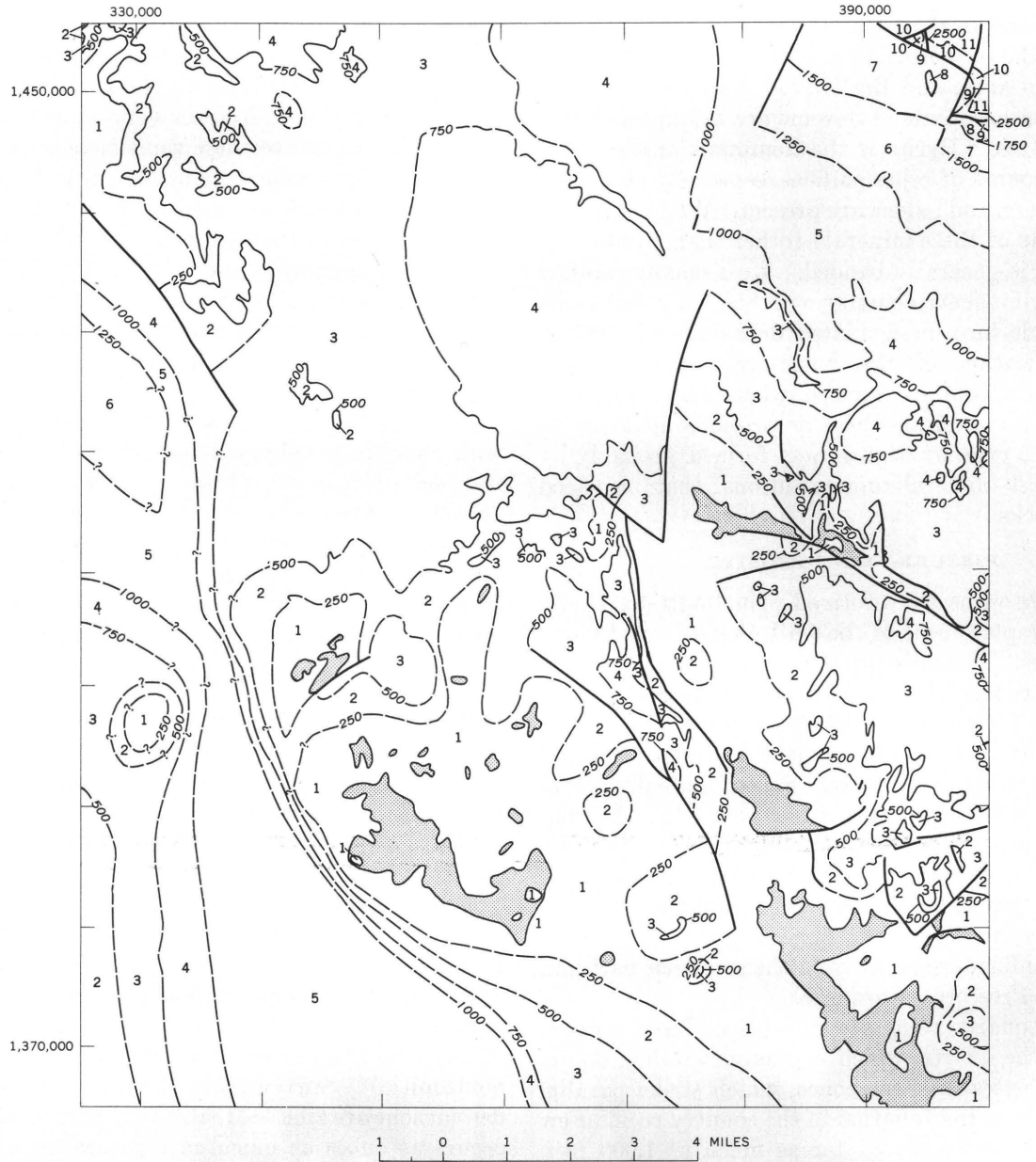
EXPLANATION

Area of outcrop of Precambrian rocks

——————?——

Isopach

Solid isopachs are drawn on exposed contacts: 0-foot isopach is the contact between Precambrian and Paleozoic or Cenozoic rocks; 500-foot isopach is the contact between the Martin and Redwall Limestones, except in the area of the Mazatzal Quartzite; and 750-foot isopach is the contact between the Redwall and Supai Formations. Dashed isopachs are approximately located; queried isopachs are doubtful

——————

Fault or monocline

Shown only where different unit thicknesses are brought into contact or where thickness lines are offset

THICKNESS OF PALEOZOIC AND CENOZOIC ROCKS, IN FEET

1	0–250	7	1500–1750
2	250–500	8	1750–2000
3	500–750	9	2000–2250
4	750–1000	10	2250–2500
5	1000–1250	11	2500–3200
6	1250–1500		

FIGURE 31.—Thickness of Paleozoic and Cenozoic rocks, Paulden quadrangle, Arizona.

bleached white, the silty layers remaining red. At the prospect called the United States mine north of the river (1,423,900 N., 399,300 E.) and in some of the Supai beds south of the river, hydrous copper carbonate and silicate minerals are disseminated in bleached sandstone or are associated with coarse calcite veinlets in sandstone. Material on dumps from small prospect pits in the Redwall Limestone south of the river (1,422,400 N., 396,000 E.) consists of coarse calcite, cubes of galena more than an inch on a side, and a little wulfenite and vanadinite. The area has been explored by shallow pits in the Redwall and by several shafts of unknown depth in the Supai (United States mine), but the deposits are probably too small and low grade to be of value. The date of the workings is unknown; it may be later than 1922, as the area is not mentioned by Lindgren (1926).

PLACER GOLD DEPOSITS

Placer gold deposits occur in Quaternary gravels along the present streams and locally as a mantle on pediment surfaces. These gravels rest on Precambrian bedrock or on the upper Tertiary(?) deposits. The placer gravel is well rounded except near the headwaters of the streams. Small nuggets have been recovered from the upper reaches, but most of the gold downstream from the Precambrian bedrock is finer grained. The gold has been derived from gold-quartz veins.

DESCRIPTIONS OF INDIVIDUAL DEPOSITS
IRON KING MINE

The Iron King ore deposit was studied by Creasey; for a detailed account of the deposit, the reader is referred to the report on the Jerome area (Anderson and Creasey, 1958, p. 155–169), from which the present brief summary has been taken. (See also Creasey, 1950, 1952; Mills, 1941, 1947.)

The Iron King lead-zinc mine is in the southeastern corner of the Prescott quadrangle and in the northern part of the Big Bug mining district. It is the leading mine in the district and the only mine in operation since 1953. The mineralized outcrop extends for only about 300 feet into the quadrangle, although the deposit is being mined for some distance to the north beneath the Cenozoic cover. Since 1936 production from this mine has come largely from north of the quadrangle boundary, although earlier production was largely from south of the boundary.

Production from the Iron King mine from 1906 to January 1, 1952, included about 21,486 ounces of gold, 6,624,101 ounces of silver, 72,573,620 pounds of lead, 209,199,140 pounds of zinc, and 6,345,740 pounds of copper from approximately 1,640,060 tons of ore (An-

derson and Creasey, 1958, p. 155). Production from 1952 through 1956 included about 97,397 ounces of gold, 3,280,850 ounces of silver, 46,790,978 pounds of lead, 117,014,330 pounds of zinc, and 2,206,888 pounds of copper from approximately 1,043,152 tons of ore (U.S. Bureau of Mines, 1953–58). The mine has been developed by seven shafts; only two of these are used and both are north of the mineralized outcrop. Some of the older shafts are caved. Levels are at 100-foot intervals, except below the 1,200-foot level, where intervals are greater; the 2,100-foot level was under development in 1958. Drifts are driven along the veins, and raises extend above them.

The deposit was localized in a sheared and deformed zone in the andesitic tuff unit of the Spud Mountain Volcanics and is about parallel to the regional foliation. Intense cataclastic deformation occurred along this zone. The rocks were then hydrothermally altered, and early vein minerals were introduced. These vein minerals were granulated, and a still later period of deformation produced a fracture cleavage on the earlier deformation.

During the early period of mineralization or hydrothermal alteration following the early period of deformation, quartz, pyrite, and ankerite were concentrated in well-defined veins in en echelon shears along the east or footwall side of the sheared zone. Disseminations and narrow veinlets of these minerals and of sericite were deposited west of the veins. The veins and the sporadically mineralized zones to the west were then intensely sheared, especially the northern parts, and in these new openings sphalerite, arsenopyrite, galena, tennantite, sparse chalcopyrite, sericite, and probably pyrite, ankerite, and quartz were deposited.

Except where it occurs in veinlets, the quartz of the early phase of mineralization or hydrothermal alteration cannot be distinguished from the quartz originally present in the metamorphic rocks. Pyrite and ankerite form veinlets and disseminated crystals and grains. Pyrite is associated with other alteration minerals. Ankerite is associated with pyrite and quartz; it also veins the late-stage sulfide minerals.

The twelve sulfide veins that lie along the footwall (east) side of the alteration zone are well defined, and most of the production of the mine has come from them. They crop out in an area that is about 2,500 feet long by 100 feet wide. The other sulfide veins in the alteration zone west of the footwall crop out erratically and are mostly nonproductive.

Fracturing and shearing controlled the size and shape of the alteration zone and the widths, lengths, and special relations of the veins. The veins appear to be slightly discordant to the structure of the alteration zone.

Each of the twelve en echelon veins extends in a horizontal plane farther north than the adjacent vein to the east. In a vertical plane, each vein extends to a higher altitude than its eastern neighbor. The veins strike about N. 22° E., dip 71° W., and plunge northward between 55° and 60°. They range in width from 1 to 14 feet and are hundreds of feet long. The contact between massive sulfide and wallrock is abrupt.

Fine-grained massive sulfides and massive quartz make up the vein material. The color of the massive sulfides ranges from pale yellow to nearly black, depending on the ratio of pyrite to sphalerite and carbonate. Quartz is gray, white, and greenish gray. Differences in the relative amounts of pyrite, sphalerite, or gangue produce a fine banding in most of the ore; banding is indistinct or absent in nonproductive parts of the veins.

Pyrite, arsenopyrite, sphalerite, chalcopyrite, galena, and tennantite comprise the sulfide minerals, of which pyrite is dominant. Ankerite, quartz, sericite, and a little residual chlorite constitute the nonsulfide minerals; of these minerals quartz and ankerite are dominant; either one may be more abundant except in the northern ends of the veins, where quartz is almost the only nonsulfide mineral.

Deposition of ore-forming minerals (chiefly sphalerite) in fractures or microscopic shear planes in early vein filling and variation in relative rates of deposition of the vein minerals probably caused the banding in this deposit. Mineral zoning is characteristic of the deposit and is generally similar in each vein. The northern end of each vein consists mostly of massive quartz, south of which the vein is massive sulfide—largely sphalerite and galena—the content increasing to a maximum and then decreasing gradually to the south as the pyrite content increases.

Postmineralization structures include faults, joints, and probably fracture cleavage. Larger faults that offset veins are reverse strike faults and are nearly parallel to the veins.

FISSURE VEINS IN THE SOUTHERN PART OF THE PRESCOTT QUADRANGLE

Although mineralized fissure vein deposits are widespread in the Precambrian rocks along the southern part of the Prescott quadrangle, none appears to be of any economic importance, and production from them has been very small. They have been prospected intermittently since the early days of mining, and shafts 100 or more feet deep have been sunk along some of them. The veins are in the northern margins of the Big Bug, Walker, and Groom Greek districts and in the Prescott and Lynx Creek districts. Because of the similarity of the deposits and the indefinite boundaries of the districts, they are not discussed by district.

The Silver Belt-McCabe vein is about 1,500 feet northwest of the Iron King deposit. It was traced by Creasey (Anderson and Creasey, 1958, p. 169) for about 14,000 feet; only about 1,200 feet of the vein is within the Prescott quadrangle. The Kit Carson vein lies about 1,300 feet northwest of the Silver Belt-McCabe vein and was traced by Creasey (Anderson and Creasey, 1958, p. 174) for about 4,000 feet, only about 500 feet being exposed within the map area. Both veins are buried to the north beneath the upper Tertiary(?) gravels. The strike of the northern sectors of these veins is about N. 30° E., about parallel to the Iron King zone. The Silver Belt-McCabe vein dips 70°–80° NW., but the Kit Carson vein dips steeply southeast. The veins may intersect at depth. Several prospect pits and shallow shafts were dug in the part of the veins within the map area. Gold and silver ore was produced from three mines on the Silver Belt-McCabe vein, south of the Prescott quadrangle, in the early days of mining in the district.

The shear zones containing the veins consist of fissile rock containing abundant chlorite. The wall rock, Spud Mountain breccia, is foliated but not fissile, because actinolitic hornblende rather than a micaceous mineral is present. Fissile somewhat bleached areas, generally only a few feet wide, make up the veins, but some bleached zones on the Silver Belt-McCable vein south of the map area are 15 feet wide. The ore shoots are lenses or pods, most of which are narrower than the part of the vein in which they occur.

The drusy character of these veins, in contrast to the massive character of the Iron King deposits, and some of the quartz veins in the area suggest that these deposits formed at moderate depths and after the major Precambrian deformation. The shear zones in which the vein material occurs, on the other hand, are micaceous; they parallel the structure produced by Precambrian deformation in the area, so that a Precambrian age for their formation is probable.

On the west side of the Spud Mountain about 3,000 feet northwest of the Kit Carson vein, shear zones occur in breccia of the Spud Mountain Volcanics adjacent to the Spud fault and in gabbro and granodiorite within the fault. They strike N. 20°–45° E. and dip steeply east or west. Several veins have been prospected. Quartz, carbonate (at least some of which is probably ankerite), pyrite, arsenopyrite, galena, and chalcopyrite were noted on some of the dumps along these shear zones. Many of the quartz pods and lenses in portions of the shear zones contain minor amounts of pyrite and copper carbonates.

East-trending steeply northward-dipping shear zones and quartz veins in granodiorite and gabbro north and

south of the old State Route 69 (near 1,295,500 N., 370,000 E.) have been prospected, some of them by shafts 100 or more feet deep. The highly sheared zones are generally 1–4 feet wide, but locally pods of quartz are as much as 10 feet wide. Chlorite or sericite has been formed along some of the shear zones. Large areas of the granodiorite to the northeast show minor silicification, sericitization, and some chloritization. Minute pyrite crystals are rather widely disseminated, and quartz, quartz-tourmaline, and tourmaline veins are abundant. Both massive and drusy quartz veins occur in the area. Pyrite and chalcopyrite were noted in specimens from the drusy quartz. Carbonate, fine tourmaline needles as individual crystals and as masses, pyrite, and locally chalcopyrite and malachite occur in the massive quartz veins. During development work on the Gold Coin group (1,293,600 N., 368,300 E.) in 1950, scheelite was found together with chalcopyrite and minor amounts of galena; gold in pockets was reported. Two tons of gold ore were shipped in 1950; 110 tons, in 1946; 1 carload, in 1939; and 2 carloads, in 1935 (U.S. Bureau of Mines, 1935–58).

The New Strike prospect (1,276,200 N., 357,200 E.) is located on a strong shear zone that strikes about N. 12° W. and dips about 80° W. about parallel to the foliation in the rhyolitic tuff host rock, Texas Gulch Formation. The prospect has been explored by an adit and several shallow shafts and pits for a distance of about 1,500 feet. According to the U.S. Bureau of Mines (1935–58), 1,171 tons of zinc-lead ore was shipped in 1942, 1943, 1946, and 1949. The prospect was reopened briefly in the fall of 1952. The rocks in the shear zone have been silicified and sericitized and contain quartz, sericite, carbonate, chlorite, and epidote. Pyrite and sphalerite were noted on the dump.

The Bullwhacker prospect (1,291,000 N., 352,000 E.) in what has been called the Prescott district occurs in unnamed basaltic flows of the Alder(?) Group that have been intruded by gabbro. According to Blake (1898, as quoted in Wilson and others, 1934, p. 28), the mine "sometimes called the Bowlder claim * * * is notable for bearing coarse gold of high grade in a small quartz vein. The vein varies in thickness from a few inches to a foot * * *. There is apparently one ore 'shoot' or chimney pitching northward. The claim has been worked to a depth of 132 feet by a shaft, and most of the pay ore [has been] extracted (1886) to that depth." The shaft was caved at the time of Lindgren's visit (1926, p. 108). Additional prospecting has been done since then, as several shafts in the vicinity were observed that are not mentioned in either of the reports. According to Lindgren the "vein of massive quartz is

several feet wide and trends N. 18° E., probably with the schist * * *. The massive milky-white quartz contains a little pyrite in crystals and stringers." Calcite is associated with quartz in some of the specimens on the dump, and a little malachite coats fractures.

About seven-tenths of a mile east-northeast of the Bullwhacker prospect, several shallow shafts and pits have been dug in a quartz vein that trends about N. 25° W. and dips about 80° E. In places the quartz vein is as much as 5 feet wide. Copper stains are abundant on the quartz specimens on the dumps.

The Whitehorse prospect (near 1,285,500 N., 370,500 E.) is dug in quartz veins in gabbro that is cut by many pegmatite, aplite, and granodiorite dikes. The exact vein from which some of the high-grade gold ore was produced about 1900 (Mr. G. S. Fitzmaurice of Prescott, oral commun., 1955), is not known as several adits and pits have been dug in quartz veins in the area. The gold is reported to have been in visible flakes. Specimens on some of the dumps contain pyrite and a little chalcopyrite. The quartz is vuggy and the vugs contain quartz crystals, a botryoidal manganese mineral, and fibrous malachite.

About 2,000 feet northeast of the Whitehorse prospect, an east-trending shear zone, which dips about 65° N., contains a milky vuggy quartz vein. Limonitic stains after sulfide are abundant. Galena and pyrite are in fractures, and crystals of pyrite, one-eighth inch in size, are imbedded in the quartz. Near the quartz vein, epidote veins are abundant in the gabbro. Their relation to the quartz veins and to mineralizing solutions is not known, but epidote is not abundant in the adjacent areas.

FISSURE VEINS IN MINERAL POINT DISTRICT AND ADJACENT AREAS

Some prospecting has been done on quartz veins in Precambrian rocks in the Mineral Point district (east-central part of the Prescott-Paulden area) and along the Verde River in the eastern part of the Paulden quadrangle.

Lindgren (1926, p. 102) mentioned Ford's copper prospect and "Peter's silver mine" in the Mineral Point district (probably near sec. 7, T. 16 N., R. 1 E.). He stated that shafts were sunk in copper-stained schist at Ford's prospect and that at Peter's mine a 2-foot vein of quartz in sheared red granite (alaskite) contained a little pyrite, galena, sphalerite, and black streaks of felty tourmaline. The Old Hopkins mine (pl. 1, 1,345,700 N., 394,500 E.) produced some gold, according to G. S. Fitzmaurice (oral commun., 1953) of Prescott. Production of gold, silver, and copper from the Mineral Point district from 1932–57 is given in table 14.

TABLE 14.—*Value of gold, silver, and copper recovered from the Mineral Point district, 1932–57*

[Minerals Yearbooks, U.S. Bur. Mines, 1932–57]

1932–34	0	1940	$7,844
1935	[1] $3,238	1941	70
1936	9,462	1942–45	0
1937	0	1946	35
1938	5,217	1947–57	0
1939	2,753		
		Total	28,619

[1] According to Minerals Yearbook, the 1935 production from the district was entirely from lode mines, but according to Wilson (1952, p. 57), $3,194 of placer gold was produced in 1935.

Most quartz veins in the Mineral Point district are 6 inches to 4 feet wide and occur in shear zones. They strike from north-northwest to northeast, except for a few that strike eastward. The dips are steep. The quartz is massive and glassy or milky. Pyrite occurs in small cubes, and minor amounts of copper staining (malachite, azurite, and chrysocolla) indicate the presence of primary copper minerals, probably chalcopyrite.

LYNX CREEK PLACER DISTRICT

Gold placer deposits occur over a distance of more than 16 miles along Lynx Creek and some of its tributary gulches from near Walker (fig. 1), about 3 miles south of the Prescott quadrangle, to its junction with the Agua Fria River, just east of the map area.

HISTORY OF OPERATIONS AND PRODUCTION

Operation of the Lynx Creek placers can be briefly summarized as follows: (1) early (prior to 1885) small-scale operations, and (2) later large-scale operations, mostly unsuccessful, and intermittent small-scale operations, especially during economic depressions.

The placers were discovered in 1863 by a party of California miners headed by Captain Joe Walker, and more than 200 men were soon working them, according to State Historian Hall (Wilson, 1952, p. 39). Active work with hand rockers, pans, and small sluices continued for several years before the richest gravels were exhausted. Of the 100 men reported to be working these placers prior to 1885, some recovered about $20.00 a day, according to Gilmore (Wilson, 1952, p. 39), and one man is reported to have recovered $3,600 in 11 days from the lower reaches of the creek, according to Shananfelt (Wilson, 1952, p. 39–41).

Much money has been spent in efforts to work the placers on a large scale; these operations have been confined to the area near the highway bridge over Lynx Creek (1,292,500 N., 362,700 E.) and near the Fitzmaurice property along the east-trending portion of the creek (sec. 22, T. 14 N., R. 1 W., through sec. 19, T. 14 N., R. 1 E.; 366,700 E., to 387,700 E.). These opera-

tions are summarized below, mostly from data given by Wilson (1952, p. 41–42).

In the late 1880's, an Englishman, B. T. Barlow-Massick, built a small dam above the highway bridge across the creek and installed a 30-inch pipe from the dam for about 2 miles down the creek for use in hydraulic mining of the gravels. The dam was soon destroyed by a flood.

From 1892 to 1895 a steam shovel was in operation on a gravel flat about half a mile below the bridge. About 1900, the Speck Co. tried out an old dredge a short distance below the bridge, but the roughness of the bedrock prevented success. Later, Mr. F. G. Fitzmaurice of Prescott, who owned placer claims on lower Lynx Creek for many years, operated the Speck Co. dredge for a short time, but after recovering about $800 worth of gold, the dredge fell apart. A large expensive patented gold-saving machine was tried out nearby at about this time but, also, without success.

In 1927, the Lynx Creek Mining Co. attempted large-scale operations with a movable plant consisting of an excavator, a stacker, screens, and sluices. A large yardage of material was treated. In 1932, a California-type dredge was installed on the Fitzmaurice property below the lower dam (sec. 22). The dredge was operated from March to July 1933 by the Calari Dredging Co. In one 60-day period, 60,000 cubic yards of gravel, yielding approximately 32 cents per cubic yard, was treated. The operation is described in some detail by Wilson (1952, p. 41–42).

Upper Lynx Creek from the area called Bigelow Flat (1,279,000 N., 359,700 E.) to half a mile below the highway bridge was leased by a Mr. Barnes, according to F. G. Fitzmaurice (oral commun., 1953) and operated by doodle bug during 1940–41. Doodle bug is a term used in placer operations for unconventional methods of getting the gravel to a conventional gold-saving machine. It is used where lack of water or other factors make conventional dredging operations impractical. It may consist of dragline, power shovel, or other improvised equipment.

Other dredging operations are summarized by Wilson (1952, p. 42) as follows:

Arizona Dredging and Power Co.: Latter part of 1933.

Lynx Creek Placer Mine Co., 1934–40: Treated 556,115 cubic yards of gravel in 1938 and 542,815 cubic yards in 1939 with large floating washing plant and two draglines; was largest producer of placer gold in Arizona (mostly on Fitzmaurice property).

Phoenix Lynx Creek Placers Co.: 1934.

Rock Castle Placer Mines Co.: Last quarter of 1939; handled about 12,000 cubic yards of bench gravel (above the Lynx Creek Placer mine dredge) by

means of a dry-land dredge equipped with four bowl-amalgamators.

Placer King Mines, Inc.: In September 1940 took over property and equipment of Lynx Creek Placer Mine Co.

Big Bug Dredging Co.: 1941.

Minona Mining Co.: 1948–49, on Fitzmaurice property. Other dredges at several properties: 1940–42.

Parker and Raymond: 1952–53, dragline dredge.

Intermittent small-scale placer operations have been carried on for many years. According to A. S. Konselman (Wilson, 1952, p. 42), the average earnings during the spring and summer of 1933 amounted to 50 cents per day per man; at this time approximately 30 men were recovering gold by rocking and sluicing largely in dry side gulches on upper Lynx Creek. According to F. G. Fitzmaurice (oral commun., 1953) as many as 500–600 men worked the placers during 1933–34. One 160-acre plot is reported to have had 100 men working on it.

Total production from Lynx Creek was probably about $2 million. Records of early-day yield are not available, and much of the recovery by individuals has not been recorded or the records were not accurately kept. The principal producing periods were prior to 1885 and 1933–42. It is not possible to make sense out of the various estimates and records of production from the district, nor to be certain how much of the production has come from the portion of the district that lies within the Prescott quadrangle. Most of the production, however, probably came from within the Prescott quadrangle, as all the large-scale operations have been from this part of the district. Production from 1914 to 1957 is given in table 15. The district has accounted for about 20 percent of the placer gold produced in the State and about 34 percent of that produced in Yavapai County.

GEOLOGY AND OCCURRENCE OF THE GOLD

The geology along Lynx Creek is shown on plate 1. A stock of granodiorite considered by Lindgren (1926, p. 21–22) as possibly post-Precambrian but by Wilson (1937, fig. 5, p. 34) as Precambrian in age is south of the map area near Walker. Wilson's map also shows schist and undifferentiated diorite and granite in this area. Within the Prescott quadrangle, the north-trending part of Lynx Creek is cut on Prescott Granodiorite, gabbro, unnamed tuffaceous rocks of the Alder(?) Group, fine-grained granite, coarse-grained granite, and rocks of the Texas Gulch Formation. The east-trending part of the creek east of coordinate line 370,000 E. is cut on upper Tertiary(?) rocks that consist of well-cemented coarse gravel close to Precambrian bedrock but grade eastward into fine-sand, silt, clay,

TABLE 15.—*Value of gold and silver production of the Lynx Creek placers, 1914–57.*

[Mineral Resources of the United States, U.S. Geol. Survey, 1914–23, and U.S. Bur. Mines, 1924–31; and Minerals Yearbooks, U.S. Bur. Mines, 1932–57. Data for the years 1914–31 taken from Wilson, 1937 facing p. 16.]

Year	Value	Year	Value
1914	$3,733	1936	$144,328
1915	4,587	1937–38	73,981
1916	1,372	1939	92,324
1917	2,424	1940	71,257
1918	1,647	1941	153,650
1919	1,225	1942	3,055
1920	0	1943	280
1921	1,104	1944	0
1922	1,225	1945	0
1923	2,356	1946	1,859
1924	765	1947	0
1925	314	1948	1,969
1926	445	1949	12,822
1927	0	1950	70
1928	0	1951	105
1929	2,764	1952	0
1930	2,378	1953	1,896
1931	1,034	1954	0
1932	4,563	1955	35
1933	26,672	1956	0
1934	126,681	1957	0
1935	100,905		
		Total	[1] 843,825

[1] Total may include values of some placer gold from the part of the district that lies south of the Prescott quadrangle.

and limy beds. The Precambrian formations and foliation within them trend northward; dips are steep to vertical. Gold is found in gravels along the entire length of Lynx Creek. It was probably derived from gold-quartz veins in the Walker district. Where the creek bed is cut on Precambrian rocks, a distance of about 8 miles, placers occur as thin benches or bars a few yards in width. Where the creek bed is cut on upper Tertiary(?) deposits, placer gravels attain a maximum width of about 1,000 feet and a thickness, according to Wilson (1937, p. 35), of 8–24 feet. Wilson stated that some gold was said to be present throughout this thickness, but the richest material is at the bottom of the gravels and in a 4-foot streak about 2 feet higher. Gold occurs along some small dry side gulches tributary to upper Lynx Creek.

Lindgren (1926, p. 109) stated that the average value of the placers was reported at 18 cents per cubic yard. He reported: "At Walker the placers yielded nuggets worth as much as $80, about $16 an ounce. Lower Lynx Creek produced a finer grained gold of higher value, worth about $18 an ounce. Such an enrichment in the value of the gold is common and indicates a solution of the silver by the waters." According to Wilson (1952, p. 43), the "gold of lower Lynx Creek ranges from finely divided material up to $6 to $8 nuggets, and

is associated with considerable hematitic and magnetitic black sand." During the operations of the Calari Dredging Co. in 1933, 85–90 percent of the gold in the gravels was extracted. "It ranged in size from flour up to fragments 0.1 inches in diameter * * *" (Wilson, 1952, p. 42).

OTHER PLACER DEPOSITS

Placer gold occurs along the upper branches and main course of Granite Creek, mostly south of the Prescott quadrangle, although gold has been recovered nearly as far north as the Granite Dells. Some gold has been reported in washes and in pediment and terrace gravels along Granite Creek north of the Granite Dells and near Del Rio, about 20 miles north of Prescott (Lindgren, 1926, p. 54). The Granite Creek placers were discovered in the 1860's and worked to a considerable extent during the 1880's. The New England Gulch, a tributary, was reported to have been very rich; one old-time placer miner recovered about $20,000 worth of gold prior to 1922 (Wilson and Tenney, 1932, p. 37). Some small nuggets were found when excavating for buildings in Prescott, according to Mr. H. R. Wood (Wilson, 1952, p. 56). Granite Creek placer production from 1931 to 1957 is given in table 16.

TABLE 16.—*Recorded production of placer gold from Granite Creek, 1931–57*

[Mineral Resources of the United States and Minerals Yearbooks, U.S. Bur. Mines, 1931–57]

1931	$390	1941	$245
1932	623	1942–43	0
1933	414	1944	70
1934	144	1945–46	0
1935	84	1947	35
1936	70	1948–57	0
1937–38	0		
1939	385	Total	[1] 3,020
1940	560		

[1] Wilson (1952, p. 57) listed Granite Creek placer production 1931–49 as $1,983.

An area locally called The Nugget Patch (1,290,000 N., 370,000), between the headwaters of Clipper Wash and a wash that enters Lynx Creek below the Lower Dam, is reported to contain gold in black sands, probably derived from the underlying quartz veins in gabbro. A little development work was done in 1948 by Mr. D. P. Lawson, but the operations were hampered by lack of water.

NONMETALLIC DEPOSITS

BUILDING STONE

Precambrian, Paleozoic, and upper Tertiary(?) rocks are used as building stone and in road construction. The Prescott Granodiorite near Prescott is the most widely used of the Precambrian rocks, principally for foundations and trim in homes and larger buildings— for example, the trim on Yavapai County Court House (1916) in downtown Prescott. The granodiorite is fine to medium grained and takes a good polish; the large poikilitic microcline crystals, as much as an inch across, give a pleasing effect when the light is reflected from their cleavage planes. Mazatzal Quartzite and some interbedded conglomerate are used in and near the village of Chino Valley for foundations and home construction.

Upper Tertiary(?) rocks used in home construction include some of the tuffaceous sedimentary rocks, especially the orange-colored tuff used for trim and other construction when sufficiently indurated. A gray rhyolite tuff bed north of Prescott was used in constructing the Armory in Prescott and a few fireplaces. The tuff (described on p. 73) crops out beneath basalt near the tops of two hills south of Willow Creek: (1) On the east side of the hill near 1,306,700 N., 332,200 E., and (2) on the north end of the hill near 1,305,000 N., 331,800 E., where it has been quarried. Attempts have been made to quarry the Glassford cinder cone for cinder blocks, but apparently the large bombs and blocks of basalt make the material undesirable.

Sandstone is quarried in the extreme northeastern corner of the Paulden quardangle (secs. 26, 27, 34, and 35, T. 19 N., R. 1 E.). Many more quarries are north and east of the quadrangle. The Coconino Sandstone and some of the sandstone beds near the top of the Supai Formation are strongly crossbedded on a large scale, and much of the rock splits readily along crossbeds into thin slabs and sheets. Sandstone that splits into pieces not more than 2 inches thick and as much as 4–6 feet square (minimum of 18 inches on a side) is sold as flagstone for exterior use, chiefly in steps, sidewalks, and patios. Sandstone that is more than 2 inches thick is cut into strips 2–4 inches thick and about 3½ inches wide for use as exterior decoration or veneers on buildings. Very large pieces are cut into building blocks. A more detailed account of this resource is given by Lehner (1958, p. 587–588).

LIMESTONE

Limestone is widespread in the Paulden quadrangle, but only parts of units 1, 2, and 4 of the Redwall are pure enough to be suitable for use as raw material for cement and lime. Limestone was being quarried in 1928 (Tenney, 1928, p. 109) at Cedar Glade (Drake) in the north-central part of the quadrangle. The broken limestone was trammed to the kiln, where it was burned and shipped as lime. The Drake operation was one of

the three principal producers in Yavapai County for a long period prior to 1928 (Wilson and Roseveare, 1949, p. 25). Open pits and remnants of kilns are (1) along Limestone Canyon (NW¼SE¼ sec. 34, T. 19 N., R. 2 W.), (2) about three-fourths mile southwest of Drake, and (3) about 1½ miles north-northeast of Paulden. In 1956, the limestone near Drake was drilled, but the project was dropped, in part because of lack of sufficient water and good clay in the area.

WATER RESOURCES OF THE PRESCOTT AREA

A study of the water resources of the Prescott area was made in 1945 and 1946 by personnel of the Ground Water Branch of the U.S. Geological Survey. The study was made under a cooperative agreement at the request of the Honorable James Whetstine, at that time Mayor of Prescott, and an informal report on the preliminary results of the study was submitted to the city in September 1945.

Geologic and hydrologic fieldwork was carried on by K. K. Kendall and H. M. Babcock of the Ground Water Branch with assistance and cooperation by Mayor Whetstine and by Mr. Charles Shaw, at that time Water Superintendent for Prescott. The information presented in this section is condensed from the preliminary results of K. K. Kendall and H. M. Babcock. Record of wells and springs in the Prescott area, collected during the investigation, is shown in table 17. The location of these wells and of other wells in Chino-Lonesome Valley is shown on plate 3.

HISTORY OF USE OF GROUND AND SURFACE WATER

Prescott was founded in 1864, and since then the problem of an adequate water supply has been an ever-present concern. Until 1884 the inhabitants of the city depended entirely on shallow wells for their water supply. At that time a dam was constructed on Miller Creek to impound the surface flow, and water was pumped from the storage reservoir to a tank above the city. As this supply was inadequate and the water of poor quality, a large portion of the water supply continued to be obtained from wells. In 1891, an infiltration gallery, a permeable structure equivalent to a horizontal well, was constructed in the channel of Granite Creek. As the city continued to grow, the supply from this gallery became inadequate, and in 1899 another gallery was constructed nearby. The demand for water soon outgrew the supplies available from the infiltration galleries, and in 1901 a pipeline was constructed to Del Rio Springs (near Puro, 1,391,000 N., 342,200 E., pl. 2), about 19 miles north of Prescott. An adequate supply was available from this source, but the cost of pumping a distance of 19 miles and lifting the water about 1,000 feet was considered excessive.

In an attempt to obtain a cheaper water supply, a dam (Goldwater Lake) was built in 1923 on Bannon Creek about 3 miles south of Prescott (1,273,500 N., 337,300 E.). Later, another dam was built a short distance upstream, and several small dams were constructed on nearby streams. Water was piped from these smaller dams to the reservoirs on Bannon Creek. Upon completion of these storage reservoirs, the pipeline to Del Rio was abandoned and later removed.

In 1945 Prescott was dependent primarily on this system of surface storage reservoirs for its water supply. Some additional water was obtained from the infiltration galleries on Granite Creek and from a privately owned well about 4 miles north of the city—No. 1, sec. 14, T. 14 N., R. 2 W. These sources were inadequate, and a period of severe drought complicated the situation.

As the investigation by the U.S. Geological Survey in 1945 and 1946 did not indicate an adequate water supply close to Prescott, in 1947 the city drilled two wells (Nos. 6 and 7, sec. 22, T. 16 N., R. 2 W.) that tapped the Chino artesian basin. The wells were located approximately 5 miles south of Del Rio Springs, thereby reducing the piping costs by an estimated $140,000. The first well was completed in October 1947 and yielded more than 1,000 gpm (gallons per minute) during a pumping test of several hours. The second well, a quarter of a mile to the north, was completed in December of the same year. The yield here was about 1,850 gpm, which equaled the capacity of the testing equipment. Water from these wells was piped to Prescott in May 1948, and the wells are now the principal source of supply. Surface water from Goldwater Lake is still used, and much of the water that supplies Miller Valley comes from wells tapping a small artesian basin in the area.

Water for domestic use outside the city of Prescott is obtained principally from wells. Water for irrigation near the village of Chino Valley is obtained from deep wells that tap the Chino artesian basin and is supplemented by water brought along an irrigation ditch to Chino Valley from artificial Watson Lake in the Granite Dells. Water from springs along Del Rio Creek, at and south of Puro (1,391,000 N., 342,200 E.) and from nearby wells, for many years supplied water to Grand Canyon Village and still supplies Ashfork and Seligman on the Santa Fe Railroad. Water for stock on the range is obtained from "tanks"—basins formed mostly by earthen dams across gullies where runoff is impounded. This supply is supplemented by water pumped from shallow or deep wells.

TABLE 17.—*Record of wells and springs in the Prescott area*

[All wells are drilled unless otherwise noted in the remarks column. Well and spring records were collected by H. M. Babcock and K. K. Kendall of the U.S. Geol. Survey and by John Gibbs (1945–46). Pump and power: Cf, centrifugal; J, jet; C, cylinder; T, turbine; B, bucket; G, gasoline; E, electric; H, hand; W, windmill; and N, none. Use of water: D, domestic; S, stock; I, irrigation; P, public supply; and N, none. Measuring point was generally top of casing, top of pump base, top of water-pipe clamp, or top of well curb]

Section and well	Owner	Driller	Well Altitude (feet above sea level)	Depth (feet)	Diameter (inches)	Water level (depth below measuring point in feet)	Date of measurement	Pump and power	Use of water	Temperature (°F)	Remarks
			T. 13 N. R., 2 W.								
Sec. 2, well 1	J. Roberts			30	60	22.3	6/ 5/46	Cf, G	D	56	Dug well; reported water from coarse gravel.
3, well 1	E. H. Smith	White		107	6	[1] 102.0		J, E	D, I	63	Reported water from caliche.
2	Boyd Tenny			25	60			C, W	D		Dug well; reported water from caliche.
4, well 2	G. E. Jones			16	72			C, E	D, I	61	Dug well; reported water from fractured quartz 15–16 ft.²
5, well 1	H. Cory	Bob Kuhne		360	8	[1] 100.0		T, E	D	63	Reported water from weathered granite.²
2	M. E. Claw			20	60	8.6	6/17/46	J, E	I	59	Dug well.
9, well 1	A. F. Bumpas	Bob Kuhne		130	6			J, E	D	64	Reported water from weathered granite.
12, well 1	H. B. Warbass			22	60	[1] 15.0		B, H	D		Reported discharge, 6 gpm from alluvial fill.
			T. 14 N., R. 2 W.								
Sec. 10, well 1	San Dreta	White & Kuhne	5,219.9	894.0	6	84.7	7/ 1/46	N	N		Reported discharge, 60 gpm with 70-foot drawdown when used.
14, well 1	E. Weston	E. Weston	5,196.2	223.0	10	[1] 48.0	9/ /46	T, E	D, S, P, I		Reported water from coarse gravel at 215 ft. Reported discharge, 250 gpm.
3	do	do	5,200.0	1,013.0	14	[1] 50.0		N	N		Reported well can be bailed nearly dry.
16, well 1	Johnson		5,206.8	120.0	6	28.2	8/10/46	Cf, E	D	65	Dug to 60 ft; drilled 60–120 ft.
2	do		5,209.1	130.0	6	17.3	7/ 1/46	C, W	S	65	Reported water from hard rock 128–130 ft.
3	Ralph Murphy		5,227.5	30.0	60	22.4	do	C, W	D, I	57	Dug well.
4	W. H. Handcock				60			C, W	D, S	61	Do.²
18, well 1	Roy Haines			30.0	60	10.5	6/13/46	C, H	D	59	Do.²
2	U.S. Forest Service							N	D, S		Spring, measured flow 2 gpm 7/10/46.
3	D. W. Fuller			60.0	6	11.9	6/13/46	Cf, G	D, S, I	64	
4	B. A. Logan			100.0	6			C, W	S, I	60	
19, well 1	L. C. Holmes	Fred Green		97.0	6			J, E	D, S	63	Reported 25-ft drawdown after pumping 5 hours.²
2	B. A. Logan			100.0	6			C, E	D	60	
3	L. W. Keeley			48.0	60			C, E	D	61	Dug well.
20, well 1	Roy C. Saline			12.0	60	6.4	6/13/46	Cf, E	D, S	57	Dug well; reported water from decomposed granite.²
21, well 1	Dan Sidel	Bob Kuhne	5,350.0	290.0	6			C, W	D		(²).
2	J. C. Brown	Fred Green	5,565.0	304.0	6	170.0	7/18/46	J, G	D	65	Reported discharge, 5 gpm.²
5	do		5,518.8	62.0	48	49.2	7/ 5/46	N	N		Dug well.
22, well 2	E. Weston	E. Weston	5,452.6		4	212.0	8/12/46	N	N		
3	do	do			36	13.5	7/ 5/46	N	N		Dug well.
23, well 1	City of Prescott	J. Pulleum	5,196.7	479.0	6	[1] 55.0	1946	N	N		City test well 3.²
2	do	do	5,199.4	44.0	60	1.45	12/ 1/46	N	N		Dug to 34 ft. Test well 1.
3				61.0	60	26.8	7/ 9/46	C, H	D, S	59	Dug well.
24, well 1	W. R. Storm		5,250.7	91.0	48	83.2	8/ 8/46	C, W	D, S	62	Dug well; reported water from weathered granite.²
26, well 2	City of Prescott	J. Pulleum	5,214.0	149.0	8	5.8	11/ 7/45	N	N		Measured discharge about 3 gpm, with 14-ft drawdown, July 1946. Test well 2. Originally pumped at 40 gpm; later, it produced less than 3 gpm.²
3	U.S. Veterans Adm		5,215.8	25.0	72	1.7	11/ 9/45	N	N		Dug well.
4	City of Prescott			9.0	30	3.7	8/22/45	N	N		

See footnotes at end of table.

Table 17.—*Record of wells and springs in the Prescott area*—Continued

Section and well	Owner	Driller	Altitude (feet above sea level)	Depth (feet)	Diameter (inches)	Water level (depth below measuring point in feet)	Date of measurement	Pump and power	Use of water	Temperature (°F)	Remarks
						T. 14 N., R. 2 W—Continued					
Sec. 27, well 1	U.S. Veterans Adm		5,272.5	413.0	8	[1] 26.0		N	N		Reported discharge, 5 gpm.[2]
2				16.0	60	6.0	6/20/46	C, W	S	64	Dug well.
28, well 1	Yavapai County Hospital.	Bob Kuhne	5,376.6	252.0	6	[1] 46.0	6/12/46	T, E	D, I	63	Measured discharge, 10 gpm, with 56-ft drawdown, July 1946. Water reported to stand near surface in winter. After pumping all summer (about 6 months) water is down more than 100 ft.
2	Black			85.0	6			C, W	D	62	
3	Yavapai County Hospital.		5,401.1	40.0	120	11.3	7/17/46	T, E	I	57	Dug well; reported pumps dry in 5 hours.
4	----do		5,401.7	180.0	12	2.8	6/12/46	J, E	I		Reported discharge, 10 gpm.
5	----do	H. Maxwell	5,379.0		72	21.6	7/17/46	C, E	I		Dug well, reported discharge, 3 gpm.
6	Stephenson			22.0	60	[1] 11.0		E	D	61	Dug well.
7	J. F. Scott			180.0	6	[1] 15.0		J, E	D, I	60	([2]).
29, well 1	C. J. Walworth			16.0	60	7.3	6/13/36	Cf, E	D	59	Dug well.[2]
2	----do			19.1	60	14.1	---do	Cf, E	D	64	Do.
3	C. A. Holz			20.0	60	10.1	---do	Cf, E	D	59	Dug well; reported pumped dry in 5 hours.
4	----do			18.0	60	16.0	---do	C, H	I	58	Dug well.
5	J. D. Garrett			11.0	60	6.0	---do	Cf, E	D	57	Do.
6	D. Haymore			65.0	6	[1] 63.0		Cf, E	D, S	59	Reported well can be pumped dry in 3 days.
7	V. Ramuz	Bob Kuhne	5,389.6	168.0	6	[1] 18.0		Cf, E	D	60	Reported discharge, 10 gpm.
8	G. D. Owens			55.0	48	[1] 4.0		C, E	D		Dug well.[2]
9	L. Weil		5,377.1	256.0	8	17.8	8/ 8/46	C, E	D	59	Reported discharge, 40 gpm.
10	L. R. Templin			16.0	60	[1] 11.0		Cf, E	D, S	65	Dug well, reported water from decomposed granite.[2]
30, well 1	H. A. McDowell			16.0	60	10.0	6/14/46	C, E	D, S		Dug well.
31, well 1	Docherty			39.0	72	[1] 4.0		J, E	D, I	60	Dug well; estimated discharge, 15 gpm.
32, well 1	H. Fee			44.0	60	27.0	6/18/46	J, E	D	60	Dug well.
2	F. W. Steed	Bob Kuhue		41.0	6	[1] 12.0		Cf, E	D	61	Well is dug 20 feet and drilled 21 feet.
33, well 4	D. Miller	O. Cook		115.0	6	[1] 20.0		C, E	D	64	Reported water from alluvial fill and decomposed granite.
5	V. B. Balcom			140.0	6	[1] 25.0		E	D, I	64	
6	A. B. Romero			15.0	60	[1] 8.0		J, E	D	61	Dug well.[2]
7	J. J. Pruitt			83.0	8	[1] 50.0		C, E	D, I	59	Dug to 33 feet; reported discharge, 5 gpm.[2]
8	Deshane			20.0	60			J, E	D, I	59	Dug well.[2]
9	H. Allan				60	[1] 10.0		Cf, E	I	60	Dug well; reported struck alkali water at 85 ft.
10	A. Rivas			30.0	48	[1] 20.0		N	N	55	Dug well.[2]
11	J. E. Benagas			17.0	48	10.0	6/19/46	B, H	D	59	Do.
12	D. Hyslip			41.0	60			C, E	D		Dug well: reported 1-ft drawdown after pumping 4 gpm for 4 hours.
13	E. L. Lee			23.0	60			C, H	D	56	Dug well.
14	E. Leva			12.0	48	9.0	6/18/46	N	N	60	Do.
15	A. N. Garcia			45.0	48	17.0	6/19/46	N	N	55	Do.
34, well 1	City of Prescott	Bob Kuhne		472.0	8			N	N	67	Artesian well; flows 7 gpm; reported drawdown, 68 ft when pumping 52 gpm.[2]
2	----do	Fred Green		265.0	6	19.0	7/12/46	N	N		Measured discharge, 10 gpm, 6/12/46.
3	KYC Radio Station			256.0	8	[1] 59.0		C, E	D		Reported discharge 10 gpm.
6	M. F. Tallent			12.0	48	[1] 9.0		C, H	D	58	Dug well.
7	T. W. Mayfield			18.0	60	[1] 10.0		Cf, G	D, I		Dug well; reported discharge 6 gpm.
35, well 1	Vandenberg			8.0	60	[1] 4.0		C, W	D, S, I	60	Dug well; reported drawdown, 1 ft after pumping 12 gpm for 8 hours.[2]

See footnotes at end of table.

TABLE 17.—*Record of wells and springs in the Prescott area*—Continued

Section and well	Owner	Driller	Well Altitude (feet above sea level)	Depth (feet)	Diameter (inches)	Water level (depth below measuring point in feet)	Date of measurement	Pump and power	Use of water	Temperature (° F)	Remarks
						T. 14 N., R. 3 W.					
Sec. 13, well 1	U.S. Forest Service								S		Spring; estimated flow 1 gpm.
24, well 1	Tom Iglehart			51	60	45.0	6/14/46	Cf, E	D		Dug well; reported water from weathered granite.
						T. 15 N., R. 2 W.					
Sec. 17, well 1	R. E. Perkins		5,057.0	430	8	329.9	6/ 5/46	C, W	S	63	
23, well 1	......do	White	5,076.0	578	8	391.0	...do	C, W	D, S	68	
25, well 1	City of Prescott	E. Weston	5,010.0	839	8	1 384.0		T, G	D	62	Reported drawdown, 200 ft, pumping 200 gpm.
2	......do	Churchill	5,014.0	812	14	332.9	6/ 5/46	N	N		
30, well 1	Webb		5,185.0	150	6	1 100.0		C, G	S		Reported discharge, 10 gpm.
2	C. Brown		5,198.9	180	6	1 100.0		C, G	I, S		Reported discharge, 21 gpm.
32, well 1	Webb	J. Pulleum		132	10	Dry		N	N		Not completed as of October 1946.

1 Water level reported.
2 See table 18 for water analysis.

Perennial flow in streams is limited to the Verde River and two of its tributaries. Granite Creek has a permanent flow of water below a spring (1,401,500 N., 346,000 E.) where the creek crosses a fault about 0.8 mile south of the Verde River. Del Rio Creek issues from springs that tap the Chino artesian basin, and flows north to the headwaters of the Verde River. Hell Canyon, a tributary of the Verde River, has a permanent flow for a few hundred feet below King Spring (1,435,600 N., 376,900 E.) where it crosses a fault, but water soon disappears into the upper Tertiary(?) gravel. A few springs are found in the southern part of the area, especially along and west of Lynx Creek. Generally water flows down intermittent streams and smaller gulches and gullies in winter for short periods owing to runoff of rain and melting snow and in summer for a few hours following rains, which may be of torrential proportions. Major gulches that cross Precambrian rocks in the southern part of the area may have sustained flow for four or five months in the winter and for shorter periods in the summer. Once the water reaches the alluvium of the valleys, however, it disappears within a short distance.

GROUND-WATER RESOURCES

Only the sedimentary and associated volcanic rocks of late Tertiary(?) age in the Prescott area contain sufficient water for large-scale production. Therefore, most of the investigation was concerned with these materials. The water-bearing properties of the upper Tertiary(?) deposits are discussed in detail; those of the Precambrian rocks are discussed only briefly. (See pl. 1 for distribution of the rocks discussed.)

OCCURRENCE OF GROUND WATER

PRECAMBRIAN ROCKS

The Precambrian schist is not porous and cannot be considered a good aquifer. Shallow wells, however, may obtain small supplies of ground water from faults, open joints, and planes of foliation in the weathered zones of the schist.

Limited supplies of water can be obtained from shallow wells in the granitic rocks, especially along joints, faults, and weathered zones and locally along the contact zones between granitic rocks and schist. The amount of water that can be withdrawn from wells in the granitic rocks is generally not more than 1 or 2 gpm. In several mines, however, water flows from large fractures in such quantities as to hinder mining operations.

UPPER TERTIARY(?) ROCKS

For ease in discussing the water-bearing properties of the upper Tertiary(?) rocks, the three basalt flows in the Prescott area are called the lower, middle, and upper basalt flows. Distribution of the middle and upper basalt flows is shown in figure 24. The basalt flows are separated by fanglomerate and tuffaceous rocks. Orange tuff underlines the middle basalt flows.

The lower basalt flows in the Prescott area are a possible source of domestic ground-water supplies

where the rock is brecciated, but large supplies cannot be developed. Small supplies of ground water might be obtained from the middle basalt flows in areas where joint zones occur below the water table. The upper basalt flows on the ridge south of Willow Creek (1,305,-500 N., 336,500 E.) and east of Granite Creek are above the water table and therefore are not an aquifer. Intrusive bodies of basalt and andesite are probably not important aquifers as they are so small. Small supplies might be obtained from joint zones in these rocks.

The sedimentary deposits above the middle basalt flows on the east-trending ridge south of Willow Creek and on the east end of Granite Creek and the fanglomerates south of Prescott are above the water table and therefore are not aquifers. The fanglomerate part of the beds below the orange tuff is generally not a good aquifer. However, sufficient water for domestic and stock purposes can be obtained from it in areas where it lies below the water table. Some of the white pumice tuffs and coarse lapilli tuffs northwest of Prescott, mostly below the orange tuff, are porous and would probably be good aquifers if they were below the water table. However, they are not extensive. Most of the remaining tuffaceous materials in this area are tightly cemented and would yield very little water to wells.

The sedimentary deposits and associated volcanic rocks that underlie the lower and, locally, the middle basalt flows and that compose the valley fill are better aquifers in the Prescott area than are the overlying deposits. However, most of the fanglomerate is poorly sorted and composed of boulders in a matrix of clay, silt, sand, pebbles, and cobbles. Ground water occurs principally in the small voids or interstices in these materials. Although many alluvial fans in other regions contain good aquifers, most of the fanglomerate that composes the valley fill in this area is tightly cemented and poorly sorted, so that it is relatively impermeable and does not yield water readily to wells. Most of the wells in the valley fill yield small quantities of water, and the drawdowns are large. Well 1, sec. 28, T. 14 N., R. 2 W. (pl. 3; table 17), which is 252 feet deep, produced about 10 gpm with a 56-foot drawdown. Well 2, sec. 26, T. 14 N., R. 2 W., which is 149 feet deep, produced 3 gpm with a 14-foot drawdown. Well 1, sec. 10, T. 14 N., R. 2 W., which is 894 feet deep, produced 60 gpm with a 70-foot drawdown.

Well 1, sec. 14, T. 14 N., R. 2 W., which is 223 feet deep, differs from the other wells in the area. The discharge of this well is about 250 gpm. The water is reported to be derived from about 8 feet of coarse river gravel and cobbles near the bottom of the well. A complete log of this well is not available, but from a description of the water-bearing materials penetrated,

it is apparent that the water is coming from a buried river channel. The course of this buried channel is probably northwest, parallel to the southwest side of Granite Dells and then curved northward between the Dells and Granite Mountain into Chino Valley. Well 3, sec. 14, T. 14 N., R. 2 W., which is located a few hundred feet east of Well 1, sec. 14, T. 14 N., R 2 W., was drilled to a depth of 1,013 feet and produced very little water; it may have been drilled to one side of the channel.

QUATERNARY DEPOSITS

The recent alluvium, located along creeks and washes, is generally less than 30 feet thick. It is composed of unsorted poorly bedded clay, silt, sand, pebbles, and cobbles. Although it is permeable and yields water to wells quite readily, it is too thin to be a source of large quantities of water. An infiltration gallery intercepts most of the underflow in the Recent sand and gravel of Granite Creek.

MOVEMENT OF GROUND WATER

The water that enters the valley fill percolates downward to the water table and thence moves through the valley fill in a general northward direction toward Chino Valley and Del Rio Springs. The ground water is discharged from artesian wells in Chino Valley and from the springs.

In Miller Valley ground water moves southeast, in the general direction of the course of Miller Creek. Most of the underflow of Miller Valley is probably forced to the surface at the narrow constriction above the confluence of Miller Creek with Granite Creek, although some of it may flow northeastward between the two prongs of granodiorite (1,297,000 N., 333,000 E.). The underflow from Granite Creek moves northeastward towards the narrows north of the Veterans Hospital at Whipple, at which point most of it is intercepted by the infiltration gallery. Below the gallery the movement of ground water is to the north, west of Granite Dells.

SOURCE OF GROUND WATER

The principal sources of ground water in the Prescott area are (1) seepage losses from surface flow of washes and (2) direct infiltration from rainfall and melting snow. Much more recharge is contributed by seepage losses than by direct infiltration from precipitation.

Most of the washes lose water rapidly by downward percolation through the coarse alluvium and fanglomerate at the edges of the mountains. The larger washes, such as Granite and Willow Creeks, have more sustained flow than the many small washes of the area, affording an opportunity for recharge throughout the length of their courses across the valley fill south of

Granite Dells. Recharge also occurs by infiltration from surface reservoirs in which the waters of these two creeks are impounded.

WATER-BEARING PROPERTIES OF VALLEY FILL

The valley fill comprises a heterogeneous mixture of gravel, sand, and clay intercalated with volcanic rocks. Mechanical analyses of drill cuttings from well 1, sec. 23, T. 14 N., R. 2 W., are typical of these materials. In 27 out of 37 samples analyzed from a depth of 18–479 feet, 30–60 percent of the sample passed through a 100-mesh screen. In seven samples it was less than 30 percent, and in the remaining three, it ranged from 65 to 90 percent. In 18 of the 37 samples, less than 30 percent of the sample was retained on a 28-mesh screen. In only five did 50–58 percent of the sample remain on the 28-mesh screen. In the other samples it was 30–50 percent. This preponderance of fine-grained material indicates a low permeability.

The rate of flow (transmissibility) of water through the valley fill is very low, as is shown by the large drawdown required to cause the water to flow into the wells drilled in this material. To determine the rate of flow, pumping tests were made on well 1, sec. 28, T. 14 N., R. 2 W., in Miller Valley and on well 2, sec. 26, T. 14 N., R. 2 W., below the highway bridge over Granite Creek. The drawdown in the wells during the tests and the rates of recovery of the water levels after pumping ceased were measured. From these data, the average coefficient of transmissibility (rate of flow) of the aquifer was computed by the Theis recovery formula (Wenzel, 1942, p. 126) as follows:

$$T = \frac{264q}{s} \log_{10} \frac{t}{t'},$$

in which T=coefficient of transmissibility; q=discharge of the pumped well, in gallons per minute; s= the residual drawdown, in feet; t=the time since pumping began, in any unit; and t'=the time since pumping stopped, expressed in the same unit as t. The coefficient of transmissibility has been defined by Theis (1935, p. 520) as the number of gallons of water that will move in 1 day through a vertical strip of the aquifer 1 foot wide at a hydraulic gradient of unity.

The pumping test on well 1, sec. 28, T. 14 N., R. 2 W., was made on July 18 and 19, 1946; a turbine pump was used. An average discharge of about 10 gpm was maintained for 25 hours. The coefficient of transmissibility was computed to be about 440 gpd per sq ft. The test on well 2, sec. 26, T. 14 N., R. 2 W., was made on July 9, 1946; a centrifugal pump was used. An average discharge of about 3 gpm was maintained for 6 hours. The coefficient of transmissibility was computed to be 70 gpd per sq ft.

The materials composing much of the valley fill also are probably poor aquifers because they are similar to those penetrated by the two test wells.

QUALITY OF WATER
COLLECTION AND ANALYSES OF SAMPLES

The chemical character of waters of the Prescott area has been determined on the basis of analyses of 29 samples of ground and surface water. The samples were collected and analyzed by the U.S. Geological Survey during 1946 and 1947. These analyses (table 18) show the quantities of mineral matter dissolved in the waters in terms of parts by weight of dissolved solids per million parts of water. On the basis of the analyses, the waters in the area may be evaluated for various uses to the extent that such uses are affected by dissolved mineral matter. The analyses do not, however, show the sanitary condition of the waters. The significance of the various constituents and properties reported in waters is discussed in annual reports of the U.S. Geological Survey entitled, "Quality of surface waters of the United States."

CHEMICAL CHARACTER OF THE WATER

Waters of the Prescott area are, in general, moderately mineralized; very few of those sampled contained enough mineral matter to impart an objectionable taste. Most of them contain less than 300 ppm (parts per million) of hardness, and some contain less than 100 ppm. A few contain as much as 400 or 500 ppm.

Only one of the water samples tested for fluoride contained more than 1.5 ppm, and it was only slightly above 1.6 ppm, the allowable amount set by the U.S. Public Health Service (1946).

SURFACE WATER

In past years the main portion of the public water supply was obtained from Goldwater Lake, a reservoir south of Prescott on Bannon Creek, a tributary of Granite Creek. The quality of water from this source is indicated on table 18. These samples were collected in 1947 at a time when a long-continued drought had depleted the supply. The samples, therefore, probably contain a higher than normal concentration of dissolved matter. The water contained a moderate amount of dissolved matter, mainly calcium and bicarbonate. Many more samples, taken at different times with different quantities of inflow, would be needed before any conclusion could be drawn as to the average quality of water in this reservoir.

Very little information is available regarding the quality of surface waters from other sources in and near Prescott. Analyses of samples taken from low flow of the Hassayampa River approximately 8 miles south

TABLE 18.—*Analyses of water from wells, springs, and surface waters in the Prescott area*

[In parts per million, except specific conductance. Analyses by the U.S. Geol. Survey, except well 2, sec. 26, T. 14 N., R 2 W., which was analyzed by the University of Arizona. Samples collected by H. B. Babcock and K. K. Kendall of the Geol. Survey]

Location and well	Date of collection	Depth (feet)	Specific conductance (K ×10⁵ at 25°C)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na, K)	Bicarbonate (HCO₃)	Sulfate (SO₄)	Chloride (Cl)	Fluoride (F)	Nitrate (NO₃)	Borate (BO₃)	Dissolved solids	Total hardness as CaCO₃
Wells														
T. 13 N., R. 2 W.:														
Section 4, well 2	6/17/46	16	74.8	84	23	40	319	39	43	0.6	32	--------	419	304
5, well 1	6/19/46	360	64.2	82	18	26	311	11	47	1.0	.8	--------	339	278
9, well 1	6/17/46	130	59.8	62	30	61	440	27	14	.6	1.2	--------	412	278
T. 14 N., R. 2 W.:														
Section 16, well 4	6/12/46	--------	87.6	109	26	18	268	50	87	.4	28	0.2	450	379
18, well 1	6/13/46	30	41.5	44	17	22	224	22	10	.6	6.7	.2	233	180
19, well 1	do	97	71.4	86	32	26	401	32	27	.6	.5	.1	402	346
20, well 1	do	12	54.3	53	21	38	276	43	17	1.0	5.0	.1	314	218
21, well 1	6/12/46	290	46.6	58	15	22	245	16	24	.6	1.0	.1	257	206
2	do	304	49.0	60	18	24	270	11	29	.4	2.0	.1	277	224
23, well 1	5/26/46	479	42.3	10	3.4	85	213	9.3	25	1.6	.3	--------	240	39
24, well 1	7/ 8/46	91	51.0	74	9.5	13	160	20	16	.6	93	--------	305	224
26, well 2	6/12/46	148	--------	82	15	17	255	34	44	--------	--------	--------	537	266
27, well 1	6/24/46	413	48.7	--------	--------	--------	257	--------	31	--------	--------	--------	--------	--------
28, well 7	6/18/46	180	35.7	42	9.4	18	163	10	19	.6	13	--------	192	144
29, well 1	6/13/46	16	42.6	43	11	12	104	28	23	.4	37	.1	206	152
5	do	11	22.5	23	6.8	13	80	26	9	.2	9.9	.2	127	86
8	6/14/46	55	169	171	64	16	274	72	295	.4	9.7	.2	763	690
10	do	16	18.8	20	5.7	9.9	54	25	8	.2	16	.1	111	74
30, well 1	do	16	94.2	102	30	7.1	159	66	93	.2	78	.1	455	378
33, well 6	6/20/46	15	117	142	42	36	215	179	123	.5	84	--------	712	527
7	6/18/46	85	54.6	62	14	29	176	31	34	.8	59	--------	316	212
8	6/20/46	20	79.1	80	29	36	164	45	62	.2	157	--------	490	318
10	6/18/46	30	63.8	67	20	22	140	85	40	.4	46	--------	349	249
34, well 1	6/14/46	472	44.7	--------	--------	--------	206	--------	21	--------	--------	--------	--------	--------
35, well 1	6/21/46	8	80.7	64	65	24	450	50	33	.6	14	--------	472	427
Surface Water														
Del Rio Spring, T. 17 N., R. 2 W., sec. 34	8/19/46	--------	56.1	41	25	47	278	32	31	0.8	1.3	--------	315	206
Goldwater Reservoir, T. 13 N., R. 2 W.	10/18/47	--------	34.1	40	14	14	162	43	7	.3	.2	--------	211	158
Lower Hassayampa River, T. 12 N., R. 2 W., sec. 11	9/30/46	--------	75.4	--------	--------	--------	55	400	2	.2	--------	--------	--------	435
Upper Hassayampa River, T. 12 N., R. 2 W., sec. 11 [1]	do	--------	112	--------	--------	--------	--------	1,250	11	--------	--------	--------	--------	840

[1] This sample contained 209 parts of free H₂SO₄, and a pH of 3.6.

of Prescott are given in table 18. At this point the river water passes over mine tailings, and the acidity and the high sulfate content are the result of contamination from this source. Too few analyses of the waters of the Hassayampa River are available to determine the average quality of the water.

GROUND WATER

Granitic rocks.—Water from shallow wells in the western part of the city of Prescott and from wells southwest and northwest of the city comes from the weathered zone of the granitic rocks or from the disintegrated granitic material overlying the bedrock. This water is rather low in dissolved solids, chiefly calcium and bicarbonate. The concentration generally ranges from about 100 to 300 ppm, but some water contains as much as 500 ppm. Most of the wells are shallow, and local contamination may increase the amount of dissolved solids normally present in water from the granitic rocks. Samples from several of the wells contained excessively high concentrations of nitrate. Considerable amounts of chloride and sulfate occur in the more highly mineralized waters.

Volcanic rocks.—Several wells in the area obtain water from tuffs or from basaltic or other volcanic rocks. These wells are located mostly in the eastern part of Prescott. Water from these rocks is rather uniform in composition, containing between 300 and 500 ppm of dissolved solids, which typically consist of about equal amounts of calcium, magnesium, and sodium; bicarbonate is the principal anion. The silica content of these samples was not determined. However, ground waters in similar rocks elsewhere in Arizona contain considerable amounts of silica.

Fanglomerate.—Water from fanglomerate, the principal aquifer in the Prescott area, contains 150–500 ppm of dissolved solids, mainly calcium and bicarbonate. Small amounts of both sulfate and chloride are generally present. The sulfate content of water from the fanglomerate is characteristically lower than the chloride content, whereas the sulfate content of nearly all water from other formations in the area exceeds the chloride content. This relationship has been of some value in correlating the ground waters of the area with aquifers from which they were derived. Incomplete

data indicate that at least some of the waters from the fanglomerate are high in silica.

Recent alluvium.—A few wells in the Prescott area obtain water from Recent alluvium along stream channels. Samples of this water contained about 500–1,000 ppm of dissolved matter, chiefly calcium, magnesium, and bicarbonate. Relatively large amounts of sulfate and chloride occur in the more highly mineralized waters from the alluvium.

CONCLUSIONS

The only area near Prescott favorable for ground-water development, apparently, is in the valley fill between Prescott and Granite Dells. The adequacy of this source is in doubt. A study of the avaliable well records and well logs and of the geology of the area indicates that the fanglomerate will not transmit water rapidly, except along buried stream channels, as is shown by well 1, sec. 14, T. 14 N., R. 2 W., which produced 250 gpm from a buried stream channel.

The ground water in the area is generally of good chemical quality, although most of it is much harder than the surface water. Fluoride content in the ground water is generally below the deleterious level.

The Chino artesian flow comes from "porous basalt" and has proved to be an adequate supply for the city. Supplementary water is obtained from the Goldwater reservoirs. Private wells also supply water for many residences outside the city limits, especially those in Miller Valley, whose wells tap a small artesian basin. The water in this basin comes from fanglomerate that underlies basalt.

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