Geology of the Clarkdale Quadrangle Arizona

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GEOLOGY OF THE CLARKDALE QUADRANGLE, ARIZONA

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ABSTRACT

The 15-minute Clarkdale quadrangle is in north-central Arizona, in Yavapai and Coconino Counties. It was mapped in 1952 and 1953 to determine the stratigraphic and structural setting, and the depth of sedimentary cover in the area north of the Precambrian massive sulfide copper deposits at Jerome, Ariz.

The quadrangle includes three major topographic divisions. Part of the Colorado Plateau projects into the northern limits of the quadrangle and is bounded by an abrupt cliff referred to as the Mogollon Rim. Part of the Black Hills (Woodchute Mountain) extends into the south edge of the quadrangle. In the area between, low cuestalike hills are traversed by the Verde River, which follows a meandering course through the quadrangle from the west-central boundary to the southeast corner.

The stratigraphy includes Precambrian rocks which crop out in small areas chiefly in the vicinity of Jerome and in the southwest corner of the quadrangle. They are overlain unconformably by a thin unit—the Tapeats sandstone(?) (Cambrian). Upon the Tapeats(?) rests the Martin limestone (Upper Devonian) with seemingly conformity, which in turn is overlain unconformably by the Redwall limestone (lower Mississippian). The Redwall is overlain unconformably by the Supai formation (Pennsylvanian and Permian), here subdivided into three members. Above the Supai in normal stratigraphic succession are the Coconino, Toroweap, and Kaibab formations (Permian); the only unconformity occurs between the Toroweap and Kaibab. Mesozoic rocks are not present in the quadrangle.

Lava, gravel, carbonate lakebeds, and alluvium overlie considerable areas of the Paleozoic rocks. The lava and associated gravel beds are separated by structural and physiographic features into two ages: Pliocene(?) (Hickey formation) and Pliocene(?) to Pleistocene(?) (Perkinsville and Verde formations).

The structural features of the quadrangle, disregarding the Precambrian, belong to two general periods; an early period (late Triassic, Cretaceous, or early Tertiary age) which predates the Hickey formation (Pliocene ?), and a late period (late Tertiary or Quaternary) which postdates the Hickey. An uplift of the region to the southwest occurred in the early deformation and thereby tilted the Paleozoic strata producing a regional dip to the northeast of about 8°. Some normal faulting accompanied this early deformation. Erosion then beveled the tilted strata so that the oldest rocks are exposed in the southern and southwestern part of the quadrangle. The youngest rocks crop out to the northeast. During the Pliocene (?), the early lava flows of the Hickey formation were ex-

truded throughout most of the area. After this extrusion, the late and strongest deformation occurred; it consisted principally of normal faults accompanied by slight rotation of the individual fault blocks and uplift of the Colorado Plateau. Also, local monoclinal folding took place. It was at this time that the Black Hills were blocked out by marginal northward- and northwestward-trending faults. This late faulting also caused the reversal of the drainage which previously had been to the north.

The Verde formation, which comprises lava, lakebeds, and gravel, accumulated in a basin on the east side of the Black Hills. At the same time lava and gravel of the Perkinsville formation accumulated north and northwest of the Black Hills.

Pediment gravel of Quaternary age is present in the southeastern and eastern parts of the quadrangle. Recent river terraces and riverwash are present in parts of the valley of the Verde River.

The well-known copper deposits of the Jerome district have been the chief mineral resource in the quadrangle, but the deposits are mined out. The only commodity commercially exploited now is building stone which is quarried from the upper member of the Supai and from the Coconino sandstone in the northern part of the quadrangle.

INTRODUCTION

The study of the Clarkdale quadrangle was made by the U. S. Geological Survey to obtain the regional setting of the important copper mines at Jerome, to obtain more data about the structure north of Jerome, and to gather information on the thickness of the Paleozoic cover over the Precambrian rocks which are host rocks for the ore deposits at Jerome. In May 1951, about 12 square miles of the Clarkdale quadrangle centering around the mines at Jerome were mapped as part of the study of the Jerome area (Anderson and Creasey, 1957).

PREVIOUS WORK

Much of the previous work in the area has been concerned with the local geology of the ore deposits centering around Jerome. Because this report is confined largely to the regional geology, only references related to regional problems are considered.

Early work in the area was of a stratigraphic nature, and Ransome (1916) wrote a brief description of the stratigraphic section around Jerome with notes on the stratigraphy between Jerome and Payson.

Reber (1922) after years of experience and observations in the district wrote an excellent description of the geology and ore deposits of the Jerome area.

During part of his reconnaissance mapping for the Arizona Bureau of Mines, Jenkins (1923) was the first to study and map the Verde formation in the valley of the Verde River and to report a detailed account of these deposits.

The first published map of the area accompanied Lindgren's report (1926) on the Jerome and Bradshaw Mountains quadrangles. The map was very generalized and the report was primarily concerned with the mines and prospects and did not treat the regional geology in detail.

Stoyanow (1936) studied the Devonian strata in the Jerome area as a part of a regional correlation study of the Paleozoic formations in Arizona. A similar study was made on the Redwall limestone in the Jerome area by Gutschick (1943).

Mahard (1949) made a comprehensive study of the late Cenozoic chronology of the upper valley of the Verde River, which included primarily the geologic history of the valley.

Aerial mapping in Sycamore Canyon just north of the Clarkdale quadrangle by Price (1950a) revealed evidence of a northward-flowing drainage before the early basaltic eruptions on the plateau. Price (1950b) also mapped the Kaibab limestone and the Moenkopi formation (Price, 1949) which proved to be one of the southernmost occurrences of the Moenkopi in Arizona.

The most recently published work which concerns the area, in part, is that of McNair (1951), who extended his previous Paleozoic stratigraphic studies in northwestern Arizona into the Jerome area. He believed that the basal sandstone of Paleozoic age is Devonian and related to the Martin limestone rather than the Tapeats sandstone of Cambrian age.

ACKNOWLEDGMENTS

The writer is grateful to Nick Perkins and his sons for their cordial cooperation in allowing the use of their cabin during the course of the mapping in the remote northeast quarter of the quadrangle and for their useful information on trails and general accessibility of much of that little frequented area. Stratigraphic information was contributed by E. D. McKee, of the University of Arizona.

The writer was assisted by H. C. Rainey from June to October 1952 and from October 1952 to February 1953 by D. D. Dickey, who also aided the writer in measuring sections and compiling the illustrations.

GEOGRAPHY

LOCATION, CULTURE, AND ACCESSIBILITY

The Clarkdale quadrangle lies mostly in Yavapai County, central Arizona, but includes an area in Coconino County along the north boundary. It is bounded by parallels 34°45′ and 35° and meridians 112° and 112°15′ and covers about 245 square miles (fig. 70).

The principal towns in the quadrangle are Jerome and Clarkdale. Jerome is on the steep east slope of Woodchute Mountain near the center of the south boundary of the quadrangle where the United

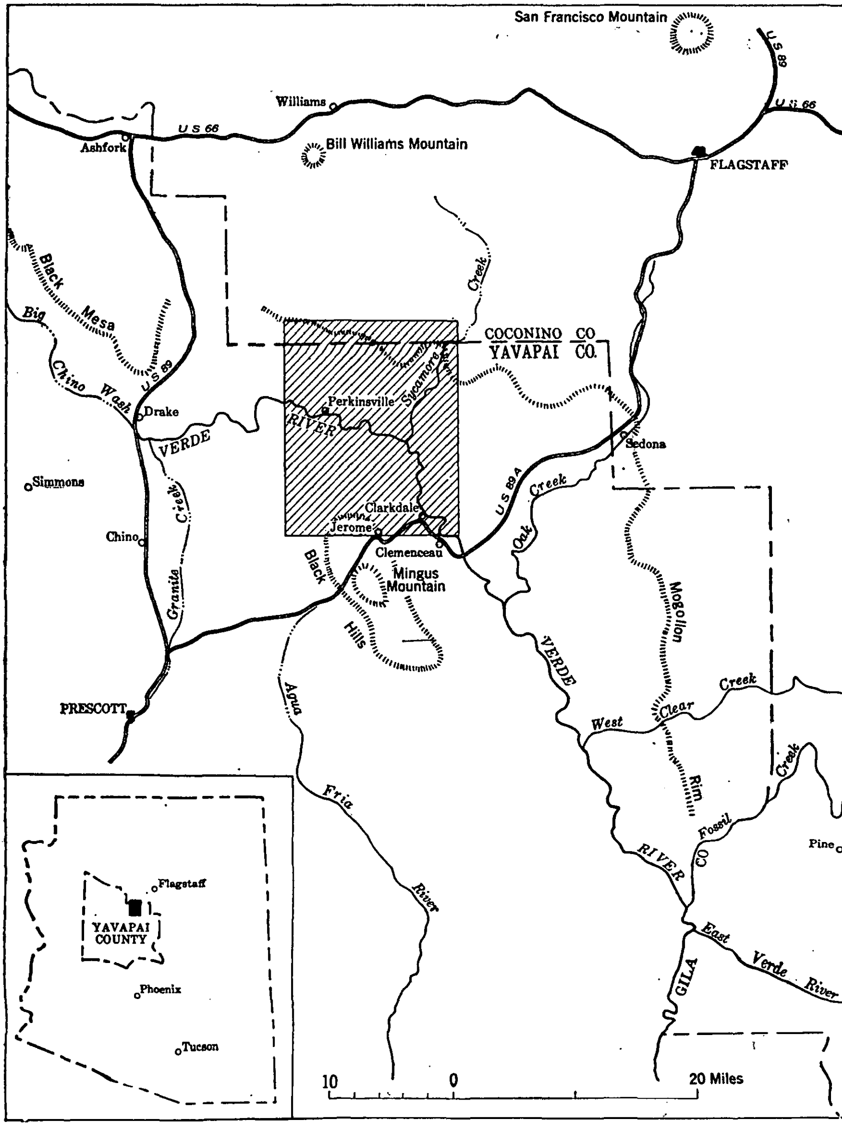

Figure 70.—Index map of area.

Verde and United Verde Extension mines are located. The economy of Jerome depended upon mining, but today the mines are closed. The population of the town decreased steadily after the United Verde Extension mine closed in 1938, and rapidly after the United Verde mine closed in February 1953. At present (1953), only a few families remain, and the town already has acquired the title of "the largest ghost town in the West." Clarkdale, which is 4 miles east-northeast of Jerome in the valley of the Verde River, is owned and controlled by the Phelps Dodge Corp. The town grew around the smelter and concentrator for the United Verde mine, and when the smelter was closed in June 1951 the population of Clarkdale decreased. The concentrator, however, remained active until February 1953 for milling copper-zinc ore.

Sparsely inhabited areas are present in the quadrangle. These areas include the small settlement called Centerville, 1 mile south of Clarkdale, which grew as a result of the smelter activity at Clarkdale. Another small settlement is Tapco which is associated with the generator plant of the Arizona Power Co. and is about 1 mile north of Clarkdale. Perkinsville comprises the small group of houses clustered along a branch of the Atchison, Topeka, and Santa Fe Railway on the north side of the Verde River in the west-central part of the quadrangle. The economy of this sparsely populated community depends upon ranching, farming, and railroad maintenance work.

Many Indian ruins are present within the quadrangle and the largest of these has been preserved and made into a national monument—the Tuzigoot National Monument—about 1½ miles east of Clarkdale. The museum located at the ruins contains several pieces of copper ore which were probably used by the Indians for pigments to color their garments and bodies. Other ruins in the quadrangle include a cave and pueblo site at Perkinsville; many pueblos and a few caves in the Sycamore Basin country in the northeastern part of the quadrangle; and a small cliff-dwelling in the east wall of Sycamore Canyon, about 2 or 3 miles above its mouth.

A branch line of the Atchison, Topeka, and Santa Fe Railway connects Clarkdale with Drake which is west of the area mapped (fig. 70). From Clarkdale the railroad follows the Verde River across most of the quadrangle. Clarkdale is connected to Jerome by the Tunnel and Smelter Railroad which formerly carried ore from the mine to the smelter. Since the mine closed this railroad has not operated.

Jerome is on U. S. Highway 89A, which connects Flagstaff and Prescott (fig. 70). This highway is the only paved road in the area. An improved dirt road connects Jerome, Perkinsville, and Williams, which is to the north on U. S. Highway 66. An improved dirt road connects U. S. Highway 89 near the town of Chino Valley with Perkinsville, and a graded road about 5 miles north of Perkinsville connects the Perkinsville-Williams road with U. S. Highway 89 to the west near Drake.

In this report, a 10,000 foot grid based on the Arizona (Central) rectangular coordinate system is used for some localities within the quadrangle. This grid is shown on plate 45.

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PHYSICAL FEATURES

The Clarkdale quadrangle includes a representative part of the "mountain region" which extends northwest-southeast through central Arizona and a representative part of the "plateau region" which extends over the northern and northeastern parts of the State, as defined by Ransome (1904, p. 14–15).

The "mountain region" in the area mapped is limited to the south-central part of the quadrangle where Woodchute Mountain is a part of a short south-southeastward-trending range known as the Black Hills. The Black Hills are characteristic of the mountain region where short and generally parallel ranges are separated in part by intermontane valleys filled with deposits to unknown depths. Flanking the Black Hills on the east is the valley of the Verde River and on the west are Lonesome and Chino Valleys.

Woodchute and Mingus Mountains just south of the quadrangle are the highest mountains in the Black Hills, and both are capped with lava and are mesalike. The summits are relatively flat, and steep to vertical cliffs surround their margins.

Northward from the base of Woodchute Mountain, an expanse of relatively low hills extends about 6 or 7 miles to where the meandering Verde River has cut a deep gorge into the rocks.

The great erosion scarp that marks the south margin of the Colorado Plateau is 5–8 miles beyond the river. It is almost 1,800 feet high, and is often referred to as the Mogollon Rim. This rim is serrate in outline as a result of youthful streams cutting steep-walled canyons back into the tableland, and at places severing parts of the plateau from the main mass to form outlying mesas such as Black Mountain in the east-central part of the quadrangle. The surface of the plateau extends northward and is relatively flat, forming an even skyline, except locally where volcanic mountains such as San Francisco and Bill Williams Mountains interrupt this regularity.

The maximum relief of 4,516 feet in the area is from the summit of Woodchute Mountain, which has an altitude of 7,834 feet, to the bottom of the Verde River in the southeast corner of the quadrangle, which has an altitude of 3,318 feet. The summit of Casner Mountain which is in the northeastern part of the quadrangle is 6,500 feet above sea level and is the highest part of the plateau in the quadrangle. The surface of the relatively low but dissected area between the plateau and Woodchute Mountain, slopes toward the Verde River, and has a relief of about 500 feet; the altitude ranges from 4,500 and 5,000 feet.

The Verde River is the only large perennial stream in the quadrangle. The river enters the west-central part of the quadrangle, flows in a meandering easterly and southerly direction, and exits at the southeast corner of the quadrangle. Sycamore Creek, which is the major tributary of the Verde River, is perennial in the lower 4 miles of its course; the flow is sustained chiefly by Summers spring.

CLIMATE AND VEGETATION

The climate of the area is arid to semiarid. Weather data are available for Jerome, which is at an altitude of 5,250 feet, and for Clemenceau, which is in the valley of the Verde River 0.7 mile south of the quadrangle boundary at an altitude of 3,460 feet.

The average annual temperature of Jerome is 60°F; the average daily minimum temperature is 48.9°F; and the average daily maximum temperature is 71.2°. The summer and winter temperatures of Jerome are lower than those at Clarkdale or Clemenceau because of the difference in altitude. The higher altitudes of the summit areas of Woodchute Mountain and the plateau result in cool summers and cold winters in those places.

Average temperature, in degrees Fahrenheit

City	Length of record, in years	January	July	Maximum	Minimum
Clemenceau	16	44.3	84.0	110	9
Jerome	39	42.3	78.8	105	7

The precipitation averages reveal two seasons of precipitation during the year—one in the summer, the other in the winter. The summer rains begin in late June or early July and last through August. August usually is the wettest month of the year, and June normally is the driest. The summer rains are local showers or thunderstorms, which form quickly and result in sudden downpours that cause torrential steamflows. Along the Mogollon Rim, the prevailing westerly and southwesterly winds of the desert regions cool as they rise and cause considerable precipitation. In this area precipitation is high compared with that of the State as a whole.

Average precipitation, in inches

City	Length of record, in years	Monthly												Annual
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Clemenceau	16	0.95	1.12	0.66	0.72	0.27	0.24	1.38	1.80	1.70	0.61	0.77	1.07	11.29
Jerome	39	1.86	2.11	1.70	.98	.51	.36	2.79	2.93	1.42	1.13	1.33	1.67	18.79

During the winter February is the wettest month. Snowfall is normal above the 5,000 foot altitude and much snow accumulates on the summit area of Woodchute Mountain and on the plateau. At the

6,000-foot altitude it frequently attains depths of ½–2 feet; at the 7,000-foot altitude, 1½–3 feet. Little snow falls at Jerome, and practically none in the valley of the Verde River.

Vegetation in the Clarkdale quadrangle shows effects of the wide range in altitude and the resulting climatic conditions. This vegetation (Humphrey, 1950; Little, 1950) is typical of the Upper Sonoran zone and may be grouped into four types: pine forest, pinyon-juniper woodland, chaparral, and grassland. The zones or belts of these principal types of vegetation are not sharply limited but blend into one another, and the precipitation, altitude, type of soil, and many other factors regulate the distribution of the vegetation types.

The pine forest is restricted to the higher altitudes, commonly above 6,000 feet. The ponderosa pine (*Pinus ponderosa*), also called western yellow pine, is the most abundant tree of this forest and occurs on the summits of the Black Hills and on the plateau to the north. Within the pine forest, near its lower limits, are small but compact thickets of Gambel oak (*Quercus gambeli*) and New Mexico locust (*Robinia neomexicana*). Some maple trees are also found in the canyons of Woodchute Mountain along the lower fringes of the pine forest.

The pinyon-juniper woodland type of vegetation covers more of the quadrangle than does any other. It extends from the foothills of Woodchute Mountain northward across the Verde River to the base of the plateau. The pinyon pines (*Pinus edulis*) are scarce, but three varieties of juniper trees are abundant. They are Utah juniper (*Juniperus utahensis*), oneseed juniper (*Juniperus monosperma*), and alligator juniper (*Juniperus pachyphloea*). Of these, the Utah juniper is the most abundant and is restricted to an altitude below 7,000 feet on the Colorado Plateau. The alligator juniper is generally found in the chaparral zone on the high north slopes of Woodchute Mountain.

Chaparral is a brush-type vegetation, thick in some places and open in others; it grows best on the north slopes and foothills of Woodchute Mountain and on the steep rocky slopes and ridges of the plateau escarpment in the northern part of the quadrangle. Shrubs of this belt are of many species, but the shrub live oak (*Quercus turbinella*) is most common. Other abundant shrubs are manzanita (*Arctostaphylos pungens*) and catclaw (*Acacia greggi*). Locally abundant are mountainmahogany (*Cercocarpus* sp.), apacheplume (*Fallugia paradoxa*), and cliffrose (*Cowania stansburiana*).

The grassland in the quadrangle is limited to the valley of the Verde River although many grasses are interspersed among the stands of juniper, which have encroached upon former grasslands as in the northwestern part of the quadrangle. The predominant grasses of this vegetation type are blue grama, black grama, hairy grama, and side-oats grama.

Several species of cactus, predominantly cholla and pricklypear (*Opuntia* sp.), are widely scattered among all the vegetation types except the ponderosa pine. Century plant or mescal (*Agave parryi*) is abundant at the lower altitudes of the chaparral on the east and north sides of Woodchute Mountain.

Along Sycamore Creek and the Verde River large willow, cottonwood, sycamore, and some walnut trees are abundant because of the moist soil.

GENERAL GEOLOGY

The rock formations of the Clarkdale quadrangle, whose distribution and structure are shown on plates 45 and 46, represent the Proterozoic, Paleozoic, and Cenozoic eras. Rocks belonging to the Mesozoic era are absent. The formations are shown schematically on plate 47.

OLDER PRECAMBRIAN ROCKS

The Precambrian rocks in Arizona are divided into two major systems, older Precambrian and younger Precambrian (Butler and Wilson, 1938, p. 11; Anderson, 1951, p. 1333). Only the older Precambrian rocks are present in the area of this investigation.

The Precambrian rocks in the Clarkdale quadrangle were not studied in detail by the writer. The subdivisions and names (pl. 45) are those used by Anderson and Creasey (1957) in their report on the Jerome area except for the Spud Mountain volcanics in the southwest corner of the quadrangle, which were identified in the field by Anderson.

The Precambrian rocks comprise metamorphosed volcanic and intrusive formations. The volcanic rocks are subdivided into the Spud Mountain volcanics, the Deception rhyolite, and the Grapevine Gulch formation; the intrusive rocks are gabbro and quartz porphyry. Although all the Precambrian rocks have been altered by regional metamorphism, and, around the ore deposits at Jerome by hydrothermal alteration, Anderson and Creasey were able to determine their original nature and to map each separately. The Deception rhyolite is a fine-grained compact rock that is commonly porphyritic and contains phenocrysts of quartz and feldspar. The Grapevine Gulch formation consists of fine- to medium-grained tuffaceous sedimentary rocks. The Spud Mountain volcanics comprise andesitic breccias and tuffaceous rocks; the breccias are characterized by large equant saussuritized crystals.

The quartz porphyry consists of relict phenocrysts of quartz in a matrix now altered to quartz and sericite. The gabbro is a dark granular rock containing hornblende and saussuritized plagioclase. The quartz porphyry is older than the gabbro, and both intrude the volcanic formations.

The reader is referred to the report on the Jerome area by Anderson and Creasey (1957) for the detailed geology of the Precambrian rocks.

UNCONFORMITY AT THE BASE OF THE PALEOZOIC ROCKS

The base of the Paleozoic rock sequence is separated from the older Precambrian basement complex by a conspicuous unconformity. The horizontal to mildly diping Paleozoic cover rests upon a surface of acutely deformed Precambrian rocks which were intruded by igneous bodies.

The erosional surface on the older Precambrian rocks in the quadrangle appears to be one of very low relief, although not much is known about it because of the few exposures. The basal sandstone of Paleozoic age which rests on this surface is locally absent because of minor topographic highs that rise as much as 50 feet above the general level. Elsewhere in the Mingus Mountain area scattered hills of the older Precambrian rocks are as much as 400 feet above the normal surface.

PALEOZOIC SEDIMENTARY ROCKS

Except in the southwest corner, the Clarkdale quadrangle contains rocks of Paleozoic age, and in most parts, they are exposed. In the southeast and northwest corners of the quadrangle these rocks are partly concealed by Cenozoic deposits. The total thickness of the Paleozoic rock sequence is about 3,350 feet, and the ages of the rocks range from Cambrian (?) to Permian. The Paleozoic rocks dip, in general, about 8°–10° NE. in much of the quadrangle, but they are horizontal in the Colorado Plateau in the northeast corner of the quadrangle. Recent erosion has beveled the inclined strata, so that the older formations crop out in the southwestern part of the quadrangle, with successively younger formations cropping out to the northeast.

In the southern part of the quadrangle, the Paleozoic rocks crop out around the margins of Woodchute Mountain, and in the northern part, they are conspicuously displayed in the precipitous cliffs of the Mogollon Rim, which marks the south edge of the Colorado Plateau. In the middle part of the quadrangle they crop out in a series of northwestward-trending ridges, locally accentuated by faults of similar strike.

TAPEATS SANDSTONE (?)

DISTRIBUTION

The Tapeats sandstone (?) has the smallest areal distribution of any of the Paleozoic formations in the Clarkdale quadrangle, and the combined outcrops cover less than 1 square mile. There are five small areas where the Tapeats (?) is exposed as inliers in younger Paleozoic and Tertiary rocks.

Most of the Tapeats sandstone(?) outcrops are in the southwest corner of the quadrangle. This is due to the regional northeast tilt, which results in successively younger rocks cropping out to the northeast. Probably the best exposed section of Tapeats(?) in the quadrangle is in Munds Draw (coordinates N. 1,374,000; E. 402,000).

On the east side of Woodchute Mountain above the dump of the United Verde mine at Jerome, the Tapeats(?) crops out between the Haynes fault and other faults of that area. Another exposure of Tapeats(?) is about 1½ miles northeast of the pit at Jerome. Here it crops out in a continuous exposure for nearly 3,000 feet in the opencuts of the Verde Tunnel and Smelter Railroad, which formerly connected the smelter at Clarkdale with the United Verde mine (coordinates N. 1,368,000; E. 444,000).

The two other occurrences of Tapeats(?) are in the Verde River canyon between Perkinsville and the Packard Ranch (coordinates N. 1,410,000; E. 427,000 and N. 1,406,000; E. 450,000).

THICKNESS AND STRATIGRAPHIC RELATIONSHIP

The thickness of the Tapeats sandstone(?) in the quadrangle ranges from a few inches to about 60 feet. The greatest thickness is in Munds Draw where the formation is 60 feet, although about 1 mile to the south it is only 25 feet. The Tapeats(?) exposed on the east side of Woodchute Mountain near Jerome averages 50 feet in thickness. Near Packard Ranch in the Verde River canyon it is 40–60 feet, whereas west of Mormon Pocket in the Verde River canyon (coordinates N. 1,410,000; E. 427,000), it has a maximum thickness of about 15 feet. Nearby it wedges out and the overlying Devonian limestone rests directly on Precambrian rocks.

The range in thickness of the Tapeats(?) largely results from the uneven Precambrian surface upon which it was deposited. Because of the few exposures of the basal contact of this sandstone in the quadrangle, the relief of the underlying Precambrian surface is not well known, but in the Mingus Mountain quadrangle to the south, Anderson and Creasey state that Precambrian topographic highs rise into the overlying Martin limestone in many widely distributed areas.

The Martin limestone of Devonian age overlies the Tapeats sandstone(?) and the contact between them appears to be gradational. The contact has been arbitrarily placed at the base of the first massive limestone bed which overlies yellow to green limy siltstone and marl.

Krieger (oral communication, 1953), who mapped the Paulden quadrangle (adjacent on the west), stated that she has found a possible stratigraphic break between the Tapeats(?) and the overlying Martin limestone of Devonian age.

LITHOLOGY

The lithology of the Tapeats sandstone(?) in the Clarkdale quadrangle shows no significant deviation in the widely separated outcrops. In nearly every exposure a basal crossbedded sandstone forms a ledge that averages 50 feet in thickness. Above this sandstone is a sequence of weaker rocks, 10–15 feet thick, that consists of calcareous shaly siltstone and mudstone. Where the basal sandstone unit locally is cut out against topographic highs on the old Precambrian surface, the upper shaly unit rests directly upon the Precambrian rocks.

The lower unit of the Tapeats (?) is composed of medium- to coarse-grained sandstone including lenses of granules and pebbles; the pebbles are as much as one-half inch in diameter. The unit displays well-defined cross lamination in beds which range from a few inches to about 15 feet in thickness. However, not all beds show cross lamination. Lenses of granules and pebbles formed as shallow, cut-and-fill channels are relatively common. Individual laminae are well defined but adjoining strata commonly have marked contrast. The contrasts between individual laminae give an overall heterogeneous appearance to the unit. The sand is bonded with a siliceous-ferruginous cement which differs in abundance from place to place. Where the iron content is low and silica high the rocks are very hard and relatively light in color. Inversely, where the iron content is high and silica low, the rocks are somewhat friable and are relatively dark. Most commonly, however, the rocks are very ferruginous, which makes the unit appear a dusky red to dark reddish brown; the predominant color is reddish brown. The sand grains, granules, and pebbles in the Tapeats(?) consist chiefly of jasper, quartz, and chert, with subordinate amounts of feldspathic and unidentified dark minerals.

The upper unit of the Tapeats sandstone (?) consists of shaly siltstone and mudstone. This unit is very thin bedded and weathers to a slope, in contrast to the ledge-forming unit below. It ranges in thickness from 10 to 15 feet. Dark-reddish-brown slightly fissile mudstone in beds 5 feet thick, rest directly on the basal sandstone unit. Structureless siltstone, in beds 2–3 inches thick, is intercalated among them. The lower reddish-brown beds grade upward into lighter rocks that range from shades of yellowish gray and pale olive to dusky yellow. The lighter beds are slightly calcareous structureless mudstone and siltstone and are separated by fissile shale partings 1–6 inches thick; these shale partings are light green and dark red. The bedding appears to be irregular but individual beds cannot be traced readily because this unit is poorly exposed. Some thin sandstone beds are at the top of the Tapeats(?) in a few places but are not everywhere present where the Tapeats(?) is exposed throughout the quadrangle. Some siltstone beds in the upper unit of the Tapeats sandstone (?) are very micaceous.

AGE AND CORRELATION

The basal sandstone of Paleozoic age in the Clarkdale quadrangle appears to be gradational upward into the Martin limestone of Devonian age, as it does in the Mingus Mountain quadrangle, but it also appears to be the stratigraphic equivalent of the Tapeats sandstone of Cambrian age in the Grand Canyon.

The strongest evidence in support of a Devonian age for the Tapeats (?) is the gradation into, conformity with, the overlying Martin limestone. However, this may be more apparent than real in the light of Krieger's recent investigations (oral communication, 1953) where she has found a possible break above the Tapeats(?) in the Paulden quadrangle, which adjoins the Clarkdale quadrangle on the west. The area of Tapeats (?) which Krieger mapped is only a few miles from the Tapeats sandstone at Simmons (fig. 70). McNair (1951) traced the Tapeats from the Grand Canyon south and eastward to Simmons. McKee (written communication, 1953) has found many Cambrian trilobites in the shales overlying the Tapeats at Juniper Mountain (Camp Wood quadrangle) and stated that from there to the Clarkdale quadrangle, exposures are fairly continuous along the north side of Chino Valley. Less significant reasons for considering the basal sandstone of the Paleozoic as Tapeats sandstone of Cambrian age are based partly on its stratigraphic position and partly on lithologic similarity to known Tapeats.

No new evidence on the age of the Tapeats(?) was found in the Clarkdale quadrangle; this report, therefore, follows Anderson and Creasey (1957) who, because of the lack of a positive age and because the term Tapeats had been previously used, preferred to continue using Tapeats, but appended a query to express uncertainty.

MARTIN LIMESTONE

DISTRIBUTION

The Martin limestone is limited chiefly to that part of the quadrangle which is south of the Verde River. The most extensive exposures are along the southwest boundary of the quadrangle where the Redwall limestone of Mississippian age has been eroded from the footwall blocks adjacent to large normal faults. In the vicinity of Jerome the Martin limestone crops out beneath younger rocks that compose Woodchute Mountain, and extends southward in a peripheral band around Mingus Mountain to the south. Outcrops of this limestone also are abundant along the footwall of the Verde fault and subsidiary faults where erosion has exposed them. Northward, between Woodchute Mountain and the Verde River, the Martin limestone is exposed along many of the fault scarps. It is well exposed in the canyons of the Verde River and Sycamore Creek, and in a small area in S O B Canyon (coords. N. 1,395,000; E. 447,400). The only exposure of the Martin north of the Verde River is in Sycamore Canyon.

THICKNESS AND STRATIGRAPHIC RELATIONSHIP

The thickness of the Martin limestone, which was measured in four widely separated localities, averages about 455 feet. It is 465 feet thick in the Mingus Mountain quadrangle, 2½ miles south of Coyote tank (coordinates N. 1,365,700; E. 407,500), and in Haynes Gulch (coordinates N. 1,368,000; E. 433,000); just north of Jerome, it is 441 feet thick. A section in the Verde River canyon (coordinates N. 1,409,500; E. 427,500), west of Mormon Pocket, revealed 444 feet of Martin, and at the Packard Ranch area in the Verde River canyon (coordinates N. 1,407,000; E. 449,400) it is 480 feet—the thickest section in the Clarkdale quadrangle.

Where there are local topographic highs on the old Precambrian surface, the Martin limestone rests directly on Precambrian rocks. Elsewhere, the Martin limestone rests on the Tapeats sandstone(?). Because the contact between the Martin and the underlying Tapeats sandstone(?) appears to be gradational, the contact has been placed arbitrarily at the base of the lowest massive limestone bed, which locally has some sandstone lenses in its basal part. The contact between the Martin and the overlying Redwall limestone is unconformable. The cut surface on the Martin limestone shows very little relief over short distances, and has a relief that averages 10–15 feet, with a maximum of 35 feet as observed over wide distances.

LITHOLOGY

Though Martin limestone is the formal designation, this formation consists of limestone, dolomitic limestone, dolomite, some limy siltstone and sandstone, and copious amounts of disseminated argillaceous and arenaceous impurities among the carbonate rocks. The formation as a whole is progressively darker from bottom to top as the result of an increase in impurities. The formation is uniformly bedded and forms steplike slopes. These characteristics help to easily distinguish it from the overlying Redwall limestone, which is more massive and lighter.

The Martin limestone has comparatively few fossils, and the lower part of the formation seems to be barren. The beds generally are fossiliferous towards the top of the formation, and a few are very fossiliferous, containing abundant gastropods, brachiopods, and corals. No fossils were collected and no paleontologic data were gathered while mapping the quadrangle.

In the Jerome area the Martin limestone can be subdivided into four parts which may be classified as members in detailed mapping. They do not correspond to the subdivisions of Huddle and Dobrovolny (1945; 1952, p. 73), who arbitrarily divided the Martin farther east into three members. The units chosen were used chiefly for structural control in this study. Although they are not differentiated on plate 45, they are described individually and are designated from bottom to top as units *A*, *B*, *C*, and *D*.

Unit A.—Unit *A* includes a nonpersistent basal sandstone and a thin-bedded dark-gray dolomitic limestone, which ranges from 20 to 50 feet in thickness. The basal sandstone, of local occurrence in the Clarkdale quadrangle, has a uniform texture containing well-rounded and frosted grains. In places it contains limonitic spots, which give it a "freckled" appearance. It is lenticular and seldom more than 1½ feet thick. This sandstone may be reworked Tapeats sandstone(?). The overlying ledge-forming dolomitic unit is very persistent and has uniform lithologic characteristics which make it an excellent marker bed. Stoyanow (1936, p. 497) has noted this unit at Jerome and says that it can be recognized at the headwaters of the East Verde River near Pine and Payson. It is also present near Simmons, about 20 miles to the west, and probably extends northward from there.

The dolomitic limestone ranges from light brownish gray to brownish gray, and contains minor areas of yellowish gray and pale red, visible upon close inspection. The colors appear to be locally affected by the coarseness of grains and by the percentage of the argillaceous impurities. Acid tests indicate that the rock is more dolomitic where it is coarse grained and more calcitic where it is fine grained. The fine-grained areas which are lighter in color occur interstitially in larger areas of coarse-grained material. The grain size as a whole ranges from fine to coarse, but medium to coarse sizes are predominant. Possibly much of the coarseness is due to recrystallization.

Beds range from ¼ inch to 3 feet in thickness, and the thinner beds alternate with the more massive ones. Weathering of the faces of the thicker beds has etched out textures and structures of these rocks so that it is not uncommon to see crossbedding, channeling, and fragments of limestone in relief on the surfaces. These features indicate that, although the carbonate materials are of subaqueous origin, they were mechanically transported and deposited.

The massive beds which commonly are more dolomitic and coarser grained than the thin ones show many ovoid to circular accretionary masses of white calcite. Chert occurs as nodules and lenses in the upper few feet of the unit.

Unit B.—Overlying the brownish-gray lower unit is a sequence of uniformly thin-bedded aphanitic light-colored slightly dolomitic limestone beds which are designated as unit *B*. This unit generally is homogeneous in appearance, and probably is the most prominent of the section because it is light and is limited at top and bottom by darker units. Because of its thin bedding, this unit commonly forms a slope. It ranges in thickness from 80 to 110 feet but averages about 85 feet.

Unit *B* is characteristically light gray to white on the weathered surfaces and pinkish gray on the unweathered surfaces. Locally, one or two beds near the bottom of the unit may be dark gray. The thickness of individual beds ranges from a few inches to several feet, and probably averages about 8 inches. The limestone beds are separated by shaly interbeds or partings as much as 3 inches thick. On slopes the shaly mudstone is not conspicuous and may go undetected, whereas in cliffs or steep walls, the shale interbeds are more distinct. The shale is dark gray and appears as a dark band between the lighter beds, which emphasizes the uniform bedding of the unit. A good example of this may be seen about 1 mile north of Jerome on the Jerome-Perkinsville road. The limestone is very aphanitic and in most places does not show stratification on unweathered surfaces. Disseminated sand grains stand out in relief on the weathered surfaces of some beds and locally on unweathered surfaces. Chert is fairly abundant as nodules, lenses, and thin layers parallel to the bedding; it is in shades of light yellow to dark gray or black, and is present in the limestone and the shale interbeds.

Within 6–10 feet of the top of the unit is a persistent sandstone bed that ranges from 1 to 3 feet in thickness. In some places, it is so well cemented with silica that it is more nearly an orthoquartzite than a sandstone. Chert is moderately common along this bed or zone. Some limestone grains are admixed with quartz sand grains in a few localities. The sandstone weathers from a light rusty brown to a darker brownish red, hence, the local name "Red Marker" has been applied. This horizon marker has been used extensively in the vicinity of Jerome for determining offsets on faults of minor displacement.

Unit C.—Unit *C* overlies unit *B* with a distinct and abrupt lithologic change. In contrast to the underlying unit *B*, unit *C* is much darker and coarser grained, has fewer shale partings, is thicker bedded, and forms receding ledges. The thickness of this unit ranges from 65 to 80 feet but averages about 70 feet. Unit *C* is characteristically a sequence of mottled dolomitic limestone beds. The mottling, produced by a difference in grain size, is similar to that in the lower unit. The fine-grained areas are pale red to grayish orange pink, and the medium-grained areas are yellowish gray to light olive gray. The mottling appears to result from partial recrystallization. The size and shape of the recrystallized areas is variable, but on any given surface it is generally measured in inches. The beds range from less than an inch to about 4 feet in thickness. Stratification is not evident within most beds. Very few thin partings of shale are present. Vugs of coarsely crystalline calcite are abundant.

Unit D.—In contrast to all the other units of the Martin limestone, each of which is uniform in character, unit *D* shows the greatest variation in lithology, color, and texture. This unit includes all the rock types of other units, in alternating sequence. Such diverse lithology produces alternating dark and light beds which gives the unit a heterogeneous appearance. The unit ranges from 260 to 270 feet in thickness and consists chiefly of dolomitic limestone and limestone, with lesser amounts of interbedded calcareous shaly siltstone and sandstone. The limestone is less dolomitic and more argillaceous and arenaceous towards the top, except in the uppermost 50 feet.

For the most part, the lower fourth of unit *D* consists of interbedded light-gray aphanitic dolomitic limestone similar to the limestone of unit *B*, light-olive-gray to dark-gray medium- to coarse-grained dolomitic limestone and (or) dolomite, and medium- to light-gray thin-bedded finely laminated dolomitic limestone. Chert layers and lenses are abundant in the thin-bedded zones. The bedding ranges from a few inches to several feet in thickness and is uniform and regular.

Above the lower fourth of the unit, the section becomes more argillaceous so that shaly mudstone and platy siltstone become prominent lithologic types. Because much mud apparently was introduced, the dolomitic limestone beds are contaminated with argillaceous impurities that cause a purple to red mottling. In many places, interbeds of purple or lavender calcareous shaly mudstone separate these impure dolomitic beds.

A little less than half way up the unit, beds that total about 40 feet in thickness consist of alternating thin-bedded impure slabby dolomitic limestone and purple calcareous shale. This part of the unit forms a slope and includes most of the argillaceous impurities.

Argillaceous materials are also present, but in lesser amounts, scattered throughout the overlying beds, except in the top 50 feet of the unit. These uppermost beds consist of grayish-orange-pink medium-grained dolomitic limestone that is uniformly bedded and crops out in steplike ledges.

A few distinctive beds in unit *D* merit individual attention as they constitute key or marker beds. In the Jerome area, two beds are lithologically unique in the section. These are light-olive-gray medium- to coarse-grained dolomitic limestone beds that contain many inclusions of fine-grained moderate red sandstone in irregularly shaped masses which range from less than an inch to about 9 inches in diameter. Each of these beds is 2 feet thick. They occur 40 and 50 feet respectively above the base of the unit. Also a 7-foot massive yellowish-gray fine-grained dolomitic limestone, bearing an abundance of solitary- and colonial-type corals, occurs 150 feet above the base of the upper unit. This bed may be fossiliferous only locally, because in other areas the fossils could not be located. A prominent feature in the Verde River canyon near the mouth of Sycamore Canyon, is a 3-foot ledge of sandstone, 175 feet above the base of the upper unit.

AGE AND CORRELATION

In Arizona, Devonian strata have been referred to as the Temple Butte limestone, a name proposed by Walcott (1890, p. 50) but used only in the Grand Canyon area in the northern part of the State; the Martin limestone, a name that Ransome (1904, p. 33) assigned to the Devonian rocks at Bisbee, but which has been used mostly in the central and southeastern part of the State; and the Jerome formation, a name used by Stoyanow (1926, p. 316–317) for the Devonian rocks in north-central Arizona.

Huddle and Dobrovolny (1945) demonstrated that the Martin limestone of the Globe-Miami area probably is continuous with the Devonian strata of the Pine-Payson area and stated that "there seems to be no reason for recognizing the Jerome formation of Stoyanow." For this reason Anderson and Creasey (1957) decided to use the name Martin for the Devonian rocks in the Jerome area also. This report follows that usage.

Ransome (1916, p. 161) took a random faunal sample from a fossiliferous bed in the upper part of the Martin limestone at Jerome. The fauna, examined by Kindle, was assigned to Late Devonian age.

Stoyanow (1936, p. 495–500) studied the Devonian section at Jerome and listed fossils and their locations in the section which proved Late Devonian in age.

McNair (1951, p. 516) compared the Martin limestone of the Jerome area with the Devonian strata of the Grand Canyon and reported that the purple soft, crumbly, silty beds, which are more abundant in the Martin limestone toward the north, are also a conspicuous rock type of the Temple Butte limestone.

The upper part of the Martin limestone of central Arizona is of Late Devonian age, but the lower and middle parts may be Middle Devonian, according to Huddle and Dobrovolny (1952, p. 67, 86), who stated that their fossil collection indicates that the Martin may contain equivalents of some of the faunal zones of the Devils Gate formation of Merriam in central Nevada.

REDWALL LIMESTONE

DISTRIBUTION

The Redwall limestone occurs sporadically throughout the south half of the Clarkdale quadrangle, except in the southeast corner where it is entirely hidden by younger rocks. It occurs extensively along the west margin of the quadrangle as far north as the Verde River, and in the vicinity of Jerome it forms a peripheral band that crops out on the steep slopes around Woodchute and Mingus Mountains to the south. Also, east of the Verde fault, the Redwall has been exposed by subsidiary faulting and large patches of the formation crop out north of Woodchute Mountain where erosion has stripped the overlying Supai formation from uplifted fault blocks. The Redwall occurs along scarps of the north-northwestward-trending faults which branch from the Verde vault in the vicinity of the Jerome area. A small and isolated occurrence of it may be seen in S O B Canyon. Almost a continuous exposure occurs along the entire course of the Verde River from where it enters the quadrangle on the west to where Sycamore Creek joins it.

The only exposures of the Redwall limestone north of the Verde River are in Sycamore Canyon, along the scarp of the Railroad fault on the west side of Packard Mesa, and along the scarps of the Verde and Orchard faults east and northeast of Perkinsville. The best exposures are in Sycamore Canyon, the Verde River canyon, and in the vicinity of Jerome.

THICKNESS AND STRATIGRAPHIC RELATIONSHIP

The Redwall limestone ranges in thickness from 235 to 285 feet within the quadrangle, but probably averages about 250 feet. The greatest thickness in any of the five sections measured is in Haynes Gulch in the vicinity of Jerome, where the section is 285 feet thick. The thinnest section, 235 feet, is in S O B Canyon. The Redwall is 255 feet (incomplete section) in Little Coyote Canyon on the west side of Woodchute Mountain about 2 miles south of the quadrangle border; 252 feet in the Verde River canyon (coords. N. 1,412,000; E. 423,000); and 241 feet in Sycamore Canyon (coords. N. 1,413,400; E. 454,000). These data show that the Redwall limestone is progressively thinner from Jerome towards the northeast.

The Redwall limestone unconformably overlies the Martin limestone of Late Devonian age, and is unconformably overlain by the Supai formation. The exact position of the contact between the Martin and the Redwall is not everywhere discernible because the lowest unit of the Redwall contains reworked sediments from the Martin and therefore resembles the Martin. The zone of reworked material is as much as 35 feet thick in places but at other places it is absent, owing to the relief on the Devonian surface. The contact is gently undulating and from a distance the two formations appear conformable. The base of a massive bluish-gray oolitic limestone member, which directly overlies the reworked residual material above the Martin limestone, was used for mapping the contact between the Redwall and the Martin.

The contact between the Redwall limestone and the overlying Supai formation is easily determined. It can readily be observed on the east and north sides of Woodchute Mountain along the road from Jerome to Perkinsville. The Redwall generally is a massive limestone that forms conspicuous cliffs. The top of this limestone commonly forms a bench from which the soft red shale and siltstone of the basal Supai formation have been eroded. The contact is irregular; the local relief is as much as 15–30 feet in a lateral distance of 100 feet, and fragments of limestone and chert fill the hollows.

LITHOLOGY

The Redwall limestone, which is generally a cliff-forming unit, consists chiefly of light-gray to white aphanitic to coarsely crystalline thin- to thick-bedded limestone. It has an overall massive appearance, which is due partly to the homogeneity of the beds but chiefly to planes of separation between many of the beds which are so inconspicuous when viewed from a distance, that the formation appears to be a single stratum. The limestone generally is fossiliferous throughout, though locally beds are barren. The limestone characteristically contains solution channels and caverns, many of which have collapsed or have been filled. Where they have collapsed, large blocks of limestone conglomerate that fill them are cemented with a bright red, claylike sediment, which probably is a residue from solution of the limestone. The channel-filling consists chiefly of chert released by solution from limestone matrix. The caverns are both vertical and horizontal in attitude; the horizontal ones extend along the strike of the bedding. Many of these occur along the Chino Valley-Perkinsville road where the road meanders through Wildcat Draw just outside of the west border of the quadrangle.

Woodell (Stoyanow, 1936, p. 514), Gutschick (1943), and Gutschick and Easton (1953) have studied the Mississippian strata in the Jerome area in detail. Woodell divided the limestone into six faunal zones and listed the species of fossils present in each. Gutschick (1943, p. 2–5), who studied the Redwall limestone from the Pine-Payson area northwestward along the margin of the Colorado Plateau to near Seligman, Ariz., divided the formation into four members. The four members as designated by Gutschick are as follows, from the base upward: (I) A white crystalline oolitic limestone member; (II) a fine-grained cherty porous limestone member; (III) a massive coarsely crystalline limestone member; and (IV) a gray, micro-oolitic aphanitic limestone member. The units used in describing the Redwall in the text of this report correspond to the members of Gutschick, but the contact between units 3 and 4 was located in a different place. In this report it is placed at the base of the bluish-gray micro-oolitic limestone near the top of the formation, whereas Gutschick and Easton (1953, p. 4) placed it about 25 feet below where they believed that they recognized a disconformity. No disconformity could be found at this horizon by the writer.

Although the four members of Gutschick were recognized during the present study, they were not mapped separately except in a few local areas where detailed information was desired for interpreting the structure. For this reason they are not shown on plate 45. In order to describe the Redwall limestone as adequately as possible, each of the four units is described separately.

Unit 1.—Unit 1 of the Redwall consists of a lower thin-bedded clastic unit that constitutes reworked deposits of the Martin limestone, and an upper unit that constitutes bluish-gray oolitic thick-bedded limestone. The lower unit consists chiefly of limestone, arenaceous limestone, and calcareous sandstone—materials which resemble many of the Upper Devonian lithologies. This unit wedges out against topographic highs that remain on the upper surface of the Martin limestone. As much as 35 feet of these beds has been measured in some places. The beds are very light gray and lavender to pink; the pink results from impurities. Most of the beds in the lower part of the unit are thin, but higher up they are moderately thick (several feet). Locally a thin zone of sandstone, partly conglomeratic, is present at the base. The thin beds normally weather to slopes.

The upper part of unit 1 consists of massive beds of aphanitic oolitic limestone, which range from 25 to 55 feet in thickness, and is characteristically bluish gray and cliff forming. The rock generally is a mass of conspicuous oolites, which stand out in relief on weathered surfaces.

Gutschick and Easton (1953, p. 3), stated that an unconformity which cuts out the oolitic limestone to the north and northwest, is at the top of their member I. They believed that because of this unconformity the oolitic limestone is not recognized in the Grand Canyon area. Huddle and Dobrovolny (1952, p. 87), however, traced this unit laterally into a rubble breccia that consisted of large limestone and chert blocks in a matrix of red sandy mudstone. This relationship conforms with observations made by the writer in the Clarkdale quadrangle, and indicates that the oolitic blue limestone unit is conformable with the overlying member, but that laterally parts of it that were especially susceptible to solution formed in caves that later collapsed to form thick irregular breccia zones.

Unit 2.—Unit 2, which ranges from 55 to 80 feet in thickness, is a light gray to cream fine-grained cherty limestone. The abundance of chert in this unit is characteristic. The chert, which is white to yellow and weathers to a rusty brown, occurs as nodules, lenses, and layers within the beds and along the bedding planes of the limestone. Fossils are commonly preserved in the many chert nodules. Where this unit is exposed to weathering, large blocks of chert are scattered about on the surface. The limestone occurs as beds 2–5 feet thick, and is fine to medium grained. It is fossiliferous though not abundantly so. This unit appears to have been especially susceptible to the formation of caverns. These caverns have collapsed or been refilled with limestone and chert breccia.

Unit 3.—Unit 2 is overlain conformably by unit 3. Unit 3 is a yellowish- to light-gray homogeneous coarsely crystalline crinoidal limestone, which probably averages 100 feet in thickness. It is thick bedded and the most fossiliferous unit of the formation. The weathered surface of the limestone is rough as a result of its coarse crystallinity and the abundance of small crinoidal discs that it contains. Unit 3 differs from unit 2 in grain size, color, and absence of chert.

Unit 4.—Unit 4 consists of a bluish-gray aphanitic to oolitic cliff-forming limestone that is present nearly everywhere in the Clarkdale quadrangle except where it has been removed by pre-Supai erosion. It averages about 40 feet in thickness, and resembles the oolitic phase of unit 1, except that it is more aphanitic, lighter, and has smaller oolites that can be recognized only with the lens. This unit, because of its color and its cliff-forming tendencies, forms a nearly continuous band at the top of the formation, visible for several miles or more.

AGE AND CORRELATION

In Arizona, rocks of early Mississippian age have been called the Redwall limestone in the northern part of the State and the Escabrosa limestone in the southeastern part of the State. The Redwall, as originally defined by Gilbert (1875, p. 162, 177–186), included rocks both older and younger than Mississippian. Later, Noble (1922, p. 26, 54), who made detailed studies in the Grand Canyon area, restricted the name to strata of Mississippian age. The Escabrosa limestone was a name proposed by Ransome (1904, p. 42–44), for the strata of Mississippian age in the Bisbee area of southern Arizona, and this term has been widely used in the southeastern part of the State. In central Arizona, Huddle and Dobrovolny (1952, p. 86) have shown that the two formations probably are continuous and form a single mappable unit. In their report dealing with the Mississippian limestone of central Arizona, they use the name Redwall limestone.

The Mississippian strata in the Jerome area have long been referred to as the Redwall limestone. Ransome (1916, p. 162) reported that the faunas show close affinities with the lower Burlington (lower Osage group). Stoyanow (1936, p. 505) stated that the Escabrosa and the Redwall limestone formations are not exactly taxonomic equivalents but overlap each other; he believed that the Redwall began somewhat later than the Escabrosa. He further stated (Stoyanow, 1936, p. 514) that species collected by Woodell in the Redwall limestone of the Jerome area indicate that the faunas range from late Kinderhook into Keokuk and Burlington times.

Gutschick (written communication, 1955) assigned his member I to Kinderhook age and placed the break between Kinderhook and Osage between his member I and II. He correlated his member II with the top of the Alamogordo and the base of the Nunn members of Laudon and Bowsher of the Lake Valley limestone in New Mexico. His member III is Osage in age and correlated with the Burlington limestone of the Mississippi Valley. Gutschick tentatively placed his member IV in the uppermost part of the Osage (Keokuk affinity) but felt that this did not necessarily preclude a Meramec assignment.

SUPAI FORMATION

DISTRIBUTION

The Supai formation has greater areal distribution in the quadrangle than any other formation, and presents a vast expanse of red rocks that extend from the north side of Woodchute Mountain northward and northeastward in many places to the limits of the quadrangle. Elsewhere, the Supai is present for the most part, as inliers or outliers except for the southeastern part of the quadrangle where it is covered by the younger Verde formation. The Supai formation has a general northeasterly dip except in the northeastern part of the quadrangle where it flattens as it approaches the Mogollon Rim. Erosion has beveled these dipping beds so that they thin to the south and are largely absent on Mingus Mountain south of the quadrangle.

THICKNESS AND STRATIGRAPHIC RELATIONSHIP

The Supai formation ranges from 1,550 to 1,665 feet in thickness within the Clarkdale area. The latter figure was determined by McKee (oral communication, 1953) from a section in Sycamore Canyon. McKee believes that the basal 332 feet of the section is equivalent to the Naco formation of Pennsylvanian age, but this part is included in the Supai in this report. The 1,550 feet of Supai was measured in a composite section from the Verde River in the vicinity of Mormon Pocket north to Henderson Flat at the base of the Mogollon Rim. Most of the Supai, particularly the lower and upper parts, forms cliffs, which confine examination to the few accessible canyon walls or slopes.

Hughes (1949, p. 33; 1952) measured a maximum of 1,155 feet of Supai at Black Mesa about 10 miles south of Ashfork. In the vicinity of Fossil Creek, Huddle and Dobrovolny (1945) measured 2,200 feet of Supai; this excluded the basal 470 feet which they assigned to the

Naco formation of Pennsylvanian age. McNair, (1951, p. 530) measured a section of the Supai in Chino Valley near the south edge of Picacho Butte; it totaled 1,052 feet.

The Supai formation rests unconformably on the Redwall limestone. The unconformity is marked by an erosion surface on the Redwall limestone which shows a relief of about 15 to 30 feet in the area. Upon this surface rests a basal limestone conglomerate and (or) chert breccia of the Supai which is held together by a matrix of red mud. The contact is conspicuous because of the striking difference in lithology and color between the two formations.

Overlying the Supai formation in the Clarkdale quadrangle is the Coconino sandstone, whereas in the Grand Canyon area the Hermit shale separates the Supai from the Coconino. The contact between the Supai and the Coconino is intertonguing. The contact has been assigned primarily on the basis of differences in the type of crossbedding shown by each formation. Crossbedding in the upper part of the Supai formation consists of thick coextensive sandstone beds that contain one or more sets of torrential-type cross laminae, the beveled surfaces of which are covered by horizontal beds of very thinly laminated siltstone and fine-grained sandstone. In contrast, the Coconino sandstone is considered to be an eolian deposit, and displays giant, wedge-shaped, crossbeds throughout its vertical range.

McKee (oral communication, 1953), in his regional studies has recognized the problem of drawing a boundary between the Supai and the Coconino and has arbitrarily placed the upper limits of the Supai at the top of the uppermost flat-bedded siltstone or sandstone, and this procedure is followed through this report.

LITHOLOGY

The Supai formation, which is a red-bed deposit, consists of both detrital and chemical rocks. The detrital rocks, which are the most abundant, occur chiefly as sandstone, siltstone, and shaly mudstone, whereas the chemically deposited rocks, which consist of limestone and chert, and are most abundant near the base, constitute a very minor part of the formation. Such a diversity of sedimentary rocks indicates that the formation must have accumulated in a complex environment.

The Supai formation has been divided into members in order to interpret structure more precisely. The subdivision of the formation into members is based on the divisions of Huddle and Dobrovolny (1945) which include lower, middle, and upper members. McKee (oral communication, 1953), recognized these same subdivisions in Oak Creek Canyon and elsewhere. These members are distinctly different in lithology, color, and topographic expression.

Lower member.—The lower member of the Supai formation ranges from 580 to 625 feet in thickness and consists chiefly of sandstone and siltstone and minor amounts of shaly mudstone; it contains a few limestone beds, and some chert breccia and (or) limestone conglomerate. In the lower part of the member the beds are thinner. Shaly mudstone is commonplace, so that the unit forms a gentle slope at the base but is increasingly steep toward the top, as the amount of shaly mudstone decreases. Some beds crop out prominently, other beds are concealed; the result is a stairlike slope typical of nearly flatlying beds of different composition. The lower member of the Supai is the only one exposed south of the Verde River. Prominent outcrops of this member north of the river make up the top of Packard Mesa, form the clifflike walls of the inner gorge of Sycamore Canyon from its mouth almost to the northeast corner of the quadrangle, and crop out in large areas northeast and northwest of Perkinsville, in places where overlying Tertiary or Quaternary gravel has been eroded away.

Many beds of the lower member of the Supai are lenticular. The sandstone beds commonly are laminated or cross laminated. They are generally fine grained and in places grade into siltstone. Conglomerate deposits are lenticular and contain medium-gray limestone and pale-red siltstone pebbles, which are as much as an inch in diameter. The few limestone beds in the lower part of the member are light bluish gray to light brownish gray aphanitic to coarsely crystalline, and form conspicuous ledges 1–6 feet thick. The siltstone is pale to dark reddish brown and thin to thick bedded. Many beds are cross laminated. The thin beds are more friable and are a deeper red than the thick beds.

At the base of the lower member is a conglomerate and (or) breccia zone locally as much as 15 feet thick, which rests unconformably on the Redwall limestone. The conglomerate consists of pebbles and boulders of limestone, which are loosely cemented with a purplish-red and green to gray silty shale. Many spherical to ovoid chert concretions which range from several inches to several feet in diameter, and which show concentric banding of many colors, weather out from this zone. Some chert fragments are present in the conglomerate, but they are rare in comparison with limestone gravel. The conglomerate occurs in pockets, and was undoubtedly derived from the Redwall limestone with little transportation. In other places a breccia consists entirely of chert and is dark reddish brown and poorly sorted. It has an even upper surface. The chert fragments range from a fraction of an inch to as much as an inch in diameter. The conglomerate is common in the vicinity of Jerome and Woodchute Mountain. Elsewhere, in the area west of Antelope Hills, the breccia is more common.

Approximately the basal third of the lower member of the Supai, overlying the basal breccia or conglomerate beds, is composed chiefly of siltstone, but contains some shaly mudstone. Intercalated within this part of the member are beds of limestone conglomerate, limestone, and sandstone. This part of the member forms a moderate slope.

The upper half to two-thirds of the basal member is comprised chiefly of sandstone, but contains thin intercalated siltstone and some limestone beds. The bedding is thicker and more massive toward the top of the member so that in most places this part forms a very steep slope or, more commonly, a cliff. The upper 70–90 feet is a conspicuous sandstone unit, which is pale red to pink, very fine grained, thick bedded, with cross laminae in the beds, partly calcareous, and cliff forming. Its surfaces weather pale reddish brown to light brown. This massive cliff-forming sandstone contrasts sharply to the overlying, slope-forming sequence of siltstone and conglomerate of the middle member.

Middle member.—The middle member which ranges from 250 to 300 feet in thickness, is present only north of the Verde River; erosion has stripped it from the area south of the river. The middle member topographically forms broad flat areas with a few gently rolling and rounded hills such as occur north of the Mormon Pocket area and northwest of Black Mountain in the Cow and Henderson Flats. It forms a moderate slope above the inner walls of Sycamore Canyon west of Black Mountain where erosion is especially active. The middle member also crops out north and south of the Drake road where it leaves the west side of the quadrangle north of coordinate N. 1,440,000; within a mile radius circumscribing the intersection of coordinates N. 1,430,000 and E. 420,000; and north along the course of Sycamore Canyon to where it leaves the northeast corner of the quadrangle.

The principal rock in this member is siltstone, but it is intercalated with conglomerate, sandstone, and some limestone. The siltstone ranges in color from reddish brown to grayish red. Throughout the member, zones of thin layers alternate with beds that are from 6 inches to 3 feet thick. Massive siltstone beds are relatively resistant to weathering and form weak rounded ledges. Some of the siltstone beds are calcareous and contain nodules; they have been traced laterally into gray limestone.

Few of the conglomerate beds are thicker than 3 feet, although one bed at the top of the member is nearly 10 feet in places. Probably 25 percent of the middle member consists of conglomerate beds; the so-called "intraformational conglomerates" of the Supai. The conglomerate beds are very lenticular and many grade both laterally and upward into siltstone. The gravel constituents of the conglomerate include pale-brown to pale-red siltstone (some of which is laminated), and light-brownish-gray to medium-gray limestone. The pebbles range from ½ to 5 inches in diameter, but more commonly are an inch or less; they are well rounded. The matrix is usually a pale-red to reddish-brown siltstone.

The sandstone is limited to perhaps three or four beds that are thick in comparison with the other rocks of this member. The sandstone is light brown to pale reddish brown, fine grained, and generally forms resistant, rounded ledges. Some beds are calcareous and show prominent cross lamination. They commonly range from 5 to 10 feet in thickness.

Limestone is the least common rock type in the middle member. Only a few beds are present in most sections. Locally a dark-pinkish-gray aphanitic sandy cross-laminated limestone occurs at the base of the member. This limestone weathers into a pitted surface and is lighter on the weathered than on the unweathered surfaces. It wedges laterally and commonly is 1–1½ feet thick, though in a few places it is almost 5 feet thick.

The contact between the middle and upper members is placed at the base of the lowest reddish-orange to light-brown friable large scale cross-laminated sandstone. The sandstone weathers into slabs several inches thick and is typical of the sandstone throughout the upper member. Inasmuch as the upper member is predominantly a sequence of medium- to coarse-grained sandstone, its basal contact is prominent.

Upper member.—The upper member of the Supai formation ranges from 650 to 750 feet in thickness, and is present only north of the Verde River. This member forms a wide peripheral band around Black and Casner Mountains, and comprises nearly half the rocks that make up the precipitous Mogollon Rim, which projects into the northern part of the quadrangle and extends along Sycamore Canyon where it has been cut into the Colorado Plateau. In the northwest quarter of the quadrangle most of the upper member of the Supai is covered by lava and gravel so that inliers of this member occur in many of the drainage systems which traverse the beds of lava and gravel.

The contact between the middle and upper members is characterized by a sharp break in topography and lithology. In contrast to the slope-forming, dominantly siltstone sequence of the middle member, the upper member is a sequence of sandstone and a few interbedded siltstone beds that form cliffs, buttresses, and pinnacles.

This member contains about eight times as much sandstone as siltstone. The sandstone has a distinct outcrop and color which is not readily confused with lithologic characteristics in other members; it is dominantly reddish orange though some is light brown to moderate reddish brown. Most of the sandstone is cross laminated on a large scale, and, the rock weathers into slabs and plates. The sandstone beds generally are very friable and form a sandy soil. Some are calcareous and most are medium to coarse grained. The bedding is massive; some beds measure more than 150 feet in thickness, and, commonly, include a few partings or lenses of flat-bedded siltstone. Irregular folding due to penecontemporaneous deformation is conspicuous in the upper member at Sand Flat (coordinates N. 1,446, 500; E. 421,200), but was not seen anywhere else.

Intercalated in the upper member are beds of pale-reddish-brown siltstone which range from a few feet to almost 30 feet in thickness, and probably averages 6–8 feet. The siltstone beds show irregular wavy laminae. Cross laminae, in most places, are absent, and the horizontal bedding of the siltstone beds is usually very noticeable where they separate strongly cross-laminated sandstone. The siltstone weathers into rounded ledges.

The contact between the upper member of the Supai and the Coconino sandstone is difficult to determine in places. Because there are no siltstone beds in the Coconino of other areas, and because at close range the crossbedding in the upper member of the Supai resembles that of the Coconino, the contact is arbitrarily placed at the top of the uppermost flat or horizontally bedded red siltstone. However, in many places talus blocks of the Coconino sandstone conceal parts of the upper Supai so that locally it is difficult to locate the uppermost siltstone. The Coconino sandstone is typically buff to cream, but locally may have the same reddish color as the Supai. However, the color boundary commonly is in close coincidence with the top of the uppermost flat-lying bed of the Supai. The Supai has horizontal-bedding planes, throughout, whereas the Coconino has huge, sweeping planes that separate individual wedges or sets of crossbedding. The structures of the eolian Coconino sandstone are on such a large scale that they have very shallow angles and are almost horizontal in places. The low angles of these parting planes add difficulty in placing the contact on the basis of the highest horizontal-bedding plane. From a distance, a greater length of the contact can be observed, and the boundary at once becomes evident.

AGE AND CORRELATION

The Supai formation, as originally defined by Darton (1910, p. 25–27) in the eastern Grand Canyon region of northern Arizona, included about 800 feet of red sandstone and shale underlying the Coconino sandstone and overlying the Redwall limestone. As defined by Darton the Redwall limestone included rocks of both Mississippian and Pennsylvanian or Permian age, but Noble (1922, p. 59–62) redefined the Supai formation, assigning to it about 250 feet of red shale, purple and gray limestone with chert and red calcareous sandstone formerly included in the Redwall. Noble also redefined about 300 feet of red shaly siltstone and fine-grained sandstone from the top of the Supai and assigned to it the name Hermit shale. When redefining the Supai formation, Noble (1922, p. 62) regarded the entire Supai as probably Pennsylvanian in age.

The Supai formation, as now classified, is Permian and Pennsylvanian. Work by Huddle and Dobrovolny (1945) has resulted in an attempt to define the age of the Supai formation more closely. They stated that the formation transgresses time lines and probably ranges in age from Des Moines (Pennsylvanian) through Leonard (Permian). In addition, they reported that the lower member probably ranges from Des Moines through Wolfcamp, and interfingers with the underlying Naco formation (Pennsylvanian). Also, they correlated the middle member of the Supai with the Abo formation of New Mexico and assigned it to Leonard age and possibly in part to Wolfcamp age. They assigned the upper member entirely to Leonard age and equated it with the Yeso formation of New Mexico.

In recent years there has been a tendency among geologists to separate beds of Pennsylvanian age from the Supai formation. In the Clarkdale quadrangle, however, the lack of an unconformity, the apparent absence of fossils, and the similarity of lithology in the Pennsylvanian and the Permian beds make this separation impractical.

Ransome (1904, p. 44–54) introduced the term Naco for limestone of Pennsylvanian age overlying the Escabrosa limestone of early Mississippian age in the Bisbee quadrangle. Later, the limits of the Naco were extended northwestward from Bisbee to the Globe-Miami area of Arizona.

Huddle and Dobrovolny (1945) further extended the limits northward into the Pine-Payson area of central Arizona, which is about 50 miles southeast of Jerome. Here, they differentiated strata of Pennsylvanian age from the Supai formation and referred them to the Naco formation. The Naco-Supai contact was placed above a sequence of gray limestone and shale beds and below a sequence of beds consisting of sandstone, shale, and some limestone. They regarded the Naco as of Pennsylvanian age, ranging from Lampasas to Virgil.

Jackson[1] and Winters (whose stratigraphic work in the Fort Apache area of Arizona has not been published but is quoted by Jackson) removed the Pennsylvanian beds from the Supai and assigned them to the Naco. The similarity between the Permian and

[1] Jackson, R. L., 1951, The stratigraphy of the Supai formation along the Mogollon River, central Arizona: Unpublished thesis in files of the University of Arizona.

Pennsylvanian rocks forced these workers to select for the contact an arbitrary plane above the highest bed containing a marine Pennsylvanian fauna.

Winters[2] regarded the Pennsylvanian-Permian boundary proposed by Huddle and Dobrovolny (1945) as an arbitrary one which forms an unnatural break in a continuous rock sequence that has similar lithology and faunal assemblages; therefore, he assigned 410 feet to the proposed boundary. Winters' Naco formation has an uppermost bed of gray ripple-marked fossiliferous thin-bedded limestone, which is overlain by gray reddish-brown claystone that grades upward into noncalcareous siltstone and sandstone. From fusilinids present in the limestone, Winters established a Virgil age for the upper Naco.

West of Fort Apache, where Winters had worked, Jackson[3] found fossils of Des Moines age at Fossil Creek, in the Pine-Payson area, in the highest fossiliferous unit of the Naco. Jackson stated that the distribution of the lithologic assemblages between the Fossil Creek and the Fort Apache areas clearly indicate a regression of the Pennsylvanian sea toward the south and southeast as sedimentation exceeded subsidence. He suggested also in his stratigraphic work, the name Packard Ranch member for a subdivision of the Supai (lower half of lower member in this report) which he could trace to the east. He stated that his Packard Ranch member becomes more calcareous eastward and intertongues with the Naco, and is evident, therefore, that the basal part of the Supai is of Pennsylvanian age in that area.

Gilluly, Cooper, and Williams (1954) have subsequently assigned the name Naco to a group, subdivided into several formations.

COCONINO SANDSTONE

DISTRIBUTION

The Coconino sandstone which is believed to be an eolian deposit, underlies much of the plateau of northern Arizona. Its occurrence in the northern part of the Clarkdale quadrangle marks its southernmost limits in this area. Within the quadrangle, the Coconino crops out almost continuously around the upper margin of Black Mountain. Pre-Tertiary erosion has removed a considerable part of the formation around the south and west margins of the mountain, so that in many places only thin remnants are left.

The Coconino standstone is a prominent feature along the Mogollon Rim where it forms the highest cliff in the upper wall. In the northwestern part of the Clarkdale quadrangle, much of it is covered by lava and gravel, and the largest surface exposures in the quadrangle are in the Sand Flat area.

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[2] Jackson, op. cit.
[3] Idem.

THICKNESS AND STRATIGRAPHIC RELATIONSHIP

The Coconino sandstone ranges from 500 to 650 feet in thickness in the quadrangle. According to McKee (1934, p. 82) at Pine, Ariz., (about 55 miles southeast of the quadrangle) the Coconino is 1,000 feet thick, which is the thickest section known. McNair (1951, p. 533–534) measured a section of the Coconino at Aübrey Cliffs (about 65 miles northeast of the quadrangle) which totaled 405 feet. Noble (1922, p. 67) reported a thickness of 30 feet of Coconino sandstone near the upper end of Kanab Canyon of the Grand Canyon area. Farther north near the Arizona-Utah border, the Coconino disappears. The thickness of the Coconino sandstone therefore increases southward from the north boundary of the State.

The Coconino sandstone conformably overlies the Supai formation, and passes laterally into its upper part through intertonguing. Within the quadrangle, exposures favorable for the study of the contact between the Supai and the Coconino sandstone are few because in most places this contact is on the side of inaccessible cliffs. The contact is discussed on page 538.

The contact between the Coconino sandstone and the overlying Toroweap formation is sharp. The crossbedded upper levels of the Coconino sandstone are beveled to a smooth plane, and this is overlain by a thin, horizontal layer of fine grayish-orange to light-brown sandstone, which forms the base of the Toroweap formation. Horizontal beds of the Toroweap are in marked contrast to the large scale crossbeds of the Coconino. Basal beds of the Toroweap form a narrow band atop the Coconino that can be seen for miles along the Mogollon Rim.

From work in western Arizona, Longwell (1928, p. 39) was uncertain whether the Coconino-Toroweap contact was an unconformity or a surface separating rocks of different origin. McKee (1938, p. 15), however, believed that the two formations are conformable over a wide area and that the Toroweap represents a change in conditions of sedimentation. McKee noted particularly the lack of relief, basal conglomerate, and other evidence which might indicate an interval of erosion preceding deposition of the Toroweap. He argued that "extensive truncation of sloping laminae in the Coconino to a perfectly flat surface can be accounted for only by a beveling of sediments while still unconsolidated."

LITHOLOGY

The Coconino sandstone is a massive very pale-orange to grayish-orange fine-grained conspicuously crossbedded quartz sandstone. The most outstanding and characteristic features of this homogeneous formation are its uniform massiveness, large-scale crossbedding, and uniform fineness of grain size.

Almost all the sand grains in the Coconino are of quartz but they include very minor amounts of clay and iron oxides, and scattered traces of feldspar and heavy minerals. The grains generally are well cemented by silica. In places the sandstone is almost as resistant as quartzite; elsewhere, it is moderately firm to friable. The grains are uniformly small (0.125–0.25 millimeter) and are rounded to subangular. Most of the grains are pitted and frosted; some grains are stained with iron oxide but a few are clear.

Iron oxides and claylike impurities form thin threadlike lines between laminae as observed on surfaces broken oblique to the planes of laminae. These impurities are red to lavender and are as much as several inches thick at the base of the large wedge-shaped crossbeds. Some brown to purplish-brown diffusion bands are cut at an angle across the lamination planes. The smooth surface of these slabs have an attractive color banding.

The entire formation consists of sweeping crossbeds as much as 50 feet long, which are truncated and then overlain by other crossbeds, so that the beds form irregular wedges. Each wedge consists of thin, inclined laminae which form subparallel concave curves that flatten downward and become tangential to a plane of truncation at their lower ends. The wedges differ considerably in thickness, and the cross-laminae dip at angles of 15°–30°. The dip of a majority of the foreset beds in the Clarkdale quadrangle is to the south, and this prevailing direction is responsible for the shape of the erosional pinnacles and peaks between Henderson and Cow Flats. Here the peaks have asymmetrical profiles and the slopes are more gentle on the south than on the north. This erosional pattern apparently is caused by the sandstone on the south sides weathering along dip slopes of the crossbeds, whereas that on the north sides breaks along vertical joints to form cliffs.

The Coconino sandstone typically weathers into slabs and blocks and readily splits into individual thin beds with smooth even surfaces along the bedding planes. Strong northeastward- and northwestward-trending joints in the northeast corner of the quadrangle have also been a factor in causing the sandstone to weather into blocks. Ripple marks occur locally on the surfaces of slabs.

AGE AND CORRELATION

Darton (1910, p. 21, 27) proposed the name Coconino for the exposures of the sandstone in the walls of the Grand Canyon. The Hermit shale below the Coconino in the Grand Canyon region has been determined by White (1929) as late early Permian in age from its flora, and, according to McKee (1938, p. 217), the Kaibab limestone above the Coconino is definitely of middle Permian (Leonard) age. The Coconino, therefore, must also be of Permian age. Footprints, especially *Laoporus*, correlate with Lyons sandstone of Colorado, and others (McKee, written communication, 1955).

TOROWEAP FORMATION

DISTRIBUTION

The Toroweap formation was defined by McKee (1938, p. 12) from his extensive studies in northwestern Arizona. He subdivided the Kaibab limestone—originally described by Darton (1910, p. 28)—into the Toroweap formation and the Kaibab limestone (restricted). This division was based on unconformable relationship between the two formations, on characteristic faunas of each formation, and on distinctive lithology of each formation.

In the Clarkdale quadrangle the Toroweap formation occurs only in the northern part, and it extends no more than 2¾ miles south of the north boundary. The Clarkdale quadrangle is about the southern limit of the formation in this part of Arizona. The Toroweap forms a narrow band immediately above the Coconino sandstone and below the Kaibab limestone in the summit areas of Casner Mountain and the Mogollon Rim. North of Sand Flat and east of the Perkinsville-Williams road the formation crops out from beneath the lava about 1½ miles east of Sand Flat and forms a part of the Mogollon Rim.

THICKNESS AND STRATIGRAPHIC RELATIONSHIP

The thickness of the Toroweap formation in the Clarkdale quadrangle ranges from 150 to 165 feet as measured at three localities within a distance of 9½ miles. The thickness of the Toroweap measured by McKee (1938, p. 187–188) in Aubrey Cliffs, which is northwest of Seligman, Ariz., is 299 feet thick. It is 361 feet thick (McNair, 1951, p. 535) at South Hurricane Cliffs in the Grand Canyon region. The Toroweap becomes thicker from the quadrangle toward the northwest corner of the State.

The Toroweap formation conformably overlies the Coconino sandstone with a sharp contact. The conspicuous crossbedding of the Coconino is beveled on top and covered by horizontal bedding of the Toroweap.

The Kaibab limestone overlies the Toroweap formation and the contact between these formations is easily recognized. The upper part of the Toroweap consists of soft mudstone and siltstone beds which readily break down into slopes, whereas the Kaibab limestone is a cliff-forming unit. The contact is placed immediately below the uppermost yellow massive sandstone at the base of the Kaibab limestone. This sandstone grades upward into the overlying limestone, and is believed to be reworked Toroweap. The upper contact of the Toroweap is a gently undulating surface. In most places the contact, where exposed, is on the face of a cliff, so cannot be studied in detail. Talus from the overlying Kaibab limestone commonly conceals it. McKee (1938, p. 28–35) cited many places in other parts of the region where there is evidence of an unconformity between these two formations.

LITHOLOGY

The Toroweap formation, defined by McKee (1938, p. 12, 17), includes those beds of sandstone, limestone, and gypsum unconformably beneath the Kaibab limestone and conformably above the Coconino sandstone. At the type locality in Toroweap Valley in the Grand Canyon area, McKee (1938, p. 13, 17–28) divided the formation into three members: upper red member (α) that represents a time of receding sea, middle limestone member (β) that represents a time of a sustained sea, and lower member (γ) that represents a time of advancing sea. He reported that eastward these members lose their identity through interfingering of units where the formation consists of sandstone only. For this reason, he divided the formation laterally into western and eastern phases and designated the intermediate area, where sedimentary types are mixed, as the transitional phase of deposition.

In the Clarkdale quadrangle the lithology of the Toroweap indicates that it is a part of the transitional phase where possibly the members of the western phase are partly formed and intertongue with sandstone of the eastern phase. Here the formation can be subdivided lithologically into three main units, which consist from bottom to top of red to buff sandstone, calcareous sandstone and arenaceous limestone, and alternating red and buff sandstone, siltstone, and some shale including a few white fine-grained pure sandstone beds intercalated. These units may be the easternmost, recognizable equivalents of McKee's three units.

The basal rock unit is a grayish-orange medium-grained argillaceous sandstone, which grades upward into a grayish-orange-pink to light-gray fine-grained calcareous sandstone in the eastern part of the quadrangle. The uppermost 2 feet of this unit is a white coarse-grained clean sandstone. Bedding is massive, and the unit commonly forms a cliff. Westward this unit of sandstone grades laterally into pale-reddish-brown and grayish-orange very fine grained calcareous sandstone which is in beds 1–10 inches thick. This unit is progressively calcareous and thicker from east to west. It ranges in thickness from 9 feet in the eastern part to 15 feet in the western part of the Clarkdale quadrangle. Probably this unit is laterally equivalent to the lower red member (γ) of McKee's western phase of deposition of the Toroweap formation.

In the Clarkdale quadrangle, the most prominent unit of the Toroweap formation is the middle unit. The eastern part of this unit is very calcareous sandstone which grades laterally to the west into a very sandy limestone. The unit increases in thickness westward from 15 to about 80 feet, but averages about 50 feet throughout the area. It forms a massive cliff and because of its yellowish-gray color, which is in contrast to the darker units above and below, it appears at a distance as a narrow ribbon visible for many miles along the upper part of the Mongollon Rim, above the precipitous Coconino Cliffs.

East of the quadrangle the middle unit of the Toroweap loses its identity in a sequence of sandstone beds that constitute the eastern phase. The basal few feet of this unit is composed of siltstone which contains a light-greenish-gray and grayish-orange-pink mottling. The unit as a whole characteristically weathers into cavities, several inches in diameter, that appear to have been formed by the weathering out of fossils; however, these cavities are the result of differential weathering, for no fossils were seen in the Toroweap formation in this locality. This unit probably grades laterally into the middle or limestone member (β) of McKee's threefold division of his western phase.

Above the arenaceous limestone–calcareous sandstone (middle) unit is a sequence of alternating grayish-orange to buff and pale-reddish-brown sandstone and siltstone and some shaly mudstone. This upper unit averages about 90 feet in thickness, and is a typical redbed series. Most of the rocks in this sequence are very friable, soft, and break down easily into slopes. The unit is progressively more thin bedded, more calcareous, and includes more redbeds westward from the Clarkdale quadrangle. In the eastern part of the quadrangle, in contrast, redbeds are absent and the section consists of light noncalcareous sandstone only. A few light-gray to white and a few variegated reddish-brown clean sandstone beds are intercalated in this sequence. The upper unit probably is equivalent to the upper red member (α) of McKee's western phase of deposition.

AGE AND CORRELATION

McKee (1938, p. 217) reported that the marine fauna of the Toroweap formation is not yet well enough known for critical analysis. Because the overlying Kaibab limestone (as redefined by McKee) has been definitely established as being of middle Permian (Leonard) age, and because the upper part of the Supai formation and the Coconino sandstone are definitely Permian, the Toroweap formation must be of Permian age.

KAIBAB LIMESTONE

DISTRIBUTION

Darton (1910, p. 28) changed the name Aubrey limestone of Gilbert (1875, p. 177) to Kaibab limestone, because the term Aubrey had been adopted by the U. S. Geological Survey for the group of which this limestone forms a part. From detailed work in the Grand Canyon area, Noble (1914, p. 70) divided the Kaibab limestone into members because large parts of it are not limestone, but sandstone, red beds, and gypsum. Following the work of Noble, other workers, especially McKee, have studied the Kaibab limestone in great detail. In 1938, McKee published the results of his study; he reported that the Kaibab, as originally defined, contained the deposits of two, rather than one, advances and retreats of the sea. He therefore divided the Kaibab into two formations—the Kaibab limestone and the Toroweap formation. This classification and terminology is used in this report.

The Kaibab limestone is restricted to the northern part of the Clarkdale quadrangle where it occupies summit areas as a narrow white peripheral band near the top of Casner Mountain and along the Mogollon Rim. In many places, overlying basalt conceals the Kaibab, but the basalt has been eroded from large areas of the flat plateau surface, north of Henderson Flat, and in these places the Kaibab is exposed. Even at a distance the Kaibab can easily be differentiated from the underlying Toroweap, and, like the Toroweap, it can be traced for many miles along the Mogollon Rim.

THICKNESS AND STRATIGRAPHIC RELATIONSHIP

A complete section of the Kaibab limestone does not exist in the Clarkdale quadrangle. The limestone is thickest where it is protected from present erosion by overlying basalt, but even in these places, a considerable part of it had been removed before extrusion of the basalt. The maximum thickness of the Kaibab limestone in the quadrangle is about 250 feet. About 2 miles north of the quadrangle and on the west side of Sycamore Canyon, McKee (1938, p. 186–187) measured a complete section of Kaibab that totaled 360 feet.

The Kaibab limestone unconformably overlies the Toroweap. The contact between the two formations is gently undulating in the Clarkdale quadrangle, and although this does not prove an unconformable relationship, the detailed work of McKee (1938, p. 28–35) in northern Arizona, establishes the unconformity. In the Clarkdale quadrangle, the contact is in most places inaccessible, for it is concealed by talus from the Kaibab. This contact is considered to be at the base of a yellow fine-grained sandstone which grades upward into limestone of the Kaibab. The sandstone appears to be reworked sediment from the Toroweap formation.

The Kaibab limestone is in places exposed at the surface but elsewhere is covered by basalt of probable Tertiary or later age. A conspicuous unconformity exists between the Kaibab and the overlying basalt.

LITHOLOGY

The Kaibab is a heterogeneous mixture of rock types, only part of which are limestone. It consists of beds of sandy limestone and sandstone that alternate with layers of chert. Although the Kaibab was not studied in great detail in this investigation, its lithology and general character suggest that in the Clarkdale quadrangle it is characteristic of facies 2 of the beta member as described by McKee (1938, p. 45, 46–47).

The Kaibab as a whole is relatively thin bedded and commonly forms a cliff or a steep slope composed of small cliffs and ledges. Most of the bedding planes are distinct and some are abundantly fossiliferous, especially containing large brachiopods of the genus *Dictyoclostus*. Chert is increasingly abundant upwards in the section and, on the surface of the plateau, in places where the Kaibab has been exposed to erosion, fragments of chert weathered from the formation blanket the surface.

At the base of the Kaibab is a grayish-orange fine-grained calcareous sandstone, 6–18 feet thick, which grades upward into a very pale-orange to pale-yellowish-orange sandy limestone. The sandstone contains very fine wavy laminations, but generally has a massive appearance. This sandstone seems definitely to consist of sediments of Toroweap age reworked by the transgressing Kaibab sea. The sandstone in many places contains horizontal lavender streaks which represent argillaceous impurities. It weathers as a cliff wall but is slightly recessed with respect to the overlying limestone. Rocks of the Toroweap below the basal sandstone of the Kaibab are much softer, and thus form slopes.

The limestone beds of the Kaibab range from 1 to 8 feet in thickness, are moderate to very sandy, and are very pale orange to pale yellowish orange and light gray. The bedding is fairly regular. The light-gray limestone is generally less sandy than the pale-yellowish-orange limestone. Scattered calcite crystals (1–4 millimeters) are characteristic. Sand grains are fine and uniform in size, are subrounded to subangular, and are predominantly of quartz.

The sandstone beds are conspicuous in the sequence about 150–200 feet above the base of the Kaibab. They are yellowish gray to nearly white, calcareous, fine grained and somewhat friable. The sand grains are subrounded to subangular. Crossbedding is present but not prominent. The bedding of the sandstone is more massive than that of

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the limestone, and ranges in thickness from several feet to as much as 15 feet.

Only a few thin beds of chert are present in the lower part of the Kaibab. The chert is more abundant towards the top, and particularly so, about 230 feet up. Much of the chert occurs as large balls almost 8 inches in diameter. The resistance of chert to weathering results in its accumulation as chips and blocks concentrated on the surface of the Kaibab. The chert is dull yellowish gray to nearly white and shows relict textures of sand grains. The weathered surfaces of the chert are grayish orange or dark brown.

AGE AND CORRELATION

The Kaibab limestone is Permian in age. McKee (1938, p. 217) reported that he had established a middle Permian (Leonard) age by the brachiopod fauna of the formation. He correlated the Kaibab with the upper part of the Leonard formation of Texas and believed it to be equivalent to the San Andres formation of New Mexico, the Chiricahua of Stoyanow in southern Arizona, and probably the Phosphoria formation, in part of Utah, Idaho, and Wyoming.

UNCONFORMITY AT THE BASE OF THE TERTIARY ROCKS

Based upon the proximity of Lower Triassic rocks of the Moenkopi formation [4] (Price, 1949) in Sycamore Canyon to the north of the Clarkdale quadrangle, it is evident that during the interval between Triassic and late Tertiary, the area was uplifted and tilted to the northeast. If Jurassic or Cretaceous sediments were ever deposited in this region, erosion, since then, has erased all evidence. Erosion removed about 2,100–2,300 feet of Paleozoic rocks from the Woodchute Mountain area, and 3,200–3,600 feet from the Mingus Mountain quadrangle, farther south (Anderson and Creasey, 1957). An unknown thickness of Precambrian rocks probably have been eroded. A surface marked by considerable relief was formed by erosion of these rocks. Tertiary basalt and gravel of the Hickey formation accumulated on this erosion surface.

CENOZOIC ROCKS

Lacustrian deposits and thick accumulations of other sediments, which consist mostly of coarse materials but contain some fine sediments, were deposited in many valleys and in basins of central Arizona as a result of uplift and crustal disturbances during late Miocene or early Pliocene time. Furthermore, interbedded lava flows indicate that volcanism was widespread in this region. The thickness of the deposit is variable, and for most areas is unknown. In some localities

[4] Price, W. E., Jr., 1948, Rim rocks of Sycamore Canyon, Arizona: Unpublished thesis in files of the University of Arizona.

data from wells give a minimum figure, which exceeds several thousands of feet. The deposits are nearly barren of fossils, and only locally have they been dated precisely through discovery of vertebrate remains. In most places, their age must be considered tentative.

Within the Clarkdale quadrangle Cenozoic rocks consist of the Hickey formation of probable Pliocene age; the Verde and Perkinsville formations, which are tentatively correlated with each other, and which are younger than the Hickey; Quaternary gravel; and Recent river terrace and riverwash deposits. The Hickey formation is separated from the Perkinsville and Verde formations by structural, physiographic, and, in part, lithologic evidence.

HICKEY FORMATION

DISTRIBUTION

The Hickey formation was named by Anderson and Creasey (1957) from exposures of lava flows and gravel on Hickey Mountain, which is just south of Woodchute Mountain. According to Anderson and Creasey some of the lava and gravel in Lonesome Valley on the west side of Hickey and Mingus Mountains also are part of the Hickey formation. The physical continuity between rocks of the Hickey formation in Lonesome Valley and those on the summit of Mingus Mountain is broken by the marginal fault along Mingus Mountain. From the summit area of this mountain, the Hickey formation extends northward into the Clarkdale quadrangle.

The Hickey formation in the Clarkdale quadrangle is, to a large extent, confined to the high topographic features. Areas which structurally have been lowered and isolated from the larger masses are exceptions. The sedimentary rocks of the Hickey formation in the Clarkdale quadrangle appear to be stream deposits, confined to northward- and northeastward-trending relict channels beneath the volcanic flows. Judging from the pattern of outcrops (pl. 45), two major channels seem to be represented: one trends northeastward from the southwest corner of the quadrangle, and the other trends northward from Jerome; they join near the headwaters of S O B Canyon, and extend from there in a northeasterly direction, and pass through the west side of Black Mountain. Other minor channels tributary to the major ones are present in many places at the base of the volcanic flows of the Hickey formation.

The volcanic rocks of the Hickey formation cover the top of Woodchute Mountain and extend southward as a capping on Mingus Mountain. On the north side of Woodchute Mountain, they occur on the tops of ridges which radiate out from the mountain. Large patches of the volcanic rocks occur northward from Jerome in the hanging-wall block of the Verde fault. Much of the Hickey probably extends eastward from the Jerome area for some distance, probably as faulted segments, under the younger Verde formation. In the central part of the quadrangle the Hickey blankets the Antelope Hills, and occurs as isolated remnants on both sides of the Verde River in the vicinity of Mormon Pocket. Black and Casner Mountains are also capped with Hickey formation. Atop the plateau it forms outliers and parts of a broad, volcanic sheet that extends far to the north over the plateau surface.

THICKNESS AND STRATIGRAPHIC RELATIONSHIP

Regionally, the Hickey formation is variable in proportion of volcanic to sedimentary rocks. Flows coalesce and interfinger with each other and with thick deposits of detrital material which accumulated in valleys and basins. In the Clarkdale quadrangle, the Hickey formation consists of much more volcanic than sedimentary rocks.

The thickness of the Hickey formation is extremely variable, owing to the fact that it accumulated on a highly irregular surface. The quadrangle has no complete sections because erosion has removed different amounts from the top of the formation.

The most conspicuous exposure of the Hickey formation occurs on Woodchute Mountain. Here, about 1,400 feet of volcanic flows occur plus about 50 feet of gravel in minor channels at the base of the flows. In the Antelope Hills in the central part of the quadrangle, the volcanic rocks of the Hickey formation range in thickness from 100 to 300 feet. The thickness of the volcanic rocks of the Hickey formation on Black Mountain ranges from almost 50 feet on the northeast side to more than 500 feet on the southwest side. On Casner Mountain and on the part of the plateau which projects into the northern part of the quadrangle these volcanic rocks are as much as 250 feet thick and are even thicker to the north away from the plateau edge.

The channels containing the sedimentary rocks of the Hickey formation range from a few feet to more than several hundred feet in depth. The maximum thickness of the sedimentary rocks of the Hickey formation within the Clarkdale quadrangle is on the west side of Black Mountain along Sycamore Canyon.

Deformation and erosion followed accumulation of the Hickey formation so the younger Verde and Perkinsville formations overlie it unconformably. In the southwest corner of the Clarkdale quadrangle Quarternary gravel beds, which extend southwestward into Lonesome Valley, mask the Hickey formation. This gravel may represent the means by which the extensive pediment surface was carved in the valley.

LITHOLOGY

Sedimentary rocks.—The sedimentary deposits of the Hickey formation in the Clarkdale quadrangle are believed to be relics of former stream deposits beneath the volcanic rocks and they consist of materials that are variable both in composition and in grain size. Also, the thickness of these deposits within the quadrangle ranges from a few inches to about 200 feet. The gravel grades from fine to coarse and includes some silt and sandy beds and lenses. The degree of sorting and the formation of bedding differ greatly. The sandy beds are well sorted and many are intercalated as lenses within beds that contain large boulders. These rest in a matrix of unsorted cobbles, pebbles, and silt. There are also local, well-bedded gravel beds throughout the formation. Most beds contain some angular to subrounded boulders 2–4 feet in diameter, although the average diameter of the gravel probably is 2–8 inches.

The degree of consolidation of the gravel in the Hickey formation is variable, and in many places the gravel beds are so weakly bound together that they do not withstand weathering. Elsewhere the gravel is well lithified with lime cement and clay matrix.

Gravel of the Hickey formation includes lithologic representatives of the Paleozoic formations within the quadrangle; a small amount of basaltic material derived from the penecontemporaneous Tertiary volcanic rocks of the Hickey formation; and Precambrian rocks that consist of quartz diorite porphyry, Deception rhyolite, breccia of the Spud Mountain volcanics, foliated rocks that include hornblende schist, alaskite, aplite, quartz porphyry, and rocks that resemble those of the Grapevine Gulch formation and gabbro. Basaltic gravel of Tertiary age forms a minor percentage of the total deposits. Inasmuch as the channels that contain these gravel deposits are below all the lava flows in the quadrangle, the presence of lava among the gravel indicates that some volcanism was active in the region to the south and east of the quadrangle before the major outpouring of lava during Hickey time. Probably the source of the gravel was to the southwest of the Clarkdale quadrangle, although more information on the Precambrian rocks of central Arizona is necessary before a more positive statement can be made. Many of the gravel deposits of Precambrian rock types appear to have been derived from sources of restricted occurrence. Anderson (oral communication, 1953) stated that foliates such as the hornblende schist are common in the Prescott quadrangle where the grade of metamorphism is higher than in the Mingus Mountain quadrangle. Furthermore, he reported that there is no alaskite and very little aplite in the Mingus Mountain quadrangle, whereas Krieger [5] has mapped these rocks in the southeastern corner of the Prescott quadrangle. The breccia of the Spud Mountain volcanics has been mapped by Anderson and Creasey (1957) along the west margin of the Black Hills in the Mingus Mountain quadrangle,

[5] Krieger, M. H., A study of the geology of the Prescott quadrangle, Ariz., unpublished report.

and Kreiger has mapped large areas of the breccia in the Prescott quadrangle.

Volcanic rocks.—The volcanic rocks of the Hickey formation consist almost entirely of basalt flows, but contain small amounts of detrital accumulation of basalt, andesite flows, and thin beds of pumiceous tuff.

The individual flows range in thickness from about 20 to almost 60 feet, but probably average 40–50 feet. They are massive—although in places somewhat vesicular—and some have scoriaceous tops. Brecciated zones consist of angular fragments and blocks of both scoriaceous and massive material. Columnar jointing is common and is most frequently observed on steep slopes or cliffs where talus does not obscure the tiers of the flows.

The basalt of the Hickey formation is typically medium gray to grayish black on fresh surfaces but weathers brown on exposed surfaces. Megascopically it is mostly porphyritic with an aphanitic groundmass. A majority of the phenocrysts are glassy olivine, or iddingsite pseudomorphs after olivine, but augite and feldspar crystals have been recognized in hand specimens. Under the microscope the basalts appear completely holocrystalline. The textural varieties range from intergranular, where interstitial augite occurs in an aggregate of grains and not in large crystals, to subophitic, where the plagioclase and olivine crystals are separated by interstitial pyroxene and scattered iron ores. Intergranular textures are the most common.

The mineralogy of the basalts consists of a typical olivine basalt assemblage. Minerals present are olivine, plagioclase, pyroxene, magnetite, and some calcite. The olivine crystals are euhedral and are porphyritic or glomerophorphyritic; olivine also is present in the groundmass. Some olivine phenocrysts show rims, as well as whole crystals, which are altered to iddingsite, and still others are serpentinized. The interstitial olivine in the groundmass is less altered than the phenocrystic olivine. Plagioclase feldspar occurs as phenocrysts but more commonly is confined to the groundmass. The plagioclase is between An_{60} and An_{70}. The pyroxene is a greenish-gray augite with a weak purplish tint. The plagioclase and pyroxene appear to have two distinct associations within the groundmass; in some rocks the plagioclase feldspar is in euhedral prisms in a matrix of olivine and pyroxene, whereas in other rocks interstitial plagioclase separates euhedral pyroxene prisms. Magnetite occurs either as dust particles throughout the rock, or as scattered grains of coarse size. The rock is a light gray where the magnetite is in large grains, and grayish black where the magnetite is disseminated as fine dust. Calcite in the basalt is assumed to be secondary.

Basalt in dikes, which are present at the base of the Mogollon escarpment just north of Henderson Flat and on top of Packard Mesa above the Verde River, is similar in mineralogic structure and assemblage to that in the flows. Some of the dikes also have calcite amygdules. Many dikes that are too small to map, are present along the Jerome-Perkinsville road in the vicinity of Woodchute Mountain.

In areas where there is little topographic relief, the basalt decomposes at the surface and forms a thin layer of brown powdery soil. The residual soil contains abundant angular fragments and boulders with rounded edges which were derived from the lava.

Included in the volcanic rock series are local biotite- and hornblende-bearing lava flows, which probably are andesites but which are too small to differentiate on plate 45. Localities in which these rocks were noted are on top of the hill at First View Pass on the Jerome-Perkinsville road (coordinates E. 432,500; N. 1,374,500), at the base of the volcanic rocks of the Hickey formation southwest corner of the quadrangle (coordinates E. 406,500; N. 1,371,000) and in the hill which projects into the west boundary of the quadrangle (coordinates N. 1,371,000). Similar rocks may occur elsewhere among the volcanic rocks of the Hickey formation. In the Prescott quadrangle, to the southwest, Krieger [6] separated biotite and hornblende andesites from the upper Tertiary (?) rocks; large areas of andesite occur in the Paulden quadrangle.

The tuffaceous and basaltic sedimentary rocks of the Hickey formation are composed of pyroclastic materials and of materials derived from the basalt flows, which accumulated in local depressions during lulls of volcanism. The rocks are pale red, grayish red, and light brownish gray and are well sorted and bedded. The detritus is nearly all basalt; it ranges from microscopic particles to pieces the size of hickory nuts, all of which are subangular to subrounded. Locally the sedimentary rocks contain vitric and crystal fragments. Opaline material commonly fills the interstices surrounding large particles. A good exposure of these sedimentary rocks is in the roadcut leading to the summit of Black Mountain on the east side. Thin wedges of rocks also are present between flow-layers on Woodchute Mountain. They have been described by Anderson and Creasey (1957) and occur along Highway 89A where it crosses the summit of Mingus Mountain.

A single deposit of tuffaceous sedimentary rocks, that contains largely pumice, quartz grains, and a few scattered crystal grains of olivine, pyroxene, and unidentifiable minerals, is present in the southwest corner of the quadrangle (coordinates N. 1,376,000; E. 407,500). This deposit is in beds 1/8–1 inch thick. They are white and gray in

[6] Krieger, M. H., op. cit.

alternating bands which are reminiscent of varved sediments. Most of the light beds generally are coarse grained and are composed almost wholly of pumice fragments, but they contain some quartz grains and scattered dark minerals; all grains are rounded to subrounded. Comparable pumice-bearing, tuffaceous sediments were recognized by Anderson and Creasey (1957) in one small area in the Mingus Mountain quadrangle and Krieger (written communication, 1955) has found similar beds associated with andesite in the Pauldren quadrangle. Widespread occurrences of rhyolitic tuff are common near Prescott and farther south.

AGE AND CORRELATION

The age of the Hickey formation is unknown because no diagnostic fossils have been discovered in it. Kreiger [7] and Anderson and Creasey (1957) had assigned the Hickey to the Pliocene (?), but this age determination is based largely on inference which can be summarized as follows: (1) Much of the satisfactory dating of the Cenozoic basin deposits in central Arizona, which are similar to the Hickey formation, has been made to the Pliocene epoch (Gidley, 1922 and 1926; Knechtel, 1936, p. 86–87); (2) fragmentary antelope and llamalike camel bones found in late Tertiary (?) rocks near Prescott do not preclude the possibility of a Pliocene age (Anderson and Creasey, 1957); (3) the complexity of geologic events subsequent to deposition of the Hickey formation does not favor a Pleistocene age for the Hickey; and (4) general similarity to gravel of early Pliocene age, 20 miles south of Prescott near Milk Creek in the Walnut Grove basin (Anderson and Creasey, 1957).

The possibility exists that gravel at the base of the Hickey is significantly older than gravel deposits such as those in Lonesome Valley which are higher in the section. The youngest formation older than the Hickey known in the vicinity of the Clarkdale quadrangle is the Moenkopi formation of Triassic age. Any gravel that accumulated between Moenkopi and the beginning of Hickey time might be included in the basal gravel of the Hickey formation, for there is no criterion by which they could be separated. Price (1950a, p. 505–507), who studied these gravel deposits about a mile north of the Clarkdale area in Sycamore Canyon, believed that they are probably Miocene to Pliocene in age.

Robinson (1913) recognized three general periods of volcanic activity of the San Franciscan field in the Flagstaff-Williams area of the plateau—first period, basalt flows; second period, andesite and rhyolite flows; and third period, basalt flows. In the Clarkdale quadrangle, two periods of volcanism are recognized—older basalt flows (Hickey)

[7] Krieger, M. H., op. cit.

and younger basalt flows (Perkinsville and Verde). It is possible that the volcanic rocks of the Hickey represent Robinson's first-period basalt flows, and that the younger volcanic facies of the Perkinsville and Verde represent his third-period basalt flows. Robinson (1913, p. 88) stated that some of the basalt of the third period flowed off the edge of the plateau and reached the lower country to the south, which is precisely the relationship of the volcanic flows of the Perkinsville and Verde formations. Robinson (p. 91–92) placed the first-period basalt in late Pliocene. He arrived at this age determination by correlating a supposed peneplain, upon which the older basalt rests, with a similar feature in the physiographic cycles of southern Nevada in the Basin and Range province. However, significant data obtained by Koons (1945) on the prelava surface of erosion, indicates that early concepts of a buried peneplain are not supported by the facts. Robinson's age designation, therefore, seems inconclusive.

Lake deposits of the Bidahochi formation in the Hopi Butte Country east-northeast of Flagstaff are of middle or late Pliocene age (Williams, 1936; Hack, 1942). Stratigraphically, this formation has been shown to be older than the oldest lava of the San Franciscan field by Childs (1948, p. 378) who traced a pediment which truncates the Bidahochi formation from the Hopi Buttes to northeast of Flagstaff, where Robinson's first-period basalt is above the pediment. He therefore suggests a very late Pliocene or early Pleistocene age for the oldest basalt.

In the Clarkdale quadrangle evidence shows that erosion produced about 1,300 feet of relief after the accumulation of the Hickey but before the accumulation of the Perkinsville and Verde formations. This erosion, introduced by regional uplift, resulted in southward drainage, which generally has persisted to the present, and this pattern was well established before the accumulation of the lava of the Perkinsville and Verde formations. This sequence of physiographic events in relation to the general periods of basalt flows in the quadrangle, conform to the sequence described by Robinson (1913, p. 92–95) for the Flagstaff region, Koons (1945, p. 179–189), for the western Grand Canyon region, and to those of Maxson (1950, p. 14) from work in the Grand Canyon. Koons correlated the stages of eruption in the Uinkaret volcanic field with the stages postulated by Colton (1937) in the San Franciscan field, and he stated that the oldest flows antedate cutting of the Grand Canyon.

From his studies on the age of the Colorado River, Longwell (1946, p. 832) suggested that the plateau was uplifted in late Miocene or early Pliocene time. This age is tentatively based on the fact that the Muddy Creek formation is the youngest formation through which the river cuts. The Muddy Creek formation is believed to be as old as Miocene.

The local Cenozoic volcanic history of the Clarkdale quadrangle may be correlated with the general history of the Colorado Plateau, which is based on relationship of the lava to topography. Although the chronology of the volcanic history is clear in each area, attempts to date these events in terms of absolute geologic time is difficult.

The earliest series of plateau lava flows and those of Woodchute and Mingus Mountains are probably contemporaneous, but this cannot be proved. Undoubtedly, lava from different centers coalesced with other lava that erupted within the same general period. The location of these areas of coalescence is unknown because of the similarity of the extrusive material from the different centers. Woodchute and Mingus Mountains are composed of a very thick sequence of lava flows and a few interbedded sedimentary deposits, therefore, they probably are close to a locus of extrusion.

Basaltic dikes north of Henderson Flat are considered to be feeders for the volcanic flows in the Hickey formation for the following reasons: These dikes are not spatially associated with the young basalt of the Perkinsville and Verde formations which, for the most part, flowed south into the quadrangle from the plateau. With the exception of Black Mesa southwest of Perkinsville, no centers of eruption of the young lava flows are recognized within the Clarkdale quadrangle. In contrast, dikes spatially associated with the volcanic flows of the Hickey formation are common throughout the quadrangle. The spatial relationship of dike to flow is particularly close on the Sycamore Canyon side of Casner Mountain.

INTERMEDIATE BASALT

Basalt flows intermediate in age between those of the Hickey and those of the Perkinsville and Verde occur west of Black Mountain along both sides of Sycamore Canyon. On the west side of the canyon they occur at the intersection of coordinates N. 1,420,000; E. 453,000 and N. 1, 424,000; E. 456,000. Also north of here two very small exposures are present. On the east side of the canyon the only exposure occurs at the intersection of coordinates N. 1,418,000; F. 456,500.

The intermediate basalt ranges in thickness from 50 to 150 feet and consists of several flows. The lowermost flow rests on a smooth surface of the Supai formation which is inclined slightly southward. The northernmost isolated patch of basalt on the west side of Sycamore Canyon is a plug. No gravel is associated with these lava flows.

Both megascopically and microscopically the intermediate basalt, which is typical olivine basalt, is similar to other basalt flows in the quadrangle. It is holocrystalline throughout, with an intergranular texture. As seen in thin section, the phenocrysts consist of olivine, plagioclase, and augite, separated by interstitial olivine, plagioclase, and aggregate augite. The plagioclase is calcic labradorite; the olivine is partly altered to iddingsite. A high percentage of magnetite grains, distributed throughout the groundmass, also occur in the basalt.

The lava of the Hickey formation is older than the intermediate basalt, which was first recognized because of its relationship to topography. The base of the basalt flows is 500 feet lower than the base of the lava of the Hickey which indicates the amount of erosion which must have taken place here between the two periods of extrusion. There is no gravel beneath the intermediate basalt. Gravel beneath the lava of the Hickey on Black Mountain are in channels which are at a higher altitude than the topographic surface upon which the intermediate basalt rests. If the surface upon which the intermediate basalt now rests was present at the time of deposition of the Hickey, then there should be gravel beneath the intermediate lava owing to its relationship to topography at that time.

The volcanic rocks of the Perkinsville and Verde are younger than the intermediate basalt, which was extruded before the canyon-cutting phase of Sycamore Canyon. This is indicated by the presence of basalt on both sides of the canyon. The volcanic rocks of the Perkinsville and Verde, on the contrary, were extruded after the area had become incised, because these flows occur near the bottom of the present canyon. It is unlikely that the intermediate basalt is equivalent to the Verde or Perkinsville and extruded from separate vents on the two sides of the canyon; there is no evidence of a vent on the southeast side.

The intermediate basalt represents a local phase of volcanism most closely related in time to the latest general time of volcanism (Perkinsville and Verde) rather than to the older time (Hickey). Only a tentative age can be assigned to the intermediate basalt, and Pliocene (?) to Pleistocene (?) age is favored.

VERDE FORMATION

DISTRIBUTION

Jenkins (1923) was the first to map, study, and describe the lakebeds in the drainage basin of the Verde River. He assigned to these beds the name Verde formation. The lakebeds are confined to this basin on the west by the Black Hills; on the east and north by the deeply dissected Mogollon Rim; and on the south by hills of volcanic rocks. The Verde formation is a thick sequence of limy lacustrian deposits, the areal extent of which covers more than 300 square miles, including a maximum width of 15 miles and a length of 40 miles. The northwest limits of this formation occur in the southeast quarter of the Clarkdale quadrangle.

Marginal to, and intertonguing with the fine-grained lakebed facies of the Verde formation is a gravel facies. This facies extends westward from Clarkdale almost to Jerome, but northward it diminishes in width toward the S O B Canyon area where it forms a narrow band of gravel cropping out from beneath the fine-grained carbonate facies. Isolated patches of gravel occur near the junction of the Verde River and Sycamore Creek. A few patches of the gravel are present on the south slopes of Black Mountain and in the upper part of Sycamore Canyon.

The volcanic rocks of the Verde formation consist of basalt flows interbedded with the gravel and fine-grained carbonate rocks. Basalt flowed down Sycamore Canyon and then followed the course of the Verde River canyon. Remnants of this flow are exposed intermittently along the inner walls of Sycamore Canyon. The largest continuous segment of the flow is exposed from the confluence of Sycamore Canyon and the Verde River canyon, south along the Verde River to a point about 3 miles north of Clarkdale, where it is concealed by younger lakebeds of the Verde formation.

THICKNESS AND STRATIGRAPHIC RELATIONSHIP

The total thickness of the Verde formation is not known because a complete section is not exposed. Jenkins (1923, p. 71) reported that the log data from a well above the smelter at Clarkdale, together with the thickness of additional beds exposed nearby at the surface, indicate a total thickness of 1,400 feet or more for this area. Also, with information from a well 2 miles south of Camp Verde at the south end of the drainage basin of the Verde River, plus the surface exposure, he obtained a total minimum thickness of 2,000 feet. Mahard (1949, p. 104) measured an incomplete but detailed section along the west bank of the Verde River, 1 mile north of the smelter, which totaled 733 feet. He also measured a section 1,040 feet thick 2 miles north of where U. S. Highway 89A crosses the Verde River. These figures of Mahard must be increased by an unknown thickness lying below the present river level if a complete thickness is to be calculated. Within the Clarkdale quadrangle, a little more than 1,000 feet of the Verde formation is exposed.

Following deposition of the Hickey formation, a prolonged period of erosion ensued, and this was followed by faulting and uplift relative to the areas to the west and north of the quadrangle. Accumulation of the Verde formation followed shortly thereafter, and it is in unconformable relationship with all the older formations with which it comes into contact. The gravel and lava of the Perkinsville formation accumulated at about the same time as the Verde and they are tentatively correlated with it. Quaternary gravel beds have subsequently formed as pediment veneers, terraces, and river wash on the Verde formation.

South from the junction of Sycamore Canyon and Verde River canyon, two flows are exposed along the walls of the river gorge. The lower lava has been interpreted by Mahard (1949) to have flowed down S O B Canyon, and the upper lava from Sycamore Canyon. Observations by the writer, however, indicate that both flowed from Sycamore Canyon. The older flow is a single layer of basalt; its base is at an altitude of 4,000 feet in Sycamore Canyon but descends below the present Verde River bed opposite S O B Canyon—a drop in altitude of about 550 feet. In the mouth of Sycamore Canyon, this older flow is about 50 feet higher than the younger, showing that Sycamore Creek cut down its floor about 50 feet between the time of the first and second lava flows. Downcutting during this interval may have removed all vestige of the early flow up Sycamore Canyon. The lava in S O B Canyon is almost accordant with the underlying Supai formation that dips about 15° E; this gives the erroneous impression that the lava flowed down S O B Canyon. Actually it is part of the Hickey formation which was deformed during the period of structural adjustment which preceded deposition of the lavas of the Verde formation. This structure is a southern extension of a monocline which is prominent about 1½ miles to the north. It has been referred to by Mahard (1949, p. 122) and Jenkins (1923, p. 70) as the "Railroad Bend Structure" (see page 578). The lava in S O B canyon is a continuation of one of the flows of Hickey age partly covered by the Verde formation to the southwest.

Outside the limits of the Clarkdale quadrangle, other occurrences of lava has been reported interbedded with the lakebeds. Mahard (1949, p. 108–118) reported two thin lava flows interbedded with the lakebeds at a point 8 miles north of Camp Verde where the Montezuma Castle highway follows the valley of Dry Beaver Creek. He stated that 100 feet of lakebeds separate the lower and upper flows, which are 23 and 34 feet thick, respectively, and that they can be traced northward to House Mountain. Jenkins (1923, p. 69) wrote that the old Verde lake was formed through the damming of the Verde River by surface lava flows. About 6–8 miles south of Camp Verde, lava and lakebeds are interbedded in about equal amounts.

LITHOLOGY

Most of the Verde formation consists of fine-grained carbonate rocks including limestone, calcareous sandstone, limy siltstone, and marl. Marginal to, and intertonguing with these carbonate rocks that are interpreted as lake deposits, are gravel beds accumulated as fans along steep hills that probably surrounded the basin. Interbedded with these two types of rock in parts of the basin are basalt flows which are considered a part of the Verde formation. These three rock types are described separately below.

Fine-grained carbonate facies.—The fine-grained carbonate rocks of the Verde formation consist of limestone, calcareous sandstone, and calcareous clay which are lenticular, and variable in proportion from place to place. Mahard (1949, p. 104–105) concluded from studies of two sections, which he measured 5 miles apart, that none of the detailed units recognized in either section could be correlated. He also noted that the uppermost beds in both sections are largely composed of limestone. He stated—

> the Verde formation is not composed of beds which were uniformly spread over wide areas but instead is built up of thin lenses of material of varying composition, the lenses overlapping and interfingering with one another.

Limestone is the most conspicuous lithologic type in the Verde formation, probably because of its normal light color and its resistance to erosion. Most of the beds are characteristically white, though some are light gray or pink. The rock is very hard, impure, aphanitic, and vuggy. Jenkins (1923, p. 77) suggested that the hardness probably has resulted from reprecipitation. The beds, which range from 1 to 10 feet in thickness, weather into shelves or ledges, and some cap hills. Most of the limestone beds are argillaceous, and contain many rounded grains of quartz. Small tubelike structures, about the diameter of a pencil, and several inches long, are present in many of the beds; these tubes closely resemble plant stems.

Sandstone, siltstone, and marl alternate with limestone beds. These rocks are most abundant near the margins of the formation and in the lower parts of exposures. Most of them are pinkish gray to grayish orange. A majority of the sandstone beds are fine grained and calcareous, and most of the grains are rounded quartz. The siltstone and marl are likewise calcareous. These lithologic types are not as resistant to weathering as limestone. They are friable, and weather into slopes, to form colluvial material.

Saline deposits are reported about 20 miles south of the Clarkdale quadrangle in the Verde formation in the vicinity of Camp Verde by Jenkins (1923, p. 73–75). He stated—

> here must have been the deepest portion of the old lake in which the strata were formed, for here its sediments are thickest, and here deposits of salts (sodium sulfate, principally) are found in quantities, showing that at times where the lake evaporated down to brine the only remaining portion of the body of water was at this place.

Gravel facies.—The gravel deposits are gray and consist of coarse to fine gravel, sand, and silt. Sand and gravel both are very lenticular, and many small channels of gravel are cut throughout the sand layers.

The lithology of the gravel differs from place to place and reflects the types of bedrock surrounding the basin of accumulation. The gravel consists of abundant Precambrian rock fragments below Jerome, whereas largely rocks of Paleozoic and Tertiary ages are commonly found on the south slopes of Black Mountain. The gravel in Sycamore Canyon, beneath and above the intracanyon basalt flow, is comprised mostly of rock types from the Mogollon Rim. The gravel is progressively much finer towards the area of fine-grained carbonate deposits. These beds appear to have been deposited primarily as fans, which extended into the old Verde lake, periodically interrupting accumulation of fine-grained lake deposits. The result is an interfingering of gravel and lake deposits.

Gravel of the Verde formation weathers into a loose, incoherent surface accumulation on the tops and sides of hills, and well-preserved exposures are few. The best exposures of these deposits are along U. S. Highway 89A between Jerome and Cottonwood, where roadcuts reveal the details of bedding and plainly show the interfingering relationship between gravel and lakebeds.

Volcanic rocks.—Lava of the Verde formation is basaltic rock similar to that which occurs in other formations of the Clarkdale quadrangle. The flows are holocrystalline olivine basalt, showing intergranular texture. Interstitial pyroxene crystals occur as aggregates. Probably a little more secondary interstitial calcite is found in these rocks than in other basalts. Columnar jointing is typical but there is no evidence of pillow structure in the flows, indicating that the old Verde lake may have been dry at the time of extrusion.

AGE AND CORRELATION

No diagnostic fossils have been found in the Verde formation. Jenkins (1923, p. 76–77) found a few poorly preserved gastropods, similar in appearance to some fresh-water types, which he collected south of Black Mountain (coordinates N. 1,404,000; E. 468,500). From a collection of mollusks made by Mahard (1949, p. 119) from the summit of a lakebed mesa, 1 mile north of the Clarkdale smelter on the west side of the Verde River, the following genera were identified: *Sphaerium* sp., *Lymnaea* sp., *Physa* sp., *Gyraulus* sp., *Pupilla* ? sp. Mahard stated that species of these genera indicate an environment of submerged plants in a body of water not more than 10 feet deep. This may account for many tubelike structures, in some of the limestone, which appear to be plant stems.

Jenkins (1923, p. 77) suggested that the Verde formation is late Tertiary or very early Pleistocene in age, because he considered the lava, with which the Verde formation is associated, to be of late Tertiary age. Mahard (1949, p. 126) similarly postulated a late Pliocene or Pleistocene age for the Verde formation. This is based on Robinson's (1913) conclusions that all igneous activity associated with the San Francisco Mountain area falls within these time limits. However, as previously stated (page 555) Robinson's dating of the earliest lava was based on invalid evidence.

The lava, which is interbedded with the lakebeds of the Verde formation and which represents the youngest period of volcanism recognized in the area, may be correlative with Robinson's third-period basalt flows. Robinson (1913, p. 93–95) placed these lava flows in the Quaternary period (Pleistocene) because of the relationship of the lava to topography and the lack of appreciable erosion. He noted that the third-period flows followed youthful drainage courses (as shown by the lava in Sycamore Canyon) and flowed off the plateau edge, which shows little subsequent recession.

From studies of the glaciation of San Francisco Mountain, Sharp (1942) found evidence of Wisconsin glaciation which spread outwash later covered by third-period basalt flows of Robinson. This, of course, dates the basalt at base of the San Francisco Mountains, but it does not show that the Perkinsville and Verde lava flows are correlative with Robinson's third-period basalt flows. Maxson (1950, p. 14) favored a Pleistocene age for young lava that has flowed down tributary canyons to the Grand Canyon and cascaded down the walls of the Grand Canyon. However, it is not intended here to conclude that all lava flows which have flowed over canyon walls or on canyon floors are Pleistocene, but to indicate that they may be of the same general period of extrusion in this region.

The Verde formation accumulated after the major movement of the Verde fault which elevated and blocked out the Black Hills on the east, of which Woodchute Mountain is a part. The block faulting of the Black Hills may have started in late Tertiary time. The geologic history following the accumulation of the Verde formation includes the formation of three pediment levels (Anderson and Creasey, 1957) on the Verde formation, and the dissection of lakebeds of the Verde by erosion so that the present relief is now more than 1,000 feet in the area.

A tentative age assignment from late Tertiary (probably Pliocene) to Pleistocene is inferred.

Even though a precise age cannot be determined for the Verde formation, the relative age in relation to other formations within the quadrangle seems clear. The Verde is doubtless younger than the Hickey, and is correlated with the Perkinsville. This correlation is based on the belief that structural control was the cause of accumulation in both formations, and in relation to the present erosion cycle. Both the Verde and the Perkinsville accumulated after faulting of the Hickey, and uplift of the Black Hills mountain block. Volcanism during accumulation is a feature common to both formations. The lava flows of the Perkinsville which spread south over the rim of the plateau into the northern part of the Clarkdale quadrangle, are interpreted as contemporaneous with those intercalated in the Verde.

PERKINSVILLE FORMATION

DISTRIBUTION

The Perkinsville formation is named from the excellent exposures of gravel and intercalated lava flows on the north side of the Verde River near Perkinsville. This formation, for the most part, crops out in the northwest quarter of the Clarkdale quadrangle, although a broad but short belt extends southward along the western part to the foothills on the northwest side of Woodchute Mountain. The formation extends far to the west of the quadrangle in a sheetlike deposit, consisting of gravel intercalated with lava; it also extends northward in old surface depressions on the plateau.

A period of erosion followed deposition of the Hickey formation. Subsequent to this erosion, there was strong tectonic activity, which consisted chiefly of normal faulting, but also of mild tilting of the strata. The topography of structural troughs where the Perkinsville accumulated largely controlled the distribution of the formation.

THICKNESS AND STRATIGRAPHIC RELATIONSHIP

The thickness of the Perkinsville formation is variable, owing to the mode of accumulation. The thickest part within the Clarkdale quadrangle is between Black Mesa and the Orchard fault (coordinates N. 1,401,400; E. 411,750) where a drill hole cut through 200 feet of gravel before reaching the sandstone surface of the Supai below. The relief on formation outcrops in this vicinity is about 300 feet, indicating total thickness of about 500 feet. Exposures elsewhere in the quadrangle indicate thicknesses of 300 feet or more which seem to be normal.

The Perkinsville unconformably overlies all older formations in the Clarkdale quadrangle. The only younger deposits are overlying Quaternary terrace gravel beds along the Verde River at Perkinsville and perhaps vestiges of pediment gravel which could not be differentiated. Riverwash also is present but is not shown on the geologic map of the area.

LITHOLOGY

Sedimentary rocks.—The sedimentary rocks of the Perkinsville formation consist primarily of coarse to fine gravel, but sand, silt, and some limestone are also present. The gravel beds were derived chiefly from two source areas. Those north of the Verde River are from the rim sector of the plateau farther north. They consist of almost 60 percent basalt; but also contain sandstone from the Coconino, several rock types from the Supai formation, and limestone from the Kaibab, and chert. The Toroweap, which is friable for the most part, probably contributed materially to the matrix of the gravel. Gravel south of the Verde River was derived chiefly from the Woodchute Mountain block and the hills west of the southwestern part of the Clarkdale quadrangle, and was spread northward to the Verde River area. Basalt constitutes almost 60 percent of these gravel beds. They also contain rock types representative of all the Paleozoic and Tertiary formations in the southern part of the quadrangle. Cobbles and boulders of Precambrian rocks are abundant, in contrast to a lack of these types north of the Verde River. Most Precambrian rock types appear to have been derived from gravel deposits of the Hickey formation, rather than directly from Precambrian bedrock.

The gravel of the Perkinsville formation is increasingly coarse toward source areas; sand and silt deposits are abundant near the Verde River. Good exposures of sand and silt occur along the railroad east of the highway bridge near Perkinsville, and gravel beds are well exposed for several miles up Munds Draw south of the Verde River and in the northward-trending canyon on the north side of the river at Perkinsville. The gravel is fairly well bedded, rounded, and evenly sorted. Bedding is less evident to the north and to the south, away from the Verde River, for the gravel weathers into loose, unconsolidated accumulations on the tops and slopes of hills, masking the character and detail of depositional structures.

West and northwest of Black Mesa, along the west boundary of the Clarkdale quadrangle but south of the Verde River is a white limestone bed about 4–6 feet thick, which is interbedded with gravel. This limestone is thicker and more prominent west of the quadrangle limits than near Black Mesa. The limestone is more resistant to weathering than the gravel beds and therefore forms a weak ledge which interrupts the gentle sloping profile of the gravel hills. Fragments of detrital sediment are scattered throughout most of the limestone. The limestone breaks into heavy very irregular angular chunks.

Volcanic rocks.—The volcanic rocks of the Perkinsville formation except those on Black Mesa and two isolated exposures that form a thin band between gravel beds just south of the mesa came from north of the Clarkdale quadrangle. These flows were all extruded probably in the vicinity of Bill Williams Mountain which is 13 miles north of the Clarkdale quadrangle, and flowed south along topographic depressions and drainage courses to spill over the plateau rim. One point of entry into the Clarkdale area is where the Railroad fault splits into several branches, and forms a notch in the rim of the plateau. The other point of entry was in the northwest corner of the quadrangle where there appears to have been an erosional recess that funneled and guided the flows. The lava flowed over irregular topography in that part of the quadrangle, but farther south it flowed over an even surface of gravel. Here the lava flows fanned out and spread with a uniform thickness of about 50 feet.

The lava of the Perkinsville formation is normal olivine basalts—except for one flow which is andesite. The lava flows generally have a fresher appearance than do the Hickey and intermediate basalt in the quadrangle. They have relatively uniform texture, but differ in porosity. The tops of some flows are scoriaceous and amygdaloidal; the amygdules are composed chiefly of calcite. Lower parts of the lava flows are massive and dense. Nearly everywhere the basalt flows are grayish black to dark gray on fresh fracture. They weather into irregular, lumpy surfaces, and detached blocks form rounded surfaces. The residue forms a fine brown to gray soil.

The basalt flows of the Perkinsville formation are generally holocrystalline and porphyritic. Phenocrysts are chiefly olivine and show a glomeroporphyritic texture. The olivine crystals are changed, in part, to iddingsite. In a few places where they are scarce, they may have been altered to magnetite. A few phenocrysts of augite and plagioclase feldspar are present. The basalt shows, for the most part, a distinct intergranular texture where interstitial augite occurs as an aggregate of grains and not in large crystals. Some of the augite is slightly purple indicating a titaniferous variety. The plagioclase is calcic labradorite. The groundmass is composed of small feldspar laths (labradorite) containing augite, olivine, and magnetite grains.

Only one small occurrence of andesite has been noted. It is 1¼ miles north of the junction of the Drake and Perkinsville-Williams roads. The rock is light gray containing prominent, black, hornblende needles that are in strong contrast to the background. The rock is an olivine-hornblende andesite with a pilotaxitic texture—one in which the groundmass occurs as a felt of microlites. The hornblende is oxyhornblende, which has an extinction angle that reaches a maximum of 5°; part of the hornblende is replaced by magnetite. The olivine is microporphyritic, and some hypersthene is present. The microlite crystals of plagioclase feldspar are too small to be determined, but they are assumed to be composed of calcic andesine.

AGE AND CORRELATION

No fossils have been found in the Perkinsville formation, therefore, its precise age is not known. Tentatively, the Perkinsville is believed to be Pliocene (?) to Pleistocene (?) in age, and is correlated with the Verde. The reasons for this age assignment have been discussed in connection with the Verde formation which is believed to have accumulated contemporaneously.

QUATERNARY GRAVEL

DISTRIBUTION

Quaternary gravel covers a small part of the area within the Clarkdale quadrangle, and is confined to three widely separated localities. One of these is in the southwest corner where a large sheet of Quaternary gravel forms the floor of Chino Valley. Another gravel locality is in the valley of the Verde River. Here the gravel extends from a locality west of Clarkdale, through Clarkdale, and southeastward into the Mingus Mountain quadrangle, where it is very extensive. The third area in which the gravel occurs is on the southeast side of Black Mountain along the east border of the quadrangle. Here, also, the gravel is part of a thin, alluvial veneer that extends eastward from the quadrangle.

THICKNESS AND STRATIGRAPHIC RELATIONSHIP

The Quaternary gravel in all three localities described above occurs as an alluvial veneer on flat, but gently sloping, pediment surfaces. The gravel ranges in thickness from a few inches to as much as 30 feet, but commonly is less than 5 feet. The pediment surfaces are trenched by channels which increase in depth toward the Verde River. The best exposures of these gravel beds are in some of the channels that U. S. Highway 89A crosses between Clarkdale and Cottonwood. At these localities exposures of the carved surface of the Verde formation beneath the gravel show the remnant of a pediment.

The gravel unconformably overlies all older formations with which they come into contact. In turn, the gravel deposits along the Verde River have cut terraces and are covered by riverwash of Recent age, which has collected in the drainage systems that dissect them.

LITHOLOGY

The Quaternary deposits consist of fine to coarse gravel that is subrounded, but poorly sorted and occurs in a matrix of fine-grained sediment. The gravel beds are not consolidated, except locally where cemented by caliche. Most of the beds contain rock types of Precambrian and Paleozoic ages and also Tertiary basalt. Only the gravel southeast of Black Mountain is barren of Precambrian rock types. The Quaternary gravel in the southeastern part of the quadrangle has a high percentage of Precambrian fragments; whereas gravel in the southwest corner of the quadrangle has a high percentage of Paleozoic fragments. The gravel beds are dark reddish brown where composed of a high percentage of Precambrian fragments, but are gray where they consist chiefly of Paleozoic fragments.

RECENT ALLUVIAL RIVER TERRACES AND RIVERWASH

The terrace sediments were deposited by the Verde River upon its flood plain at a time when the river had attained a temporary base level and was broadening its valley by lateral planation. Subsequent rejuvenation of the river has resulted in cutting downward, sideward, headward, and removing the earlier sediments except for segments, now terraces, along the flanks of the valley.

Alluvial terraces and riverwash occur mostly in and along the channel of the Verde River from a point about 3 miles north of Clarkdale, south to where the river leaves the quadrangle. In the Packard Ranch area where the Verde River and Sycamore Creek join, terrace deposits and riverwash are present, but the terrace deposits are so small that they were included with the riverwash in mapping. Along the Verde River at Perkinsville, the riverwash and the terrace deposits are differentiated.

The alluvial river terraces are 5–10 feet high and border the wide wash of the Verde River bed. The deposits consist of a wide succession, and mixture, of unconsolidated clay, silt, sand, and gravel; finely stratified. Most of the sediment was derived from rocks of Paleozoic age, and, locally, much of the silt was derived from heterogeneous poorly sorted lakebeds of the Verde formation.

The thickness of the riverwash has not been determined, however, the deposits are not believed to be very thick. The riverwash contrasts strongly to the terrace deposits in that the wash is generally much coarser; it consists of fine to coarse gravel, which is poorly sorted. During floods large boulders are carried downstream, and as the floods ebb, finer sediment is deposited and fills in and around the boulders.

STRUCTURE

GENERAL FEATURES

The structural features of the Clarkdale quadrangle are here limited to the deformation recorded by the Paleozoic and Cenozoic rocks; not enough Precambrian rocks are exposed in the quadrangle to warrant a discussion of Precambrian structural features. In the adjoining Mingus Mountain quadrangle Precambrian features have been described in the comprehensive report by Anderson and Creasey (1957).

Although the physiographic boundary between the Colorado Plateaus province and the Basin and Range province is along the Mogollon Rim in this region (Fenneman, 1931), the area included in the Clarkdale quadrangle closely resembles a southern block of the Colorado Plateaus province in which erosion has cut deeper (to Precambrian rocks in Prescott area) than farther north, but where major uplift is essentially vertical along normal faults. The structural types in the quadrangle differ little if any from those farther north in the main plateau. Therefore, the Prescott-Jerome-Clarkdale area may be thought of as blocks raised higher than the more northerly plateau blocks, and stripped of much, and all in some areas, of Paleozoic and Mesozoic formations. These views concur with and are outlined in more detail by McKee (1951, p. 486).

DEFORMATION OF PALEOZOIC AND CENOZOIC ROCKS

No evidence of any orogenic disturbances in the Clarkdale quadrangle occurs from the close of Precambrian through the time in which the Kaibab limestone of Permian age was deposited. Statewide, as far as known, the local pre-Devonian disturbance southeast of the Pine-Payson area (McKee, 1951, p. 488) is the only occurrence during Paleozoic time. Minor epeirogenic disturbances are reflected by changes in lithologic character and unconformable relationship between the different Paleozoic formations. Similarly, the interval which separates the Kaibab (middle Permian) from the Moenkopi (Early and Middle (?) Triassic), recognized by Price (1949) a mile or so north of the quadrangle, is marked by a conspicuous unconformity that indicates epeirogenic disturbance only.

A general early period of deformation in the Clarkdale quadrangle is postulated to have taken place between the time when the Moenkopi was deposited and that when the Hickey formation accumulated. The sedimentary rocks in the quadrangle do not indicate whether there was more than one episode of disturbance, and if so, when such occurrence might have taken place during this broad interval of time (post-Lower Triassic-Pliocene?).

However, McKee (1951, p. 494) stated—

> the first extensive uplift in Arizona after the pre-Cambrian probably came during the Upper Triassic epoch. At that time the region south of the Colorado Plateau apparently was uplifted for the Shinarump of Late Triassic age was deposited as a broad sheet of gravel over much of northeastern Arizona and adjoining areas.

McKee (1951, p. 495–496) further cited evidence for Cretaceous uplift in southeastern, southern, and southwestern Arizona where many gravel and conglomerate beds were deposited during this epoch.

A second major period of deformation in the area, after the accumulation of the Hickey formation, but before the deposition of the Verde and Perkinsville formations also is postulated. This deformation was the strongest subsequent to Precambrian time. Strata were elevated, tilted, and faulted, and locally, faults pass into monoclinal folds.

Included with this late period of deformation are minor faults which displace the Verde and Perkinsville formations. These faults represent recurrent movement along previous fault planes.

EARLY PERIOD OF DEFORMATION

Deformation that affected the rocks of Paleozoic age only, in the Clarkdale quadrangle, resulted in gently tilting these rocks to the northeast and in displacement by faults. Uplift and tilting of the strata are indicated by the sedimentary rocks of the Hickey formation. These are stream gravel beds, left as relics of a former northeastward-trending drainage system. They rest on Precambrian in the southeast corner of the quadrangle and on upper Paleozoic rocks in the northeast corner. The gravel contains fragments of Precambrian and early Paleozoic rocks so could only have come from the southwest. Similar gravel has been reported in the area north of the Clarkdale quadrangle by Price (1950a) and in Oak Creek canyon by Mears (McKee, 1951, p. 498). Further evidence of pre-Hickey uplift and tilting lies in the fact that the volcanic rocks of the Hickey formation overlap successively older rocks from northeast to southwest. The Paleozoic rocks in this area also once extended from the present plateau area to the south and west, as pointed out by McKee (1951, p. 486). To what degree the strata were tilted can only be estimated because later deformation has further changed the structure. Probably the dip was a few degrees.

Faults, which displace Paleozoic rocks, but not the Hickey formation of late Tertiary age, are present in the foothills on the east and north sides of Woodchute Mountain. One such fault, which has a vertical displacement of about 150 feet, occurs at the intersection of coordinates N. 1,378,000 and E. 430,000. Another minor fault is present at the intersection of coordinates N. 1,375,000 and E. 439,000. Other small faults are also present in these areas. Movement on the Bessie fault (1 mile east of Jerome), which is related to the pre-Hickey period of deformation, was recognized by Anderson and Creasey (1957) in the Mingus Mountain quadrangle, but has not been recognized in the Clarkdale quadrangle.

The Coyote fault in the southwest corner of the Clarkdale quadrangle, which is the major marginal fault on the west side of Woodchute and Mingus Mountains, gives evidence of at least two movements. The first is related to the pre-Hickey; the second is related to the post-Hickey.

Before the accumulation of the Hickey formation the west block along the Coyote fault was uplifted relative to the east block so that the Martin limestone of Devonian age was brought into juxtaposition with the Redwall limestone of Mississippian age. The evidence of this is shown by the lava flows of the Hickey formation that rest on the Martin west of the fault and on the Redwall east of the fault. The vertical displacement for this movement near the south boundary of the quadrangle is about 500 feet. Southward in the Mingus Mountain quadrangle, the initial movement on the fault had a minimum vertical displacement of 800 feet, as determined by Anderson and Creasey (1957).

The second movement along the fault was reverse to the first; the west block moved down relative to the east block. The Hickey formation is displaced about 250 feet vertically at the south boundary of the quadrangle, and the displacement decreases to a few feet just north of where section *D-D'* crosses the fault as shown on plate 45.

In the northeast quarter of the Clarkdale quadrangle the age of five faults can be determined with respect to the Hickey formation. Four of these are older than the Hickey and one is younger. The faults which are older than the Hickey formation and therefore belong in the early period of deformation include both northeastward- and northwestward-trending structures. Some faults in this area occur where the Tertiary rocks are not present, so that no clear-cut evidence exists to determine whether they are older or younger than the Tertiary rocks.

Faults, in the central part of the quadrangle near Mormon Pocket and 2 miles north of Perkinsville, may or may not belong to the early structural period because the age cannot be determined with respect to the Hickey formation. However, east of where the Perkinsville-Williams road leaves the north edge of the quadrangle, and north of Sand Flat, the northwestward-trending faults are dominant, and some do not displace the Hickey formation. Here, they fan out and form a series of step faults, where the downthrow is on the same side of the several subparallel faults.

In the northwest quarter of the quadrangle a northwestward-trending fault is concealed beneath the volcanic rocks of the Perkinsville formation except for a short segment exposed in Bear Canyon. The stratigraphic throw on this fault in Bear Canyon is about 600 feet with the south side upthrown. In cross section *A-A'* (pl. 46) the fault shows a vertical displacement of 550 feet. Similarly, a cross section drawn from the most southerly outcrop of the Coconino about 1,000 feet west of the Railroad fault southwesterly into section 27 indicates that a fault displaces the Paleozoic rocks about 500 feet. This fault presumably occurred in the early period of deformation because the upthrown block was eroded level with the downthrown block before the accumulation of the Perkinsville. The formation accumulated soon after the late period of intense deformation so that in most places the formation accumulated in structural troughs and against fault scarps (Orchard fault).

Many faults in the northern part of the quadrangle strike N. 50° W. and N. 45° E., and where the dips could be measured are essentially vertical. The displacement ranges from 50 to 150 feet, but most commonly are about 50 feet. Well-defined joint systems, common to the northeastern part of the quadrangle, are similar in strike to the faults and are also essentially vertical. Price[8] who mapped an area of Sycamore Canyon about 8 miles long north of the Clarkdale quadrangle, noted that all the faults in that area also had a northeasterly or northwesterly trend. He stated that the northwestward-trending faults are most prominent, and dip at high angles between 70°–90°. He mentioned also that the northwesterly faults tended to produce grabens and were definitely older than the basalt on the plateau.

The time of the early period of deformation can only be inferred. McKee (1951, p. 494) stated that the first uplift, for which there is evidence in Arizona after the Paleozoic era, came during the Triassic period when the region south of the Colorado Plateau was uplifted to form the source for the Shinarump conglomerate of Late Triassic age which was deposited as a broad sheet of gravel throughout much of the northeastern part of the State. However, the sedimentary evidence, particularly in southern, southwestern, and western Arizona (McKee, 1951, p. 495–496), shows that, there, deformation was regional during Cretaceous time. Evidence cited by Babenroth and Strahler (1945, p. 149) indicates that the East Kaibab monocline and associated faulting in the Grand Canyon area clearly formed during Late Cretaceous to early Tertiary time (Laramide time). The early period of deformation in the Clarkdale quadrangle may have occurred at this time.

LATE PERIOD OF DEFORMATION

The strongest deformation in the area since the close of the Precambrian era occurred in the late period of deformation and the structural features are characterized chiefly by northward to slightly northwestward-trending normal faults. In general the only recognizable folds are very minor and gentle monoclines. However, locally they may be strong, where the strata did not yield to faults, at least above the basement rocks.

The late period of deformation resulted in block faulting and uplift. One block, however, relative to adjacent blocks, became the horst block of Woodchute and Mingus Mountains. On the north side of Woodchute Mountain, transverse faults occur between the marginal longitudinal faults.

Structural features occurring in this period of deformation produced the major topographic features and the present drainage system. This deformation also produced the basins in which the Perkinsville

[8] Price, W. E., Jr., op. cit.

and Verde formations accumulated but other factors also influenced the accumulation of these formations.

The late period of deformation probably took place in late Tertiary time, and is a part of the deformation that produced the Basin and Range province. The deformation occurred after the accumulation of the Hickey formation (Pliocene?) and before the deposition of the Perkinsville and Verde formations (Pliocene or Pleistocene).

FAULTS

Verde fault.—The Verde fault extends north-northwestward from Jerome, with a sinuous trace, to about a mile north of Perkinsville, where it ends against a transverse fault. Southward from Jerome, it extends southeastward along the east margin of the Black Hills, of which Mingus Mountain is a part. The Verde fault has the greatest vertical displacement of any fault in the Clarkdale quadrangle.

The dip of this fault plane differs along the strike and generally becomes steeper toward the north. South of Jerome, the fault has a dip as low as 45° E. At Jerome, the dip is about 60° E., and, about 1 mile north, the dip is 55° E. To the north, the dip of the fault plane becomes steeper, and 2½ miles north of Jerome, the dip is as much as 80° E.

Just north of where coordinate N. 1,380,000 intersects the Verde fault, a pod-shaped block is wedged along the fault plane. South of this block, the Verde fault characteristically and persistently dips to the east, but north of it, the Verde fault dips to the west. In the vicinity of this pod-shaped block is a point of minimum vertical displacement along the Verde fault, which had a scissorslike movement; the fault both north and south of the block is the normal type. An alternate interpretation is that two different faults intersect. Either interpretation is possible, but as there is no break in the trend of the faulting, the Verde fault is regarded as a single structure throughout. The northern segment dips 60°–80° W., but most commonly 75°–80° W. Small blocks (horses) of mappable size are wedged along the fault plane and are common of this segment.

About 2⅓ miles north of the south boundary of the Clarkdale quadrangle the Verde fault splits into two branches, although it is possible that the split may be due to the intersection of two different faults. The west branch is essentially vertical where it parts from the Verde fault. To the northwest, along the trace of this branch, the dip of the fault plane is 75°–80° W. This branch dies out about 4 miles northwest from where it parts from the Verde fault.

The stratigraphic throw on the Verde fault differs greatly along its length. In the vicinity of Jerome, it is about 1,500 feet; about 1¾ miles north of Jerome it is only 450 feet. Part of the difference is due to the transverse Haynes fault which joins the Verde fault just north of Jerome. The Haynes fault is a northward dipping normal fault having a stratigraphic throw of about 750 feet, which accounts for much of the northward decrease in the throw on the Verde fault. The remainder (300 feet) must take place between Jerome and a point 1¾ miles to the north. Where coordinate N. 1,378,000 intersects the main branch of the Verde fault, the throw is only 150 feet. The western branch of the Verde fault, 2⅓ miles north of Jerome, has a vertical displacement of 50-75 feet (west side down), whereas the main eastern branch has a vertical displacement of about 100 feet (east side down). This is near the hinge point of the Verde fault. North of the junction of the two branches in the vicinity of Bakers Pass tank, the throw on the Verde fault is more than 400 feet (west side down); it is about 445 feet where the Verde River crosses the fault at coordinate N. 1,410,000. Where the fault ends against a transverse fault, the vertical displacement is more than 400 feet.

South of the Verde River, an eastward-trending fault, which is younger than the Verde fault, but which formed during the same period of deformation, displaced the Verde fault a little more than 100 feet laterally.

Movement also occurred on the Verde fault during the Precambrian; it has been discussed at length by Anderson and Creasey (1957) who stated that the maximum vertical displacement of the Precambrian movement is about 1,000 feet; the maximum total net slip, which includes Precambrian and later displacement, is about 3,300 feet; its approximate bearing and plunge are N. 85° E. and 50° E.; and the rake is about 66° S. These calculations are based on the assumption that the intersection of a small mass of Deception rhyolite defines a point on the Verde fault that can be recognized on both the hanging wall and the footwall of the Verde fault.

Reverse drag on the hanging wall of the Verde fault north of Jerome indicates movement during the early period of deformation. However, this is local and may be due in part to adjustment of the fault block during, or following, the main faulting.

Anderson and Creasey (1957) reported recurrent movement along the Verde fault during or after the accumulation of the Verde formation. Where the recurrent movement was recognized, the Verde fault plane dips 35°–45° E., and 6–12 inches of crushed gravel lies against a slickensided wall of Precambrian rocks. It was not possible to determine the vertical displacement because of no reference planes for measuring it, and because deposition and faulting may have occurred simultaneously.

Fault complex north of Hopewell.—The most complexly faulted area in the Clarkdale quadrangle is east of the Verde fault and north of Hopewell, where many closely spaced faults have disturbed the strata. Because of the mapping scale, many faults in this area are not shown on plate 45. All are normal faults and are parallel to subparallel except a few which have sinuous traces. Most of them dip east, but a few dip west. Generally those that dip east have the greatest stratigraphic throw.

The net stratigraphic throw across this faulted area, is difficult to determine precisely, but the general approximation was calculated at several places. In each of three evenly spaced sections, drawn perpendicular to the general strike of the faults, the sum of the stratigraphic throws of the westward-dipping, normal faults was subtracted from the sum of the eastward-dipping faults to determine the net displacement. One cross section, drawn N. 65° E. through the intersection of coordinates N. 1,372,300 and E. 440,000, showed a net throw of about 650 feet with east side down. Another section north of the first and trending N. 75° E. through the intersection of coordinates N. 1,379,100 and E. 440,000, revealed a net throw of about 235 feet with the east side down. The third section, still farther north, in the vicinity of Bakers Pass, drawn N. 70° E. through the intersection of coordinates N. 1,385,500 and E. 440,000, indicated a net throw of about 250 feet with the west side down. The fact that to the south, the sum of the throws on the eastward-dipping faults is greater than the westward-dipping faults, and that to the north near Bakers Pass the reverse is true, seems significant when compared with the movement on the Verde fault in this area. Nearby is the place where the Verde fault plane changes in dip from east, through the vertical, to west. The net stratigraphic throws of the fault complex north of Hopewell indicate a hinge-type movement like that on the Verde fault—down on the west, north of the hinge, and down on the east, south of the hinge.

Bessie fault and other small faults.—A few faults in the Clarkdale quadrangle displace the Verde formation. Largest of these is the Bessie fault, which is exposed in the quadrangle for 1 mile. To the north, it becomes obscured by the gravel facies of the Verde formation, and to the south, it is exposed in the Mingus Mountain quadrangle for a short distance before it dies out. The Bessie fault in the Mingus Mountain quadrangle (Anderson and Creasey, 1957) seems to have had three periods of movement, but in the Clarkdale quadrangle only two periods can be ascertained. During the first period the Redwall limestone was moved down on the east into juxtaposition with the Precambrian rocks. This displacement was about 550 feet. The second movement was during or after the accumulation of the gravel facies of the Verde formation and displaced these gravels about 50 feet. The Bessie fault is essentially vertical where

U. S. Highway 89A crosses and northward it flattens until at a point one-half mile north of the highway it dips 55° E.

The Bessie fault and other small faults which displace the Verde formation are present in the vicinity of Hopewell. East of and parallel to the Bessie fault, and east of Jerome in Deception Gulch, post-Verde faulting is well exposed in the roadcut of U. S. Highway 89A.

Coyote fault.—The Woodchute-Mingus Mountain block in the southwest corner of the quadrangle is bounded on the west by the Coyote fault, which also had two periods of movement. The earlier movement occurred before the accumulation of the Hickey formation; the lava of this formation rests on Precambrian rocks west of the fault because the Paleozoic rocks had been eroded after the west block was uplifted during the early deformation. (See page 569). Later movement on the Coyote fault occurred after the accumulation of the Hickey formation, and is contemporaneous with the major movement on the Verde fault. Displacement on these two faults resulted in the elevation of the Woodchute-Mingus Mountain block.

The Coyote fault which shows post-Hickey movement has a strike length of about 1 mile in the Clarkdale quadrangle. The north end of this fault is approximately where cross section *D–D′* (pl. 1) intersects the trace of the fault. North of this point the Hickey formation is not dislocated. Southward, the Coyote fault extends into the Mingus Mountain quadrangle where it is referred to by Anderson and Creasey (1957) as a fault zone; although it is poorly exposed as much as 15 miles south of the Clarkdale quadrangle, segments are recognized. The lava, which overlaps the fault, north of cross section *D–D′*, doubtless is the same lava cut by the fault along the south boundary of the quadrangle. The vertical displacement of the Coyote fault can be determined from the base of the lava on both sides of the fault. It ranges from a knife edge where cross section *D–D′* intersects the fault to nearly 250 feet at the south boundary of the Clarkdale quadrangle. In the Mingus Mountain quadrangle, Anderson and Creasey stated that the maximum vertical displacement is about 1,200 feet.

Orchard fault.—The Orchard fault, which is several miles east of the Coyote fault, extends northward along coordinate E. 420,000 from the west flank of Woodchute Mountain to a point about 2 miles north of the Verde River, where it is concealed by the Perkinsville formation. It is a normal fault and dips to the west. The fault is well exposed, except where the gravel of the Perkinsville formation was deposited against and overlapped the fault scarp, and, even in these localities where erosion locally has removed the gravel, traces of the fault are revealed.

On the west flank of Woodchute Mountain, the dip of the fault plane ranges from 85° W. to vertical. Here, the vertical displacement is about 250 feet. From the point where the Haynes fault offsets the Orchard fault, northward to Perkinsville, the dip of the fault decreases to 70°–80° W. The vertical displacement is difficult to determine along the fault between these two points because the gravel of the Perkinsville formation conceals the Paleozoic rocks in the downthrown block. Therefore, only the approximate vertical displacement can be given; it is about 600 feet where coordinate N. 1,400,000 intersects the fault. Just north of Perkinsville, the fault plane dips 60°–65° W., the lowest recorded along its trace. In this area, the minimum vertical displacement is probably about 250 feet, although it could be as much as 550 feet.

Like the Verde formation, the Perkinsville is in fault contact with the Paleozoic rocks in places where recurrent movements occurred along preexisting faults (Orchard fault). The precise displacement cannot be determined, but it is believed that the movement was not much more than 50 feet. The evidence for this minor adjustment includes the outcrop pattern, and faceted and minutely striated pebbles of the gravel along the fault plane. These zones of faceted pebbles are no more than an inch or so wide.

The Orchard fault is offset more than 500 feet laterally by the transverse Haynes fault, and also by a small one about ¾ mile to the south. However, some faults parallel and subparallel to the Haynes fault are cut by the Orchard.

Haynes fault.—The Haynes fault extends from the Verde fault at Jerome, northwestward across the north slope of Woodchute Mountain for about 4¾ miles, seemingly where it dies out. It is a normal transverse fault that dips about 70°–80° N. The relative displacement of the Haynes fault is unique, because the other transverse faults between the Verde and Orchard faults are downthrown on the south.

In the vicinity of Jerome the Haynes fault becomes compound, and the stratigraphic throw of this compound zone is about 750 feet. About 1 mile west along the fault the stratigraphic throw is about 100 feet less. Farther to the west, but east of the Orchard fault, only the vertical displacement, about 500 feet, can be measured by using the base of the Hickey formation. This may not be significant because the base of this formation is irregular in this area. West of the Orchard fault, the approximate vertical displacement of the base of the Hickey formation is 150 feet.

As the vertical displacement decreases to the west along the Haynes fault, it is possible that there was rotation along a hinge west of the Orchard fault and that west of this hypothetical hinge, the Haynes continues as a southward-dipping fault. A fault with the south side downthrown on the projection of the Haynes was not connected with the Haynes fault on the map because such connection could not be found in the field and because the relative movement of each is reversed.

Railroad fault.—The Railroad fault extends from the Verde River, northwestward along the west side of Packard Mesa, to the boundary of the Clarkdale quadrangle and beyond. At the southwest corner of the Packard Mesa the fault bifurcates. One branch swings eastward to an almost due east course and passes near the juncture of Sycamore Creek and the Verde River and extends beneath the Verde formation. The other branch continues southward across the Verde River as far as S O B Canyon, where it seemingly dies out. Of these two branches, the one to the east has the greater stratigraphic throw.

On the west side of Packard Mesa in the vicinity of coordinate N. 1,426,000, the Railroad fault bifurcates, and still farther north between Henderson Flat and the quadrangle boundary, the fault has at least four prominent branches. Only the easternmost branch is exposed along its full strike length, and details of the western branches are concealed by the Perkinsville formation.

The Railroad fault is a normal type with the west side downthrown. About 2¼ miles north of the Verde River the fault plane dips 75° W. From here to the north it was not possible to measure the dip because of poor exposures, but the relationship of the trace of the fault to the topography indicates steep or vertical dips to the west. At the southwest corner of Packard Mesa near coordinate N. 1,410,000 the fault dips 80° W. South of this point, the branch which swings to the east becomes slightly steeper on the curve and dips 85° SW. The other branch, which continues to the south, remains at a constant dip of 80° W.

The stratigraphic throw on the Railroad and subordinate faults is variable; where coordinate N. 1,410,000 intersects the fault, it is about 800 feet. South of this point, where the branch veers to the east it is 600 feet. On the branch that continues to the south it is about 150 feet. To the north where coordinate N. 1,426,000 intersects the fault, a branch trends westward. The throw on the east branch is about 250 feet, and on the west branch it is about 500 feet. The total throw on both branches is essentially the same as it is to the south, where there was a single plane of movement. Northwest of Henderson Flat, where cross section *A–A′* (pl. 45) intersects the fault zone, the fault has four branches, three of which are downthrown on the west, and the westernmost branch is downthrown on the east. The net stratigraphic throw across this group of faults is the west side down about 450 feet. This figure was obtained by subtracting the stratigraphic throw of the westernmost upthrown block from the total throw of the downthrown blocks of the three eastern branches. The data show that the Railroad fault decreased in throw about 350 feet to the north as it approached the Colorado Plateau.

Other faults.—Other faults of the late deformation that merit consideration are for the most part along the west margin of the quadrangle.

The many faults between Black Mesa and coordinate N. 1,380,000 are all the normal type. These faults trend about the same as the others in the quadrangle. Only three have continuity along the strike and have a stratigraphic throw of 150 feet or greater. One trends east-northeastward along the Chino-Perkinsville road, south of coordinate N. 1,390,000. This fault is downthrown on the south and has a stratigraphich throw of about 300 feet. It displaces another moderately large fault that trends northwestward near the quadrangle boundary. The latter fault splits into two branches where it curves sharply to the west. The blocks form a steplike arrangement across these branches and are successively downthrown to the northwest. The only other large fault in this area is the eastward-trending fault at the south end of Black Mesa, which dips 80° S. and has a stratigraphic throw of about 400 feet. This fault is probably the extension of the eastward-trending fault, south of the Verde River in the central part of the quadrangle, but this interpretation cannot be proved, because of cover by the Perkinsville formation.

FOLDS

A few folds in the Clarkdale quadrangle consist of local steepening of the dip and indicate drag in areas of strong faulting. Minor undulations or gentle warps are present in places. Nearly everywhere, except in the vicinity of the plateau, the pre-Perkinsville and pre-Verde strata have a homoclinal dip to the northeast, and probably average between 6° and 10°. These strata were tilted, in part, during the early period of deformation; but most of the tilting resulted from the late period of deformation, as shown by the fact that the Hickey formation dips to the northeast also. Furthermore, restoration of fault blocks to their position in pre-Hickey time will not produce an acceptable reconstruction of the geologic conditions that existed at the time of deposition of this formation. Some warping and tilting must have taken place during the late period of deformation.

The most pronounced fold in the quadrangle is a monocline, which is along the Verde River, about 1 mile south of its junction with Sycamore Creek (coordinates N. 1,400,000; E. 453,000). Here, the beds of the Supai formation strike about N. 10° E. and dip as much as 60° E. The lava which flowed down Sycamore Canyon rests against the flank of this fold. Overlapping both the lava and the Supai formation are lakebeds of the Verde formation with a normal depositional contact. As a result of sagging and compaction during or shortly after their deposition on the steep hill slope of the Supai formation, the lakebeds dip about 15° E. away from the steeply inclined beds of the Supai. Jenkins (1923, p. 70) reported this structure in his report on the lakebeds which he named the Verde formation and concluded that the lava and the lakebeds were faulted against the Supai. Later Mahard (1949, p. 122) visited this locality and reported that the lakebeds and lava flows of the Verde are not in fault relationship with the Supai formation. The Verde formation doubtless rests on the Supai with a normal depositional contact.

This monocline extends to the south beneath the Verde formation and is exposed again in S O B Canyon where lava of the Hickey formation, which rests on the Supai, is also involved in the flexure. The lava of the Hickey dips steeply to the east there. Mahard (1949) believed that these lava deposits were part of a post-Hickey flow which flowed down S O B Canyon before the deposition of the Verde formation. However, the lava flows were tilted by folding (pre-Verde flexure) and are not initial flow attitudes.

PHYSIOGRAPHY

Most of the present topographic features have resulted from the latest period of deformation, and subsequent erosion has carved the faulted and tilted bedrock to form the present surface. The dominant physiographic features in the quadrangle include Woodchute Mountain, which is the northern part of a fault block; the Colorado Plateau, which is bounded on the south by a precipitous cliff (Mogollon Rim), that overlooks the lowland to the south; eroded fault scarps and small cuestalike ridges between Woodchute Mountain and the plateau; and pediments on the flanks of Woodchute and Black Mountains.

The drainage of the quadrangle is external. Although the drainage of the main part of the plateau north of the quadrangle is northward, many youthful streams have eroded deep through its margin (Mogollon Rim) and drain south in the quadrangle.

Woodchute Mountain.—Woodchute Mountain along the south-central part of the quadrangle is the north end of a short mountain range called the Black Hills—an elongated fault block about 20 miles long and 6 to 12 miles wide. The Black Hills are bound on the west by the Coyote fault and on the east by the Verde fault.

The eastern profile of Woodchute Mountain is broken by a pronounced escarpment caused by the Verde fault. It separates the higher and much steeper cliffs of Woodchute Mountain from the lower long, smooth, rounded fingerlike ridges that extend out to form the foothills. The fault scarp is thoroughly dissected so that the only topographic expression of its position is an abrupt change in slope. At present the valley of the Verde River is being exhumed so that most of the long, uniformly sloping foothills are composed of coarse gravel of the Verde formation.

Woodchute Mountain is steep and dissected on the north and west. The north side has long irregularly trending and sloping spurs separated by youthful canyons, the courses of which are influenced by the structure.

The summit of Woodchute Mountain is relatively flat and mesalike. It is controlled largely by the flat attitude of the lava flows that cap it. Woodchute Mountain is at an altitude of 7,834 feet which is about the same altitude as Mingus Mountain to the south.

The valley of the Verde River bounds Woodchute Mountain on the east and the relief between the two is about 4,500 feet. Lonesome Valley bounds the mountain on the west, and the relief between the center of the valley and the top of the mountain is about 3,000 feet.

Colorado Plateau.—The dominant physiographic feature in the northern part of the quadrangle is the south edge of the Colorado Plateau. Here, the Mogollon Rim, the precipitous cliff that marks the south edge of the plateau, rises abruptly from the valley of the Verde River. Many steep-sided, narrow canyons of which Lonesome Pocket and Sycamore Canyon are examples have been carved into the plateau and along its borders. Dissection has resulted in isolating some areas from the main plateau mass to form flat-topped buttes and mesas. Black Mountain is an example.

The plateau is more than 6,400 feet in altitude and has a relief of about 1,800 feet. The resistant sandstone of the upper member of the Supai formation and the monolithic Coconino sandstone comprise two-thirds of the height of the escarpment. The other third is cliff-forming units of Kaibab limestone and basalt flows. About 150 feet of the Toroweap formation forms a slope.

Area between Woodchute Mountain and Colorado Plateau.—The surface of the area between the Colorado Plateau and Woodchute Mountain, although dissected, is gently inclined toward the Verde River on each side. The altitude of this surface ranges from about 5,000 at the base of the higher land masses to about 4,300 feet near the Verde River. Many eroded fault scarps interrupt this area of low relief and add a general cuestalike appearance to the topography. Also, resistant units in the Supai formation, and differential weathering between the base of the Supai and the underlying Redwall limestone, add to this cuestalike appearance.

In the area of the Perkinsville formation, lava and gravel have covered earlier irregular topography and reduced the relief to a relatively even surface. Gravel fanned out towards the Verde River from the Woodchute Mountain block and from the plateau scarp, during its formation, and filled in structural troughs and depressions.

The lava flowed over the Mogollon Rim into the valley of the Verde River, covering lower gravel, and these lava flows in turn were covered by more gravel.

Pediments.—Pediments, which form relatively smooth slopes, are limited to the bases of certain parts of Woodchute and Black Mountains. In the valley of the Verde River a low level pediment surface was carved on the Verde formation in the vicinity of Clarkdale and south beyond the Clarkdale quadrangle boundary. Part of a pediment surface which was cut on both the Verde and the Supai formations extends from the southeast side of Black Mountain beyond the limits of this quadrangle. The pediment surfaces dip only a few degrees and are mantled with a veneer of gravel. Planed bedrock surfaces below the gravel veneer are clearly exposed in the valley of the Verde River. The pediments have been trenched subsequent to their formation by a dendritic arrangement of gulches and arroyos and the flat-topped interstream remnants are covered with a veneer of red gravel which ranges in thickness from a few inches to perhaps 30 feet. The depth of dissection increases progressively toward the master streams.

In the southwest corner of the Clarkdale quadrangle on the west side of Woodchute Mountain is part of the vast surficial deposit of gravel which extends far to the west in Lonesome Valley and forms a veneer on a pediment surface.

Drainage.—The drainage of the Clarkdale quadrangle is dendritic. The master through-flowing stream is the Verde River which enters the west-central part of the quadrangle and follows a meandering course southeastward. The chief tributary of the Verde River in the quadrangle is Sycamore Creek. All the drainage lines in the quadrangle extend to the Verde River, except for some in the southwest corner of the quadrangle that reach the Verde River by a circuitous route—through Granite Creek in the Prescott and Paulden quadrangles.

The Verde River is perennial and locally braided. Sycamore Creek is perennial below Summers Spring, 4 miles above its mouth. All other streams in the quadrangle are ephemeral, and flow only when water is supplied by local storms. At such times the flow rarely lasts for more than a few hours at any one locality.

GEOLOGIC HISTORY

The geologic history of the Clarkdale quadrangle is moderately clear from the present back to the time when a prolonged interval of erosion had reduced to flatness the surface of the Precambrian rocks. Upon the surface which was cut across the structural planes of the Precambrian rocks, sediments apparently accumulated from nearby Precambrian hills during early Paleozoic time and filled in the lower parts of the surface. These sediments, which are poorly sorted and variable in composition, indicate a mixture of detrital fragments which had little transportation. They probably represent, to a large extent, regolith reworked by the wave action of an advancing sea of Cambrian(?) age which spread over the area from the north and northwest.

If it is assumed that the basal Paleozoic rocks are the Tapeats sandstone of Cambrian age, then this area of deposition represents the southeast margin of the shelf that bordered the Cordilleran geosyncline. The seas which at the beginning of Cambrian time covered only the extreme western part of Arizona, transgressed southeastward as the basin was depressed. The transgression of the sea seemingly extended farthest south into the Jerome area during deposition of the Tapeats sandstone(?) as shown in the eastern part of the Grand Canyon. Whether the Bright Angel shale and the Mauv limestone of Cambrian age were ever deposited in the Jerome area is not known, although both are present about 47 miles west-northwest of Jerome near Walnut Creek Ranger Station in the Camp Wood quadrangle. After regression of the Cambrian sea, the Jerome area was a site either of erosion or of nondeposition, because there is no record of Ordovician nor Silurian deposits in central Arizona. Although the relationship between the Tapeats sandstone(?) and the overlying Martin limestone of Devonian age appears to be gradational in the Clarkdale quadrangle, Krieger[9] has found a possible unconformity between the Tapeats(?) and the Martin limestone, which suggests, perhaps, the hiatus or unrepresented interval of time.

The Martin limestone was deposited in a Late Devonian sea which, in a general way, followed the trend of the Cambrian(?) transgression from the northwest. The first deposition of the Martin must have been in waters agitated by currents, because the basal unit is a clastic, crossbedded limestone. The Devonian sea deposited this basal unit concordantly on the Cambrian(?) sandstone. Although the bulk of the Martin is dolomitic limestone, the abundance and distribution of sand and clay impurities clearly indicate that a source of terriginous material was present throughout the accumulation of the formation. Local beds of limy sandstone accumulated where, for a time, detrital impurities predominated. Coral reefs in the upper part of the Martin indicate that locally, at least, the sea was relatively shallow.

When the area was later inundated by the early Mississippian sea, which encroached from the north and northwest, the uppermost strata of the Martin were reworked and redistributed to form thin, wavy, conglomeratic beds of sand. As the sea advanced, the bluish-gray

[1] Krieger, M. H., op. cit.

oolitic limestone of the lower member of the Redwall limestone was deposited in it. As deposition continued beds of light-gray crinoidal limestone were laid down. After deposition of the crinoidal limestone, more calcareous oolites were laid down. Toward the close of early Mississippian time, the sea withdrew from the area toward the geosyncline to the northwest. Erosion of Redwall limestone surface followed retreat of the sea, and an irregular surface with a relief of 30 feet or so was carved.

The Clarkdale area, in what probably was late Pennsylvanian time, seemingly was a mud flat, marginal to a marine basin, the waters of which had transgressed from the northwest to connect with marine waters from the southeast. In the low areas, on the eroded surface of the Redwall, limestone conglomerate and chert breccia collected. A few thin beds of limestone in the lower part of the redbeds of the Supai formation may represent extended tongues of deposits formed in these seas.

Permian deposition was a continuation of the Pennsylvanian, as shown by the redbeds of the Supai which accumulated to a great thickness. These sediments, perhaps in part, represent a mud flat environment marginal to a marine basin, and in part, deltaic deposits brought in by a drainage system from the north. The upper part of the Supai interfingers with the overlying Coconino sandstone. Because there is a vertical alternation between these two formations, it is assumed that sedimentation was continuous throughout much of the area, during the changes from environments of deposition of Supai time to those of the Coconino time.

Deposition of the sand of the Coconino began at the close of Supai sedimentation when the red silts and sands were covered by eolian sand transported into the area from the north. The sand was deposited as large dunes, and the area became a desert, which stretched far to the north and probably to the south. Thus, the climatic changes from the time of deposition of the Supai to that of the Coconino was perhaps one of gradual change toward aridity.

An encroachment from the northwest of the sea, in which sediments were deposited during Toroweap time, caused the termination of Coconino deposition. This is indicated by the remarkably level contact, where the uppermost beds of the Coconino were beveled and the sands reworked while still unconsolidated, for there is no surface of relief at the top of the Coconino sandstone. The lithology of the Toroweap indicates a shallow oscillating sea. The arid to semiarid climate represented by the Coconino persisted throughout Toroweap time. The average grain size of the sediments in the Clarkdale quadrangle is fine, and it is assumed that the surrounding topography was flat and featureless. The Toroweap sea regressed to the northwest after the Toroweap had been deposited. During the hiatus that followed channels were eroded locally but no great time elapsed as indicated by the minor amount of erosion accomplished and by faunal evidence from the Toroweap and the overlying Kaibab limestone.

Following this brief erosion period, the Kaibab sea spread into the Clarkdale quadrangle and deposited the Kaibab limestone. In the quadrangle, these sediments, in general, consist of alternate layers that range from sandy limestone to limy sandstone, but westward they grade into beds of limestone, and eastward into pure sandstone of the shore facies.

From the end of Kaibab deposition in middle Permian time, when the sea withdrew toward the west, there is no evidence of sedimentary deposition in the Clarkdale quadrangle until Late Tertiary time. However, the presence of Lower Triassic rocks to the north allows reasonable inference to be made concerning the gap in the geologic history of the area. The Moenkopi formation of Early Triassic age rests unconformably on the Kaibab limestone in Sycamore Canyon, about 2 or 3 miles northeast of the quadrangle. The time represented by the unconformity was sufficiently long to allow the consolidation of sediments deposited during Kaibab time which are represented in the Triassic conglomerate beds and, as indicated by fossils, was equal to the duration between middle Permian (Guadalupian) and early part of Early Triassic (pre-Meekoceras). The Moenkopi is a continental red bed deposit in the Sycamore Canyon area, which was formed on a vast flood plain covered with streams, lake basins, and playas. According to McKee (1938) the Moenkopi occupies a low, flat area that bordered an Early Triassic seaway on the northwest. Because there is an average thickness of 250 feet of these sediments in Sycamore Canyon, the top being erosional, they most likely once extended farther south and covered the Clarkdale quadrangle. It is probable that the Shinarump conglomerate and Chinle formation of Triassic age extended throughout the Clarkdale area too.

If the clastic sediments of the Shinarump conglomerate and Chinle formation were ever deposited over the Clarkdale quadrangle, it is then necessary to postulate that a region somewhere to the south and southwest was uplifted (Late Triassic uplift) before or during that time of deposition to provide the source material.

Assuming that the Shinarump and Chinle were deposited in the area, it can be inferred that an uplift perhaps in Cretaceous or early Tertiary time then followed, because the strata were tilted, faulted, and eroded before deposition of the Hickey (Pliocene ?). McKee (1951, p. 495–496) has pointed out the evidence for uplift during Cretaceous time and Babenroth and Strahler (1945) have shown that the Kaibab monoclinal flexure occurred during early Tertiary time.

There is no evidence in the quadrangle that can be used for dating the crustal disturbances which occurred between the Moenkopi and Hickey times of deposition. The disturbance could be Late Triassic, Early Cretaceous, or early Tertiary, or a combination of these times.

Gently dipping sedimentary rocks were truncated by erosion so that the oldest Paleozoic rocks were exposed to the southwest and progressively younger strata exposed to the northeast. Upon this surface the drainage during Pliocene(?) time cut deep channels leading northward. The stream gravel which accumulated in these channels forms part of the Hickey formation, and reflects a source in the direction of Prescott. Some of these gravel beds were carried in their channels far northward in the area that is now the Colorado Plateau. At the same time volcanism in the form of widespread eruptions of basalt and, locally, of andesite, occurred mostly from local vents or fissures. The basalt, in the Hickey formation, overlapped successively younger rocks ranging in age from Precambrian in the southwestern part of the Clarkdale quadrangle, to Permian in the northeastern part of the quadrangle. An extremely thick sequence of flows on Woodchute Mountain indicates that it was a site of extrusion, probably fissure eruptions. Vents of Bill Williams Mountain at Williams, Ariz., of the San Francisco Mountain at Flagstaff, and others, likewise contributed lava flows that accumulated in the plateau part of the Clarkdale quadrangle.

After the accumulation of the Hickey formation the area of the Clarkdale quadrangle was subjected to a period of strong deformation which tilted and block-faulted the rocks. These structural features are referred to as the late period of deformation in the quadrangle and occurred probably during late Tertiary time. During this crustal disturbance, the Woodchute-Mingus Mountain block was elevated along boundary faults; most of the normal faults which extend north and northwest across the area were formed; and the plateau was uplifted relative to the Basin and Range province to the south and southwest. It was from this time of deformation that the present southward flowing drainage originated.

This late period of deformation in the Clarkdale area initiated a vigorous cycle of erosion. Much of the Hickey formation was eroded, and the escarpment of the plateau was carved. While erosion was cutting away the land, a brief and localized spurt of volcanism took place. Basalt, intermediate in age between Hickey and Perkinsville or Verde rock, was extruded on the west side of Black Mountain. This basalt rests on the middle and upper members of the Supai formation, whereas basalt flows of the Hickey formation rest on Coconino sandstone. This difference in age is a means of determining the amount of erosion that took place between the Hickey time of eruptions and that of the intermediate basalt. Furthermore, the intermediate basalt is present on both sides of the present Sycamore Canyon, which indicates that the floor of Sycamore Canyon was not appreciably lower than the base of the lava at the time that they were extruded.

As erosion progressed during what probably was Pliocene or Pleistocene time, gravel deposits of the Verde formation started to accumulate along the east side of the horst block of the Woodchute and Mingus Mountains, and at the same time gravel of the Perkinsville formation was accumulating between Woodchute Mountain and the plateau to the north. While this deposition was taking place, Sycamore Creek was actively cutting its canyon. During this episode, volcanic activity was renewed. Lava flowed across and dammed the south end of the valley of the Verde River. This barrier impounded a lake in which the lakebeds of the Verde were deposited. Lava also flowed off the plateau in the northern part of the Clarkdale quadrangle and spread as a thin sheet over the lower gravel of the Perkinsville, and some lava flowed down Sycamore Canyon. Gravel continued to accumulate along the east side of the horst block of the Woodchute and Mingus Mountains, and interfingered with the lakebeds; whereas between Woodchute Mountain and the plateau, the gravel of the Perkinsville continued to accumulate.

After the deposition of the Verde and Perkinsville formations, the lava barrier at the south end of the valley of the Verde River presumably was breached, lowering the base level of the drainage. This rejuvenated the streams and caused the meanders of the Verde River to be incised and superposed upon the underlying structure. Accelerated stream erosion also caused deposits of the Verde formation in Sycamore Canyon to be removed.

Some time after, or during the accumulation of the Perkinsville and Verde formations, there was a minor recurrent movement along some of the faults which displaced strata of these formations.

Changes in base level have resulted in the formation of pediment surfaces at different levels in the valley of the Verde River, and terraces have been formed along the Verde River. Although the drainage which traverses the Clarkdale area contains wash material, there is no extensive deposition at the present time.

MINERAL RESOURCES

The mineral resources of the Clarkdale quadrangle include copper and some associated gold and silver, building stone, and limestone. Although all these, except the limestone, have been produced commercially, the only product of considerable value has been the copper.

The copper deposits are all in the southern part of the quadrangle and center around Jerome; they are chiefly of two types: massive sulfide replacement bodies of Precambrian age, and Tertiary lava and gravel which have been impregnated with supergene chrysocolla. The massive sulfide deposits consist of an aggregate of sulfide minerals, such as pyrite, chalcopyrite, sphalerite, and galena; gangue minerals are scarce or absent. The ore deposits of the Jerome area have been studied recently in great detail by Anderson and Creasey (1957).

The Redwall, which is a relatively pure limestone, has been exploited as a source of lime in a few places. It was quarried from small pits, and presumably used as a flux. Locally some limestone has been quarried for road aggregate and railroad ballast.

Sandstone is the only resource that is being actively exploited at present in the quadrangle. Many small quarry sites dot the landscape in the northern part of the quadrangle, near the Mogollon Rim where the sandstone of the upper member of the Supai and the Coconino crops out. Probably the greatest quarrying activity in the quadrangle is near Sand Flat east of the Perkinsville-Williams road in Coconino County, where the Coconino sandstone is quarried. Red sandstone of the upper member of the Supai is quarried between Black Hills tank and Rafael tank, north of coordinate N. 1, 430,000 and east of Perkinsville-Williams road. A number of quarries are in the northwest corner of the quadrangle, near where coordinate E. 410,000 intersects the Yavapai-Coconino County line. Here an inlier of Coconino sandstone and Supai formation crops out, and both formations are quarried.

The sandstone beds of the upper member of the Supai and of the Coconino are strongly crossbedded on a large scale and split readily along the crossbedding planes, so that large flat, smooth sheets and slabs of sandstone can be obtained with little effort. These beds range in thickness from 1 to 8 inches or more and have uniform texture. Sand grains range from medium to fine grained. Different types of cement or bond of the grains produces a number of colors. Although the Coconino sandstone is buff, in general, it locally ranges between grayish orange and grayish yellow because of slight differences in the proportion of its iron oxide and (or) siliceous bond. Likewise, the generally reddish orange of the Supai has a cement of calcium carbonate and a matrix of clay, which differs in proportion, so that in some places the rocks are pale red, and in others are lavender or moderate red.

Most of the quarry sites are located where individual crossbeds are thin and easy to split, because thin flagstone commands a higher market price than thick blocks. In quarrying, an operator may have to cut through a thick bed to find thin-bedded rock, but, generally he selects a site where the rock is chiefly thin bedded, usually in 1- to 3-inch beds. Subordinate to the thin bedded and easy splitting qualities of the rock, the location of the quarry is next governed by the color of the rock. The most popular colors are red, lavender, and yellow. Buff to grayish-orange rock is very commonplace and not in great demand.

The sandstone quarries are open pits, of which many are worked into a hillside. The overburden or waste is cleared away by hand, or, in a few places, by bulldozers. Some drilling and blasting are done: a row of holes is drilled 6–8 feet back from the face, and blasting charges are put in the holes; but this method is wasteful. For lifting or splitting the beds, wedges usually are driven into notches.

The stone is quarried chiefly for flagstone which may be as much as 2 inches thick with a minimum of 18 inches on a side. Most of the flagstone is in slabs about 4–6 feet square. Stone that is more than 2 inches thick is quarried for building purposes. At the quarries the stone is neither cut nor prepared in any way for the market. It is sold in the dimension that it was quarried, the size only determining whether it is flagstone or "cutting stone." Flagstone is used chiefly for exterior steps, sidewalks, and platforms. The large-dimension stones are cut by stone dealers into strips 2–4 inches thick and about 3½ inches wide, for use as exterior decoration or veneers by the building industry, and the very large pieces are cut into building blocks.

The production of stone in the Clarkdale quadrangle is estimated at 50–100 tons per month, but at times operations halt during the winter. Individual producers commonly quarry out a truckload and sell it at Drake, Ariz., where there is a cutting machine and loading dock. The stone is shipped from there to the West Coast. At the quarry, flagstone sells at $12 per ton, and cutting stone at about $6–$8 per ton. The largest producing quarries are northwest of the Clarkdale quadrangle from where the sandstone is shipped to Ashfork.

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