Areal Geology of the Little Cone Quadrangle Colorado

By A. L. BUSH, O. T. MARSH, *and* R. B. TAYLOR

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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Description of the stratigraphy and structure of a quadrangle that contains some of the significant vanadium deposits of the Placerville district. Prepared on behalf of the U.S. Atomic Energy Commission and published with the permission of the Commission

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[Plates in pocket]

AREAL GEOLOGY OF THE LITTLE CONE QUADRANGLE, COLORADO

By A. L. Bush, O. T. Marsh, and R. B. Taylor

ABSTRACT

The Little Cone quadrangle includes an area of about 59 square miles in eastern San Miguel County in southwestern Colorado. The quadrangle contains features characteristic of both the Colorado Plateaus physiographic province and the San Juan Mountains, and it has been affected by geologic events and processes of two different geologic environments.

The continental sedimentary rocks of the Cutler formation of Permian age are the oldest rocks exposed in the quadrangle. Deposition of the Cutler was followed by a long period of erosion and peneplanation. There is no marked angular discordance between the Cutler and the overlying Dolores formation in the Little Cone quadrangle, but there is in areas some tens of miles east and west of the quadrangle where some crustal warping took place.

The continental sedimentary rocks of the Dolores formation of Late Triassic age are red beds that are similar in gross lithology to those of the Cutler. The Dolores formation is subdivided into five general units that persist throughout the quadrangle and for some tens of miles to the north, south, and east. A second long period of erosion followed deposition of the Dolores.

The Entrada sandstone of Late Jurassic age overlies the Dolores formation, and is in turn overlain by the Wanakah formation, also of Late Jurassic age. The Wanakah consists of the Pony Express limestone member at the base, the Bilk Creek sandstone member near the center, and a "marl" member at the top. The Morrison formation, which overlies the Wanakah, consists of the Salt Wash sandstone member in the lower part and the Brushy Basin shale member in the upper part. A period of erosion, probably of relatively short duration, followed deposition of the Brushy Basin member.

The Burro Canyon formation of Early Cretaceous age occurs as discontinuous bodies that fill channels cut in the top of the Morrison formation. Deposition of the Burro Canyon formation was followed by another period of erosion, which in turn ended with deposition of the Dakota sandstone of Late Cretaceous age. The Dakota sandstone grades upward into the Mancos shale, also of Late Cretaceous age.

The Paleozoic and Mesozoic formations were broadly folded during Laramide time as part of an orogeny of regional extent, and the San Juan Mountains area was uplifted as a broad dome. Extensive erosion followed deformation, and the Cretaceous rocks in the area of the Little Cone quadrangle and the Mesozoic and Paleozoic rocks eastward from the quadrangle were successively bevelled. The Telluride conglomerate of Oligocene(?) age was laid down on this surface. In the Little Cone quadrangle several hundred feet

of the Telluride was deposited upon a considerable thickness (probably 3,000 feet or more) of the Mancos shale. At Telluride, about 12 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; at one time they had a thickness of probably 1,000 feet or more in the quadrangle. They have been eroded completely from the quadrangle, but are present in the San Miguel Mountains a few miles to the south and southeast.

During the middle Tertiary, probably during the Miocene, the sedimentary rocks were cut by many igneous bodies. Four major rock types are represented; in decreasing order of abundance they are granogabbro, granodiorite, rhyolite(?), and microgabbro. The granogabbro is by far the most abundant, and it forms the Flat Top Peak plug, the Little Cone laccolith, several sills in the Dakota sandstone and the Mancos shale, and a few dikes. The granodiorite forms sills in the Dakota sandstone and the Mancos shale, and the rhyolite(?) forms a single major sill in the Dakota. The microgabbro forms dikes that cut rocks as young as the Mancos shale. Metamorphic effects adjacent to the intrusive bodies generally are restricted to baking that extends only a few feet out into the enclosing rocks; in many places no metamorphic effects are evident.

The rocks in the Little Cone quadrangle were displaced along numerous faults in middle Tertiary time, probably after the igneous rocks were injected. All of the faults are normal, and have vertical or very steep dips. In part, the faults form two long and narrow northward- and northwestward-trending grabens that extend into the adjoining Placerville quadrangle to the north. The graben faults form two systems, one trending northward to northwestward, and the other trending northwestward, that are probably contemporaneous. Other faults trend eastward to northeastward; some of these appear to be related to the intrusion of the igneous rocks.

At the end of the Tertiary, probably in the early Pleistocene, the general area was again uplifted and subjected to extensive erosion. The Mancos shale was stripped from the northern part of the Little Cone quadrangle, and in this part of the area, the upland surfaces formed on top of the Dakota sandstone were largely controlled by the geologic structure.

During the Quaternary a basalt flow was erupted on Specie Mesa on a surface that cuts both the Mancos and the Dakota. The surface preserved beneath the flow has virtually the same position and slope as the adjacent present-day surfaces. Pleistocene deposits consist of (a) high-level or older drift that is unrelated to the present drainage systems and is correlated with the Cerro glacial stage of early Pleistocene age, and (b) younger drift and valley fill within the valleys of the present drainage systems that are correlated with the Durango or Wisconsin glacial stages and may represent both. Recent surficial, landslide, and spring deposits are also present.

Within the Little Cone quadrangle and in the Placerville quadrangle to the north and the Gray Head quadrangle to the east, the Entrada sandstone of Late Jurassic age contains vanadium deposits with which are associated large but low-grade amounts of uranium. These deposits form a practically continuous layer about 10 miles long and 1 to 1½ miles wide, and possibly a second layer of smaller dimensions. Placer gold deposits in terrace gravel and valley fill of Pleistocene age and in alluvium of Recent age contain the only other ores.

INTRODUCTION

LOCATION, ACCESSIBILITY, AND CULTURE

The Little Cone quadrangle is one of five adjoining 7½-minute quadrangles in eastern Miguel County, Colo. (fig. 42) studied in

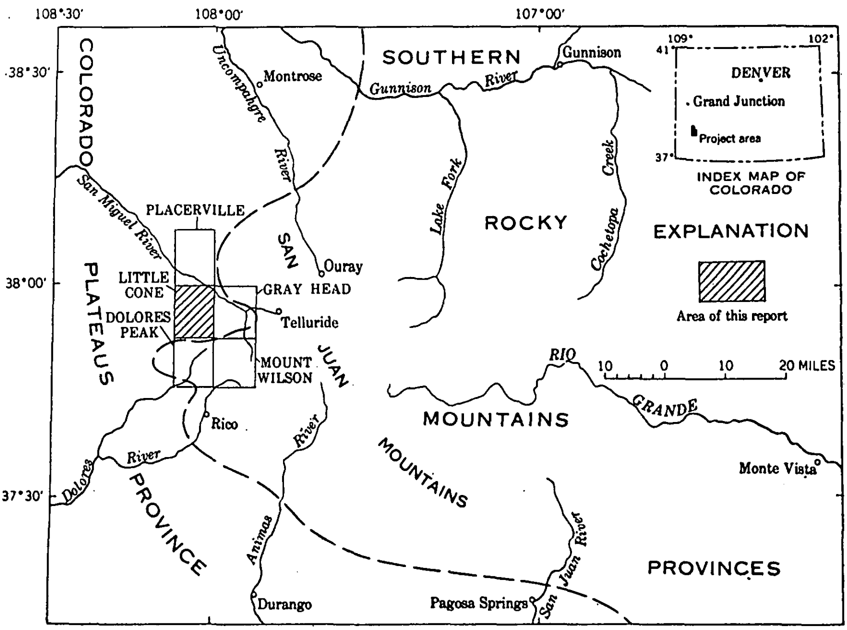

FIGURE 42.—Index map showing the Little Cone and adjoining quadrangles, southwestern Colorado.

connection with their vanadium-uranium deposits. The quadrangle includes an area of about 59 square miles within and near the border of the Colorado Plateaus physiographic province. It is bounded on the south by the San Miguel Mountains, a westward extension of the San Juan Mountains, and shares geologic characteristics of both the plateau and mountain country.

State Highway 145 crosses the northeast corner of the quadrangle and connects the town of Saw Pit with Placerville to the west and Telluride to the east. A network of dirt roads gives access to the mesa tops and the valleys of Fall Creek and Elk Creek; these roads are not passable in winter.

About 100 persons live year round in the quadrangle; most of them are at Saw Pit, which is in the northeast corner of the quadrangle and is the only settlement. Sheep and cattle raising, lumbering, and intermittent vanadium mining are the productive industries.

TOPOGRAPHY, CLIMATE, AND VEGETATION

The Little Cone quadrangle contains three major topographic divisions: mesas make up about 25 percent of the area; steep-walled canyons, incised below the mesas, constitute about 15 percent of the area; and mountain slopes, rising above the mesas, cover about 60 percent of the area. Altitudes range from 7,400 feet in the San Miguel River canyon to 11,981 feet at the summit of Little Cone.

The mesa surfaces generally reflect the top of the nearly flat lying resistant Dakota sandstone. The mesas are concentrated chiefly in the north half of the quadrangle where their average altitude is about 9,200 feet. East of Fall Creek the upland surface is called Wilson Mesa; west of Fall Creek it is known as Specie Mesa. Frazier Flats, the mesa northeast of Woods Lake, is capped by a sill and has a nearly level surface at an altitude of 10,000 feet.

Fall Creek, the quadrangle's main drainage, flows northward across the quadrangle and empties into the San Miguel River in the northeast corner. Most of its course is in a steep-walled canyon that is incised as much as 2,100 feet below the mesa tops. West of Fall Creek Little Cone rises almost 3,000 feet above Specie Mesa and occupies fully one-quarter of the quadrangle.

The mean annual rainfall at the lowest altitudes in the quadrangle is less than 10 inches; although no records are available for the mesa tops within the quadrangle, the mean annual precipitation recorded at comparable altitudes nearby is about 15 to 20 inches. The heaviest rainfall occurs on the higher mountain slopes. Thunderstorms are most frequent in July and early August, although sporadic showers may come at any time during the summer. Hail or sleet may also be expected during the rainy reason. The first snowfall is usually in late September or early October; generally snow remains on the higher slopes until the middle of July, although commonly a few patches last through the summer. Mean summer temperature in the northeast corner of the quadrangle is about 65° F, and mean winter temperature is 25°–30° F. On the mesas the average temperatures are about 10° lower.

Vegetation in the Little Cone quadrangle is closely linked to the contrasting climatic zones that are controlled by altitude differences. Cottonwood, willow, and alder are found along the canyon bottoms. Dense thickets of scrub oak and serviceberry interspersed with stands of mountain juniper, pinyon pine, aspen, and Engelmann spruce cover the canyon walls. The relatively protected, north-facing slopes are usually the more densely wooded. Aspen, scrub oak, black sage, and various grasses flourish on the mesa tops. The shrublike vegetation of the mesa tops gives way on the mountain slopes to forests of aspen, ponderosa pine, and Engelmann spruce, with evergreens predominating. Timberline on Little Cone is at about 11,400 feet, but the top of Flat Top Peak, at about 11,600 feet, is covered with dwarfed timber.

SCOPE AND PURPOSE OF THE WORK

The Entrada sandstone of Late Jurassic age contains large tabular deposits of vanadium and subordinate amounts of uranium in several areas along the west flank of the San Juan Mountain region in southwestern Colorado. These deposits are practically continuous, and they form several elongate belts whose horizontal dimensions are measurable in miles. The belts are known in the Placerville district of San Miguel County, the Barlow-Hermosa Creek district of Dolores and San Juan Counties, and the Lightner Creek district of La Plata County. The Placerville district is the most important in terms of known reserves, size of deposits, and past production.

The study was undertaken to determine the origin and habits of the vanadium-uranium deposits, their resources, and their relations to the igneous rocks and metalliferous deposits of the San Juan igneous province. In addition, the work included the areal geologic mapping of about 300 square miles—five 7½-minute quadrangles (fig. 42)—which cover the vanadium belts of the Placerville district and the igneous 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.

This program of study was done on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission.

PREVIOUS WORK

Cross (1899) described the geology of the 15-minute Telluride quadrangle, which adjoins the Little Cone quadrangle to the east. Bush and others (1959) have described the physical and historical geology of the Placerville quadrangle, which adjoins to the north.

Hess (1911, 1933), Fischer (1937, 1942), and Fischer and others (1947) have described the geology and petrology of the vanadium-uranium deposits and have presented maps showing their distribution in the northeast corner of the Little Cone quadrangle.

FIELDWORK AND ACKNOWLEDGMENTS

A small strip along the north border of the Little Cone quadrangle was mapped by A. L. Bush, C. T. Pierson, and W. F. Weeks in 1953 and 1954 in connection with the mapping of the Placerville quadrangle. The remainder of the quadrangle was mapped during parts of the 1955 and 1956 field seasons by O. T. Marsh, C. S. Bromfield, R. B. Taylor, Bush, and Pierson.

Geologic mapping was done at a scale of 1:20,000 on topographic maps; some mapping was also done on aerial photographs at scales of 1:18,700 and 1:37,400, then transferred to the topographic base. Location was by inspection and resection, aided by corrected barometric readings.

The authors gratefully acknowledge the assistance of the residents of the quadrangle, in particular Mr. Easton S. Bray and Mrs. Delphane B. Bray of Woods Lake, and Mr. Clarence E. Ross.

REGIONAL GEOLOGY

The rocks exposed in the Little Cone quadrangle and in the country for many miles to the north and west consist of relatively flat lying sedimentary rocks that range in age from Permian to Cretaceous. Generally the mesa tops are capped by the Dakota sandstone or Mancos shale, both of Cretaceous age; the older rocks are exposed in the walls of steep-sided youthful canyons. A few miles north of the quadrangle the sedimentary rocks rise over the Precambrian core of the Uncompahgre Plateau. North and west of the quadrangle these rocks have been warped into a series of broad folds that plunge gently northwestward and merge with the "salt anticlines" of southwestern Colorado and southeastern Utah (the Paradox fold and fault belt of Kelley, 1955). The southeastern extensions of some of these warps are present in the Little Cone quadrangle.

The sedimentary rocks are overlain by a great pile of Tertiary volcanic rocks and are cut by many Tertiary intrusive rocks in the San Juan Mountains, a few miles to the east and south of the quadrangle. Most of the igneous rocks in the Little Cone quadrangle are concentrated in the south half, where they form intrusive bodies within the sedimentary rocks. These bodies include a cupola on a stock, a laccolith, and numerous sills and dikes. The igneous rocks are more numerous in the San Miguel Mountains to the south, where the intrusive rocks cut both sedimentary and volcanic rocks.

A few miles east of the Little Cone quadrangle the pre-Tertiary sedimentary rocks are warped into a broad dome whose apex lies a few tens of miles farther east. The dome is bevelled by a smooth erosion surface upon which lies the oldest Tertiary formation, the Telluride conglomerate. Eastward from the Little Cone quadrangle the Telluride conglomerate progressively overlies older formations, which range from the Mancos shale of Late Cretaceous age to the Precambrian basement complex (Burbank, 1930, p. 184).

Hundreds of feet of volcanic rock of Miocene(?) or Miocene age overlies the Telluride conglomerate in the region. These rocks include, in ascending order, the San Juan tuff, the Silverton volcanic series, and the Potosi volcanic series. Erosion during the late Tertiary and the Quaternary removed the Telluride conglomerate and the thick volcanic sequence that once covered the Little Cone quadrangle.

Vertical or steeply dipping normal faults are numerous in the Little Cone quadrangle and adjacent areas to the east, north, and west. Many of these faults bound long narrow grabens, which trend north or northwest, and which characteristically swing eastward at their south or southeast ends. Vertical offsets on the faults are commonly a few hundred feet, and in a few cases are as much as 700 feet. The narrow grabens are the most striking structural feature of the plateau country north and northwest of the San Miguel Mountains.

SEDIMENTARY AND IGNEOUS ROCKS

RELATIONS OF THE SEDIMENTARY ROCKS

About 4,400 feet of upper Paleozoic and Mesozoic sedimentary rocks are exposed in the Little Cone quadrangle. The oldest rocks crop out in the northeast corner where Fall Creek and the San Miguel River have cut down into the Cutler formation of Permian age. The base of the Cutler is not exposed within the quadrangle; it is exposed a few miles south of the area near Rico. The Dolores formation of Late Triassic age rests disconformably upon the Cutler, and, in turn, is overlain disconformably by the Entrada sandstone of Late Jurassic age. Above the Entrada is the Wanakah formation of Late Jurassic age, which consists of the Pony Express limestone member at the base, the Bilk Creek sandstone member in the middle, and the "marl" member at the top. The Pony Express limestone member is present only in the northeast corner of the quadrangle; it was not deposited elsewhere in the quadrangle. The Morrison formation, the uppermost Jurassic formation in the area, conformably overlies the Wanakah and consists of the Salt Wash sandstone member at the base and the Brushy Basin shale member at the top. At the base of the Salt Wash is a distinctive sandstone unit that is probably the equivalent of the Junction Creek sandstone of southwestern Colorado. The oldest Lower Cretaceous unit is the Burro Canyon formation, which apparently is present only as local fillings in channels cut into the top of the Brushy Basin shale member. Where the Burro Canyon is absent, the Dakota sandstone rests on an erosion surface formed on the Brushy Basin. Some miles west of the quadrangle the contact between the Burro Canyon and the Dakota is disconformable, but evidence is insufficient to determine whether the two formations are disconformable within the Little

Cone quadrangle. The youngest sedimentary rock in the area is the marine Mancos shale of Late Cretaceous age which in places has a transitional contact with the Dakota sandstone.

The sedimentary formations exposed in the Little Cone quadrangle are summarized in a generalized columnar section (pl. 18). They are described in somewhat greater detail in the report on the Placerville quadrangle (Bush and others, 1959).

Quaternary stream gravel and Recent alluvium are found along the canyon bottoms. Glacial drift is sparsely distributed on the upland surface.

Probably at least 3,000 feet of older Paleozoic rocks underlies the formations exposed in the Little Cone quadrangle. This estimate is based on data from oil wells to the northwest and exposures near Rico and Ouray, to the south and east (fig. 42). These unexposed beds probably include the Elbert formation and the Ouray limestone of Devonian age, the Leadville limestone of Mississippian age, the Molas and Hermosa formations of Pennsylvanian age, and the Rico formation of Pennsylvanian and Permian(?) age.

PERMIAN SYSTEM

CUTLER FORMATION

In the Little Cone quadrangle the Cutler formation crops out only in the northeast corner, along lower Fall Creek and the San Miguel River (pl. 19). Both the Cutler and the overlying Dolores formation are red beds; they are grossly similar lithologically, but the Cutler can be distinguished at a distance by its distinctly purplish cast.

A striking feature of the Cutler formation is the abundance of conglomerate beds, which make up 25 to 40 percent of the exposed thickness of the formation. These beds average 5 to 10 feet in thickness, but some are as thick as 20 feet. Pebble- and cobble-conglomerate beds are most common, though fragments range in size from granules to boulders. Most of the fragments are well rounded; they consist chiefly of granitic rocks, greenstone, and quartzite. Diorite and metasedimentary rocks such as schist are less common. Greenstone conglomerate beds are rare in the upper 350 feet of the Cutler, but lower in the formation they are quite abundant. The conglomerate matrix consists of medium to coarse grains of quartz and feldspar.

Perhaps 60 percent of the Cutler formation consists of arkosic sandstone that is cemented by calcite and stained red by hematite. Most of the grains are medium to coarse and subrounded to subangular; although generally poorly sorted, they tend to be better sorted in the uppermost 150 to 200 feet of the formation. Mica is commonly abundant.

Limy siltstone and thin mudstone beds are present in minor amount. In many places they have been bleached from their usual red color to gray green. Thin lenticular gray limestone beds are sparsely distributed throughout the formation.

Beds in the Cutler formation are not persistent over long distances. Lenses of conglomerate, sandstone, and siltstone range in length along the outcrop from a few tens of feet to a few thousand feet and commonly the conglomerate beds occupy channels cut in the underlying rock. Many of the beds of the Cutler display either planar or festoon cross-stratification.

The total thickness of the Cutler formation is not known, as the base is concealed below present erosion levels. About 800 feet of the Cutler is exposed in the Little Cone quadrangle, and a maximum of about 1,100 feet is exposed in the Placerville quadrangle half a mile to the north. Exposures near Rico and Ouray, and data from deep oil wells to the west and northwest, suggest that the total thickness of the Cutler in the Little Cone and Placerville quadrangles is on the order of 4,000 feet. This figure is very approximate, however, for in other areas the Cutler is known to range widely in thickness within short distances.

Section of the Cutler formation 1 mile southeast of Placerville (half a mile north of the Little Cone quadrangle) on the north side of the San Miguel River canyon

	Feet
Triassic: Dolores formation: Maroon sandstone and siltstone overlying basal quartz-pebble conglomerate	54
Erosional unconformity.	
Permian:	
Cutler formation:	
Sandstone and conglomeratic sandstone, grayish- and purplish-red, medium-fine-grained; arkosic granitic conglomerate in lower 10 feet; micaceous conglomerate at top	75
Sandstone and sandy mudstone, arkosic, very thinly bedded and laminated	42
Sandstone, conglomeratic sandstone, and conglomerate, pale-red, grayish-red, and purplish-red, arkosic, fine- to medium-fine-grained, thinly bedded and laminated	131
Sandstone and conglomerate, pale-red and grayish-red, arkosic, micaceous, very fine to medium fine grained, thinly bedded	115
Sandstone, conglomeratic sandstone, and conglomerate, pale-red grayish-orange-pink, purplish-red, grayish-red; pebbles to boulders of quartzite, granite, slate, and greenstone; irregularly bedded	104
Sandstone, pale-red and pale reddish-brown, arkosic, very thinly bedded and laminated	64
Sandstone, conglomeratic sandstone, and conglomerate, reddish-brown and various shades of red; pebbles to boulders of greenstone and granite; very thinly bedded and laminated	131
Sandstone, pale-reddish-brown, some grayish-red, arkosic, micaceous, very fine to medium grained, very thinly bedded	68

Section of the Cutler formation 1 mile southeast of Placerville (half a mile north of the Little Cone quadrangle) on the north side of the San Miguel River canyon—Continued

	Feet
Permian—Continued	
Cutler formation—Continued	
Arkose and conglomeratic arkose, pale-red and grayish-orange-pink, medium to very coarse grained, massive to thinly bedded; grades laterally into coarse conglomerate lentils	112
Greenstone conglomerate, abundantly arkosic, many granite and slate fragments of pebble to small boulder size; lenticular and channel filling	11
Sandstone, conglomeratic arkose, and conglomerate, pale-red, grayish-red, pale-reddish-brown, grayish-orange-pink; conglomerate pebbles to cobbles of quartz, quartzite, and slate; very fine to coarse grained, thinly bedded sandstone, massive in middle part	82
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 Little Cone quadrangle the Cutler formation is separated from the Dolores formation of Late Triassic age by a disconformity that marks a long period of erosion. The erosion surface has only minor relief, which indicates that it was formed at or near base level under stable conditions. The two formations appear to be conformable where viewed at close range, but there is a suggestion of slight angular discordance where several thousand feet of the contact are viewed from a distance. Near Ouray there is a marked angular unconformity between the formations; east of Ouray the Cutler has been eroded and the Dolores rests on rocks of Pennsylvanian age (Cross and Howe, 1905; Burbank, 1930). In the Little Cone and Placerville quadrangles the contact between the beds of the Cutler and Dolores formations is marked by a quartz-pebble conglomerate that is the basal unit of the Dolores.

Although the Cutler formation is generally unfossiliferous, vertebrate remains have been discovered in the upper part of the formation in the southern part of the adjoining Placerville quadrangle. These specimens have been identified by A. S. Romer and G. E. Lewis (written communications, May 17 and June 23, 1955) as two amphibians, *Eryops* sp. and *?Platyhyatrix*, and several small reptiles, including a primitive diadectid, *Ophiacodon* sp., a small sphenacodontoid comparable to *Aerosaurus*, *Sphenacodon* sp., and a small pelycosaur comparable to *Nitosaurus*. Romer and Lewis (written communication, June 28, 1955) conclude that the fauna in the Cutler from the Placerville area may correlate with a similar fauna from the Abo sandstone in the El Cobre Canyon area, New Mexico. They add that this correlation "is reasonable, but there is little positive evidence * * *. 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."

TRIASSIC SYSTEM

UPPER TRIASSIC SERIES

DOLORES FORMATION

The Dolores formation crops out along the San Miguel River and along the bottom and lower slopes of Fall Creek canyon from Elk Creek northward (pl. 19). The red beds typically form sheer cliffs and steep rubbly slopes.

The Dolores consists of 70 to 75 percent interbedded sandstone and siltstone and 25 to 30 percent conglomerate and minor amounts of mudstone and thin limestone. The rock types intergrade and interfinger extensively, and crossbedding and channeling are common. No single stratum can be traced any great distance laterally. The formation is divisible into five parts, which in ascending order are: 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, sandstone and a minor amount of siltstone.

Unit A is a distinctive white or light-gray quartz-pebble conglomerate throughout most of the Little Cone and Placerville quadrangles. Bedding is generally irregular, although locally rude cross-stratification can be seen. In general the unit thins irregularly across the quadrangle, from about 65 feet in the central part to about 20 feet in the eastern part. Throughout most of the quadrangle the unit is about 40 feet thick. Subangular to subrounded pebbles and granules of vein quartz and quartzite make up from 60 to 80 percent of unit A; the remainder is predominantly coarse-grained quartz sand with scattered granules of limy siltstone and metamorphic rocks, and coarse grains of feldspar. Locally the conglomerate facies gives way to a coarse-grained sandstone facies without apparent change in composition.

Unit B is 120 to 140 feet thick and consists dominantly of sandstone and siltstone. The most distinctive feature of this unit, however, is the abundance of limestone-pebble conglomerate which in places constitute 35 or 40 percent of the unit. The conglomerate beds are light reddish brown or shades of gray, brown, and purple. Most of the beds are quite lenticular; they fill channels cut in the underlying rock and are irregularly bedded to rudely cross-stratified. They are composed of granules and pebbles of siltstone and limestone embedded in a matrix of limy siltstone. Near the base of the unit the conglomerate contains abundant granules and pebbles of quartz and quartzite.

The sandstone and siltstone beds are grayish red to light reddish brown. Stratification ranges from thin even lamination to thick irregular bedding. Most of the sandstone is very fine grained and in places micaceous. Both the sandstone and siltstone beds are cemented with calcite.

Unit C is about 180 to 250 feet thick and characteristically has few if any limestone-pebble conglomerate beds. Sandstone and siltstone similar to that of unit B constitute 75 to 90 percent of the section. Reddish-brown limy mudstone is present in places. The upper and lower parts of the unit are composed of cross-stratified irregularly bedded sandstone, siltstone, and mudstone; the middle part is evenly bedded rather than cross-stratified and contains very few thin mudstone beds. Each of these three subzones ranges widely in thickness, and in many places the upper subzone is missing.

Unit D ranges in thickness from 90 to 125 feet, and is similar in lithology and sedimentary structures to unit B. Limestone-pebble conglomerate and thin limestone beds are characteristic but less abundant than in unit B. In unit D cross-stratification is more prevalent than even bedding.

Unit E, the uppermost part of the Dolores formation, consists of a sequence of well-sorted light-reddish-brown siltstone and very fine grained sandstone. The thickness of unit E ranges from 20 to 55 feet at most places, although locally it may be as much as 70 feet; generally the unit is exposed in cliffs. Although devoid of limestone-pebble conglomerate beds, in places it contains thin limestone lenses. Beds are thick and irregularly stratified or crossbedded. Characteristically, this unit contains little mica. Unit E is similar in lithology and stratigraphic position to the Wingate sandstone of Late Triassic age and is tentatively correlated with it (Bush and others, 1959). The nearest exposure of the Wingate is in the valley of Tabegauche Creek about 32 miles northwest of the Little Cone quadrangle.

In the northeast corner of the Little Cone quadrangle the thickness of the Dolores formation ranges from about 460 to about 490 feet. The formation thins eastward; at Telluride 12 miles to the east the Dolores is 300 feet thick, and 5 miles northwest of its exposures in the Little Cone quadrangle it is 580 feet thick.

The Dolores formation is separated from the overlying Entrada sandstone by a disconformity that represents a long period of erosion. Relief on the erosion surface does not exceed 15 feet. In places the contact is sharp; elsewhere it is gradational, where the uppermost sediments of the Dolores apparently have been reworked into the basal part of the Entrada.

Section of the Dolores formation on the west side of Fall Creek, about 1.7 miles south-southwest of the junction of Fall Creek and the San Miguel River

Upper Jurassic: Entrada sandstone at top: Crossbedded, mixed grain sandstone at base, overlain by well-sorted sandstone.

Erosional unconformity.

Upper Triassic:

Dolores formation:

	Feet
Unit E (Wingate sandstone equivalent):	
Sandstone and siltstone, interbedded, dominantly pale-reddish-brown; sandstone, very fine grained, well-sorted; bedding ranges from regular to irregular, very thinly laminated to structureless, crossbedded in places; forms steep broken cliff	111
Thickness of unit E	111
Unit D:	
Siltstone (40 percent) and sandstone (60 percent) interbedded, grayish-red and pale-reddish-brown; purplish cast is very common in this unit; sandstone, very fine grained, some fine-grained; abundantly crossbedded, bedding ranges from dominantly very thin bedded to thick bedded; few thin mudstone units; forms steep slope below cliff of unit E	63
Sandstone and limestone-granule conglomerate, interbedded, light-brown and reddish-brown; sandstone, fine-grained, limy; limestone conglomerate ranges from 5 to 40 percent of unit along outcrop, unit very lenticular, forms short steep cliff	11
Mudstone and silty mudstone, pale-reddish-brown; very fine grained sandstone (2 feet thick) near middle; unit grades to muddy sandstone at top, weathers to small polygonal fragments	32
Siltstone, pale-reddish-brown, very thinly laminated to very thinly bedded, ranges from irregularly bedded to crossbedded; forms slope	17
Limestone-granule conglomerate, reddish-brown	1
Sandstone and siltstone, interbedded, pale-reddish-brown; sandstone, very fine grained, thin-bedded; siltstone very thinly and irregularly bedded; forms steep, rounded cliff	8
Total thickness of unit D	132
Unit C:	
Siltstone and muddy siltstone, pale-reddish-brown, very irregularly bedded; weathers to typical polygonal angular fragments; forms characteristic slope and short ledge profile	48

Section of the Dolores formation on the west side of Fall Creek, about 1.7 miles south-southwest of the junction of Fall Creek and the San Miguel River—Continued

	Feet
Upper Triassic—Continued	
Dolores formation—Continued	
Unit C—Continued	
Siltstone, grayish-red and pale-reddish-brown; very thinly laminated, almost fissile in parting; large-scale crossbedding; few thin very fine grained sandstone beds; sandstone (4 feet thick) at base; mudstone very scarce; forms cliff	48
Total thickness of unit C	96
Unit B:	
Muddy siltstone and siltstone, pale-reddish-brown and grayish-red; very thinly and irregularly bedded; numerous gray-green spots; a few beds 1 to 2 feet thick of very fine grained sandstone; numerous stringers of limestone-granule conglomerate, as much as 1 foot thick; reworked mudstone at top (4 feet thick) contains pebbles and cobbles of limestone-granule conglomerate; forms long slope	45
Sandstone and siltstone, moderate orange-pink to moderate reddish-orange in lower 15 feet, pale-reddish-brown and grayish-red above; numerous gray-green spots; micaceous; very thinly and irregularly laminated, a few thin to thick beds; some crossbedding; limestone-granule conglomerate at middle; forms alternate ledges and slopes	49
Section offset 1,100 to 1,200 feet northeast, along west side of Fall Creek.	
Covered interval	13
Siltstone and very fine grained sandstone, moderate reddish-orange; thinly and irregularly bedded; nodular weathering	8
Covered interval	14
Siltstone, moderate reddish-orange; nodular weathering; interbedded limestone-granule conglomerate and fine-grained sandstone, both pale red at middle	5
Total thickness of unit B	134
Unit A:	
Conglomeratic sandstone and sandstone, grayish-orange-pink; intermixture of quartz (25 to 40 percent) and limestone (60 to 75 percent) granules, thickly and irregularly bedded; contains a few muddy siltstone interbeds (1 to 2 feet thick); this unit appears to represent the quartz-pebble conglomerate	18
Thickness of unit A	18
Total thickness of Dolores formation	491
Erosional unconformity.	
Permian: Cutler formation at base: Interbedded arkosic sandstone, conglomerate, siltstone, and muddy siltstone.	

The Dolores formation as originally defined by Cross (1899) included the entire red-bed sequence in the Telluride area. In 1905, Cross and Howe separated the Cutler formation from the Dolores, but no attempt has been made since to divide the Dolores into members. According to Baker and others (1936, p. 2, 22) most of the Dolores formation is equivalent to the Chinle formation and the Shinarump conglomerate of former usage (now known as the Shinarump member of the Chinle formation of the Colorado Plateau—Stewart, 1957). Baker and others (1936) consider 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 concur with these conclusions.

The basal quartz-pebble conglomerate (unit A) resembles the Shinarump and Moss Back members of the Chinle formation of southeastern Utah (Stewart, 1957), both in lithology and depositional environment, and may correlate with either of these members. Unit E at the top of the Dolores is lithologically quite similar to the Wingate sandstone and is tentatively correlated with it. Units B, C, and D are correlated with the middle and upper parts of the Chinle formation, although for the present they are not correlated with specific members.

Previously the age of the Dolores formation was regarded as Late Triassic and Jurassic(?). However, the Wingate is now considered to be Late Triassic, rather than Jurassic(?) (Harshbarger and others, 1957, p. 8); and the age of the Dolores formation, therefore, also has been revised to Late Triassic (Bush and others, 1959).

The Dolores formation is sparsely fossiliferous. Most of the fossils have been found in limy sandstone and in limestone-pebble conglomerate, but phytosaurian teeth have been found in the basal quartz-pebble conglomerate. No fossils have been reported from the equivalent of the Wingate sandstone, unit E. According to Cross (1899), fossils from the Dolores formation include crocodile and phytosaurian teeth, ganoid fish remains, a species of megalosauroid dinosaur, a variety of Unio, a gastropod, and a conifer, *Brachyphyllum munsteri*. The leaves of a primitive palm or palmlike monocotyledon, *Sanmiguelia lewisi* (Brown, 1956, p. 205), were discovered in 1953 near the top of unit B. According to Brown, if these leaves are actually remains of primitive palms, "this is the earliest known angiospermous flowering plant."

JURASSIC SYSTEM

UPPER JURASSIC SERIES

In the Little Cone quadrangle Upper Jurassic rocks form steep slopes and cliffs along the canyons of Specie Creek, Fall Creek and its tributaries, and the San Miguel River (pl. 19). This series includes in ascending order, the Entrada sandstone, the Wanakah formation, and the Morrison formation. The maximum thickness of these formations totals about 1,000 feet; a probable average thickness for the Upper Jurassic series is about 860 feet.

ENTRADA SANDSTONE

The Entrada sandstone is the thinnest, yet one of the most distinctive formations in the western San Juan Mountains. In the Little Cone quadrangle its thickness ranges from 30 to 65 feet and it averages about 50 feet. The grayish-yellow color of the massive smoothly rounded cliffs contrasts strikingly with the darker hues of the underlying red beds.

The Entrada consists of two distinct lithologic units, separated by a diastem. The lower unit, which makes up 75 to 90 percent of the formation, is a massive sweepingly crossbedded sandstone. It is composed principally of fine to medium, rounded to subrounded, highly spherical quartz grains. The lower 5 to 10 feet are characterized by thin lenticles of coarse to very coarse frosted quartz grains, but in places the frosted quartz grains occur throughout the unit. Where the contact of the Dolores and Entrada is gradational the formations are divided at the lowest occurrence of these large frosted grains. The upper part of this massive unit is generally well sorted. The upper unit of the Entrada is very thinly to thickly bedded, and more evenly stratified than the lower unit. Generally it is somewhat finer grained and more limy than the lower unit. Feldspar is commonly absent, and heavy minerals are scarce.

The Entrada sandstone is conformably overlain by the Pony Express limestone member of the Wanakah formation in the northeast corner of the quadrangle, and elsewhere by the Bilk Creek sandstone member of the Wanakah.

Section of the Entrada sandstone on the north side of Aspen Draw, about 0.6 mile southeast of the junction of Fall Creek and the San Miguel River

	Feet
Upper Jurassic:	
Wanakah formation at top: Basal unit, black dense fetid limestone (Pony Express limestone member).	
Entrada sandstone:	
Sandstone, pale-yellow-orange and yellow-gray, very fine grained; thinly and irregularly bedded, contact with overlying Wanakah interfingering over a few inches	2
Sandstone, pale-yellow-orange, fine-grained; sweepingly crossbedded; forms rounded massive cliff	8
Sandstone, vanadiferous, black and grayish-yellow-green; crossbedded, upper contact sharp, lower contact gradational	1

Section of the Entrada sandstone on the north side of Aspen Draw, about 0.6 mile southeast of the junction of Fall Creek and the San Miguel River—Con.

Upper Jurassic—Continued	
Entrada sandstone—Continued	Feet
Sandstone, moderate orange-pink and pale-greenish-yellow, fine-grained; sweepingly crossbedded; "chrome" band, pale-green, 1 foot thick, cuts across bedding 3 feet below top; forms rounded massive cliff	11
Sandstone, light-grayish-orange; mixed grain, very fine grained matrix with lenticles of very coarse frosted quartz grains; small-scale faint crossbeds; forms steep rounded massive cliff	30
Sandstone, yellow-gray, very fine grained; large amount of interstitial green clay; irregularly bedded	3
Sandstone, yellow-gray, very fine grained; scattered grains and stringers of grains of coarse chert and frosted quartz; irregularly and thin bedded; in places forms massive rounded cliff	6
Total thickness of Entrada sandstone	61

Erosional unconformity.

Upper Triassic: Dolores formation: Interbedded mudstone and siltstone at top, moderate reddish-brown, irregularly bedded, forms covered slope.

WANAKAH FORMATION

The Wanakah formation comprises three thin units: the Pony Express limestone member at the base, the Bilk Creek sandstone member, and the marl member at the top. On the geologic map (pl. 19) the Wanakah is not subdivided because the members are too thin to be shown separately at the scale of the map.

PONY EXPRESS LIMESTONE MEMBER

The Pony Express limestone member is present only in the northeast corner of the Little Cone quadrangle, where it crops out along both sides of the San Miguel River east of Fall Creek and along the east side of Fall Creek (pl. 19 and fig. 43). The pinchout of the limestone lies to the west and southwest (fig. 43); it can be most closely located on the east side of Fall Creek, about 1½ miles south of the San Miguel River.

The limestone is bluish black to grayish black, compact, and microcrystalline. Broken pieces have a petroliferous odor. A distinctive feature of the Pony Express is the undulant parting, called crinkly bedding, whose surfaces generally are 3 to 5 inches apart. The origin of this feature is not known; it may be due to preconsolidation slumping, or it may be a type of ripple mark. In the Little Cone quadrangle the Pony Express averages about 3 feet in thickness, but it thickens eastward and is about 11 feet thick near the northeast corner of the quadrangle. Although the limestone is

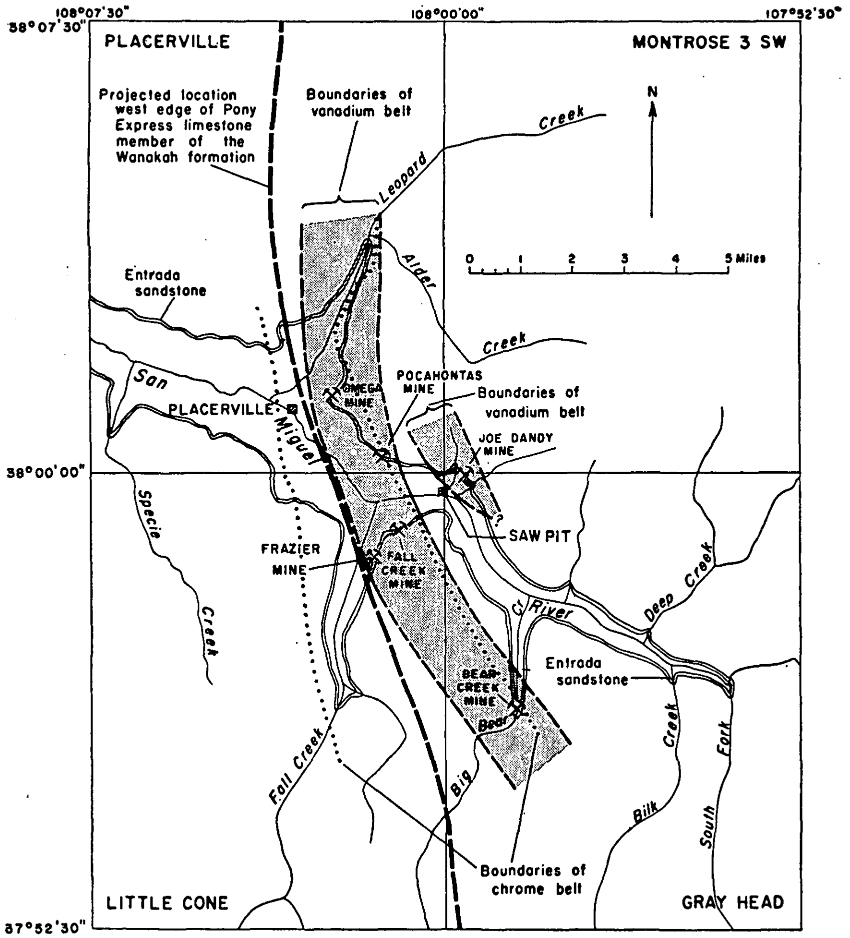

FIGURE 43.—Index map of the Placerville district, San Miguel County, Colo., showing the approximate distribution of the Entrada sandstone and the overlapping relation of the vanadium belts, the chrome belt, and the west edge of the Pony Express limestone of the Wanakah formation (in part after Fischer and others, 1947).

largely unfossiliferous, marine fish remains have been reported from the Piedra River area, Archuleta County, Colo., (Read and others, 1949; J. B. Reeside, Jr., written communication, July 20, 1956) and ostracods have been found near Durango, Colo., (Reeside, op. cit.).

The Pony Express can be recognized over an area of a thousand square miles or more and with relatively short breaks in exposure can be traced into and correlated with the Todilto limestone of New Mexico and eastern Arizona.

The Pony Express limestone member was precipitated from brackish water in a broad shallow arm of the Todilto sea. The deeper parts of this arm lay near and south of Ouray, Colo.

BILK CREEK SANDSTONE MEMBER

In the Little Cone quadrangle the Bilk Creek sandstone member of the Wanakah crops out along Fall Creek, Elk Creek, and the San Miguel River. North of Von Fintel Draw it overlies the Pony Express limestone member; but to the south and west, where the limestone is absent, the Bilk Creek rests upon the Entrada sandstone.

The Bilk Creek is typically a light shade of greenish, yellowish, or brownish gray. Bedding is thin and even. In the Little Cone quadrangle the Bilk Creek ranges in thickness from 21 to 28 feet and averages about 26 feet. The grains are fine and very fine, well rounded, and fairly well sorted; they consist chiefly of quartz cemented with calcite. Clay is more abundant than in the Entrada; feldspar is absent. Heavy minerals include barite, zircon, tourmaline, rutile, and anatase.

The top of the Bilk Creek is marked by a thin red sandstone ledge about 2 to 3 feet thick, which Cross (1899) called the "carnelian sandstone." This distinctive blocky sandstone is remarkably persistent over an area covering perhaps several thousand square miles. The sand grains range from fine to coarse. The term carnelian refers to the occurrence of authigenic red chert grains throughout the unit.

The Bilk Creek sandstone member probably correlates with part of the Summerville formation of the Colorado Plateau.

MARL MEMBER

Overlying the Bilk Creek sandstone member is a sequence of limy siltstone beds and a few thin sandstone beds that ranges in thickness from 47 to 80 feet within the quadrangle. Although lithologically the unit is not a marl, custom has so firmly established the use of the term that the unit will be referred to in this paper as the "marl" member of the Wanakah. Most of the marl member ranges from yellowish and greenish gray to reddish brown. The siltstone beds are thinly to thickly bedded and irregularly stratified. They contain large amounts of quartz, small amounts of feldspar and chert, and abundant calcareous cement. Red chert is a distinctive though minor constituent, especially in the thin sandstone beds. The sandstone is very fine and fine grained, thinly and evenly bedded, and grades laterally into sandy siltstone. Both the upper and lower contacts of the marl member are sharp and conformable. The member correlates with part of the Summerville formation of the Colorado Plateau.

Section of the Wanakah formation on the north side of Aspen Draw, about 0.6 mile southeast of the junction of Fall Creek and the San Miguel River

	Feet
Upper Jurassic:	
Morrison formation at top: Basal unit, evenly bedded grayish-orange and grayish-yellow sandstone in persistent beds; ranges from very thinly laminated to thickly bedded (Junction Creek sandstone equivalent)	17.5
Wanakah formation:	
Marl member:	
Sandstone and mudstone, interbedded; sandstone, pale-grayish-orange, lenticular, in beds 2½ to 3 feet thick; mudstone, grayish-orange, thinly and irregularly bedded; unit forms steep ledge and slope, protected by overlying unit with which it is in sharp contact	12.0
Sandstone, grayish-orange, very fine grained, structureless; slightly calcareous	5.5
Muddy siltstone and minor amount of sandstone, interbedded; siltstone, light-olive-gray, irregularly bedded, in beds as much as 1½ feet thick; calcareous; sandstone, yellow-gray, fine-grained, well indurated, in lenticular beds 2 to 10 inches thick; numerous grains of carnelian chert	48.0
Covered interval	4.0
Total thickness of the marl member	69.5
Bilk Creek sandstone member:	
Sandstone, very light gray, fine-grained; persistent unit of constant thickness; structureless; called carnelian sandstone because of the pink to red chert grains	2.5
Sandstone, very pale orange to grayish-orange, very fine grained, calcareous; contains considerable interstitial clay; limonite spots common; irregularly bedded to structureless; forms alternate ledges and slopes	26.0
Total thickness of Bilk Creek sandstone member	28.5
Pony Express limestone member:	
Limestone, medium dark-gray, cryptocrystalline; fetid odor on fresh surfaces; "crinkly" bedded in units 2 to 6 inches thick; interbedded laminae of very fine grained limy sandstone near base, olive gray; few small-scale crossbeds in lower part. Contact with underlying Entrada sandstone interfingering over a few inches	6.0
Thickness of Pony Express limestone member	6.0
Total thickness of Wanakah formation	104.0
Entrada sandstone: At top, thinly and irregularly bedded, very fine grained sandstone, yellowish-gray.	

MORRISON FORMATION

The Morrison formation makes up about 85 percent of the volume of the Upper Jurassic series in the Little Cone quadrangle. Here the formation ranges in thickness from about 680 feet to about 760 feet. The lower half of the formation, the Salt Wash sandstone member, crops out as a series of sandstone ledges; the upper half, the Brushy Basin shale member, forms soil- or debris-covered slopes and is poorly exposed.

SALT WASH SANDSTONE MEMBER

The Salt Wash sandstone member consists of a thick series of light-yellow-brown lenticular sandstone beds, interbedded with red or reddish-brown siltstone and mudstone. Within the quadrangle the Salt Wash ranges between 320 and 370 feet in thickness and averages about 360 feet.

At the base of the member is a sandstone unit whose continuity and even bedding contrasts with the lenticular irregularly bedded sandstone above. This basal unit is known to persist over several hundred square miles; it occupies the stratigraphic position of the Junction Creek sandstone of southwestern Colorado (Goldman and Spencer, 1941) and may be equivalent to it.

Sandstone makes up about three-fourths of the Salt Wash member. The sandstone lenses range in length, along the outcrop, from a few tens of feet to a few hundred feet and in thickness from a few feet to about 25 feet. Channeling and cross-stratification are common; a few thin evenly bedded sandstone beds are present. The sandstone is mostly fine and medium fine grained, moderately well sorted, and consists principally of well-rounded grains of quartz and small amounts of chert and feldspar. Heavy minerals include zircon, tourmaline, anatase, rutile, barite, leucoxene, ilmenite, and magnetite. Clay and mud are abundant both interstitially and as lenticular partings within the sandstone or as galls concentrated along bedding planes. Bone fragments are found in many places, and plant remains are locally abundant.

The mudstone and siltstone beds that are interbedded with the sandstone range from about 1 to 10 feet in thickness. In many places they have been altered from red or reddish brown to gray or green (Weeks, 1951). Near the top of the member they form a continuous sequence about 40 to 60 feet thick, in which sandstone interbeds are practically absent. This sequence closely resembles the Brushy Basin member.

At the top of the Salt Wash member is a sandstone unit generally about 15 feet thick that resembles in lithology the thick sandstone

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lenses below. Although this sandstone may vary somewhat in stratigraphic position and appears to be absent in places, it is sufficiently persistent that its upper surface is taken as the contact between the Salt Wash and Brushy Basin members. The alternation and interfingering of sediments like those of the Salt Wash and Brushy Basin indicates that deposition was essentially continuous throughout the Morrison formation.

BRUSHY BASIN SHALE MEMBER

The Brushy Basin shale member of the Morrison formation is rarely well exposed. It lacks thick resistent strata and commonly supports a dense vegetal cover. Within the quadrangle it averages about 360 feet in thickness and ranges from 320 to 390 feet. The member consists mostly of mudstone interbedded with sandstone, siltstone, conglomeratic sandstone, and a few lenticular limestone beds. The mudstone is mostly red, although shades of green, purple, and gray are common. It is thinly bedded and contains considerable amounts of sand, silt, and bentonitic clay. A few lenses of conglomeratic sandstone, which contain pebbles of red, green, and purple chert, occupy channels within the member.

The base of the Brushy Basin member is taken as the top of the uppermost typical sandstone of the Salt Wash member; where this sandstone is absent, the contact is arbitrarily placed as nearly as possible at the same stratigraphic position. Generally the Brushy Basin is overlain disconformably by the Dakota sandstone of Late Cretaceous age. Locally, however, channels cut into the upper surface of the Brushy Basin member are filled with thick conglomeratic sandstone of the Burro Canyon formation of Early Cretaceous age.

Section of the Morrison formation on the west side of Leopard Creek, about 3.3 miles north of its junction with the San Miguel River, and about 4.2 miles north of the Little Cone quadrangle

	Feet
Lower Cretaceous: Burro Canyon formation at top: Basal unit, cross-bedded sandstone grading laterally into cherty conglomerate	8
Erosional unconformity.	
Upper Jurassic:	
Morrison formation:	
Brushy Basin shale member:	
Siltstone, sandstone, and mudstone, shades of purple, gray, and green; sandstone thin and very fine grained, limy	90
Mudstone, siltstone, and sandstone, shades of green, gray, purple, and red; sandstone thin and very fine grained; mudstone bentonitic	100
Siltstone, sandstone, and mudstone, shades of green, gray, purple, and red; limy	45
Mudstone and siltstone, shades of red, some of purple and green; thinly bedded; limy	53

Section of the Morrison formation on the west side of Leopard Creek, about 3.3 miles north of its junction with the San Miguel River, and about 4.2 miles north of the Little Cone quadrangle—Continued

	Feet
Upper Jurassic—Continued	
Morrison formation—Continued	
Brushy Basin shale member—Continued	
Mudstone, siltstone, and some sandstone; sandstone lenticular, pale-reddish-brown	85
Sandstone, siltstone, and some mudstone; sandstone and mudstone, shades of reddish-brown; siltstone, brownish-gray, limy	17
Total thickness of Brushy Basin shale member	390
Salt Wash sandstone member:	
Sandstone, grayish yellow-orange, thinly to thickly bedded, crossbedded, conglomeratic at base	18
Mudstone, siltstone, and sandstone; mudstone, shades of red, some grayish green; siltstone, light olive-gray and pale-red, limy; sandstone pale reddish-brown, very fine grained	63
Sandstone, some mudstone; sandstone, grayish-yellow-orange, thinly bedded, lower half crossbedded; mudstone, shades of red and green; entire unit limonitic	52
Sandstone, mudstone, and siltstone; sandstone, grayish-orange-green and grayish-yellow-orange, thinly to thickly bedded, crossbedded; mudstone, shades of red, purple, and reddish-brown; thinly bedded; siltstone, shades of gray, grayish-green, and purple; limy	65
Covered interval	12
Sandstone, siltstone, some mudstone; sandstone, grayish-yellow-orange and light-brown, thinly to thickly bedded; siltstone and mudstone, shades of red	20
Sandstone, grayish-orange-pink and pale-greenish-yellow; mostly fine grained; thickly and massively bedded, abundantly crossbedded	56
Sandstone and mudstone; sandstone, pale-yellowish-orange, mostly thinly bedded, some thickly bedded, fine- to medium-fine-grained; mudstone, shades of gray or grayish-green, thinly bedded	53
Sandstone (Junction Creek equivalent), pale-yellowish-orange and yellowish-brown, very fine to medium grained; ripple marked at top; abundant limonite spots; thinly and thickly bedded, evenly bedded; some clayey sandstone and thin sandstone interbeds, grayish-green or shades of gray	26
Total thickness of Salt Wash sandstone member	365
Total thickness of Morrison formation	755
Wanakah formation: Brown and red siltstone and thin sandstone beds of the marl member.	

CRETACEOUS SYSTEM

Two-thirds of the Little Cone quadrangle is underlain by Cretaceous rocks. The oldest unit of the system is the Burro Canyon formation of Early Cretaceous age. The Burro Canyon is present as isolated channel fillings which are exposed only along Fall Creek east of the summit of the Little Cone; thus, in outcrop area the formation constitutes much less than 1 percent of the Cretaceous rocks in the quadrangle. Above the Burro Canyon is the Dakota sandstone of Late Cretaceous age, overlain by the Mancos shale of Late Cretaceous age.

The maximum aggregate thickness of Cretaceous formations in the quadrangle totals about 2,700 feet, although this maximum thickness is not all present at any one place. The original thickness of the system is unknown because the upper part of the Mancos has been removed by erosion.

LOWER CRETACEOUS SERIES

BURRO CANYON FORMATION

The Burro Canyon formation fills channels cut in the top of the Brushy Basin shale member of the Morrison formation. The formation is exposed in only a few places along Fall Creek and these exposures are too sparse to determine the trend of the channels. In the Placerville quadrangle a few miles to the north the fragmentary evidence available suggests that the Burro Canyon channel fillings have a northerly or northwesterly trend. Along Fall Creek the width of the channels as seen in outcrop ranges from a few hundred to a few thousand feet. These exposures are too small to be mapped separately at the present scale; on the geologic map they are included with the Brushy Basin member of the Morrison formation.

Generally the Burro Canyon forms a sheer-faced ledge of conglomeratic sandstone from 30 to 60 feet thick, which is overlain in places by as much as 10 feet of green and gray noncarbonaceous mudstone and siltstone. The sandstone is yellowish gray, massive, and crossbedded, and consists of medium-sized grains of quartz and a minor amount of weathered feldspar. Fragments of white and yellow chert are abundant. The conglomeratic portions comprise granules and pebbles of chert, quartz, sandstone, and quartzite.

The Dakota sandstone of Late Cretaceous age overlies the Burro Canyon formation, probably disconformably. The basal unit of the Dakota is commonly a conglomeratic sandstone, very similar in lithology to the sandstone of the Burro Canyon. The principal distinction between the two units is the presence of plant fragments and carbonaceous mudstone in the Dakota and their absence in the

Burro Canyon. In addition, mudstone of the Burro Canyon is characteristically green, whereas green mudstone is lacking in the Dakota.

The unit is similar in lithology and stratigraphic position to the Burro Canyon formation at its type locality on the Colorado Plateau (Stokes and Phoenix, 1948) and is accordingly correlated with it.

Section of the Burro Canyon formation on the west side of Fall Creek, about 1.5 miles south of the junction of Elk and Fall Creeks

	Feet
Upper Cretaceous: Dakota sandstone at top: Basal ledge, yellowish-gray conglomeratic sandstone, some carbonaceous flecks	32
Erosional unconformity (?).	
Lower Cretaceous:	
Burro Canyon formation:	
Mudstone, green and grayish-green, some light-brown	5
Sandstone, grayish-yellow-orange, thickly bedded, conglomeratic in places	32
Total thickness of Burro Canyon formation	37
Erosion surface.	
Upper Jurassic: Morrison formation (Brushy Basin shale member): Green and reddish-brown mudstone at top, interbedded mudstone, siltstone, and a few thin sandstone beds below.	

UPPER CRETACEOUS SERIES

DAKOTA SANDSTONE

The Dakota sandstone crops out mainly in the north half of the Little Cone quadrangle. The formation forms the resistant rimrock of the canyons along the courses of the main drainages and underlies most of the mesa tops where the softer Mancos shale has been stripped by erosion. The formation ranges in thickness from about 160 feet to about 225 feet; generally it is about 180 feet thick.

The Dakota is made up of three distinct lithologic units. At the base is a massive sandstone that commonly forms a vertical cliff. The middle unit consists of shale and siltstone beds that form a short slope. The upper unit comprises interbedded sandstone and shale that form ledges and slopes. The basal unit and especially the middle unit appear to thicken somewhat from west to east across the north half of the quadrangle.

The basal unit of the Dakota is a massive conglomeratic sandstone that ranges in thickness from 20 to 73 feet, and averages about 50 feet. The sandstone is light yellowish gray and fine to medium grained. Lenses and stringers of white chert and quartzite pebbles as much as 3 inches in diameter are scattered throughout. A few thin beds of black carbonaceous mudstone interrupt this otherwise massive unit.

The middle unit is generally 30 to 70 feet thick and consists of black carbonaceous shale, siltstone, and a few sandstone beds. Impure coal seams as much as 3 feet thick occur locally; one of these along upper Fall Creek has been prospected, but has not proved to be commercially exploitable.

The upper unit is made up of 30 to 90 feet of thin to moderately thick sandstone and carbonaceous shale. The sandstone is similar to that of the basal unit except that it is not conglomeratic. The amount of sandstone decreases upward toward the base of the overlying Mancos shale.

The Dakota sandstone rests disconformably upon the Brushy Basin shale member of the Morrison formation; locally along upper Fall Creek it overlies the channel-filling Burro Canyon formation, also probably disconformably. The Dakota grades upward into the Mancos shale with no apparent time break; the contact is difficult to locate precisely, both because of its gradational nature and because it is commonly concealed by a mantle of soil that has crept down from the Mancos shale. For mapping purposes, the contact was arbitrarily placed at the top of the uppermost prominent sandstone bed of the Dakota.

On the basis of stratigraphic position and lithology, the formation is correlated with the Dakota sandstone of Late Cretaceous age of the Colorado Plateau; however, no diagnostic fossils have been reported from the unit in the western San Juan Mountains.

Section of the Dakota sandstone on the south side of Lou Hall Gulch, about 1.1 miles west of the junction of Fall Creek and the Lou Hall Gulch drainage

Upper Cretaceous:	
Top of exposure on small hill top, no Mancos shale present.	
Dakota sandstone:	Feet
Largely covered interval: aboundant purple sandstone float throughout, some blocks nearly in place; unit probably consists of interbedded sandstone and carbonaceous shale, and probably represents uppermost beds of the Dakota	58±
Sandstone, light-grayish-orange, medium-grained; evenly bedded in units 2 to 4 inches thick; forms rim of mesa	4
Shale, carbonaceous, dark-gray; fissile; poorly exposed	19
Sandstone, pale-grayish-orange, medium-grained; evenly bedded in 6- to 12-inch units; blocky; contains considerable organic debris; forms ledge	6
Shale, carbonaceous, dark-gray to black; forms slope	11
Sandstone, pale-grayish-orange, medium-grained; evenly bedded in 2- to 12-inch units; blocky; "glistening" surface characteristic; one 8-inch carbonaceous shale unit near top; forms cliff	22
Shale, carbonaceous, dark-gray to black; thinly laminated and fissile; many thin interbedded sandy layers, somewhat irregularly laminated; basal few inches of shale are baked by underlying sill	4
Rhyolite(?) sill, forms cliff	28

Section of the Dakota sandstone on the south side of Lou Hall Gulch, about 1.1 miles west of the junction of Fall Creek and the Lou Hall Gulch drainage—Continued

	Feet
Upper Cretaceous—Continued	
Dakota sandstone—Continued	
Shale, carbonaceous, dark-gray to black	6
Sandstone, light-gray, fine-grained, blocky, contains organic debris	3
Shale, carbonaceous, dark-gray to black; poorly exposed	19
Sandstone, gray, fine-grained, well-sorted, structureless to faintly crossbedded in lower 13 feet, massive, irregularly parted, thinly and evenly bedded in upper 3 feet (beds 1 to 12 inches thick); forms cliff	16
Shale, carbonaceous, dark-gray to black; contains a few thin (2 to 14 inches) ripple-marked sandstone interbeds	10
Sandstone, conglomeratic, and sandstone, gray to white where fresh, yellowish- and grayish-brown on weathered surfaces; sandstone matrix is medium grained; conglomeratic in lower 32 feet; gravel consists of white clay pebbles and chert pebbles, as much as 1-inch in diameter; crossbedded; forms cliff	43
Total thickness of Dakota sandstone (exclusive of sill)	221±

Upper Jurassic: Morrison formation (Brushy Basin shale member): Reddish-brown and light-gray mudstone and lenticular sandstone.

MANCOS SHALE

The Mancos shale underlies about 50 percent of the Little Cone quadrangle, principally in the southern half. The thickest section of Mancos remaining, perhaps as much as 2,700 feet thick, is in the southeast corner of the quadrangle, although even here erosion has removed an undetermined thickness at the top of the formation. In general the Mancos shale is the least resistant of all the major rock units exposed in the western San Juan Mountains. It has been eroded back from the underlying Dakota sandstone over much of the quadrangle and now principally forms the lower slopes of the mountains. Despite its vulnerability to erosion, the Mancos forms precipitous slopes far up on the flanks of the highest peaks, where numerous sills and other intrusive igneous bodies protect the underlying weak shales against rapid erosion, or where the shales were baked and hardened during metamorphism.

Within the quadrangle the Mancos is so homogeneous that none of the various members, which have been recognized elsewhere, can be distinguished. Except for a few thin sandstone and lenticular limestone beds, the formation consists entirely of olive-gray, dark-gray, and black limy marine shale that weathers light gray. In places the shale appears massive, although finely and evenly laminated; but typically it is quite fissile and extremely thinly bedded.

The limestone beds are found chiefly near the base of the Mancos and are mainly fine-grained oblate nodules or irregular masses as much as 2 feet in diameter. The rock is dark gray on unweathered surfaces and weathers to light gray or rusty yellow brown. Some of the nodules are septarian, crisscrossed with veinlets of brown calcite.

A few thin sandstone beds occur throughout the Mancos; probably none are over 4 feet thick in the Little Cone quadrangle. They are light brown, very thinly bedded (strata ½ to 6 inches thick) and finely and evenly laminated. Small-scale crossbedding, ripple marks, and casts of worm burrows are present locally.

No worthwhile stratigraphic section of the Mancos can be given, as exposures of the Mancos shale are only partial sections that cannot be correlated.

Fossils of marine pelecypods and cephalopods are relatively common in the Mancos shale in the Little Cone quadrangle. The most common diagnostic types are listed below.

Diagnostic fossils found in the Mancos shale in the Little Cone and Gray Head quadrangles, Colorado

[Identifications by J. B. Reeside, Jr.]

Fossil	Western American ages	European stages
Ostrea congesta Conrad *Inoceramus* aff. *I. subquadratus* Schlüter *Inoceramus* aff. *I. stantoni* Sokolow *Inoceramus grandis* (Conrad) *Inoceramus* aff. *I. deformis* Meek *Baculites asper* Morton	Niobrara	Coniacian
Prionocyclus wyomingensis Meek	Late Benton (Carlile)	Turonian
Gryphaea newberryi Stanton	Middle Benton (Greenhorn)	Cenomanian

TERTIARY SYSTEM

Through the western part of the San Juan Mountains, a sedimentary rock, the Telluride conglomerate, lies at the base of the Tertiary section; it is overlain by volcanic rocks and intruded by plutonic and hypabyssal igneous rocks, both of Tertiary age. Formerly both the Telluride conglomerate and the volcanic rocks extended across the Little Cone quadrangle; they have been removed by erosion, so that at present the only rocks of Tertiary age that are in place within the quadrangle are hypabyssal intrusive bodies. The sedimentary and volcanic rocks of Tertiary age are still present in the adjoining Dolores Peak, Mount Wilson, and Gray Head quadrangles, and transported masses of these rocks occur in the talus and glacial drift in the southern part of the Little Cone quadrangle.

The igneous rocks constitute only a small fraction of the rocks of the Little Cone quadrangle, both in volume and in area of outcrop. Granogabbro, granodiorite, and their finer grained equivalents are the predominant rock types. These form numerous sills as well as some discordant bodies that generally occur in the Mancos shale. Rhyolite(?) and porphyritic microgabbro are present in markedly lesser volume. The rhyolite(?) forms a sill in the Dakota sandstone, and the microgabbro forms narrow dikes that cut the entire section of sedimentary rocks. Age relations among the igneous rocks are not clear, and it is not possible to determine even a tentative time sequence based on data obtained in the quadrangle.

In the description that follows, the igneous rocks are named according to the Johannsen system of classification (Johannsen, 1931). Differences in usage from the Johannsen classification are specifically noted. The rock types are described in order of decreasing abundance, and the order does not indicate age relations.

GRANOGABBRO AND MICROGRANOGABBRO

Granogabbro and micrograngabbro make up the bulk of the igneous bodies in the southern part of the Little Cone quadrangle and the northern part of the adjoining Dolores Peak quadrangle (fig. 44). By definition quartz is an essential constituent of granogabbro and there is a predominance of calcic plagioclase (An_{50-90}) over orthoclase. The prefix "micro" (Hatch and others, 1949, p. 212) is affixed to designate varieties of granogabbro in which the average grain size is less than 1 mm, but greater than the limit of unaided vision.

MINERALOGY AND PETROGRAPHY

The granogabbro characteristically has a seriate porphyritic texture, is light to dark gray on unweathered surfaces, and weathers to shades of brown with red or yellow tones. The phenocrysts are plagioclase crystals that range progressively from 5 mm in length to minute grains in the very fine grained groundmass. They show complex oscillatory zoning and even very small crystals have a large number of zones. The crystals are sodic labradorite (An_{52-58}), with narrow rims of andesine (An_{35}) and rare cores of labradorite (An_{62}). Orthoclase and quartz, both intersertal, are present only in the groundmass, which is generally composed of anhedral grains (xenomorphic granular). Augite, the dominant ferromagnesian mineral, is present in the groundmass as small blocky crystals that are rarely over 1 mm in length. A few samples contain hypersthene, but in most samples it has been completely altered to nontronite.

Sparse remnants of hornblende phenocrysts are surrounded by apparent reaction rims of pyroxene, magnetite, and plagioclase. Magnetite, biotite, and apatite are the common accessory minerals; sphene and zircon are rare.

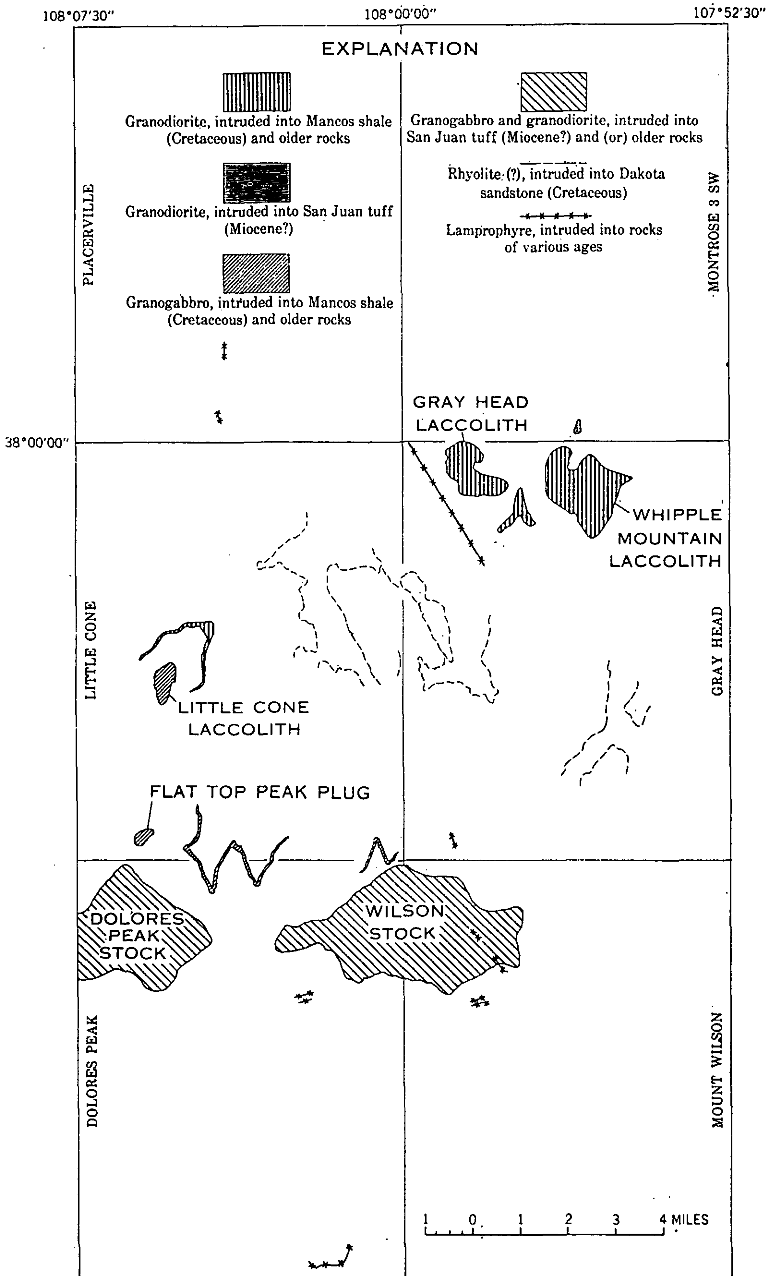

FIGURE 44.—Index map of part of the western San Juan Mountains area, showing the distribution of the major igneous bodies in the vicinity of the Little Cone quadrangle, Colorado.

The granogabbro is pervasively altered and most samples contain 20 to 30 percent of the secondary minerals. Calcite, chlorite, and lesser amounts of uralite, sericite, and epidote are present throughout the rock. Pyrite is common in much of the granogabbro; it is most abundant in the small intrusive bodies in the southeast corner of the quadrangle, particularly in those near the Wilson stock, which lies just south of the quadrangle (fig. 44). In the weathered granogabbro, the secondary minerals consist largely of limonite, clay minerals (particularly nontronite), and leucoxene. Calcite has also been dissolved near the surface, leaving small pits and openings.

Obvious contact metamorphic effects around the intrusive bodies in the Little Cone quadrangle are limited to a zone of baked and hardened sedimentary rocks a few inches to a few feet thick. This zone is thicker around the larger bodies, but is thin even along the contact of the large Dolores Peak stock, just south of the quadrangle. The degree of metamorphism also is more intense near the larger masses. Nearly everywhere the granogabbro is in contact with the generally homogeneous Mancos shale, and variations in degree of metamorphism due to changes in the host rock are not apparent. A hornfels containing recrystallized quartz, feldspar, and a biotite-type mica is the most highly metamorphosed rock developed from the Mancos. Thermal effects apparently were dominant in the metamorphism, as no minerals were formed that would require contributions of elements from the magma.

DISTRIBUTION AND OCCURRENCE

Most of the granogabbro masses are intruded into the Mancos shale, and are concentrated in the southern part of the quadrangle (pl. 19). These masses are regarded as peripheral intrusions related to igneous centers in the stocks of the Dolores Peaks and the Wilson group (parts of the San Miguel Mountains) which lie just south of the quadrangle (fig. 44). Direct connections have not been observed, but the stocks offer a nearby source of granogabbro magma; the rocks in the border zone of the stocks are very similar in mineralogy and bulk composition to the peripheral bodies, and they differ appreciably only in grain size.

One sill of microgranogabbro cuts the upper part of the Dakota sandstone and the base of the Mancos shale in the east-central part of the Little Cone quadrangle (pl. 19). It too probably represents an intrusion peripheral to the stock centers.

LITTLE CONE

The most prominent intrusive body in the Little Cone quadrangle is a mass of granogabbro, nearly 800 feet thick, that forms the upper part of Little Cone (pl. 19), and stands as a floored, unroofed remnant of a somewhat larger body. The mass has a base that dips slightly south and is essentially concordant to the underlying Mancos shale. On the east side of the peak is a single downward projection of microgranogabbro, about 100 feet wide, that extends at least 100 feet vertically below the main level of the floor. The central part of this projection is a zone of autobreccia about 15 feet wide, with fragments of microgranogabbro in a matrix of microgranogabbro.

Erosion has destroyed most of the evidence for the original form and extent of the Little Cone body. Three general concepts of the form of the body are consistent with the field data: a laccolith that was fed through a channel beneath the present remnant; a sill of relatively uniform thickness, whose feeding channel perhaps was beneath the present remnant; and a laccolithic bulge on a sill, or a bysmalith, that was fed laterally from the uppermost intrusive mass on Flat Top Peak to the south (pl. 19). Essentially the first and second possibilities differ only in the rate of thinning of the igneous body.

The downward projection of microgranogabbro on the east side of Little Cone is believed to be a part of the feeding conduit for the igneous mass. The smaller grain size and the presence of autobreccia in the "feeder," as well as the extent of the downward projection itself, support this interpretation. The presence of this conduit beneath the Little Cone remnant thus supports the concept of a locally derived laccolith or sill. This in itself does not rule out the possibility of a former lateral connection between Little Cone and Flat Top Peak above the present surface, but it does make such a connection unnecessary.

If the Little Cone body is considered to be the remnant of a sill, its present thickness of about 780 feet suggests that it must have had a large areal extent, probably measurable in tens of miles. Erosion remnants similar to Little Cone are absent, however, in nearby areas that should have been similarly protected from erosion. The drainage patterns in the Little Cone quadrangle and nearby areas to the west appear to have been controlled, at least in part, by discrete resistant masses in the Mancos shale, one of which was located at the site of Little Cone. Both of these observations suggest that the Little Cone body had a limited areal extent of only a few miles.

It seems unlikely that the Little Cone body is the remnant of a laccolithic bulge on a sill, or of a bysmalith, fed laterally from the Flat Top Peak body. The Little Cone body is from 6 to 13 times as thick as the possibly sill-like northern part of the Flat Top Peak mass (780 feet versus 60 to 120 feet). Comparable thickenings have not been observed in sills elsewhere in the western part of the San Juan Mountains. Erosion has removed any evidence that the Little Cone remnant is part of a bysmalith; no bysmaliths have been identified in the western part of the San Juan Mountains. As was mentioned above, the drainage patterns suggest control by discrete resistant masses in the Mancos shale, rather than by a mass that connected Flat Top Peak and Little Cone.

The authors consider the Little Cone mass to be most logically interpreted as a laccolith, fed at least in part from below the present remnant, and reflecting in present plan the laccolith's original form.

The granogabbro of Little Cone is remarkably uniform from bottom to top of the laccolithic remnant. The basal few feet of the mass apparently cooled more rapidly than the rest of the intrusive rock; it has a finer grained groundmass and approaches a micro-granogabbro. Plagioclase crystals generally are 2 mm or less in length throughout the intrusive remnant, except that the larger crystals in this range are more abundant away from the base. The rock near the surface is strongly weathered, chiefly to nontronite, which makes the rock characteristically dark yellowish brown. Nontronite may form as much as 30 percent of the rock, and in many cases it obscures the original mineralogy.

Xenoliths of at least three rock types are present, but none are abundant. Hardened, baked inclusions of Mancos shale are most common. Blocks of a very coarse grained oligoclase-rich gneiss and of gneissic amphibolite are probably derived from the Precambrian rocks and were dragged to their present position by the magma during intrusion.

Jointing produces an apparent three-part zoning on the east side of Little Cone. The upper and lower zones have nearly vertical closely spaced jointing, and the rock has weathered into jagged spires. The central zone has more widely spaced joints that are subparallel to the outcrop; they produce a smoothly curving surface that has weathered to a lighter color than the zones above and below. A regular columnar jointing was found in the lowest 10 to 20 feet of the laccolith in the two places where the basal part is exposed; everywhere else the contact is covered by talus.

FLAT TOP PEAK

Granogabbro, closely resembling that of the Little Cone laccolith, forms the uppermost intrusive body in the Mancos shale on Flat Top Peak in the southwest corner of the quadrangle (pl. 19). The grain-size range is the same, finer grained near the contacts, grading to coarser grained toward the center. Alteration and weathering are similar to that of Little Cone; xenoliths are less abundant.

Only part of the original shape and size of the intrusive body can be determined. The contact between the intrusive rock and the Mancos shale is entirely concealed by talus around the northeastern half of the peak, and is only partly exposed along the southwestern half. A small patch of Mancos shale is preserved at one point on the top of the peak. On the western side of the peak (pl. 19) there are a few exposures of the basal contact of the granogabbro. In the northern of the basal exposures the granogabbro appears to be a concordant floored body; to the southwest the relations are not as clear, but the mass appears to be locally crosscutting in the Mancos. A small sill-like offshoot is exposed a few tens of feet downslope from the main mass. The granogabbro ranges in exposed thickness from 60 to 120 feet along the northeastern half of the peak. Along the southeastern side of the peak the granogabbro is a discordant mass in the Mancos, with no suggestion of a floor for the bulk of the body. The mass is at least 700 feet long, of unknown width, and has a very steeply dipping surface that crosscuts the Mancos over an observed vertical range of at least 200 feet. Thin sills finger out southward for short distances from the discordant body.

The form of the Flat Top Peak remnant is somewhat more complicated than the Little Cone laccolith. As mentioned above some of the exposures of the basal contact on Flat Top Peak suggest a floored intrusive body, other exposures suggest a discordant body. Although there are no exposures of the contact along the northeastern half of the peak, there is an accordance in the altitude of the highest float concentrations and exposures of the Mancos shale that is suggestive of a flat contact between the Mancos and the granogabbro. In addition there is a markedly flat-topped surface on this part of the peak. The surface is formed on the granogabbro, but in one place it shows a skin of Mancos lying on the granogabbro. These bits of evidence and interpretation suggest to the authors that the northeastern half of the Flat Top Peak remnant is a sill, whose thickness probably ranges from 60 to 120 feet.

Part of the southwestern half of the peak is believed to be a rather large discordant body, from which the thick sill to the northeast has been fed, and from which several thin sills extend southward. Only a part of the walls of the discordant body are exposed, on the south side of the peak; it is possible, therefore, that the mass is a restricted "feeder" similar to that on the east side of Little Cone. In contrast, however, most of the rock in the Flat Top Peak discordant body is granogabbro rather than microgranogabbro, there is very little autobreccia in the mass, and the discordant mass appears to widen with depth. These observations lead the authors to believe that a large part of the southwestern half of the Flat

Top Peak remnant is a pluglike mass rather than a restricted feeder. The nearest exposure of the Dolores Peak granogabbro stock is about half a mile south of Flat Top Peak, just south of the quadrangle. The Flat Top Peak plug is related to this stock and may even be a cupola of the stock.

A further clue to the form and size of the Flat Top Peak mass was sought in the size and intensity of the contact metamorphic aureole that surrounds the peak. The Mancos shale is baked and hardened in a zone as much as a few tens of feet thick adjacent to the igneous rock in the southwestern half. Lack of exposures prevents a comparison of the zone along the northeastern half of the peak with that along the southwestern half, and so there is no indication as to comparative form. However, the intensity of metamorphism and the thickness of metamorphosed rock are comparable to the contact aureole around the north end of the Dolores Peak stock, where the Mancos shale is also in discordant contact with the igneous body. It can be concluded that the degree of metamorphism does not disprove the concept of a plug or cupola at Flat Top Peak. Regardless of the form of the body, its limited areal extent and the presence of Mancos shale on the top of Flat Top Peak suggest that the igneous rock never extended very far above the present surface.

DIKES AND SILLS

A microgranogabbro dike trends northwest and crops out along the crest of the divide between the drainage of Elk and Big Bear Creeks in the southeast corner of the quadrangle (pl. 19). The dike has a mapped length of about 0.8 miles, but the outcrops are poor and discontinuous. In the extreme southeast corner of the quadrangle a discordant arm of the Wilson stock cuts the Mancos shale. On section *B–B′* (pl. 19) this arm is shown as a satellitic intrusive body on the flank of the stock; however, it may be more of a vertical dike with parallel walls, and without any widening of the mass with depth.

Almost all the sills of microgranogabbro are concentrated in the southern part of the quadrangle and are confined to the Mancos shale (fig. 19). A microgranogabbro sill that reaches a maximum thickness of 60 feet underlies the area called Frazier Flats. The sill's irregular map pattern is caused by rolls and undulations of the mass across the bedding of the Mancos. Another major sill with a thickness of as much as 120 feet rings Flat Top Peak at a general altitude of about 10,400 feet. This sill probably is a direct offshoot from the Flat Top Peak plug and is shown thus on section *B–B′* (pl. 19). It seems likely that it never extended more than an additional half a mile to the north. A more extensive sill crops out on the flanks of canyons in the dissected drainages of Fall and Muddy Creeks, from the east slope of Flat Top Peak (at an altitude of about 10,000 feet) to a point east of Woods Lake, and southward into the Dolores Peak quadrangle. Its minimum lateral dimensions are 2 miles east-west by 1¾ miles north-south, and its thickness is as much as 160 feet. It is broken by two faults of small offset.

A number of minor sills cut the Mancos shale in the southeast corner of the quadrangle. They are thin (5 to 20 feet), lenticular, and locally cut across the bedding of the shale. These are the sills that have been strongly pyritized near the Wilson stock.

An apparently discontinuous micrograngabbro sill crops out at the head of the lower canyon of Elk Creek and on Wilson Mesa to the northeast, along the east-central border of the Little Cone quadrangle. The sill lies in the upper part of the Dakota sandstone and the basal part of the Mancos shale. It is as much as 14 feet thick, and appears to be absent locally within the area of outcrop.

MICROGRANODIORITE AND RHYODACITE

The granodiorite family is characterized by a predominance of sodic plagioclase (An_{10-50}) over orthoclase, and by quartz as an essential constituent. To preserve uniformity with the definition of granogabbro as used in this paper, the ratio of plagioclase to orthoclase is taken as being greater than 2 to 1. The intrusive bodies of this composition in the Little Cone quadrangle are of small size. Resultant rapid cooling has produced fine-grain sizes ranging from the "micro" category to aphanitic, and the rocks are all classed as microgranodiorite or rhyodacite respectively. In this paper the term "rhyodacite" does not imply that the body is of extrusive origin.

MINERALOGY AND PETROGRAPHY

The granodioritic rocks are commonly seriate porphyries, or porphyries without a distinct break in grain size from the larger phenocrysts to the small crystals in the very fine grained groundmass. The rocks are light to medium gray on unweathered surfaces and weather to shades of brown. Plagioclase crystals are as much as 2 mm in length in the phenocrysts, are unzoned or only slightly zoned, and have a composition of An_{35-38}. Plagioclase of similar composition is present also in the groundmass. Hornblende is present both as corroded phenocrysts as much as 1 cm long and as small crystals in the groundmass. In addition to plagioclase and hornblende, the groundmass contains quartz and accessory magnetite, biotite, and apatite. In texture the groundmass is a felted mass of microlites (pilotaxitic). Alteration is universal in all samples. Calcite and chlorite are the most common alteration minerals, sericite and epidote are rarer. Hornblende phenocrysts in many cases have been completely replaced by calcite and chlorite, and are recognizable from their shape alone. Weathering yields clay minerals (chiefly kaolin and nontronite), limonite, and leucoxene. The combination of alteration and weathering has obscured details of the original mineralogy and composition, and has made microscopic determination difficult.

The microgranodiorite-rhyodacite rocks are not as uniform in composition as the granogabbro rocks. There are considerable variations in the percentage of hornblende and plagioclase, and in a few cases the percentage of quartz and potassium feldspar is low enough to classify the rock as diorite or andesite.

The granodioritic rocks contrast with the granogabbroic rocks in the following ways: (a) The granodiorite has andesine (An_{35-58}) without prominent zoning, the granogabbro has highly zoned labradorite (generally An_{52-58}); (b) the granodiorite contains more hornblende and less augite than the granogabbro; and (c) the texture of the groundmass of the granodiorite is pilotaxitic, that of the granogabbro is xenomorphic granular. In hand specimen only samples of microgranodiorite high in hornblende can be distinguished readily from microgranogabbro. In thin section microgranodiorite low in hornblende can be distinguished from microgranogabbro with ease only if the samples are unweathered; the differences are obscure in rocks that are altered even slightly.

DISTRIBUTION AND OCCURRENCE

The microgranodiorite-rhyodacite rocks form sills and small dikes that cut the Dakota sandstone and the Mancos shale in the southern part of the Little Cone quadrangle (pl. 19). Although no immediate source of the magma is apparent, it is possible that the magma was derived by differentiation from the magmas that formed the stocks of the Wilson group and the Dolores Peaks to the south (fig. 44). Equivalent rock types are found in the stocks, although no physical connections with the intrusive masses in the Little Cone quadrangle have been observed.

The thickest microgranodiorite sill crops out at an altitude of about 10,500 feet on the lower slopes of Little Cone where the sill cuts the Mancos shale. The sill is about 120 feet thick at its northeasternmost exposure and it wedges out to the southwest. The middle part of the sill is fine grained; at both its upper and lower borders the rock is finer grained, commonly microgranular, with sparse phenocrysts of hornblende. Another microgranodiorite sill, about 90 feet thick, cuts the Mancos shale on the slopes of Flat Top Peak, and crops out at an altitude of about 10,900 feet. In contrast to the Little Cone sill it contains abundant phenocrysts of hornblende. A dike of this microgranodiorite branches from the west end of the sill, and other dikes of the same rock type lie farther south.

Granodioritic rocks form several other intrusive bodies in the southern part of the Little Cone quadrangle; these are classed as rhyodacite because of their microgranular to asphanitic texture. Just east of the divide between Little Cone and Flat Top Peak, a thin, discontinuous sill and two branching dikes of rhyodacite cut the Mancos shale. Southeast of Woods Lake three rhyodacite sills (containing sparse hornblende phenocrysts) crop out on the ridges west of Elk Creek, and one of these extends eastward to the ridge between Elk and Big Bear Creeks. Two other rhyodacite sills are in the Dakota sandstone along the valleys of Fall and Muddy Creeks, 1½ miles north of Woods Lake.

PORPHYRITIC MICROGABBRO

The microgabbro of the Little Cone quadrangle is medium- to dark-gray porphyritic dike rock, with phenocrysts set in a very fine grained groundmass. In the most common type of microgabbro, tabular phenocrysts of plagioclase (An_{76-80}), 5 to 10 mm long, constitute about 18 percent of the rock, and are accompanied by a few subhedral phenocrysts of augite. The groundmass, which makes up over 80 percent of the rock, has a diabasic texture; laths of plagioclase (near An_{60}, with narrow more sodic outer zones) are separated by intersertal pyroxene. The common accessory minerals are magnetite, biotite, and apatite. Alteration has produced carbonate minerals, uralite (fibrous amphibole replacing pyroxene), bastite (serpentine replacing pyroxene), and less commonly chlorite and fibrous zeolites.

Most of the microgabbro dikes are in the northeast quarter of the Little Cone quadrangle (pl. 19). An eastward-trending dike, 4 to 5 feet thick, cuts the sedimentary rocks in the canyon of Fall Creek just north of Von Fintel Draw, and pinches out in the lower part of the Morrison formation. An extension of this dike zone crops out in the San Miguel River valley in the Gray Head quadrangle to the east. Here the dike cuts rocks only as young as the Dolores formation, but the top of the dike has been eroded. In the extreme northeast corner of the Little Cone quadrangle (pl. 19) two eastward-trending dikes as much as 6 feet wide cut rocks at least as young as the basal part of the Morrison formation. At the surface the southern dike ends against a normal fault, but this relation does not indicate that the dike is younger than the fault. Rather the dike terminates beneath the surface on the downthrown side of the fault, and crops out again in the valley to the east.

Eastward in the Gray Head quadrangle these dikes join and continue for about 1 mile. Another dike, 10 to 12 feet thick, cuts the Mancos shale 1 mile northwest of Flat Top Peak in the southwest corner of the quadrangle.

A variant of the microgabbro rock type lacks plagioclase phenocrysts, and contains augite phenocrysts, as much as 5 mm long, that constitute about 15 percent of the rock. It forms a single, nearly vertical dike about 3 feet thick that cuts across Fall Creek just south of Von Fintel Draw. This dike also appears to terminate in the lower part of the Morrison formation.

RHYOLITE(?) AND PORPHYRITIC RHYOLITE(?)

Rhyolitic(?) rocks form sills in the Dakota sandstone in the Little Cone quadrangle. Weathering produces a distinctive and characteristic pinkish-buff color from the light-gray unweathered rock, and accentuates closely spaced lamellar parting surfaces that approximately parallel the contacts of the sills.

The rock is pervasively altered at all its exposures. Relicts of amphibole phenocrysts range from 2 to 15 mm in length and constitute as much as 5 percent of the rock. These have been completely replaced by chlorite and carbonate and can be identified only by their shape. About 65 percent of the groundmass is feldspar which has also undergone alteration. In the identifiable grains there is a preponderance of plagioclase (near An_4), in elongate twinned laths, over orthoclase. Quartz, as isolated grains or grain clusters, constitutes about 10 percent of the groundmass. Even in the freshest samples about 25 percent of the rock is composed of alteration products—chiefly chlorite and carbonate minerals. The rocks are also weathered, and some near-surface samples are made up entirely of quartz, chlorite, kaolin, and limonite.

The rock cannot be classified precisely, because the original ratio of plagioclase to orthoclase cannot be determined accurately. In the identifiable grains there is more plagioclase than orthoclase. This probably represents an original predominance, but this is not certain. In view of this uncertainty, the common term "rhyolite" will be used in this paper, with a query (?) to indicate the uncertainty, and with no connotation that the rock has an extrusive origin.

The rhyolite(?) forms a very extensive sill of northwest trend in the northeastern part of the Little Cone quadrangle. From its exposures at the head of Lou Hall Gulch (pl. 19), the sill extends southeastward for 9 miles, and crops out in the valleys of the adjoining Gray Head quadrangle. Its northeast dimension appears to be about 3 miles. Throughout most of the area of outcrop the sill ranges in thickness from 20 to 25 feet. In Lou Hall Gulch the sill forms a nearly vertical cliff, but in most places it crops out as a steep slope that at a distance resembles the well-bedded middle part of the Dakota sandstone into which it is intruded. A discontinuous rhyolite(?) sill of limited extent crops out along Elk Creek in sec. 6, T. 42 N., R. 10 W. (pl. 19).

In almost all exposures the rock is porphyritic rhyolite(?), but where the main sill reaches its maximum thickness of 28 feet along the south side of Lou Hall Gulch, a central zone of even-textured rhyolite(?) can be distinguished from upper and lower zones of porphyritic rhyolite(?). The upper 5 feet and the lower 8 feet have the pinkish-buff color and fissile parting that characterize the porphyritic rhyolite(?). The central rhyolite(?) zone has irregular, nearly vertical jointing without the fissile parting. Hornblende relicts in the upper zone of the sill have a strong N. 55° W. orientation; these are believed to indicate the main flow direction, which, in at least this part of the sill, is parallel to the northwest elongation of the whole mass.

AGE OF THE TERTIARY IGNEOUS ROCKS

The igneous rocks described above cannot be dated within close limits. Within the Little Cone quadrangle the Mancos shale of Late Cretaceous age is the youngest rock cut by the granogabbro and granodiorite bodies and by the microgabbro dikes. The rock relations do not indicate a minimum age.

The maximum age of the granogabbro can be estimated more closely by reference to relations in nearby areas outside the quadrangle. The granogabbro bodies are mineralogically similar to the Dolores Peaks granogabbro stock and to part of the Wilson stock to the south (fig. 44) and likely are offshoots from them. The Wilson stock cuts across both the Telluride conglomerate of Oligocene(?) age and the San Juan tuff, which Burbank (1947, table 7) considers to be of Miocene(?) age. Thus it appears likely that the granogabbro bodies are no older than Miocene in age, and may be younger.

A similar age can be assigned to many of the other igneous bodies. The granodiorite bodies are mineralogically similar to the granodioritic rock that also forms a part of the Wilson stock, and they may be offshoots from the stock. Although the microgabbro and rhyolite(?) bodies cannot be dated more closely than younger than the Mesozoic sedimentary rocks they cut, an age comparable to that of the granogabbro and granodiorite appears reasonable.

TERTIARY(?) SYSTEM

CLASTIC DIKES

A single clastic dike cuts the Cutler formation in the extreme northeast corner of the Little Cone quadrangle (pl. 19). It is composed mostly of angular to rounded rock fragments of Precambrian crystalline and volcanic rocks, and of Paleozoic sedimentary rocks. No fragments of rocks younger than the Cutler formation were identified in the dike. The dike has a thickness of about 3 feet, a traceable length of a few hundred feet, and an observed vertical extent of less than a hundred feet. It has been intruded along a northwestward-trending normal fault of small displacement.

Similar clastic dikes in the Placerville quadrangle, a little more than a mile to the northwest, have been described by Haff (1944) and Bush and others (1959). Other clastic dikes in the western San Juan Mountains have been described by Ransome (1900, 1901), Irving and Cross (1907), Spurr (1923), Burbank (1930), and Dings (1941). The reader is referred to these reports for detailed descriptions and consideration of various theories of origin. The writers concur with Burbank (1930, p. 200) in believing that the injection of the dikes resulted from the violent escape of volcanic gases, vapors, and solutions that had been temporarily trapped beneath an impervious blanket of sedimentary rocks.

The clastic dikes of the Placerville district are classed as Tertiary(?) in age for several reasons. In the Placerville quadrangle (Bush and others, 1959), the dikes end against normal faults that are believed to be younger than igneous rocks of probable Miocene age. The dike in the Little Cone quadrangle occupies a normal fault of similar age. Volcanic activity was widespread throughout the San Juan Mountains in Miocene and Pliocene time, and it seems reasonable to refer the violent escape of gas and vapor to this time.

QUATERNARY SYSTEM

PLEISTOCENE SERIES

PORPHYRITIC BASALT

The youngest igneous rock in the Little Cone quadrangle is a black porphyritic basalt. Augite, with hourglass zoning, and olivine form phenocrysts as much as 2 mm long. These are set in a dark-brown glassy groundmass, partially devitrified, that also contains microlites of calcic plagioclase. Some of the flow rock is scoriaceous; much is stony and compact, with widely scattered vesicles.

The basalt forms a thin flow on the surface of Specie Mesa, 1 mile north of Little Cone (pl. 19); it has an areal extent of about half a square mile, and generally a thickness of a few feet. Isolated remnants of the basalt, and local concentrations of the float suggest that originally the flow may have had an area only 2 to 3 times its present extent. The flow lies partly on the Mancos shale, and to the north overlaps onto a surface cut on the Dakota sandstone.

There appears to have been a minimum relief of 350 feet on the northward-sloping surface now preserved below the basalt flow.

Fissures from which basalt was erupted are exposed nearby, but the main vent appears to be beneath the flow itself. The main remnant of the flow thickens abruptly from a few feet to as much as 80 feet at its south end; farther south a single patch of flow has a maximum thickness of less than 15 feet. The thickest part of the flow is interpreted to lie above the main vent. To the south of the main flow area there is also a vertical dike, 1½ to 4 feet thick, and two small probably discordant masses. The dike rock contains less olivine than the rock of the main flow and has very small vesicles. These discordant masses may also be part of the feeder system for the main flow.

The assignment of Quaternary age to the lava flow and the associated dike is based largely on topographic evidence. The buried surface on which the lava flowed corresponds closely, in slope, configuration, altitude, and position, to the present surfaces nearby. In general the present surfaces are cut near the contact of the Dakota sandstone and the Mancos shale.

No evidence has been observed to date the basalt flow in terms of the Quaternary glacial history of the area.

GLACIAL DRIFT

Despite the nearness of the glaciated San Miguel Mountains just south of the quadrangle, there are only a few masses of transported rock material within the Little Cone quadrangle that can be classed with certainty as of glacial origin. It seems likely that glaciers were not very extensive in the western part of the San Miguel Mountains during at least the latest glacial stage. The most prominent cirques lie in the highest mountains just south of the southeast corner of the Little Cone quadrangle. The deposits of glacial drift are concentrated in the southeast corner of the Little Cone quadrangle, directly down drainage from these cirques (pl. 19).

Glacial drift of at least two ages can be distinguished in the quadrangle. Atwood and Mather (1932) have discussed the evidence for multiple glaciation in the San Juan Mountains and have distinguished three glacial stages, which they have designated the Cerro (oldest), Durango, and Wisconsin (youngest) stages. In the discussion that follows, these terms are used in the sense that Atwood and Mather (1932) gave them, in the absence of more recent published correlations for the San Juan area. It appears reasonable that the oldest drift in the quadrangle correlates with the Cerro stage, but the younger drift cannot be classed with certainty as either Durango or Wisconsin, and it may well be that both younger stages are represented. Valley-fill deposits in the San Miguel River canyon may correlate with the Wisconsin stage of glaciation.

Older drift.—The few remaining patches of older drift lie at altitudes that range from 9,000 to 10,125 feet. In most cases they cap ridges or small hills that are 200 to 300 feet above the present drainage courses. The distribution of these patches does not appear to be related to the present drainage, and the sloping surface on which they were deposited has undergone considerable dissection since their deposition. The patches are as much as 20 feet thick.

The drift is composed largely of pebble- to boulder-size, angular to subrounded fragments of granogabbro, hornfels of the Mancos shale, Telluride conglomerate, San Juan tuff, and the Silverton volcanic series. In some of the patches there are individual blocks as much as 13 feet long; characteristically the largest blocks are composed of welded tuff. Generally the rocks are deeply weathered.

Younger drift.—The younger drift is concentrated along the valley of Big Bear Creek, in the southeast corner of the quadrangle (pl. 19). In the southern part of the area mapped as younger drift, the drift caps a ridge as much as 450 feet above the present creek level, and here it may represent in part a lateral moraine. To the north the drift descends into the valley bottom and merges with another drift ridge that also may be a lateral moraine. In the valley bottom the drift has been incised by the creek, and the base of the drift lies 30 to 40 feet above the drainage level.

The materials composing the drift are angular to subrounded pebbles, cobbles, and boulders of granogabbro, granodiorite, Mancos shale, Telluride conglomerate, and San Juan tuff. Generally the rocks are unweathered or only slightly weathered. Welded tuff is absent, and blocks larger than 4 feet long are also absent. The younger drift is thus more representative of the formations exposed at present in the mountains to the south than is the older drift.

The younger drift also forms an eastward-trending lateral moraine nearly 1 mile long, which lies about a quarter of a mile northwest of Woods Lake, in the southern part of the quadrangle (pl. 19). At its west end the base of the moraine is about 300 feet above the valley of Fall Creek; at its east end the moraine is 60 to 80 feet above the valley. This drift closely resembles the other deposits of younger drift, particularly in size, shape, and degree of weathering of the rocks. It differs only in that blocks of the Telluride conglomerate and the San Juan tuff are lacking.

The younger drift cannot be classed either as Durango or Wisconsin to the exclusion of the other. In the Gray Head quadrangle to the east, drift of both stages can be recognized and are lithologically similar in composition and in stage of weathering. They can be told apart only by their position relative to the drainage system; the Wisconsin drift lies in the bottom of the valleys, the Durango drift is higher on the slopes, but still within the main valleys. It is possible, therefore, that the younger drift deposits in the Little Cone quadrangle are in part remnants of deposits of Durango age, which merge at lower altitudes with deposits that are of Wisconsin age.

TERRACE GRAVEL AND VALLEY FILL

A few deposits of poorly sorted partly consolidated gravel are found along the course of the San Miguel River, and a single deposit lies at the junction of Elk and Fall Creeks (pl. 19). Numerous other deposits are present in the Placerville quadrangle and for a few miles farther west. The deposits lie on narrow terraces and partly fill an earlier stage valley of the San Miguel River. Generally the base of the deposits lies 40 to 100 feet above the present drainage level; the tops of the deposits are as high as 400 feet above the river. One deposit, along the north boundary of the quadrangle, exposes a gravel bank 60 to 80 feet thick, composed of rudely stratified poorly sorted gravel. The material ranges from medium-grained sand to boulders 3 feet in size.

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. In addition there is a fairly large percentage of sedimentary rocks, with representatives of all the formations known in the area. All these rocks are now exposed along the headwaters of the San Miguel River and its tributaries.

The gravel deposits fill the valley of an earlier stage of the San Miguel River, and in a few places in the adjoining Placerville quadrangle and to the west the base of this old valley is exposed, still filled with 100 feet or more of gravel. It is unlikely that a youthful stream would aggrade to the extent of several hundred feet of valley fill during the normal course of erosion, particularly where it has a fairly steep gradient and carries large amounts of water. These deposits probably represent glacially derived material, transported during one of the glacial stages that affected the San Juan Mountains. The rather minor amount of downcutting since deposition of the gravel suggests that the deposits may correlate with the retreat of the Wisconsin glaciers.

PLEISTOCENE AND RECENT SERIES

COLLUVIUM

Throughout much of the central and almost all of the southern parts of the Little Cone quadrangle, extensive colluvial deposits mantle the underlying rocks. Generally these deposits are found in the area underlain by the Mancos shale, which is slippery when wet and is particularly subject to soil creep and landsliding even on relatively gentle slopes.

Although the general term "colluvium" includes both landslide deposits and talus, accumulations of these deposits are sufficiently large and distinct to be mapped separately and are thus distinguished on the geologic map (pl. 19). These probably are Recent in age and will be discussed in subsequent sections. The colluvium described in this section is restricted, therefore, to commonly thin sheetlike deposits that mantle the mountain and foothill slopes, and that are probably in part of Pleistocene age, as well as Recent.

The colluvial material is composed of blocks and fragments of Mancos shale, and blocks of granogabbro, granodiorite, Telluride conglomerate, and sandstone of the Mancos shale. The soil creep and landsliding responsible for the accumulation of colluvium are so effective that concentrated taluslike accumulations are found several miles from the nearest known outcrops of the various rock types.

Only a few of the larger colluvial accumulations are shown separately on the geologic map (pl. 19). These indicate the distance the surficial material has moved from the higher mountain slopes that provided the contained fragments.

RECENT SERIES

TALUS

Deposits of talus consisting of fragments of igneous rock and Mancos shale surround the higher peaks and lie at the foot of the steep cliffs formed on the sills that cut the Mancos. Where the lower ends of the talus have moved by talus creep and solifluction, the talus merges downhill with the colluvium. Generally only the larger areas of talus are shown on the geologic map (pl. 19); small areas are shown where they obscure some of the geologic contacts. In a few places the talus takes the form of small rock streams, but these have not been shown separately on the map.

ALLUVIUM

Unconsolidated deposits of alluvium and small torrential fan deposits are present along the courses of the San Miguel River and Fall Creek. They have been grouped together on the geologic map (fig. 3). They are as thick as 20 feet.

The materials that make up the alluvium range in size from fine-grained sand to boulders 4 feet in longest dimension; generally they are subangular to rounded. 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 that range in age from Permian to Tertiary, which have been both derived locally and transported from areas upstream beyond the bounds of the quadrangle. No sorting is apparent in the alluvium, in contrast to the rude sorting present in the Pleistocene valley fill.

Small roughly conical torrential fan deposits are present at the mouth of Lou Hall Gulch, Von Fintel Draw, and some of the other minor valleys that join Fall Creek (pl. 19). The materials are generally angular, unsorted, and as much as 10 feet in size; they are products of cloudburst or flash-flood runoffs. The fans coalesce with the alluvium at their downstream ends; upstream they come to a sharp apex that is commonly several feet above the bed of the minor valleys.

SPRING DEPOSITS

Deposits of calcareous tufa mantle the valley walls on the west bank of Fall Creek about half a mile south of its junction with Elk Creek and in the valley of Big Bear Creek near the east boundary of the quadrangle (pl. 19). The travertine is highly porous, and is much permeated with limonite.

Neither of the deposits can be definitely associated with faults or fractures. The Fall Creek deposit may be on a small fault or fracture associated with a northward-trending fault of about 70 feet displacement that lies some distance to the west. The fault or fracture can neither be proved or disproved from existing exposures. The Big Bear Creek deposit lies at the edge of a ridge of glacial drift overlying the Mancos shale, and may be localized at the contact of the more permeable drift and the impermeable Mancos. Again the presence of a fault or fracture cannot be determined from the available exposures.

STRUCTURE

REGIONAL SETTING

The Little Cone quadrangle lies in the transition zone between structural features characteristic of the Colorado Plateau to the west and of the San Juan Mountains to the east and south; elements of both types of features are present. Features of the plateau-type (faulted, gently dipping beds that form broad warps) are dominant in the quadrangle. These broad warps represent the southeast end of the Paradox fold and fault belt (fig. 45).

Domes common to the San Juan Mountains lie a few miles to the east and to the south (fig. 45). The San Juan dome (Burbank,

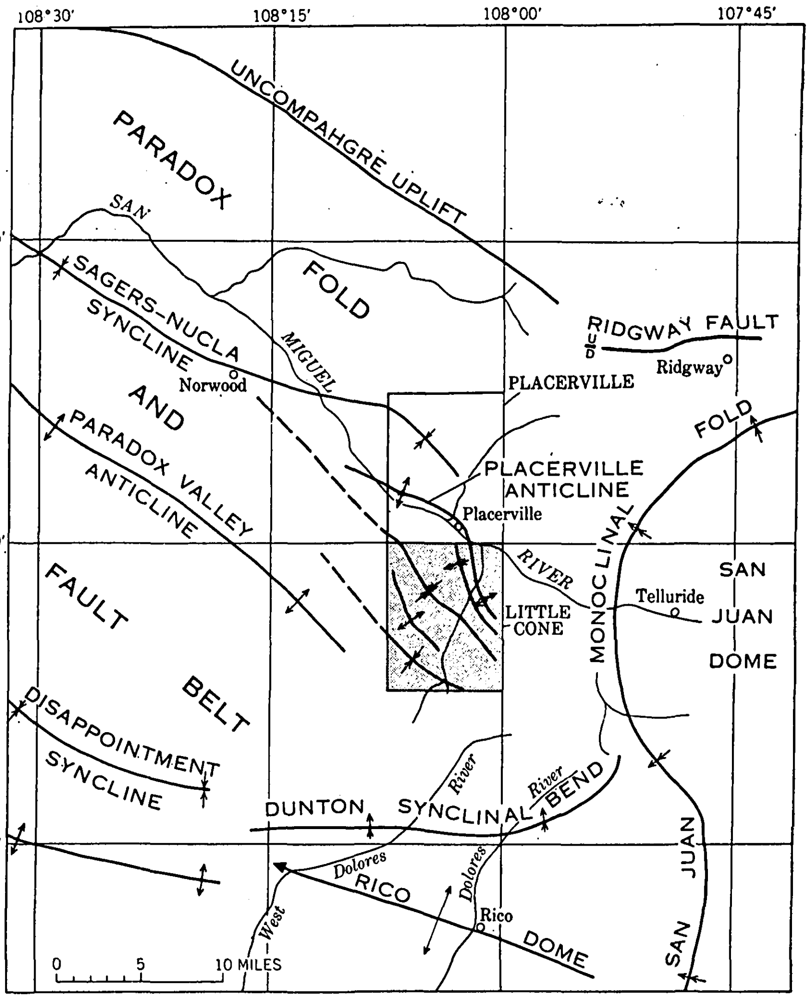

FIGURE 45.—Index map showing the major structural features of the region surrounding the Little Cone quadrangle, Colorado.

1930; Kelley, 1955), marked by the San Juan monoclinal fold about 6 miles to the west, has had little apparent influence on the structure of the quadrangle. The Rico dome (Cross and Larsen, 1935), which lies some 12 miles to the south, has affected the quadrangle structure, and the rocks of the southernmost part of the quadrangle rise to the south as a homocline that merges with the dome's north flank at the Dunton synclinal bend.

GENERAL FEATURES

The sedimentary rocks of the quadrangle are warped into a series of gentle shallow folds of various widths, whose axes have sinuous northward to northwestward trends. Along the quadrangle's south margin the folds merge with a homocline that has a general low northerly dip, and that is continuous in dip with the steeper north flank of the Rico dome. The formations exposed in the mapped area generally dip less than 5°. Locally, where the formations are warped by monoclinal flexures, dips are as steep as 25°, and near some faults drag results in even steeper dips.

The principal fold is the Little Cone syncline, which extends through the center of the quadrangle (fig. 46). To the northeast

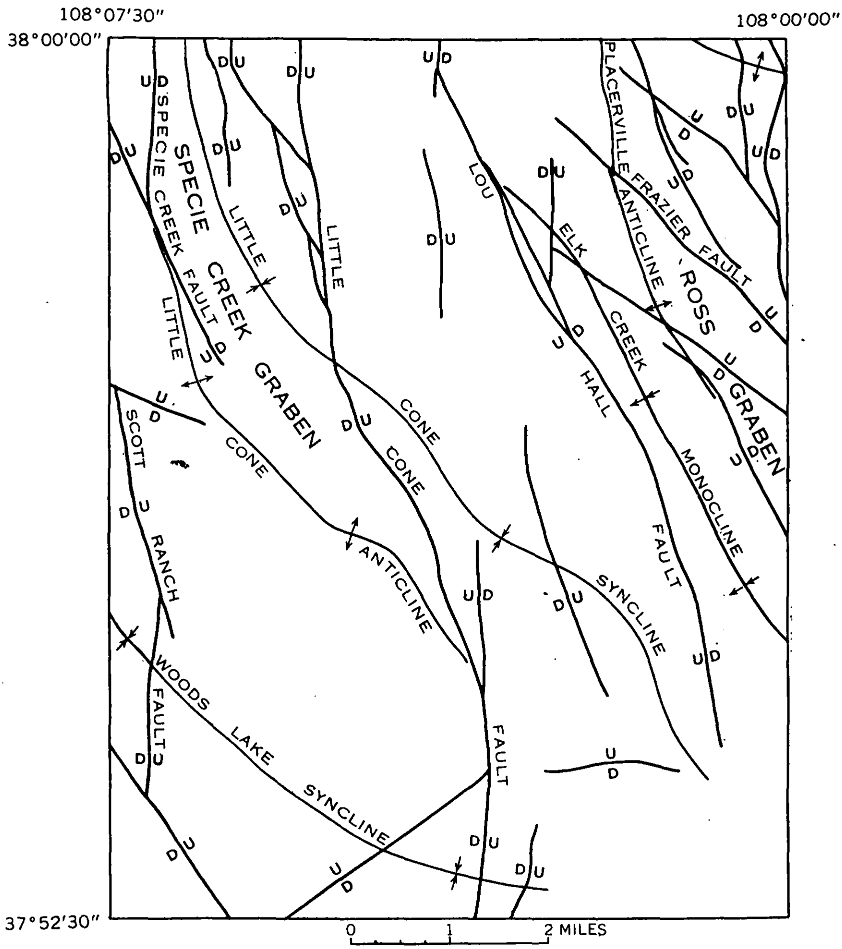

FIGURE 46.—Index map showing the major folds and faults in the Little Cone quadrangle, Colorado.

are the Elk Creek monocline and the southeast end of the Placerville anticline; to the south and southwest are the Little Cone anticline, Woods Lake syncline, and the structural slope that rises to the Rico dome.

Faults of minor to moderate displacement are superimposed on the broad folds, locally accentuating or decreasing the folds' structural relief (fig. 46). Most of the faults belong to a northward to north-northwestward-trending system, but in the northeast corner and in a few places along the west side of the quadrangle, faults of a northwestward-trending system are present. These apparently are the same systems that are well developed in the adjoining Placerville quadrangle to the north (Bush and others, 1959). A subordinate number of faults trend easterly to northeasterly. All displacements are normal; typically the faults dip steeply or are vertical. Graben structures are present, but they are less common than in the Placerville quadrangle, and they die out south of the center of the Little Cone quadrangle. Generally most faults of the northward-trending system die out as they approach the stocks and related sills in the southern part of the quadrangle. Faults apparently related to the centers of igneous activity are present in the southern part of the mapped area and in the high mountains to the south.

The reliability of the structural data and interpretations shown on the geologic map and sections (pl. 19) decreases from north to south across the quadrangle. In the northern third of the quadrangle there are a sufficient number of data points on the Dakota sandstone and older formations, adequately distributed, to give a fairly reliable picture. In the central third of the quadrangle there are fewer points, inadequately distributed, but sufficient to provide some control on structural features whose trend is similar to those of the northern third. In the southern third of the quadrangle there are very few data points, and these are concentrated along Fall and Muddy Creeks in the center of the quadrangle. In this area the structural interpretations are based on projection from far distant points, and on the assumption that there are no abrupt major changes in type or amplitude of the structures. The overall decrease in reliability is due to the presence of the thick cover of Mancos shale in the southern part of the quadrangle; there are no persistent stratigraphic zones that can be correlated from outcrop to outcrop in the lower 2,000 feet or more of the Mancos, and the formation has been so extensively disrupted by landslide, that observable bed attitudes have only local significance.

FOLDS

LITTLE CONE SYNCLINE

The Little Cone syncline, which is the principal fold in the Little Cone quadrangle, is a broad, somewhat asymmetric syncline that is sinuous but has an overall northwest trend (pl. 19 and fig. 46). It is traceable for about 7½ miles from near the center of the quadrangle to the northwest corner, and thence northwest for at least several miles. The syncline probably extends for several miles to the southeast, into the Gray Head quadrangle.

The Little Cone syncline is probably a branch of the Sagers-Nucla syncline (Kelley, 1955, p. 38) whose southeast end is in the adjoining Placerville quadrangle (Bush and others, 1959). The Sagers-Nucla syncline is one of the major structures of the Paradox fold and fault belt (fig. 45); it extends for several tens of miles farther to the northwest, where Cater (1955a) calls it the Dolores River syncline.

Within the quadrangle the northeast limb of the syncline is more clearly defined than the southwest limb. Structural relief along the northeast limb, between the trough of the syncline and the crest of the adjoining Placerville anticline, ranges from about 300 to 800 feet, and dips along this limb range from less than 1° to about 5°. The folds are complicated both by numerous normal faults, and by a monoclinal flexure, the Elk Creek monocline (fig. 7), that lies high on the flank of the Placerville anticline. Dips are as steep as 25° in parts of the monocline.

The southwest flank of the syncline is less well defined, largely because of difficulty in obtaining reliable attitudes of beds in the Mancos shale. Sill attitudes can be used only with a large degree of uncertainty, for the sills commonly transgress the bedding, both upward and downward, by "jumps" of several tens of feet, and in places as much as 100 feet. The general dip of the southwest flank appears to be about 1° to 2° NE., and the beds rise to the crest of the adjoining Little Cone anticline (pl. 19 and fig. 46) with a structural relief that ranges from 100 to a little more than 200 feet.

The syncline is doubly plunging, so that the trough plunges gently southeast and more steeply northwest from a point about 2 miles north-northeast of Little Cone. The northwest steepening of the plunge has probably been accentuated by the Specie Creek graben, which crosses the syncline.

PLACERVILLE ANTICLINE

The Placerville anticline is best formed in the adjoining Placerville quadrangle (fig. 45), where it is a relatively narrow northwestward-trending fold that plunges gently northwest, and is broken along its axis by a normal fault of several hundred feet displacement. In the southeast corner of the Placerville quadrangle the anticline divides into several subsidiary folds, which pass into a poorly defined faulted dome. From this dome a gently southward-plunging anticline trends south and thence southeast for a distance of about 5 miles across the northeast corner of the Little Cone quadrangle (pl. 19 and fig. 46); the anticline probably continues for some distance into the adjoining Gray Head quadrangle, but normal faulting has so disrupted the fold and has so rotated blocks within the fold that it cannot be clearly defined there.

In the Little Cone quadrangle the Placerville anticline is asymmetric, with a steeper southwest limb. This asymmetry is caused by the northwestward-trending Elk Creek monocline, a flexure that lies high on the flank of the anticline and that parallels the anticline except at its north end. In addition, the attitude of the beds and the shape of the fold have been changed by faulting. Within the quadrangle there is a structural relief of nearly 400 feet along the axis of the anticline. Before faulting there was probably between 600 and 700 feet of closure on the anticline, as measured in the Placerville quadrangle.

LITTLE CONE ANTICLINE

The Little Cone anticline is a generally northwestward-trending structure 6 miles or more in length and perhaps 2½ miles wide at its broadest point (pl. 19 and fig. 46). It appears to lie largely within the quadrangle, though it may extend for a mile or so north-northwest beyond the quadrangle boundary; it appears to die out in the southeast corner of the quadrangle. Structural closure on the anticline is estimated at about 200 feet.

The evidence for the anticline consists largely of a few altitudes and bed attitudes on the Dakota sandstone, at opposite ends of the fold, about 6 miles apart. No reliable attitudes within the Mancos shale were obtained, but the attitude of the base of the Little Cone laccolith, dipping slightly to the south, suggests that the laccolith is localized over and just south of the crest of the anticline.

It may be that the configuration of the anticline has been altered by an igneous body at depth, from which the Little Cone laccolith was derived, and that the double plunge of the Little Cone syncline, mentioned above, is also a reflection of such a deep-seated igneous body.

WOODS LAKE SYNCLINE

Southwest of the Little Cone anticline, the beds are warped into the Woods Lake syncline (pl. 19 and fig. 46). Along the south and southwest flanks of the syncline the beds rise on the homocline that merges with the Rico dome (fig. 45). Very little structural data is available for this syncline. Its overall trend appears to be to the northwest, based on the position of the north limb as seen near the junction of Fall and Muddy Creeks, the trend of the adjoining Little Cone anticline, and the position of points of observation on the Dakota sandstone a mile or so west of the quadrangle's west border. No information is available on the direction or amount of plunge of the syncline, but the structural relief between its trough and the crest of the Little Cone anticline appears to be on the order of 300 to 400 feet. This order of magnitude is determined by the position and southerly dip of the Dakota sandstone near the junction of Fall and Muddy Creeks, and by the position and northerly dip of the granogabbro sills in the Mancos shale along the south border of the quadrangle.

The position of the axis and the attitude of the southern limb of the Woods Lake cyncline are indicated by three relations: (a) at its southernmost exposures near Woods Lake in the Little Cone quadrangle, the Dakota sandstone dips about 10° S., (b) 1 mile south of these exposures of the Dakota, sills in the Mancos shale dip 1½° NE., and (c) at the next exposure of the Dakota, 5½ miles to the south on the West Dolores River in the Dolores Peak quadrangle, the Dakota dips northward and is 800 to 900 feet higher than at the Woods Lake outcrops. This limb of the syncline merges with the north flank of the Rico dome and forms a monocline that has a general dip of about 2° NE.

These concepts are incorporated in the sections shown on plate 19. The position of the pre-Mancos sedimentary rocks cannot be considered reliably located on the sections, but on the assumption that there are no abrupt changes in type or amplitude of the structures, it is likely that the formations are located vertically within a limit of error of about 200 feet.

OTHER FOLDS

The Elk Creek monocline is the most prominent of the other northwestward-trending flexures in the quadrangle. The southwestward-dipping monocline has a length of about 6 miles, and a structural relief of 300 to 400 feet between its synclinal and anticlinal beds. Dips on the monocline range from 4° to 25° SW. Its synclinal bend is a more abrupt flexure than the anticlinal bend. The Lou Hall fault closely parallels the axis of the synclinal bend and in places coincides with its axial plane. The fault is discussed in greater detail in a following section, but it is to be noted here that it is a normal fault, downthrown on the northeast side, whose structural displacement is in the opposite direction to the structural relief across the Elk Creek monocline.

There is no direct evidence to explain the proximity of the monocline and the fault, or the opposition of the movements. The authors favor the interpretation that the Elk Creek monocline is localized over a deep seated normal fault, and that the Lou Hall fault may reflect reverse movement on this fault at a later time.

A shallow syncline and an eastward-trending anticline lie northeast of the Placerville anticline, in the extreme northeast corner of the quadrangle; both extend into the adjoining Gray Head quadrangle to the east, and join the Placerville anticline in the Placerville quadrangle to the north.

FAULTS

Numerous faults cut the rocks of the Little Cone quadrangle. Displacements on the faults range from a few feet to as much as 450 feet; their lengths range from a few tens of feet to more than 10 miles. Most of the faults belong to a major set with a northerly to north-northwesterly strike (fig. 46). A second set with a northwesterly strike is represented by a smaller number of faults in the northeast corner and along the west side of the quadrangle. In addition there are faults of easterly to northeasterly trend; a number of these represent cross faults related to the northerly set, others appear to be related to the igneous masses in the southern part of the quadrangle. All the faults are of the normal type, and almost all dip steeply or are vertical.

Graben structures (fig. 46) are striking in the Little Cone quadrangle, but they are fewer in number and not so well formed as those of the Placerville quadrangle to the north. They die out southeastward, and appear to be absent in the western part of the San Miguel Mountains.

The faults in both of the northward to northwestward-trending sets belong to a single major fault system. This system dies out to the south and southeast, toward the intrusive masses in the San Miguel Mountains, with a decrease in the number of faults as well as a hinging out of individual faults. None of the faults of this system cut the main mass of the San Miguel Mountains, although many of them cut the sills related to the intrusive rocks of the mountains. There is no similar fault system south of the San Miguel Mountains.

The faults along the south boundary of the quadrangle do not fit into the major system. Graben structures are absent, and the eastward and northeastward-trending faults are unrelated to the northward- or northwestward-trending sets. Some of the faults here appear to be tangential, others to be radial to the stocks of the San Miguel Mountains. They are not known to extend across the mountain masses, but similar faults are present south of the mountains.

SPECIE CREEK GRABEN

The Specie Creek graben lies in the northwest corner of the quadrangle, and extends northward into the Placerville quadrangle (pl. 19 and fig. 46). Its overall length is about 5½ miles, with a length of about 4 miles in the Little Cone quadrangle. The graben ranges in width from ½ to 1½ miles, with a maximum aggregate displacement on the lowest segment of the complex downthrown block of almost 400 feet near the north boundary of the Little Cone quadrangle. Along the graben the trend swings from southward in the north half to south-southeastward in the south half. This easterly swing of the southern part of the graben is duplicated in every graben in both the Placerville and Little Cone quadrangles. The reasons for this swing cannot be determined with certainty.

Both the bounding faults and the interior faults of the Specie Creek graben have vertical or steep dips. Along the west-bounding fault, the Specie Creek fault (pl. 19), there are several large fault slivers, and total displacement on the fault zone is as much as 250 feet. This fault can be traced with certainty for a distance of 3 miles within the quadrangle; it probably continues to the south for a mile or more, but where its displacement at the surface is entirely within the Mancos shale there is no definite evidence as to its position or extent. The east-bounding fault, a branch of the Little Cone fault, has a maximum displacement along the graben of about 130 feet. Several large fault slices border the graben along its southeast end; these are bounded by the branches of the Little Cone fault, which extends 6 miles or more to the south boundary of the quadrangle.

In the central part of the graben two other normal faults, both with downthrown west sides, displace the beds a total of about 100 feet. These faults generally parallel the axis of the graben, and one has the common southeast swing at its south end. Movement along these faults has resulted in an accentuation of the plunge of the Little Cone syncline within the boundaries of the Specie Creek graben.

ROSS GRABEN

The northwestward-trending Ross graben crosses the central part of the east boundary of the quadrangle (pl. 19 and fig. 46). Within the quadrangle the graben can be traced for a distance of about 1½ miles. To the southeast the graben extends for at least 2 miles into the Gray Head quadrangle. The graben is about 0.8 mile wide at its northwest end, and it widens to about 1 mile at the quadrangle boundary. Farther southeast, in the Gray Head quadrangle, it broadens to 1½ miles. At both ends the graben is complicated by normal faults within its borders, and at the northwest end it impinges on the Placerville anticline.

Structural details of the Ross graben are obscure because of the difficulty of obtaining attitudes and determining stratigraphic position in the Mancos shale, and are further complicated by intragraben faults and by creep of debris from the Mancos over the Dakota sandstone. It seems certain that the maximum displacement along the southwest-bounding fault within the quadrangle is at least 200 feet at the quadrangle boundary. The maximum displacement within the quadrangle along the Frazier fault on the northeast side of the graben is about 350 feet, also at the quadrangle boundary.

The Frazier fault (pl. 19 and fig. 46), which bounds the graben on the northeast, belongs to the northwestward-trending fault set. Throughout much of its length it is a pair of faults, a few hundred feet apart, with approximately equal displacement on each. The total displacement increases from about 100 feet on the west side of Fall Creek to about 320 feet at the head of the canyon of Von Fintel Draw, and to at least 350 feet at the east border of the quadrangle. The fault dips steeply southwest; where seen in underground workings of the Frazier mine on Fall Creek, and the Big Bear Creek mine in the Gray Head quadrangle, the dip ranges from 70° to 75° SW.

The southwest-bounding fault is a simpler structure, apparently vertical, along which the displacement increases uniformly southeastward from the hinge point to about 200 feet. A short northeasterly fault, within the graben, abuts against the southwest-bounding fault near the east boundary of the quadrangle, and increases the bounding fault's displacement by about 40 feet, so that at the quadrangle's edge the displacement is about 250 feet. It seems likely that the bounding fault nearly corresponds with the axis of the southeast end of the Placerville anticline.

LITTLE CONE FAULT

The Little Cone fault has a minimum length of 11 miles; it extends completely across the Little Cone quadrangle and for a mile or so north into the Placerville quadrangle and south into the Dolores Peak quadrangle (pl. 19 and fig. 46). The fault is downthrown on the west side; the plane is nowhere exposed, but the nearly straight trend across nearly 2,000 feet of relief indicates the overall dip is steep or vertical. About 1½ miles north of Little Cone the fault splits, and two branches continue northward. The west branch forms the east-bounding fault of the Specie Creek graben, and appears to have the greater displacement. At the north border of the quadrangle the displacement is 120 to 140 feet on the west branch, and 40 to 80 feet on the east branch. Near the junction of the two branch faults, the cumulative displacement across them is about 200 feet.

About 1 mile northeast of Little Cone the Little Cone fault cuts a thick granodiorite sill. The apparent displacement here is about 100 feet. Farther southeast, near the junction of Fall and Muddy

Creeks the fault has a displacement of about 180 feet. At this point a minor northward-trending fault, with the east side downthrown about 40 feet, joins the Little Cone fault. At the south boundary of the quadrangle the apparent displacement is about 40 feet, measured between two sill exposures.

LOU HALL FAULT

The Lou Hall fault roughly parallels the Little Cone fault, and lies 2 to 2½ miles northeast of it (pl. 19 and fig. 46). The fault has a slightly sinuous north-northwest trend; it extends for 8 miles, from the center of the north quadrangle boundary nearly to the southeast corner of the quadrangle. Again the fault plane is nowhere exposed, but the trace of the fault across the topography indicates the plane has a steep dip to the northeast.

Throughout most its length the Lou Hall fault is a single plane of fracture, but in the vicinity of Lou Hall Gulch the fault divides into three planes and forms one small and one large fault block. At the north border of the Little Cone quadrangle the displacement is about 40 to 60 feet, and decreases rapidly to the north. Along the north side of Lou Hall Gulch the displacement across the three branches is about 350 feet. Displacement is about 450 feet where the fault crosses Fall Creek, and it decreases thence southeastward to 340 feet at the north crossing on Elk Creek, and about 300 feet at the south crossing on Elk Creek. Generally the Lou Hall fault parallels the Elk Creek monocline, lies close to the monocline's synclinal bend, and in places coincides with the axial plane of the bend.

OTHER FAULTS

The Scott Ranch fault (pl. 19 and fig. 46) parallels the west boundary of the quadrangle and appears to be the east-bounding fault of another graben; most of this graben lies in the adjoining quadrangle to the west. The fault is located definitely only at its north end. To the south its trace is believed to coincide with a topographic lineament. For most of its extent the surface expression of the fault lies in the Mancos shale, where the Mancos has been extensively landslipped. The west side of the fault is downthrown and at its north end within the quadrangle, the displacement is less than 160 feet. This displacement is reduced by the cross fault at the north end of the Scott Ranch fault, and the displacement in the adjoining quadrangle is only about 20 feet.

Most of the faults along the south boundary of the Little Cone quadrangle appear to be related to the igneous intrusive masses, but there is no apparent systematic distribution within the quadrangle. They are arranged tangentially or radially to the stocks in the Dolores Peaks and the Wilson mountain groups. Similar faults south of these mountain groups have been noted in reconnaissance work, but as yet the faults are not known to extend across the mountains.

Elsewhere in the quadrangle are numerous cross faults, most of which abut against major faults of the northerly or northwesterly sets; few of the cross faults intersect these major faults. They seem to have relieved stresses developed along the major faults, rather than stresses across these faults.

AGE RELATIONS OF THE FAULTS

There is very little evidence in the Little Cone quadrangle as to the relative ages of the fault sets that trend northerly, northwesterly, and easterly to northeasterly. The evidence in the Placerville quadrangle suggested that the northerly set was slightly older than the northwesterly set (Bush and others, 1959). The best that can be said from the evidence in the Little Cone quadrangle is that nothing was seen to definitely contradict this dating. Where the two sets intersect, there is no regularity to the offset of one set of faults by the other. It seems likely that the faulting is all essentially contemporaneous, although there may have been later periods of renewed movement.

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 is represented in the Little Cone quadrangle by an erosional unconformity with no definite angular discordance.

The principal deformations in the Little Cone quadrangle involve all the Paleozoic and Mesozoic formations. The beds have been warped and cut by later faults, but within the quadrangle there is little direct evidence of the age of the folding. At the end of the Cretaceous or in the 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. It appears likely that the folding in the Little Cone quadrangle dates from this general time. It has been noted above that the Little Cone syncline is probably a branch of the Sagers-Nucla syncline, which is physically continuous with the folds dated as Laramide by Cater (1954, 1955b).

The faults are probably late Miocene to late Pliocene in age. They cut sills in the Mancos shale that are probably Miocene or younger in age, as has been described in the preceding discussion of the age of the igneous rocks. A basalt flow of Quaternary age has covered a surface controlled by downfaulted blocks of the Dakota sandstone in the north-central part of the quadrangle. In addition glacial drift of early Pleistocene age is known to extend across a fault of the northerly set in the Placerville quadrangle (Bush and others, 1959).

GEOMORPHOLOGY

According to Atwood and Mather (1932, p. 21–26) the widespread San Juan peneplain was developed across the entire San Juan volcanic pile near the end of the Pliocene. This erosion surface, projected into the Little Cone quadrangle, is several hundred to a few thousand feet above the present surface. Within the bounds of the quadrangle the peneplain probably was cut on the San Juan tuff, the Telluride conglomerate, and possibly the Mancos shale, and these formations probably were bevelled successively from east to west. Erosion of the peneplain began with regional uplift of the San Juan dome in early Pleistocene time; Atwood and Mather (1932, p. 27–28) have termed this the Florida erosion cycle. In general erosion proceeded only to the level of the Dakota sandstone during the Florida cycle.

UPLAND SURFACES

The upland surfaces of the quadrangle can be divided into mesa tops formed on the relatively flat lying beds of the Dakota sandstone, mountain slopes formed on the less resistant strata of the Mancos shale, and peaks and high benches underlain by igneous rocks. Much of the northern part of the quadrangle is a stripped surface underlain by the Dakota sandstone (pl. 19) and reflects in the topography the warped, faulted attitudes of the sedimentary rocks. Fault-line scarps on the mesa tops are present along most of the major normal faults, and both the Specie Creek and Ross grabens have topographic expressions that reflect the geologic structure.

The mountain slopes have gentle to moderate inclinations, but they are extensively modified and locally steepened by landslipping that is present almost everywhere in the central and southern parts of the quadrangle. The slopes are interrupted by flat benches underlain by sills, such as Frazier Flats (pl. 19). Commonly the topography downhill from the sills is very irregular, as large sill blocks become involved in the landslips.

Both Little Cone and Flat Top Peak are igneous masses that have protected the underlying or surrounding nonresistant Mancos shale. In the extreme southeast corner of the quadrangle the steep slopes formed in the Mancos have been upheld by a framework of sills and dikes.

DRAINAGE SYSTEMS

In all of their lower courses, and in much of their middle courses the streams flow in youthful V-shaped valleys incised as much as 2,100 feet below the mesa tops. Again in their upper courses the stream valleys are generally straight, V-shaped, and have high gradients. Along the south border of the quadrangle the valleys of Fall, Muddy, Elk, and Big Bear Creeks show evidence of glaciation, with steep sides and a U-shaped profile (pl. 19); the valley bottoms, however, are slightly incised by recent downcutting.

The drainage systems of the quadrangle are only partly adjusted to the structure. In general the minor drainages are structurally controlled where they have cut down to the level of the Dakota sandstone, or have cut below it, but structural control is lacking where these streams flow in the Mancos shale. Von Fintel Draw, the lower course of Elk Creek, and parts of Lou Hall Gulch are obviously influenced by the northwestward-trending structural elements, but the control is not a rigid one. The middle course of Specie Creek is localized within the Specie Creek graben, as is the creek's lower course in the Placerville quadrangle to the north.

Fall Creek, the main drainage of the quadrangle, is structurally controlled for only a short distance in the southern part of the quadrangle, where it follows the trace of a normal fault. To the north Fall Creek cuts across the predominantly northwestward-trending structural elements at an acute angle.

The San Miguel River, the master drainage of the area, crosses a zone of intense faulting where it passes through the northeast corner of the quadrangle. The development and control of the San Miguel River has been discussed in the report on the adjoining Placerville quadrangle (Bush and others, 1959) and is only summarized here. The present river course was localized along the edge of an ice lobe in early Pleistocene time, and has since been structurally controlled in the Placerville quadrangle where it generally follows a west-northwestward-trending fault, and has migrated downdip by erosion on the southwest flank of the Placerville anticline. In the adjoining southeast corner of the Placerville quadrangle and in the northeast corner of the Little Cone quadrangle, the river has apparently been forced to swing around the south and southwest borders of a small dome. This dome appears to be a part of the Placerville anticline, accentuated by numerous sills that cut and thicken the Dakota sandstone.

Stream capture appears to have taken place in the northwest corner of the quadrangle, where there is a windgap at an altitude of 8,900 feet between the drainages of Specie and Saltado Creeks (pl. 19). It appears likely that before capture the upper drainage of Saltado Creek flowed into Specie Creek. A short drainage of steep gradient, eroding headward along the present course of lower Saltado Creek, has beheaded these old western tributaries to Specie Creek. The windgap itself is localized at the junction of several normal faults.

Woods Lake, near the center of the south border of the Little Cone quadrangle, has been formed near the ends of the glaciated valleys of Fall Creek and Muddy Creek. Although the deposits that have dammed the valleys are likely moraines, landslipping has completely destroyed their form, and has contributed to the damming of the streams. The gradient of Muddy Creek downstream from Woods Lake is steeper than that of Fall Creek; it appears that stream capture will take place here in the future, and that Muddy Creek will become part of the main drainage.

LANDSLIDES

Landslipped masses are abundant in the Little Cone quadrangle; most of them are in the area underlain by the Mancos shale. A few are in the Brushy Basin shale member of the Morrison formation along the steep-sided canyons. This report follows the classification of Sharpe (1938) in the brief description that follows.

The landslips along the canyon of Saltado Creek in the northwest corner of the quadrangle are earthflows. There is no definite slippage plane on which movement has taken place, rather the material has moved mainly by flowage. The movement is mostly within the Brushy Basin member of the Morrison formation, but blocks of the overlying Dakota sandstone are involved. Generally the beds have a westerly or northwesterly dip of a few degrees, and the movement has been largely downdip.

Other landslips involving the rocks of the Brushy Basin member of the Morrison formation and the Dakota sandstone are present along the steep-sided canyons of Fall Creek, Lou Hall Gulch, and Elk Creek. These are classed as slumps, in which the masses moved more or less coherently, rather than by flowage. Typical ridge and trough topography is developed, and large disrupted masses of the Dakota sandstone cover the surface of the slumps. Most of the movement was along planes in the Brushy Basin member.

By far the largest number of slips have occurred in the Mancos shale, and it is little exaggeration to say that they are practically ubiquitous. No effort has been made to show all these masses on the geologic map (pl. 19). In general only those areas of landslip that cover significant contacts are delineated.

Both slumps and earthflows are present in the landslipped Mancos; slumps appear to be more abundant. Many of them involve only the Mancos shale as bedrock, others affect the numerous sills that cut the Mancos shale. All of the slips of both types involve other types of colluvium, which may have moved by a combination of soil creep and solifluction.

The talus that surrounds the higher peaks and lies at the foot of the steep cliffs developed on the sills has formed by rockfall, and moved by a combination of talus creep and solifluction.

MINERAL DEPOSITS

The Entrada sandstone contains tabular deposits of vanadium with subordinate amounts of uranium; these deposits have been commercially productive. In addition a few gold-bearing placer deposits are present along the bottom of the San Miguel River valley and in elevated gravel as much as 200 feet above the present stream level. Some gold was produced from these placers late in the 19th and early in the 20th centuries.

Only a summary of the mineral deposits is given here. Reference is made to several published reports for additional information.

VANADIUM-URANIUM DEPOSITS

The Entrada sandstone of Late Jurassic age contains tabular uraniferous vanadium deposits in the northeast corner of the Little Cone quadrangle. The deposits form a virtually continuous layer that is beltlike in plan (fig. 43) and that extends northwestward into the Placerville and southeastward into the Gray Head quadrangles. The entire area is known as the Placerville district. The vanadiferous layer overlies a chrome-bearing layer of similar habit and distribution, but of low metal content. Both layers underlie the west 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 and others (1947) have given general descriptions of the mineralogy and geology of these deposits.

Mining was most intensive from 1910 to 1920 and from 1940 to 1944. Intermittent operations, resulting in the production of a few thousand tons of ore, have been undertaken since 1947. A general survey of the production for the entire Placerville district indicates that 240,000 to 250,000 short tons of ore has been mined since 1910; the average grade of ore was 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 mined to a minimum thickness of 18 inches. In places where the grade of ore is higher than average, the ore has been mined to a thickness of 1 foot.

The mineralized rock forms wavy, practically continuous layers that are beltlike in plan (fig. 43). In the Little Cone quadrangle the main layer crops out around the northernmost corner of Wilson Mesa where it extends from the eastern workings of the Fall Creek mine westward for 0.5 miles, thence southward for about 1 mile along the east side of Fall Creek, and thence southeastward for 0.3 miles along the northeast side of Von Fintel Draw. Exposures are poor on the south side of Von Fintel Draw, but the layer appears to be absent. As is shown in figure 43, the layer can be traced northwestward in the adjoining Placerville quadrangle along the north side of the San Miguel River, and thence northward along both sides of Leopard Creek as far as Alder Creek. To the southeast the layer crops out again in the Big Bear Creek valley in 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 second vanadium layer, northeast of the main layer, is exposed for a length of a few hundred feet in the extreme northeast corner of the Little Cone quadrangle (fig. 43). Only a very small part of the layer lies within the bounds of the quadrangle, but 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. Most of it is in the adjoining Placerville and Gray Head quadrangles, and the southwest quarter of the Montrose 3 SW quadrangle.

In both belts, the layer of mineralized rock follows an undulant, intraformational unconformity in the upper part of the Entrada sandstone; in most places along the unconformity, 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 is 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 and forms "rolls;" where it does so there is commonly a plane of fracture that parallels the abrupt edge and lies 1/8 to 1/4 of an inch within the roll. The ore breaks to this fracture in mining, and leaves 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.

The layers range in thickness from a small fraction of an inch to more than 20 feet. The average thickness of each vanadium layer is probably less than 1 foot, but each layer contains several widely separated ore bodies 1 foot to 5 feet thick. 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 trends 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. The vanadium minerals impart a greenish color to the rock; the color deepens with increase in the concentration of vanadium. High-grade vanadium ore, 4 percent or more V_2O_5, is dark greenish gray to nearly black. The average grade of the ore, as mined, is about 1.75 percent V_2O_5.

Primary uranium minerals as yet have not been found; the uranium may occur absorbed in the vanadium minerals, in other clay minerals, or as minute, discrete mineral grains. In places the secondary uranium minerals, carnotite, or tyuyamunite, are present where the ore is oxidized.

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.

Underlying the western vanadium layer in the Entrada sandstone (fig. 43) 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 that 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 the part of the Entrada sandstone that 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 present but not exposed in the Little Cone quadrangle. The limestone is found from Von Fintel Draw northward, underlying the corner of Wilson Mesa, it is absent south of Von Fintel Draw and along the west side of Fall Creek. The western, major vanadium belt underlies this thin margin of the Pony Express limestone member (fig. 43), and lies perhaps 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.

PLACER GOLD DEPOSITS

In the period 1878–1940 placer mining for gold was carried on in a desultory fashion along the San Miguel River in the Little Cone 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 Little Cone 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 to 1941 (Vanderbilt, 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.

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 gravel. Observations of the contact of the bedrock and the gravel in a few placer drifts indicates 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 Little Cone 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 7 miles east of the quadrangle, the gravel carried "from 10 cents in surface dirt per yard to $1.50 in bedrock." Burchard (1883, p. 521), in the "Report of the Director of the Mint" 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 Saw Pit, 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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