Areal Geology of the Placerville Quadrangle San Miguel County Colorado

GEOLOGICAL SURVEY BULLETIN 1072-E

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By A. L. BUSH, C. S. BROMFIELD, *and* C. T. PIERSON

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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AREAL GEOLOGY OF THE PLACERVILLE QUADRANGLE, SAN MIGUEL COUNTY, COLORADO

By A. L. Bush, C. S. Bromfield, and C. T. Pierson

ABSTRACT

The Placerville quadrangle includes an area of about 59 square miles in eastern San Miguel County in southwestern Colorado. It is within and adjacent to the northeastern boundary of the Colorado Plateaus physiographic province. The precipitous front of the San Juan Mountains lies only 3 miles to the east. The quadrangle includes features characteristic of both the plateaus and the mountains, and has been affected by geological events and processes of two different geologic environments.

Within the Placerville quadrangle, and in the Little Cone quadrangle to the south and the Gray Head quadrangle to the southeast, the Entrada sandstone of Late Jurassic age contains vanadium deposits. These deposits form an essentially continuous layer 9 to 10 miles long and 1 to 1½ miles wide. Associated with the vanadium is a small but significant percentage of uranium. The occurrence of these deposits in close proximity to the intrusive and extrusive rocks and base- and precious-metal deposits of the San Juan Mountains affords an unusual opportunity to study the relations between the various types of deposits and the igneous province. Accordingly an area of about 300 square miles is being studied and mapped in detail. This large area, comprised of the Placerville, Little Cone, Gray Head, Dolores Peak, and Mount Wilson quadrangles, includes the sedimentary rocks and vanadium-uranium deposits characteristic of the Colorado Plateau and the Tertiary extrusives, stocks, sills, dikes, and vein deposits characteristic of the San Juan igneous province. The present report describes the areal geology of the Placerville quadrangle.

Rocks exposed in the Placerville quadrangle are mainly flat-lying sedimentary formations that range in age from Permian to Cretaceous. These formations have been broadly folded, broken into numerous elongate fault blocks, and, in the southeastern corner of the quadrangle, intruded by dioritic sills and dikes of Tertiary age.

Several thousand feet of Paleozoic rocks probably underlie the quadrangle; these rocks are known only from deep oil wells and from exposures some miles to the south and east. At one time a few thousand feet of Upper Cretaceous and Tertiary sedimentary rocks and Tertiary volcanic rocks were present in the quadrangle above the present surface levels; they were removed during extensive erosional periods following the end of the Cretaceous period and at the end of the Tertiary. Pleistocene deposits include glacial drift on the upland

surfaces, and valley fill and terrace gravels in the valleys of the major drainages. Alluvium, torrential fans, landslides, and spring deposits, all of Recent age, are present along the major canyons.

The continental sediments of the Cutler formation of Permian age were deposited on an aggrading plain of low relief, near a highland mass that lay some miles to the east and north. A long period of erosion and peneplanation followed, at the end of which crustal warping took place in areas some tens of miles east and west of the quadrangle. In the Placerville quadrangle there is no marked angular discordance between the Cutler and Dolores formations. The continental sediments of the Dolores formation of Late Triassic age indicate the resumption of depositional conditions similar to those of the Cutler, but the highland mass apparently was lower or farther away from the quadrangle than in Cutler time, possibly both.

A second long period of erosion followed, and was succeeded by the eolian and fluviatile deposits of the Entrada sandstone of Late Jurassic age. The advance and retreat of a shallow Late Jurassic embayment is marked by the sediments of the overlying Wanakah formation. The Pony Express limestone member at the base of the Wanakah formation was deposited in shallow brackish water; the Bilk Creek sandstone member indicates a return to depositional conditions similar to those of the Entrada sandstone; the marl member at the top of the Wanakah was also deposited in shallow, probably fresh water. The overlying Morrison formation of Late Jurassic age was deposited by broadly meandering streams on a low, flat-lying plain, probably remote from the source areas of the sediments.

A period of erosion, probably of relatively short duration, preceded the deposition of the Burro Canyon formation of Early Cretaceous age. In the Placerville quadrangle the Burro Canyon is discontinuous, filling channels cut in the top of the Morrison formation. Another period of erosion was followed by deposition of the continental and littoral sediments of the Dakota sandstone of Late Cretaceous age with thin coaly layers and carbonaceous shales that probably represent lagoonal deposition. Sedimentation of the Dakota passed transitionally into deposition of the Mancos shale in the transgressing marine waters of the Late Cretaceous seas.

The rocks of Paleozoic and Mesozoic age were broadly folded during Laramide time, as part of the same orogeny that influenced the "salt anticlines" of southwestern Colorado and southeastern Utah. At about the same time uplift in the San Juan Mountain area to the east produced a broad dome. Extensive erosion followed, and the rocks of Mesozoic age in the area east of the quadrangle were successively beveled. The Telluride conglomerate of Tertiary (Oligocene?) age was laid down on this surface. At Telluride, about 15 miles east of the quadrangle, the Telluride conglomerate lies upon the Dolores formation. Volcanic rocks of Miocene(?) and Miocene age were deposited widely upon the Telluride conglomerate and at one time may have covered the Placerville quadrangle to a depth of several hundred feet or more.

During middle Tertiary time monchiquitic dikes, and sills and dikes of dioritic and andesitic composition were intruded into the sedimentary rocks. The major masses of igneous rock consist of diorite, diorite porphyry, andesite, and andesite porphyry that appear to have formed from the same dioritic magma. A few miles east of the quadrangle, similar dioritic rocks form laccoliths in the Mancos shale and a stocklike mass that appears to cut the Tertiary volcanic rocks.

Gravity faulting occurred in the quadrangle in middle Tertiary time, resulting in the formation of numerous grabens. The faults displace both the sedimentary rocks and the intrusive rocks. A northward-trending graben system formed first and in turn was offset by a northwest-trending system. In part, the two systems may have been contemporaneous. Other normal faults followed, possibly contemporaneous in part with the northwest-trending system.

Clastic dikes, tentatively considered to be Tertiary in age, were intruded into the sedimentary rocks as high as the Dolores formation. They follow a west-northwestward-trending joint set along which their extent is measurable in thousands of feet, both laterally and vertically. The dikes consist of both rounded and angular fragments of sedimentary, igneous, and metamorphic rocks that could have been derived from the Cutler and Hermosa formations of Paleozoic age.

At the end of the Tertiary period (possibly in the early Pleistocene) the general area was again uplifted and subjected to extensive erosion. The Mancos shale was largely stripped from the Placerville quadrangle, and the upland surfaces, formed on top of the resistant Dakota sandstone, were largely controlled by the geologic structure. The drainages, too, are believed to have been structurally controlled. Piedmont glaciation of the Cerro stage followed and disrupted the preglacial drainage system. During the retreat of the piedmont glaciers the San Miguel River was superposed across the structural trends by adjustment to an ice lobe that still occupied, and thus blocked, the preglacial river valley. Leopard Creek, the major tributary to the San Miguel River within the quadrangle, was also superposed across the structure by the damming action of the ice lobe. With final retreat of the ice the major drainages were left trapped in their incised valleys; the minor drainages, however, once again became adjusted to the structure. Stream capture has taken place at several places and is likely to occur at several other places in the future.

The mineral deposits within the quadrangle include the tabular vanadium-uranium deposits in the Entrada sandstone, uraniferous and nonuraniferous copper-"hydrocarbon"-bearing veins of probably Tertiary age in the Cutler and Dolores formations, and placer gold deposits in terrace gravels and valley fill of Pleistocene age and in Recent alluvium.

INTRODUCTION

LOCATION, ACCESSIBILITY, AND CULTURE

The Placerville quadrangle includes an area of about 59 square miles in eastern San Miguel County, in southwestern Colorado (fig. 13). It lies within and along the northeastern boundary of the Colorado Plateau which here borders the western flank of the San Juan Mountains. The quadrangle shows geologic features characteristic of both the plateau country and of the San Juan igneous province.

The village of Placerville is near the confluence of Leopard Creek and the San Miguel River. It is served by State Highway 62, which follows Leopard Creek and connects with U. S. Highway 550 and the Denver and Rio Grande Western Railroad at Ridgway, 23 miles to the northeast. State Highway 145, which follows the San Miguel River valley, connects Placerville with Telluride in the San Juan Mountains 16 miles to the east and with Norwood on the plateaus 17 miles to the west. A network of dirt roads gives access to Iron Springs and Hastings Mesas, and to the north part of Specie Mesa; these mesas make up about 65 percent of the area of the quadrangle (pl. 4). Until

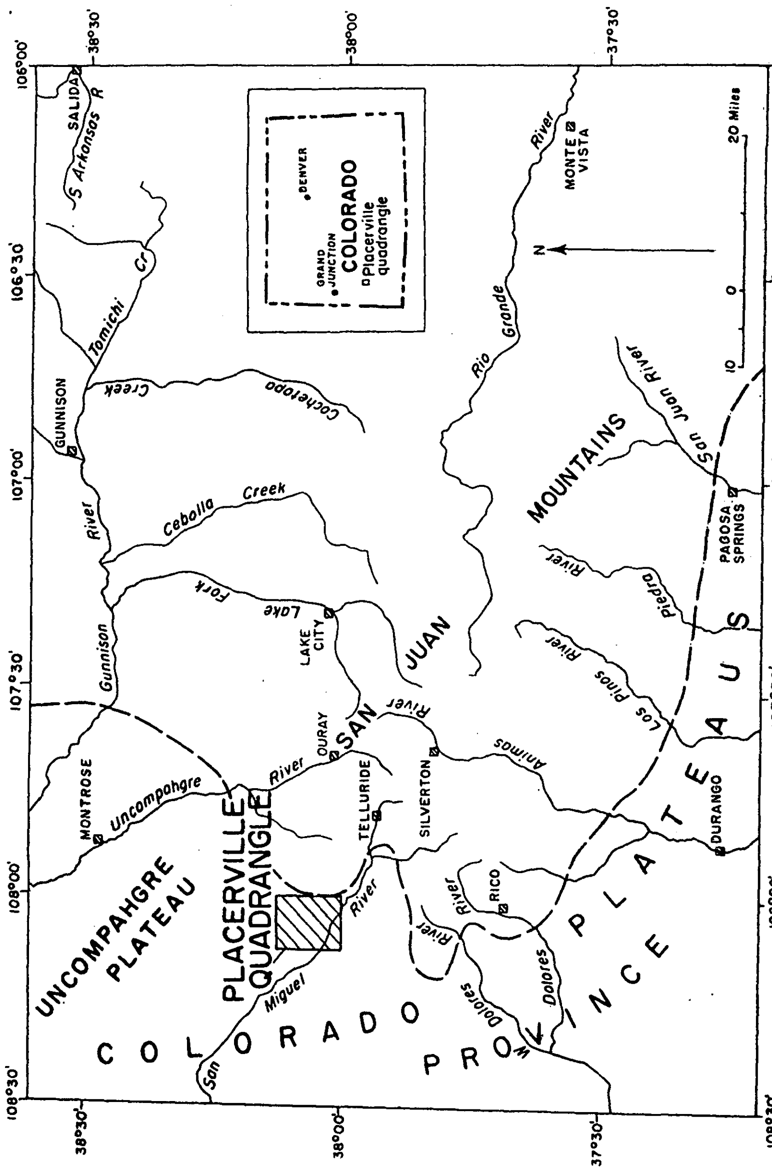

FIGURE 13.—Index map of part of southwestern Colorado, showing location of the Placerville quadrangle and its relation to the Colorado Plateaus and the San Juan Mountains.

1951, Placerville was also served by the narrow gauge Rio Grande Southern Railroad, which connected Ridgway with Placerville, Telluride, and other towns along the western flank of the San Juan Mountains. The old roadbed is still visible along Leopard Creek and eastward from Placerville along the valley of the San Miguel River.

In 1955 Placerville had a population of about 100 persons. A few families live along the valleys of Leopard Creek and the San Miguel River. During the late spring, summer, and early fall a few people engaged in raising sheep and cattle live on the mesas, but there is no year-round settlement there. The total population of the Placerville quadrangle is thus about 150 persons. Sheep and cattle raising, a small tourist industry, desultory mining, and, in 1954 and 1955, two sawmill operations constitute the extent of industry within the quadrangle.

TOPOGRAPHY, CLIMATE, AND VEGETATION

The quadrangle is typical of the eastern margin of the Canyon Lands subdivision of the Colorado Plateaus physiographic province (Fenneman, 1931, p. 307–308). About 65 percent of the area is relatively flat-topped plateau country and the remaining 35 percent consists of steep-walled canyons of youthful streams, canyons as much as 2,200 feet deep. Total relief within the quadrangle is about 2,600 feet; the altitude ranges from 7,040 feet where the San Miguel River leaves the quadrangle along its western border, to 9,650 feet along the southern rim of Hastings Mesa in the southeastern corner of the quadrangle. Altitudes on the mesa tops range generally from 8,100 to 9,200 feet; the average altitude is about 8,800 feet.

The broad mesa that lies north of the San Miguel River and west of Leopard Creek is known locally as Iron Springs Mesa. Its rolling surface rises smoothly to the north and northeast to merge with the broad Uncompahgre Plateau, about 5 miles to the north. Hastings Mesa, whose dissected western border lies along the eastern edge of the quadrangle, merges to the northeast with the Uncompahgre Plateau; to the east its surface rises steeply toward the western border (the Last Dollar Range) of the San Juan Mountains. The nearest peaks, 12,000 feet or more in altitude, are but 3 miles away. A small part of Specie Mesa occupies the southwestern corner of the quadrangle. Specie Mesa merges to the south with the lower slopes of the Little Cone and the San Miguel Mountains, 4 to 6 miles distant.

Small discontinuous rock-held benches and terraces are numerous along the walls of San Miguel canyon, but generally they are rare in the canyons of Specie and Leopard Creeks, the other perennial streams. Small alluvial flats are common along the courses of the San Miguel River and Leopard Creek; they are absent elsewhere.

The Placerville quadrangle is subject to two general climates. The mesas in the eastern part of the area have rainy summers and severe winters, whereas the canyon bottoms, and the mesas in the western part of the quadrangle, are generally drier and have milder winters. This difference depends largely on relative altitude and proximity to the mountain groups that make up the western part of the San Juan Mountains. Placerville has a mean annual rainfall of less than 10 inches (see following table); although no records are available for the mesa tops within the quadrangle, records from stations at similar elevations nearby suggest that the mean annual precipitation is about 15 to 20 inches, increasing rapidly with elevation and with nearness to the main mountain masses. Mean summer temperatures at Placerville are about 65° F., and mean winter temperatures are 25° to 30° F. On the mesas the average temperatures are about 10° lower. May, June, and November are commonly the driest months of the year. Summer precipitation is generally erratic; brief thunderstorms are most common in July and early August.

Precipitation and temperature near Placerville, Colorado

[Compiled from the annual summaries (through 1954) of climatological data, U. S. Weather Bureau, Denver, Colo., and from Sherier (1934)]

Place	Elevation (feet)	Years of record	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Average monthly and annual precipitation, in inches															
Redvale	6,570	9	1.22	0.83	0.94	1.37	1.03	0.84	2.20	1.66	0.97	1.68	1.08	1.19	15.01
Norwood	7,000	21	1.09	1.14	1.34	1.48	1.03	.88	1.57	2.37	1.47	1.27	.92	1.11	15.27
Placerville	7,300	7.5	.58	1.06	.92	.85	.44	.45	.86	.90	.88	.51	.42	.66	7.33
Telluride	8,700	43.5	1.78	1.84	2.49	2.46	1.84	1.23	2.44	3.06	1.93	1.85	1.35	1.56	23.82
Savage Basin	11,522	16	3.43	4.00	4.44	4.57	2.68	.75	3.02	3.32	2.80	3.00	2.93	3.11	38.05
Average monthly and annual temperatures (° F.)															
Redvale	6,570	9	22.6	28.3	36.4	44.5	54.0	63.2	68.0	66.4	58.6	47.3	36.8	25.4	46.0
Norwood	7,000	21	23.0	27.4	34.2	42.1	51.9	60.5	66.7	64.8	58.2	47.8	32.3	26.0	44.9
Telluride	8,700	44	21.5	24.0	28.4	37.2	45.4	53.4	58.6	57.0	51.4	42.1	31.0	22.8	39.4

Vegetation in the quadrangle includes representatives of both the foothills (6,000–8,000 feet) and montane (8,000–10,000 feet) zones. Narrowleaf cottonwoods, willows, and alders grow in the main drainage bottoms. Mountain juniper and pinyon pine are abundant on southward-facing valley slopes, and various species of cacti (pincushion, devilsclaw, and other cacti) are common, as is soapweed, a yucca plant. Rocky Mountain scrub oak is abundant on the more densely wooded northward-facing slopes and aspen and Engelmann spruce are also present, particularly at higher altitudes. Ponderosa (western yellow) pine is present on both slopes, just below and at the mesa rims. Scrub oak and serviceberry are the most ubiquitous plants, occurring from canyon bottoms to the mesa tops. On the mesa tops aspen, scrub oak, black sage, and various grasses are the main vegetation; juniper and pinyon pine are common on the mesa tops at lower elevations in the western part of the quadrangle.

SCOPE AND PURPOSE OF THE WORK

Along the western flank of Colorado's San Juan Mountain region, the Entrada sandstone of Late Jurassic age contains large tabular vanadium deposits. The deposits are essentially continuous, forming elongate belts with horizontal dimensions measurable in miles. The deposits also contain a small but significant percentage of uranium. The vanadium belts occur in three general geographic areas: the Placerville district of San Miguel County; the Barlow Creek-Hermosa Creek district of Dolores and San Juan Counties; and the Lightner Creek district of La Plata County. Of these, the most important in terms of reserves, size of deposits, and past production, is the Placerville district.

The purpose of the work is to determine the origin and habits of the vanadium-uranium deposits, their resources, and their relationship to the intrusive and extrusive rocks and the base- and precious-metal deposits of the San Juan igneous province. In addition to the detailed mapping and study of various types of ore deposits, the program of study includes the areal geologic mapping of about 300 square miles, five 7½-minute quadrangles, which cover the vanadium belt of the Placerville district, and the intrusive and extrusive rocks and ore deposits of the San Miguel Mountains (a western segment of the San Juan Mountains). The present report describes the areal geology of one of these quadrangles, the Placerville quadrangle.

This program of study is being done by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

PREVIOUS WORK

In 1895 and 1896, Whitman Cross mapped the 15-minute Telluride quadrangle, which adjoins the Placerville quadrangle. Cross defined and named many of the sedimentary rock units in his report (Cross and Purington, 1899), and outlined the geology of the general area of which the Placerville quadrangle is a part. Purington described briefly the geology of the placer deposits and the gold-bearing pyrite deposits in limestone in the Telluride quadrangle; similar deposits are also present in the Placerville quadrangle.

Hillebrand and Ransome (1900, 1905) described carnotite and other vanadiferous minerals from the Placerville district; Hess (1911) first described the geology and vanadium deposits of the district. Hess (1933) and Fischer (1937, 1942) gave general descriptions of the vanadium deposits, and Hess (1911, 1933) also described some of the vein deposits of the district. Fischer, Haff, and Rominger (1947) mapped the vanadiferous Entrada sandstone along parts of Leopard Creek and the San Miguel River. The mineralogy of uraniferous vein deposits in the quadrangle has been briefly described by Kerr and others (1951). In 1951, V. R. Wilmarth and R. C. Vickers (written communication, 1952) mapped and described the geology of the two most important uraniferous vein deposits, and in 1952, Wilmarth and C. C. Hawley (written communication) made a more detailed study of the occurrence and mineralogy of the deposits. They mapped the area containing the uraniferous vein deposits (about 3 square miles) by plane-table methods at a scale of 1: 6,000. A part of this mapping has been incorporated in the geologic map (pl. 4) which accompanies this report. The area involved (about 1.7 miles long and 0.3 to 0.5 mile wide) extends southeastward from the Black King mine along the Black King fault zone to a point half a mile east of Placerville.

FIELDWORK AND ACKNOWLEDGMENTS

In the course of a resource appraisal of vanadium-uranium deposits during the summer of 1952, the senior author spent about 6 weeks mapping the vanadium-uranium mines of the Placerville district; he was assisted by Leonid Bryner. Areal geologic mapping in the Placerville quadrangle was done during the periods June–October 1953, and June–October 1954. Field checking was done in parts of May, June, and July, 1955.

Field mapping was done by corrected barometric traverse, inspection, and resection methods along the drainages and in other areas of steep topography. In areas of relatively flat topography, location was determined by inspection of aerial photographs at scales of 1: 18,900 and 1: 37,800. All geology was plotted either directly on topographic sheets at a scale of 1: 15,840 (4 inches equals 1 mile) or transferred from the photographs.

During the 1953 season, the senior author was assisted by Wilford F. Weeks and Charles T. Pierson, and in 1954 by Calvin S. Bromfield as well as Weeks and Pierson. Mr. and Mrs. Fay E. Lambert of Placerville were constantly helpful in keeping base station barometric records.

Much of the information in the following sections of the text regarding grain size, sorting, and heavy mineral content of the various formations, has been supplied by R. A. Cadigan of the U. S. Geological Survey (written communications, 1955).

REGIONAL GEOLOGY

Within the Placerville quadrangle and to the northwest, west, and south, the sedimentary rocks of late Paleozoic and Mesozoic age are warped into a series of northwestward-trending anticlines and synclines. These broad folds plunge gently to the northwest where they merge with a part of the group of salt anticlines of southwestern Colorado and southeastern Utah. North of the Placerville quadrangle these beds, interrupted in a few places by normal faults, rise over the Precambrian rocks that form the core of the Uncompahgre Plateau. To the south the Paleozoic and Mesozoic strata are covered by younger sedimentary and volcanic rocks, and are intruded by stocks, sills, and dikes in the Wilson and Dolores Peaks mountain groups, which together form the range known as the San Miguel Mountains.

In the southeastern quarter of the Placerville quadrangle, a number of andesitic and monchiquitic dikes cut the sedimentary rocks of pre-Cretaceous age. In the extreme southeastern corner of the quadrangle, sills and dikelike discordant bodies of dioritic composition intrude Cretaceous strata—the Dakota sandstone and the overlying Mancos shale. These dioritic intrusives are related to other dioritic laccoliths, sheets, and stocks that are larger and more abundant east of the quadrangle.

A few miles east of the Placerville quadrangle, a Tertiary (Oligocene?) formation, the Telluride conglomerate, lies on a smooth erosion surface. Eastward this surface bevels all the Mesozoic and upper Paleozoic rocks until near Ouray, Colo., the Telluride conglomerate rests on the Precambrian basement complex (Burbank, 1930, p. 184). Layered Tertiary volcanic rocks cut by stocks, sills, and dikes overlie the Telluride conglomerate. The volcanic rocks, in ascending order, consist of the San Juan tuff of Miocene(?) age, and the Silverton and Potosi volcanic series of Miocene age. South of the Placerville quadrangle a basaltic flow of limited areal extent rests on an erosion surface cut in the basal part of the Mancos shale; this flow is of late Tertiary or Quaternary age. At the end of the Tertiary period several hundred feet of the Telluride conglomerate and middle Tertiary volcanic rocks covered the area of the Placerville quadrangle. They have since been removed by erosion.

Many normal faults displace the sedimentary and igneous rocks within the quadrangle. Most of them form pairs that bound long narrow grabens. Vertical offsets on these faults range from a few feet to as much as 700 feet.

SEDIMENTARY ROCKS

The bedded rocks exposed in the Placerville quadrangle are of late Paleozoic and Mesozoic age. Their aggregate thickness is about 3,100 feet; 3 miles east of the quadrangle an additional 1,500 feet or more of younger Mesozoic beds are present. Their lithologic and stratigraphic characteristics are described in the generalized stratigraphic column (pl. 5).

The oldest unit exposed is the Cutler formation of Permian age. The Dolores formation of Late Triassic age lies disconformably on the Cutler, and the oldest Upper Jurassic formation, the Entrada sandstone, lies disconformably on the Dolores. Conformable upon the Entrada is the Wanakah formation, consisting of the Pony Express limestone member at the base, the Bilk Creek sandstone member, and a marl member at the top. Conformably above these is the Morrison formation (consisting of the Salt Wash sandstone member at the base and the Brushy Basin shale member) of Late Jurassic age. The Burro Canyon formation of Early Cretaceous age can be identified only where it fills channels cut in the Brushy Basin. The Dakota sandstone of Late Cretaceous age disconformably overlies the Brushy Basin, or the Burro Canyon where present. The Mancos shale of Late Cretaceous age conformably overlies the Dakota sandstone.

Thin unconsolidated deposits of Pleistocene and Recent age are exposed in the valley bottoms, on remnants of elevated river terraces and in a few places on the upland surfaces.

Older Paleozoic rocks probably lie beneath the Placerville quadrangle between the exposed upper Paleozoic formations and the Precambrian basement complex. Exposures near Rico, about 17 miles to the south, and at Ouray, 17 miles to the east (fig. 13), and cuttings from deep oil wells 15 miles to the northwest and 10 miles to the west show the presence of Paleozoic rocks at least as old as Devonian. These unexposed beds probably include the Elbert formation and the Ouray limestone of Devonian age, the Molas and Hermosa formations of Pennsylvanian age, the Rico formation of Pennsylvanian and Permian(?) age, and the lower part of the Cutler formation of Permian age. Interpolation between the scattered points where information is available suggests that the total thickness of these beds beneath the Placerville quadrangle may be in the order of 3,000 feet.

During most of the Paleozoic era, marine conditions prevailed throughout the region. In late Paleozoic time the region was elevated and sediments were deposited under continental, fluviatile conditions. Widespread erosion in late Permian and earliest Triassic time was followed by the deposition in Triassic time of additional continental sediments. Renewed erosion preceded the deposition of the upper Jurassic beds. A cycle of subsidence and elevation during the Late Jurassic epoch is marked by thin brackish water and marine sediments, followed by a thick sequence of continental deposits. Subsidence began once more in Early Cretaceous time, and culminated in the marine deposits of the thick Mancos shale.

PERMIAN SYSTEM

CUTLER FORMATION

The Cutler formation is exposed along the bottom and the lower slopes of the San Miguel River valley, and along the lower reaches of the river's tributaries (pl. 4). The conglomerate and conglomeratic sandstone units of the formation form very steep slopes, sheer cliffs, and benches; the finer grained units cap the terraces and form gentle to steep slopes. Many of the cliffs reach heights of 80 to 100 feet or more, where the more easily eroded siltstone and fine-grained sandstone units are capped by thick resistant conglomerate strata. The formation is dominantly red, with a pronounced purplish cast, although in detail there are numerous red-brown, gray-green, and yellow-gray units. The purplish cast contrasts with the brick-red color of the overlying Dolores formation, and serves to differentiate these red-bed units when viewed from a distance.

The most striking features of the Cutler formation are its numerous thick prominent conglomerate beds, and the overall arkosic character of the formation. In general, conglomerate and conglomeratic sandstone make up 25 to 40 percent of the exposed thickness of the formation. The fragments range in size from granules to boulders, but pebble and cobble conglomerates are most common. Generally the fragments are rounded; angular and subangular fragments are rare. The most abundant conglomerate constituents are granitic rocks, greenstone, and quartzite; schist, other metasedimentary rocks, and diorites are less common. In places limestone and limy siltstone granules and pebbles are present, but not abundant. Greenstone conglomerate appears to be scarce in the top 350 feet of the formation; below this upper unit it constitutes a striking and characteristic part of the formation. Individual conglomerate beds attain thicknesses of 15 to 20 feet, although the average thickness is probably 5 to 10 feet. The conglomerate matrix is composed of medium- and coarse-grained quartz and feldspar. Hematite staining is common in the matrix, less so in the gravel.

Arkosic sandstone makes up the bulk of the Cutler formation, averaging perhaps 60 percent. Facies changes from conglomerate to conglomeratic sandstone to sandstone are common, and the lateral change in many places occurs in very short distances. Most of the sandstone is poorly to very poorly sorted. In the upper 150 to 200 feet of the formation there is an increase in the proportion of well-sorted sandstone, although the total thickness of well-sorted beds remains small. The finer sand grains are commonly subrounded, whereas the medium and coarse sand grains are subrounded to subangular. All size fractions from very fine to very coarse grained are present, but most of the units are medium to coarse grained.

Almost all the sandstone is arkosic, much of it is abundantly micaceous as well. Some of the sandstone contains appreciable amounts of clay. Lime is the usual cementing material, and hematite staining is abundant.

Limy siltstone beds make up a small proportion of the sediments, and thin mudstone beds (less than 1 foot thick) are present in very minor amounts. These fine-grained units are generally red, but in numerous places they apparently have been bleached to various gray-green hues. Thin discontinuous unfossiliferous gray limestone beds make up perhaps 1 to 2 percent of the formation. Locally the limestone beds contain pebbles of limy siltstone and limestone.

The lithologic units of the Cutler formation are not persistent over long distances. Lenses of conglomerate, sandstone, and siltstone interfinger, or grade laterally one into another. Along the outcrop individual lenses range from a few tens of feet to a few thousand feet across. Many of the units show cut-and-fill structures; commonly the conglomeratic beds occupy channels cut in the underlying rocks. Cross-stratification is present in many of the beds, and both torrential and festoon cross-strata are represented. Other beds are horizontally or irregularly stratified.

A maximum of about 1,100 feet of the Cutler formation is exposed within the Placerville quadrangle, and an unknown thickness at the base is concealed. Interpolation of the total thickness of the Cutler from exposures near Rico and Ouray, and from deep oil-well drill holes to the west and northwest, suggest that the total thickness of the Cutler in the Placerville-Telluride area is in the order of 2,000 feet. The margin of error for this estimate is large, as the drill-hole information in other areas indicates that the Cutler is variable in thickness within short distances.

The following stratigraphic section was measured 1 mile southeast of Placerville, on the north side of the San Miguel River canyon.

	Feet
Triassic: Dolores formation at top. Basal quartz-pebble conglomerate overlain by maroon sandstone and siltstone	54
Disconformity.	
Permian:	
Cutler formation:	
1. Sandstone and conglomeratic sandstone, arkosic, grayish- and purplish-red, very fine grained to medium-grained, mostly fine grained, crossbedded; granitic conglomerate in lower 10 feet; micaceous conglomerate at top; contact with Dolores formation sharp; intergrades with unit below	75
2. Sandstone and sandy mudstone, arkosic, very thinly bedded and very thinly laminated, crossbedded	42

Permian—Continued	*Feet*
Cutler formation—Continued	
3. Conglomerate sandstone and conglomerate, arkosic, purplish-red; very thinly bedded at top, crossbedded, very poorly sorted	38
4. Sandstone and conglomeratic sandstone; conglomerate beds very arkosic and micaceous; pale-red and grayish-red; interbeds of fine- and medium-grained sandstone, well sorted, thinly bedded and laminated, crossbedded; interfingers and intergrades with unit below	77
5. Conglomeratic sandstone, arkosic, grayish-red, crossbedded; in places grades to a pebble-sized conglomerate; interfingers and intergrades with unit below	16
6. Sandstone, arkosic, micaceous, pale-red and grayish-red; fine- and medium-grained interbeds; well sorted, thinly to very thinly bedded, very thinly to irregularly parted, crossbedded	61
7. Arkosic conglomerate and arkose, some chert; grayish-red; conglomerate cobble size or less, mostly pebble size; upper 10 feet very poorly sorted arkose	42
8. Sandstone, arkosic, pale-red, very fine grained and fine-grained, shaly	12
9. Conglomeratic sandstone, arkosic, pale-red and grayish-orange-pink, irregularly bedded; contains some pebble-size arkosic conglomerate, particularly at top; transitional with unit below	29
10. Sandstone and conglomerate, arkosic, purplish-red and grayish-red; conglomerate composed of much quartzite, granite, slate, and considerable greenstone; ranges to boulder size; amount of conglomerate decreases toward top	75
11. Sandstone and silty sandstone, arkosic, abundantly micaceous, pale-red and pale red-brown; well sorted, very thinly bedded and very thinly laminated, shaly and fissile; abundantly crossbedded at very low angles	64
12. Conglomeratic sandstone, arkosic; and conglomerate, grayish-red and purplish-red; conglomerate contains abundant greenstone and granite, ranging to boulder size; sandstone very poorly sorted, very thinly bedded, crossbedded at base, channel filling	28
13. Sandstone and silty sandstone (65 percent), arkosic; interbedded with arkosic conglomerate and conglomeratic arkose (35 percent); sandstone generally pale reddish brown, conglomerate and arkose grayish red, pale red, and grayish orange pink; greenstone scarce in conglomerate; sandstone very thinly laminated and irregularly parted; entire unit poorly sorted, crossbedded, channel filling	103
14. Sandstone and silty sandstone, arkosic, abundantly micaceous; dominantly pale reddish brown; some grayish red; poorly sorted fine and medium grained in middle part; finer grained above and below; very thinly bedded, very thinly to irregularly parted, some fissile; crossbedded near center	68

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Permian—Continued	*Feet*
Cutler formation—Continued	
15. Arkose and conglomeratic arkose, pale-red and grayish-orange-pink, poorly sorted, medium-grained to very coarse grained; grades laterally into coarse conglomerate lentils; 8 feet of massive very argillaceous pale-red sandstone, with clay pellets, at the base of the upper third of the unit; thin bedded and micaceous at top; crossbedded	59
16. Sandstone and silty sandstone, pale-red and grayish-red, micaceous, irregularly bedded, lenticular	53
17. Greenstone conglomerate, abundantly arkosic; with numerous granite and slate fragments; ranges to small boulder size; lenticular and channel filling	11
18. Sandstone, micaceous; grayish red below, pale reddish brown at top, very fine grained, thinly to very thinly bedded; some shaly; nodular weathering at top	27
19. Arkosic conglomerate and conglomeratic arkose, grayish-orange-pink and pale-red; conglomerate ranges to cobble size, is composed mostly of quartz, quartzite, and slate; arkose is medium and coarse grained; unit is crossbedded, massive, channel filling	12
20. Sandstone, micaceous, pale-red and grayish-red, poorly sorted, very fine to medium-grained; thinly to very thinly bedded; silty mudstone near base; clay-pebble conglomerate grades laterally to sandstone at top of lower third; crossbedded	43
21. Covered interval to base of section (river level)	50
Base of Cutler formation not exposed.	
Total thickness of Cutler formation above river level	985

In the Placerville quadrangle the Cutler formation is separated from the overlying Dolores formation, which is of Late Triassic age, by a disconformity that marks a long period of erosion. The erosion surface has only minor relief, indicative of stable conditions and maintenance at or near base level. No significant angular discordance is evident between the two formations, but a slight angular discordance is suggested where relatively long exposures are viewed from a distance. Near Ouray, Colo., there is marked angular unconformity between the formations, and east of Ouray the Dolores rests on Pennsylvanian rocks where the Cutler has been eroded (Cross and Howe, 1905; Burbank, 1930). Throughout the Placerville quadrangle the contact between the Cutler and Dolores formations is sharp, marked by a characteristic clean quartz-pebble conglomerate that is the basal unit of the Dolores. In the western San Juan Mountains the Cutler formation cannot be subdivided into members, despite the formation's thickness.

For many years the Cutler formation in the San Juan Mountains has been considered to be essentially unfossiliferous. In 1951 and 1952, parts of three vertebrate fossils were found in the Placerville quadrangle by V. R. Wilmarth, C. C. Hawley, and R. C. Vickers of the U. S. Geological Survey. Additional specimens have been found by G. E. Lewis of the U. S. Geological Survey and A. S. Romer of Harvard University. Romer and Lewis (written communications, May 17 and June 23, 1955) have tentatively identified and correlated the fauna from the Cutler, and the following quotation is taken from their preliminary data (written communication, June 28, 1955).

The fossils have not been completely removed from the rock matrix and fully prepared to date. At this time the degree of preparation does, however, permit us to give the following stratigraphic paleontologic interpretation as to the age relations of the Cutler fauna:

We have tentatively identified the following:

- Class Amphibia:
  - Superorder Labyrinthodontia:
    - Order Rhachitomi:
      - Small *Eryops* sp.
      - ?*Platyhyatrix*.
- Class Reptilia:
  - Subclass Anapsida:
    - Order Cotylosauria:
      - Small, primitive diadectid.
  - Subclass Synasida:
    - Order Pelycosauria:
      - *Ophiacodon* sp.
      - Small sphenacodontoid comparable to *Aerosaurus*.
      - *Sphenacodon* sp.
      - Small pelycosaur comparable to *Nitosaurus*.

The best-known fauna from a stratigraphic unit of somewhat comparable position in this broad region of the United States is the Abo sandstone of New Mexico, in whose outcrops in the Arroyo de Agua area occurs a well-known vertebrate fauna of essentially the same age as the fauna from the Moran and Putnam formations of the lower part of the Wichita group of Texas. The fauna from the Cutler formation of the Placerville, Colorado, area seems to be somewhat more primitive and older than that of the Moran and Putnam formations of Texas and the Abo sandstone of the Arroyo de Agua area of New Mexico.

A second, smaller, Abo fauna from New Mexico comes from the El Cobre canyon area, it is suspected—but not proved—to be somewhat more primitive and older than the fauna from the Arroyo de Agua area. Correlation of the Cutler fauna from the Placerville, Colorado, area with the El Cobre Canyon Abo fauna is reasonable, but there is little positive evidence.

The several world authorities on the Pennsylvanian-Permian boundary are not agreed on the systematic position of the Wichita group; its age as to era is still a moot question. There is general agreement that the overlying Clear Fork group is definitely Lower Permian, and that the underlying Cisco group is definitely Upper Pennsylvanian.

We conclude tentatively that the Cutler formation of the Placerville, Colorado, area is of pre-Wichita age, and may be either very low Permian or uppermost Pennsylvanian.

The beds of the Cutler formation were deposited under continental conditions. This is attested to by the lenticular poorly sorted rocks, abrupt lateral facies changes, and cut-and-fill structures. The thick heterogeneous section of sedimentary rocks, with a very high proportion of conglomerate and coarse clastics, indicates deposition near the source of the sediments. West and southwest of the Placerville quadrangle the strata of the Cutler are progressively finer grained and more evenly bedded. The source of the sediments thus appears to be the ancestral Rocky Mountains of central Colorado, whose nearest element, the Uncompahgre-San Luis highland (Baker, Dane and Reeside, 1933), lay a few tens of miles to the north and east of the Placerville quadrangle. This positive element became active late in the Paleozoic era, and remained a highland until Late Jurassic time.

The Cutler formation was deposited on an aggrading alluvial plain of low relief by streams flowing off the highland mass. The prevalence of cobble and boulder conglomerates in the formation suggest that the highland had a rather steep front, and that torrential outwash was common. The scarcity of greenstone conglomerate in the upper part of the formation is indicative of either a change in the source of the sediments, or of the disappearance of greenstone from the source area. Fragments of metasedimentary rocks are also less abundant in the upper part of the formation. Within the areas of Precambrian rocks now exposed, metasedimentary rocks and greenstone are found in the main San Juan Mountain mass, some tens of miles east and southeast of the Placerville quadrangle (the San Luis highland); granitic rocks lie generally north and northeast in the Uncompahgre Plateau (the Uncompahgre highland).

TRIASSIC SYSTEM

UPPER TRIASSIC SERIES

DOLORES FORMATION

The red beds of the Dolores formation crop out along the lower and middle slopes of the San Miguel River canyon, and along the river's tributaries within the quadrangle. The characteristic topographic expression is as ledgy cliffs and steep rubbly slopes, with a few narrow rock-held benches. In many places a sandstone facies at the top of the formation makes a sheer unscalable cliff that is 50 to 70 feet high.

Interbedded sandstone and siltstone comprise the bulk of the formation, averaging 70 to 75 percent. Conglomerate is the next most abundant rock type; mudstone and thin limestone are minor in amount. Both interfingering and gradation between the various rock types are common. Many of the units are cross-stratified, others are horizontally or irregularly bedded. Cut-and-fill structures are abundant, particularly at the base of the conglomerates and the coarser sandstones. Most individual units are not continuous laterally in detail. In general, however, the formation consists in ascending order of the following lithologic assemblages: Unit A, a basal quartz-pebble conglomerate; unit B, interbedded sandstone, siltstone, and limestone-pebble conglomerate; unit C, interbedded siltstone, sandstone, and a minor amount of mudstone; unit D, interbedded siltstone, sandstone, and limestone-pebble conglomerate; and unit E, an upper zone of sandstone and minor siltstone.

The basal quartz-pebble conglomerate (unit A) is a distinctive and persistent unit throughout the Placerville quadrangle. It is generally white or light gray, contrasting markedly with the purplish hues of the underlying Cutler formation and with the red-brown hues of the overlying strata of the Dolores. The unit consists largely (60–80 percent) of subangular to subrounded grains of vein quartz and quartzite mostly of granule and pebble size. The remainder of the unit is generally coarse grained quartz sand. Scattered granules of limy siltstone and fine-grained green metamorphic rocks and coarse grains of feldspar are also present. Locally the dominant conglomeratic facies gives way to a coarse-grained sandstone facies, but the composition does not appear to change. Siliceous cement is predominant throughout the zone. Irregular bedding is most prevalent, but rude cross-stratification is present in many places. The thickness of the unit ranges from about 20 to 65 feet, averages about 40 feet, and decreases generally from west to east across the quadrangle.

A thick sequence of interbedded sandstone and siltstone (unit B) characterized by the presence of limestone-pebble conglomerate overlies the quartz-pebble conglomerate. The sandstone and siltstone are dominantly grayish red to pale or light reddish brown; the limestone-pebble conglomerate is light reddish brown and shades of gray, brown, and purple. Most of the sandstone is silty or very fine grained; little is coarser than fine grained. In places the sandstone contains a moderate amount of light-colored mica (muscovite?). Calcareous cement is present in all units, although commonly the siltstone is more limy than the sandstone. Stratification ranges from very thinly laminated to thick bedded, and from evenly to irregularly bedded. Generally, thick-bedded units are irregularly bedded. Many of the beds show low-angle cross-stratification.

Limestone-pebble conglomerate is the most distinctive feature of this zone, constituting as much as 35 or 40 percent of the zone. In many places near the base of the unit the conglomerate contains a considerable admixture of quartz and quartzite granules and pebbles. Above this mixed conglomerate the composition is generally uniform; angular, subrounded, rounded, flattened and squeezed granules and pebbles of reddish limy siltstone, silty limestone, and limestone are surrounded by a matrix of limy limestone. Thus some of the gravel represents fragments from preexisting rock, others apparently were still muddy at the time the pebbles were formed. Individual conglomerate lenses thin markedly in short distances, interfinger with other siltstone or sandstone beds, or grade into them. Bedding ranges from irregular to rudely cross-stratified in the conglomerate. Much of the conglomerate fills small channels cut in underlying sandstone and siltstone. The total thickness of the sandstone-siltstone-conglomerate zone is variable; generally it is between 120 and 140 feet.

The next overlying lithologic assemblage (unit C) is characterized by the paucity or absence of limestone-pebble conglomerate. Sandstone and siltstone beds of the same lithologic types as in the underlying zone constitute perhaps 75 to 90 percent of the section and in places red-brown limy mudstone occurs. Light-colored mica is rare to sparse as an accessory mineral. The zone can be subdivided into three subzones, primarily on the basis of sedimentary structures. The lower and upper subzones are characterized by cross-stratified and generally irregularly bedded sandstone, siltstone, and mudstone. Much of the cross-stratification is of the torrential type. The middle subzone contains very few thin mudstone beds, is not cross-stratified, and generally is regularly bedded. Each of the three subzones is widely variable in thickness; in many places the upper subzone is missing. The total thickness of the zone is about 190 feet, and is surprisingly constant, though there is good evidence that the unit thins eastward, beyond the eastern border of the quadrangle.

The overlying sequence (unit D) is very similar in lithology to unit B. Limestone-pebble conglomerate and thin limestone are present, but are less abundant than in the lower sequence. The sandstone and siltstone are well sorted, and a moderate amount of light-colored mica is present. Sedimentary structures are similar, with both evenly bedded and cross-stratified units; the cross-stratified units are dominant in the zone. The thickness ranges from 90 to 125 feet; the average is about 100 feet.

At the top of the formation is a sequence of light-reddish-brown very fine grained sandstone and siltstone (unit E), devoid of limestone-pebble conglomerates, but in a few places containing a very thin discontinuous limestone lens. The unit generally consists of several thick beds, irregularly bedded or sweepingly crossbedded. Unit E is similar in lithology, sedimentary structures, and stratigraphic position to the Wingate sandstone of Late Triassic age, and is provisionally correlated with it. The nearest exposure of the known Wingate is in the valley of Tabeguache Creek about 25 miles northwest of the Placerville district. Commonly unit E forms a steep or vertical cliff. In numerous places where the sand content increases, a single sweepingly crossbedded massive ledge is formed, which weathers to a smooth vertical unscalable cliff. Good sorting is characteristic of the unit, and mica is rare or absent. The thickness is generally 20 to 55 feet, increasing in places to 70 feet.

The thickness of the Dolores formation is variable throughout the quadrangle, but generally it decreases eastward from about 580 feet along the western border to 480 feet along the eastern border, and to about 460 feet a few miles farther east where the base of the formation disappears below the surface. In the vicinity of Telluride, Colo., about 12 miles to the east, the formation is about 300 feet thick.

The basal contact of the Dolores formation with the underlying Cutler formation is a sharply marked erosional surface with a minor amount of detailed relief. The quartz-pebble conglomerate fills shallow channels in the Cutler and overlaps the low interstream divides. The lack of distinctive traceable units in the upper part of the Cutler prevents an estimate of the total relief on this erosion surface. Angular discordance between the formations cannot be proved but a slight angular discordance is suspected. The interval represented by erosional unconformity was of long duration, as is indicated by the early Permian, or older, age of the Cutler as tentatively classified on faunal evidence.

The contact of the Dolores formation with the overlying Entrada sandstone is likewise disconformable; it too represents a long period of erosion. In places the contact is sharp; yellowish-gray, fine- and medium-grained mixed-grained sandstone of the Entrada lies upon red-brown very fine grained sandstone or siltstone of the Dolores. Elsewhere the contact is a transition zone, with the fine material of the Dolores reworked and adulterated with coarser constituents characteristic of the Entrada. Where the contact is not sharp, a color change from red brown to yellowish gray seldom corresponds with the lowest appearance of a mixed-grain sandstone, which is considered to be the characteristic feature of the basal Entrada. The detailed relief on the erosion surface separating the Dolores and the Entrada approaches 15 feet as a maximum.

The following stratigraphic section was measured about 4 miles west of Placerville, opposite the mouth of Specie Creek, on the north side of the San Miguel River valley.

	Feet
Upper Jurassic: Entrada sandstone at top. Basal crossbedded, mixed-grain sandstone unit, overlain by even-grained sandstone	25
Erosional unconformity.	
Triassic:	
Dolores formation:	
Unit E (Wingate sandstone equivalent):	
1. Sandstone, moderate reddish-orange, very fine grained, slightly crossbedded, well-sorted; very few accessories, slightly calcareous; very thick bedded, forms massive, spalling cliff; reworked at top into yellowish-gray Entrada sandstone, contact marked by appearance of frosted medium to coarse quartz grains	16
2. Siltstone, pale reddish-brown, very calcareous, nodular-weathering; very thin, irregular bedding	2

	Feet
Triassic—Continued	
Dolores formation—Continued	
Unit E (Wingate sandstone equivalent)—Continued	
3. Sandstone, moderate reddish-orange, very fine grained, very slightly calcareous; similar to unit 1; forms cliff	15
4. Siltstone, pale reddish-brown, very slightly calcareous, nodular-weathering; very thin, irregular bedding; forms slope	4
5. Sandstone, moderate reddish-orange, very fine grained, calcareous; similar to unit 1; forms massive cliff	13
Thickness of unit E (Wingate sandstone equivalent)	50
Unit D:	
1. Sandstone and some siltstone, pale reddish-brown; sandstone very fine grained, slightly crossbedded; alternately slabby and nodular weathering in upper 10 feet, well-sorted, few accessories; locally forms massive spally cliffs, elsewhere forms slope and ledges	49
2. Sandstone, pale reddish-brown, very fine grained, slightly calcareous, very thickly bedded, well-sorted; very few accessories; forms rounded spalling cliff	13
3. Siltstone, pale reddish-brown and pale reddish-purple, slightly calcareous, very irregularly bedded; irregularly distributed gray-green alteration spots; forms rubbly slope and nodular-weathering cliff	18
4. Sandstone, pale reddish-brown, limy, well-sorted; very few accessories; massive	6
5. Siltstone, light reddish-brown, limy, very thinly bedded; large-scale crossbedding; thin lenticular mudstone partings	7
6. Sandstone, pale reddish-purple, very fine grained, well-sorted, very thinly laminated, fissile; large-scale crossbedding; poorly exposed	25
7. Siltstone, pale reddish-purple, slightly limy, very thinly bedded, shaly; spots of greenish alteration; low-angle crossbeds	6
8. Limestone and limestone-granule conglomerate, interbedded and interfingered, light greenish-gray and reddish-gray; limestone is ripple marked	4
Thickness of unit D	128
Unit C:	
9. Siltstone, light reddish-brown, limy, very irregularly bedded; has a few thin lenses of silt granules and limy pebbles; high-angle crossbeds	7
10. Sandstone, pale reddish-brown, very fine grained to fine-grained, well-sorted; ripple marks common; very thinly bedded and laminated, very fissile, breaks in thin conchoidal plates; abundant green alteration; abundant low-angle (festoon) crossbeds; forms prominent cliff	58

Triassic—Continued	*Feet*
Dolores formation—Continued	
Unit C—Continued	
11. Sandstone, light-gray, some purplish cast, fine- and medium-grained, poorly sorted; numerous black accessories; limy clay galls in upper 2 feet; thin bedded, very thinly but irregularly parted; abundant festoon crossbeds	12
12. Siltstone, grayish-red and light reddish-brown, limy; top 8 feet nodular weathering; poorly exposed; forms rubbly slope, with talus of small equidimensional blocks	30
13. Sandstone and some siltstone, light reddish-brown, very fine grained, thickly bedded, thinly and irregularly parted; thin limestone-granule conglomerate at top; poorly exposed; forms rubbly slopes	32
14. Sandstone and some siltstone, grayish-red; some gray-green bleaching; very fine grained, limy, very thinly bedded and thinly laminated; crinkly in upper 8 feet; sweeping low-angle crossbeds; poorly exposed; forms rubbly slopes and thin ledges	52
Thickness of unit C	191
Unit B:	
15. Limestone-pebble and granule conglomerate, interbedded, light reddish-brown and grayish-red; gray-green bleaching in places; some cobble-size material; groundmass usually fine grained or silty; thin and thick bedded; bone fragments near base; few thin interbeds of very fine grained sandstone and siltstone; forms alternating slopes and ledges	35
16. Siltstone, light reddish-brown, limy, thickly and irregularly bedded; not laminated; few thin sandstone beds, light reddish brown, thinly and evenly laminated, above center of unit; forms rubbly slopes	49
17. Limestone-pebble conglomerate and interbedded very fine grained sandstone and siltstone, pale to light reddish-brown	4
18. Siltstone, pale reddish-brown, very limy, thickly and irregularly bedded, thinly parted; nodules of limestone-pebble conglomerate at top; forms rubbly or platy slope	8
19. Covered interval; talus like unit 20	20
20. Siltstone and very fine grained sandstone, interbedded, pale reddish-brown, slightly micaceous, very thinly bedded and laminated; crossbedded on a fine scale; poorly exposed; forms slopes covered with rubble or irregular conchoidal plates	20
21. Covered interval, possibly siltstone	6
Thickness of unit B	142

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	Feet
Triassic—Continued	
Dolores formation—Continued	
Unit A:	
22. Conglomeratic sandstone and sandstone, interbedded and gradational, pale-red to pale-brown, poorly sorted; assemblage of quartzose sandstone, quartz-granule conglomerate, and limestone-granule conglomerate; limestone granules most abundant at top; crossbedded, varying markedly laterally, mostly low angle; forms thick-bedded ledge; fills and overlaps small channels cut in unit below	7
23. Siltstone and fine- to medium-grained sandstone, grayish-red and yellowish-gray, limy; occasional quartzite pebbles in sandstone layers	16
24. Quartz-pebble and quartz-granule conglomerate and conglomeratic sandstone, generally light gray, very poorly sorted; dominantly composed of granules and pebbles of quartz and quartzite; small amount of feldspar, limy siltstone, and fine-grained green metamorphic rocks; thickly bedded; crossbedded in places	41
Thickness of Unit A	64
Thickness of Dolores formation below Wingate sandstone equivalent (units A through D)	525
Total thickness of Dolores formation, including Wingate sandstone equivalent (units A through E)	575
Erosional unconformity.	
Permian:	
Cutler formation: Red, purplish-red, and grayish-red arkose, arkosic sandstone, and conglomerate.	

As originally defined by Cross and Purington (1899) the Dolores formation included the entire red bed sequence in the Telluride area. In the Ouray area the Cutler formation was separated from the Dolores by Cross and Howe (1905) and no attempt to further subdivide the Dolores has been made. Baker, Dane, and Reeside (1936, p. 2, 22) consider that the greater part of the Dolores formation represents the Shinarump conglomerate (now classed as a member of the Chinle formation) and the Chinle formation of the Colorado Plateau; that a thin equivalent of the Wingate sandstone is present at the top of the Dolores; and that the Kayenta, Navajo, and Carmel formations are not represented. The authors are in general agreement with this conclusion.

The fivefold subdivision of the Dolores formation permits a more rigorous analysis of the unit's correlation with other Triassic rocks of the Colorado Plateau. The basal quartz-pebble conglomerate (unit A) in some ways resembles the Shinarump member of the Chinle formation of southeastern Utah, although it appears to have been derived from a local northern or northeastern rather than an eastern and southeastern source. It may correlate with the Shinarump or the Moss Back members of the Chinle formation (Stewart, 1957). The uppermost subdivision of the Dolores (unit E) bears strong lithologic affinities to the Wingate sandstone, and is provisionally correlated with it. Although not mapped separately in the field, it is included in the map explanation as an equivalent of the Wingate sandstone. The medial zones of the Dolores are correlated with the Chinle formation, but for the present they are not correlated directly with any members of the Chinle; additional study may make such detailed correlation possible.

These correlations result in a redefinition of the age of the Dolores formation. Previously the Dolores has been considered to be of Late Triassic and Jurassic(?) age. In parts of Arizona, the Wingate sandstone is overlain by the Dinosaur Canyon member of the Moenave formation (Harshbarger and others, 1957), which contains a fauna whose affinities appear to be more closely allied to Triassic than Jurassic types. The Wingate, therefore, is now considered to be late Triassic, rather than Jurassic(?). Accordingly the age of the Dolores formation also has been revised to Late Triassic (Brown, 1956).

The Dolores formation is sparsely fossiliferous. Most of the fossils have been found in limy sandstone and in limestone-pebble conglomerate but phytosaurian teeth are found in the basal quartz-pebble conglomerate. No fossils have been found in the uppermost unit of the formation, the Wingate sandstone equivalent. The fossils of the Dolores formation were first described in Cross and Purington (1899), who stated that they included crocodile teeth, ganoid fish remains, a gastropod, a variety of *Unio*, a species of megalosauroid dinosaur, and a plant identified by David White as *Pachyphyllum münsteri*. Unidentifiable plant and bone fragments have also been known for many years.

In 1953 G. E. Lewis of the U. S. Geological Survey discovered fragments of a large leaf about 145 feet above the base of the Dolores formation, in the southeastern corner of the quadrangle. Well-preserved, nearly complete specimens were found by G. E. Lewis and R. W. Brown in 1954, and additional ones by Brown in 1955. Brown (1956) has named these specimens *Sanmiguelia lewisi;* he concluded that they are the leaves of a primitive palm, or of a palmlike monocotyledon, and that they "are the oldest known megascopic remains of the flowering plants." Previously, according to Brown (1956), the fossil record of the palms dated from the Jurassic Lias of Normandy, and the first authentic remains of palms found in the United States were from Upper Cretaceous strata. Brown also identified coniferous twigs from the Dolores, pointing out that they are *Brachyphyllum münsteri*, a correction of the identification as *Pachyphyllum* by David White, in Cross and Purington (1899).

The Dolores formation is dominantly fluviatile, and was deposited under generally semiarid, terrestrial conditions on an aggrading plain of low relief. The source of the sediments was probably the Uncompahgre-San Luis highland, lying north and east of the area. The conglomerate at the base apparently represents the reworked, residual detritus of a long period of erosion, transported by the renewed potency of the streams as a result of moderate uplift of the highland mass and deposited for the last time during Late Triassic time. The distribution of coarser grained units in the lower part of the formation and of finer grained units above, suggests that during the rest of the Triassic period the highland mass was slowly worn down toward base level. The limestone-pebble conglomerate is considered to be intraformational conglomerate, representing the breaking up and reworking of thin limestone and silty limestone beds deposited in transitory shallow flood-plain lakes.

JURASSIC SYSTEM

UPPER JURASSIC SERIES

The Upper Jurassic rocks of the Placerville quadrangle include, in ascending order, the Entrada sandstone and the Wanakah and Morrison formations. Their maximum total thickness is about 970 feet, but generally they total about 820 to 850 feet. They form the middle and upper slopes of the youthful valleys throughout the quadrangle, cropping out as sheer vertical cliffs and steep ledgy slopes.

ENTRADA SANDSTONE

Throughout the western San Juan Mountains, the Entrada sandstone forms a distinctive light-colored smooth and massive rounded cliff, capped by a few feet of thin rounded ledges. This topographic expression reflects the dominantly twofold lithologic subdivision of the formation. The bulk of the formation, constituting the lower 75 to 90 percent, is a large-scale cross-stratified, fine- to medium-grained, well-sorted sandstone. It is everywhere light colored, buff, tan, or various shades of yellow and gray. Thin stringers of coarse to very coarse frosted quartz grains are characteristic of the lower 5 to 10 feet of the unit; they contrast strongly with the usual grain size of the sandstone, and their lowest occurrence marks the contact between the Dolores formation and the Entrada where the contact is transitional. Most of the unit is thick bedded, cross-stratified, and massive. In some places thin even horizontal bedding is present, usually at or near the base of the unit.

The upper unit of the formation is commonly very thin to thick bedded and horizontally stratified. Generally it is somewhat finer grained than the lower unit, although in many places there is no distinction in grain size. The entire formation has a calcareous cement, but the upper unit is commonly more limy than the lower. The two units are separated by a diastem, along which the relief approaches a maximum of 15 feet.

The quartz grains are subrounded to rounded, and show a high degree of sphericity. Feldspar is lacking in the Entrada, and the heavy mineral content (zircon, tourmaline, barite, anatase, rutile) is low. The suite suggests a sediment that has undergone more than one cycle of transportation and deposition. In total thickness the Entrada ranges from 40 to 75 feet; generally the lower unit varies from 30 to 55 feet, the upper from 5 to 20 feet.

The following stratigraphic section was measured on the west side of Leopard Creek, about 2.8 miles north of its confluence with the San Miguel River.

	Feet
Upper Jurassic:	
Wanakah formation at top: Basal unit, dense petroliferous limestone and limy sandstone of the Pony Express limestone member	3.5
Entrada sandstone:	
1. Sandstone, grayish-orange and yellowish-gray, fine- and medium-grained, well-sorted, limy, poorly cemented; pits and cavities due to weathering of clayey spots and zones; thinly bedded; contact with unit below irregular; contact with Pony Express member of Wanakah formation gradational in places	1.5
2. Sandstone; lithologically similar to unit 1, but very thickly and massively bedded; crossbedded; forms rounded cliff	20.0
3. Sandstone, greenish-gray, fine- to medium-grained, limy, well-sorted; vanadiferous, contains a few thin siliceous sandstone lenses; friable; slightly crossbedded	1.5
4. Sandstone, grayish-orange, fine-grained, moderately well sorted, thinly bedded; pale-greenish band (possibly chromium bearing) in middle	2.0
5. Sandstone, grayish-orange and very pale orange, fine-grained, moderately well sorted to well-sorted; massively bedded; large-scale tangential crossbeds in upper two-thirds; medium to coarse frosted quartz grains follow crossbeds and are scattered throughout, mostly in lower 8 feet and from 18 to 25 feet above base; greenish cast near top of unit; forms massive rounded cliff; contact with underlying Dolores formation transitional because of reworking, but marked by lowest appearance of frosted quartz grains	45.0
Total thickness of Entrada sandstone	70.0
Erosional unconformity.	
Triassic: Dolores formation: Grayish-orange and pale-greenish-yellow very fine grained sandstone at top.	

The erosional unconformity at the base of the Entrada sandstone represents a long period during which the Moenave, Kayenta, Navajo, and Carmel formations of the Colorado Plateau were deposited. The

Pony Express limestone member of the Wanakah formation conformably overlies the Entrada in the eastern part of the quadrangle. The contract is generally sharp, although in places there is gradation between the units and the Entrada appears to interfinger with the Pony Express on a small scale. The Pony Express limestone member pinches out to the west, near the middle of the quadrangle. West of this pinchout the Bilk Creek sandstone member of the Wanakah formation conformably overlies the Entrada, and the contact, although sharp and marked on the outcrop by a small erosional niche, is inconspicuous. The upper surface of the Entrada is slightly irregular; a few broad channels or scours, 1 to 2 feet deep, are present. With only short gaps in exposure the Entrada sandstone can be traced into the much thicker Entrada of Utah, and there is little doubt of its correlation with the Entrada of the type section.

The basal few feet of the Entrada sandstone was deposited on a subaerial plain of very low relief. The top of the Dolores formation was reworked into the Entrada along the shallow drainages, and aeolian sand was deposited on the interstream divides. Thereafter the bulk of the formation in the Placerville area was deposited by wind. Large scale crossbeds of an aeolian type predominate, but they are truncated by flat bedding planes that may represent the advance and retreat of large shallow bodies of water. Drainages were widely separated and ephemeral, as few characteristics of fluviatile sandstones are present. Thus the sediments may have been deposited largely as beach sands and dunes near the margin of a large embayment. In eastern Utah, marine deposits of Late Jurassic age underlie and overlie the Entrada sandstone; the embayment may have been a part of this marine invasion. Fluviatile conditions were reactivated during deposition of the upper part of the Entrada, causing the deposition of thin evenly bedded sandstone characteristic of quiet streams flowing near base level. Ripple marks are present at places in the upper standstone beds. In a few places the uppermost part of the Entrada intergrades with the overlying Pony Express limestone member of the Wanakah formation, suggesting an oscillatory migration of the strand line as the shallow brackish water margin of the embayment in which the Pony Express was deposited advanced over the area. In the Placerville district the direction of advance appears to have been from the east and southeast.

WANAKAH FORMATION

The Wanakah formation is composed of three thin lithologic units: the Pony Express limestone member at the base, the Bilk Creek sandstone member, and the marl member at the top. Largely because these units are too thin to be represented satisfactorily at the scale of the accompanying geologic map (pl. 4), they are not differentiated on the map. Some evidence, as is brought out below, is available to indicate that the individual members correlate with rock units that are considered to be formations elsewhere in southwestern United States.

A measured section of the Wanakah formation is given at the end of the description of the marl member.

PONY EXPRESS LIMESTONE MEMBER

The Pony Express limestone member is present in the eastern half of the Placerville quadrangle, along the north side of the San Miguel canyon east of Placerville, and along Leopard Creek (pl. 4 and fig. 16). The limestone pinches out along the west side of Leopard Creek, about 1 mile north of Placerville, and the line of the pinchout apparently trends northward from this point and is concealed below Iron Springs Mesa. Southeastward the line of the pinchout extended across the course of the present river valley and has been removed by erosion. Wherever it is exposed, the Pony Express crops out as a thin vertical cliff.

Throughout most of the San Juan Mountains the unit is a bluish-black to grayish-black dense unfossiliferous microcrystalline limestone, with a fetid petroliferous odor from freshly broken surfaces. Near the base the limestone is commonly sandy, and in places it appears gradational into very limy sandstone of the Entrada. The unit is very thin bedded and the individual beds are "crinkly" or undulant, showing a type of ripple bedding. Characteristically its outcrop shows a mosaic or psuedo-breccia of small slabby blocks. Gypsum and bluish shale interbeds are increasingly common to the east, toward the deeper parts of the basin in which the Pony Express was deposited, but are absent in the Placerville quadrangle. Fossils of a possible marine fish fauna have been reported by Read and others (1949) from the Piedra River area, Archuleta County, Colo. J. B. Reeside, Jr. (written communication, June 20, 1956) reports that these fish have been identified by D. H. Dunkle as marine Jurassic, and that ostracodes occur at Durango, Colo.

The thickness increases irregularly eastward from the pinchout line (where the limestone grades into a thin, very limy sandstone) to about 8 or 9 feet at the southeastern corner of the quadrangle. In general both the basal contact with the Entrada sandstone and the upper contact with the Bilk Creek sandstone member are sharp. In a few places the Bilk Creek has filled desiccation cracks in the upper surface of the Pony Express.

The name Pony Express was first applied to the basal unit in the Wanakah member of the Morrison formation (Burbank, 1930), and later was raised in rank to a member of the Morrison formation (Goldman and Spencer, 1941). It is now considered to be a member of the Wanakah formation (Eckel, 1949). The constantly increasing information available from geologic mapping indicates that the Pony

Express is a distinct continuous unit, recognizable over an area of a thousand square miles or more. With relatively small gaps in exposure the Pony Express can be traced into, and correlated with, the Todilto limestone of New Mexico and eastern Arizona.

The Pony Express limestone member was deposited as a chemical precipitate in a shallow, but broad, brackish-water arm of the Todilto sea. In the Placerville district the inundation proceeded from the east or southeast, with the deeper parts of the basin apparently in the vicinity of Ouray and southward. Ripple bedding and the psuedo-brecciation of the limestone, which probably is due to desiccation cracking, suggest the shallowness of the water. Possibly the area of deposition was a type of broad tidal flat, subject to periodic inundation and desiccation, with brackish-water ponds recurrently trapped on its surface.

BILK CREEK SANDSTONE MEMBER

Throughout the Placerville quadrangle the Bilk Creek sandstone member of the Wanakah formation crops out as a rounded cliff or as thin rounded ledges making a moderate slope. In the eastern half of the quadrangle it lies upon the Pony Express limestone member. To the west the Bilk Creek rests upon the Entrada sandstone; from a distance the cliffs formed by the two formations appear to merge into a single unit.

The sandstone is composed mainly of fine-grained and very fine grained quartz grains, with a higher clay content than the underlying Entrada. Feldspar is absent and the chert content is low. Calcareous cement is present throughout the formation and is abundant in some zones. The sand grains have a high degree of sphericity and are rounded, and as a whole the unit is moderately well sorted. Commonly the Bilk Creek is light colored—greenish, yellowish, or brownish gray—and in places it has faint pink or purple hues. The unit is thinly and evenly bedded and horizontally stratified, but in a few places there are faint small-scale low-angle cross-strata. The heavy-mineral suite includes barite, zircon, tourmaline, rutile, and anatase. Disseminated pyrite grains are present in some places in the sands.

At the top of the Bilk Creek sandstone member is a distinctive thin blocky remarkably persistent reddish sandstone, the carnelian sandstone of Cross and Purington (1899) and of Goldman and Spencer (1941). It ranges in thickness from 1 to rarely 3 feet, and it is generally 2 to 2½ feet thick. It is fine to medium grained, with some coarse grains, and is poorly sorted. The term "carnelian" derives from the widespread occurrence of red chert grains, many of which are autochthonous, throughout this thin unit. The carnelian sandstone is present throughout the quadrangle, and over an additional area of several hundred square miles to the east and south.

The Bilk Creek sandstone member ranges in thickness from 15 to about 40 feet; the average thickness is slightly under 30 feet. Generally the member is thickest in the southeastern quarter of the Placerville quadrangle. The contact with the underlying beds is sharp and planar in almost all exposures. In a few places in the eastern part of the quadrangle, where the unit lies on the Pony Express limestone member, sand grains of the Bilk Creek have filtered down into desiccation cracks in the Pony Express. The contact with the Entrada sandstone in the western part of the quadrangle is also sharp, although it is inconspicuous because of the lithologic similarity between the upper part of the Entrada and basal part of the Bilk Creek. Characteristically, however, the contact is marked by an erosional niche cut in the usually rounded cliff. At the top of the carnelian sandstone the contact with the overlying marl member is everywhere sharp and planar.

In previous reports the Bilk Creek has been considered to be a member of the Morrison formation (Goldman and Spencer, 1941) and as a member of the Wanakah formation (Eckel, 1949). It is a distinctive, traceable, and continuous unit over a large area, recognizable from Ouray southward to Durango and from the La Plata Mountains eastward beyond the Animas River. Goldman and Spencer (1941) identified the unit in McElmo Canyon, west of the La Platas, and at Uravan, west of the Placerville area. The member appears to correlate with the lower part of the Summerville formation of the Colorado Plateau.

The sediments of the Bilk Creek sandstone member were laid down on a broad, flat plain under conditions similar to those of the upper part of the Entrada sandstone. Deposition was largely from sluggish streams flowing very close to base level. Much of the deposition may have taken place in a shallow arm of the sea, similar to but more extensive than the Pony Express sea. The thin but extremely persistent carnelian sandstone at the top of the member probably was deposited entirely in the seaway, within reach of the wave base, and its sediments were constantly reworked and spread over the sea floor as an even, uniform blanket. It seems certain that this unit represents a time plane over its entire area of deposition.

MARL MEMBER

In this paper the marl member of the Wanakah formation refers to the section of fine-grained limy beds overlying the Bilk Creek sandstone member and underlying the Morrison formation. In all exposures the marl member forms a steep slope, mantled by a rubble of small, 1 to 2 inch, equidimensional blocks. A few thin sandstones form intermittent ledges in the slope. In a few places the upper part of the marl forms a steep cliff, where it is protected by the overlying Morrison.

The term "marl" is probably somewhat misleading as the descriptive lithologic adjective to be applied to the upper member of the Wanakah formation. Generally the unit is not as limy as the term "marl" implies. Many of the beds are only moderately calcareous; the abundantly calcareous beds are in most places few in number. Limy siltstone appears to be a far more accurate descriptive term.

The bulk of the member consists of limy siltstone units which range in color from yellowish and greenish shades of gray to various hues of reddish brown. The silts are poorly sorted to moderately well sorted, and in many places they contain very fine grained and fine-grained sand. Quartz is the major constituent, and small amounts of chert and feldspar also are present. Red chert grains are a distinctive accessory mineral, particularly in thin sandstone interbedded with the siltstone. Thin lenticular silty limestone units are present in a few places throughout the unit. The siltstone units are thin to thick bedded and irregularly stratified. They are limy, in places very limy, and nodular weathering is generally common. The thin sandstone units are very fine grained and fine grained, moderately to poorly sorted, thinly and regularly bedded. Individual beds of sandstone are not persistent; laterally they grade into sandy siltstone.

The marl member ranges in thickness from 37 to 65 feet; the average thickness is 50 to 55 feet. The contact with the underlying Bilk Creek sandstone member is sharp, planar, and conformable. The contact with the overlying Morrison formation is also sharp, but in numerous places is marked by an irregular surface with a detailed relief of a few feet.

The limy siltstone units were first named by Goldman and Spencer (1941) who designated them as the Wanakah marl member of the Morrison formation. Eckel (1949) and Read and others (1949) refer to it as the marl member of the Wanakah formation. The marl member correlates with at least a part of the Summerville formation of the Uravan area, Colorado, and of the Colorado Plateaus to the west. It may correlate with all of the Summerville formation at Uravan.

The marl member of the Wanakah formation was deposited in a shallow marginal area of the Summerville sea to the west. The source of the sediments may have been the low-lying highland masses to the north and east, which contributed only very fine detritus to the basin of deposition.

The following stratigraphic section of the Wanakah formation was measured on the west side of Leopard Creek, about 2.8 miles north of the confluence with the San Miguel River.

	Feet
Upper Jurassic:	
Morrison formation at top: Basal unit, evenly bedded, yellowish-orange and yellowish-brown, fine-grained to very fine grained sandstone	10
Wanakah formation:	
Marl member:	
1. Sandstone (carnelian), yellowish-gray, fine- and medium-pale red, grayish red; variably limy, nodular weathering very common; thinly bedded and irregularly bedded units alternate; sandy and muddy siltstones common; thin even-bedded muddy siltstones and some thin sandstone in upper 6 feet, nearly fissile; a few thin (1–2 feet) very fine grained, blocky, grayish-green sandstone beds scattered throughout section; forms rubbly slope	26
2. Covered interval, probably gray and red siltstone	18
Thickness of marl member	44
Bilk Creek sandstone member:	
1. Sandstone (carnelian), yellow-gray, fine- and medium-grained, well-sorted; single bed, blocky; rounded at top; numerous and distinctive autochthonous red chert grains; forms persistent ledge	2
2. Sandstone, light greenish-gray and light yellowish-gray, very fine grained and fine-grained, limy; infrequent limonite spots; well sorted; massively bedded, thickly laminated; forms rounded spalling or slabby cliff	15
3. Sandstone, similar to unit 2 above; alternately moderately well sorted and well-sorted; limonite spots; massively bedded, but very thinly and irregularly laminated and parted; forms slabby cliff; contact with unit below sharp but irregular	12
Thickness of Bilk Creek sandstone member	29
Pony Express limestone member:	
1. Limestone, blue-gray, dense, microcrystalline, petroliferous; has fetid odor on fresh surfaces; nonfossiliferous; thinly bedded, has characteristic outcrop of "biscuit-shaped" crinkly blocks; forms vertical ledge	3
2. Sandstone and limestone; interbedded dark-gray to grayish-black, very fine grained and fine-grained, very limy sandstone and dense, microcrystalline blue-gray petroliferous limestone; crinkly bedding prominent; units 1 and 2 form short vertical cliff; contact with Entrada sandstone gradational in places	1
Thickness of Pony Express limestone member	4
Total thickness of Wanakah formation	77
Entrada sandstone: Grayish-orange and yellowish-gray, thinly and thickly bedded, crossbedded, fine- and medium-grained sandstone.	

MORRISON FORMATION

The Morrison formation makes up about 80 percent of the total thickness of Upper Jurassic rocks in the Placerville quadrangle. They crop out as a thick steep band of ledgy cliffs and poorly exposed slopes and form the upper valley walls of all the drainages throughout the quadrangle.

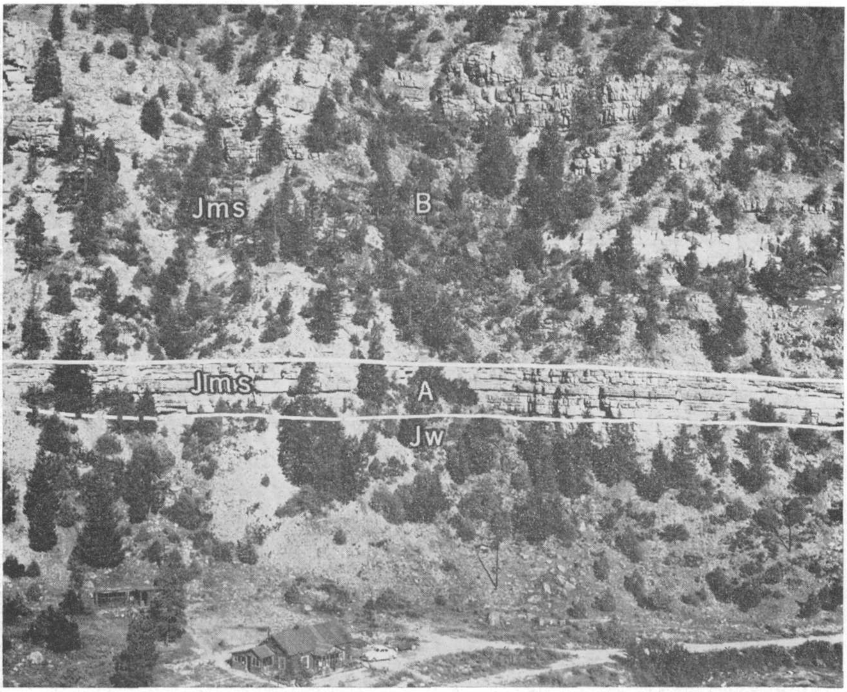
The formation is composed of the basal Salt Wash sandstone member and the overlying Brushy Basin shale member. The members contrast quite markedly throughout the Colorado Plateau, but particularly so in the western San Juan Mountains. The formation is variable in thickness, ranging up to 755 feet, but averaging about 700 feet. A measured stratigraphic section of the formation is given at the end of the description of the Brushy Basin shale member.

SALT WASH SANDSTONE MEMBER

The Salt Wash is dominantly a thick complex of interbedded lenticular sandstone, siltstone, and mudstone, with a few tens of feet of thin persistent horizontally bedded sandstone at the base. Thin limestone lenses are present in a few places near the base, and the entire Salt Wash member is abundantly limy. In the Placerville quadrangle the sandstone and siltstone units comprise from 70 to 85 percent of the section; they are commonly exposed as cliffs and ledges. The sandstone is very fine grained to medium grained, mostly fine and medium grained. The grains are rounded to well rounded, and have a high degree of sphericity. Most of the sand is moderately well to well sorted. The most abundant constituent is quartz; small amounts of chert and a very little feldspar are present. The heavy-mineral suite includes zircon, tourmaline, anatase, rutile, barite, leucoxene, ilmenite, and magnetite. Gray-green and red-brown clay is abundant throughout the sandstone of the Salt Wash as disseminated flecks and as galls concentrated along bedding or crossbedding planes. Thin lenticular mudstone seams are also numerous in the sandstone. Bone fragments are present in many places, and accumulations of plant fossils occur in the thicker sandstone units.

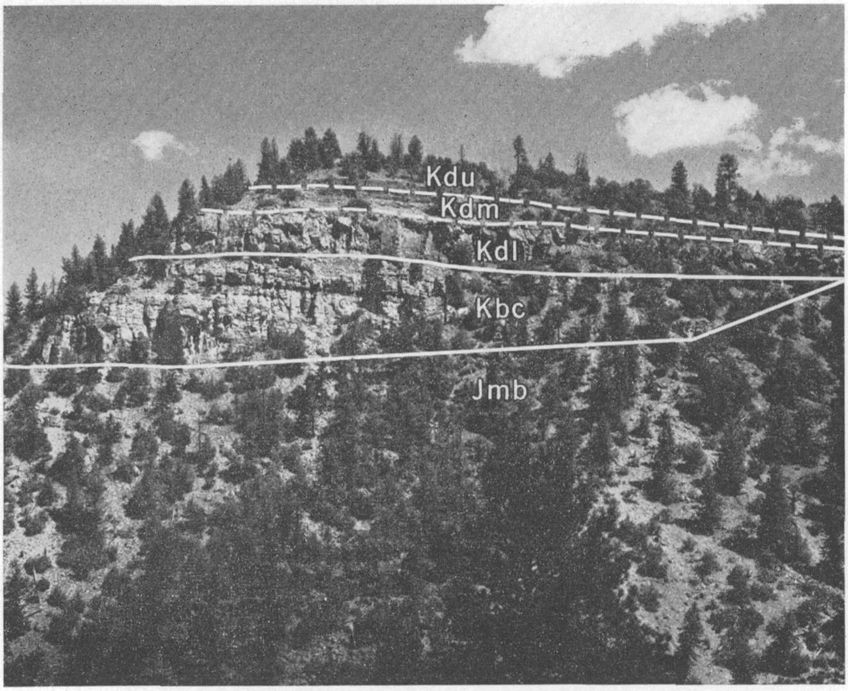
Above the basal few feet the sandstone beds are lenticular, ranging in length along the outcrop from a few tens of feet to a few hundred feet. Individual lenses vary from a few feet to as much as 25 feet in thickness. They are thin to thick bedded, irregularly bedded, and many of the lenses are cross-stratified. Cut-and-fill structures and channels filled with sandstone are abundant. Thin relatively even bedded sandstone is present in small amounts, interbedded with mudstones and siltstones. Generally the sandstone is light colored, light yellow brown, buff, or pale shades of grayish orange and pink.

The mudstone and siltstone beds are dominantly red or red brown, but in many places they are various shades of gray or green. Field



SALT WASH SANDSTONE MEMBER OF THE MORRISON FORMATION

Even-bedded persistent sandstone unit, *A*, at base of Salt Wash sandstone member of the Morrison formation, overlain by typical irregularly bedded, lenticular sandstone and mudstone beds, *B*, of the Salt Wash, *Jms*. The even-bedded unit, *A*, may correlate with the Junction Creek sandstone of southwestern Colorado. Wanakah formation, *Jw*, at bottom of photograph. West side of Leopard Creek, south of Alder Creek.



RELATIONSHIP OF THE MORRISON AND BURRO CANYON FORMATIONS AND THE DAKOTA SANDSTONE AT THE CONFLUENCE OF ALDER AND LEOPARD CREEKS

The Burro Canyon, *Kbc,* fills a broad channel (here 70 feet deep) cut in the Brushy Basin shale member of the Morrison, *Jmb,* and is overlain by the Dakota sandstone. The basal part of the Dakota is a thick sandstone ledge, *Kdl,* overlain by a sequence of coaly and carbonaceous shale beds, *Kdm,* and at the top by interbedded thin sandstone and shale beds, *Kdu.*

relations suggest this change to be one of alteration from the red, and laboratory studies by Weeks (1951) indicate that the color change is due to the reduction of ferric to ferrous iron in the clay.

Generally the uppermost 80 to 100 feet of the Salt Wash sandstone member contrasts markedly in proportion of mudstone to sandstone with the lower part of the Salt Wash. In most places 50 to 70 feet of red-brown argillaceous siltstone or silty mudstone overlies the dominantly sandstone section below. In this part of the member sandstone is minor in amount, thin and even bedded, though lenticular. Above this is a 15 to 30 feet thick lenticular crossbedded sandstone ledge, identical in character with the heavy sandstone of the underlying Salt Wash. This assemblage is persistent throughout the quadrangle, although the sandstone ledge is not a single continuous stratum. The upper boundary of the Salt Wash is placed at the top of this sandstone, although the sandstone probably varies in stratigraphic position within a range of about 25 feet, and in places is apparently absent.

The Salt Wash sandstone member ranges from about 300 to 365 feet in thickness, but commonly it is about 320 feet thick. It lies conformably on the Wanakah formation, on a slightly irregular surface. The contact with the overlying Brushy Basin shale member of the Morrison formation is more difficult to locate, as the uppermost typical sandstone of the Salt Wash is not a continuous stratum. In general, deposition appears to have been continuous, or with only short intervals of erosion, between the Salt Wash and Brushy Basin members.

The Salt Wash member was deposited by aggrading braided streams on a large alluvial plain or fan (Craig and others, 1955). The thick crossbedded lenticular sandstone represents channel deposition; the thin-bedded sandstone, mudstone, and siltstone largely represent deposition on the flood plain lateral to the channels during times of widespread flood. The highland masses that were positive elements all through the early part of the Late Jurassic epoch were submerged during Morrison time, and deposition was continuous across their sites. Craig and others (1955) consider the source of sediments of the Salt Wash to have been southwest of south-central Utah, probably in west-central Arizona.

The evenly and horizontally bedded persistent sandstones at the base of the Salt Wash contrast markedly with the rest of the member (pl. 6). They form a distinct continuous unit that can be traced throughout the Placerville and adjoining quadrangles. In the Placerville quadrangle the unit ranges from 8 to 28 feet in thickness; about 15 miles south of Placerville it is 55 to 60 feet thick. The relationship of the unit to the Junction Creek sandstone of Goldman and Spencer (1941) has not been determined, but the unit appears to be absent where typical Junction Creek is present. The unit may be a facies of the Junction Creek, with the sediments deposited in, and reworked by, the waters of a waning Late Jurassic seaway.

BRUSHY BASIN SHALE MEMBER

Exposures are consistently poor on the steep slopes formed by the Brushy Basin shale member, for the member generally supports a dense growth of pinyon pine, cedar, and scrub oak. Talus from the overlying Cretaceous rocks also mantles the slopes.

The member is composed dominantly of mudstone, interbedded with thin sandstone, siltstone, lenses of conglomeratic sandstone, and a very few thin discontinuous limestone beds. The mudstone is variegated, generally with shades of red, green, purple, and gray, of which red is most common. They are characterized by a high sand and silt content, but individual units grade from limy claystone to limy siltstone. Bentonitic clays of probable volcanic origin form an important part of the claystones and mudstones. Generally the mudstones are thinly to very thinly and irregularly bedded. Thin blocky sandstones interbedded with the mudstone are characteristically red, limy, and fine to very fine grained, and in places they are cemented by silica. Lenses of conglomeratic sandstone fill channels within the member; they are few in number and small in extent, though they attain a thickness of 5 to 15 feet. Characteristically the gravel ranges as large as pebble size; small grains of red, green, and purple chert are common.

The Brushy Basin shale member ranges in thickness from about 330 to 390 feet. The contact with the underlying Salt Wash sandstone member has been placed at the top of the uppermost channel-filling sandstone typical of the Salt Wash, and where this sand is absent it has been arbitrarily placed at about the same stratigraphic horizon. Deposition was essentially continuous from Salt Wash through Brushy Basin time. Throughout most of the area the Brushy Basin is overlain by the Dakota sandstone of Late Cretaceous age along an erosion surface of low relief which marks a probable disconformity. In places, however, a thick lenticular channel-filling conglomerate or conglomeratic sandstone intervenes between the Brushy Basin and the Dakota. This unit is considered to be equivalent to the Burro Canyon formation of Early Cretaceous age of southwestern Colorado and southeastern Utah (Stokes and Phoenix, 1948). Where the Brushy Basin is overlain by the sandstone of the Burro Canyon or the Dakota the contact is sharp and easily discernible although in many places not well exposed. However, gray and green mudstone and claystone are interbedded with sandstone of the Burro Canyon, and where the sandstone is absent they cannot be differentiated from the Brushy Basin.

Craig and others (1955) suggest that the source of the Brushy Basin member was largely in west-central Arizona, although there may have been some contribution of sediments from other areas. The sediments were deposited on an alluvial plain in a fluvial and lacustrine environment. Volcanic ash falls also contributed to the sediments, and many of the ash deposits were reworked and redeposited.

The following stratigraphic section of the Morrison formation was measured on the west side of Leopard Creek, about 3.3 miles north of its confluence with the San Miguel River.

	Feet
Lower Cretaceous: Burro Canyon formation at top. Basal unit cross-bedded grayish-yellow-orange sandstone; fine and medium grained, grading laterally into chert-rich conglomerate	8
Erosion surface.	
Upper Jurassic:	
Morrison formation:	
Brushy Basin shale member:	
1. Siltstone and mudstone, purple; some gray and green at top; few thin very fine grained sandstones. Forms slope broken by a few ledges	24
2. Siltstone, muddy siltstone, and some sandstone, grayish-green and light olive-gray, nodular weathering; some gray, green, and olive-gray somewhat bentonitic mudstone; a very few thin very fine grained limy sandstones. Forms slope broken by a few discontinuous ledges	66
3. Mudstone and some siltstone; red in lower 10 feet; green and gray in central 30 feet; green, gray, purple and light olive gray to top; olive-gray limy siltstone at and below center of unit; some thin very fine grained sandstone; siltstone and mudstone intergradational; mudstone somewhat bentonitic. Forms smooth slope	51
4. Mudstone and siltstone, grayish-green and light olive-gray; some moderate red; about 30 percent siltstone, nodular weathering; mudstone somewhat bentonitic; some thin very fine grained sandstone. Forms ledgy slope	49
5. Siltstone, moderate red and pale-green, limy. Forms rubbly, nodular ledge	8
6. Siltstone and sandstone, interbedded; siltstone (40 percent of unit), purplish- and grayish-green; mudstone, pale-red, moderate-red, light-gray and medium-gray. Forms slope	37
7. Mudstone and siltstone, interbedded; mudstone about 75 percent of unit, generally red, some purple, green, and grayish green, limy and silty; siltstone limy and thinly bedded; green, grayish green, and reddish; thin red limestone lens above center. Forms slopes with a number of nodular weathering ledges	44
8. Siltstone and mudstone, interbedded, about equal proportions; similar to unit 6. Forms ledgy slope	9
9. Mudstone and siltstone; similar to unit 7, but contains a few very fine grained, reddish sandstone lenses. Forms slopes and ledges	85

	Feet
Upper Jurassic—Continued	
Morrison formation—Continued	
Brushy Basin shale member—Continued	
10. Sandstone and siltstone, interbedded; sandstone is reddish, very fine grained, limy, thinly bedded, blocky; siltstone is brownish gray; limy; small amount of reddish mudstone. Forms series of small ledges	17
Thickness of Brushy Basin shale member	390
Salt Wash sandstone member:	
1. Sandstone, grayish-yellow-orange, medium-grained; conglomeratic at base, with stringers of clay and chert as granules and pebbles; limy, abundant limonite spots; thinly to thickly bedded; thinly to very thinly parted; crossbedded. Forms series of ledges	18
2. Siltstone and mudstone, interbedded; light olive-gray and pale-red siltstones in lower 10 feet, with some red sandy mudstone and reddish very fine grained sandstone; silty reddish-brown mudstones and limy siltstones in upper 6 feet; thinly to very thinly bedded in lower unit. Forms slope	16
3. Mudstone, moderate red, some grayish-green, slightly silty; interbeds of light olive-gray limy siltstone; blocky, rounded weathering; reddish very fine grained sandstone near top. Forms slope with a few ledges	47
4. Sandstone, grayish-yellow-orange; ranges from fine grained in lower 30 feet to medium grained in upper 15 feet; thinly bedded, thinly parted; lower 30 feet crossbedded; reddish and some greenish mudstone interbeds at and above center, clay flecks and galls. Entire unit limonitic; interfingers with unit below and forms steep ledgy cliff	52
5. Sandstone, mudstone, and limy siltstone; interbedded in about equal proportions; sandy mudstone is reddish and purplish; sandstone fine and fine to medium fine grained, grayish green with orange cast, very lenticular, nodular weathering, thinly and very thinly bedded, very thinly parted, crossbedded; limy siltstone is gray, grayish green and purplish. Forms steep ledgy slope	20
6. Sandstone, grayish-yellow-orange, fine-grained; some clayey interbeds, abundant limonite spots, thickly bedded, irregular and lenticular, crossbedded. Forms ledgy cliff	35
7. Mudstone, reddish-brown and grayish-red; some silty mudstone layers; thinly bedded, nodular and orbicular weathering, limy; lenticular; some pale olive-gray siltstone in upper 4 feet. Forms slope	10
8. Covered interval	12
9. Sandstone, grayish-yellow-orange and light brown, fine- to medium-grained; limonite spots; thinly to thickly bedded, very thinly parted at top (shaly); crossbedded. Forms ledgy cliff	9

	Feet
Upper Jurassic—Continued	
Morrison formation—Continued	
Salt Wash sandstone member—Continued	
10. Siltstone, reddish cast, argillaceous, fine-grained; with some red mudstone interbeds; greenish clay near top	11
11. Sandstone, grayish-orange-pink and pale greenish-yellow; reddish cast; dominantly fine grained, limonitic, clayey; thickly bedded, irregular, very thinly to thinly parted. Forms slabby cliff	9
12. Sandstone, grayish-orange-pink, pale greenish-yellow, dominantly fine grained; some very fine grained zones; limonitic; massively bedded, abundantly crossbedded on large scale. Forms smooth, rounded cliff like those of Entrada sandstone; not characteristic of Salt Wash	47
13. Sandstone, pale yellowish-orange, fine-grained; limonite spots; thin interbeds of grayish-green mudstone; "warty" weathered surfaces common; mostly thinly to very thinly bedded, some thickly bedded; lenticular and interfingering; very thinly parted; cross bedded at moderate angles. Forms steep ledgy cliff	42
14. Sandstone, pale yellowish-orange, fine- to medium-grained; some silty mudstone interbeds; thinly and irregularly bedded; poorly exposed. Forms steep slope	11
15. Sandstone, pale yellowish-orange, fine- and medium-grained; abundant limonite spots; thickly bedded at base, thinly to very thinly laminated in upper 9 feet; few thin mudstone interbeds; ripple marked at top; even bedded. Forms steep and ledgy cliff	14
16. Sandstone, clayey sandstone, and silty mudstone; interbedded clayey zones are greenish; mudstone is grayish green or gray	3
17. Sandstone, pale to dark yellowish-orange and pale or light yellowish-brown, very fine grained to fine-grained, limy; abundant limonite spots; few thin clayey zones; thinly to thickly bedded; even bedded, but in a few places with faint, low-angle crossbeds. Makes continuous blocky cliff	9
Thickness of Salt Wash sandstone member	365
Total thickness of Morrison formation	755
Wanakah formation (marl member): Brownish and reddish limy siltstone and some thin very fine grained blocky sandstone.	

CRETACEOUS SYSTEM

The Cretaceous rocks of the Placerville quadrangle form the uppermost parts of the steep canyon walls and underlie all of the upland surfaces. The stratigraphic section, in ascending order, consists of the discontinuous Burro Canyon formation of Early Cretaceous age, the Dakota sandstone, and the Mancos shale of Late

Cretaceous age. Their aggregate thickness in the quadrangle is about 650 feet.

LOWER CRETACEOUS SERIES

BURRO CANYON FORMATION

Discontinuous lenses of the Burro Canyon formation are present in a few places within the Placerville quadrangle particularly along the western border and near the confluence of Leopard and Alder Creeks (pl. 7). The formation was not mapped separately in the field, and is included with the Brushy Basin member of the Morrison formation in plate 4. Commonly the unit crops out as a thick ledge, forming a steep to vertical massive cliff, underlying very similar cliffs developed on the basal ledge of the Dakota sandstone.

The Burro canyon formation is comprised of conglomerate and conglomeratic sandstone, which grade into one another, with a minor amount of interbedded gray and green mudstone and siltstone. The conglomeratic gravel consists of granules and pebbles of chert, quartz, sandstone, and quartzite. The matrix is generally medium grained; as a whole the unit is poorly to moderately sorted. White, yellow, and buff chert fragments are abundant, and a minor amount of weathered feldspar is present. The sandstone or conglomerate is commonly massive, thick bedded, and cross-stratified at a relatively low angle. The basal part of the Dakota sandstone is very similar in lithology to the Burro Canyon, but its interbedded mudstone and siltstone beds contain fossil plant material in abundance. In isolated exposures the association of gray or green mudstone or siltstone in the Burro Canyon is the criterion for discriminating it from the Dakota.

The lenticular, channel-filling Burro Canyon formation ranges up to about 70 feet in thickness, but its extent along the outcrop is commonly only a few thousand feet, and in places only a few hundred feet. The formation is missing over a large part of the area. The fragmentary evidence available suggests that the channels in which the Burro Canyon was deposited have a northerly or northwesterly trend.

The Burro Canyon formation fills channels in the moderately dissected upper surface of the Brushy Basin shale member of the Morrison formation. It is possible that mudstone units of the Burro Canyon extend laterally beyond the channel fillings, and overlie mudstone of the Brushy Basin, but exposures are insufficient to allow tracing of these units beyond the channel-filling sandstone, and the mudstone of the two formations are too similar to be differentiated in isolated outcrops. The Dakota sandstone of Late Cretaceous age overlies the Burro Canyon, probably disconformably; the length of time represented by this erosional break can not be evaluated in the Placerville quadrangle.

The following stratigraphic section was measured on the west side of Leopard Creek, about 3.3 miles north of its confluence with the San Miguel River.

	Feet
Upper Cretaceous (Dakota sandstone) at top: Basal unit, fine- and medium-grained yellowish-gray sandstone and cherty conglomeratic sandstone, crossbedded, with plant fossils	21
Erosional unconformity(?).	
Lower Cretaceous:	
Burro Canyon formation:	
1. Sandstone and mudstone, interbedded; yellowish-gray sandstone with green and grayish-green mudstone; mudstone abundant in the upper 5 feet; massive sandstone at base, conglomeratic, with white chert grains and pebbles, crossbedded. Forms steep ledgy cliff	10
2. Mudstone, green and grayish-green; some light brown, sandy; variable in thickness along outcrop	5
3. Sandstone, grayish-yellow-orange, fine- and medium-grained, poorly sorted; conglomeratic in places, with white chert grains and pebbles; thickly bedded; crossbedded. Forms steep cliff	8
Total thickness of Burro Canyon formation	23
Erosion surface.	
Upper Jurassic:	
Morrison formation (Brushy Basin shale member): Interbedded reddish, purplish, grayish, and greenish muddy siltstone and mudstone, with a few thin, very fine grained sandstone beds.	

The Burro Canyon formation of the Placerville quadrangle is correlated with the Burro Canyon of the Uravan area, in Colorado, on the basis of its position between the Brushy Basin shale member of the Morrison formation and the Dakota sandstone, and on its lithologic similarity to part of the undoubted Burro Canyon (Stokes and Phoenix, 1948). Particularly diagnostic is the association of gray and green mudstone with the conglomeratic sandstone, in contrast to the association of dark organic mudstones, shales, and siltstones with the Dakota sandstone. In addition, plant fragments and other organic debris appear to be absent in the Burro Canyon rocks.

UPPER CRETACEOUS SERIES

DAKOTA SANDSTONE

Throughout the quadrangle the Dakota sandstone forms the rimrock of the major canyons. The formation is exposed for long stretches along the canyon rims of the San Miguel River, Specie Creek, Leopard Creek, and along McKenzie and North Creeks in the extreme northwest corner of the area. In addition the Dakota crops out over the major part of Hastings Mesa, Iron Springs Mesa, and Specie Mesa. Generally its upper surface forms a stripped plain, upon which there are small remnants of the Mancos shale.

The characteristic topographic expression of the Dakota sandstone reflects its three lithologic subdivisions (pl. 7). The massive basal sandstone of the Dakota forms a prominent cliff wherever it is exposed. A thin section of shaly beds above the basal sandstone forms a short slope. The interbedded sandstones and shales of the upper part of the formation form alternate slopes and ledges.

The basal unit of the Dakota sandstone is a massive generally crossbedded sandstone layer which averages about 40 feet in thickness. The sandstone is commonly light yellowish gray, fine to medium grained, and contains conglomeratic lenses and streaks. The conglomeratic lenses usually consist of subangular to subrounded granules and pebbles of white chert and quartzite. Thin gray to black carbonaceous mudstone seams are present at places in the sandstone.

The middle unit of the formation consists of 30 to 60 feet of interbedded dark-gray to black carbonaceous shale, siltstone, and some subordinate thin sandstone units. Locally, thin discontinuous coaly beds occur in this middle unit. One of these has been prospected along the north bank of Alder Creek, but none of the small coaly lenses has been attractive enough to invite systematic exploitation.

The upper unit is composed of 50 to 100 feet of alternating thin- to medium-bedded sandstone and carbonaceous shale. This unit characteristically weathers to a receding ledge and slope profile. The sandstone is well sorted, generally quartzitic, and blocky. Sand-trail markings characterize some bedding surfaces; worm borings are common. The interbedded shale, which is similar to the shale of the middle unit, makes up only a subordinate part of the upper unit. Toward the top of the formation, near its contact with the Mancos shale, the shale beds become dominant.

The Dakota sandstone overlies the Brushy Basin shale member of the Morrison formation, or locally the Burro Canyon formation, where the latter formation is present. The contact with either of the underlying formations is probably a disconformity, but there is no evidence in the Placerville quadrangle of the length of time involved. Where the Dakota overlies the Brushy Basin the contact is sharp, with little relief along its surface. The thick light-colored sandstone and conglomeratic sandstone of the Dakota contrasts strongly with the purple, green, and red mudstone of the Brushy Basin. Where the Dakota overlies the Burro Canyon the contact is more difficult to ascertain. The sandstone of the Burro Canyon is similar lithologically to the basal unit of the Dakota sandstone; however, they contain thin green mudstone seams in contrast to the dark gray or black carbonaceous mudstone of the Dakota. The contact, as mapped on this basis, shows little relief along its surface.

The contact between the Dakota sandstone and the overlying Mancos shale is conformable and appears to be gradational. The transition between the formations takes place over an interval of about 20 to 30 feet. It is marked by a decreasing proportion of thin sandstone and an increasing proportion of dark-gray to black shale. The sandstone in the lower part of the interval contains abundant carbonized woody fragments characteristic of Dakota sedimentation. Toward the top of this interval thin lenticular limestone beds are present and *Gryphaea newberryi* shells are common, both of which are considered to be diagnostic of the lower part of the Mancos shale in the western San Juan Mountains. In mapping, the uppermost prominent sandstone ledge was arbitrarily taken as marking the top of the Dakota sandstone. This ledge is 20 to 30 feet below undoubted Mancos shale.

The thickness of the Dakota sandstone is usually difficult to determine with certainty. In most places the Mancos shale has been stripped from above the Dakota sandstone, and a small but unmeasurable amount of the upper part of the Dakota has also been eroded. Elsewhere the contact of the Dakota and the Mancos is present on the mesa tops, and is generally covered by soil, or is at best poorly exposed and difficult to locate.

However, a fairly close estimate of the thickness of the Dakota sandstone can be made in at least two places where the overlying Mancos shale is present. The complete section of the Dakota is exposed in a small gully about 5,500 feet north-northwest of the Pocahontas mine, in the southeastern corner of the quadrangle (pl. 4). Here the Dakota is about 210 feet thick. Another exposure is on North Creek, in the extreme northwestern corner of the quadrangle, where the formation has a thickness of approximately 160 feet. Elsewhere, at places where most of the formation can be readily measured, the full thickness is not preserved; an unknown but probably small amount has been stripped off along with the Mancos shale.

The following partial section, considered to be representative of the Dakota standstone in the Placerville quadrangle, was measured on the north side of McKenzie Creek (pl. 4).

Top of mesa and exposure.

Upper Cretaceous:

Dakota sandstone:

	Feet
1. Small, but unknown thickness removed by erosion.	
2. Sandstone, yellow-brown, very fine grained; abundant dark carbonaceous streaks; thin bedded, flaggy toward top	7
3. Siltstone and very fine grained sandstone, yellow-brown; abundant dark carbonaceous streaks	3
4. Sandstone, light yellow-brown to light-gray, very fine grained to fine-grained, thick-bedded to very thick bedded; unit is blocky and forms ledge; a few muddy sandstone partings throughout unit	9
5. Siltstone and shale, dark-gray to black, carbonaceous	4
6. Sandstone, light yellow-brown, fine-grained to very fine grained, very thick bedded, massive. Forms blocky cliff	8

	Feet
Upper Cretaceous—Continued	
Dakota sandstone—Continued	
7. Siltstone, dark-gray to black, carbonaceous. Forms slope; weathers in small fragments	3
8. Sandstone, light yellow-brown, fine- to medium-grained, thin-bedded, slabby; abundant limonite spots and some carbonaceous partings	3
9. Shale and siltstone, black, carbonaceous. Forms covered slope	5
10. Sandstone, light yellow-brown, very fine grained, thin-bedded, slabby, thinly laminated; abundant black carbonaceous films along laminae surfaces	2
11. Siltstone and shale, black, carbonaceous. Forms covered slope	1
12. Sandstone, light-gray, very fine grained; abundant limonite spots and dark carbonaceous streaks. Weathers rusty brown; forms ledge	1
13. Siltstone, black, carbonaceous. Forms covered slope	1
14. Sandstone, light yellow-brown, fine-grained, thick bedded; forms blocky ledge; abundant iron oxide spots; weathers with iron-stained surface; carbonaceous streaks and films common; worm tubes(?) perpendicular to bedding	4
15. Sandstone, tan, fine-grained, thick-bedded; forms rounded weathered ledge; iron oxide spots common; carbonaceous streaks and films near top	3
16. Shale and siltstone, dark-gray to black, carbonaceous, very thin bedded; some fissile; many carbonaceous and woody fragmental remains, probably some thin coaly layers. Forms slope	37
17. Sandstone, light-gray to white, fine- to medium-grained; contains lenses and streaks of conglomeratic sandstone with granule- to pebble-size fragments of white chert and quartzite; very thick bedded, crossbedded. Forms massive cliff at base of formation	42
Partial thickness of Dakota standstone	133

Erosional unconformity.

Lower Cretaceous:

Burro Canyon formation: fine-grained light-colored crossbedded cherty sandstone and conglomeratic sandstone, with thin green silty partings.

No identifiable fossils were found in the Dakota sandstone in the Placerville quadrangle, so that the age of the formation here is not based on paleontologic evidence. However, where it is possible to differentiate the Burro Canyon from the Dakota, the Dakota is considered to be of Late Cretaceous age.

The environment in which the Dakota sandstone was deposited was partly continental, partly littoral. The crossbedded sandstone and conglomeratic sandstones of the basal part of the unit are dominantly of fluviatile origin, deposited on a low lying flat plain near the strand line of the advancing Late Cretaceous seas. The carbonaceous shales and thin coaly layers of the middle part of the Dakota were probably deposited in restricted lagoons formed along the edge of the marine embayment. The alternation of thin-bedded sandstone and carbonaceous shale in the upper part of the Dakota probably represents near-shore deposition in the marine waters of the Late Cretaceous sea.

MANCOS SHALE

The Mancos shale has been removed by erosion over most of the area of the Placerville quadrangle. It is seen only locally as thin erosion remnants on the mesa tops, or in downfaulted blocks (grabens) where the shale has been protected from erosion. Conspicuous examples of such protected masses are in the south end of Sheep Draw graben and in the Sawdust Gulch and Alder Creek grabens (pl. 4). The most prominent erosion remnant is at the south end of Hastings Mesa, in the southeastern corner of the quadrangle. Here, dioritic sills have been intruded into the Mancos shale and have retarded erosion. The topography developed on the Mancos shale is generally subdued and gently rolling. Outcrops are few, and the surface is usually covered with several feet of soil.

The Mancos shale in the Placerville quadrangle consists of a monotonous sequence of gray to black marine shale interspersed with a few thin lenticular limestone beds, some of which contain fossils. The shale is generally dark gray to black on fresh surfaces; it weathers light gray to olive drab, and it is typically fissile. Thin-bedded medium-gray to dark-gray limestone, that weathers to light gray or yellowish brown, occurs as lenticular and concretionary masses at several horizons. Very thin bedded gray coarsely crystalline fossiliferous limestone is found near the south end of Sheep Draw and in the Alder Creek graben between Alder Creek and Massy Gulch. This limestone, which may not represent a single continuous layer, is found 15 to 50 feet above the base of the formation.

At one locality in the northwest corner of the quadrangle a thin bentonitic layer is present near the base of the Mancos shale. Outcrops are poor, but at several points along a distance of one-quarter of a mile bentonitic material is found; its presence is manifested by the characteristic swollen crackly surfaces of the exposures.

The maximum thickness of Mancos shale remaining in the quadrangle probably does not exceed 400 feet or so. Thicknesses ranging up to 2,000 feet in adjacent areas to the south and east (Cross and Purington, 1899, p. 4), however, testify to the former presence of much greater thicknesses within the quadrangle. At least 300 feet of Mancos shale is present north of Alder Creek, within the Alder Creek graben, but this section is almost entirely concealed by soil cover. The most continuously exposed partial section is along the western side of

Sheep Draw, at its southern end. Here about 80 feet of section crops out. The base of the Mancos is not exposed, but it probably is not more than 80 feet beneath the base of this outcrop.

The following partial section of Mancos shale was measured at the south end of Sheep Draw, west of the stock ponds (sec. 23, T. 44 N., R. 11 W., pl. 4).

Top of hill and exposure.	
Upper Cretaceous:	
Mancos shale:	*Feet*
1. Very large but unknown thickness removed.	
2. Shale, dark-gray, fissile; a few fragments of very fine grained shaly light-gray to gray-green sandstone and siltstone; some very thin bedded saccharoidal to coarsely crystalline gray fossiliferous limestone float	40
3. Limestone, medium-gray; weathers yellow brown; dense; occurs as lenses	1
4. Shale; dark-gray with olive-green cast; poorly exposed; at 12 to 14 feet above base of unit some very thin bedded (¼–1 inch) float fragments of very fine grained sandstone and siltstone	17
5. Limestone, medium-gray; weathers yellow brown; dense; occurs as lenses	3
6. Abundant gray-shale float; a few fragments of very fine grained sandstone and siltstone, as in unit 4 above	20
Partial thickness of Mancos shale	81
Base of formation not exposed, but estimated at about 80 feet below last measured unit.	

The Mancos shale conformably overlies the Dakota sandstone. The contact is well exposed in only a few places and generally appears to be gradational. In the field the contact has been arbitrarily placed at the top of the highest thin-bedded light-colored sandstone containing organic material. Some of the overlying shale is carbonaceous and may properly belong with the Dakota sandstone. Thin limestone beds that carry *Gryphaea newberryi* are interbedded with the shale a few feet above the uppermost sandstone layer of the Dakota. These limestone beds are considered to be diagnostic of the basal part of the Mancos shale in the Placerville area.

QUATERNARY SYSTEM

PLEISTOCENE SERIES

GLACIAL DRIFT

Atwood and Mather (1932) have discussed the evidence for multiple glaciation in the San Juan Mountains and have distinguished three glacial stages. These they have designated the Cerro, Durango, and Wisconsin stages. Only the till considered to be correlative with the oldest of these, the Cerro till, has been recognized in the Placerville quadrangle, but terrace gravels situated on bedrock benches up to 200 feet above the San Miguel River may possibly be related to younger glacial or interglacial stages.

Only a few small remnants of till are still found in the area. Two small outcrops of undoubted glacial till are found on the mesa top west of the stock ponds at the south end of Sheep Draw (pl. 4); a third is present in the northeast part of the area on the east side of Gutshall Gulch. In addition to these remnants of glacial drift, scattered erratics are found, a few as far to the northwest as the corner of the quadrangle near Sawdust Gulch.

The drift, as characterized by the larger of the outcrops, ranges in thickness from a thin cover to a maximum of about 35 feet, and consists of a poorly sorted mixture of gravel ranging in size from granules to boulders as much as 15 feet in diameter. The larger boulders are rare, however, and those 1 to 3 feet in diameter predominate.

The rocks composing the till are all foreign to the quadrangle and are overwhelmingly of igneous origin. In the size range from 1 to 3 feet, boulders of dark-gray to black vesicular basalt are most abundant, followed by dark-gray andesite and pale-red to pale-purple felsite porphyry. In the granule- and pebble-sized ranges the felsite porphyry type is most common; the scarce but extremely large boulders are also of pale-red felsite porphyry.

These rocks represent, in general, the upper part (the Silverton and Potosi volcanic series of Tertiary age) of the thick volcanic pile that forms the nearby main mass of the San Juan Mountain region. The San Juan tuff and the Telluride conglomerate, also of Tertiary age, which are now well exposed on the mountain slopes beneath the Silverton and Potosi volcanic series, are not represented in the rocks observed in the drift. Atwood and Mather (1932) generally attribute their absence to the stage of erosion that had been reached in the early San Juan Mountains at that time. It is difficult to see how the Telluride conglomerate and the San Juan tuff could have escaped exposure and erosion at a time when the underlying Mancos shale was being eroded at the foot of the mountains, and the overlying Silverton and Potosi volcanic series were being eroded in the mountains. Regardless of the amount of regional or differential uplift the difficulty remains.

An alternative explanation might be that the Telluride conglomerate and the San Juan tuff were exposed and eroded, but their resistance to erosion and weathering was so low that they were selectively removed from the glacial drift, both during glacial transport and by weathering since deposition. A minor piece of contributary evidence supporting this hypothesis is the relative scarcity of fragments of the

Telluride and San Juan in the terrace gravel and Recent alluvium a few miles from the present-day precipitous mountain front.

The basaltic boulders in the glacial drift may have been derived from a relatively small, thin flow that is present on the surface of Specie Mesa, about 5 miles south of the large drift area at the south end of Sheep Draw. The occurrence is in the adjoining Little Cone quadrangle. The age of the basalt is as yet not definitely know. The flow covers what is essentially the present erosion surface, although a small amount of denudation has probably taken place. Such relations allow for an age ranging from older than the Cerro stage (early Pleistocene) to as young as Recent. Atwood and Mather (1932) also mention the widespread occurrence of basaltic boulders in the Cerro drift. They attribute them largely to erosion of volcanic rocks of the Hinsdale formation, which they state was deposited on the surface of the San Juan peneplain. The original extent of the Hinsdale formation in the western San Juan Mountains is not known; the possibility that the basaltic boulders in the glacial drift of the Placerville quadrangle were derived from the Hinsdale can thus be advanced only as a speculation.

The Cerro glaciation was the most extensive of the three Pleistocene glacial stages that have been recognized in the San Juan region. The ice was not restricted to the valleys, but spread over the lower divides and moved across the lowland areas adjacent to the mountains (Atwood and Mather, 1932, p. 28). The deposits in the area mapped represent remnants of more widespread morainal drift, believed to be a product of the piedmont glaciers of the Cerro glacial stage. Concentrations of the glacial drift in the Placerville quadrangle are about 7 and 11 miles respectively from the Last Dollar Range to the east and the San Miguel Mountains to the south. Glacial erratics presumably of the same stage extend several miles farther from the mountain masses.

TERRACE-GRAVEL DEPOSITS

Numerous deposits of poorly sorted, partly consolidated gravel are found along the course of the San Miguel River, both within the quadrangle and to the east and west. In addition, a few deposits are found along the course of Leopard Creek (pl. 4). The deposits mantle narrow terraces and fill an earlier stage valley of the San Miguel River.

Bedrock is nowhere exposed in the present river bed, which is filled with 5 to 20 feet of Recent alluvium. The lowest elevation of the base of the gravel deposits is about 30 feet above the river, and thus the deposits lie about 35 to 50 feet above the lowest erosion level. The upper boundary of the gravel deposits lies 100 to 300 feet above the river, so that the maximum thickness of the gravels still remaining approaches 250 feet in a few places.

Good exposures are present in a few places where the gravel has been cut in old placer workings or have been exposed in road cuts. One of these, about 200 yards south of the southern boundary of the quadrangle exposes a gravel bank 60 to 80 feet thick. The deposit is rudely stratified, although very poorly sorted within each unit. The material ranges in size from medium-grained sand to boulders 2 or 3 feet in longest dimension. Most of the material is cobble sized and poorly to moderately indurated.

The gravel is composed predominantly of well-rounded fragments of extrusive igneous rocks from the San Juan tuff and the Silverton volcanic series and of intrusive rocks (diorites and monzonites). In addition, however, there is a fairly large percentage of sedimentary rocks, including the red beds of Paleozoic and Mesozoic age, the light-colored sandstone of the Jurassic system, the Dakota sandstone, and the red beds of the Telluride conglomerate of Tertiary age. All these rocks are now exposed in the headwaters of the San Miguel River.

The gravel deposits fill the valley of an earlier stage of the San Miguel River. In a few places the base of this old valley is exposed, still filled with 100 feet or more of gravel. It is difficult to conceive of a youthful stream, carrying large amounts of water, aggrading to the extent of 250 feet or more of valley fill during the normal course of erosion. Rather it suggests the dumping of glacially derived material transported during one of the glacial stages that affected the San Juan Mountains.

Correlation of the gravel deposits with either the Durango or Wisconsin glacial stages of Atwood and Mather (1932) depends largely on the conclusion of these workers that the present drainage patterns were essentially established prior to the Durango glacial stage. The absence of Durango till in the river valley east of the Placerville quadrangle led Atwood and Mather (1932, p. 128) to the further conclusion that the San Miguel River canyon presumably had been greatly deepened after Durango glaciation. Conclusive evidence of the amount of this deepening, however, is lacking in the Placerville quadrangle. In the northwestern part of the San Juan Mountains the amount of valley deepening since the Wisconsin stage has been estimated by Atwood and Mather (1932) to range from a few tens to a few scores of feet. The base of the gravel and valley fill in the Placerville quadrangle lies some 35 to 50 feet above the level of the present river bottom. If Atwood and Mather's (1932) conclusions and assumptions are correct, these glacial deposits are probably of Wisconsin age, and they are so considered in this report.

RECENT SERIES

ALLUVIUM

Unconsolidated deposits of alluvium in the stream valleys and of torrential fan deposits, both of Recent age, have been grouped together on the geologic map (pl. 4). Throughout the Placerville quadrangle the bed of the San Miguel River has a filling of alluvium that ranges in thickness from a few feet to as much as 20 feet. The Cutler formation, in which the lower part of the valley is cut, is nowhere exposed in the river bed.

The materials that make up the alluvium range in size from fine-grained sand to boulders 3 or 4 feet in longest dimension; generally they are subangular to rounded in shape. Intrusive and volcanic igneous rocks derived from the San Juan Mountains make up a very large proportion of the material; the remainder consists of sedimentary rocks which range in age from Permian to Tertiary, and which have been both derived locally and transported from areas upstream beyond the bounds of the quadrangle. No sorting is apparent in this alluvium, in contrast to the rude sorting present in the Pleistocene terrace gravel. At numerous places along the course of the San Miguel River, and on Leopard Creek northeastward from the confluence of Alder Creek, small alluvial flats have been mantled with finer grained material, and a rich fertile soil has been developed. A small amount of farming, largely the raising of hay and the cultivation of kitchen gardens, is done along these alluvial flats.

Small roughly conical torrential fan deposits are present at the mouth of nearly every minor drainage course along Leopard Creek and the San Miguel River. The materials are almost entirely angular and subangular; they range in size from coarse-grained sand to boulders, some of them 8 or 10 feet in longest dimension. The rocks are completely unsorted; they are the detritus of the numerous cloudburst- or flash flood-type runoffs common along the short steep-gradient drainages of the quadrangle. At their downstream terminations the fans coalesce with the alluvium of the major valleys. Upstream they come to a sharp apex that is commonly several feet above the bed of the minor drainages.

SPRING DEPOSITS

Travertine deposits of Recent age are present at three localities in the Placerville quadrangle (pl. 4): on the east side of Leopard Creek, a few hundred feet north of Massy Gulch; on the east side of Specie Creek, in the southwestern corner of the quadrangle; and on the south side of the San Miguel River across from the town of Placerville. Water flows from the springs at Placerville and on Specie Creek, but the Leopard Creek spring appears to have stopped flowing in the recent past. Chemical analyses of the spring waters are given in the table following the description of the Placerville spring.

LEOPARD CREEK SPRING

At the Leopard Creek deposit, a mantle of travetine, 5 to 10 feet or more thick, has been deposited on the steep east valley wall, in part forming a narrow terrace. This mantle extends from about 80 feet above stream level to the stream bed, and has a lateral extent of several hundred feet. The deposit is located on the Alder Creek fault, a normal fault with a displacement at this point of about 700 feet. At the spring deposit the Entrada sandstone on the footwall of the fault is in contact with the upper part of the Brushy Basin shale member of the Morrison formation on the hanging wall. No water is flowing from the spring at present, unless it flows within the porous travertine and is discharged into Leopard Creek below stream level.

Semiquantitative spectrographic analysis of a sample from the Leopard Creek deposit shows, in addition to the main component calcium, subordinate (0.01 to 0.46 percent) amounts of silicon, aluminum, iron, magnesium, and strontium, as well as minor (0.0001 to 0.01 percent) amounts of manganese, titanium, sodium, barium, zirconium, boron, vanadium, nickel, and copper.

SPECIE CREEK SPRING

About 1.2 miles upstream from the mouth of Specie Creek two spring deposits are present along the east valley wall. The deposits are about one-tenth of a mile apart. Cool alkaline spring water issues from the northern deposit at a rate of almost 45 gallons per hour; and travertine is being deposited along the valley wall and as a small terrace engulfing alluvium along the stream bed. The northern deposit is located on a north-trending normal fault that has a displacement of about 50 feet. At the deposit the Entrada sandstone on the west (hanging wall) side of the fault is in contact with the upper part of the Dolores formation on the east (footwall) side.

No water is flowing at the southern spring deposit, unless it flows within the porous travertine. The spring deposit also mantles the east valley wall and has a vertical extent of 60 feet or so, a lateral extent of several hundred feet, and a thickness of 5 to 10 feet. It is located along a northward-trending normal fault which joins the fault of the northern deposit a few hundred feet to the south. At the deposit the fault has a displacement of about 200 feet, and both the west (footwall) and east (hanging wall) sides of the fault are in the Dolores formation.

PLACERVILLE HOT SPRINGS

The largest springs in the quadrangle, on the south side of the San Miguel River at Placerville, are variously known as Lemon hot springs or Placerville hot springs (local usage) or as Geyser Warm Spring

(George and others, 1920, p. 227). They were discovered during the course of placer mining in the area. Spring waters containing appreciable carbon dioxide and a perceptible amount of hydrogen sulfide flow from the spring at a temperature of 94° F. according to George and others (1920, p. 227). The rate of flow has not been accurately measured, but it appears to be in excess of 100 gallons per hour. A large deposit of complex composition, principally travertine, has been formed; it is several hundred feet long, more than 150 feet wide, and is 8 to 15 feet or more in thickness. The spring waters which issue from the Cutler formation some distance above river level form a spring deposit which has engulfed the Recent alluvium in the river bed and formed a large terrace. The spring has been developed commercially by the excavation of tunnels and rooms in the deposit, and a bathing pool has been provided for the use of the public.

The deposit is located at the junction of two northeastward-trending normal faults, which have a combined displacement of at most only a few feet, and which disappear and end under the alluvium in the river bed.

Analyses of the spring waters in the Placerville quadrangle are given in the following table.

Analyses of spring waters in the Placerville quadrangle, Colorado

	Specie Creek spring [1]		Placerville hot springs [1]		Placerville hot springs [2]	
	Parts per million (ppm)	Equivalents per million (epm)	Parts per million (ppm)	Equivalents per million (epm)	mg per l (approx. ppm)	Reacting value percent (approx. epm)
Silica	12.0		100.0		98.8	
Sulfate	263.0	5.48	886.0	18.44	878.7	21.74
Bicarbonate	928.0	15.21	1,110.0	18.19	1,005.0	19.56
Carbonate						
Phosphate	.2		.2			
Chloride	92.0	2.59	261.0	7.36	259.9	8.70
Fluoride	.4	.02	4.4	.23		
Nitrate	.7	.01	.3			
Iron	.05		.09			
Aluminum	.3					
Iron and aluminum oxide					Tr.	
Calcium	99.0	4.94	154.0	7.68	156.9	9.30
Magnesium	48.0	3.95	9.7	.80	13.0	1.27
Potassium	43.0	1.10	77.0	1.97	130.0	3.96
Sodium	312.0	13.57	764.0	33.22	677.0	34.94
Manganese			.3			
Lithium					3.1	.53
Total	1,798.65		3,366.99		3,222.4	
Physical characteristics:						
Dissolved solids ppm	[3] 1,170		[3] 2,810		[4] 2,764	
Total hardness as $CaCO_3$ ppm	444.0		424.0		[5] 446	
pH	7.4		6.5		[6] N. D.	
Radiochemical data: Uranium ppm [7]	0.006		0.016		N. D.	

[1] Analysis by Quality of Water Branch, U. S. Geological Survey, October 10, 1955.
[2] Analysis published as "Geyser Warm spring" in George, R. D., and others (1920, p. 393).
[3] Residue evaporated to dryness at 180° C.
[4] Residue evaporated and dried at 120° F.
[5] Calculated from published analysis.
[6] Not determined.
[7] Analyst: J. P. Schuch, U. S. Geological Survey, Sept. 28, 1955.

IGNEOUS ROCKS

Dioritic or andesitic rocks make up most of the igneous rocks of the Placerville quadrangle, forming sills and a few discordant bodies intruded into the Dakota sandstone and the Mancos shale, and steeply dipping dikes that cut all the rocks older than Cretaceous. The remainder of the igneous rocks are dikes of biotite monchiquite. Contact metamorphic effects are absent around all of the intrusives; the injected melts apparently were relatively cool and dry. All of the intrusive rocks are confined to the southern third of the Placerville quadrangle; the greatest concentration of intrusive bodies is in the extreme southeastern corner (pl. 4). Both in area of outcrop and in total volume the igneous rocks are only a small fraction of 1 percent of the rocks of the quadrangle.

ROCK TYPES

DIORITE AND DIORITE PORPHYRY

The diorites and diorite porphyries form sills and closely associated discordant intrusives. On fresh surfaces the rocks range in color from light gray to brown. Colors of weathered surfaces are light brown, yellow brown, reddish brown, or dark brown. The grain sizes of the diorites range from medium to coarse; the maximum dimensions of grains are in the range 1 to 7 mm. The phenocrysts of the diorite porphyries are medium grained in the range 1 to 4 mm. The groundmass of the porphyries usually is fine grained but ranges to microcrystalline; where microcrystalline, the rock is classed as an andesite porphry.

The minerals of the diorites and the diorite porphyries are plagioclase (An_{55}), hornblende, green biotite, and small amounts of quartz, orthoclase, apatite, sphene, pyrite, and magnetite. Limonite, carbonate, kaolinite, sericite, epidote, and chlorite occur as alteration products.

ANDESITE AND ANDESITE PORPHYRY

Most of the andesitic rocks of the Placerville quadrangle are andesite porphyries. The porphyries that form sills are similar petrologically to the diorites and diorite porphyries; those that form dikes differ appreciably from the dioritic rocks.

The sill-forming porphyries are bluish gray to dark gray on fresh surfaces and weather brown to reddish brown. The phenocrysts are medium grained and range from 1 to 5 mm in length. They consist of plagioclase ($An_{52\pm}$), hornblende, and green biotite. The groundmass is very fine grained to cryptocrystalline and is composed of plagioclase (probably in the andesine range), hornblende, biotite, and small amounts of quartz, pyrite, and magnetite. Carbonate and limonite are the main alteration products.

The dike-forming andesite porphyry is rich in pyroxene. The rock is iron gray on fresh surfaces and brown on weathered surfaces. Medium- to coarse-grained phenocrysts ranging from 1 to 7 mm in length are set in a fine to very fine grained groundmass. The phenocrysts consist of plagioclase (An_{65}) and augite. The groundmass is composed mainly of plagioclase (An_{55}), carbonate pseudomorphs after augite and biotite, and small amounts of magnetite and biotite.

Other dikes are composed of altered andesite. The dike rock is highly altered, fine grained, and nonporphyritic; it is purplish gray on relatively fresh surfaces and weathers reddish brown. Alteration has proceeded to such a point that definite identification of the original rock type is not possible; the rock is tentatively identified as an andesite. Under the microscope the main constituent is carbonate, which is probably the alteration product of both plagioclase and mafic minerals. Some biotite is recognizable, and fine grained anhedral quartz is found in spherulites.

BIOTITE MONCHIQUITE

Several dikes west of Placerville are composed of biotite monchiquite. The rock is olive green to black and weathers reddish brown. Subhedral to euhedral medium-grained phenocrysts of biotite and augite ranging from 1 to 4 mm in length are set in a fine-grained or microcrystalline groundmass. The groundmass is composed of fine-grained biotite, augite, analcite(?), magnetite, and about 20 percent carbonate. The carbonate is an alteration of the mafic minerals.

DISTRIBUTION AND OCCURRENCE

SILLS

All the sills have been intruded into the Cretaceous rocks in the extreme southeastern corner of the Placerville quadrangle. The sills crop out along the southern rim of Hastings Mesa, where they cut the Dakota sandstone, and on the surface of the mesa, where they are in the Mancos shale (pl. 4). In a number of places, the injected material has broken across the beds forming small discordant discontinuous masses that apparently connect several of the sills. The sill rocks are similarly petrologically to the diorite and diorite porphyry of the Gray Head laccolith and the intrusive mass of Whipple Mountain, both of which lie just east of the quadrangle's east boundary. The sills apparently are related to these larger intrusive bodies.

North of the Pocahontas mine the Dakota sandstone is cut by five sills (pl. 4) that are separated vertically by a few feet to several tens of feet of beds. In the following discussion these sills are numbered 1 through 5, from bottom to top. Sills 1, 3, and 5 are andesite porphyries, with maximum thicknesses of 5, 10, and 15 feet respectively. Sill 2 is composed of diorite and diorite porphyry, and ranges in thickness from 30 to 80 feet. Sill 4 is composed of andesite and diorite with intergradational textures, and ranges in thickness from 15 to 35 feet. The thinner sills are the more lenticular and appear to have less areal extent. At the eastern border of the quadrangle sill 1 is absent, sills 2 and 3 crop out as rather short lenses, and sill 5 lies directly upon or merges with sill 4. As a group the sills appear to rise in the Dakota sandstone from the eastern border of the quadrangle west-northwestward along the southern rim of Hastings Mesa. For example, sill 2 is about 70 feet above the base of the Dakota at its easternmost exposure, about 120 feet above the base at a point due north of the Pocahontas mine, and about 175 feet above the base at its westernmost exposure.

Numerous sills cut the basal part of the Mancos shale at the south end of Hastings Mesa. The area is one of poor exposure and complicated structure, so that correlation of sill outcrops is uncertain. The sills are composed of diorite, diorite porphyry, and andesite porphyry, and here they appear to be gradational facies of a single rock type. The apparent range in thickness is from a few feet to 60 feet, and possibly more. The sills range in position from about 10 feet above the base of the Mancos along the eastern edge of Hastings Mesa to as much as 200 feet above the base near the westernmost sill exposures (pl. 4). This range in position appears to repeat the rise of the sills in a westward direction in the Dakota sandstone below. However, it is not possible either to prove or disprove that the sills transgress the Mancos sufficiently to link all the exposures. It is unlikely that all the exposures shown on plate 4 represent the same sill, some of the outcrops may be of discordant masses.

DIKES

A northwestward-trending dike zone, about 125 feet wide, crops out about 1.2 miles southwest of Placerville (pl. 4). The dike zone is composed of several branching steeply dipping dikes of biotite monchiquite that range in width from 1 to 10 feet. The dikes are exposed only where they cut the Salt Wash sandstone member of the Morrison formation. The rocks of the dike zone are highly sheared, but there appears to have been only minor displacement of the sedimentary rocks on either side of the zone. Another biotite monchiquite dike of north trend and steep dip cuts the Cutler formation about 1.2 miles west-northwest of Placerville. The dike follows a nearly vertical northward-trending fracture along which there has been no movement.

An eastward-trending steeply dipping dike of andesite porphyry, rich in pyroxene, cuts the Cutler formation north of Placerville. The dike is at least 1.2 miles long and ranges in width from less than 1 foot to about 7 feet. At several places northeast of Placerville the dike has been offset by normal faults that are part of the Black King fault system (pl. 4). Near its eastern end the dike coincides with a normal fault of 12 feet displacement. Slickensided surfaces along the dike suggest that there has been some postdike movement, but the existence of the fault before dike intrusion is not precluded.

Two west-northwestward-trending steeply dipping dikes of altered andesite crop out in the bottom of a small stream just north of the Leopard Vanadium mine (pl. 4). The dikes are exposed in the Wanakah formation and the Salt Wash sandstone member of the Morrison formation. The dikes, which range in width from 2 to 4 feet, are apparently controlled by a joint zone along which there has been a small amount of movement since the intrusion of the dike.

At the southern end of Hastings Mesa diorite and diorite porphyry masses, some of indeterminate form, have discordant relationships to isolated outcrops of Mancos shale. The masses are composed of the same rock types that form the sills, and so it is believed that the sills and the discordant masses were derived from the same melt and were injected at about the same time. Some of the discordant masses are dikelike bodies, lenticular in plan, which pinch and swell irregularly along their strike from a few feet to as much as 20 feet. They trend eastward, parallel to the branching faults that mark the eastern end of the Black King fault (pl. 4). As exposures are generally poor, some of the apparently discordant relationships of the dioritic rocks to the Mancos shale may actually be due to displacement by the branching faults. Elsewhere these discordant relationships may have been caused by heaving or shouldering during igneous intrusion.

The relationships of the dikelike bodies to sills are not clearly understood. The steeply dipping dikelike masses at the southern rim of Hastings Mesa cut across the contact between the Dakota sandstone and the Mancos shale, but the masses are not exposed below the upper part of the Dakota. The contact of the dikes with the sills in the Dakota is nowhere exposed. Thus it is not possible to state definitely that the dikes are deep seated and represent the feeding channels for the intrusive rocks that form the sills. It is also possible that the dikes are only restricted crosscutting conduits between sills, and that the sills are intruded laterally from feeding channels some distance away.

AGE OF THE IGNEOUS ROCKS

Definite determination of the age of the intrusive rocks is not possible. Within the quadrangle the youngest sedimentary rock that has been invaded is the basal part of the Mancos shale of Late Cretaceous age. The dioritic intrusive rocks are mineralogically similar to, and genetically related to, the dioritic intrusive of the Gray Head laccolith just east of the Placerville quadrangle, which in turn appears to be related to the dioritic intrusive of Whipple Mountain about 1 mile farther northeast. The Whipple Mountain intrusive and a related igneous body cut the Mancos shale and the San Juan tuff (Cross and Larsen, 1935, pl. 1); the San Juan tuff is considered to be of Miocene(?) age by Burbank (1947, table 7). Accordingly, the dioritic intrusions of the Placerville quadrangle are considered to be of Miocene(?) or younger age.

The biotite monchiquite and andesitic dikes present a more involved problem. The youngest sedimentary rock known to be cut by the andesitic dikes within the quadrangle is the Salt Wash sandstone member of the Morrison formation of Late Jurassic age. Similar dikes in the contiguous Gray Head quadrangle to the southeast cut at least the basal part of the Dakota sandstone of Late Cretaceous age. None of the dikes are known to cut the dioritic intrusives; they are offset by the same fault system that offsets the dioritic intrusives. It is probable that the andesitic dikes were derived from the same magma as the dioritic intrusives and may be of Miocene(?) age. The biotite monchiquite dikes are younger than the Salt Wash sandstone member of the Morrison formation, but no additional evidence is available for more precise dating. They are thus classed only as younger than Jurassic in age.

CLASTIC DIKES

In addition to the dikes, sills, and other masses of igneous rocks that intrude the sedimentary rocks of the quadrangle, the Permian and Triassic beds are cut by five clastic dikes of considerable horizontal and vertical extent. The clastic dikes are shown on the geologic map south and southeast of Placerville (pl. 4).

Similar clastic dikes are known at several places in the western San Juan Mountains. They have been extensively described in the literature by Ransome (1900, 1901), Irving and Cross (1907), Spurr (1923), Burbank (1930), and Dings (1941). The petrology and geologic relations of the longest dike in the Placerville quadrangle have been described in considerable detail by Haff (1944) and a general description has been supplied by V. R. Wilmarth and C. C. Hawley (written communication). In view of the numerous previous descriptions and the detailed petrologic work by Haff (1944), a comprehensive study of the dikes was not made in the course of the present work.

The dikes occupy a set of west-northwestward-trending fractures, which, according to V. R. Wilmarth and C. C. Hawley (written communication), parallel a strong, essentially vertical joint set. In places, however, the dikes are deflected from their generally steep dip along gently dipping, "flat" joints for a foot or two. The clastic dikes generally range in thickness from about 6 inches to 6 feet; their average thickness is about 1½ to 2 feet. They have a maximum length of more than 4,200 feet and an exposed vertical range of as much as 1,000 feet.

Rock fragments within the dikes range in shape from angular or subangular to subrounded, with some rounded fragments. Most of the fragments are 1 to 3 inches in largest dimension; however, some of the fragments are as much as 8 inches across. They are composed of gneiss, mica schist, sericite phyllite, granitoid rocks, rhyolitic and intermediate eruptives, nonfossiliferous limestone, calcareous sandstone, and red and black shale. Commonly the schist and shale fragments have tabular shapes. A greater number of these are oriented parallel to the walls of the dikes than would be expected if the orientation were truly random.

Haff (1944, p. 213) suggests that the source of the clastic material was in the Precambrian basement complex. He further states:

> A possible source for some of the extraneous fragments might be sought in the coarsely conglomeratic beds of the Cutler formation. However, though some of these conglomerates are arkosic, for the most part those exposed near Placerville consist predominantly of intermediate eruptive rock fragments. The latter are only sparsely represented in the clastic dikes. It seems most likely, therefore, that the abundance of granitic and metamorphic fragments in these dikes indicate a pre-Cambrian source.

In contrast, V. R. Wilmarth and C. C. Hawley (written communication) state that "all the materials with the exception of the fissile black shales could have been derived from the boulder conglomerates and sandstones of the Cutler formation," although they do not imply that the materials could have come only from the Cutler. The conglomerate in the Cutler formation in the Placerville and neighboring quadrangles contains abundant fragments of granitic and metamorphic rocks, as well as arkose, sandstone, and red shale. In addition, the basal part of the Cutler formation, which is exposed north of Rico, Colo., about 17 miles south of the Placerville quadrangle, contains abundant arkosic material. At the same locality the Hermosa formation of Pennsylvanian age contains fissile black shale, and it is probable that the Hermosa underlies the Cutler in the Placerville area.

Burbank (1930, p. 200) has suggested that the injection of the clastic dikes of the Ouray district resulted from the

> violent escape of volcanic gases and vapors and accompanying solutions, which had become temporarily trapped beneath an impervious blanket of sedimentary rocks.

Haff (1944) has proposed the same hypothesis for the origin of the clastic dikes of the Placerville quadrangle. The writers concur, and suggest that the Hermosa formation most probably constituted the impervious blanket of sedimentary rocks in the sense mentioned above by Burbank.

There is insufficient evidence to date the clastic dikes precisely. They are younger than the Triassic, as they cut both the Permian and Triassic rocks, but their relationship to the Jurassic rocks is not apparent. The dikes may terminate upward within the Dolores formation. It seems unlikely that 4 of the 5 dikes would end laterally at about the same distance from the present outcrop belt of the Upper Jurassic formations (pl. 4), unless controlled by the same structure that controls the outcrop belt. At the surface these four dikes end against northward-trending normal faults that are believed to be of Miocene or Pliocene age, suggesting that the dikes are younger than the faults. Volcanic activity was widespread throughout the San Juan Mountains area during the Tertiary period; the violent escape of volcanic gases, leading to the injection of the clastic dikes, most likely occurred during this period. The dikes are considered to be Tertiary (?) in age, and possibly younger than the normal faults.

STRUCTURE

REGIONAL SETTING

The Placerville quadrangle lies in the border region between the Colorado Plateau and the San Juan Mountains. A part of the rugged western front of the mountains rises about 3 miles east of the quadrangle; to the south the San Miguel Mountains, a western outlier of the San Juan Mountains, are about 7 miles distant. Structures characteristic of both the plateau and the mountains are present within the quadrangle, but, despite the nearness of the high mountains, the geology and topography are more characteristic of the plateau province.

Structurally the Placerville area lies near the boundary of two tectonic provinces—the Paradox fold and fault belt, and the Uncompahgre uplift—and a few miles west of a third, the San Juan dome (fig. 14). The Sagers-Nucla synclinal axis, one of the features of the Paradox fold and fault belt, passes through the quadrangle in a southeasterly direction and from its northeast flank the beds rise gently toward the axis of the Uncompahgre uplift.

The formations exposed in the mapped area generally dip less than 5°. Locally, where the formations are disturbed by broad flexures, dips range to as much as 15°; and near some faults, drag results in dips as steep as 60° or 70°. The principal broad structural feature of the quadrangle is the shallow Sagers-Nucla syncline, whose axis plunges gently northwest from the south end of the Sheep Draw graben (fig. 15). Faults of minor to moderate displacement are commonly superimposed on the broad folding. Most faults belong to two systems, one of which trends northward and the other northwestward. A subordinate number of faults trend eastward to northeast-

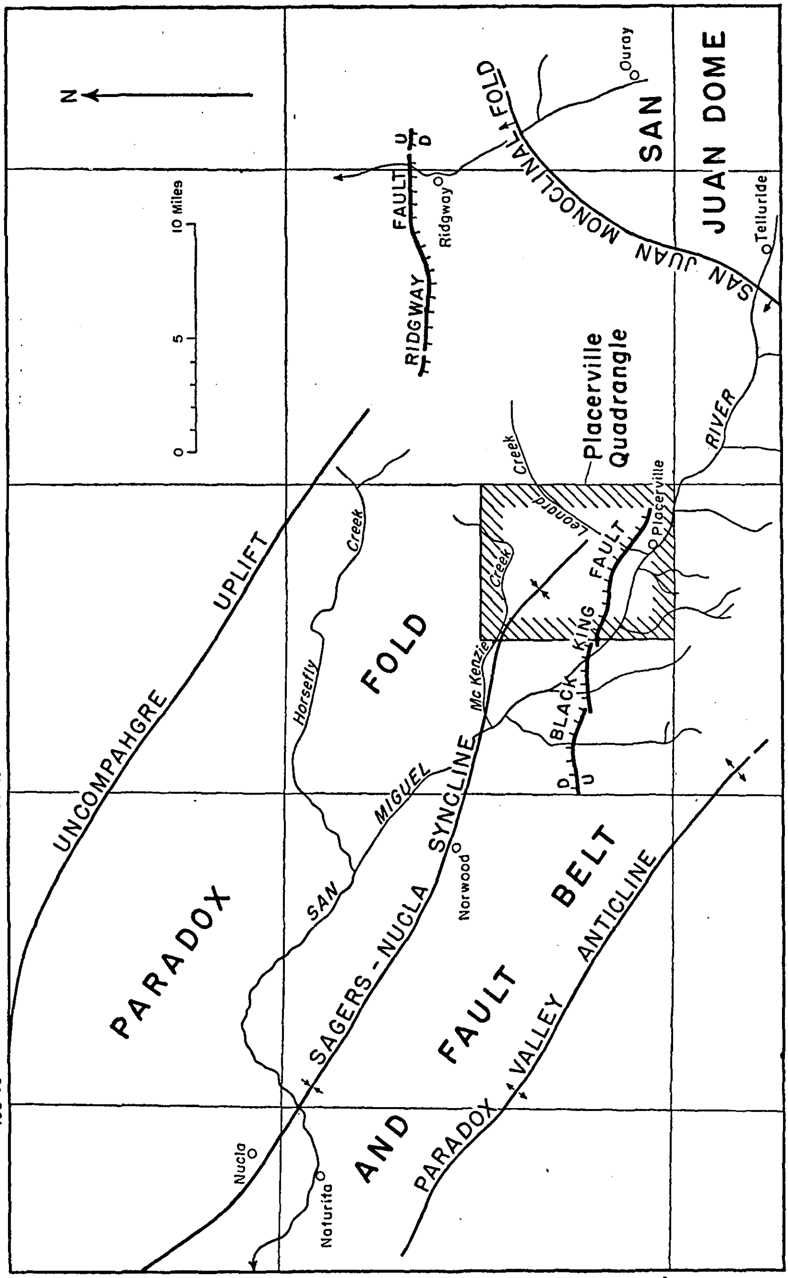


FIGURE 14.—Generalized structure map of the area surrounding the Placerville quadrangle, Colorado.

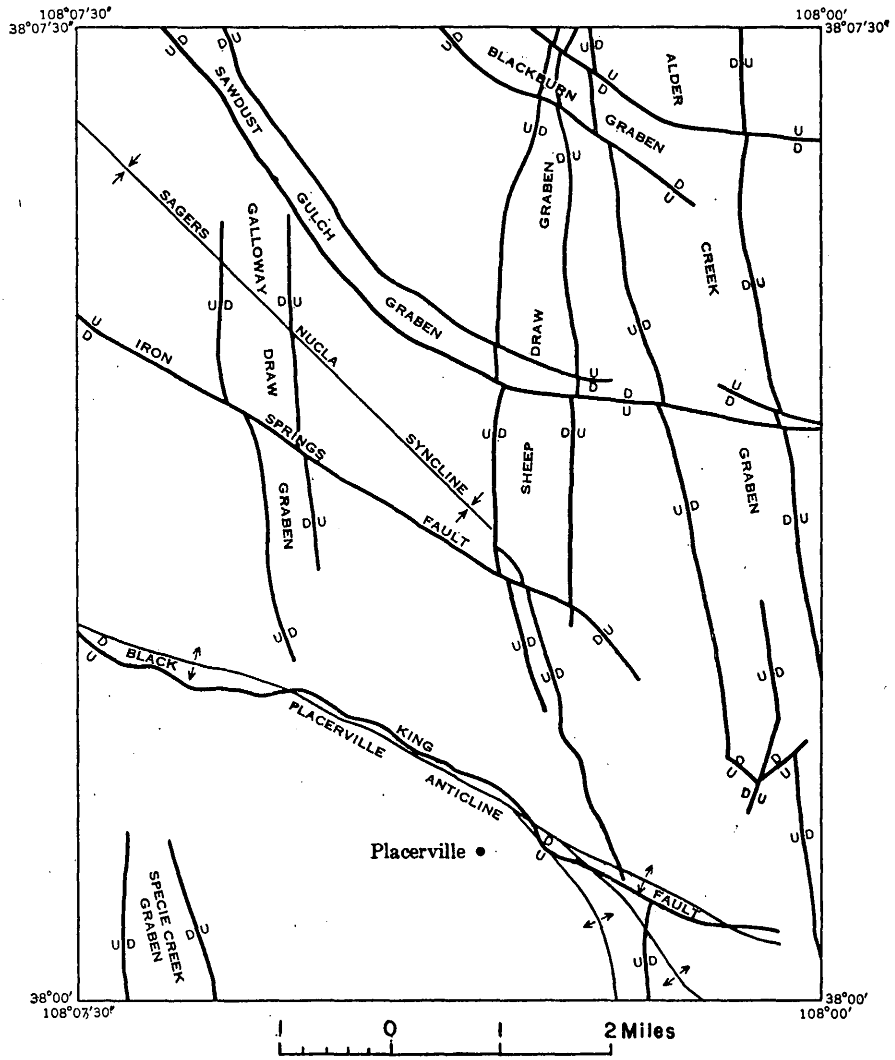


FIGURE 15.—Sketch map showing the major structural features of the Placerville quadrangle, Colorado.

ward. All displacements are normal; typically the faults dip steeply or are vertical. Graben structures are common and comprise some of the most conspicuous structural features of the quadrangle.

FOLDS

SAGERS-NUCLA SYNCLINE

The major fold of the Placerville quadrangle is a broad open syncline about 5 miles wide that extends northwestward from Leopard Creek beneath Iron Springs Mesa (pl. 4). This fold is the southeastern end of the Sagers-Nucla syncline (Kelley, 1955, p. 38), which extends for several tens of miles farther to the northwest (fig. 14), where Cater (1955a) calls it the Dolores River syncline. The southwest limb dips 3° to 5° NE. and can be recognized as far south as the north rim of the San Miguel River valley; the northeast limb dips generally 2° to 10° SW. The syncline dies out to the southeast, east of Leopard Creek, but near its end dips are somewhat steeper than average, ranging from 10° to 15° NW. In the Placerville quadrangle the axis of the syncline plunges about 225 feet per mile (2° to 3°) to the northwest.

OTHER FOLDS

From the southwest flank of the Sagers-Nucla syncline the beds rise southwest to form the Placerville anticline of west-northwest trend. This anticline is broken near its axis by the Black King fault, whose trend is roughly parallel to the axis of the anticline (pl. 4). The northwesterly plunge of the fold continues beyond the western boundary of the map area. To the east the anticline merges into a dome in the southeastern corner of the quadrangle. East of Placerville the dome is broken by the eastward-trending Black King fault, and by numerous northward-trending faults.

On Specie Creek in the extreme southwestern corner of the quadrangle there is a suggestion of another synclinal structure, again with northwestward-trending plunge and axis. This syncline is probably a lobe of the Sagers-Nucla syncline.

A small northeastward-plunging anticline follows the east side of Leopard Creek from just north of the Omega mine to Alder Creek (pl. 4). Its northwest flank dips from 5° to 7° NW.; its east flank dips 2° to 3° NE.

A number of other minor folds are present in the area. These are especially numerous and best observed in the Dakota sandstone on the mesa top around the south end of Sheep Draw. The axes of the folds and flexures trend northwestward, subparallel to the axis of the Sagers-Nucla syncline. These folds are small features, generally less than 10 to 20 feet in amplitude and less than half a mile in length. They are minor corrugations superposed on the major syncline, and those observed probably are confined to the relatively thin incompetent beds of the upper part of the Dakota sandstone.

A peculiar type of minor folding is found in sec. 17, T. 44 N., R. 11 W. A sharp fold of 20- to 40-foot amplitude is present on the southwest limb of the Sagers-Nucla syncline. The axis of the fold has a sinuous course and is roughly horseshoe shaped, open to the south. In general the fold is asymmetric; its steeper limb is to the south or concave side, and its gentler limb is on the north or convex side. Dips from 40° to 60° on the steeper limb are not uncommon, whereas dips of 20° are more characteristic of the gentler limb. It is possible that this sharp "wrinkle" represents a local buckling of the relatively incompetent thin sandstones and interbedded carbonaceous shales in the upper part of the Dakota sandstone, acting in response to compressive stresses originating in the folding of the larger syncline.

FAULTS

Numerous faults cut the formations exposed in the Placerville quadrangle. The throws of the faults range from a few feet to as much as 700 feet; their lengths range from a few tens of feet to more than 10 miles. The majority of the faults strike either northward or northwestward. A few faults strike eastward or northeastward.

Grabens are perhaps the most striking structural feature in the area (fig. 15). Both northward-trending and northwestward-trending grabens are present. They have vertical displacements that range from those of the Alder Creek graben (pl. 4), which is downthrown as much as 700 feet, to those of smaller grabens, which are downthrown 50 feet or less.

ALDER CREEK GRABEN

The Alder Creek graben, the largest in the Placerville quadrangle, has a length of more than 9 miles and a width of about 1 mile within the quadrangle (pl. 4). In general it trends about N. 10° W. Near its northern end the graben is intersected by the northwestward-trending Blackburn graben (in sec. 36, T. 45 N., R. 11 W., and sec. 31, T. 45 N., R. 10 W.). North of this intersection the Alder Creek graben continues for some distance beyond the north boundary of the quadrangle and its simple form is complicated by other normal faults within and parallel to the graben structure

Near its southern end the relatively simple graben is intersected by a complex of cross faults, whose exact nature and relations are obscured by a thick soil cover (sec. 30, T. 44 N., R. 10 W., pl. 4). Beyond the southeastern corner of the quadrangle the graben structure continues to the south for a distance of a mile or two. In this area it is a fairly complpex structure, with numerous cross faults that are also largely concealed by a thick soil cover. The graben is also intersected in the vicinity of Haskill Hill and Massy Gulch by the eastern extension of the Sawdust Gulch graben.

Along the length of the graben the bounding faults are remarkably parallel and maintain a separation of about 1 mile. The maximum throw on both faults is in the area where they cross Leopard Creek. Here the eastward-bounding fault, called the Alder Creek fault (pl. 4), has a displacement of approximately 700 feet, and the westerly bounding fault, called the Leonard fault, has a displacement of about 325 feet. North and south from this area the throw on the downfaulted block decreases.

Both the Alder Creek fault and Leonard fault are laterally offset where they are crossed by faults of the northwest system near the north quadrangle boundary, in the neighborhood of Haskill Hill and Massy Gulch, and on Hastings Mesa (pl. 4 and fig. 15). Two echelon faults mark the west side of the graben on Hastings Mesa and further complicate structural relations in the vicinity of the offsets. The fault planes are rarely exposed, but traces of the faults across irregular topography, plus the few dips observable, indicate that the faults are vertical or dip very steeply toward the downthrown side.

SHEEP DRAW GRABEN

The northward-trending Sheep Draw graben, reflected in the topography as a very marked valley, has a length of about 5 miles and a width that ranges from about three-fourths of a mile in its southern and middle parts to less than one-fourth of a mile at its northern end.

Structural details of the Sheep Draw graben are obscured by soil cover on the mesa top and the exact nature and pattern of the bounding faults are not well known. However, toward the south end of Sheep Draw the western boundary of the graben consists of at least two faults, downthrown to the east with a cumulative displacement of about 300 feet. Northward along the west side of the graben the bounding structures are shown on the map as a single fault, the Sheep Draw fault. Displacement along this fault ranges from 150 to 350 feet. The maximum displacement of 350 feet is probably just south of the point where McKenzie Creek crosses the Sheep Draw fault. Near the north margin of the Placerville quadrangle the trace of the fault begins to bear somewhat east of north, but north of the quadrangle it again curves to the north and northwest.

The eastern boundary of the graben consists of faults with considerably smaller average displacement than that of the western bounding fault. At the south end of Sheep Draw the eastern bounding fault has apparently died out. To the north near the Haskill Hill road the fault is interpreted as passing into a monoclinal flexure which in turn dies out just south of the road. At this point, however, several subparallel faults, which trend northwestward to northward and are downthrown to the west, reconstitute the east side of the graben as a faulted structure (pl. 4). Northward from the north boundary of T. 44 N., R. 11 W., the Sheep Draw fault and the eastern bounding fault of the graben converge, and they are interpreted to join just north of the quadrangle boundary.

The Mancos shale is downfaulted against the Dakota sandstone at the surface along a great part of the length of the Sheep Draw graben. At the north end of the graben, however, both the Dakota sandstone and the Brushy Basin shale member of the Morrison formation are exposed in fault contact with the Mancos. At the few places where dips can be seen in the central and southern parts of the graben the dips are at low angles to the west. At the north end of the Sheep Draw graben, the downthrown beds generally strike northeastward and dip at moderate angles to the southeast.

Both bounding faults of the Sheep Draw graben are offset laterally where they are intersected by faults of the northwest system, as the Iron Springs fault, the Sawdust Gulch graben faults, and the Blackburn graben faults (pl. 4).

SAWDUST GULCH AND BLACKBURN GRABENS

The Sawdust Gulch and Blackburn grabens are the two prominent northwestward trending grabens which cross the Sheep Draw and Alder Creek grabens. The northwestward trending grabens offset the northward-trending grabens and probably are younger.

The Sawdust Gulch graben enters the Placerville quadrangle near the northwest corner and trends southeastward for about 3 miles, then swings gradually to the east and intersects the Sheep Draw graben (pl. 4). Along most of its length the Sawdust Gulch graben maintains an average width of approximately one-quarter of a mile but gradually narrows to the southeast. As a simple graben the structure has essentially disappeared at the west rim of Leopard Creek. Within the quadrangle the well defined graben has a length of approximately 5 miles.

The southern bounding fault of the Sawdust Gulch graben extends eastward for at least 2 miles beyond the limits of the graben, within the quadrangle, and is present for some distance beyond the quadrangle's eastern boundary. East of Leopard Creek the graben is partly reconstituted by an eastward-trending fault zone (shown on pl. 4 as a single fault). There is a minimum displacement of about 160 feet along the southern bounding fault in the northwestward-trending part of the Sawdust Gulch graben. Displacements elsewhere along this fault are difficult to estimate because of the scarcity of outcrops and the lack of marker beds. On the west side of Sheep Draw the Dakota sandstone crops out on both sides of the fault, and the displacement is probably much less than 150 feet.

The displacement along the northeasterly bounding fault of the Sawdust Gulch graben is generally less than that of its southwestern counterpart. At the north edge of the map the throw is estimated at less than 50 feet, and at its eastern end, east of Sheep Draw, the displacement is only 5 to 20 feet.

The Blackburn graben lies in the northeastern part of the quadrangle, where the graben's bounding faults outline a markedly linear northwestward-trending valley. The Blackburn graben intersects the Sheep Draw graben and continues farther to the northwest beyond the boundaries of the quadrangle. Southeastward along the graben the bounding faults diverge; the southwest fault appears to die out west of Gutshall Gulch, and the northeasterly fault swings from a southeasterly trend to an easterly trend and extends beyond the map boundary.

The Blackburn graben exposes Dakota sandstone in the trough, faulted against Dakota sandstone on either side of the structure. The amount of displacement on the faults is not readily known, but near McKenzie Creek the southwest fault of the graben is thought to have a displacement of less than 40 feet. The northeasterly bounding fault, near its intersection with the upper part of Gutshall Gulch, also has a displacement of about 40 feet.

OTHER GRABENS

The Galloway Draw graben is about 3 miles long and about half a mile wide. The displacement of the bounding faults is not known, but it probably is small. The beds of Dakota sandstone that locally crop out in the graben are considered to be the same beds that form the upper surface of the adjoining upraised blocks. If this supposition is true the displacement of the downthrown block is probably no more than 20 to 40 feet. Both bounding faults are offset by the northwestward-trending Iron Springs fault.

The north end of the Specie Creek graben is present in the southwestern corner of the quadrangle (pl. 4). Within the quadrangle the graben has a length of about 1.6 miles and a general width of about half a mile. Displacement along the western bounding fault reaches a maximum of about 200 feet at the south boundary of the quadrangle. The eastern bounding fault has a maximum displacement within the quadrangle of about 100 feet. Near the center of the graben, along the south quadrangle boundary, two other northward-trending normal faults are present. Their western sides are downthrown, with a small displacement on the western fault, and a maximum displacement of about 80 feet on the eastern fault. The graben dies out 4 miles or so south of the quadrangle boundary.

A complicated grabenlike structure is present in parts of secs. 22, 26, 27, 35, and 36, T. 44 N., R. 11 W. It has a pronounced wedge-shaped section that suggests that the grabenlike form may die out a few hundred feet below the surface, in contrast to the other grabens in the quadrangle which generally appear to extend downward for several thousand feet.

BLACK KING FAULT

The Black King fault (pl. 4 and fig. 15) is the most important fault in the area that is not a part of the graben structures. The fault trends west-northwestward from the southeastern corner of the Placerville quadrangle to and beyond the west boundary of the quadrangle. It has a total length within the quadrangle of about 7 miles; it ends about half a mile west of the western boundary. Farther to the west, echelon faults which parallel the trend of the Black King fault are traceable for at least 9 miles to a point about 5 miles south of Norwood (fig. 14).

The maximum displacement along the Black King fault is at a point about 1.2 miles nearly due east of Placerville. Here, beds near the top of the Cutler formation on the south (footwall) side of the fault are in contact with the Salt Wash sandstone member of the Morrison formation on the north. The displacement represented is in the order of 600 to 650 feet. Westward from this point the throw decreases; at the White Spar mine the throw is about 450 feet, near the Black King mine the throw is about 350 feet, and at the western quadrangle boundary the throw is only 90 feet. A short distance beyond the map edge the fault dies out. Farther west it is succeeded by another fault whose throw increases westward.

East of the point of maximum throw, two closely spaced northward-trending faults end against the footwall of the Black King fault. The cumulative throw of these two faults is in the order of 550 feet and is down to the east. The effect of this movement is to counteract the throw of the Black King fault east of the fault junctions, and thus to reduce the throw substantially. At its east end on Hastings Mesa the Black King fault is interpreted to pass into a monoclinal fold, which dips to the north.

The trace of the fault as shown on the geologic map is rather sinuous. Measured dips range from 55° N. to vertical, though the average dip is approximately 70° to 75° N. In several places, such as near the White Spar mine, the Black King mine, and about 2 miles west of the Black King mine, a number of minor branching faults are present, in places causing a braided-fault pattern.

V. R. Wilmarth and C. C. Hawley (written communication) have examined the copper- and hydrocarbon-bearing vein deposits that occur along the Black King fault. A very similar mineral assemblage occurs in numerous dominantly northwestward-trending normal faults, roughly parallel to the Black King fault, which form a zone about three-quarters of a mile wide along the lower course of Leopard Creek (pl. 4). Most of these faults are relatively short, in contrast to the long faults that bound the grabens. For these reasons, this zone of faults is believed to be more closely related to the Black King fault than to the northwest system of grabens and may have been formed at the same time as the Black King fault.

The relationship of the Black King fault to the northward- and northwestward-trending fault and graben structures is not known.

Nowhere does the Black King fault intersect these other structures. The fault zone related to the Black King fault, however, intersects the southern extension of the Sheep Draw fault. Although exposures are poor, this end of the Sheep Draw fault is considered to be offset by the Black King fault zone. At one place in the upper part of the Cutler formation the extension of the Sheep Draw fault shows considerable drag and contains pyrite and copper minerals. It is the only one of the graben-bounding faults that is known to be mineralized. Tentatively it is suggested that mineralizing solutions, rising along the fault zone associated with the Black King fault, found their way into the Sheep Draw fault at its intersection with the fault zone.

IRON SPRINGS FAULT

Like the Black King fault the Iron Springs fault is not a graben-bounding structure. It extends from the western boundary of the quadrangle for a distance of about 6 miles along the general course S. 50° E., (pl. 4 and fig. 15). It appears to be a part of the major northwestward-trending system, and where it intersects northward-trending faults (in the Galloway Draw and Sheep Draw grabens) they are offset by it. The fault continues for a mile or more to the northwest beyond the quadrangle boundary. Southeastward the fault is present in the vicinity of the Leopard Vanadium mine, but dies out within 1,000 feet or so to the southeast.

The northeast side of the fault is upthrown between 20 and 100 feet. The fault is exposed where it cuts the Dakota sandstone on the west side of Leopard Creek. Here the fault zone is 12 inches wide, choked with a breccia of generally elliptical Dakota sandstone fragments, and is very heavily iron stained.

OTHER FAULTS

A number of steeply dipping northward-trending faults are present in the extreme southeastern corner of the quadrangle. Most of these normal faults are downthrown to the west, with displacements that range up to 350 feet. Several of them appear to abut against the Black King fault.

A few short northward-trending faults are present on Hastings and Iron Springs Mesas. In general these appear to be satellitic to the northward-trending, graben-bounding faults. In places, short segments of the northward-trending major faults have northeasterly trends. Other faults of easterly and northeasterly trend are present on Hastings Mesa and the north end of Specie Mesa. Most of these faults represent either the branching ends of faults of the major northward-trending system, or cross faults developed by differential displacement during the formation of the northward-trending grabens.

AGE OF THE FAULTS

In general the northwestward to westward-trending faults in the Placerville quadrangle displace the northward-trending faults, and therefore, are believed to be the younger. The most clearly defined examples are at the intersection of northward-trending Sheep Draw graben by the northwestward-trending Blackburn and Sawdust Gulch grabens; the intersection of Alder Creek graben by the south bounding fault of Sawdust Gulch graben, near Haskill Hill and Massy Gulch; and the intersection of Galloway Draw graben by the Iron Springs fault.

On the other hand, a few faults of northerly strike apparently terminate against faults of northwesterly or westerly strike. Examples of this relation are seen in a minor northward-trending fault which appears to end against the north bounding fault of the Blackburn graben, and in several northward-trending faults which appear to end against the Black King fault in the southeastern corner of the quadrangle.

The age of the Black King fault is difficult to determine. Faults of the Black King fault zone are believed to offset the southern extension of the Sheep Draw fault. If it is correct to suppose that all the northwestward-trending faults of the Black King fault zone were formed contemporaneously, then it appears that the Black King fault is somewhat younger than the major northward-trending fault system. The Black King fault zone may be contemporaneous, at least in part, with the major northwestward-trending fault system. Here the absence of mineralized material along the northwest system may be due to lack of access to the mineralizing solutions.

The meager evidence suggests that the northward-trending fault system is oldest, followed by the northwestward- and westward-trending fault systems (including the Black King fault), although the systems may have developed in part contemporaneously. A few northward-trending faults, particularly in the southeastern corner of the quadrangle may be younger than, or partly contemporaneous with the major northwestward-trending system.

JOINTS

The formations in the quadrangle have been extensively jointed, the amount varying with the lithology. Joints are poorly developed in the thick homogeneous beds, as the Mancos shale and the Entrada sandstone, and are well developed in thin evenbedded strata, particularly the thin sandstones of the Dolores and Morrison formations and the Dakota sandstone.

A well-developed conjugate joint system cuts the upper Dakota sandstone throughout the quadrangle. One joint set trends northwestward between N. 45° W. and N. 75° W.; the other ranges from due north to N. 50° E. The northwesterly set is the more consistent in direction and apears to be the stronger of the two sets. On a typical outcrop the joints are spaced from 4 inches to 2 feet apart, averaging perhaps 8 inches apart. The strike of the joints is quite uniform and a number of measurements taken close together seldom vary more than 10°. Their dip is uniformly vertical to steeply southwesterly. In contrast to the stronger set, the northward- to northeastward-trending set is generally less closely spaced and the strike may vary as much as 30° between adjoining joint planes. Individual joints are less persistent than in the northwesterly set; commonly they terminate at northwesterly joints.

In addition to variations of jointing with lithologic type the degree of development of joints also varies from place to place. Apparently there are linear zones in which there are swarms of joints, separated by intervals with less dense spacing of joints. This variation in spacing probably is a result of nonuniform relief from regional stresses within the small area of a single quadrangle.

Many of the dikes in the quadrangle, and the dikes near Big Bear Creek in the Gray Head quadrangle to the southeast, parallel joint trends, both in strike and dip. Inasmuch as any single joint is generally not continuous for any great vertical distance, dikes have to "jump" from joint to joint along their vertical extent. This "jump" may be a matter of a few inches, or it may be as much as 10 feet. In detail, these offsets may result in an echelon outcrop pattern, both vertically and laterally along the dike.

AGE OF DEFORMATION

Marked angular discordance is known between the Cutler and Dolores formations near Ouray, Colo. (Burbank, 1930, p. 169), a few miles to the east, and in the area of the salt anticlines of southwestern Colorado, a few tens of miles to the northwest (Dane, 1935, p. 43; Stokes and Phoenix, 1948; Cater, 1955a). This deformation at the end of the Paleozoic era is represented in the Placerville quadrangle by an erosional unconformity, with no definite angular discordance.

The principal deformations in the Placerville quadrangle involve all the rocks of Paleozoic and Mesozoic age. The beds have been folded, and later cut by faults, but within the quadrangle there is little direct evidence of the age of the folding. At the end of the Cretaceous period or in early Tertiary (Laramide) time compressive stresses were active in the area of the salt anticlines, some 40 miles to the northwest (Cater, 1954, 1955b; Kelley, 1955, p. 39–40), and the area of the San Juan Mountains, a few miles to the east was raised as a dome. Cross and Larsen (1935, p. 16–17) suggest two additional elevations of the area during the Eocene epoch. It appears likely that the folding in the Placerville quadrangle dates from this general time. It has been noted that the Sagers-Nucla syncline is physically continuous with the folds dated as Laramide by Cater (1954, 1955b).

The evidence points strongly to the conclusion that the faults are Miocene to late Pliocene in age. The youngest formation cut by the faults is the Mancos shale of Late Cretaceous age; the Cerro till, which is of probable early Pleistocene age according to Atwood and Mather (1932, p. 110), lies undisturbed across the southern extension of the Sheep Draw fault (pl. 4). The relations of the faults to the sills in the quadrangle gives the best evidence for dating the faults. The faults displace the sills and dikes and are thus of postintrusive age. The sills are mineralogically similar to and genetically associated with the Gray Head laccolith, which is just east of the southeastern corner of the quadrangle, and which is considered to be of Eocene or Miocene age (Cross, and Purington, 1899, pl. 2 and p. 14). The Gray Head laccolith has a similar relationship to the intrusive mass of Whipple Mountain, about 2 miles farther east. The Whipple Mountain intrusive has both concordant and discordant relationships to the Mancos shale, and a related igneous body to the north is intruded into the San Juan tuff of Miocene(?) age (Cross and Larsen, 1935, pl. 1). The weight of the evidence, then, indicates that the faults were formed either during Miocene or Pliocene time.

The gravity faults and graben structures of the Placerville quadrangle probably resulted from tensional forces. This region may have been differentially uplifted during both Miocene and Pliocene time. It seems generally accepted that in Miocene time epeirogenic uplift of the Colorado Plateau region (including the San Juan Mountains area) was in progress (Hunt, 1953, p. 210; Kelley, 1955, p. 88). Renewed domal uplift of the San Juan Mountains area has been postulated at the end of the Tertiary period (Atwood and Mather, 1932, p. 20).

Removal of material at depth may also have been a real factor in developing tensional stresses in the rocks. Volcanic activity started on a vast scale in the San Juan region in Miocene time (Cross and Larsen, 1935, p. 17, 50, 51). This activity continued into Pliocene time, and on a reduced scale into the Quaternary period. The volume of lavas erupted during the Miocene epoch alone, in the extrusion of the San Juan tuff, the Silverton volcanic series, and the Potosi volcanic series has been estimated by Cross and Larsen (1935) at about 6,500 cubic miles. It is likely that the area affected by removal from below of this volume of subcrusted material extended for some miles beyond the northern and western boundaries of the present mountain mass. West and northwest of the Placerville quadrangle, the amount and intensity of crustal block faulting decreases markedly; this area may have been beyond the influence of the removal of material during volcanism.

GEOMORPHOLOGY

Near the end of Tertiary time the Placerville quadrangle was covered by an unknown thickness of Mancos shale, Telluride conglomerate, and San Juan tuff. According to Atwood and Mather (1932, p. 21–26) a widespread erosion surface called the San Juan peneplain was developed across the entire San Juan dome near the end of the Pliocene epoch. This surface probably lay several hundred feet above the present upland surface of the Placerville quadrangle. Denudation of this surface began with regional uplift of the San Juan dome in early Pleistocene time. This denudation has been termed the Florida erosion cycle by Atwood and Mather (1932, p. 27–18). The major portion of the erosion of the rocks overlying the Dakota sandstone in the quadrangle was accomplished during this preiod.

UPLAND SURFACES

At the end of the Florida erosion cycle the upland surfaces were essentially as they are now. Most of the Mancos shale had been removed, and as the resistant strata of the Dakota sandstone were exposed, the influence of the local structures on the topography became dominant. Generally, erosion on the uplands has proceeded to the level of the upper beds of the Dakota, so that much of the area is now a stripped plain that reflects the deformed, faulted attitudes of the sedimentary rocks. Faultline scarps are developed on the upland surfaces along nearly all the normal faults and thus the numerous intersecting grabens have a topographic expression that reflects the geologic structure. This is particularly true in the Alder Creek and Sheep Draw grabens, although the other grabens show this feature also.

The Mancos shale is preserved in only a few places on the upland surfaces, generally where it has been downfaulted in the grabens, and has thus been protected from erosion. A thin layer of Mancos forms the upland surface in parts of the Sawdust Gulch and Sheep Draw grabens, and a thick section (300 to 350 feet) has been preserved in the Alder Creek graben between Massy Gulch and Alder Creek.

DRAINAGE SYSTEMS

The present day drainage system of the quadrangle is only partly adjusted to the structure. The minor drainages, Alder Creek, the lower course of Gutshall Gulch, Specie Creek, Galloway Draw, and parts of the drainages of Sawdust Gulch, Sheep Draw, and McKenzie Creek appear to follow the trends of grabens or the plunging axis of the major syncline. Leopard Creek, the major tributary of the San Miguel River, ignores the structural features and crosses many of them at nearly right angles on its course to join the San Miguel River. The course of the San Miguel River appears to be structurally controlled to a fairly large degree; it flows around the structural high of the sill area in the southeastern corner of the quadrangle, and parallels the trend of the Black King fault through the rest of the quadrangle.

A tentative explanation of the development of the drainage systems requires a reconstruction of the San Miguel River's Pleistocene history. At the end of the Florida erosion cycle the ancestral San Miguel River and its tributaries had denuded the quadrangle to approximately the level of the present upland surfaces. At this stage the Dakota sandstone was widely exposed and it is postulated that the drainage system was adjusted to the structure (pl. 8*A*). If so, the ancestral San Miguel flowed northwest down a synclinal valley in the northern quarter of the quadrangle, and elsewhere was adjusted to the Alder Creek and Sheep Draw grabens. The northward-flowing tributaries to the south were adjusted to the structure of the Galloway Draw, Sawdust Gulch, and Sheep Draw grabens. In the extreme southwest corner of the quadrangle an ancestor of Specie Creek was controlled by another small graben.

According to Atwood and Mather (1932, p. 28) the period of erosion was ended by a domal uplift of the main San Juan Mountain mass, with an ensuing period of glaciation (the Cerro glacial stage) during which the ice sheet covered all of the quadrangle and extended beyond its borders for several miles. Drift of Cerro age has been recognized at several places on the upland surfaces in the Placerville quadrangle, and for some miles to the north, south, and west. During recession of the Cerro ice sheet, the present writers believe, a lobe of ice still filled the ancestral San Miguel River valley while the higher upland surfaces a short distance to the south became ice-free (pl. 8*B*). Melt water and runoff from the ice lobe to the north and from the mountain glaciers to the east, southeast, and south were concentrated into the glacial San Miguel River, whose course was at the southern edge of the ice lobe. The volume of water and the gradient of the underlying surface was sufficient to give the stream considerable cutting power, and it quickly incised its bed. The river was trapped in its new course, which lay on the southern flank of the preglacial valley, some 400 to 600 feet above the old bed. In its new course the river captured the southern headwaters of the northward-flowing tributaries to the ancestral stream.

At a somewhat later stage in the recession of the Cerro ice sheet the edge of the active ice lobe in the ancestral valley is believed to have become stationary near the present site of Leopard Creek (pl. 8*C*). Special conditions are called for to explain the course of Leopard Creek, for the ancestral valley could have provided an easy northwest course for the melt waters from the ice lobe. The drainage that developed, however, ignored both the reexposed synclinal structure and the several grabens which it crosses at nearly right angles. Three different sets of conditions may have obtained: (1) a northeastward-trending recessional moraine may have been formed, damming the northwesterly course and forcing the runoff to cut a channel southward to the glacial San Miguel River; (2) a similar situation may have been created by a stagnant mass of ice, broken from the active lobe, that effectively blocked the course of the old valley; (3) rapid headward erosion of a small southward-flowing tributary at the southwest corner of the temporarily stationary lobe may have captured all the runoff along the western and northwestern edges of the ice lobe.

The major objection to the existence of a recessional moraine is that no trace of it remains, and it is somewhat unlikely that a moraine large enough to provide an effective dam would have been completely removed. Either of the two other sets of conditions is possible; no evidence has been found to determine which is more likely.

At this time or shortly thereafter, northwesterly drainage in the old ancestral valley was resumed, tributary to glacial McKenzie Creek. Much of this drainage was adjusted to the structure, following the grabens, minor faults, and the synclinal axis. Stream capture occurred at two places. Haskill Creek, a short, steep-gradient southward-flowing tributary to glacial Leopard Creek, was formed (pl. 8*C*). The creek followed a part of the course of the ancestral San Miguel River, but in the opposite direction. Eroding headward, Haskill Creek captured the drainage of Gutshall Gulch and the southern part of the drainage in Sheep Draw graben, thus beheading the drainage of Sawdust Gulch.

With the disappearance of the Cerro ice sheet present-day drainage was essentially established. The course of the ancestral San Miguel River east of Leopard Creek was uncovered and the old valley was occupied by northwestward-flowing Alder Creek, which now has a backhand relationship to the Leopard Creek drainage (pl. 8*C*). The San Miguel River has greatly deepened its valley. In so doing, it is proable that it was controlled by the Black King fault, at least until the river level reached the top of the resistant Cutler formation. It then began to widen its valley, and because of the general southerly and southwesterly dip of the Cutler, it has migrated laterally to the south, downdip. An asymmetric valley has thus been formed with a steep south wall, close to which the river flows, and a relatively wide gently sloping elevated flat to the north, as far as the Black King fault. North of this fault the north valley wall again is steep. It is apparent that the fault still controls a part of the valley form, although it no longer controls the river course.

One windgap (point "*A*", pl. 8*D*) has been formed along the old course of the Galloway Draw drainage, at the north rim of the river valley. A short steep-gradient stream now flows south to the San Miguel River through this gap. A short southward-flowing tributary to the drainage of Haskill Hill (in Sheep Draw) is now separated from the headwaters of McKenzie Creek by a low divide. Because of its short course and steep gradient it is probable that this tributary will erode headward and capture the headwaters of McKenzie Creek in the future. A windgap will thus be formed along the western boundary of the Sheep Draw graben (point "*B*", pl. 8*D*). A short, northward-heading tributary on the west side of Leopard Creek, south of Sheep Draw (point "*C*", pl. 8*D*), will probably capture the southern part of the Sheep Draw drainage.

TERRACES

Numerous small terraces are present along the courses of Leopard Creek and the San Miguel River. Almost all of them are rock-held terraces, underlain by resistant strata in the Cutler formation and by the quartz-pebble conglomerate layer in the basal part of the Dolores formation. A few are present on resistant beds elsewhere in the Dolores formation and near the top of the Salt Wash sandstone member of the Morrison formation. A few terracelike benches, from 100 to 300 feet below the mesa tops, generally represent small fault blocks, although one or two may be remnants of an early stage in the development of the San Miguel River Canyon. The most consistently formed and most prominent rock-held terrace is developed on the quartz-pebble conglomerate layer in the basal part of the Dolores formation.

LANDSLIDES

Landslides are fairly common near the mesa rims along the San Miguel River and on Specie Creek. Although most of them are too small to map, a large earthflow on Specie Creek and two areas of slump and an earthflow or mudflow on the north bank of the San Miguel River in the southeastern corner of the quadrangle are shown on the geologic map (pl. 4).

Most of the landslides have taken place along the steep upper parts of the canyon walls, where the blocky resistant ledge-forming Dakota sandstone overlies the relatively incompetent mudstones of the Brushy Basin shale member of the Morrison formation. Slumped areas, whose upper surfaces slope inward toward the canyon walls, are characteristic of these landslides. In many places these slumps have taken place where normal faults, subparallel to the canyon walls, cut the Brushy Basin and Dakota. Landslides are most prevalent where the formations dip locally toward the valleys, rather than into the mesas. In numerous places the slumped areas have moved down 100 feet or more from their starting points. Individual slumped blocks of the Dakota sandstone range in size from a few feet to as much as 15 feet in longest dimension.

On the east side of Specie Creek, in the southwestern corner of the quadrangle (pl. 4), a very large earthflow has a vertical extent of about 800 feet and covers an area of about half a square mile. The flow has originated on the east along a north-northwestward-trending normal fault. The Dakota sandstone along the western hanging wall side of the fault has been downthrown about 80 to 120 feet. The sedimentary rocks dip about 3° to 5° to the west toward the valley of the cheek. The combination of these factors has led to a large earthflow, developed in the Brushy Basin member and incorporating large amounts of the Dakota. Hummocks, ridge and trough topography, and local interior drainage are abundantly developed on the landslide surface.

In the southestern corner of the quadrangle, about 4,500 feet north of the Pocahontas mine (pl. 4), a mudflow or earthflow has brought a block of Mancos shale into contact with the Cutler formation. The vertical displacement involved here is in the order of 900 feet; the stratigraphic displacement is about 1,500 feet. The earthflow is about 3,500 feet in length and ranges in width from 100 to 200 feet at its lower end to 500 to 700 feet at its upper end. It overlies and is parallel to two eastward-trending normal faults which branch from the Black King fault. Only the Mancos shale, and thin sills intrusive into it, appear to be affected. Numerous other small earthflows in the same vicinity are too small to be shown on the geologic map.

MINERAL DEPOSITS

The mineral deposits of the Placerville quadrangle include base, precious, and rare metals. The Entrada sandstone contains tabular deposits of vanadium with subordinate uranium, and the Pony Express limestone member of the Wanakah formation contains bedded replacement deposits of gold- and silver-bearing pyrite. Ore has been produced commercially from both of these types of deposits. Copper-bearing veins, containing varying amounts of "hydrocarbon" (solid members of the petroleum group), follow northwestward-trending normal faults; in places some of the hydrocarbon is uranium bearing. Sporadic attempts have been made to produce both copper and uranium from these deposits. Gold-bearing placer deposits are present along the bottom of the San Miguel River valley and in elevated gravels as much as 200 feet above the present stream level. Some gold was produced from the placers late in the 19th century and early in the 20th.

Only a summary of the mineral deposits is given in this report on areal geology. Reference is made to several published reports for additional information. A detailed study by the U. S. Geological Survey of the ore deposits of this and several adjoining quadrangles is in progress; the results will be published in a later report.

VANADIUM-URANIUM DEPOSITS

The Entrada sandstone of Late Jurassic age contains tabular uraniferous vanadium deposits in the southeastern quarter of the Placerville quadrangle. The deposits form an essentially continuous layer that is beltlike in plan (fig. 16) and that extends southeastward into the Little Cone and Gray Head quadrangles. The vanadiferous layer overlies a chrome-bearing layer that appears to be similar in habit and distribution, but of lower metal content. Both layers underlie the western edge of the Pony Express limestone member of the Wanakah formation. Hillebrand and Ransome (1900, 1905) first described the mineralogy of the deposits; Hess (1911, 1933), Fischer (1937, 1942), and Fischer, Haff, and Rominger (1947) have given several descriptions of the mineralogy and geology of these deposits.

Mining was most intensive from 1910–20 and from 1940–44. Intermittent small-scale operations, resulting in the production of a few hundred tons of ore, have been undertaken at a few of the mines since 1947. A general survey of the production for the entire Placerville district indicates that about 240,000 short tons of ore have been mined since 1910, with an average grade of about 2.5 percent V_2O_5. The average grade of the ore bodies commonly is between 1.5 and 3.0 percent V_2O_5. As no assays were made for uranium until after World War II, little information on the uranium grade is available, and much of this has not been published. Generally, however, the content is so low that uranium can be recovered only as a byproduct. The ore bodies are mined by modified room and pillar methods. Along the edges of the relatively flat-lying stopes the ore is usually sliced to where it thins to as little as 18 inches. In places where the grade of ore is higher than average the ore has been sliced to as little as 1 foot.

The mineralized rock forms a wavy essentially continuous layer that is beltlike in plan (fig. 16). The layer can be traced southward, with only minor breaks in continuity, along the east side of Leopard

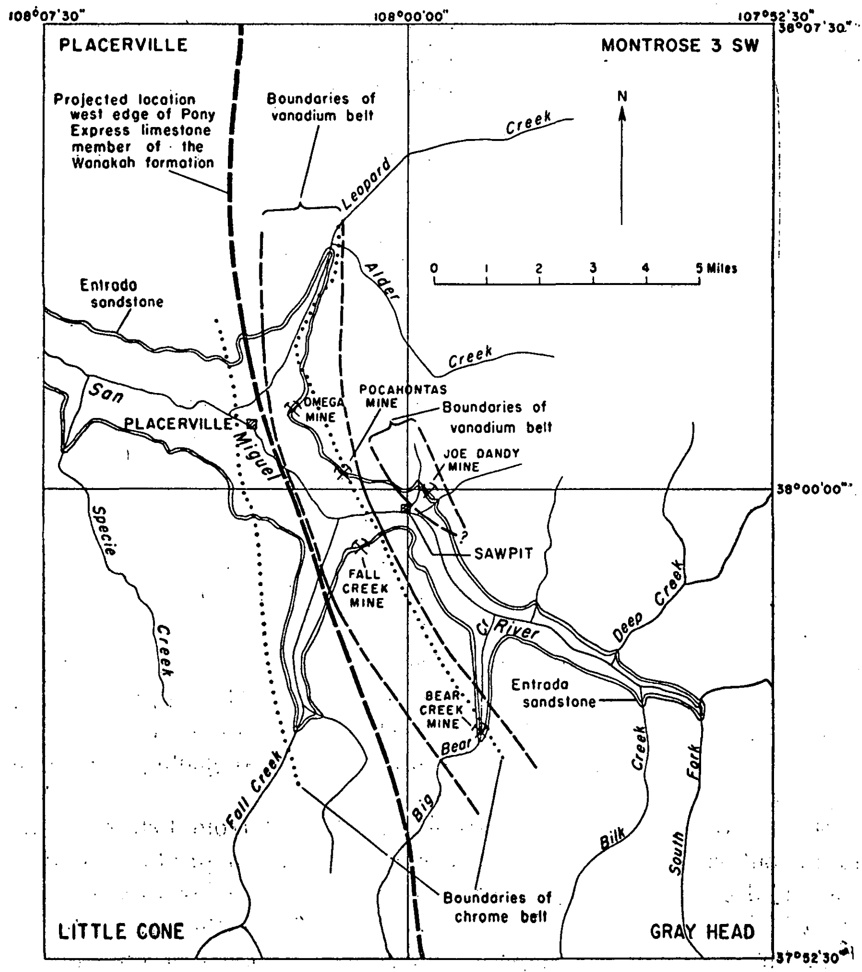


Figure 16.—Sketch map of the Placerville district, San Miguel County, Colo., showing the approximate distribution of the Entrada sandstone and the overlapping relationship of the vanadium belts, the chrome belt, and the western edge of the Pony Express limestone member of the Wanakah formation (in part after Fischer, Haff, and Rominger, 1947).

Creek from its confluence with Alder Creek to the Omega mine, and thence southeastward along the north side of the San Miguel River valley to a point about 1,500 feet east of the Pocahontas mine. Along the west side of Leopard Creek the layer is traceable southward from Alder Creek for about 2⅛ miles. This layer also crops out along the east side of Fall Creek and the south side of the San Miguel River valley in the Little Cone quadrangle. To the southeast the layer crops out again in the Big Bear Creek drainage in the west-central part of the Gray Head quadrangle. Thus the mineralized layer forms a long narrow belt that is traceable (although in part projected) for about 10 miles in length and for about 1 to 1½ miles in width.

A few hundred linear feet of a second vanadium layer is exposed in the extreme southeastern corner of the Placerville quadrangle (fig. 16). The layer crops out along the north side of the San Miguel River valley for about 1¼ miles in length and for about two-thirds to three-fourths of a mile in width. It extends from the Placerville quadrangle into the adjoining Little Cone, Gray Head, and the northwest quarter of the Montrose 3 SW quadrangles.

In general, the layer of mineralized rock follows an undulant intraformational unconformity in the upper part of the Entrada sandstone, where in most places relatively thinly and evenly bedded sandstone overlies massively bedded cross-laminated sandstone. Elsewhere the unconformity may lie within a series of massively bedded cross-laminated strata. The main mass of mineralized material can be below, above, or on both sides of the unconformity. The vertical position of the vanadium layer ranges in most places from 5 to 25 feet below the top of the Entrada sandstone. In a few places, however, it approaches within a foot or two of the overlying Pony Express limestone member of the Wanakah formation.

The mineralized layer generally follows the bedding of the sandstone, though it does not conform to it in detail. In numerous places the vanadium layer has an abrupt edge that crosses the bedding in a smooth curve, forming "rolls"; where it does so there is commonly a plane of fracture parelleling the abrupt edge and lying one-eighth to one-fourth of an inch within it. The ore breaks to this fracture in mining, leaving smooth surfaces on the backs, walls, or floors of the stopes. Elsewhere the edge of the ore is an indefinite zone a few inches to a few feet wide within which the mineralized material grades into barren rock.

Although the average thickness of each vanadium layer is probably less than 1 foot, a fairly large proportion of each layer consists of widely separated ore bodies 1 foot to 5 feet thick. The layers range in thickness from a small fraction of an inch to more than 20 feet. Commonly the ore bodies are roughly circular, elliptic, or elongate in plan. The average trends of most of the rolls and the thicker portions of the ore bodies lie nearly at right angles to the trend of the vanadium belts. In detail the elongate trends of the rolls and the thicker portions of the ore bodies may be singly curved or broadly sinuous.

The vanadium minerals impregnate sandstone, coating the sand grains, replacing and substituting for the calcite cement of the host rock, and in many places completely filling the interstices between sand grains. Roscoelite, the vanadium mica, is the major ore mineral; minor amounts of montroseite, a hydrous vanadium oxide, are present in clayey seams in the ore. Primary uranium minerals as yet have not been found; the uranium may occur adsorbed in the vanadium minerals, in other clay minerals, or as minute, discrete minerals. In places the secondary uranium minerals, carnotite and tyuyamunite, are present where the ore is oxidized. The vanadium minerals impart a greenish color to the rock; with increase in the concentration of vanadium the color deepens. High-grade vanadium ore, 4 percent or more V_2O_5, is dark greenish gray to nearly black.

Quartzitic "eyes," lenses, and nodules are common in the ore layer. Clayey seams, less than 1 inch thick, occur in places in the ore layer, most commonly at its top; they contain the highest grade vanadium and uranium ore, commonly 10 to 20 percent V_2O_5. Pyrite nodules, ranging in diameter from a small fraction of an inch to nearly 2 inches, occur in the mineralized layer in a few places; they are most common at or near the top of the layer. At one locality, about 3,000 feet west-northwest of the Pocahontas mine (pl. 4), the vanadium layer contains concretionary masses of sandstone cemented by uranium-bearing hydrocarbons, with fracture and grain coatings of yellow-green uranium-vanadium minerals.

Underlying the western vanadium layer in the Entrada sandstone (fig. 16) is a layer that contains a chromium-bearing micaceous mineral, possibly a chrome-bearing analogue of the roscoelite in the vanadium layer. Generally the chrome layer lies from 5 to 15 feet below the vanadium layer; it reflects the undulations of the upper layer, but in modified form. Like the vanadium layer, the chrome layer forms an elongate belt; it extends farther west than the major vanadium belt and apparently is absent below the minor eastern vanadium belt.

All the vanadium deposits appear to be confined to where the Entrada sandstone is overlain by the Pony Express limestone member of the Wanakah formation. The limestone thins westward to a generally northward-trending depositional edge; this edge is exposed along the west side of Leopard Creek, 1.3 miles due north of the village of Placerville. The western, major vanadium belt underlies this thin edge of the Pony Express (fig. 16), and lies approximately one-quarter of a mile eastward (basinward) from the edge of the limestone. No vanadium-uranium deposits are known in the Entrada sandstone in the Placerville district where the limestone was not deposited.

GOLD- AND SILVER-BEARING PYRITE DEPOSITS

Massive bodies of pyrite, carrying some gold, silver, lead, and zinc form bedded replacement deposits in the Pony Express limestone member of the Wanakah formation in the extreme southeastern corner of the Placerville quadrangle. Cross and Purington (1899) have described similar deposits in the Pony Express in the adjoining 15-minute Telluride quadrangle, north and northeast of the hamlet of Sawpit. Most of these deposits were in production only during the period 1890–1910.

The major primary ore minerals are pyrite and galena; in many places these are oxidized to limonite and cerussite. Gold and silver appear to be admixed with the pyrite and galena respectively, or, where oxidized, with the limonite and cerussite. Zinc occurs sparingly as sphalerite and possibly as smithsonite or aurichalcite.

The replacement bodies appear to follow fractures or faults of small displacement, generally of northwesterly trend. They are elongate masses, at least one of which is more than 1,200 feet in length, as much as 100 feet wide and 5 feet thick. The average deposit is considerably smaller, however. The deposits occur in the upper part of the Pony Express limestone, which ranges from 6 to 11 feet in thickness in this area. The limestone has been intensively leached along both the northwest faults and fractures and along crosscutting faults and fractures that have not controlled the mineralization. The area of leaching is consistently larger than the ore deposits and surrounds the deposits as a type of halo. Where leaching has been most intense the Pony Express has been reduced from a thickness of as much as 11 feet to as little as 2½ feet. Above and below the deposits the northwestward-trending faults and fractures are barren, or contain only calcite veinlets. Cross and Purington (1899) have suggested that a nearby basic dike may have been the cause of, or may have been associated with, the mineralization process. A few hundred feet east of the group of deposits, northeast and east of Sawpit, a large laccolithic mass of diorite has been intruded into the Dakota sandstone. Its relations to the replacement deposits are as yet obscure, but it may have supplied the mineralizing solutions that formed the pyrite replacement bodies.

COPPER-BEARING VEIN DEPOSITS

West-northwestward and northwestward-trending normal faults in the southern third of the Placerville quadrangle contain copper minerals, viscous asphalts, and uranium-bearing solid members of the petroleum group ("hydrocarbons"). All the known deposits are along these faults where they transect the Cutler and Dolores formations.

The mineralogy of these deposits was first described by Hess (1911, p. 150–152; 1933, p. 463). Kerr and others (1951) have also given a description of the geology and mineralogy of one of the deposits, but because their paper does not distinguish clearly between the vein deposits and the tabular vanadium-uranium deposits in the Entrada sandstone the resulting descriptions and conclusions are somewhat confused. A comprehensive and detailed study has been made by V. R. Wilmarth and R. C. Vickers (written communication, 1952), and by V. R. Wilmarth and C. C. Hawley (written communication) who have mapped and studied all of the known copper-hydrocarbon-bearing veins.

All the mineralized faults lie north of the San Miguel River. The Black King fault (pl. 4) is the southernmost of the set; it is continuously traceable for a distance of 4 miles to the west of Leopard Creek and for 1½ to 2 miles to the east. The most important vein deposits are along this fault. Along Leopard Creek the zone of mineralized faults extends about three-fourths of a mile northeast from the Black King fault. V. R. Wilmarth and C. C. Hawley (written communication) recognize two main systems of the faults in the area they mapped: "a northwest system that contains ore minerals in a calcite-barite gangue, and a north-trending system that contains only calcite veins."

The following very brief description of the deposits is quoted from material supplied by V. R. Wilmarth and C. C. Hawley:

> Uraniferous materials have been found in and adjacent to northwest-trending faults cutting the Cutler formation of uppermost Pennsylvanian or lowermost Permian age and the Dolores formation of Triassic * * * age. * * * The two most important vein deposits are in a northwest-trending fault, the Black King fault * * * In both of these deposits, and in small deposits in and near faults, most of the uranium is contained in a hardened petroliferous material of the type often called "hydrocarbon." Small amounts of uraniferous hydrocarbon are found in the Dolores formation at some distance from faults. * * * Uranium occurs in the hydrocarbon in the minerals uraninite and coffinite, and probably also as an organic complex.
>
> Tetrahedrite, sulfide minerals, and calcite and barite gangue are closely associated with the hydrocarbon in vein deposits. The metallic minerals, such as tetrahedrite, and the calcite and barite gangues were deposited from hydrothermal solutions. The uraniferous hydrocarbons were probably derived from a petroleum that was migrating in the fracture systems or was contained in adjacent sedimentary rocks.

PLACER DEPOSITS

In the period 1878–1940 placer mining for gold was carried on in a desultory fashion along the San Miguel River in the Placerville quadrangle, as well as to the east and west of the quadrangle. The earliest placer production recorded for San Miguel County by Henderson (1926, p. 226) was in 1878. The total production for the county, to which operations in the Placerville quadrangle contributed only a minor part, has probably been less than $400,000. Most of the production was prior to 1909, although there was a moderate increase in activity during the period 1932–41 (Vanderwilt, 1947, p. 203).

Placer gold has been produced mainly from the terrace-gravel deposits or "high bars", although a small amount of gold has been recovered from Recent stream alluvium where bedrock is near the surface. Most of the terrace-gravel mining was done by hydraulic methods or by drifting; the gold was recovered by sluicing. Water for these operations was obtained through flumes from the San Miguel River and from Fall Creek and other streams to the east and south of the quadrangle. Mining of the Recent alluvium in the stream valleys was by shallow excavation; stream water was used to wash the gravel.

No hydraulic mining of consequence was done in the Placerville quadrangle, but a considerable amount of gravel was processed along the San Miguel River 2 to 3 miles west of the quadrangle. Other large-scale hydraulic mining was done along the San Miguel River east of the quadrangle. The southeast extension of the terrace-gravel deposit shown at the southern boundary of the quadrangle was mined by small-scale hydraulic operations. In the Placerville quadrangle drift mines are located on the north side of the San Miguel River just east of Placerville and on the south side of the San Miguel River about 1 mile west of Placerville. Another drift mine on the south side of the San Miguel River just west of Specie Creek may have been in part a hydraulic operation.

Information from local miners indicates that the gold was for the most part of fine-grain size and that very few nuggets were found. Most of the gold is reported to have been in the base of the gravels. Observations of the bedrock-gravel contact in several placer drifts indicate that the contact is irregular and in places constitutes the bed of an earlier stage of the San Miguel River.

The amount of gold per cubic yard of gravel is not known for the deposits in the Placerville quadrangle. Henderson (1926, p. 222), in quoting the Director of the Mint's report for 1901, states that at the Keystone placers, which are along the San Miguel River about 10 miles east of the Placerville quadrangle, the gravel carried "from 10 cents in surface dirt per yard to $1.50 in bedrock." Burchard (1883, p. 521), in the Director of the Mint's report for 1882, states that the Willow Creek bar, located on the north bank of the San Miguel River between the Keystone placers and the hamlet of Sawpit, produced an average of 75 cents per cubic yard of gravel for all washings.

The main source of the placer gold was probably from the veins of the Telluride and Ophir mining districts to the east. A small amount of gold may have been derived from the Mount Wilson mining district to the south.

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