Geology of the Mount Wilson Quadrangle Western San Juan Mountains Colorado

GEOLOGICAL SURVEY BULLETIN 1227

Prepared on behalf of the U.S. Atomic Energy Commission

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By CALVIN S. BROMFIELD

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A bedded sequence of volcanic and sedimentary rocks more than 5,000 feet thick has been intruded by stocks and laccoliths

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By Calvin S. Bromfield

ABSTRACT

The 7½-minute Mount Wilson quadrangle, in San Miguel and Dolores Counties, southwest Colorado, is in the San Juan Mountains region near the boundary with the Colorado Plateaus province. The principal topographic feature in the quadrangle is the rugged east part of the San Miguel Mountains, a west-trending outlier of the San Juan Mountains region. The principal geologic features are the Wilson Peak stock and associated Black Face-Ames plutons in the eastern part of the San Miguel Mountains, the Flattop laccolith on the south edge of the quadrangle, and part of the Ophir stock on the east edge.

A bedded sequence of sedimentary and volcanic rocks, which aggregates 5,000 feet in thickness and ranges in age from Late Triassic to middle and late Tertiary, crops out in the quadrangle. The exposed Mesozoic stratigraphic sequence includes the upper 300 feet of the Upper Triassic Dolores Formation, 100 feet of Upper Jurassic Entrada Sandstone, 120 feet of Upper Jurassic Wanakah Formation, 800 feet of Upper Jurassic Morrison Formation, 0 to 40 feet of Lower Cretaceous Burro Canyon Formation, 150 feet of Upper Cretaceous Dakota Sandstone, and 1,500–2,000 feet of Upper Cretaceous Mancos Shale. Overlying the Mancos Shale with a slight angular unconformity is about 1,000 feet of the Oligocene(?) Telluride Conglomerate. Overlying the conglomerate is 600 feet of middle and upper Tertiary San Juan Formation and 500 feet or more of the middle and upper Tertiary Silverton Volcanic Group. Pre-Wisconsin, Wisconsin, and Recent glaciations have left drift deposits. Rock streams, talus, and alluvium are also present.

The bedded rocks were intruded by stocks and laccoliths ranging in composition from micrograngabbro to adamellite, by numerous dikes and sills of intermediate composition, and by several lamprophyre dikes. The Flattop laccolith is composed of monzonite porphyry and was intruded in either Laramide or middle to late Tertiary time. The Black Face-Ames pluton is composed of granodiorite porphyry and was intruded in middle to late Tertiary time. The Wilson Peak composite stock is composed of microgranogabbro, granodiorite, and porphyritic adamellite, intruded in that order in middle to late Tertiary time; the small part of the Ophir stock within the quadrangle is composed principally of microgranogabbro and probably was formed almost contemporaneously with the Wilson Peak stock.

The close association in space and time of the middle and upper Tertiary intrusive rocks to the volcanic rocks suggests they may be related genetically. Comparison of variation curves supports this inference.

The major structural features in the quadrangle are those associated with the major intrusive bodies. Where not disturbed by intrusion the bedded rocks are generally flat lying with only gentle undulations superimposed on a general southerly rise of strata toward the Rico dome to the south. Dips are generally less than 5°.

The form and relations of the Black Face-Ames plutons suggest they are probably laccoliths. A belt of sharply folded strata, which forms the asymmetric and locally faulted Cross Mountain anticline, extends 2 miles westward from the Black Face pluton, and is truncated on the west by the Wilson Peak stock. The fold probably was formed by a buried extension of the Black Face pluton.

The Wilson Peak stock is discordant to the enclosing country rocks; contacts are steep and sharp. Around somewhat more than half the stock perimeter the flat-lying bedded rocks are not significantly deformed, but on the northeast side of the stock, the beds are in part tilted away from the contact.

The eastern San Miguel Mountains resemble other laccolithic centers on the Colorado Plateaus in the close association of laccoliths or semiconcordant intrusive bodies with a stock, but differ from these centers in that there is no large dome peripheral to a centrally located, crudely circular stock such as characterizes the Henry, La Sal, and Abajo Mountains laccolithic centers.

The Wilson Peak stock and associated intrusives were emplaced by two principal mechanisms during middle to late Tertiary time when the cover over present levels of exposure was probably less than a mile thick. The Black Face-Ames plutons made room for themselves by forceful doming or lifting of their roof rocks and by forceful pushing aside of strata. Although emplacement of the Wilson Peak stock may have begun in this fashion, it was completed by a process in which piecemeal stoping was important.

The more important factors governing the contrasting mechanism of emplacement were viscosity of the magmas, character of the host rocks as they changed with increasing thermal metamorphism, and perhaps rate of intrusion.

Vein deposits closely associated with the intrusive rocks in the north half of the quadrangle have yielded metals valued at about $3 million, of which silver and gold values make up the greater part, and lead, copper, and zinc the remainder.

A small amount of coal was mined from the middle carbonaceous unit of the Dakota Sandstone prior to 1910.

INTRODUCTION

LOCATION, ACCESSIBILITY, AND CULTURE

The Mount Wilson 7½-minute quadrangle covers an area of about 59 square miles in eastern San Miguel and Dolores Counties in southwest Colorado (fig. 1). The area, bounded by meridians 107°52′30″ and 108° and parallels 37°45′ and 37°52′30″, includes the eastern part of the San Miguel Mountains.

State Highway 145, which connects Telluride with Rico, runs along the northeast edge of the quadrangle, through the valley of the Lake Fork of the San Miguel River to Trout Lake, thence southwest over Lizard Head Pass, and out of the quadrangle near its southwest corner. Access elsewhere in the quadrangle, particularly in the

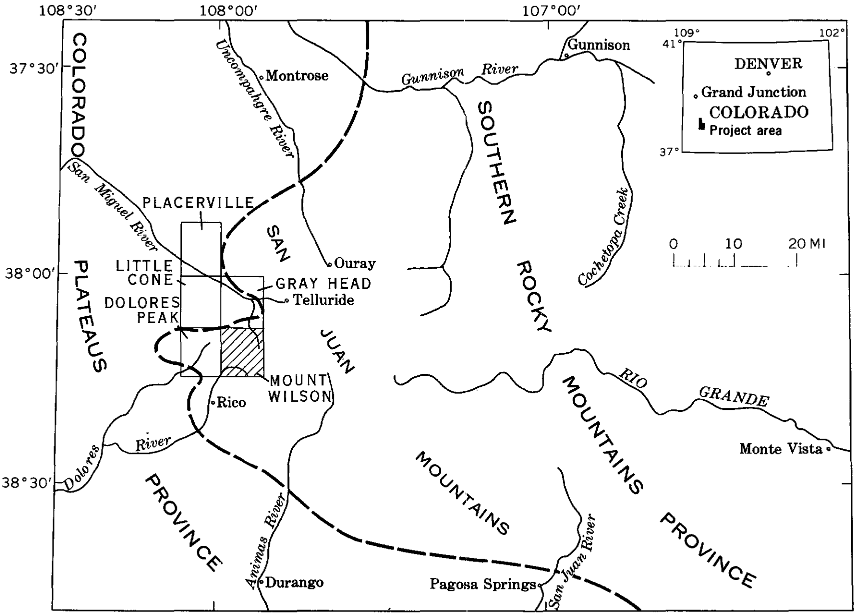

FIGURE 1.—Index map showing location of Mount Wilson and adjoining quadrangles, southwestern Colorado.

Mount Wilson Wild area, is largely by means of a few trails. All the area is in the San Juan and Uncompahgre National Forests.

The only permanent settlement is Ames, a power station of the Western Colorado Power Co., near the northeast corner of the quadrangle. Mining of silver and gold and accompanying base metals was once the primary industry within the area. Now there is only sporadic mining activity, and the principal occupations are sheep grazing and a growing tourist trade, both of which are restricted to the summer months.

This report was prepared on behalf of the U.S. Atomic Energy Commission.

TOPOGRAPHY

The Mount Wilson quadrangle lies in the San Juan Mountains region near the boundary with the Colorado Plateaus province (Fenneman, 1931). The San Juan Mountains, a westward-extending lobe of the southern Rocky Mountains, is a well-defined area of rugged mountains, nearly surrounded by lowlands or plateaus, which extends 60–70 miles north-south and about 100 miles east-west. Within this area, smaller more or less isolated mountain groups are named separately. One of these, which extends across the north half of the quadrangle, is the San Miguel Mountains, a west-trending projection or outlier of the San Juan Mountains, which rises abruptly from the mesa surface of the adjoining Colorado Plateaus province (fig. 2).

Altitudes in the San Miguel Mountains range from 14,246 feet at the summit of Mount Wilson to about 8,440 feet in the valley of the South Fork of the San Miguel River near the northeast corner of the quadrangle (pl. 1). Three peaks in the quadrangle exceed 14,000 feet in altitude—Mount Wilson, 14,246 feet; Wilson Peak, 14,017 feet; and an unnamed peak on the ridge south from Mount Wilson known locally as South Wilson, 14,110 feet. Scarcely less imposing is Gladstone Peak, 13,913 feet, which lis between Mount Wilson and Wilson Peak. At a somewhat lower altitude, and about 2 miles east of this impressive group of peaks, is the local landmark of Lizard Head, a nearly vertical rock spire which rises 300 feet from a conical base to an altitude of 13,113 feet (fig. 2).

The high mountains have been glaciated and display knife-edge ridges, cirques, and other glacial features.

South from the high peaks of the San Miguel Mountains the surface descends to the drainage of the Dolores River and its tributaries. The altitudes along this drainage range from a high of 10,222 feet at Lizard Head Pass to about 9,200 feet near the southwest corner of the quadrangle.

South and east of the Dolores River the surface rises to two prominences, Sheep and Flattop Mountains. Sheep Mountain and peaks on the ridge immediately to the east reach altitudes just over 13,000 feet. Flattop Mountain, as its name implies, is a broad, gently sloping surface which rises to a maximum altitude of 12,098 feet, just south of the quadrangle boundary.

CLIMATE

The area is characterized by short cool summers and long cold winters; heavy winter snows vary directly in amount with altitude (table 1). Savage Basin (alt 11,522 ft), about 12 miles northeast of the area and the closest place where records have been kept at high altitudes, has an average annual snowfall of 400 inches. May and June are the driest months and the time of melting snows, although much snow remains above timberline until July or August, and in a few places near Gladstone Peak and Mount Wilson permanent snowfields exist. In July and August early afternoon thunderstorms occur almost daily. September usually brings the first snows

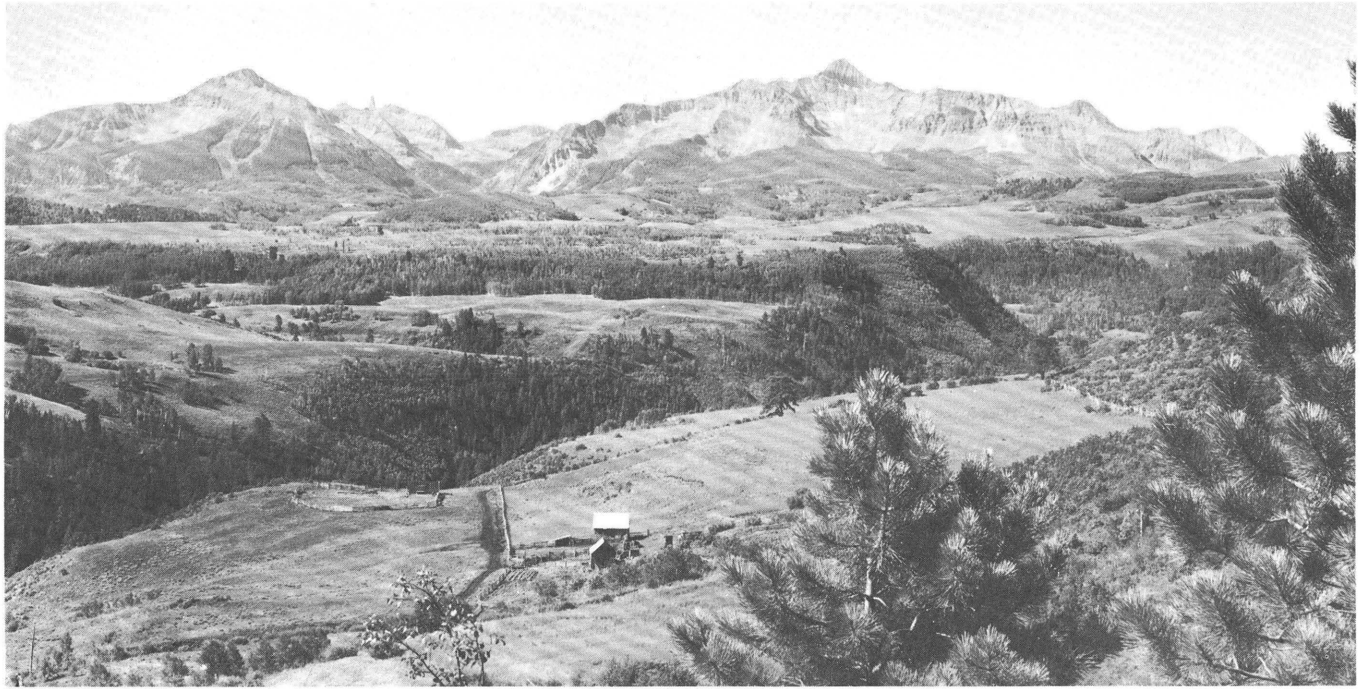

FIGURE 2.—North face of San Miguel Mountains, Mount Wilson quadrangle, as seen beyond dissected plateau in the Gray Head quadrangle. Dakota Sandstone (Upper Cretaceous) forms mesa rims, Mancos Shale (Upper Cretaceous) forms mesa surfaces and mountain slopes to slightly above timberline. Tertiary sedimentary, volcanic, and intrusive rocks form main mountain mass. Main peaks (left to right) are Sunshine Mountain (12,930 feet), the spire of Lizard Head (13,113 feet), and Wilson Peak (14,017 feet). Photograph by Whitman Cross.

to the high country, though these first snows may be followed by 4–6 weeks of beautiful clear crisp Indian summer weather before winter snows again cover the region.

TABLE 1.—*Precipitation and snowfall at stations in and near the Mount Wilson quadrangle*

[Data compiled from U.S. Weather Bur., 1933]

Place	Altitude (feet)	Years of record	Average annual precipitation (inches)	Average annual snowfall (inches)
Placerville	7,300	10	11.69	[1] 50
Ames	8,701	17	25.76	158.6
Trout Lake	9,800	17	30.03	213.7
Savage Basin	11,522	16	38.05	400.2

[1] Estimated.

VEGETATION

In the Mount Wilson quadrangle three life zones are represented: the montane (6,000 to 9,000 ft), the subalpine (9,000 to timberline at about 11,500 ft), and the alpine (above 11,500 ft). The montane zone, characterized by open ponderosa pine forest and aspen groves, is limited to areas along the South Fork of the San Miguel River in the northeast corner of the quadrangle and along the Dolores River in the southeast corner of the quadrangle. The subalpine zone, which includes much of the quadrangle, is characterized by forests of Engelmann's spruce and alpine fir interspersed with pleasant open grassy parks or meadows. Heavier forest growth on the north-facing slopes, together with considerable deadfall and soil cover, makes geologic interpretation there difficult. Timberline is between 11,000 and 11,500 feet. Here the trees are small, gnarled, and twisted to fantastic shapes by the high winds. Above timberline is the alpine zone, characterized by open meadows, especially in the mountain basins, in which grow grasses, sedges, and, in early summer, a profusion of delicate alpine wildflowers. Still higher, conditions for life grow more severe, and finally only bare rock sparsely covered with lichen is seen.

PREVIOUS INVESTIGATIONS

The first geological observations in the region of the Mount Wilson quadrangle were made by F. M. Endlich and W. H. Holmes, geologists with the U.S. Geographical and Geological Survey of the Territories under R. V. Hayden. Endlich visited the eastern part of the San Miguel Mountains in the summer of 1874, and Holmes, the famous artist-geologist, visited the western San Miguel Mountains briefly in the summer of 1876.

Endlich (1876), though he recognized some of the rocks in the mountains as igneous, did not differentiate between the intrusive and extrusive rocks. He called all the rocks trachytes and interpreted them as resting on horizontal sedimentary strata. He recognized the presence of Cretaceous strata, but he included in his "Cretaceous No. 1 unit" strata which later were assigned to the Jurassic. To the Permian and Triassic red beds below the Jurassic he assigned a Carboniferous age. His observations are largely of historic interest, because they were made hurriedly under conditions of hardship in an unexplored region.

Holmes approached the San Miguel Mountains from the west after having previously visited the El Late (now Ute) Mountains in southwest Colorado, the Abajo Mountains in Utah, and other isolated mountain groups on the Colorado Plateaus. Holmes (1877, 1878) had already recognized these mountains as centers of intrusion, and his written descriptions, sections, and matchless sketches show his grasp of their principal geologic features. His contemporary G. K. Gilbert (1877) at about the same time was developing the concept of the laccolith in the Henry Mountains to the northwest. Holmes (1878, p. 194), who recognized similar laccolithic features in the San Miguel Mountains, stated that "all that portion of the summits that rises above 12,000 feet is of trachyte underlaid by Cretaceous shales in a horizontal position."

Holmes examined the San Miguel Mountains rapidly and under difficult conditions; he failed to recognize the large Wilson Stock and the stock in the adjoining Dolores Peaks group just west of the Mount Wilson quadrangle (pl. 2).

In 1894, Cross and his coworkers began extensive studies in the San Juan Mountain region which resulted in a series of U.S. Geological Survey Atlas folios: Telluride (Cross and Purington, 1899); La Plata (Cross, Spencer, and Purington, 1899); Rico (Cross and Ransome, 1905); Silverton (Cross, Howe, and Ransome, 1905); Needle Mountains (Cross, Howe, Irving, and Emmons, 1905); Ouray (Cross, Howe, and Irving, 1907); and Engineer Mountain (Cross and Hole, 1910). These folios still form an essential first reference to an understanding of much of the geology of the San Juan Mountains. In them the broad outlines of the geologic framework of the region were established, and the sedimentary, metamorphic, and volcanic units were named and defined. The subdivision of the rock units was for the most part sound, and though in later years some units were modified and redefined, many of the names are currently in use in the San Juan Mountains and in southwest Colorado.

In the 15-minute Telluride folio (Cross and Purington, 1899), which includes all the area of the Mount Wilson quadrangle, Cross recognized the presence of an early Tertiary conglomerate between the Cretaceous shales and the overlying volcanic rocks; distinguished between extrusive and intrusive rocks; and interpreted the main intrusive mass of the eastern San Miguels as a stock rather than a laccolith. He also identified as diorite-monzonite the igneous rocks that form the Wilson Peak stock and its dual east-trending prongs, but noted that these bodies were petrographically more complex, ranging from granite to gabbro. He stated his belief that the rock types were transitional and thus not due to distinct intrusions but probably to original variation in the magma.

Larsen and Cross (1956), in a summary report on the geology and petrology of the San Juan Mountains region, discussed the San Miguel Mountains only in review of the earlier folio of Cross and Purington (1899).

PRESENT INVESTIGATION

Mapping in the Mount Wilson quadrangle was done by the U.S. Geological Survey as part of a larger project of mapping in the western San Juan Mountains. Reports have been published on the Placerville quadrangle (Bush and others, 1959) and the Little Cone quadrangle (Bush and others, 1960).

Some rock samples were collected during an initial reconnaissance of the area in August 1956. The area was mapped during parts of the summers of 1957, 1958, and 1959, and brief visits were made in the summers of 1960 and 1961 while the author was mapping in the adjacent Dolores Peaks quadrangle. In all, about 8 months were spent in the field. A. L. Bush shared in the work for 3 weeks in 1957 and for about 6 weeks in 1958. D. B. Brooks assisted for about 4 weeks in 1958, and A. L. Conroy assisted during the summer of 1959. Most of the work was done from camps established by means of pack horses.

Most of the geologic mapping was done on a topographic base at a scale of 1:20,000, though in some more detailed areas a scale of 1:12,000 was used. Aerial photographs were useful as a supplement to the topographic field sheets; both contact prints at a scale of 1:37,400 and two-times enlargements were available. A Short and Mason 16,000-foot altimeter was used in establishing locations.

The large scale employed in the present mapping allowed considerably more detail to be shown than is in the Telluride folio (Cross and Purington, 1899), which is at a scale of 1:62,500, but only a few revisions were made in the general geologic picture conveyed by the folio map. The most important revision concerns the summit of Mount Wilson and the ridge to the south which were originally mapped by Cross as part of the stock. It was found during the mapping that this area is composed of contact-metamorphosed Tertiary volcanic rocks. As a result, the name Mount Wilson stock as used by Cross (in Cross and Purington, 1899) seems inappropriate, and in this report it has been replaced by the term "Wilson Peak stock."

ACKNOWLEDGMENTS

The field investigations in the summer of 1958 were aided by Mr. Clarence E. Ross, packer, horse wrangler, and cook.

The author thanks Mr. Jack Montgomery for permission to examine the accessible workings of the San Bernardo mine, and Mr. Dan Hunter for permission to examine the accessible workings of the San Juan claims.

Analyses were made by P. L. D. Elmore, I. H. Barlow, S. D. Botts, and G. W. Chloe, of the U.S. Geological Survey. Ruth Willson of the Geological Survey compiled production data for the mines in the quadrangle.

GENERAL GEOLOGIC SETTING

The San Juan Mountains region of southwest Colorado, which covers several thousand square miles, is composed in large part of a vast volcanic pile of Tertiary age which overlies rocks ranging in age from Precambrian to Mesozoic. Intrusive into the volcanic pile and underlying rocks are several stocks and laccoliths of late Tertiary age; intrusive into the underlying rocks are several stocks and laccoliths whose age relations are uncertain.

The San Miguel Mountains, which project westward as a prong or outlier of the San Juan Mountains, are composed of several of these intrusive centers alined east-west (pl. 2). Within the Mount Wilson quadrangle are part or all of the Ophir stock, Black Face-Ames plutons, and the Wilson Peak stock; west of the quadrangle are the Dolores Peak stock and several laccoliths. Sedimentary rocks of Mesozoic and Tertiary age and overlying Tertiary volcanic rocks, though locally disturbed by intrusion, are not markedly domed as are those in the Rico Mountains intrusive center to the southwest (pl. 2), but are mostly flat-lying and marked by a general rise in strata south and southwest toward the Rico dome. The Flattop laccolith, in the south half of the quadrangle, is geologically a part of the Rico intrusive center rather than of the San Miguel Mountains. This laccolith, a large lenslike igneous mass, was intruded at or near the contact between the Dakota Sandstone and Mancos Shale (both Upper Cretaceous). Within the quadrangle erosion has removed the Tertiary volcanic and sedimentary rocks and left the Upper Cretaceous formations widely exposed.

STRATIGRAPHY

Sedimentary rocks aggregating approximately 5,000 feet in thickness and ranging in age from Late Triassic to Oligocene(?) crop out within the area. Overlying them is about 1,000 feet of middle and upper Tertiary volcanic tuffs, breccias, and flows. Various surficial deposits of Quaternary age—including talus, rock glaciers, landslide deposits, glacial deposits, and alluvium—locally cover the older rocks.

The oldest sedimentary unit exposed is the Upper Triassic Dolores Formation, which is found along the bottom of the valley of the Dolores River in the southwest corner of the area. The Dolores Formation is succeeded by Upper Jurassic units including the Entrada Sandstone, the Wanakah Formation, and the Morrison Formation. Locally the Morrison is overlain by the Lower Cretaceous Burro Canyon Formation which is apparently present only as local fillings of channels cut in the Morrison. In most places, however, the Morrison is overlain by the Upper Cretaceous Dakota Sandstone. The thick marine Upper Cretaceous Mancos Shale, the most widespread of the outcropping formations, overlies the Dakota. The Oligocene(?) Telluride Conglomerate overlies the Mancos Shale with a very slight angular unconformity; above it are the volcanic San Juan Formation and a part of the Silverton Volcanic Group, both of middle and late Tertiary age. The volcanic rocks are confined to the high ridges and are only remnants of a sequence that once was continuous with the thick San Juan volcanic pile just east of the mapped area.

The relation and relative thicknesses of the stratigraphic units are shown in the diagrammatic geologic column on plate 3.

There is no direct information on the thicknesses of older rocks of Paleozoic age which underlie the exposed formations within the quadrangle. Indirect information, based on exposures near Rico, 4 miles southwest of the quadrangle, and on the log of an oil test well at Placerville, 10 miles northwest, suggests a thickness of 5,000–6,000 feet of Paleozoic strata between the Dolores Formation and the Precambrian basement rocks. These concealed formations include, in descending order, the Permian Cutler Formation, Permian and Pennsylvanian Rico Formation, Pennsylvanian Molas Formation, Middle Pennsylvanian Hermosa Formation, Upper and Lower Mississippian Leadville Limestone, Upper Devonian Ouray Limestone and Elbert Formation, and Upper Cambrian Ignacio Quartzite.

TRIASSIC SYSTEM

UPPER TRIASSIC SERIES

DOLORES FORMATION

The Upper Triassic Dolores Formation, the oldest unit exposed within the quadrangle, crops out in the valley of the Dolores River in the southwest corner of the quadrangle and on Barlow Creek near the south edge of the area. The base of the formation is in subsurface, and the maximum thickness exposed within the quadrangle is about 300 feet, on the Dolores River near the west edge of the quadrangle. A short distance west of the quadrangle boundary the basal contact is present at the surface; there the total thickness of the formation ranges from 550 to perhaps 620 feet. This contrasts with a thickness of about 300 feet 17 miles northeast at Telluride, and compares with a maximum thickness of 580 feet northwest in the Placerville quadrangle (Bush and others, 1959, p. 317). These thicknesses indicate that the formation thickens west and southwest from the Telluride area.

The upper 300 feet or so of the Dolores Formation is characterized by a succession of prevailingly red sandstone and mudstone beds. These rocks compose the lower valley slopes of the Dolores River from near the junction of Coke Oven Creek southwest for several miles to where the formation rests upon the Permian Cutler Formation. The Cutler, though also red, is generally darker with a tendency to purple hues.

Sandstone of the Dolores Formation is very fine to fine grained, silty, and commonly calcareous. It is thin to medium bedded and exhibits slabby to flaggy parting; planar cross-stratified units are common. The sandstone weathers to form ledges, and as the silt content increases, it grades into sandy siltstone, which may be very massive but which weathers to rubbly slopes.

Limestone pebble conglomerates are a characteristic component of the lower part of the Dolores Formation in adjacent areas (Bush and others, 1959, p. 315). In a section of the Dolores Formation measured on the Dolores River about a mile west of the quadrangle, the limestone conglomerates were found to be characteristic of the

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lower 150 feet of the formation. They are sparse in the upper part of the formation and hence only a few beds 2 feet or less thick are exposed in the quadrangle. Typically these beds are composed of rounded and flattened pebbles of red silty limestone enclosed in a limy red siltstone matrix.

The contact of the Dolores Formation with the overlying Entrada Sandstone has been taken at the lowest horizon where coarse to very coarse grains of well-rounded and frosted quartz occur scattered in the typically fine- to medium-grained sandstone of the formation. The lowermost occurrence of these frosted grains, often referred to as Entrada "berries," does not usually correspond to the color break between the typical red hues of the Dolores Formation and the light color of the Entrada Sandstone. In the Mount Wilson quadrangle this color break occurs 60–90 feet below the mixed-grained sandstone, and is an undulating surface which crosscuts bedding.

JURASSIC SYSTEM

UPPER JURASSIC SERIES

ENTRADA SANDSTONE

The distribution of the Entrada Sandstone is almost identical to that of the underlying Dolores Formation. The Entrada occurs along the canyon slopes of the Dolores River and Barlow Creek in the southwest corner of the area. The formation is one of the most distinctive units in the region because it is massive and light colored, and commonly weathers to smoothly rounded forms. Inasmuch as the Entrada Sandstone is soft and friable, it generally is not well exposed; the only complete exposure in the quadrangle is on the north side of the Dolores River southwest of Coke Oven Creek. At this place the formation is about 100 feet thick, and this thickness is typical of the area. Along the San Miguel River north of the area the Entrada is 25–75 feet thick. To the south and west of the Mount Wilson quadrangle it thickens considerably; in the La Plata Mountains, for example, it is 100–275 feet thick.

The lower 20 feet or so of the Entrada Sandstone is a light-tan very fine grained sandstone which is thin to very thin bedded and contains some small-scale crossbeds. But for the presence of a few scattered frosted grains it is similar to the beds of the upper part of the Dolores Formation. It is succeeded upward by 80 feet of the massive nearly white sandstone so characteristic of the Entrada Sandstone in the western San Juan Mountains. This sandstone is friable and weathers to smooth rounded slopes that contain few parting planes. Large-scale crossbedding is common, and Entrada "berries" are concentrated in the plane of many of the individual cross-laminae. In places the upper 10–20 feet show thin even beds.

Where the Entrada is overlain by the Pony Express Limestone Member of the Wanakah Formation the upper contact is easily drawn, but where the Pony Express Limestone Member is absent and the Entrada is overlain by the Bilk Creek Sandstone Member of the Wanakah Formation the contact is somewhat subjectively determined. The sandstone of the Bilk Creek tends to have a higher clay content than that of the Entrada, and therefore the contact is usually put just above the uppermost clean sandstone.

WANAKAH FORMATION

Like the underlying Entrada Sandstone, the Wanakah Formation occurs only along the Dolores River and Barlow Creek. The formation is generally poorly exposed, though fair exposures may be seen in a few steep gullies on the west side of Barlow Creek. The Wanakah ranges from 80 to 145 feet in thickness and probably averages about 100 feet. It consists of three members: the Pony Express Limestone Member at the base, the Bilk Creek Sandstone Member, and a marl member at the top. Because the members are thin, they are not distinguished on the map.

PONY EXPRESS LIMESTONE MEMBER

The Pony Express Limestone Member is absent in all the exposures of the Wanakah Formation along the Dolores River west of the junction with Barlow Creek, but recent drilling has shown it to be present in subsurface along the Dolores River near and east of the junction with Slate Creek. A limy sandstone bed less than 1 foot thick overlies the Entrada Sandstone near the mouth of Barlow Creek and probably represents the Pony Express; on the west side of Barlow Creek at the south edge of the mapped area, 6 inches of typical dark-gray fetid Pony Express Limestone Member was noted in one outcrop. These observations suggest that the Pony Express thins westward from the Slate Creek area and probably pinches out near Barlow Creek. To the north, in the Gray Head quadrangle, the Pony Express is present along the valley of the San Miguel River, but it pinches out westward along the river in the Placerville quadrangle (Bush and others, 1959, p. 325). Projection between the Barlow Creek and San Miguel River areas suggests the general trend of the zero isopach is slightly west of north.

The Pony Express is found over an area of a thousand square miles in the west San Juan Mountains region, and, with relatively short gaps, it can be traced into and correlated with the Upper Jurassic Todilto Limestone of New Mexico.

BILK CREEK SANDSTONE MEMBER

Except locally where the Pony Express Limestone Member is present, the Bilk Creek Sandstone Member forms the base of the Wanakah Formation in the Mount Wilson quadrangle. It is a very fine grained light-yellow-brown sandstone 25–35 feet thick.

The Bilk Creek is somewhat finer grained and has a higher clay content than the underlying Entrada Sandstone. This distinction is not everywhere evident, but the zone of uncertainty is not more than a few feet. The Bilk Creek tends to be thin bedded with slabby parting, and, because it is soft and friable, it is rarely well exposed.

At the top of the member is a thin blocky remarkably persistent sandstone which was designated the "carnelian sandstone" by Cross (in Cross and Purington, 1899) because of characteristic small red chert grains in it. Though this sandstone bed is only 1–4 feet thick, it is present over several hundred square miles in the western San Juan Mountains region. The bed is fine grained to medium grained and contains coarse to very coarse well-rounded frosted quartz grains scattered throughout. Considerable gray to gray-green silt and clay occurs in the interstices.

The Bilk Creek Sandstone Member probably correlates with part of the Upper Jurassic Summerville Formation of the Colorado Plateau.

MARL MEMBER

Overlying the Bilk Creek Sandstone Member is a sequence of interbedded calcareous claystone, siltstone, and thin sandstone beds referred to the marl member of the Wanakah Formation. The sandstone, generally calcareous, is commonly light-yellow brown to pale-red brown and composed of very fine grained to medium grained subrounded to well-rounded quartz grains. The unit, characteristically thin bedded and easily weathered to form a slope, is seldom exposed, but it can be seen in part on the west side of Barlow Creek.

The member ranges in thickness from 70 feet on the south side of the Dolores River to 120 feet on Barlow Creek; the disparity in thickness within this relatively short distance may be due to an irregular contact with the overlying Salt Wash Sandstone Member of the Morrison Formation.

The marl member correlates with part of the Summerville Formation of the Colorado Plateau.

MORRISON FORMATION

The Morrison Formation is exposed along the bottom of the South Fork of the San Miguel River in the northeast corner of the area and along the valley of the Dolores River in the southwest corner of the area.

In this part of Colorado the Morrison Formation is divided into two members, the basal Salt Wash Sandstone and the overlying Brushy Basin Shale Members; both consist of sediments deposited in fluvial and lacustrine environments. The Salt Wash Sandstone Member is composed mostly of massive lenticular light-colored sandstone, whereas the Brushy Basin Shale Member is mostly variegated mudstone.

The thick sandstone units of the Salt Wash tend to form cliffs, separated by short slopes which reflect minor interbedded mudstone. The poorly exposed Brushy Basin Shale Member above it typically forms a long slope between the cliffs of the Salt Wash and the cliff and ledges of the Upper Cretaceous Dakota Sandstone above.

SALT WASH SANDSTONE MEMBER

The Salt Wash is characterized by thick massive lenticular light-colored, generally pale-yellowish-gray, fine- to medium-grained sandstone. The sandstone is commonly speckled by limonite flecks a millimeter or so in diameter that probably represent oxidized pyrite grains. The beds are cross-laminated with medium- to large-scale trough and planar crossbedding. Cut-and-fill structures are common. Flaggy to blocky splitting of the sandstone units is also characteristic.

Interbedded with the sandstone units and forming less than 25 percent of the member are mudstone and thin-bedded sandstone. The mudstone is red to red brown or shades of gray green. The proportion of mudstone increases near the top of the unit, and the contact with the Brushy Basin Shale Member is placed arbitrarily at the highest mappable sandstone of Salt Wash type.

The thickness of the Salt Wash can only be generalized because the contact with the Brushy Basin is imprecise and poorly exposed, and it varies with the pinching and swelling of sandstone lenses. The thickness is estimated to range from 340 to 420 feet.

BRUSHY BASIN SHALE MEMBER

The Brushy Basin is composed of dusky-red and grayish-green calcareous mudstone interbedded with lesser amounts of lenticular thin blocky very fine grained calcareous silty sandstone and with sparse red-brown limestone units less than 1 foot thick. The estimated thickness of the Brushy Basin is 324–400 feet.

The Brushy Basin Shale Member is generally overlain disconformably by the Upper Cretaceous Dakota Sandstone. Locally, however, channels cut into the upper surface of the Brushy Basin are filled with sandstone and conglomeratic sandstone of the Burro Canyon Formation of Early Cretaceous age.

CRETACEOUS SYSTEM

LOWER CRETACEOUS SERIES

BURRO CANYON FORMATION

A thin sandstone unit, present locally above the Brushy Basin Shale Member, is analogous both in its lithology and in its relations to the underlying formations to the Burro Canyon Formation as recognized in the Placerville and Little Cone quadrangles to the north (Bush and others, 1959, 1960), and is here correlated with that unit. The Burro Canyon fills shallow channels cut in the underlying Brushy Basin Shale Member, and its upper contact with the Dakota Sandstone is apparently concordant. The unit ranges in thickness from 0 to perhaps 40 feet in distances of a few hundred feet. Where the Burro Canyon is thickest, it is very massive and in places forms a sheer ledge beneath the cliff-forming basal sandstone of the Dakota.

The sandstone is light tan to nearly white on fresh fracture, weathers to shades of orange brown, and is composed of subangular to subrounded fine- to medium-grained quartz grains. White chert fragments are common and weathered feldspar grains are rare. The formation contains stringers or pods of quartz or chert granules and is conglomeratic in some places. It differs from the Dakota Sandstone in the absence of any carbonaceous material either interstitial to the sand grains or in mudstone seams. Sparse mudstone is gray green and resembles that in the Brushy Basin Shale Member.

Because the unit is thin and in places absent it is not differentiated on the map (pl. 1) but is included with the Brushy Basin.

UPPER CRETACEOUS SERIES

DAKOTA SANDSTONE

The Dakota Sandstone forms the rimrock along the major drainages in the area adjacent to the San Miguel Mountains and underlies wide areas of mesa or plateau country to the west. The major area of outcrop within the quadrangle is along the valley rims of the Dolores River and its tributaries. A smaller area of outcrop is near the forks of the San Miguel River, where the formation has been intruded by thick sills and irregular masses of igneous rocks. An isolated outcrop lies at the southern end of Trout Lake.

The Dakota Sandstone is resistant to erosion and, lying between two less resistant formations, tends to form ledges, usually with a cliff at the base formed by a massive basal sandstone unit.

The Dakota Sandstone is 150–200 feet thick in the area. It is composed of interbedded sandstone, carbonaceous siltstone and shale, and locally, thin coal beds. In general, the formation can be divided into three units: (1) The lowest is a 20- to 40-foot cliff-forming sandstone unit which is light gray to buff, fine grained to medium grained, and in part conglomeratic, containing lenses or stringers of quartz or chert granules and pebbles. At the base is usually a granule conglomerate of chert and quartz fragments in a fine- to medium-grained carbonaceous sandstone. The unit is thick bedded toward the base, thinner bedded at its top, and is generally characterized by large-scale low-angle trough crossbedding. The sandstone is friable in places and well indurated in others. (2) The middle unit is characterized by interbedded carbonaceous shale, siltstone, thin-bedded carbonaceous sandstone, and, locally, thin coal seams. Because of its large shale content, the unit tends to form a slope between the basal and upper units. (3) The upper unit is characterized by more sandstone and less shale than is in the middle unit. It contains dark-gray to buff rusty-weathering well-indurated, generally carbonaceous sandstone in beds 1–3 feet thick. The sandstone is interbedded with very thin bedded carbonaceous siltstone and shale. This unit forms a ledge-and-slope topography.

The contact of the Dakota Sandstone with the underlying Morrison Formation (or Burro Canyon) is a disconformity which is exposed at only a few places in this area. Variations in the thickness of the basal ledge of sandstone suggest that the disconformity has a relief of at least 5–10 feet. The Dakota Sandstone is usually regarded as chiefly a littoral deposit laid down as the Cretaceous sea first spread westward across the region.

The contact of the Dakota with the overlying Mancos Shale is conformable and apparently gradational. The Dakota is transitional upward into the Mancos Shale through a series of thin alternating sandstone beds and carbonaceous shale interbeds. For mapping purposes, the top of the uppermost mappable sand ledge was taken as the upper contact of the Dakota Sandstone. Experience indicates that this unit is not the same throughout the general area, but is probably within a 10- to 20-foot transition interval.

MANCOS SHALE

The Mancos Shale of Late Cretaceous age forms the bedrock surface over much of the area. The formation is composed of 1,500–2,500 feet of soft gray shale which is easily eroded and poorly exposed and which tends to form subdued forested slopes above the rimrock of the Dakota Sandstone (fig. 2).

The Mancos consists predominantly of black fissile shale which weathers dark to light gray. Though in a few places it may appear to be massive, everywhere it is very thinly laminated and breaks readily along the stratification planes. X-ray analyses of representative samples of the gray shale from this area show it to be largely a mixture of illite and chlorite clay material with lesser amounts of calcite and quartz. The shale is commonly slightly calcareous, and, locally, thin discontinuous dark-gray limy beds are present. These may be fossiliferous. Limy concretions as much as 3 feet in diameter are also found locally. These are generally dark gray or brownish gray on fresh fracture and weather yellowish brown. Most are septarian, traversed by a network of calcite veinlets.

The shale is locally somewhat sandy and in places it contains thin sandstone beds. About 1,500 feet above the base of the Mancos is a notably sandstone-rich zone, 50–100 feet thick, that consists of fine-grained to very fine grained light-brown to dark-gray carbonaceous sandstone which weathers tan to brown. The sandstone, which has slabby to platy parting and is interbedded with fissile gray shale and carbonaceous siltstone, is laminated and commonly is ripple marked.

Cross (in Cross and Purington, 1899) established the age of the Mancos Shale as Late Cretaceous. Marine fossils of Greenhorn, Carlile, Niobrara, and Pierre age are found in and immediately adjacent to the San Miguel Mountains (Cross and Purington, 1899; Bush and others, 1960).

The Mancos is overlain with slight angular unconformity by the Oligocene(?) Telluride Conglomerate. Within the San Miguel Mountains the contact with the Telluride is inclined gently eastward and gradually cuts down across Mancos Shale. As a result, though there is 2,500 feet of Mancos Shale a mile west of the quadrangle, at the east boundary there is only 1,500 feet. Erosion which preceded the Telluride Conglomerate removed an additional unknown but large thickness of Upper Cretaceous, and probably lower Tertiary sedimentary rocks. Near Durango, 35 miles to the south, several thousand feet of such strata is above the Mancos Shale. The nearest outcrops of any of the missing post-Mancos and pre-Telluride sedimentary rocks are 14 miles to the west where remnants of the Upper Cretaceous Mesaverde Group are preserved.

The fine-grained deposits of the Mancos Shale mark a major invasion of the sea in Late Cretaceous time. The sandy zone may reflect a minor and temporary regression.

TERTIARY SYSTEM

OLIGOCENE(?) SERIES

TELLURIDE CONGLOMERATE

Regionally in the western San Juan Mountains, the Telluride Conglomerate overlies a widespread unconformity of low relief and rests on rocks ranging from Precambrian to Late Cretaceous in age, but within the quadrangle it rests only on Mancos Shale. It is overlain by the volcanic rocks. The Telluride is generally exposed above timberline where it forms cliffs and ledges above the soft shale slopes of the Mancos (fig. 3). In the San Miguel Mountains it forms the ridges extending outward from the Wilson Peak stock, the slopes of Lizard Head, and the ridge north toward Sunshine Peak, and it caps San Bernardo Mountain northwest of Trout Lake; to the south it is found only on the slopes of Sheep Mountain in the southeast part of the quadrangle.

The Telluride is about 900–1,000 feet thick in much of the area, but in the vicinity of Lizard Head it is only 200–400 feet thick. This thinning is probably due to post-Telluride erosion.

The formation is made up of red to light-gray arkosic conglomerate, conglomeratic sandstone, sandstone, and lesser amounts of mudstone. The subangular to subrounded pebbles, cobbles, and boulders in the conglomerate include limestone, sandstone, and siltstone derived from a Mesozoic and Paleozoic terrane; quartzite, schist, and coarse-grained granites derived chiefly from a Precambrian terrane; and a gray feldspar porphyry of uncertain source. No volcanic rocks were found. Gravels probably derived from Precambrian rocks are dominant in the upper part of the formation.

FIGURE 3.—View southeast across Bilk Basin, from tarn lake at 12,600-foot altitude. Microgranogabbro in foreground at toe of snowfield; granodiorite makes blocky outcrops on far side of lake. In distance is spire of Lizard Head (13,113-ft alt), made up of rocks of the Silverton Volcanic Group, resting on tuff of San Juan Formation; cliffs at left end of ridge are of Telluride Conglomerate. Photograph by R. B. Taylor.

The unit was originally called the San Miguel Conglomerate (Cross, 1896a) but because this name was preempted, the formation was later called the Telluride Conglomerate (Cross, in Ransome, 1901). No fossils have been found in the formation either in this area or elsewhere in the San Juan Mountains, and though originally assigned an Eocene age (Cross, 1896a), it was later considered to be of Oligocene(?) age (Larsen and Cross, 1956). Van Houten (1957, p. 387) and Kelley (1957, p. 157–158), however, gave reasons for thinking the Telluride may be Eocene as originally suggested by Cross.

Even if the Telluride is of Eocene age, the unconformity between it and the Mancos Shale represents a substantial hiatus in the geologic record in the San Miguel Mountains. In the western San Juan region, as near Telluride, this unconformity is visibly angular, but within the quadrangle it shows no apparent discordance in local exposures, and appears only slightly angular when viewed from a distance. The surface of unconformity is almost planar, though irregularities of as much as 3–4 feet are seen locally.

The formation is interpreted as a fanglomerate deposited as an apron of gravel and sand in an area marginal to a broad domelike uplift that formed in the San Juan region in Laramide time.

MIDDLE AND UPPER TERTIARY

SAN JUAN FORMATION

Overlying the Telluride Conglomerate is the San Juan Formation, the oldest volcanic unit in the western part of the San Juan Mountains. Just to the east of the mapped area the formation is widely distributed, but only a few scattered erosion remnants are in the quadrangle and these together with remnants in the adjacent Dolores Peaks quadrangle are the westernmost exposures of the San Juan volcanic pile. In the San Miguel Mountains the formation is preserved only on the highest peaks and ridges immediately adjacent to the Wilson Peak stock, on the slopes of Lizard Head, and on Sunshine Peak to the north. To the southeast it occurs on Sheep Mountain. All the outcrops are above 12,000 feet altitude.

The San Juan Formation ranges widely in thickness in the mapped area because it was irregularly eroded before the succeeding Silverton Volcanic Group was deposited, but it is generally thinner than in areas to the east. South of Mount Wilson it is about 600 feet thick, and on Sheep Mountain it reaches a maximum of somewhat more than 750 feet. To the east in the adjacent Ophir quadrangle it is about 1,500 feet thick, and to the northeast, near Ouray, a maximum of more than 3,000 feet is recorded (Luedke and Burbank, 1962).

Although the rocks in the San Juan Formation are varied, they are of two general types. One is a poorly sorted laminated and thin- to medium-bedded tuffaceous sandstone or graywacke which in places is conglomeratic, containing angular volcanic pebbles. Some small-scale cross-lamination and channeling effects suggest deposition or reworking by water rather than direct subaerial deposition. The second type is a tuff breccia consisting of angular cobbles and boulders of volcanic rocks in a tuffaceous matrix. In many outcrops the contrast between fragments and matrix is indistinct. The volcanic fragments are largely porphyritic andesites and dark quartz latites which have plagioclase phenocrysts set in an aphanitic gray to purple or green groundmass. The breccia has no apparent bedding on the outcrop but from a distance it shows a vague but distinct layering.

The entire unit is generally propylitized (altered by epidote and chlorite). It is variable in color but characteristically is mottled in green, purple, and red hues.

No fossils have been found in the San Juan Formation and, in common with the other volcanic rocks, it has had various assignments based on roundabout correlations and inferences relating to older and younger formations. Cross (1896a) originally considered it Eocene in age, but later Cross and Larsen (1935) referred it to the Miocene(?). Kelley (1957) believed the San Juan may be Oligocene in age. In keeping with this uncertainty the age of the San Juan is now given as middle and late Tertiary (Luedke and Burbank, 1963). In places within the mapped area, an apparent gradational contact between the Telluride Conglomerate and the San Juan suggests that no time break intervened between the two formations. Excellent exposures of gradational contacts can be seen on the east slopes of Mount Wilson and on the west slopes of Sheep Mountain. Elsewhere, however, as on the slopes of Lizard Head, a pronounced erosion surface separates the Telluride and the San Juan, and the Telluride is thinned on the ridge leading west from Lizard Head. This relation is similar to that at Ouray, where Luedke and Burbank (1962) noted a strong erosion surface at the base of the San Juan Formation. Cross (in Cross and others, 1907, p. 7) also noted erosion locally at this contact but concluded that in most places the contact was conformable. In the Silverton area he noted (in Cross and others, 1905, p. 5) a transition and concluded that there the process of deposition was practically continuous, although marked by a sudden change to predominantly volcanic debris.

SILVERTON VOLCANIC GROUP

Volcanic rocks of the Silverton Volcanic Group are found as erosion remnants in two small areas within the quadrangle, on Lizard Head and on Mount Wilson and nearby ridges. As with the San Juan Formation, these outcrops are among the westernmost exposures of the San Juan volcanic pile. The Mount Wilson area is adjacent to the stock, and the original character of the volcanic rocks has been masked by contact metamorphism. The Silverton is best observed near Lizard Head.

On Lizard Head the Silverton Volcanic Group is composed of several distinct lithologic units. At the base is 200–400 feet of lithic crystal tuff which is succeeded upward by 10–30 feet of tuff breccia that is similar in appearance to the tuff breccia in the San Juan Formation. The breccia forms the base of the Lizard Head spire. Above this, and forming most of the spire, are at least five thin flows of porphyritic pyroxene andesite which aggregate about 250 feet in thickness. Forming the extreme tip of the Lizard Head spire is a fourth unit which was not sampled in place, but blocks presumed to have fallen from the tip suggest that Lizard Head is capped by a unit similar to the thin tuff breccia at the base of the spire.

The lithic crystal tuff has a platy structure, is pink to buff, and contains perhaps 5–20 percent phenocrysts of small feldspar and bronzy biotite grains together with angular dark volcanic fragments. The microscope shows the feldspar to be plagioclase in euhedral to subhedral crystals and in broken fragments. The composition of the plagioclase could not be determined because of alteration of the individual grains. The fragmented crystals and angular lithic fragments are set in a glassy matrix in which shard structure is discernible. In some sections the shard structure in the matrix appears to be molded around phenocrysts—a feature that suggests flowage or compression and indicates some welding.

The thin flows of porphyritic pyroxene andesite are dark gray on fresh fracture and weather to shades of brown. Conspicuous in hand specimen are lath-shaped plagioclase phenocrysts, as much as 1 cm long, which form 20–30 percent of the rock, and scattered smaller mafic grains. In thin section the plagioclase phenocrysts are found to be labradorite and the mafic grains clinopyroxene. Mafic grains of a pyramidal habit now entirely altered to serpentine may have been olivine. The phenocrysts are set in a pilotaxitic groundmass of plagioclase microlites (labradorite-andesine?). No quartz or potassic feldspar was noted. The rocks are tentatively classed as pyroxene andesite, and may be as mafic as basaltic andesite.

Like the San Juan Formation, the Silverton Volcanic Group has been assigned various ages. It was assigned to the Oligocene or early Miocene by Cross (1905), to the Miocene by Cross and Larsen (1935), and by Larsen and Cross (1956), and to the Oligocene or early Miocene by Burbank (1930). It is now assigned to the middle and late Tertiary (Luedke and Burbank, 1963).

QUATERNARY SYSTEM

PLEISTOCENE SERIES

GLACIAL DEPOSITS

During Pleistocene time the San Juan Mountains were extensively glaciated. Atwood and Mather (1932) differentiated three major glacial stages which they designated from oldest to youngest as the Cerro, Durango, and Wisconsin stages. Richmond (1954) restudied the glacial deposits on the east fork of Dallas Creek west of Ridgway on the north side of the San Juan Mountains and correlated them with the glaciations in the Wind River Mountains of Wyoming which have become a standard for correlation in the Rocky Mountains. He concluded that the Durango on Dallas Creek is of early Wisconsin age and correlative with the Bull Lake Glaciation of Wyoming and that the Wisconsin of Atwood and Mather is of late Wisconsin age and correlative with the Pinedale Glaciation of Wyoming. Further, he found that each of the Durango and Wisconsin till deposits of Atwood and Mather represents two glacial advances. Richmond (1965) later restudied the glacial gravel at Durango and concluded that the type Durango consists of moraines of Bull Lake and pre-Bull Lake age.

In the Mount Wilson quadrangle only two Pleistocene glacial units were distinguished in mapping. The older unit includes undifferentiated drift probably of both early Wisconsin (Bull Lake) and pre-Wisconsin age (pre-Bull Lake or Cerro of Atwood and Mather, 1932). The younger unit is probably of late Wisconsin (Pinedale) age.

UNDIFFERENTIATED OLDER DRIFT

The glaciations of early Wisconsin (Bull Lake) and pre-Wisconsin age were more extensive than the glaciation of late Wisconsin age. The pre-Wisconsin glaciers were piedmont glaciers and were the most extensive recognized in the San Juan Mountains; they covered the lowlands adjacent to the mountains and in places moved considerable distances from the mountains. In general, the deposits of the pre-Wisconsin glaciers do not appear to be closely related to present-day valleys.

Undifferentiated older drift is found in scattered patches from Lizard Head Pass west to the intersection of Snow Spur Creek with the Dolores River, and in fairly large morainal gravel caps and a few small patches on either side of Slate Creek. Two small patches of drift which cap the ridge above an altitude of 11,200 feet about a mile west of Slate Creek are also shown as undifferentiated drift. These consist principally of subangular pebbles and cobbles of Telluride Conglomerate, San Juan Formation, metamorphosed Mancos Shale, and intrusive and extrusive igneous rocks common to the nearby San Miguel Mountains. Boulders as much as 3 feet in diameter are present. This gravel is apparently unrelated to the present valleys, and may be a remnant of pre-Wisconsin glacial deposits.

The two extensive areas of undifferentiated drift found on either side of Slate Creek appear to be related in their distribution to the drainage pattern of Slate Creek, and are thought to be principally of early Wisconsin (Bull Lake) age, though possibly they include pre-Wisconsin drift in their higher parts. The drift on the west side of Slate Creek is a blanketlike deposit that extends from altitudes of nearly 11,000 feet down to 10,200 feet and in places is nearly a mile wide. It tails off westward into a few scattered patches of drift which extend a short way beyond the quadrangle boundary. Southwest and south of this drift, as at the abandoned sawmill at 10,200 feet near the west edge of the mapped area, glacial grooving and polishing were observed on Dakota Sandstone surfaces. Erratics of Telluride Conglomerate and stock rocks, some as much as 15 feet in largest dimension, are scattered over the area underlain by Dakota Sandstone beyond the mapped areas of drift.

The drift bodies on both sides of Slate Creek lack morainal form except locally near the creek, where hummocky topography and segments of morainal ridges are present. The drift is composed of subangular to subround cobbles and boulders of Telluride Conglomerate, San Juan Formation, and the various stock rocks from the San Miguel Mountains. The drift on the north side of the Dolores River between Snow Spur and Slate Creeks also had the same source as indicated by conspicuous boulders of granodiorite, typical of the

Wilson Peak stock, some of which are as much as 8 feet long. Spruce forest covers these slopes, and exposures are poor.

Areas of undifferentiated drift from Lizard Head Pass southwestward along Snow Spur Creek are probably of Bull Lake age and were derived from a glacier that pushed southwest over Lizard Head Pass from the Lake Fork drainage. The drift is composed of a poorly sorted mixture ranging from clay size to boulders 2–3 feet in diameter. The boulders are subangular to subround, and a few show polished and striated surfaces. Diagnostic of the source is a quartz monzonitic rock typical of the Grizzly Peak stock exposed in the cirques at the head of the Lake Fork drainage; also abundant are gravel of Telluride Conglomerate, San Juan Formation, sandstone (Dakota?), and a miscellany of less abundant rock types.

LATE WISCONSIN DRIFT

Late Wisconsin glaciers (Pinedale) in the San Miguel Mountains and San Juan region were of the alpine or valley glacier type. The distribution of glacial drift and grooves and the presence of cirques, tarn lakes, and other features common to alpine glaciation indicate that glaciers occupied, and were virtually confined to, the principal valleys in the area. The largest glacier in the area rose in the catchment area among the high peaks 3 miles southeast of Trout Lake and extended down the Lake Fork of the San Miguel River to its junction with a glacier occupying the Howard Fork. A glacier in the Slate Creek drainage extended from the cirques down to an altitude of at least 10,200 feet.

Late Wisconsin moraines are well preserved. Two late Wisconsin terminal moraines are in the valley of Lake Fork near the San Bernardo mine, and several subparallel lateral moraines are just west of Trout Lake (pl. 1). Well-preserved late Wisconsin lateral moraines are also along both sides of Slate Creek (pl. 1).

The late Wisconsin morainal deposits appear less weathered than those included in undifferentiated drift. The gravels reflect their source areas; those of Slate Creek contain abundant granodiorite and other igneous rocks of the Wilson Peak stock, whereas those of the Lake Fork contain Grizzly Peak quartz monzonite. Both also include the Telluride Conglomerate, San Juan Formation, and volcanic rocks. Along Slate Creek the late Wisconsin drift is distinguished from the older undifferentiated drifts by a greater abundance of stock rock fragments.

PLEISTOCENE AND RECENT SERIES

LANDSLIDE DEPOSITS

Extensive landslide deposits occur within the quadrangle. Hummocky boulder-strewn topography is characteristic of the landslide areas, though in general the forms are too small to show at the scale of the topographic map. Undrained depressions, unorganized drainage, and small lakes and stagnant ponds are common.

The time of origin of the landslides probably ranges from Pleistocene to the present, but no attempt was made in mapping to separate landslides on the basis of their age. Most of the slides presumably originated during and immediately after Pleistocene glaciation when the rocks were saturated with moisture and the ice support was removed from the valley sides. In many places movement has continued intermittently to the present.

The landslides of the Telluride quadrangle (which includes the area of the Mount Wilson quadrangle) were discussed in considerable detail by Cross (in Cross and Purington, 1899), by Howe (1909), and, more briefly, by Hole (1912), who also discussed the problem of differentiating landslide deposits from glacial deposits.

The Sheep Mountain landslide at the west foot of Sheep Mountain is interesting because of the presence of large blocks of rocks from the Silverton and Potosi Volcanic Groups, units no longer present on the slopes above. The nearest exposures of these rocks are at altitudes of 13,500 feet near San Miguel Peak 2 miles east of the slide. According to Cross (in Cross and Purington, 1899, p. 11), "This block shows that at the time of its fall the Potosi series extended out along the crest from San Miguel to Sheep Mountain." It is inferred that about 200 feet of the Silverton Volcanic Group, several hundred feet of the San Juan Formation, and an unknown but appreciable thickness of Potosi have been eroded from Sheep Mountain since the origin of this landslide. The fact that the landslide lies near the base of the steep slope of Sheep Mountain implies that there has been only a minor amount of slope retreat and also that the topography at the time of the initial fall must have been even more rugged than it is today.

The landslide mass that intersects Slate Creek at an altitude of about 10,800 feet (pl. 1) contains such large blocks or bodies of rock that it was initially mapped as rock in place. It is composed of Mancos Shale near the base and overlying large masses of Telluride Conglomerate, San Juan Formation, and possibly blocks of the Silverton Volcanic Group. The distribution of the various kinds of

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rocks within the slide is shown on plate 1. The area is one of poor exposures, covered for the most part with spruce forest. Attitudes taken on scattered exposures in the block of Telluride Conglomerate are fairly consistent but are anomalous with respect to those of other rocks such as the San Juan Formation and Silverton Volcanic Group. A zone of steeply dipping to overturned bedrock which passes through this area (see p. 66 and pl. 1) is not reflected in the attitudes within the slide. This fact, together with the inconsistency of position and attitude between formations and the presence of some hummocky topography and undrained depressions, suggests that the area is a landslide mass.

The area of landslide in the northeast corner of the quadrangle (pl. 1) is a part of the Silver Mountain landslide (Cross and Purington, 1899, p. 11; Howe, 1909). This landslide, probably one of the largest known in North America, is 4–5 miles long and 2–2½ miles wide, and covers an area of about 10 square miles. The foot of the landslide is at an altitude of about 8,400 feet along the Lake Fork of the San Miguel River and the landslide extends upward to an altitude of more than 11,000 feet about 1 mile east of the quadrangle boundary. Within the quadrangle, blocks of Telluride Conglomerate and San Juan Formation are more than 1,500 feet beneath their outcrops just east of the quadrangle. Glacial drift, probably correlative with that of late Wisconsin age, has been deposited on the preexisting landslide and in turn has been involved in postglacial slumping.

The area of landslide just east of Trout Lake is the foot of the Yellow Mountain landslide (Cross and Purington, 1899, p. 11; Howe, 1909). This slide, similar in composition and relations to the Silver Mountain slide, extends to the east of the quadrangle and covers an area of about 3–4 square miles.

Both Cross (in Cross and Purington, 1899, p. 10) and Howe (1909) thought that the largest landslides of the region were attributable to the inability of the soft plastic Mancos Shale to support the heavy loads of the overlying permeable Telluride Conglomerate and massive volcanic rocks and that these physical conditions, together with the bold topography, were the inherent causes of most of the major landslides in the western San Juan Mountains. Most of the landslides of the quadrangle are explained by these factors. Analogous conditions controlled the slide on the northeast flank of Flattop Mountain where clayey beds of the Brushy Basin Shale Member of the Morrison Formation underlie the Dakota Sandstone and massive igneous rocks.

Howe (1909, p. 45) believed that structural conditions played little or no part in the San Juan Mountains landslides. However, I believe that the San Juan monoclinal fold (p. 64 and pl. 2) was an important factor in the localization of the unusually large Silver Mountain and Yellow Mountain landslides. These two slides are distributed over the axis of this monoclinal fold, which is parallel to and dips westward from the mountain front. In this area the nearly horizontal Telluride Conglomerate and overlying massive volcanic rocks rested on a beveled surface cut over westward-dipping Mancos Shale and older rocks, and thus the inherent instability of the shale was here accentuated by the structural conditions. Similarly, the Slate Creek slide probably resulted in part from the structural conditions associated with the zone of steeply dipping bedrock which passes under and near the slide area.

RECENT SERIES

ROCK GLACIERS AND OTHER GLACIAL DEPOSITS

Richmond (1954) found evidence in the cirques for two glacial advances of Recent age in the Dallas Creek area on the north side of the San Juan Mòuntains. Deposits of the older advance include small moraines and old rock glaciers which support scrub spruce and grassy tundra on a thin weakly developed soil. The deposits of the younger advance are rock glaciers which have no soil and which support, at most, only lichen growth.

A small moraine that consists chiefly of granodiorite boulders and extends from about 11,240 to 11,400 feet on th ridge east from Gladstone Peak is correlated with the Recent glacial advances. A hummocky accumulation of boulders, predominantly of Telluride Conglomerate and subordinately of San Juan Formation, at the foot of the cirque north of Wilson Peak probably is mostly of Recent glacial origin, but it may be partly of landslide origin.

Rock glaciers are common in the San Juan Mountains region. Within the quadrangle, six rock glaciers are present in the area of the San Miguel Mountains and three in the Sheep Mountain area. They have been mapped separately from talus accumulations because they are distinctive features that differ in origin from the talus. The rock glaciers are accumulations of unsorted angular blocks and boulders which show more or less transverse concentric ridges at their distal ends and longitudinal ridges parallel to their length. This evidence of mass flowage, whether rapid or slow, distinguishes the rock glaciers from talus.

Some of the nine rock glaciers in the mapped area have their upper ends in cirques as high as 13,000 feet and some extend downward in narrow tonguelike form to as low as 10,000 feet. Individual rock glaciers have a vertical range of from 600 to 1,400 feet and lengths in the direction of flow ranging from 2,000 to 4,000 feet. These rock glaciers are in north-facing basins (pl. 1), with the exception of the rock glaciers in Slate Basin, just under Gladstone Peak, but even this one heads in a northeast-facing cirque in the shadow of Mount Wilson.

Several theories have been presented regarding the origin of rock glaciers. Wahrhaftig and Cox (1959, p. 383) concluded that rock glaciers in Alaska result from flow of interstitial ice and that they require a nearly glacial climate. Brown (1925) considered a rock stream in Hurricane Basin several miles southeast of Ouray, Colo., to be a fossil glacier. He reported that a mine tunnel driven headward from the toe of the rock glacier crossed through rock debris, then through rock mixed with ice, and, finally, near bedrock, through clean ice. Howe (1909) and Atwood and Mather (1932, p. 163) considered rock glaciers in the San Juan Mountains to represent landslides of a special character in which, according to Howe, "* * * the falling rock mass has been completely broken into debris, which has acquired a momentum sufficient to transform it into a rapidly flowing body. Thus the rock fragments have descended in a streamlike form far beyond the normal limit of a landslide." Richmond (1954, p. 615) considered rock glaciers in the San Juan Mountains to represent deposits associated with a late Recent glacial episode lasting from about A.D. 1640 to 1860; he did not specify mode of formation. In the Mount Wilson quadrangle the association of rock glaciers with north-facing cirques and the evidence of mass flowage seem better explained by slow movement caused by interstitial ice rather than by mass landslides.

TALUS

Talus deposits cover many of the steep slopes below the precipitous cirque walls on the high peaks. The larger areas of talus are shown on the geologic maps because locally they effectively conceal geologic bedrock contacts. Small areas and thin veneers of talus are generally not shown.

The talus consists of angular fragments of rock ranging in diameter from an inch to several feet. In several places talus extends in an unbroken smooth slope more than 1,000 feet from the bedrock outcrops above to the basins below. In many places the talus approaches a maximum angle of repose of about 35°, and at such angles it is very unstable.

ALLUVIUM

Recent alluvium has been mapped along the valley of the South Fork of the San Miguel River, at the south end of Trout Lake where the Lake Fork empties into the lake, on Slate Creek, and along the valley of the Dolores River. In the South Fork the alluvium probably ranges in thickness from a few feet to several tens of feet. Along some of the minor streams narrow strips of gravel occur, but these are generally too small to be shown at the scale of the map. Alluvial fans near the mouths of a few streams have been included with alluvium in mapping.

INTRUSIVE ROCKS

The intrusive bodies of the Mount Wilson quadrangle make up some of the major geologic features of the area (pl. 1). The major intrusive bodies are the Flattop laccolith, the Wilson Peak stock, the Black Face-Ames plutons, and part of the Ophir stock. In addition there are dikes, sills, and small irregular bodies which are especially numerous near the major intrusive masses.

In naming the igneous rocks the quantitative classification of Johannsen (1939) is followed with the exception that no suggestion as to the intrusive or extrusive origin of a rock is implied in the name given to it.

FLATTOP LACCOLITH

MONZONITE PORPHYRY

Monzonite porphyry occurs principally as a laccolith that underlies Flattop Mountain south and west of the Dolores River and east of Barlow Creek along the south boundary of the Mount Wilson quadrangle (pl. 1). The laccolith is well exposed in bold cliffs overlooking Barlow Creek. It occupies a crudely subcircular area of a little more than 6 square miles, of which somewhat more than half lies within the quadrangle. The maximum preserved thickness of the laccolith is a little more than 1,000 feet at the south edge of the area, and the original thickness was probably not much more than 1,200 feet. The laccolith tapers abruptly from its apex, and, to the north and east across the Dolores River, it dwindles to a sill of monzonite porphyry which averages 80 feet in thickness; these features suggest that the original areal extent was not much greater than now visible. As seen in cross section *C–C′* (pl. 1), the shape of the intrusive closely approaches the lenticular form of the ideal laccolith.

Several sills of nearly identical monzonite porphyry in the Mancos Shale east of the laccolith near the north and south forks in Twin Creek were probably intruded at the same time as the laccolith.

The monzonite porphyry is a distinctly porphyritic rock containing abundant phenocrysts of whitish feldspar and sparser phenocrysts of biotite; the phenocrysts average 1–3 mm in maximum diameter and are set in a medium-gray groundmass that is nearly or very aphanitic. Hornblende is identifiable in some specimens. Small pyrite grains are ubiquitous through the monzonite porphyry.

Under the microscope the feldspar phenocrysts, for the most part andesine, are seen to be altered to sericite and clay minerals. Some potassic feldspar is also present as phenocrysts. Biotite is the most common ferromagnesian mineral but colorless clinopyroxene is also abundant. Original hornblende occurs in minor amounts and is largely altered to chlorite and other secondary products. The groundmass is a microgranular aggregate of potassic feldspar, plagioclase, and minor quartz.

The proportions of quartz, potassic feldspar, and plagioclase could not be determined because of the fine-grained groundmass and pervasive alteration. This rock was classed as diorite porphyry by Cross (in Cross and Purington, 1899), and was later called monzonite porphyry (Cross and Ransome, 1905; Cross and Hole, 1910). Although chemical analysis might show the rock to be a grandiorite, the name monzonite porphyry is retained in this report.

BLACK FACE-AMES PLUTONS

The Black Face-Ames plutons are composed of granodiorite porphyry. The Black Face pluton is an elongate east-west-trending body southeast of the Wilson Peak stock. The Ames pluton, east of the stock and in contact with it, forms a narrow outcrop which crosses the northeast part of the area. Near the east margin of the mapped area, the Black Face and Ames plutons are very nearly joined in outcrop, and probably connect in subsurface (pl. 1). The Ames pluton crops out as a spectacular cliff just west of Ames, and in this area it takes the form of a sill which is as much as 800 feet thick. Along the west side of the South and Lake Forks of the San Miguel River, a thin sill of porphyritic rhyodacite lies partly upon and partly beneath the main mass of the Ames sill, forming in effect a composite sill. The rhyodacite sill continues north of the Ames pluton as a sill in the Dakota Sandstone. It is generally about 80 feet thick but in places is as much as 150 feet thick. Because the thin rhyodacite sill is extensively altered and has been split and dilated by the thick sill of granodiorite porphyry west of Ames, it is interpreted as being somewhat older than the granodiorite sill.

Locally, as on the summit of Black Face and along the abandoned railroad bed south of Ames, the granodiorite porphyry contains swarms of inclusions, principally of Precambrian rocks.

PORPHYRITIC RHYODACITE

Where freshest, the porphyry rhyodacite is a dark-gray-green fine-grained to aphanitic rock in which are scattered abundant hornblende phenocrysts as much as 3 mm long. The altered facies, which is more common, is typically a light-colored to pink mass of sericite and clay minerals in which the original minerals are no longer identifiable except as remnant outlines.

The fresh rock under the microscope shows phenocrysts of plagioclase and hornblende constituting about 25 percent of the section. The plagioclase occurs as subhedral to euhedral crystals averaging about 1 mm in diameter. The crystals show oscillatory zoning; the cores are clacic andesine and range outward to calcic oligoclase. The mafic phenocrysts are common hornblende occurring as subhedral prismatic crystals which range from 1 to 3 mm in length. The groundmass, which makes up about 75 percent of the rock, is a microcrystalline aggregate of potassic feldspar, plagioclase, and subordinate quartz. The rock probably is similar to the granodiorite porphyry in composition, and it is here classed as a porphyritic rhyodacite.

In the altered rock the plagioclase phenocrysts are replaced by sericite and clay minerals, and the ferromagnesian phenocrysts—probably originally hornblende—are altered to calcite. The groundmass, originally a microcrystalline aggregate of plagioclase, potassic feldspar, and quartz, is altered to sericite, iron oxides, calcite, and clay minerals.

GRANODIORITE PORPHYRY

The granodiorite porphyry is similar in appearance throughout the Black Face-Ames plutons. The typical rock is medium to dark gray on fresh fracture and is characteristically flecked with conspicuous dark ferromagnesian grains. The texture is everywhere porphyritic. Through increase in the coarseness of the groundmass, many specimens are seriate porphyritic (fig. 4*A*), whereas in others the contrast between phenocrysts and groundmass is more distinct and the rock is more nearly a true porphyry (fig. 4*B*).

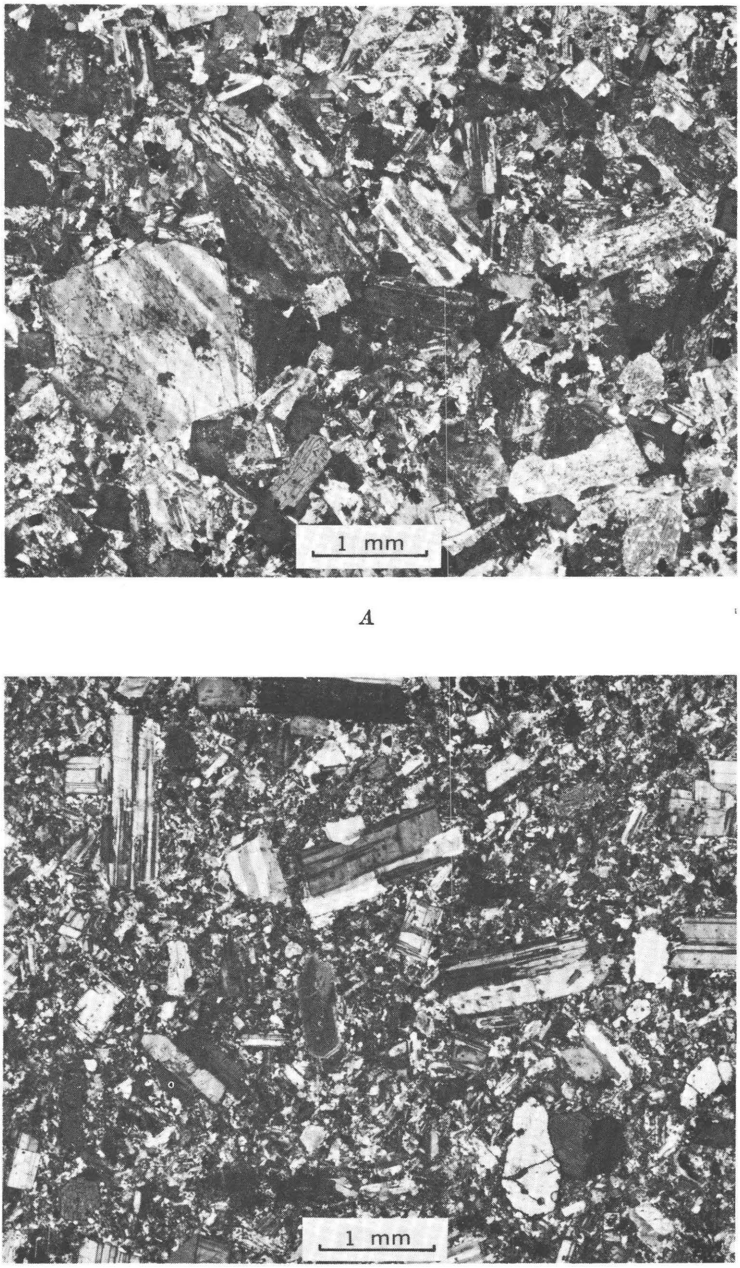


FIGURE 4.—Photomicrographs of granodiorite porphyry. *A*, Seriate texture; *B*, porphyritic texture. Photographs by R. B. Taylor.

Phenocrysts of plagioclase and mafic minerals which range from 0.5 to 3.0 mm are set in a groundmass of plagioclase, potassic feldspar, and quartz which ranges from 0.01 to 0.2 mm in grain size. The plagioclase, the most abundant of the phenocrysts, is generally euhedral, and in thin section it is shown to have oscillatory normal zoning with cores of An_{50} ranging out to An_{15} at the rims. In average it probably is an andesine. Plagioclase in the groundmass is subhedral to euhedral and is similar to that in the phenocrysts in zoning and composition.

The mafic phenocrysts consist of clinopyroxene, hornblende, and rarely orthopyroxene. The clinopyroxene is a colorless augite and occurs in euhedral to subhedral grains. Commonly it exhibits a glomeroporphyritic habit. The hornblende, which is in subhedral grains, is pleochroic from very pale brown to reddish brown and in some sections shows a reaction rim of biotite and small grains of colorless pyroxene.

No reliable modes were obtained because of the fineness of the groundmass.

INCLUSIONS

The granodiorite porphyry of the Black-Face-Ames plutons contains abundant inclusions in two zones or areas, one south and southeast of Ames and the other on the summit of Black Face (pl. 1). Elsewhere inclusions are scant.

The zone of inclusions near Ames is strikingly exposed in cuts along the abandoned narrow-gage railroad grade at the tight switchback known as the Ophir Loop just south of Ames. The zone of inclusions is exposed discontinuously over a distance of half a mile along the lower segment of the switchback; in part of this distance, inclusions make up nearly half the exposure. Identical inclusions are found about 1 mile south in a small exposure of granodiorite porphyry in the river bottom west of the San Bernardo mine (pl. 1) and at the base of the granodiorite porphyry outcrop on the west side of the river opposite Ophir Loop. Because the area between these three localities is covered by glacial drift, continuity of the inclusion zone between these outcrops is uncertain.

The inclusions range in diameter from less than 1 foot to perhaps 15 feet, but most are 1–2 feet across. They are predominantly angular to subangular, and have sharp knife-edge contacts with the granodiorite prophyry country rock that indicate little or no reaction with the original melt. Cross (in Cross and Purington, 1899) described these inclusions in detail. The most abundant rock type is an amphibolite with a distinct foliation; it consists of nearly equal proportions of amphibole and labradorite which are segregated in rods or lenses that give the rock a spotted or streaked appearance. This type of rock gives way by increase of hornblende or feldspar to rocks of nearly pure hornblende or pure labradorite. Cross (in Cross and Purington, 1899) listed other rock types as follows: (1) aplitic granite porphyry, (2) gneissoid granite, (3) banded granite gneiss, (4) mica granite gneiss, (5) various gneisses, (6) hornblende diorite, (7) diorite rich in magnetite, (8) banded rocks rich in augite, hornblende, or biotite, and (9) schistose rocks made up mostly of hornblende. In addition to these I also noted crumpled phyllitic rocks, some of which contain quartz stringers that show ptygmatic folding. In a count of about 50 inclusions in a line along the railroad cut, just over half were of the spotted amphibolite, and most of the remainder were dark rocks of types listed above. Only one was a granitic type.

In contrast, the inclusions in the granodiorite porphyry on the summit of Black Face are predominantly silicic rocks—granite, aplitic granite, gneiss, and pegmatitic granite together with scattered xenoliths of quartzite and rare biotite schist. Amphibolite and other mafic rocks of the types so conspicuous near Ames are absent. The fragments, which are subangular, range in diameter from a few inches to 20 feet. The inclusions are confined to the ridge area and extend downward from the crest only a few tens of feet, and hence evidently were concentrated just under the roof of the Black Face intrusive mass.

The inclusions in both the Ames and the Black Face localities were evidently derived from rocks in the Precambrian basement, which in this area is probably a minimum of 6,000 feet below present outcrops. Similar inclusions are rare outside the two areas described. A few xenoliths identical to some at Ames were found in the granodiorite porphyry on Bilk Creek near the 10,000-foot contour.

WILSON PEAK AND OPHIR STOCKS

The Wilson Peak stock forms Wilson Peak, Gladstone Peak, and the north slopes of Mount Wilson, and it underlies a large part of the mountain spurs and basins which surround these peaks. It is exposed through a vertical range of 4,000 feet and underlies an area of about 5 square miles, of which about 3 square miles are within the quadrangle. The stock is composite and is composed of microgranogabbro, granodiorite, and porphyritic adamellite, intruded in that order.

The Ophir stock, on the northeast border of the quadrangle, continues eastward and underlies 2–3 square miles, of which less than 1 square mile is within the quadrangle. Within the quadrangle the stock is composed principally of microgranogabbro, though in the vicinity of the San Juan claims (Matterhorn drifts of pl. 1) it is adamellite. The Ophir stock is probably also composite, though the adamellite was not mapped separately.

In the area between the two stocks, smaller irregular granodiorite masses are exposed along Wilson Creek, on the north slope of San Bernardo Mountain, and, in still smaller outcrops, on the east slope of Sunshine Mountain.

MICROGRANOGABBRO

Rocks here classed as microgranogabbro form the earliest intrusion of the composite Wilson Peak stock; they form a mass of irregular shape which crops out principally across the north part of the stock, especially at Wilson Peak and in Silver Pick Basin. Just to the west of Silver Pick Basin near Polar Peak in the adjacent Dolores Peaks quadrangle the microgranogabbro is absent, and to the east it thins to a narrow arm which finally disappears near Bilk Creek. On the south side of the stock on the north slope of Mount Wilson, microgranogabbro is found as a thin sliver between the granodiorite and the country rock, and in Bilk Basin a more extensive exposure lies peripheral to the granodiorite. Microgranogabbro also makes up most of the part of the Ophir stock that lies within the quadrangle on the east side of the Lake Fork.

The contacts of the microgranogabbro with the country rocks are sharp, discordant, and steeply dipping. In places the intrusive rock has fed sills and irregular dikelike masses out into the country rocks. Most of the sills and dikes are less than 20 feet thick.

The typical microgranogabbro is a medium-dark-gray to medium-light-gray granular rock with an average grain size of less than 1 mm. Thus the prefix "micro-" is used in the sense of Hatch and Wells (1949, p. 212) for a rock with average grain size less than 1 mm. For the most part the rock is massive, but in a few places where hornblende is common near contacts with the country rocks, alinement of hornblende prisms parallel to the contacts can be seen.

The modes of representative sections are given in table 2, and they are plotted on figure 5. Under the microscope the rock shows hypidiomorphic granular texture (fig. 6) and is seen to consist of about 50–68 percent plagioclase, 5–16 percent orthoclase, 6–15 percent quartz, and 15–25 percent mafic minerals.

The plagioclase shows oscillatory normal zoning with crystals ranging from An_{65} at the cores to mantles of about An_{35}. It is dif-

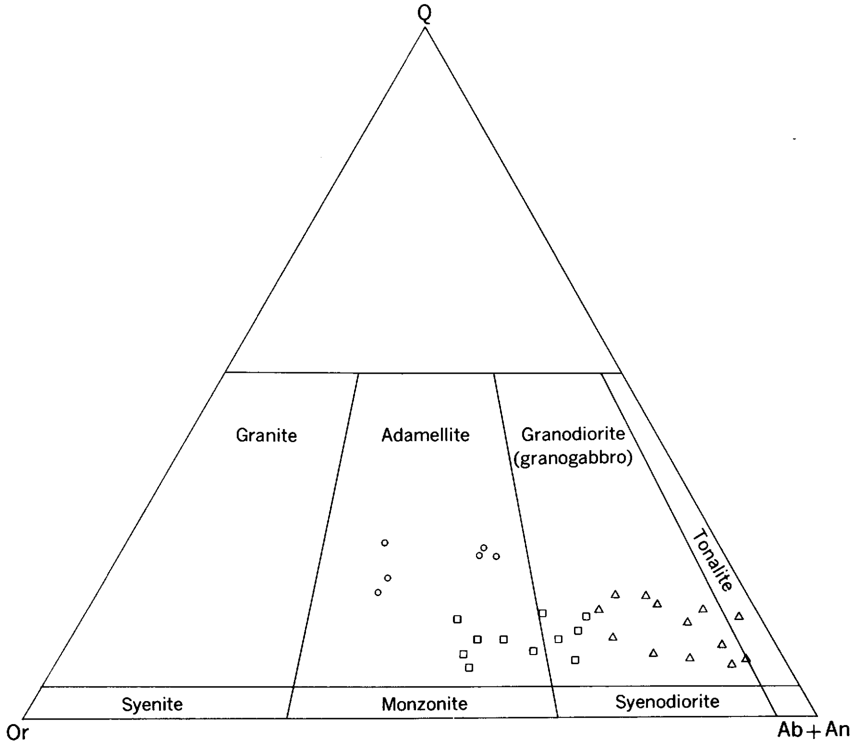
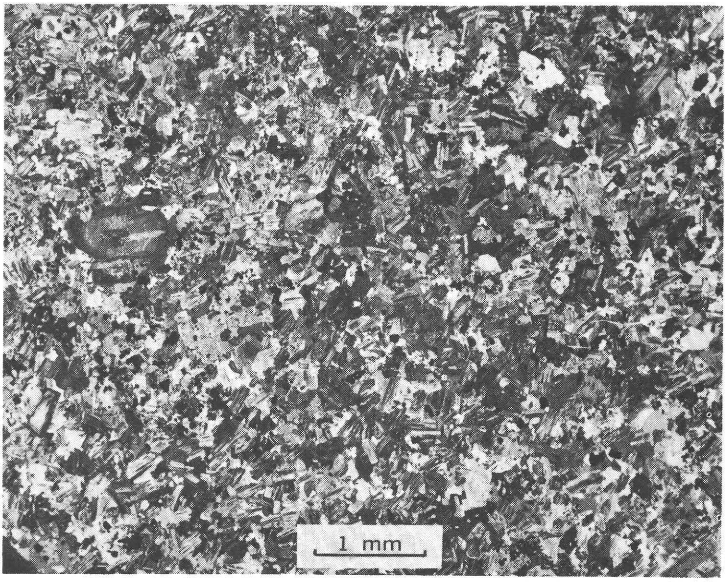


FIGURE 5.—Modal compositions of rocks of the Wilson Peak stock plotted on a Johannsen diagram. Triangles are microgranogabbro; squares, granodiorite; circles, porphyritic adamellite.

ficult to determine an average composition for the plagioclase, but several somewhat unsatisfactory values based on the areas of the zones in single crystals yielded results near An_{50}. The mineral occurs in fairly well formed crystals and is twinned according to both Carlsbad and albite laws. Potassic feldspar and quartz form anhedral grains which are interstitial to the plagioclase.

Mafic minerals include varying proportions of clinopyroxene, sparse orthopyroxene, biotite, and hornblende. Clinopyroxene or biotite may be dominant and lesser amounts of hornblende are usually present, generally as mantles over pyroxene. The accessory minerals are chiefly magnetite and apatite.

The microgranogabbro modes as plotted on the quartz-orthoclase-plagioclase diagram are rather variable (fig. 5). The plotted points lie generally in the granodiorite field of Johannsen, but as suggested by Johannsen (1932) the rock is called granogabbro because of the generally high anorthite content of the plagioclase. In some of the



A

B

FIGURE 6.—Contrasting microtextures of microgranogabbro (*A*) and granodiorite (*B*). Crossed nicols. Photographs by R. B. Taylor.

TABLE 2.—*Modes of microgranogabbro*

Field No.—	CSB-121-58	CSB-74-58	CP-11-54	CSB-71-56	CSB 90-58	CSB-59-56	CSB-73-56	CSB-36-60	CSB-4-60	CSB-2-60	ARC-44-59	CSB-120-58	CSB-96-56
Quartz	11.5	13.7	6.4	14.8	15.0	6.7	6.8	12.5	7	9	9.3	11	11
Potassic feldspar	5.1	9.7	11.9	14.0	10.2	3.7	5.6	16.2	9	5	16.0	8	2
Plagioclase	57.3	55.8	54.3	54.0	56.0	66.2	68.2	50.5	57	62	52.0	61	53
Biotite	9.5	9.8	3.4	4.8	3.6	10.4	<1.0	4.8	1	10	8.3	6	11
Hornblende	4.9	2.2	----	2.8	8.6	7.7	<1.0	<1.0	2	8	2.8	6	----
Pyroxene	[1] 7.8	5.3	[2] 12.1	[3] 5.3	1.2	<1.0	12.3	8.8	10	3	8.8	6	[4] 15
Magnetite	3.7	2.7	4.8	2.8	1.0	4.7	3.5	4.0	6	2	4.3	3	7
Accessory minerals [5]	<1.0	<1.0	<1.0	<1.0	<1.0	----	<1.0	<1.0	<1	<1	<1.0	<1	<1
Alteration products [6]	<1.0	<1.0	3.0	1.4	4.2	----	3.0	2.0	10	2	1.0	----	1

[1] Includes 1 percent hypersthene.
[2] Includes 4 percent hypersthene.
[3] Includes <1 percent hypersthene.
[4] Includes 3 percent hypersthene.
[5] Chiefly apatite.
[6] Chlorite, uralite, epidote, and sericite.

rocks the average plagioclase may be somewhat more sodic than An_{50}, and thus the rocks might be more properly designated as microgranodiorite. A few rocks may be considered quartz diorite, and some authors using a 10-percent quartz boundary would class others of these rocks as diorite or syenodiorite.

GRANODIORITE

Granodiorite crops out over about 2 square miles within the stock and is well exposed at Gladstone Peak. Other principal outcrops are in Bilk Basin and on the north-facing slopes of Mount Wilson. A narrow arm of the granodiorite extends to the east across Bilk Creek to the west side of Sunshine Mountain, and a small intrusive mass cuts the north slope of San Bernardo Mountain and the valley of Wilson Creek.

The intrusion of the granodiorite followed the intrusion of the microgranogabbro. Contacts between the two rock types are sharp (fig. 7); in places granodiorite veinlets and dikes cut the micro-

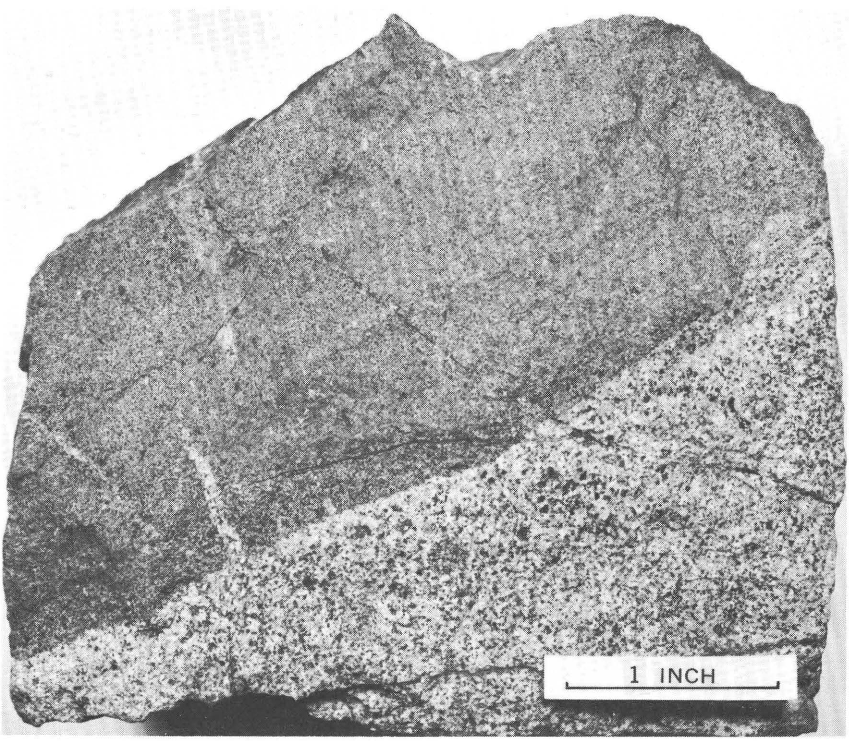


FIGURE 7.—Hand specimen showing sharp intrusive contact between microgranogabbro (above) and granodiorite. Note dikelet of granodiorite cutting microgranogabbro.

granogabbro, and, near the contact, fragments of microgranogabbro are enclosed in granodiorite. The contacts of the granodiorite with the bedded rocks are steep, discordant, and sharp.

The granodiorite is medium grained (fig. 6), it has an average grain size of 1–2 mm, and is generally medium gray to light gray, flecked with darker mafic grains. In most exposures the rock is massive; rarely, as in Navajo Basin west of the quadrangle, contorted vertical flow banding is seen.

The modes of representative granodiorite samples are listed in table 3 and are plotted on figure 5. As seen in thin section, the granodiorite has hypidiomorphic granular texture and contains about 35–50 percent potassic feldspar, 6–12 percent quartz, and 15–25 percent mafic minerals.

Plagioclase, the principal constituent, is always in excess of potassic feldspar, the ratio of Pl:Or ranging from approximately 3:1 to nearly 1:1. The plagioclase shows moderate oscillatory normal zoning with cores of An_{45-50} to outer shells of approximately An_{35}. The average composition is in the andesine range. Albite and Carlsbad-albite twinning are common, and pericline twinning also occurs. In many sections, subhedral crystals of plagioclase are included poikilitically in large ragged grains of potassic feldspar (fig. 8) and commonly show boundaries corroded by potassic feldspar. These relations suggest a late-stage introduction and active attack by potassic feldspar, which is a perthitic orthoclase. Quartz occurs as small anhedral grains interstitial to the plagioclase. Potassic feldspar and quartz usually appear to have mutual boundaries.

Mafic minerals include clinopyroxene, hornblende, and biotite, and all three are found in most specimens of granodiorite. In some rocks the dominant mafic mineral is clinopyroxene, in others hornblende, and in a few biotite. Rarely orthopyroxene is found.

The clinopyroxene is a colorless augite which occurs in euhedral to subhedral grains which commonly show basal or malacolite parting parallel to 001. The pyroxene is commonly mantled by hornblende (fig. 9*A*) and in some rocks is replaced by hornblende in a patchy pattern (fig. 9*B*). Hornblende also occurs as distinct euhedral to subhedral grains. Some hornblende shows patchy coloration that arises from slight differences in orientation and hence in pleochroism between adjacent areas; the difference in extinction angles between the separate areas is about 2°–3°. The hornblende is pleochroic from very pale brown to olive green. Biotite is pleochroic in shades ranging from straw yellow to dark reddish brown. It is

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TABLE 3.—*Modes of granodiorite*

Field No.—	CSB-61-56	CSB-57-56	CSB-53-56	CSB-75-58	CSB-56-56	CSB-49-56	CSB-77-56	CSB-31-58	CSB-130-58	CSB-35-60
Quartz	11.9	8.2	8.8	9.3	8.4	6.3	6.1	11.8	7.6	11.5
K-feldspar	17.1	24.6	28.0	17.0	19.2	18.2	30.1	29.3	30.1	19.8
Plagioclase	50.3	45.6	38.8	43.4	44.0	45.5	38.6	35.2	37.2	40.3
Biotite	5.8	6.4	5.8	9.3	4.8	2.6	5.4	6.7	7.4	3.5
Hornblende	1.2	8.6	5.8	6.8	<1.0	1.2	8.7	9.5	8.6	----
Pyroxene	8.0	3.2	6.8	[1] 8.5	9.8	14.1	[2] 6.9	[5] 5.3	[2] 6.1	12.7
Magnetite	2.6	1.8	3.2	3.4	4.8	2.5	3.5	1.8	2.5	3.7
Accessory minerals [3]	<1.0	<1.0	<1.0	<1.0	1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Alteration products [4]	<1.0	1.4	2.6	1.9	8.0	6.9	<1.0	----	----	8.5

[1] <1 percent hypersthene.
[2] Hypersthene present.
[3] Chiefly apatite, sphene.
[4] Chlorite, uralite, epidote, sericite.

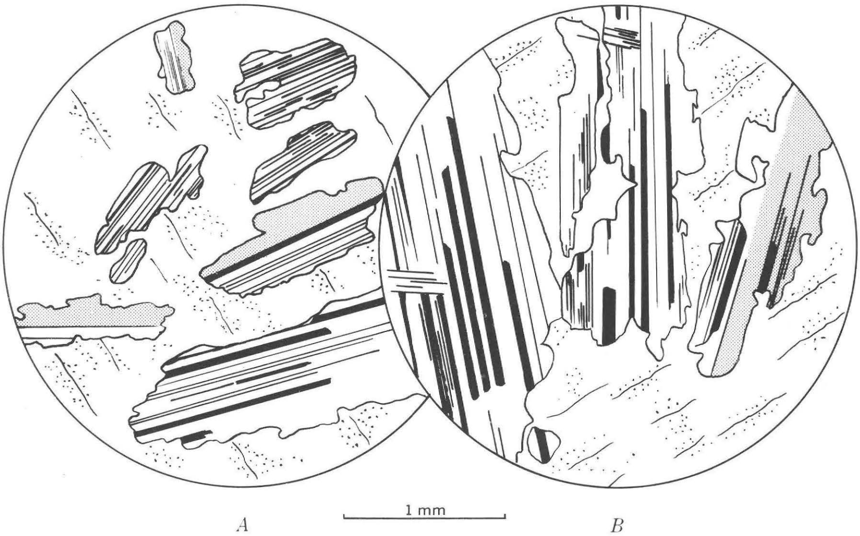

FIGURE 8.—Orthoclase poikilitically enclosing plagioclase and corroding it. *A*, granodiorite from Silver Pick Basin at 12,800-foot altitude; *B*, granodiorite from east side of Gladstone Peak at 13,080-foot altitude.

commonly anhedral and intersertal when surrounded by plagioclase crystals, but tends to be idiomorphic toward quartz and potassic feldspar.

A rock of this type does not fit readily into standard petrologic nomenclature. Figure 5 shows that the modes of granodiorite specimens from the Wilson Peak stock fall within the granodiorite and adamellite fields as defined by Johannsen (1939). Many petrologists use a 10-percent quartz (volume percent of rock) content as a dividing line between adamellite and monzonite, and, similarly, between granodiorite and its quartz-poor equivalents variously called syenodiorite, mangerite, or diorite. (See, for example, the summary of current classifications in Peterson, 1961.) In such schemes the granodiorite of the Wilson Peak stock would overlap monzonite adamellite, diorite (or syenodiorite), and granodiorite fields. Any name chosen for this rock, then, has to be applied arbitrarily unless an unwieldy compound name is used. The rock is called a granodiorite in this paper, and may be further characterized as a quartz-poor pyroxene granodiorite.

PORPHYRITIC ADAMELLITE

Porphyritic adamellite is the youngest rock within the Wilson Peak stock and occurs only in the central part of the stock. It

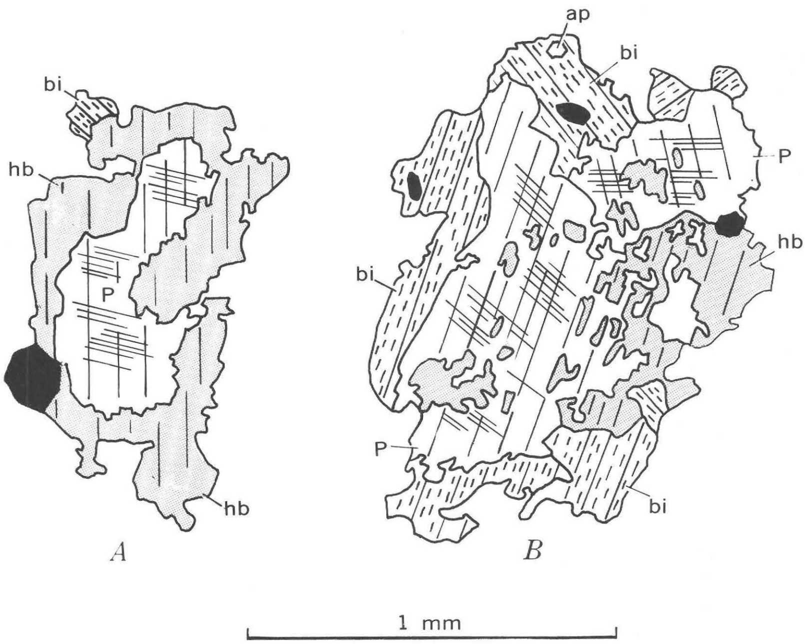

FIGURE 9.—Camera lucida drawing of ferromagnesian grains from the granodiorite. *A*, Clinopyroxene (*p*) replaced by hornblende (*hb*) which occurs as an overgrowth surrounding a clinopyroxene core; black grains are magnetite. *B*, clinopyroxene replaced in a patchy manner by hornblende; biotite (*bi*) occurs as overgrowths; apatite grains indicated by *ap*. In both *A* and *B* hornblende grows parallel to structural orientation of clinopyroxene.

intrudes the granodiorite in Navajo Basin and in Bilk Basin and intrudes the microgranogabbro in Silver Pick Basin (pl. 1). The contacts are generally sharp; small dikes and veinlets of the adamellite locally intrude the granodiorite (fig. 10).

The adamellite is a medium-grained massive rock characterized by potassic feldspar phenocrysts which average about 1 cm in length. The phenocrysts make up 20–30 percent of the rock in some places, and 10 percent or less in others. The groundmass averages about 2 mm in grain size. In general the rock is light gray to very light gray, and is distinctly lighter colored than the granodiorite or microgranogabbro. The lighter tone is in part due to coarser grain size and in part to a smaller content of mafic minerals.

The adamellite groundmass is composed of plagioclase, potassic feldspar, quartz, and varying though small amounts of hornblende and biotite. In some sections clinopyroxene is present in small amounts, but in most sections it is absent.

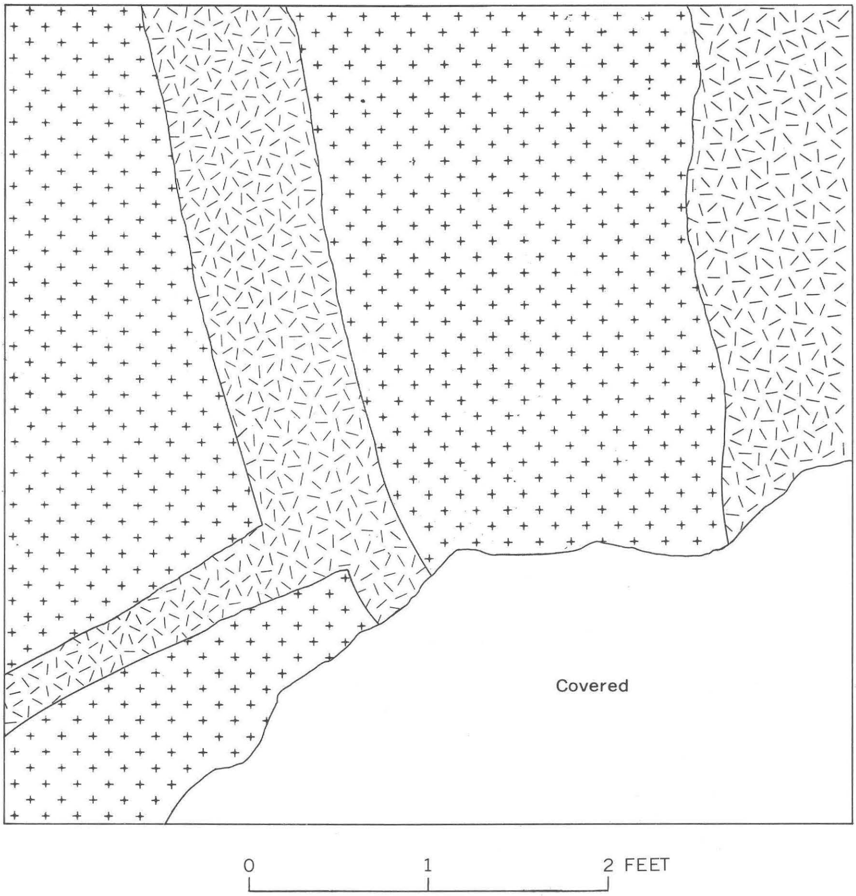

FIGURE 10.—Sketch of sharp contacts between porphyritic adamellite and granodiorite in Bilk Basin at about 13,000-foot altitude. Porphyritic adamellite (random dash pattern) forms dikes in granodiorite (crosses).

The modes of representative adamellite specimens are given in table 4, and the modal composition of quartz, potassic feldspar, and plagioclase is plotted on figure 5. As seen in thin section, the rock has a hypidiomorphic granular texture and consists of about 28–40 percent plagioclase, 28–40 percent potassic feldspar, about 20 percent quartz, and 5–8 percent mafic minerals. The sections giving the highest values for potassic feldspar (about 40 percent) contain several phenocrysts, and probably are not representative of the average rock.

The plagioclase, a sodic andesine having an average of about An_{35}, is subhedral and shows moderate oscillatory normal zoning.

TABLE 4.—*Modes of porphyritic adamellite*

Field No.	CSB-6-54	CSB-78-56	CSB-125-58	CSB-126-58	CSB-76-58	CSB-124-58
Quartz	23.2	17.6	21.3	22.8	21.6	19.2
K-feldspar	37.3	41.7	26.4	27.6	28.6	40.5
Plagioclase	28.7	31.8	43.0	41.8	40.3	31.8
Biotite	2.9	3.6	2.9	2.2	4.0	2.6
Hornblende	2.1	2.7	3.1	2.4	2.4	3.8
Clinopyroxene	------	------	<1.0	<1.0	1.2	<1.0
Magnetite	1.7	1.0	1.0	1.0	1.7	1.6
Accessory minerals [1]	1.4	<1.0	<1.0	<1.0	<1.0	<1.0
Alteration products [2]	2.7	<1.0	<1.0	<1.0	<1.0	<1.0

[1] Chiefly apatite, sphene, zircon.
[2] Chlorite, epidote, fibrous amphibole, uralite.

The potassic feldspar of both the groundmass and phenocrysts is perthitic. The phenocrysts tend to assume euhedral outline, but under the microscope the margins of individual crystals are commonly very ragged (fig. 11). Inclusions in the phenocrysts are of small quartz, plagioclase, and biotite grains. Groundmass potassic feldspar is anhedral and is interstitial to the plagioclase. Quartz is interstitial to plagioclase and the size of the individual grains is smaller.

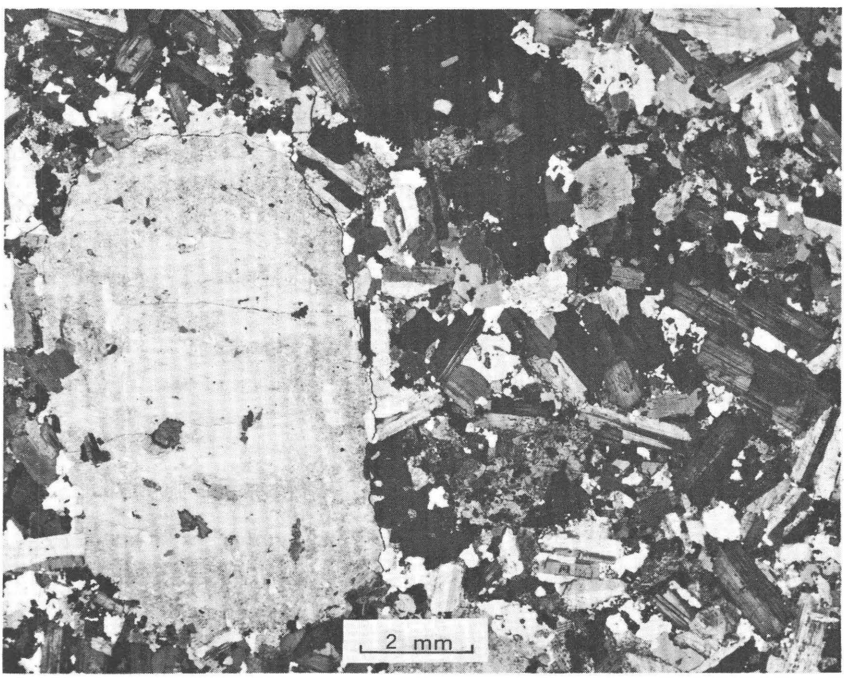

FIGURE 11.—Porphyritic adamellite, crossed nicols. Note large phenocryst of potassic feldspar enclosing smaller plagioclase, biotite, and quartz grains. Photograph by R. B. Taylor.

Mafic minerals are chiefly hornblende and biotite; clinopyroxene is found only rarely. The hornblende is pleochroic from light yellow brown to olive green and grass green. It may form subhedral to euhedral crystals against quartz and potassic feldspar. Biotite is pleochroic from straw yellow to deep brown. It is idiomorphic against quartz and potassic feldspar and may form euhedral outlines when enclosed solely by those minerals, but it tends to mold itself about plagioclase crystal outlines. The common accessory minerals are magnetite, sphene, and apatite.

AGE OF THE MAJOR INTRUSIVE ROCKS

The Wilson Peak stock intrudes the Oligocene(?) Telluride Conglomerate and the middle and upper Tertiary San Juan Formation and Silverton Volcanic Group, and thus is younger than these units. The relations are well exposed at several places in the vicinity of both Mount Wilson and Wilson Peak. To the east of the quadrangle, the Ophir stock intrudes the San Juan Formation and, though evidence of its relations to the Silverton Volcanic Group has been destroyed by erosion, it is probably younger than that group, as is the Wilson Peak stock. The intrusive relations of the Wilson Peak and Ophir stocks to the volcanic rocks are paralleled by several intrusive masses in the western San Juan Mountains—the Stony Mountain stock (Dings, 1941), the Sultan Mountain stock (Cross, Howe, and Ransome, 1905), and the Grizzly Peak stock (Cross and Purington, 1899) all pierce the middle and upper Tertiary volcanic rocks.

The Black Face-Ames plutons intrude rocks as young as the Telluride Conglomerate, but are not found in contact with the volcanic rocks. From the fact that a fold in the country rock thought to be related to the intrusion of the Black Face granodiorite porphyry is truncated by the Mount Wilson stock (p. 140), it is inferred that the Black Face pluton is older than the stock. However, the contacts between granodiorite porphyry of the Black Face-Ames plutons and the microgranogabbro of the stock south of Ames suggest liquid mixing along their mutual contacts, and it is inferred that the Black Face-Ames plutons, though somewhat earlier, were followed very shortly by the earliest phase of the stock intrusions. If this inference is correct, then the Black Face-Ames plutons are also of middle and late Tertiary age.

The age of the monzonite porphyry of the Flattop laccolith to the south cannot be closely fixed. The youngest formation intruded by the monzonite porphyry is the Upper Cretaceous Mancos Shale. A Late Cretaceous or Paleocene laccolith and stock is known at Ouray 20 miles to the northwest (Burbank, 1930, p. 201). The intrusive rocks of the Rico area, of which the Flattop laccolith is one, were considered by Cross (in Cross and Ransome, 1905, p. 11) to be most likely similar in age to the mid-Tertiary intrusive rocks of the western San Juan Mountains. The age was inferred from his conclusion that the Rico dome to which the igneous rocks are related was not truncated by the peneplain on which the Telluride Conglomerate was deposited, and, therefore, the dome and the intrusive rocks were post-Telluride in age. Cross based his argument on the observation that Blackhawk Peak (alt 12,677 feet) in the Rico area is 600 feet higher than the base of the Telluride near Mount Wilson 10 miles to the north and that there is no trace of this peneplain in the Rico area. Such high peaks, he reasoned, would have been truncated had the Rico dome been of Late Cretaceous or Paleocene age. However, just east of the mapped area the basal Telluride contact is at 11,000 feet, at Mount Wilson it is at about 12,000 feet, and west of the quadrangle on the ridges west of Mount Wilson it is at 12,400 feet; thus it is possible that in the Rico area 10 miles south of Mount Wilson the contact was higher than the altitude of Blackhawk Peak. From the evidence available within the quadrangle and adjacent areas it appears equally possible that the Flattop laccolith is Late Cretaceous to Paleocene (Laramide) or middle to late Tertiary in age.

MINOR INTRUSIVE ROCKS

LATITE

Just west of Trout Lake, along the road over Lizard Head Pass, a small mass of intrusive rock cuts the Mancos Shale. The body is about 300 feet wide and extends northeast for about 900 feet and then necks down to a narrow dike which continues a bit farther to the northeast. It is composed of an altered green to gray-green weathering porphyry which in hand specimen shows phenocrysts of plagioclase and bronzy biotite set in a dense groundmass.

In thin section the rock is seen to be too fine grained and too altered to allow precise classification, but it is here called latite. Most of the small white phenocrysts of feldspar are plagioclase showing ghosts of original Carlsbad and albite twinning although they are largely altered to sericite and clay minerals. Some phenocrysts may have been of potassic feldspar. Biotite, the common dark mineral, is fairly fresh and forms leaves which are alined parallel to a conspicuous fluidal texture. Pyroxene phenocrysts now completely altered to carbonate are suggested by the presence of hexagonal cross sections. The cryptocrystalline groundmass contains numerous plagioclase microlites.

DIKES AND SILLS OF INTERMEDIATE COMPOSITION

Numerous dikes, sills, and small irregular intrusive bodies are clustered near the main intrusive mass. This spatial association suggests close genetic relationship between the minor satellite intrusive rocks and the stock.

The dikes range in width from less than a foot to about 50 feet, but most dikes are probably 5–20 feet, and thus are somewhat exaggerated on the map. Most dikes dip steeply.

The most conspicuous group of dikes in the area is in a zone ½–1 mile wide which extends east-northeastward from the ridges south and southwest of Mount Wilson, across Bilk Basin, and thence across the ridges between Lizard Head and Sunshine Mountain, a distance of 5 miles within the quadrangle. The zone continues westward in the adjacent Dolores Peaks quadrangle, where the dikes increase in number up to a small stock about a mile west of the quadrangle boundary. Individual dikes in the zone are less than a mile long; some are exposed through a vertical range of about 1,500 feet.

The dike zone does not appear related to any obvious structural grain in the surface rock, and, in fact, near Cross Mountain it cuts without deflection across a major fold in the sedimentary rocks (see p. 66 and pl. 4). The zone may reflect the orientation of a former magma chamber at depth.

Sills are not abundant within the quadrangle. A few are found in Bilk Basin, on Cross Mountain, on the east and north of Flattop Mountain. Most of the sills are in the Mancos Shale.

Most of the dikes, sills, and small irregular intrusive bodies are of intermediate composition. They include rocks of various textures ranging from nearly aphanitic, with only a few scattered phenocrysts of plagioclase and mafic minerals, to markedly porphyritic, with phenocrysts predominating over groundmass. Specific classification of individual dikes is difficult because many are too fine grained or are too altered.

The felsic and mafic phenocrysts range in size from less than a millimeter in some rocks to 10 mm in others, and range in abundance from less than 5 to more than 50 percent of the rock. The plagioclase is commonly euhedral to subhedral and has normal oscillatory zoning with cores of labradorite grading intermittently outward to sodic andesine. The mafic minerals in general are euhedral colorless augite and brown or green hornblende; rarely, one may be present to the exclusion of the other. Biotite is sparse, and was not found as a conspicuous or exclusive mafic mineral.

The groundmass is an aggregate of plagioclase laths commonly arranged in a trachytic texture. In some rocks it includes potassic feldspar and minor quartz.

The rocks are characteristically poor in quartz and potassic feldspar, and probably are the fine-grained equivalents of the major intrusive rocks.

The small irregular plug prominently exposed on the south side of Black Face (pl. 1) was classified by Cross (in Cross and Purington, 1899, p. 7) as a camptonite, but it is here classed with the rocks of intermediate composition. The rock has a dark-gray to gray-green aphanitic groundmass containing scattered small phenocrysts of hornblende and augite, and it is similar in appearance to several of the dikes in the area. Chemically, the rock is similar to the granodiorite and microgranogabbro and has too much SiO_2 to be classed as a true camptonite (table 5).

LAMPROPHYRE DIKES

Lamprophyre forms a few dikes that crop out poorly because the rock disintegrates readily. A 2- to 3-foot-wide lamprophyre dike at an altitude of about 11,600 feet near the tarn lake southeast of Wilson Peak (pl. 1) strikes N. 30°–40° W. and has a steep dip. The dike follows fractures in the granodiorite country rock, and has an en echelon outcrop pattern. Talus cover prevents tracing of the dike far in either direction. Several lamprophyre dikes 2–5 feet wide, having northwest strikes and steep dips, crop out discontinuously in the divide area between Cross Mountain and Lizard Head. A dike on the west side of Slate Creek at 12,600 feet is 2–5 feet wide, trends N. 70°–80° E., and dips steeply. In the south part of the quadrangle, two lamprophyre dikes cut the Flattop laccolith, two are west of Coke Oven Creek on the Dolores River, and one is along the Dolores River northeast of Flattop Mountain. These dikes are generally less than 10 feet wide and stand nearly vertical.

The dike rocks are dark gray to black on a fresh face, but weather to shades of dark brown or olive brown on the outcrop. Some of the weathered surfaces are nodular. The dikes generally show more or less flattened vesicles or cavities, especially along their margins.

Two kinds of lamprophyre can be distinguished—pyroxene-hornblende lamprophyre and pyroxene-biotite-olivine lamprophyre. Typical pyroxene-hornblende lamprophyre shows under the microscope a pronounced porphyritic texture with larger euhedral crystals of colorless clinopyroxene set in an isotropic groundmass sprinkled with smaller second-generation clinopyroxene and barkevikitic hornblende crystals together with apatite needles and magnetite grains. The pyroxene crystals, which are from 0.5 to 2.0 mm in average size, tend to group together and create a glomeroporphyritic texture. The isotropic groundmass has an index less than balsam. In one thin section, areas of the groundmass are devitrified to a spherulitic aggregate of radiating fibrous feldspar having an index near balsam. The dominance of pyroxene and hornblende, together with the low index groundmass (alkali feldspar?), suggests that the rock is a pyroxene-hornblende vogesite.

The pyroxene-biotite-olivine lamprophyre typically shows in hand specimen conspicuous glistening flakes of biotite. In thin section the rock has a porphyritic texture and shows phenocrysts of biotite, clinopyroxene, and olivine ranging from about 1 to 2 mm. Biotite and pyroxene exceed olivine in amount. The proportion of biotite and pyroxene is variable; in some rocks biotite is dominant, in others pyroxene. The groundmass consists of small second-generation biotite laths and colorless clinopyroxene prisms and very fine grained interstitial material that is isotropic to slightly birefringent and has an index less than balsam. In a thin section from near the center of a dike the interstitial material of the groundmass is coarser and consists of irregular radiating aggregates of plagioclase (oligoclase?) and orthoclase.

The rock is probably a pyroxene-olivine minette, but because of the uncertainty as to the exact nature of the isotropic groundmass, the more general name pyroxene-biotite-olivine lamprophyre is used.

AGE OF THE MINOR INTRUSIVE ROCKS

The latite just west of Trout Lake cuts Mancos Shale and is thus post-Mancos in age, but it cannot be dated more closely. If this plug is related in time to the general vulcanism or major intrusion in the area, it is most likely middle to late Tertiary in age.

Most of the dikes and sills of intermediate composition are probably somewhat later than the intrusion of the Black Face-Ames granodiorite porphyry and virtually contemporaneous with the main stock intrusions. Two lines of evidence support this conclusion: (1) the east-northeast-trending dike zone cuts directly across the sharp Cross Mountain anticlinal fold formed by the intrusion of the Black Face pluton and thus is later in age; (2) some of the dikes appear to feed from the stock at several places, as just south of Sunshine Mountain and in Bilk Basin. On the other hand, some of the dikes are lithologically similar to the rhyodacite porphyry, which preceded the Black Face-Ames intrusion, and on the south slope of Cross Mountain some of the sills may have been involved in the sharp folding referred to above.

It appears possible, therefore, that several episodes of dike and sill intrusion are represented, some before and some during the intrusion of the Black Face-Ames plutons, and some contemporaneous with the stock. However, the time interval between these episodes may not have been great.

The lamprophyre dikes appear to be later than the major intrusions in the area. Two lamprophyre dikes cut the Flattop laccolith. In Bilk Basin, just below the tarn lake southeast of Wilson Peak, the pyroxene-hornblende lamprophyre cuts the granodiorite of the stock. On the north side of Navajo Basin west of the quadrangle boundary, a pyroxene-hornblende lamprophyre not only cuts the stock but cuts one of the numerous narrow quartz-pyrite veins in this area. Though the stock is thoroughly pyritized in this area, the lamprophyre is not. Thus the relations here suggest that the lamprophyre is later than both the veins and the pyritization of the stock, and it probably represents the latest phase of intrusive activity.

PETROLOGIC RELATIONS

CHEMICAL COMPOSITION OF MAJOR INTRUSIVE ROCKS

Chemical analyses and norms of rocks in the stock-associated intrusive bodies are given in table 5. The rocks contain 55–67 percent SiO_2. The analyses show that the porphyritic adamellite differs from the granodiorite and microgranogabbro in that it has higher content of SiO_2, K_2O, and Na_2O and a correspondingly lower content of the other principal oxides. The granodiorite porphyry and the granodiorite are similar in composition. The microgranogabbro and granodiorite are somewhat similar in composition but the granodiorite has a slightly higher content of K_2O, MgO, and total iron, and a lower content of Al_2O_3 than the microgranogabbro.

The norms given in table 5 are plotted on figure 12, a triangular diagram having normative quartz, orthoclase, and plagioclase for apices. Though there is some scatter in the plot of the norms, the three stock rock types tend to cluster into separate "fields."

TABLE 5.—*Analyses and norms of igneous rocks from the eastern part of the San Miguel Mountains, Colo.*

[Samples 1-15 analyzed by P. L. D. Elmore, I. H. Barlow, S. D. Botts, and G. W. Chloe by rapid methods described by Shapiro and Brannock (1956). Sample 15 analyzed by W. F. Hillebrand (in Larsen and Cross, 1956, p. 236) by standard methods. All samples are from the Mount Wilson quadrangle except 11, 13, and 14, which are from the Dolores Peak quadrangle]

	Granodiorite porphyry		Microgranogabbro					Granodiorite					Porphyritic adamellite			"Camptonite" [1]
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Analyses															
SiO_2	59.3	60.6	57.5	58.7	59.4	59.7	61.1	54.7	56.8	56.9	58.4	58.7	66.5	66.7	66.8	55.7
Al_2O_3	15.9	16.2	17.3	17.2	17.8	17.4	16.4	15.9	16.1	16.6	16.2	15.7	14.7	15.2	15.4	17.0
Fe_2O_3	2.0	3.0	2.1	2.8	3.6	2.7	3.3	3.9	3.6	3.4	3.0	2.9	2.8	2.6	2.2	2.8
FeO	3.9	3.2	4.5	4.6	3.5	3.8	3.5	5.6	4.4	5.2	4.7	4.2	1.8	2.0	2.1	5.2
MgO	2.4	2.4	2.6	3.0	2.3	2.4	2.4	4.2	3.3	3.3	2.9	3.0	1.4	1.2	1.3	3.4
CaO	4.6	5.9	4.9	6.2	5.4	5.9	5.4	6.5	5.6	6.4	5.4	5.0	2.9	2.8	3.0	6.8
Na_2O	3.2	3.4	3.7	3.5	3.7	3.6	3.6	3.2	3.6	3.4	3.6	3.6	3.5	4.0	4.0	3.3
K_2O	3.6	3.5	2.4	2.2	2.3	2.4	2.5	2.8	3.9	2.8	4.0	4.2	4.7	4.0	4.0	2.3
H_2O	1.9	1.0	2.7	1.0	1.4	.64	.84	1.4	.68	.95	.49	.65	.52	.60	.66	2.0
TiO_2	.72	.72	.68	.76	.62	.66	.64	.94	.85	.84	.75	.82	.54	.44	.46	.9
P_2O_5	.25	.26	.30	.27	.36	.32	.35	.65	.39	.52	.51	.33	.29	.28	.30	.4
MnO	.11	.12	.21	.14	.22	.16	.15	.18	.16	.16	.14	.13	.10	.08	.10	.2
CO_2	1.5	.05	.48	.05	.10	.05	.05	.18	.05	.05	.05	.05	.05	.10	.05	------
Total	99	100	99	100	101	100	100	100	99	100	100	99	100	100	100	100
	Norms															
Q	12.8	13.6	10.4	11.9	13.7	13.1	16.0	5.8	4.8	8.2	7.1	7.3	23.3	20.5	20.0	7.9
or	21.1	20.6	14.5	12.8	13.3	14.5	15.0	16.7	22.8	16.7	23.9	25.0	27.8	23.9	23.9	13.3
ab	27.3	28.8	31.4	29.3	33.5	30.4	30.4	27.3	30.9	28.8	30.4	30.4	29.3	34.1	34.1	27.8
an	18.4	18.6	22.5	25.0	23.9	24.2	21.1	20.6	16.4	21.7	16.1	14.2	10.6	11.4	12.0	25.0
wo	1.0	3.7	------	1.6	------	1.3	1.2	2.9	3.6	2.7	2.9	3.6	.8	.2	.5	------
en	6.0	6.0	6.5	7.5	4.1	6.0	6.0	10.5	8.3	8.3	7.3	7.5	3.5	3.0	3.2	17.3
fs	4.2	2.1	5.4	4.8	2.8	3.6	2.6	5.7	3.6	5.4	4.8	4.2	.1	1.1	1.2	------
mt	3.0	4.4	3.0	4.2	5.3	3.9	4.9	5.6	5.3	4.9	4.4	4.2	4.2	3.7	3.3	3.9
il	1.4	1.4	1.4	1.5	1.2	1.5	1.2	1.7	1.7	1.5	1.5	1.5	.9	.8	.9	1.6
ap	.7	.7	.7	.7	1.0	.7	1.0	1.7	1.0	1.3	1.3	.7	.7	.7	.7	1.0
C	------	------	------	------	.10	------	------	------	------	------	------	------	------	------	------	------

Sample	Laboratory No.	Field No. CSB-	Locality	Altitude (feet)
1	155746	40-59	Ames sill, west of Ames	
2	155741	10-54	Bilk Creek	10,000
3	155745	23-59	Silver Pick Basin	12,800
4	155742	32-56	Bilk Basin	11,600
5	154754	78-56	do	12,700
6	154750	121-58	Silver Pick Basin	11,040
7	154746	74-58	Bilk Basin	12,080
8	154753	49-56	do	13,080
9	155743	77-56	Navajo Basin	13,200
10	154747	75-58	Bilk Basin	12,600
11	154752	130-58	Navajo Basin	11,870
12	155744	31-58	Saddle between Gladstone Peak and Mount Wilson.	
13	154749	78-58	Elk Creek Basin	13,000
14	154751	125-58	Navajo Basin	12,000
15	154748	76-58	Bilk Basin	12,800
16			Plug on Black Face	

[1] Original analysis figures were carried to the 100th place; here they are rounded to the nearest 10th and are rearranged for easy comparison with other analyses. Original analysis also included: H_2O+, 1.49 percent; H_2O-, 0.46 percent; LiO_2, trace; SrO, 0.05 percent; BaO, 0.08 percent; and SO_3, none.

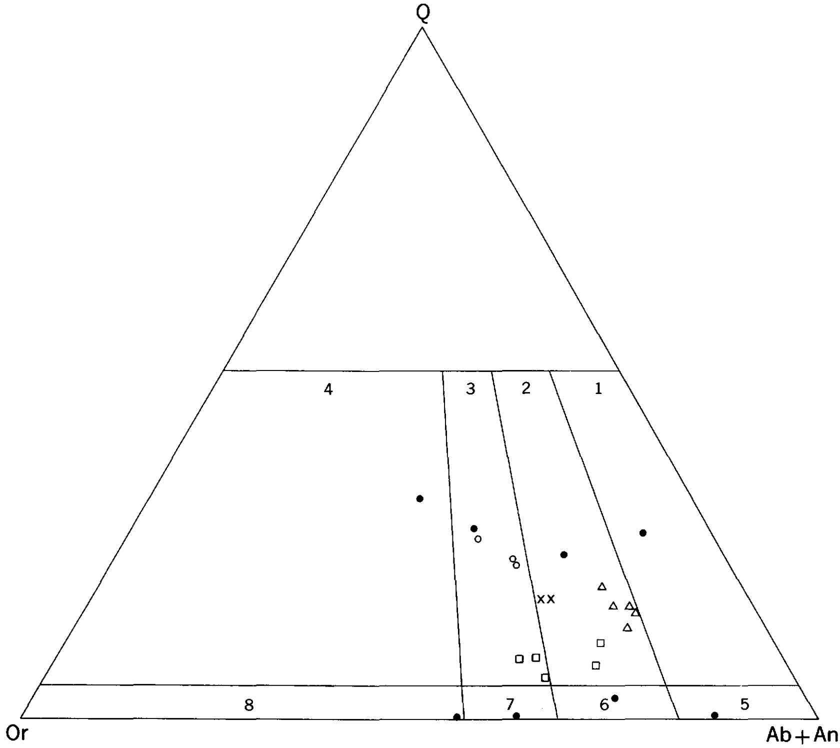

FIGURE 12.—Norms of Sna Miguel Mountains intrusive rocks. Crosses are granodiorite porphyry; triangles, microgranogabbro; squares, granodiorite; open circles, porphyritic adamellite. Solid circles are Nockolds' (1954) averages for rocks of each field. Boundaries are derived empirically from plot of Nockolds' average norms. Fields are (1) quartz diorite, (2) granodiorite or granogabbro, (3) adamellite, (4) granite, (5) diorite, (6) syenodiorite, (7) monzonite, and (8) syenite.

The plot of the modes (fig. 5) also tends to group each rock type into fields and emphasizes the considerable variation that exists within each rock type as well as between rock types. The variation in modes suggests a transition in composition from potassic feldspar-poor microgranogabbro to potassic feldspar-rich granodiorite, and rocks of the two types which plot near one another modally are probably very close in chemical composition.

The analyses of porphyritic adamellite from the stock are similar to those given by Nockolds (1954, p. 1014) for average hornblende-biotite adamellite and hypersthene-bearing adamellite. Analyses of granodiorite from the stock depart widely from average granodiorite analyses, being lower in SiO_2 and higher in total iron, MgO, and

CaO. They are intermediate in composition between Nockolds' average granodiorite and his monzonite and mangerite (syenodiorite). The microgranogabbro compositions do not depart as widely from the average as the granodiorite, but they differ from average granodiorite in lower SiO_2 and K_3O, and higher CaO.

VARIATION DIAGRAMS

The chemical data have been plotted both on the normal silica variation diagram (fig. 13) and on the variation diagram of the type proposed by Larsen (1938) (fig. 14). The Larsen diagram is used to facilitate comparison with the published data of Larsen and Cross (1956) on the San Juan volcanic rocks. The normal SiO_2 diagram is included because it lends itself more readily to interpretation of variation among the several oxides.

For the most part the analyses of the igneous rocks fall near simple curves on the variation diagrams, but the K_2O and Al_2O_3 values of the granodiorite appear to depart systematically from a simple curve. Because of the scattering of the K_2O values in the critical area between 55 and 59 percent SiO_2 (fig. 13), a precise figure cannot be given for the alkali-lime index. However, it lies between 56 and 59 percent SiO_2 and the series is calc-alkalic, as defined by Peacock (1931). Barth (1952) gave a value of 59.2 for lavas of the San Juan region.

RELATION OF MAJOR INTRUSIVE ROCKS TO IGNEOUS ROCKS OF WESTERN SAN JUAN MOUNTAINS

The calc-alkalic igneous rock series of the eastern San Miguel Mountains intrude middle and upper Tertiary volcanic rocks including the San Juan Formation and the Silverton Volcanic Group. Within the quadrangle only remnants of these flows and tuffs have survived the erosion which has exposed the Wilson Peak stock, but they correlate with the widespread volcanic units a few miles to the east (pl. 2). It is also probable that units of the overlying Potosi Volcanic Group once extended over at least a part of the area. Similarly, all the other Tertiary stocks in the western San Juan Mountains intrude the volcanic rocks, including some as young as the Potosi, and Burbank (1930, p. 208) concluded that most of these intrusive bodies were probably of post-Potosi age. In figure 15 compositions of the intrusive rocks of the eastern part of the San Miguel Mountains, as well as of other intrusive rocks that cut the volcanic rocks (Larsen and Cross, 1956), are compared with the compositional curves of the Potosi Volcanic Series of Larsen and Cross (1956). Luedke and Burbank (1963) have recently changed Potosi Volcanic Series to Potosi Volcanic Group in keeping with

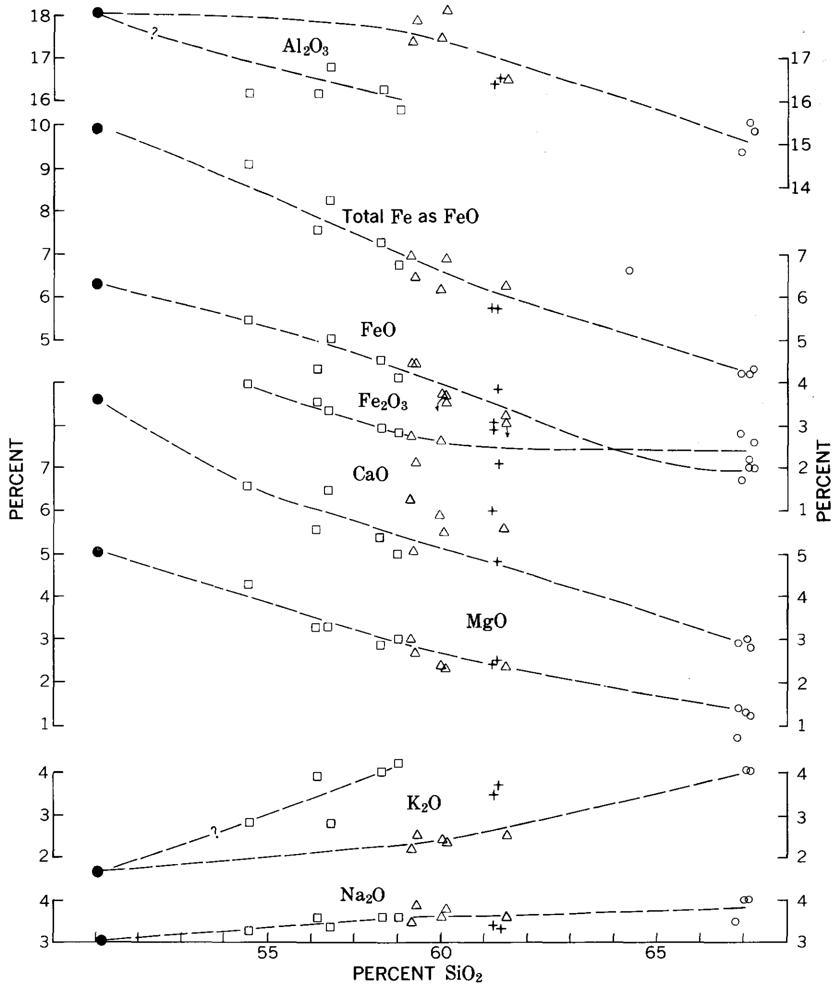

FIGURE 13.—Silica variation diagram of the major intrusive rocks of the eastern part of the San Miguel Mountains. Triangles are microgranogabbro; squares, granodiorite; crosses, granodiorite porphyry; and circles, porphyritic adamellite. Solid circles are assumed parent magma of Stony Mountain "gabbro" type. (See p. 61.)

the code adopted by the American Commission on Stratigraphic Nomenclature. This comparison is made because, as noted by Larsen and Cross (1956, p. 285), the rocks included by them in the Potosi have slight, if any, difference in chemical character, are represented by a large number of analyses, and have a wide range in chemical composition. In addition, the rocks of the Potosi of Larsen and

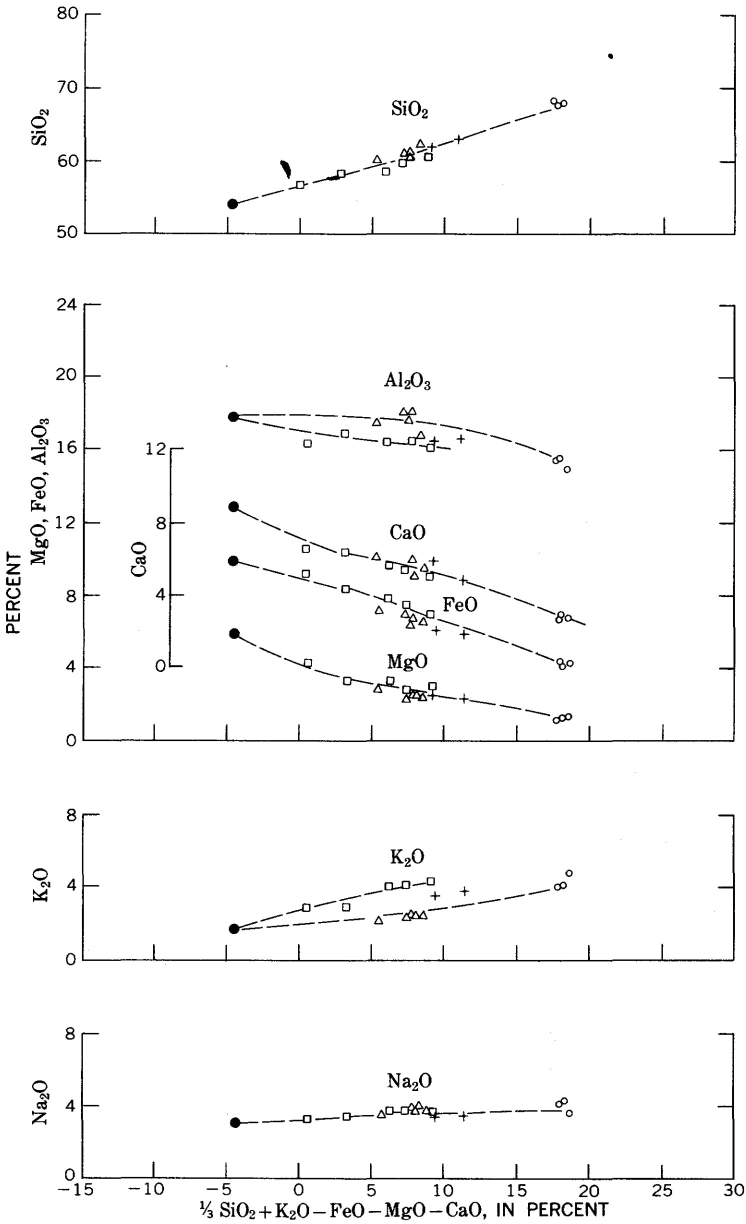

FIGURE 14.—Larsen variation diagram of the major intrusive rocks of the eastern part of the San Miguel Mountains. Triangles are microgranogabbro; squares, granodiorite; crosses, granodiorite porphyry; and circles, porphyritic adamellite. Solid circle is assumed parent magma of Stony Mountain "gabbro" type. (See p. 61.)

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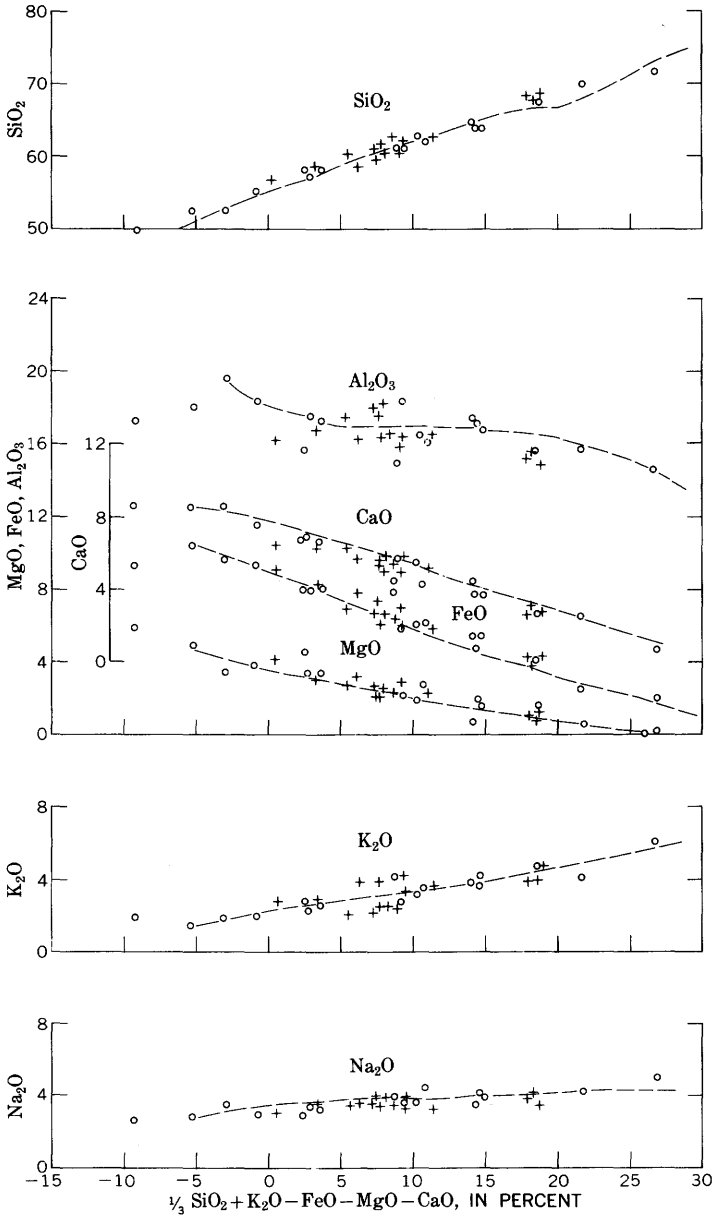

FIGURE 15.—Larsen variation diagram of the major middle and upper Tertiary intrusive rocks of the western San Juan Mountains. Crosses are rocks from the San Miguel Mountains; circles are intrusive rocks other than from San Miguel Mountains; dashed line is variation curve of Larsen and Cross's (1956) Potosi Volcanic Series.

Cross have a volume of 6,000 cubic miles, making up the greater part of the volcanic eruptions in the San Juan Mountains, and thus their curves would approach an average curve for the bulk of the San Juan volcanic rocks. The plotted points for the two sets of intrusive rocks fall near a common curve, and the two sets of intrusive rocks can therefore be reasonably supposed to have a common parent. Collectively, the intrusive compositions closely fit the curves for the Potosi of Larsen and Cross (1956).

Larsen and Cross (1956, fig. 57) showed that in the Potosi the most abundant rock types lie between positions 0 and 10, and also at approximately position 18, on the abscissa of the Larsen diagram. A similar grouping of compositions among the San Miguel intrusives (fig. 14) suggests that they and the volcanic rocks may have had a common or at least a similar parent magma. Both the intrusives and extrusives probably belong to what Kennedy and Anderson (1938) called a volcanic association.

ORIGIN OF THE INTRUSIVE ROCKS

In identifying the parent magma for an igneous rock series, the assumption is generally made that the composition approximated the mafic end of the region of continuous variation as expressed in a compositional diagram. The most mafic of the major intrusive rocks in the San Miguel Mountains is the microgranogabbro, which locally might contain as little as 55 percent SiO_2. The most mafic rock analyzed among the related major intrusive rocks of the western San Juan Mountains is a "gabbro" from the Stony Mountain stock near Ouray (Cross and Purington, 1899) which has a SiO_2 content of 52 percent. Cross noted (1896b, p. 231) that it grades into augite-diorite within the stock, and further, that this augite-diorite rock type is widespread among the intrusive rocks of the western San Juan Mountains, as in the Sultan Mountain stock near Silverton and in the Ophir stock (pl. 2). This rock type has been termed "microgranogabbro" in this report.

It seems probable that the intrusive rocks now visible in the eastern San Miguel Mountains area form a related series ranging in composition from microgranogabbro through porphyritic adamellite and that these rocks arose through the differentiation of a common parent magma similar to those discussed above.

The anomalous positions of the K_2O values on the variation diagrams (figs. 13 and 14) indicate an apparent split in the series, and suggest that the microgranogabbro and granodiorite, though still congeneric, have followed slightly different paths of differentiation from a common parent magma, or most probably that the anomalous positions of the K_2O and Al_2O_3 values on the variation diagrams may be systematic departures from a simple variation curve caused by locally operative effects which resulted in the enrichment of the magma in potassium.

The trend of the intrusive rocks from the eastern part of the San Miguel Mountains approximates that of Daly's (1933) calc-alkalic trend, as shown in figure 16. The San Miguel Mountains igneous rocks, though mainly calc-alkalic in trend, are intermediate in character compared to a typical calc-alkalic trend from Lassen Peak (Williams, 1932) and an alkalic trend from the Audubon-Albion stock (Wahlstrom, 1940), as shown in figure 17.

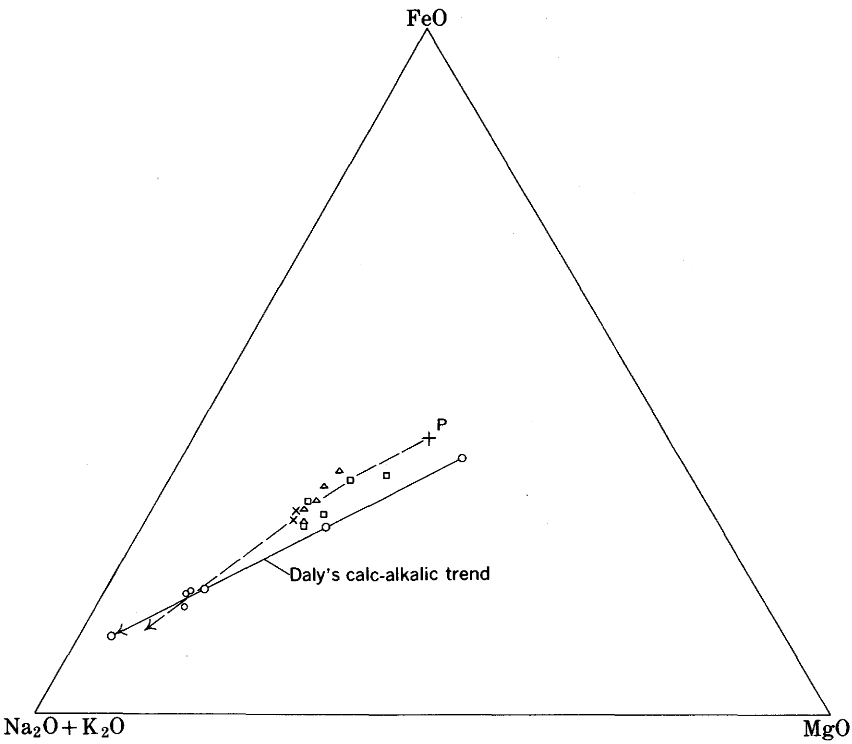

FIGURE 16.—Differentiation trend of intrusive rocks from the eastern part of the San Miguel Mountains compared with Daly's (1933) calc-alkalic series. San Miguel Mountains trend shown by dashed line. P is assumed parent magma of Stony Mountain "gabbro" type. (See p. 61.) Triangles are micrograno-gabbro; squares, granodiorite; crosses, granodiorite porphyry; circles, porphyritic adamellite.

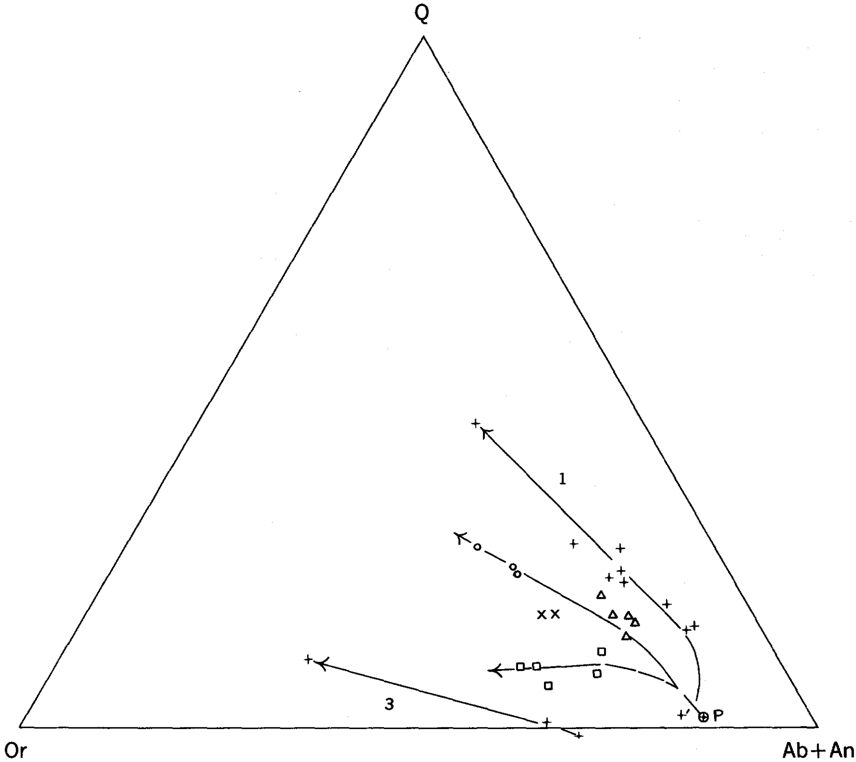

FIGURE 17.—Comparative trends of normative quartz, orthoclase, and plagioclase for rocks of (1) Lassen Peak (Williams, 1932), (2) the San Miguel Mountains, and (3 the Audubon-Albian stock (Wahlstrom, 1940). Circles represent porphyritic adamellite; squares, granodiorite; triangles, microgranogabbro; x, granodiorite porphyry. Crosses represent rocks of other two areas. P is parent magma of Stony Mountain "gabbro" type.

CONTACT METAMORPHISM

The Wilson Peak stock is surrounded by a zone of contact metamorphism which is as much as a mile wide, and probably averages about 2,500 feet in width (pl. 1). A zone of contact-metamorphosed country rock connects the arm of the Wilson Peak stock on Sunshine Mountain with the arm of the Ophir stock on San Bernardo Mountain and suggests that between these areas there is a connecting body of intrusive rock near the surface. In contrast, there is only minor contact metamorphism associated with the Black Face-Ames plutons and the Flattop laccolith, and this is limited to slight baking effects, usually restricted to a few feet or tens of feet from contacts.

The Telluride Conglomerate shows considerable bleaching within the contact metamorphic zone. Outside this zone, the formation is predominantly red, whereas inside the zone it is generally some shade of light greenish gray, due in part at least to epidote. The bleaching is not uniform; the coarser conglomeratic beds are bleached farther from the contact than are finer grained mudstone units, an effect most likely due to the greater permeability of the coarser units.

Throughout much of its perimeter the stock is in contact with the Mancos Shale. The degree of metamorphism in the shale increases toward the contact. At the outer limit of the aureole, thermal effects are manifested macroscopically by a slight hardening of the shale; as the aureole is crossed, increasing metamorphism is shown by the gradual bleaching of the normal black to dark-gray shale to very light gray, and by the gradual loss of the normal fissility of the shale until a hard dense structureless rock is left. In places, spotted slate or hornfels occurs, but they are in no systematic relation to the exposed stock contact.

As seen in thin section, the spots are very fine grained aggregates of sericite, pyrite, and the dark carbonaceous component of the shale. No cordierite or other aluminous silicates have been recognized, though some diffuse sericite-rich spots may be altered remnants of them. Phlogopitic biotite is present within a few feet of the contact; rutile, probably present in the original shale, has recrystallized to larger crystals; and the groundmass is a very fine grained mosaic of quartz and feldspar(?).

STRUCTURAL GEOLOGY

GEOLOGIC SETTING OF MOUNT WILSON QUADRANGLE

The San Miguel Mountains form a west-trending extension of the larger San Juan Mountains area at its boundary with the Colorado Plateau. Although the physiographic division between the San Juan Mountains and the Colorado Plateau is well marked by the abrupt descent from the high mountains to the generally flat mesa country of the plateau on the west, the structural boundary is less clear. The primary tectonic feature of the western San Juan Mountains is a broad dome which was formed principally in Laramide time. The western part of the dome, which protrudes from beneath the volcanic rock, is 50–60 miles across in the north-south direction. From the plateaus province to the west of the San Juan Mountains, Mesozoic and older strata rise gently but steadily toward the San Juan dome. Just to the east of the quadrangle, they bend upward along the San Juan monoclinal fold on the flank of the dome (pl. 2). Two conspicuous secondary uplifts of Laramide or middle to late Tertiary age mark the west flank of the San Juan dome. These are the Rico and La Plata domes (pl. 2), both of which are centers of intrusion.

Probably during early Tertiary time, erosion beveled the western part of the San Juan dome to a surface of low relief, and upon this surface piedmont alluvial gravel was deposited which today forms the Telluride Conglomerate. Upon this conglomerate, beginning perhaps in middle Tertiary time, a thick pile of volcanic rocks accumulated and formed a volcanic plateau some 100 miles across which contained well over 6,000 cubic miles of volcanic rocks (Larsen and Cross, 1956). During later Tertiary and Quaternary time this volcanic pile was deeply dissected to form the present rugged San Juan Mountains. Erosion by the San Miguel and Dolores Rivers and their tributaries has nearly isolated the stock-cored San Miguel Mountains from the main San Juan Mountain region to the east.

A major tectonic feature superimposed on the dome in the western San Juan Mountaines is the linked Silverton-Lake City calderas (pl. 2) of middle to late Tertiary age. The Silverton caldera, located about 10 miles east of the Wilson Peak stock area, is approximately 10 miles in diameter and is bounded by concentric and radial fractures that were the locus for numerous important mineral deposits of gold, silver, and base metals. Stocks intruding the volcanic rocks include the Sultan Mountain, Stony Mountain, the Grizzly Peak, and in a straight line, the Ophir, Wilson Peak, and Dolores Peak stocks (pl. 2).

The tectonic division of the Colorado Plateau lying to the west of the area is the northwest-trending Paradox fold and fault belt. The faults die out to the southeast, and none reach the area of the Mount Wilson quadrangle; the folds, too, die out and merge with the general rise of strata toward the San Juan Mountains.

The Mount Wilson quadrangle lies on the gentle west flank of the San Juan dome, just west of the San Juan monocline and 10 miles west of the Silverton caldera (pl. 2).

In the quadrangle, where the Mesozoic and older sedimentary strata have not been disturbed by intrusion, the formations are almost flat-lying, and only gentle undulations are superimposed on a general southerly rise of strata toward the Rico dome to the south. In this area, the dips on the flank of the Rico dome are in general less than 5°.

IGNEOUS INTRUSIONS AND RELATED STRUCTURAL FEATURES

Most of the major structural features of the Mount Wilson quadrangle are those which have been imposed on the nearly flat-lying sedimentary rocks by the intrusion of the igneous rocks. Both concordant and discordant intrusive masses were formed. The major masses of igneous rock are the Flattop laccolith and, in the San Miguel Mountains, the Black Face and Ames plutons and the Wilson Peak stock. The intrusive bodies of the San Miguel Mountains, their form and relation to the enclosing country rock, and the related Cross Mountain anticline are shown on plate 4, a structural contour map of the San Miguel Mountains area drawn on the base of the Telluride Conglomerate. The deformation shown by this surface is almost entirely the result of intrusion. The surface was chosen for contouring because it was originally a smooth, approximately plane surface of deposition, and has undergone very little deformation aside from that due to intrusive activity.

FLATTOP LACCOLITH

The Flattop laccolith underlies a subcircular area of about 6 square miles and has a maximum thickness of a little more than 1,000 feet, at the south edge of the quadrangle. On the east and north sides of the Dolores River a sill of monzonite porphyry which averages 80 feet in thickness shows that the laccolith tapered abruptly in those directions and that its extent was not much greater originally than it is now. As seen in section *C–C′* (pl. 1), the shape of the mass closely approaches the lenticular form of the ideal laccolith.

Around much of the periphery of the laccolith, the base has been uncovered by the downcutting of the canyons of the Dolores River and Barlow Creek, but it is well exposed in only a few places because of talus or dense spruce-covered slopes. Where the base is best exposed, on the east side of the laccolith near the south edge of the quadrangle, it rests concordantly on the carbonaceous shale and sandstone beds typical of the middle unit of the Dakota Sandstone. Exposures elsewhere show that this zone within the Dakota forms the floor in most places. The upper part of Dakota Sandstone forms the roof of the laccolith; this concordant contact is well exposed about a quarter of a mile south of the quadrangle boundary at the summit of Flattop Mountain.

CROSS MOUNTAIN ANTICLINE

A belt of folded strata connects the west end of the Black Face intrusive with the Wilson Peak stock. Sedimentary rocks in this belt are sharply bent into an asymmetric anticline which is overturned to the southwest and which probably is locally faulted. (pls. 1, 4, sections *A–A′*, *B–B*, and *C–C′*). The axial trace of the anticline describes a roughly crescent-shaped arc open to the northeast. At its west end, the anticline is transected by the Wilson Peak stock;

2 miles southeast the fold appears to be continuous with the fold occupied by the Black Face intrusive. The Cross Mountain anticline probably was formed by a buried extension of the Black Face intrusive as shown both by the structural relations and the presence of several dikes and small irregular intrusives of the Black Face type which cut the anticline and in part are parallel to it.

The anticline can nowhere be seen in its entirety, but the structure contours (pl. 4) suggest that the Telluride Conglomerate at the crest of the fold was elevated 2,000 feet or so above the level in adjacent areas. Dips along the southwest flank of the fold, best seen on the west side of Slate Creek, range up through vertical to overturned dips of about 50° NE. Vertical dips and overturned dips of up to 30° NE are found along the south slope of Cross Mountain. Dips along the northwest flank of the anticline range from 10° to 45° NE.

BLACK FACE PLUTON

The Black Face pluton of granodiorite porphyry crops out as an elongate east-west body about 4 miles long and about half a mile in maximum width.

The form of the pluton and its relations to the country rock suggest it is an asymmetric laccolith, though no floor has been exposed by erosion (pl. 1, section *B–B′*, and pl. 4, sections *E–E′*, *F–F′*, and *G–G′*). The roof rocks are still preserved near the summit of Black Face and at the east end of the intrusive mass. At both places the cap of Mancos Shale lies at relatively low angles in concordant relation to the underlying granodiorite porphyry. To the north the strata gradually arch over into steeper dips, concordantly following the intrusive roof.

In contrast, along the south side of the Black Face pluton the Mancos Shale is at steep angles, commonly vertical to overturned, and probably in part is faulted parallel to the contact. Locally adjacent to the pluton, overturned Mancos Shale beds dip at angles of 30°–70° into the contact. The Mancos Shale is crumpled into small-scale overturned folds which diminish in intensity outward and pass into normal flat-lying strata within a thousand feet of the intrusive contact. The pluton itself apparently has a somewhat irregular but steep southerly dip along much of its south side, but in places it is vertical.

At its west end the Black Face pluton is dominantly discordant (pl. 4, section *D–D′*). A narrow wedge-shaped mass has been injected to the north at low angles across the bedding; this wedge is underlain by Telluride Conglomerate and overlain by Mancos Shale. This inverse relation may have resulted from intrusion of magma along a low-angle fault which thrust Mancos over Telluride, although thrusts have not been recorded in the region. Perhaps more likely, the inverse stratigraphic relation is an intrusive effect resulting from dilation of the beds by the wedging action of magma.

AMES PLUTON

The Ames pluton, extending across the northeast corner of the mapped area, is composed of granodiorite porphyry which is identical to that of the Black Face pluton. The two plutons crop out within a few hundred feet of one another near the east side of the area, and probably connect in subsurface. As with the Black Face pluton, the Ames pluton has both concordant and discordant relations to the enclosing flat-lying sedimentary rocks and thus is not simply classified, but in general it has the form of an irregular sill.

Along the west side of the South Fork of the San Miguel River the sill attains a maximum thickness of about 800 feet and it crops out above the river for about a mile as a spectacular sheer cliff. The sill was intruded near the contact of the Dakota Sandstone and Mancos Shale but it does not everywhere occupy the same horizon. At the north end of the outcrop along the river the sill lies entirely within the Dakota Sandstone, which is exposed both above and below the sill. The Mancos-Dakota contact, which is normally at an altitude of about 9,400 feet in this area, has been lifted to an altitude of about 10,200 feet. To the south the sill thins to about 480 feet and jumps stratigraphically upward about 400 feet into the Mancos Shale. Farther south the contact of the sill with the enclosing strata is generally concordant; but in detail the sill here and there steps downward through the strata, so that near the south end of the outcrop the Dakota Sandstone again encloses both the top and bottom of the sill. Individual steps observed are generally 15–30 feet.

In places adjacent to the basal contact of the sill, the Mancos Shale is brecciated for distances of a foot or so from the contact, and in one exposure (fig. 18) it is folded and faulted on a small scale next to a small step in the contact. The brecciation and folding appear to have been due to frictional dragging between a relatively viscous magma and the Mancos Shale.

Although outcrops of the Ames sill or its contacts are sparse along that part of the sill extending west from the South Fork of the San Miguel River valley toward the stock, the evidence suggests that these outcrops are at or near the northernmost limit of major intrusion. First, along the river valley immediately north of an outcrop of the Ames sill which is more than 700 feet thick, only a 40-foot sill

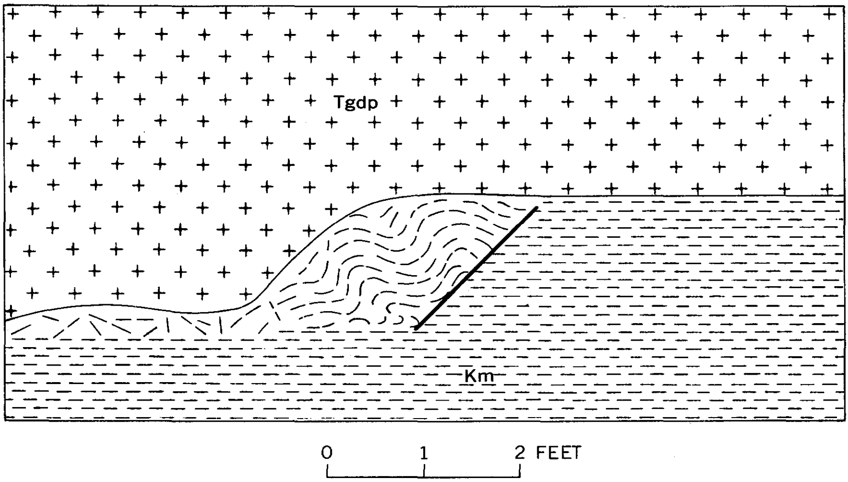

FIGURE 18.—Small-scale folding, faulting, and brecciation at base of Ames sill, west of Ames. Km, Mancos Shale; Tgdp, granodiorite porphyry.

of porphyritic rhyodacite occurs in an otherwise complete section of Dakota Sandstone (pl. 1). Here, then, was the northern limit of a blunt-edged thick sill having only a very thin short north extension. Second, exposures northeast of Sunshine Mountain and about 1½ miles west of the river valley indicate a blunt-ended sill (fig. 19). Apparently the sill expanded northward as a blunt wedge; the magma, probably very viscous, made room for itself by both lifting and crumpling the beds as it pushed forward in "snowplow" fashion through the incompetent Mancos Shale.

North of Sunshine Mountain the narrow part of the Ames pluton, though generally poorly exposed, is apparently discordant and mainly dikelike in form.

WILSON PEAK STOCK

The Wilson Peak stock crops out over an area of about 5 square miles, and it forms several of the high peaks in the San Miguel Mountains. It extends a maximum of 4 miles from east to west, and 2½ miles from north to south. The stock is very irregular in outline—one lobe extends west into Navajo Basin and two lobes extend north, the larger in Silver Pick Basin and the smaller along the ridge north of Wilson Peak. A narrow arm of the stock extends northeast across Bilk Creek and connects with a smaller area of the stock which lies on the west side of Sunshine Mountain.

The Wilson Peak stock is predominantly discordant to the enclosing sedimentary rocks, and its contacts are steep and sharp. Around

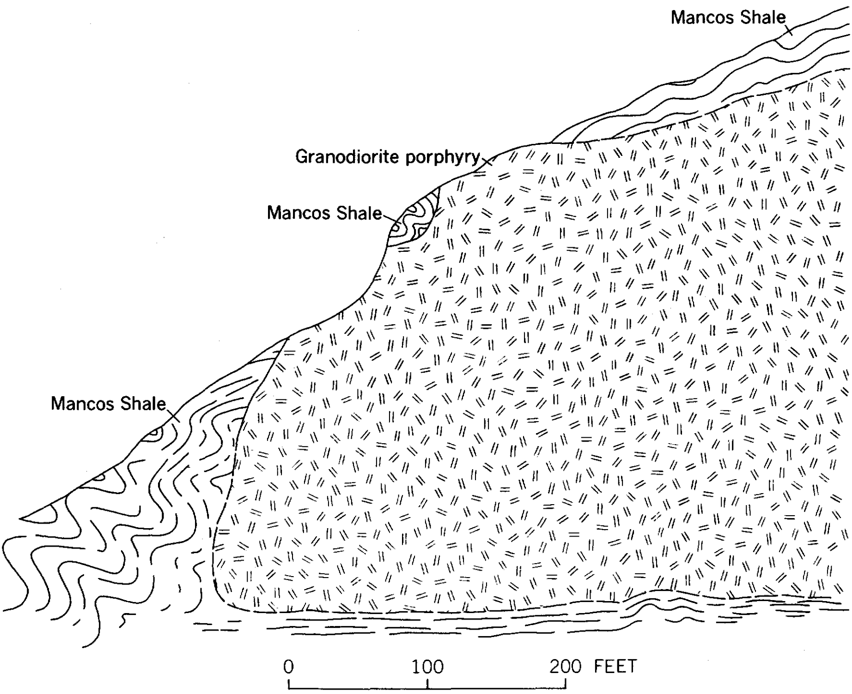

FIGURE 19.—Diagrammatic sketch of Ames sill north of Sunshine Mountain showing "snowplow" action of granodiorite porphyry magma along its blunt northern terminal edge.

somewhat more than half of its periphery, the flat-lying strata of the Mancos Shale and overlying Telluride Conglomerate continue up to the stock contact with no significant deformation (pl. 1, section *A–A′*; pl. 4). This relationship holds in general from near Mount Wilson on the southern boundary of the stock west into Navajo Basin, then east and north along the stock contact into Silver Pick Basin.

On the northeast, however, along the ridge leading east from Wilson Peak, the Telluride Conglomerate and Mancos Shale are domed and dip away from the stock contact (pl. 1, section *A–A′*; pl. 4). The steep intrusive contact cuts upward across the bedding planes of the enclosing rocks, and, though it parallels the strike of the beds in places, it cuts discordantly across the strike of the tilted beds in others. On its southeast side the stock transects the large asymmetrical overturned fold of the Cross Mountain anticline. The stock cuts the fold at nearly right angles to the anticlinal axis and is interpreted to be later than that structural feature.

That the stock has steep, nearly vertical walls is suggested by the following observations: (1) the stock does not appear to widen downward appreciably, although its contacts are exposed through a vertical range of 5,000 feet; (2) local exposures of the intrusive contact are steep to vertical; (3) the stock contact cuts in virtually straight lines across the rugged topography; and (4) sparse flow banding is invariably oriented vertically.

In plan the stock outline is markedly irregular both grossly and in detail. The contact makes sharp angular turns in the horizontal or vertical direction where it locally crosses between steep joint planes in the country rock; similar angular irregularities also exist where the contact locally turns to follow bedding planes in the sedimentary rocks (fig. 20). The resulting angular or steplike pattern is shown, at the scale of the map, on the ridge north of Wilson Peak and in Silver Pick Basin (pl. 1).

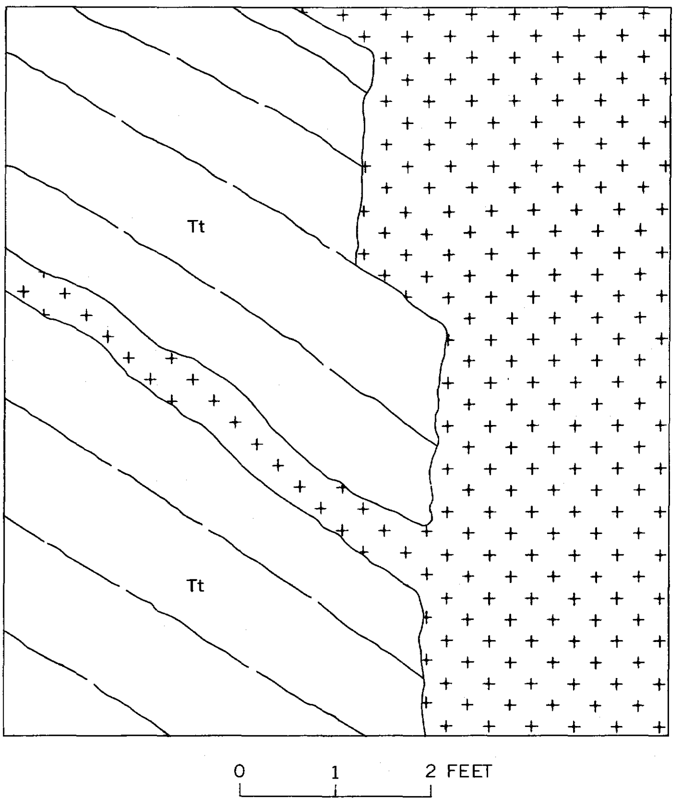

FIGURE 20.—Contact of granodiorite (crosses) with Telluride Conglomerate (Tt) at 13,000-foot altitude in upper Slate Creek.

The contacts between igneous and sedimentary rocks are generally knife-edge sharp and show no evidence of replacement or assimilation. An exception was observed in Bilk Basin near the 12,400-foot contour, where the beds have been thrust up vertically at the contact and in part are brecciated. Some blocks of the Mancos Shale hornfels contain laminae of igneous material between original shale laminae, and all the laminae show small-scale crinkling, swirling, and microfaulting that suggest the shale was in a more or less plastic state. The shale has reacted with the magma to produce pyroxene-rich contaminated igneous rock.

A contact breccia is found in places, as on the north side of Navajo Basin in the adjacent Dolores Peaks quadrangle. There, Mancos Shale adjacent to the stock is brecciated and crushed in a zone which is 2 inches to 1 foot wide. The igneous contact is nearly vertical, and the flat-lying Mancos Shale continues up to the breccia zone with no disturbance. On the west side of Bilk Basin, the sedimentary rocks adjacent to the igneous contact are crackled in a zone several feet wide, and in the intrusive rock adjacent to the contact are inclusions of hornfels, some of which are several tens of feet long. Relict laminae of the separate hornfels inclusions have a random orientation which shows that the inclusions have been rotated.

Such inclusions of wallrock are not abundant in the stock, and where present they are near the contact and generally associated with intricate contact relations, as where abundant apophyses cut the wallrock. Most of the inclusions are small, but a few are large enough to show on the map, as in Bilk Basin east and southeast of Wilson Peak. Inclusions are virtually absent in the interior of the stock.

Faulting in association with the stock is rare and on a minor scale. Near the southwest margin of the stock, west of the quadrangle boundary, are several low-angle normal faults that strike northeast and generally are downthrown to the south. The displacements are slight, ranging from 15 to 30 feet; they may be due to contractional stresses resulting from cooling of the stock.

DEPTH OF INTRUSION

Only general estimates can be made as to the amount of cover over the stock and the other plutons at the time of their intrusion. The stock now forms some of the highest peaks in the area, and it intrudes Mesozoic sedimentary rocks, Tertiary Telluride Conglomerate, San Juan Formation, and the Silverton Volcanic Group. At the time of intrusion the Potosi Volcanic Group probably extended over the area also. The Potosi is present to the north and east as erosion remnants capping the highest ridges of the western San Juan Mountains, and it is found also to the south in old landslide blocks at the foot of Sheep Mountain. Vhay (1962) gave a maximum thickness of about 1,150 feet for the Potosi and 1,400 feet for the Silverton in the area south of Telluride and just northeast of the Mount Wilson quadrangle. The cover above the present levels of observation probably was less than a mile, and perhaps it was as little as 2,000 feet when the Wilson Peak stock was emplaced.

No positive evidence can be adduced as to whether or not the stock had connection with the surface.

COMPARISON OF EASTERN SAN MIGUEL MOUNTAINS WITH LACCOLITHIC CENTERS OF THE COLORADO PLATEAU

Several authors, principally Holmes (1877) and Cross (1894, quoting Holmes), and most recently Hunt (1956, p. 42), included the San Miguel Mountains with the other laccolithic centers of the Colorado Plateau, and thus it seems appropriate to compare the intrusive features of the eastern San Miguel Mountains with the other centers. Recent work on these mountain groups include papers on the La Plata Mountains (Eckel, 1949), the Henry Mountains (Hunt, 1953), La Sal Mountains (Hunt, 1958), and Abajo Mountains (Witkind, 1964).

Hunt (1956, p. 62), who has written most widely on the laccolithic centers, characterized the typical laccolithic mountain on the Colorado Plateau as a structural dome, commonly ranging from about 6 to 12 miles in diameter and from about 2,600 to 8,000 feet in height. A subcircular stock is at the center of each dome, around which satellite laccoliths tend to be radially distributed. He showed that in these centers the early widespread intrusions of diorite porphyry and the later intrusions of monzonite porphyry were physically injected. In the La Sal Mountains, which contain a later syenitic porphyry stage, the shattered rocks around the stocks are in part replaced or assimilated.

Hunt (1956) concluded that the large domes associated with the diorite and monzonite porphyry stocks were the result of vertical push accompanying injection. He stated (1956, p. 62) that "The big mountain domes are attributed to deformation accompanying physical injection of the stocks, because the sedimentary formations turned up around the stocks cover the same area as they did in their original horizontal position. This evidence is especially forceful because of the fact that although the stocks are of different widths at the different mountains, the amount of upwarp at the domes is almost in direct ratio to the width of the stocks." Hunt suggested that all the 15 laccolithic mountain groups on the Colorado Plateau (including the San Miguel Mountains) represent a similar intrusive process which was arrested at different stages in the different mountain groups (1956, p. 62; 1958, p. 305).

Witkind (1964) found very similar conditions in the Abajo Mountains and his conclusions are compatible with Hunt's.

In the La Plata Mountains dome, numerous sills, laccoliths, and discordant porphyry bodies are cut by later equigranular stocks of diorite and syenite (Eckel, 1949). The dome has about 6,000 feet of structural relief and is about 10–15 miles across. Eckel believed that the dome was caused directly by the cumulative effect of the intrusion of numerous sills and other porphyry intrusives. The later stocks of granitoid texture do not appear to disturb the sedimentary strata adjacent to their contacts, and Eckel (1949, p. 40) attributed their emplacement principally to replacement or assimilation of the country rocks and, to a lesser degree, to mechanical disruption. Hunt (1953, p. 148) considered the late nonporphyritic intrusions in the La Plata Mountains to represent a still more advanced stage in the formation of laccolithic mountains than was found in the Henry or La Sal Mountains.

The eastern San Miguel Mountains, or Mount Wilson group, resemble the other laccolithic centers on the Colorado Plateau in the close association of laccoliths or semiconcordant intrusive bodies with a stock, and the San Miguel intrusive center shares with the other laccolithic centers the similar host rocks and preexisting structural environment of the Colorado Plateau. However, the eastern San Miguel Mountains differ from these other centers in that there is no large dome peripheral to a centrally located, crudely circular stock such as characterizes the Henry, La Sal, and Abajo Mountains laccolithic centers. Doming associated with the granitoid rocks of the Wilson Peak stock is relatively minor, though the stock is as large as or larger than the stocks at Mount Pennell or Mount Hillers, the largest in the Henry Mountains. These latter two stocks had domes 6–8 miles in diameter and structural relief of 6,000 and 7,000 feet respectively.

Along the northeast side of the Wilson Peak stock, doming of about 1,400 feet is observed (pl. 4) and the bulge of the Cross Mountain anticline, with its axis perpendicular to the stock, has a structural relief of about 2,400 feet. West of these areas of local doming, strata adjacent to the stocks are little disturbed.

If the Wilson Peak stock were intruded by the type of physical injection which apparently occurred in the Henry and La Sal Mountains, a dome having approximately 8,000–10,000 feet of structural relief would be required. Such a dome does not exist. The Wilson Peak stock in its relation to the enclosing strata thus resembles more closely the equigranular stocks in the La Plata Mountains. Both are interpreted as later than associated porphyry intrusives.

MECHANISM OF EMPLACEMENT

The problem of the mechanism of intrusion—particularly of stocks and batholiths—has been much discussed in the literature. Several mechanisms have been suggested at different times, and probably all are valid in particular instances. In general, igneous bodies may be emplaced by one or a combination of the following mechanisms: lifting the roof (laccolithic method); settling or forcing down of the floor of an intrusive (lopolithic method); forceful pushing aside of the country rocks; upward punching; stoping, either of small fragments (piecemeal stoping), or by sinking of large blocks of country rock (ring-fracture stoping or cauldron subsidence); assimilation; and replacement.

The major intrusive bodies of the San Miguel Mountains and the Flattop laccolith to the south resulted from the emplacement of magma at shallow depths in the earth's crust, and are epizonal in the sense of Buddington (1959). They probably made room for themselves partly forceful injection and partly by piecemeal stoping.

BLACK FACE-AMES PLUTONS AND FLATTOP LACCOLITH

The structural relations of the Black Face-Ames plutons (see p. 67), show very clearly that they made room for themselves by a combination of lifting or doming the strata and by forcefully shouldering aside the strata. The field evidence suggests that the Black Face magma lifted the strata in the manner of a trapdoor. Along the south side, corresponding to the opening, the strata were first probably stretched, then faulted along the south margin of the pluton, and later crumpled as the magma expanded laterally as well as vertically. The strata on the upper or north side of the pluton were domed or arched conformably above the expanding magma.

The Ames pluton, probably at least in part coextensive with the Black Face pluton, is mainly a concordant intrusive body. Near Ames, where the pluton is best exposed, it apparently made room for itself by simple dilation of the enclosing strata. The present line of outcrop between the Lake Fork of the San Miguel River and Bilk Creek is inferred to have been at or near the original north limit

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of the sill-like Ames pluton. Field relations suggest (fig. 19) that the sill expanded to the north as a blunt wedge; apparently the magma was extremely viscous and it made room for itself both by lifting the beds and by crumpling them in front of the expanding wedge.

The Flattop laccolith, which is lens shaped in cross section, arched the overlying strata as it was injected into the Dakota Sandstone. Peripherally the laccolith tapers into a thin sill (pl. 1, section *C–C′*).

WILSON PEAK STOCK

Inasmuch as no large peripheral dome is associated with the Wilson Peak stock, most of the room it occupies cannot be explained by simple physical injection of the type proposed by Hunt (1953, 1958) for the porphyry stocks of the Henry and La Sal Mountains, and by Witkind (1964) for the stocks in the Abajo Mountains. That some room was obtained by doming during or preceding the intrusion of the microgranogabbro is indicated by the structural contours in the area east of Wilson Peak toward Sunshine Mountain (pl. 4; section *A–A′* of pl. 1). The Cross Mountain anticline, adjacent to the southeast part of the stock, appears to be related to the intrusion of the Black Face pluton (p. 66). Alternatively, the anticline formed as the result of a lateral protrusion from the side of the stock, or it formed above a stocklike mass. The resulting anticlinal bulge has been truncated by later phases of stock intrusion, and neither this doming nor that northeast of Wilson Peak can explain adequately the space occupied by the Wilson Peak stock. Other mechanisms of emplacement which might be applicable to the Wilson Peak stock are upward punching, replacement and stoping.

Upward punching of magma, as noted by Lasky (1947, p. 48), implies the aggressive pushing of a plug of rock through to the surface or the compacting of the rock ahead of the "punch" into a mass of wildly disordered structure. It is difficult to imagine a stock of the irregular shape of the Wilson Peak stock being thrust upward through the strata without chaotic structures resulting adjacent to the contacts. Locally, as along the granodiorite contact just east of Gladstone Peak or along the microgranogabbro contact just west of Bilk Creek, very steep inclinations of the Mancos Shale immediately adjacent to the igneous rock suggest local powerful upward punching of magma. Other than these restricted occurrences, there is little field evidence to recommend this mode of emplacement. It is possible, of course, that such aggressive intrusion was more general at an early stage of the stock emplacement, but if so, a later, more passive process obliterated the evidence.

There seems to be no evidence to suggest replacement as an important mechanism of emplacement for the stock. Contacts between the stock and country rock are sharp. Local vertically oriented flow banding, lineation of hornblende parallel to some contacts, sills, and dikes, feeding from the stock, and the close association of the stock in place and time with volcanism all seem to point strongly to a fluid magma.

Field evidence suggests that the Wilson Peak stock completed its emplacement at the level of observation by a process in which piecemeal stoping was important. Such stoping is suggested along the boundaries of the irregularly shaped stock by (1) the steplike character of the contact in many places, due to the stock following bedding planes or fracture surfaces in the invaded country rocks; (2) small dikes, sills, or irregular apophyses frozen in relations that suggest the process of prying or wedging loose rocks along the stock contact, together with inclusion of rotated sedimentary rocks in the adjacent igneous rock. Only very few of the stoped blocks now at the levels of observation are of mappable size, and they present no convincing evidence for major stoping. There is no indication of scalloped or arcuate boundaries, ring fractures, or cauldron subsidence.

The role of assimilation in the emplacement of the Wilson Peak stock can only be speculative. Few stoped blocks are found in the interior of the stock, and presumably most of the blocks either melted or sank into the depths of the magma. Most of the stoped blocks now seen are around the margins of the stock; they presumably are those last stoped, which froze in place at the end of the stoping process and before active assimilation took place.

In summary, the field relations for the Black Face-Ames plutons and Flattop laccolith indicate emplacement by a combination of lifting of the roof and forcing aside of the walls, which resulted in concordant and semiconcordant forms. In contrast, the stock, though perhaps preceded by a phase in which there was some doming or forcing aside of walls, was emplaced in its final stages by a process in which piecemeal stoping appears to have been important.

Piecemeal stoping was visualized by Daly (1903) as the process in which stoped blocks sink in the magma as a result of differential density between the magma and the stoped country rocks. Although later Daly (1933, p. 70) still favored downward movement as the principal mechanism, he did not rule out the possibility of upward movement of some stoped blocks.

Upward movement of stoped blocks is suggested by the presence of white quartzose sandstone inclusions at several places in the stock, near the contact. An example is the sandstone zenoliths, which are as much as several tens of feet across, on the west side of Wilson Peak at an altitude of 13,200 feet. The sandstone could not have been derived from the adjacent San Juan Formation, and the closest possible source from which it may have been derived is the underlying Telluride Conglomerate, which would require an upward movement of at least 200 feet.

SOME FACTORS INFLUENCING MODE OF EMPLACEMENT

As with other intrusive centers, the question of why some intrusive bodies of the San Miguel Mountains took generally concordant forms and others took discordant forms can be approached only indirectly. All the igneous rocks are interpreted as being part of a single sequence of intrusions during middle to late Tertiary time, all are thought to have been derived from the same parent magma, and all are rather similar in composition. Yet, despite these similarities, the Black Face-Ames plutons and the Wilson Peak stock had contrasting intrusive mechanisms. Several factors may be involved, such as load, structural environment, composition of the magma, viscosity and temperature of the magma, structural susceptibility or character of the host rocks, and, probably, rate of intrusion.

The igneous rocks probably were emplaced under the same general conditions of load, for they apparently were part of a semicontinuous sequence of intrusion. The emplacement of the granodiorite porphyry of the Black Face-Ames plutons occurred first, immediately followed by that of microgranogabbro, then of granodiorite and adamellite of the Wilson Peak stock. The granodiorite and adamellite were each intruded after an interval during which the preceding magma cooled and solidified enough to fracture (p. 41, 45). How much time was needed to bring about this degree of solidification is uncertain. During this time, however, the superincumbent load probably did not vary significantly from the previously given order of magnitude of 2,000–5,000 feet.

Similarly, neither the magma composition nor the structural setting seem to be important variables. The igneous rock types involved are similar and the magmas were intruded into the same nearly flat lying formations.

Two factors that do appear to have differed between the intrusion of the early semiconcordant bodies and the later stock are the viscosity of the magma and the structural susceptibility or character of country rock.

The viscosity of the magma which resulted in the concordant and semiconcordant forms of the Black Face and Ames intrusive bodies apparently was high. This high viscosity can be inferred from the swarms of Precambrian inclusions which were carried upward 6,000 feet or more by the magma (p. 36). These inclusions range from gneissic and granitic types to amphibolite, and their densities range from about 2.6 for the granite to about 3.0 for the amphibolite. High viscosity is also suggested by the tendency of the magma, as it expanded, to crumple the incompetent Mancos Shale, as north of Sunshine Mountain or along the south side of Black Face. It is noteworthy that evidence of heat effects of the Black Face-Ames plutons is slight and in most places consists only of local "baking" of the Mancos Shale for a few feet from the contact, especially above the upper contacts of these igneous bodies. In contrast the marked aureole of contact metamorphism that surrounds the stock (pl. 1) suggests that the stock magmas were at a higher temperature and perhaps contained more volatiles than the magma that produced the Black Face-Ames plutons. Both these conditions would tend to lower the viscosity of the magma.

The structural susceptibility or character of the country rock would at first glance appear to have been a constant factor, for the different rocks were intruded into the same area, into the same structural setting, and into the same formations. However, with time the physical character of the country rock changed. Within the broad band of contact metamorphism associated with the stock (pl. 1), the Mancos Shale was transformed to a hard dense massive rock which in areas closer to the stock no longer splits parallel to bedding, but fractures randomly and conchoidally. Thus as the intrusive process continued and the country rock recrystallized, the strata became more massive, more competent, and less capable of yielding by crumpling or doming.

Rate of intrusion probably was also a factor affecting mode of emplacement. Magma in large quantity supplied rapidly would rise actively through the strata, and conditions would probably favor a forceful mode of emplacement in which the country rock would be domed upward or aside. As Weed and Pirsson (1898, p. 584–587) noted, an increased rate of intrusion has the effect of increasing viscosity; thus a forceful mode of emplacement would probably result, irrespective of whether the magma were viscous or fluid. If magma were not supplied too rapidly or in too great quantity, concordant bodies such as sills and laccoliths might be capable of absorbing the entire supply. On the other hand, if a fluid magma were more passive and were rising less aggressively, a more permissive mode of emplacement such as stoping or replacement might be favored.

It is concluded that in the eastern San Miguel Mountains the viscosity of the magma, the character of the host rocks as they changed with time, and probably the rate of intrusion were important factors in determining (1) the contrasting mode of emplacement between the early concordant and semiconcordant intrusives of the Black Face and Ames plutons and (2) the final emplacement of the stock by a process in which piecemeal stoping was probably important.

RICO DOME

The apex of the Rico dome lies about 5 miles south-southwest of the quadrangle, and the effects of this uplift are reflected in the general increase in dip of strata in the southwest corner of the mapped area (pl. 1). Along the Dolores River near Coke Oven at the west edge of the quadrangle the dips in the Dolores Formation increase to about 10° NE. On Barlow Creek at the southern edge of the area the dips also increase to 10° NE or more, and the Dolores Formation reappears at the surface. The upland area between Barlow Creek and the Dolores River is in part a dip slope on the Salt Wash Sandstone Member of the Morrison Formation.

FAULTS

Only a few faults, all of small displacement, were mapped in the Mount Wilson quadrangle; in contrast, in the Little Cone and Gray Head quadrangles (fig. 1) to the north, graben faults having as much as several hundred feet of displacement form a north- to northwest-trending system. This system dies out to the south and southeast toward the intrusive masses of the San Miguel Mountains, and the number of faults and the displacement on out of individual faults decreases none of these faults reach the Mount Wilson quadrangle.

In the Sheep Mountain area, in the southeast part of the quadrangle, several small faults were mapped. Two small nearly vertical northwest-trending normal faults on the south slope of Sheep Mountain displace the contact of the Telluride Conglomerate and Mancos Shale about 30 feet. The southernmost of the two contains a dike of intermediate composition. The north-northeast-trending fault just east of Sheep Mountain, which is a nearly vertical normal fault downthrown on the east side about 20 feet, is also partly occupied by a dike. The small fault mapped about 1½ miles south of Sheep Mountain probably is related to the landslides in that vicinity.

In the Lizard Head area are faults which may be related to stresses that arose during and after the intrusion of the Black Face-Ames plutons and the Wilson Peak stock. Several of these are northwest-trending normal faults, downthrown to the southwest, which have displacements of as much as 200 feet. A few are short east- to northeast-trending normal faults which have displacements of about 100–200 feet.

MINERAL RESOURCES

Base and precious metals and coal have been produced commercially in the Mount Wilson quadrangle. The base and precious metal ores have come entirely from veins in the north half of the quadrangle; the coal deposits are in the Dakota Sandstone and have been mined along the Dolores River in the southwest corner of the quadrangle.

Uraniferous vanadium deposits in the Entrada Sandstone, so common just to the north and northwest of the area (Bush and others, 1959), are not present where the Entrada crops out along the Dolores River, but drilling has shown vanadium to be present in subsurface to the east of the area of outcrop.

VEIN DEPOSITS

Gold, silver, lead, copper, and some zinc have been produced from the vein deposits, but the principal values of ore shipments have been in silver and gold. The value of past production in the quadrangle is probably about $3 million.

The productive veins are spatially and possibly genetically related to the several discordant intrusive masses that extend westward in a belt across the north half of the quadrangle. Within this intrusive belt the veins seem to be restricted to an east-west zone 1–2 miles wide that crosses the quadrangle from the Ames-Matterhorn area on the east to the Silver Pick-Navajo Basin area on the west. This zone closely approximates a hypothetical axis of intrusion which can be drawn joining the centers of the major igneous masses in the intrusive belt, and the zone itself may reflect the line of apex of a continuous concealed intrusive mass.

The bulk of the production from the mineralized zone has come from fissure veins within the igneous rocks. The rarity of veins in the sedimentary rocks between the outcropping intrusive bodies is probably due to the fact that these rocks are mainly Mancos Shale, which is too incompetent to provide open fissures. In only one mine has production come from the Mancos Shale, but in it the vein cuts the Mancos immediately adjacent to an intrusive body, and the formation is metamorphosed to a massive hornfels.

Fissures in the area strike westward, northeastward, and northwestward, but most of the veins that have been mined or prospected are along fissures of westerly trend and steep dip. Fissures of this group strike N. 70° E. to N. 70° W. and generally dip more than 70° to the north or south. This direction of fracturing is conspicuous in most areas of outcrop of the major intrusive masses, both in the Ames-San Bernardo mine area and in the Wilson Peak stock. It is particularly conspicuous in the Wilson Peak stock from upper Bilk Basin west into Navajo Basin where the jointing or fissuring is so closely spaced as to suggest an immense sheeting of the igneous rock.

Less obvious is a northeasterly system of joints or fissures. This trend is particularly conspicuous in the Wilson Peak stock along the ridge separating Navajo and Silver Pick Basins. The fissures dip steeply, generally to the southeast. Several veins of this trend have been prospected, but substantial production has come only from the Silver Pick vein. Steep-dipping northwest-trending joints or fissures, although common in the stock, have not been found to contain any commercial veins.

Displacements along the mineralized fissures are generally impossible to determine in the massive intrusive rocks. Where movement could be estimated, it is generally only a few feet.

The width of the workable veins ranged from about 3 inches to about 5 feet. More commonly the paystreak averages less than 2 feet in width, but the presence of several veinlets in a fissure zone may increase the width of commercial ore.

Two general types of ores can be distinguished in the area—gold ores and silver-lead ores. The two ore types are found in both westward- and northeast-trending fissures, but the known gold ores are restricted to the area near the head of Navajo and Silver Pick Basins and just west of the quadrangle boundary in the adjacent Elk Creek Basin. The only substantial producer of gold ore was the Silver Pick mine.

The gold ores are composed predominantly of pyrite and gangue; variable amounts of chalcopyrite and arsenopyrite are subordinate, and galena and sphalerite are locally present but inconspicuous. The gangue is white crystalline quartz containing some carbonate minerals and in places barite. Gold is reported to be very fine grained and seldom visible to the eye. Higher gold values are generally associated with higher amounts of chalcopyrite and arsenopyrite in the veins. Gold which occurred locally in rich pockets or streaks assayed as much as $150 a ton, but over the width of the narrow paystreaks $25 to $50 in gold per ton probably was representative of most ore mined.

The gold ores have been explored through a vertical distance of somewhat more than 1,000 feet, from an altitude of about 12,600 feet to about 13,700 feet. In this distance there was evidently no noteworthy change in character of the ores.

The silver-lead ore deposits are more widely distributed than the gold ore deposits, and include all the known veins between the east boundary of the quadrangle and Bilk Creek. Within the quadrangle the principal producers of this type of ore are the San Bernardo and Butterfly mines.

In the silver-lead ores the predominant primary sulfide minerals are galena, sphalerite, and pyrite; although generally subordinate, chalcopyrite and tenantite-tetrahedrite are common and in places are abundant. The common gangue minerals are quartz, calcite, and brown carbonate minerals; lesser amounts of barite and rhodochrosite also occur. The silver-lead ores generally contain less than 0.10 ounce of gold per ton. Silver may assay 40 ounces or more per ton locally, but available production figures from records of the U.S. Geological Survey and from Minerals Yearbooks of the U.S. Bureau of Mines suggest that the mine-run ore averaged less than 10 ounces of silver per ton.

The silver-lead ores of the area have been explored from an altitude of about 9,600 feet to at least 12,500 feet, a range of nearly 3,000 feet. The lower limit represents that imposed by the bottom of a major valley (with attendant drainage problems) rather than a change in character of the veins; similarly the upper altitude does not necessarily indicate an upper limit. Individual lodes have been explored through vertical intervals of 1,000 feet without appreciable change in character.

The patented claims in the San Miguel Mountains area are shown on plates 5 and 6.

IRON SPRINGS (OPHIR OR AMES) DISTRICT

SAN BERNARDO MINE

The San Bernardo mine is on the east slope of San Bernardo Mountain west of the Lake Fork of the San Miguel River and about 1 mile south of Ames. The vein was developed by five drifts (fig. 21), the lowest, level 5, at an altitude of 9,810 feet, and the highest, level 1, at an altitude of about 10,440 feet. The workings total about 9,000 feet in length. In 1957 the Silver Hat Mining Co. began driving a sixth level 310 feet below level 5; in 1962 this level was in 2,300 feet on the vein and was still being advanced. The upper four levels were caved, and only parts of levels 5 and 6 were accessible in 1962.

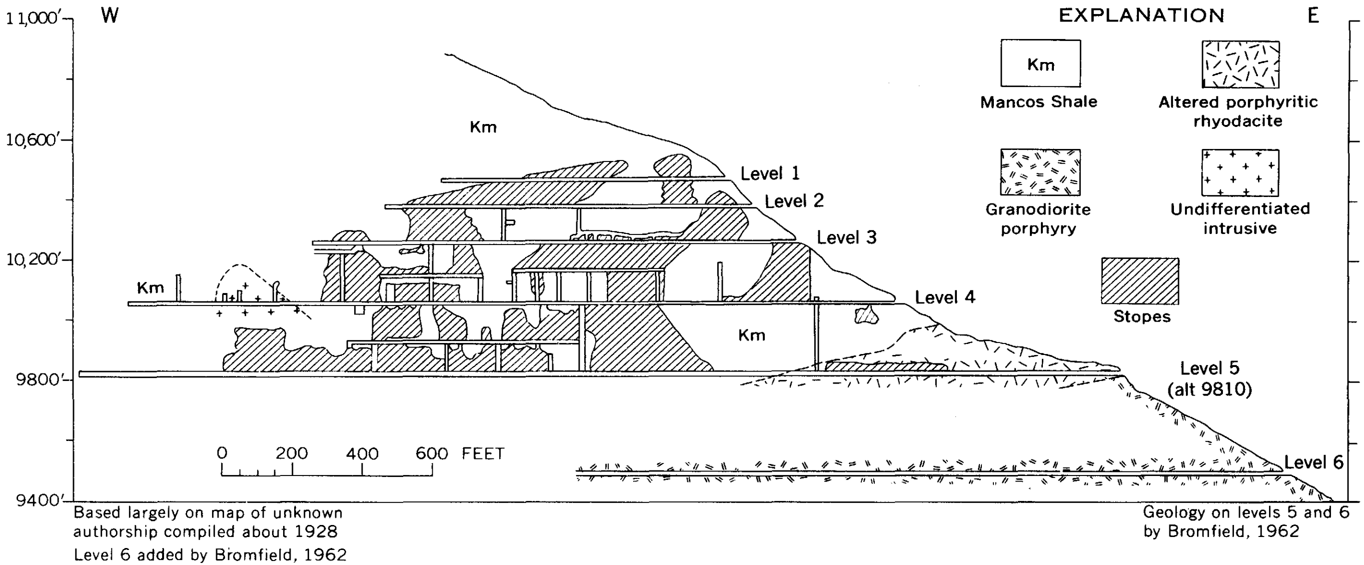

FIGURE 21.—Longitudinal section of the San Bernardo mine, San Miguel County, Colo.

Gus Gamboni, a prospector, located claims on the San Bernardo vein in the 1880's, and the mine has been worked intermittently by various operators since that time. C. W. Purington visited the property in 1896, at which time he reported (unpub. data) that it was developed by four drifts totaling several thousand feet of workings and that it had produced ore valued at about $120,000, mostly in silver. From 1919 to 1928 the mine was operated by the Otto Mining Co., and during that period silver-lead ore reportedly valued at $1 million was produced (King and Allsman, 1950, p. 35). From 1928 to 1957 there was only sporadic activity and little production.

Igneous rocks which intrude and are overlain by the Mancos Shale form the lower slope of San Bernardo Mountain in the mine area. The portals of the upper three levels are in nearly flat to gently west dipping Mancos Shale, here partly metamorphosed to a hard dense hornfels. Except for a small intrusive body penetrated on level 3 these workings were reported by Purington to be entirely in Mancos Shale. The portal of level 4 is near the concordant contact between the Mancos and the intrusive (pl. 1), but the level was reported by Purington to be almost completely in the Mancos. The portal of level 5 is in the intrusive mass on the lower slopes of the mountain, and the level passes into the Mancos Shale 900–1,100 feet from the portal. Where I observed the contact on level 5, it is concordant with the gently westward dipping shale. The portal of level 6 also is in the intrusive body, and the level was still in it at the breast, some 2,300 feet from the portal, in the summer of 1962.

The intrusive body is principally granodiorite porphyry which is continuous with the Ames sill to the north and probably with the Black Face intrusive to the southeast. The intrusive body in the vicinity of the mine is composite and is capped by the earlier porphyritic rhyodacite (see p. 32) which is locally present along the west side of the Lake Fork. The rhyodacite is thoroughly altered to a bleached sericitized rock both at the surface and underground on level 5; however, this alteration does not seem to be related to the mineralization, because it is widespread in this type of rock to the north and may be deuteric.

The San Bernardo vein trends N. 70°–80° W. and dips on the average 60°–70° S., but C. W. Purington (unpub. data, 1896) reported that near the breast on level 3 the vein dips steeply north for short distances. The fissure zone probably ranges in thickness from 1 foot or less to 8 feet, and it may contain veins or stringers. The paystreak on the upper four levels was reported by Purington to be about 8 inches wide and to favor the footwall of the fissure zone. Where I observed the paystreak, on level 6, it ranged in width from a few inches to nearly 2 feet and it was on the hanging wall as well. In places on levels 5 and 6, large cavernous openings are formed by the irregular walls of the fissure; in other places on level 6, the vein contains a loose uncemented breccia of the igneous wallrock, and this breccia has made either timbering or detours into the hanging wall necessary. Movement of the fissure walls subsequent to the ore stage of metallization has also resulted in loose brecciated ore in places. The mixture of brecciated country rock and ore is locally lightly cemented by chalcedonic quartz and pyrite crystals in films on the fragments. Unlike most other mines of the area, the great bulk of the stoping on the vein thus far has been in the metamorphosed Mancos Shale; the vein in the igneous rocks has been relatively unproductive.

The principal ore minerals are galena, gray copper, and pyrite; chalcopyrite and sphalerite are present but not conspicuous. The ore carries an appreciable silver content. According to Purington (unpub. data, 1896) ruby silver and native silver were found in places on level 3. The nonmetallic gangue minerals are chiefly quartz, barite, and carbonate minerals—probably calcite, siderite, and rhodochrosite. The quartz is principally white and crystalline and in places is vuggy. On level 6 the vein consists of quartz, pyrite, and lesser galena, chalcopyrite, sphalerite, and gray copper. The quartz-pyrite vein filling reportedly contains appreciable silver.

King and Allsman (1950, p. 35), quoting Otto Beselack, stated that vein matter from the last 230 feet of drifting on level 5 yielded, per ton, an average of 0.03 ounce of gold, 11.35 ounces of silver, 5.35 percent lead, and 0.42 percent copper; that from the last 50 feet, 0.03 ounce of gold, 20.75 ounces of silver, 10.82 percent lead, and 0.83 percent copper. No vein widths were given.

BUTTERFLY MINE

The Butterfly mine is on the east side of the Lake Fork of the San Miguel River, about 1 mile south of Ames.

The mine is developed through four adits; the lowest, or No. 4, level is at an altitude of about 9,140 feet (labeled Old Butterfly on pl. 1) and the upper, or No. 1, level is at an altitude of about 9,865 feet. The mine has about 10,000 feet of drifts and crosscuts, but at the time of my work in the area, all the workings were inaccessible.

Claims were first located at this site in 1877, but by 1896 a total of only about 350 tons of gold-silver ore having an estimated value of $3,000 had been produced (C. W. Purington, unpub. data, 1896). At that time there was about 5,000 feet of workings. In 1905 the Buckeye Mining and Leasing Co. operated a 30-stamp plate-amalgamation and concentrating mill, and from then to about 1914 the mine had substantial production. Sayer (1912), for example, reported 16,620 tons produced in the year ending March 31, 1912. A decrease in production began in 1915 but a small amount was produced each year, except two, from 1915 through 1929. The mine was idle from 1930 through 1934, but in 1935 the Butterfly Consolidated Mines, Inc., began operations, and during 1935–40 they produced 62,670 tons of ore. The company built a 250-ton mill, which burned December 6, 1940. The mine was idle during 1941–51. In 1952–53 the Mariposa Mining Co. made several small shipments, but the mine was idle from then to the time of this writing (1963). The total value of the Butterfly mine production is probably about $1 million.

The wallrock in the Butterfly workings is principally micrograno-gabbro of the Ophir stock.

The productive workings are on the westward-trending Ida and North (or Dill) veins, which strike N. 60°–80° W. The Ida vein has an average dip of about 75° S., and the North vein about 75° N. The veins worked in the Silver Bell mine just east of the quadrangle boundary are probably an easterly continuation of the vein system in the Butterfly mine.

Purington's unpublished data for 1896 indicate that the veins ranged from a few inches to 2 feet in width, but in the ore shoots they probably averaged more than 1 foot.

The primary sulfide minerals are pyrite and galena, with subordinate chalcopyrite and sphalerite. Tetrahedrite-tennantite, or freibergite, is seen locally. The principal gangue minerals are quartz, which is commonly vuggy, carbonate minerals, and barite.

The tenor of the ore is indicated by statistics in the Minerals Yearbooks of the U.S. Bureau of Mines. During 1936–40, 62,670 tons of ore from the Butterfly mine was milled which averaged, per ton, 0.055 ounce of gold, 7 ounces of silver, 1.04 percent lead, and 0.186 percent copper. Figures for zinc are incomplete.

SAN JUAN CLAIMS

The San Juan claims, sometimes referred to as the Matterhorn drifts (pl. 1), are on the east side of the Lake Fork of the San Miguel River, about 1½ miles south of Ames and opposite the San Bernardo mine. Claims were first staked at this site in 1877, and by 1883 the workings consisted of four adits, 280, 290, 120, and 30 feet long, and one 60-foot shaft or winze (Corregan and Lingane, 1883). Probably some additional workings have been driven since then. The lower adit is at an altitude of about 9,675 feet, the upper at 10,040 feet. Only the lower two levels were accessible in 1962.

The value of the output is not known but apparently it was small. There had been no systematic stoping, only "gophering" on the lower two levels.

The San Juan vein, in the Ophir stock, follows a westward-trending fissure which may be the eastward continuation of the San Bernardo fissure. The fissure is near the contact with the Mancos Shale, which lies only a few tens of feet south of the lowermost adit, but all the workings apparently were in the stock. As observed at the surface and on the two lower levels, the vein is typically 3–8 inches wide, but locally stringers in the walls increase the paystreak width to 2–3 feet. The gangue is of quartz, some of which is vuggy, a considerable amount of brown carbonate minerals, and some barite. In this gangue are bunches or streaks of pyrite, galena, sphalerite and lesser chalcopyrite and gray copper. No data on the tenor of the ore are available.

MOUNT WILSON MINING DISTRICT

MORNING STAR MINE

The Morning Star mine is on the west side of Bilk Creek, almost due west of Sunshine Mountain (pl. 1). The workings consist of three adits; the lowest is at an altitude of about 10,230 feet, the second is 125 feet higher, and the highest is about 110 feet above the second level. In 1960 the lowest level was caved 400 feet from the portal and the upper levels were caved at their portals.

It is not known when the Morning Star vein was located, but presumably sometime in the 1880's. The principal production was made from 1904 through 1914 (table 6). There is no record of production since that time.

TABLE 6.—*Production from Morning Star mine, 1904–14*

[Compiled from records of U.S. Bureau of Mines. No production recorded for 1906, 1910, and 1911]

Year	Ore (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Total value
1904	200	400.00	6,000		23,206	$12,718
1905	75	14.51	3,000		47,872	4,362
1907	160	7.98	480		160,000	11,813
1908	120	6.00	303		144,000	8,080
1909	12	.79	277		10,194	
1912	19	1.84	393	225	16,080	1,041
1913	36	1.80	942	268	34,069	
1914	45	3.88	894	465	31,209	
Total	667	436.00	12,289	958	466,630	

The Morning Star vein occupies a fissure which ranges in strike from N. 75° W. to east-west, averaging about N. 85° W., and dips 80° N. to nearly vertical. The country rock of the vein is granodiorite porphyry of the Ames-Black Face type and microgranogabbro (pl. 1). The portal of the lower level is in granodiorite porphyry, but the adit apparently crosses into microgranogabbro about 175 feet from the portal (fig. 22). The contact between microgranogabbro and granodiorite porphyry at the surface passes near the portal of the second level. Where observed, the vein has a maximum width of 5 inches, but where stoped (now timbered) it apparently was somewhat wider. The ore, as judged from material seen on the dump and in place on the lower level, is composed of galena, pyrite, sphalerite, and minor amounts of chalcopyrite in a gangue of quartz, calcite, and perhaps carbonates of magnesium, iron, and manganese.

VEINS IN UPPER BILK BASIN

Numerous veins are found in the upper part of Bilk Basin near the little tarn lake at an altitude of 12,063 feet and west toward the divide between Bilk and Navajo Basins. Several of these have been prospected in a small way by opencuts or short adits. One prospect north of the lake at an altitude of about 12,230 feet has perhaps 200 feet of workings.

The country rock in this area is microgranogabbro, granodiorite, and porphyritic adamellite of the Wilson Peak stock. The igneous rocks are cut by conspicuous steeply dipping west-trending joints or fissures which in places are so closely spaced as to form sheeted zones. The fissures are in part occupied by veinlets or stringers of sulfides in a quartz and carbonate gangue. The veins are commonly 1–3 inches wide, though the vein in the workings north of the tarn lake is about 2 feet wide. The sulfides are chiefly sphalerite and pyrite with lesser galena in a quartz and carbonate gangue. Purington (unpub. data, 1896) wrote that handpicked ore from some of these veins contained about $40 worth of gold to the ton. There is no record of production, but the amount of ore shipped was obviously very small, inasmuch as evidence of only a small amount of "gophering" was noted.

Steeply dipping fissures which trend N. 30°–45° W. in this area are barren.

SILVER PICK MINE

The Silver Pick mine is located above timberline in Silver Pick Basin just within the northwest corner of the Mount Wilson quadrangle. It is by far the principal mine in the Mount Wilson mining district and, despite its misleading name, its principal product has been gold. The Silver Pick vein was located in July 1882 and patented in October of the same year. The Mount Wilson Gold and Silver Mining Co. began to work the mine in 1883, but the

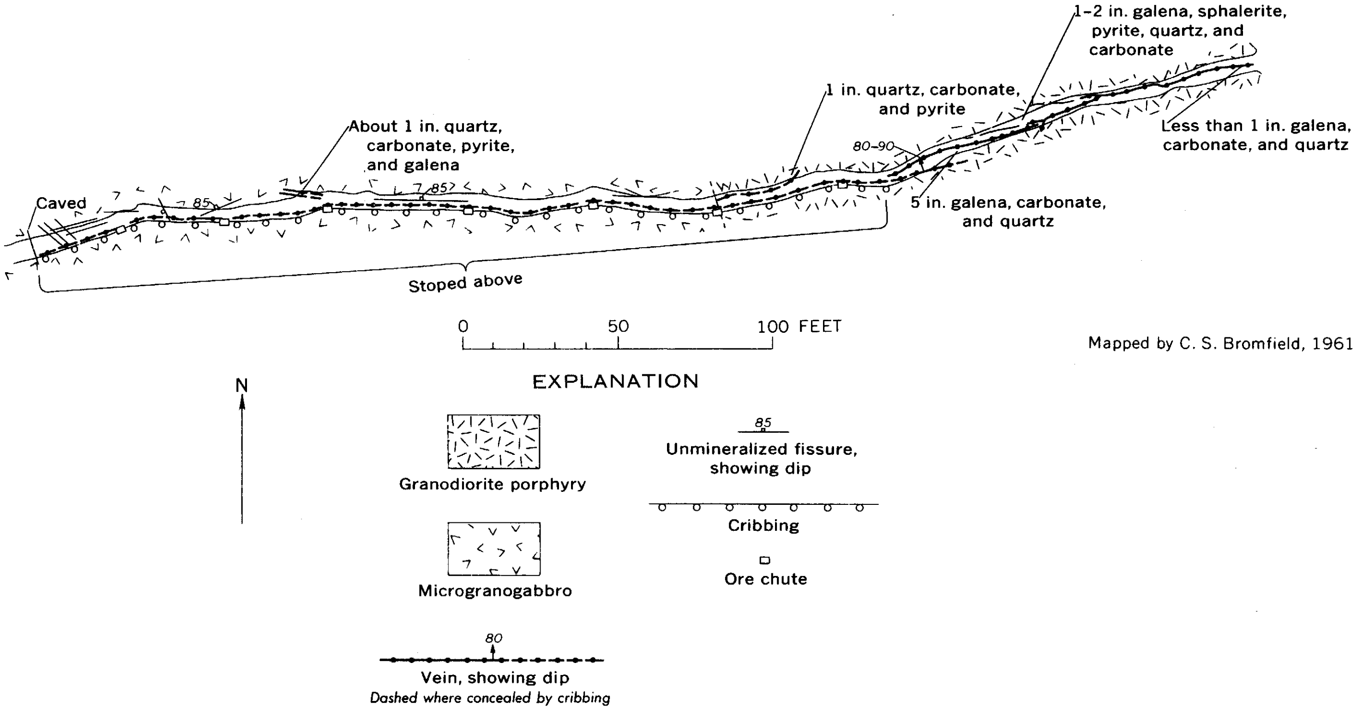

Figure 22.—Map of the lower (haulage) level of the Morning Star mine.

principal output was made during 1889–98 (table 7). About 6,030 tons of ore and concentrates produced during 1882–98 yielded about 32,000 ounces of gold, 95,000 ounces of silver, and about 3.5 percent copper. The value of this product computed at $20.57 an ounce for gold and $1.2929 (coinage value) for silver is $667,341 and $122,726, respectively, or a total of $790,067. No figures are available for the value of the copper produced. The receipts to the mine in this period, less freight and smelter charges, were $601,185.30. From 1899 through about 1902 work was done by lessees, but production was evidently small. The Gold Development Co. of Utah, which controlled the mine from 1903 to 1909, drove a crosscut (level 8) approximately 1,800 feet to intersect the vein about 400 feet beneath the old workings, but reportedly they shipped a total of only 103.8 tons, which averaged $34.62 per ton for a return of $3,593.70. Although the mine has been idle most of the time since 1909, several tons of mill cleanup and sorted high grade was shipped in the 1930's. An attempt was made to rehabilitate and open some of the old levels during 1954–58, but no production resulted from this work.

TABLE 7.—*Production from Silver Pick mine, 1882–98*

[From G. T. McCall, 1957, Geologic and engineering report on the Mount Wilson group: Prospectus of Mount Wilson Mines, Inc., Investment Service Co., Denver, Colo. No production recorded for 1883–84, 1886–88]

Year	Ore shipped [1] (tons)	Gold (ounces)		Silver (ounces)	
		Per ton	Total [2]	Per ton	Total [2]
1882	3.2	2.5	8.0	29.8	95.36
1885	4.5	4.0	18.0	27.0	121.50
1889	20.2	2.6	52.52	20.7	418.14
1890	39.9	5.7	277.43	22.0	877.80
1891	136.2	7.1	967.02	18.2	2,478.84
1892	284.7	6.8	1,935.96	14.1	4,014.27
1893	854.2	5.7	4,868.94	14.1	12,044.22
1894	1,245.1	6.0	7,470.60	17.0	21,166.67
1895	1,708.3	4.5	7,687.35	14.5	24,770.35
1896	394.9	3.8	1,500.62	15.4	6,081.46
1897	374.2	5.9	2,207.78	18.8	7,034.96
1898	964.6	5.7	5,498.22	16.4	15,819.44
Total	6,030.0		32,442.44		94,923.01

[1] Hand-sorted ore plus mill concentrates.
[2] Calculated by author.

The Silver Pick mine consists of more than 8,000 feet of workings in eight levels, seven of which are shown on figure 23. The highest level (No. 1) is at 13,200 feet altitude and the lowest (No. 8) is at 12,120 feet. No mining was done from level 8, although the crosscut probably reached the Silver Pick vein. The vein was worked through a vertical interval of more than 700 feet and horizontally for about 1,000 feet. All the workings were inaccessible in 1960.

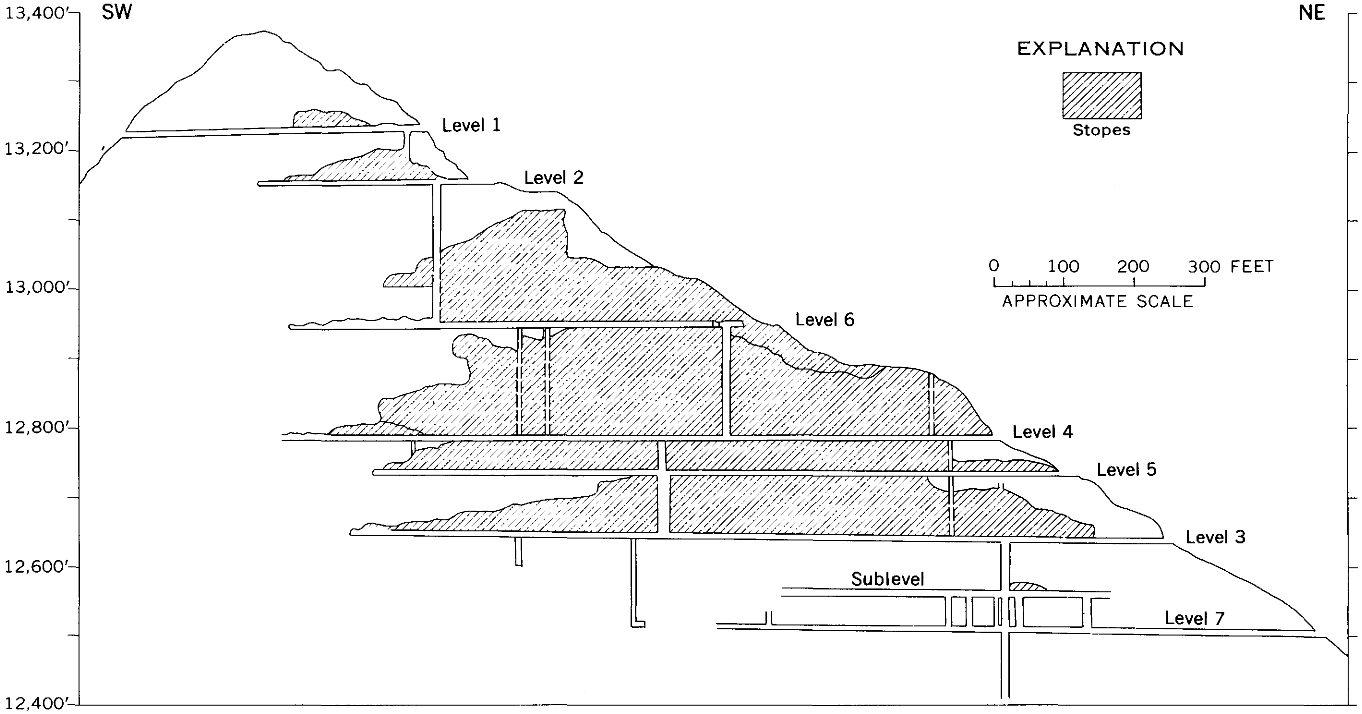

FIGURE 23.—Longitudinal section of the Silver Pick mine. Mine levels numbered in order driven. Based on map by Mount Wilson Gold and Silver Mining Co., about 1898.

The Silver Pick vein, which is 3–6 inches wide, trends N. 40°–60° E. and dips about 75° SE; it cuts microgranogabbro, granodiorite, and porphyritic adamellite of the Wilson Peak stock. A conspicuous set of westward-trending joints also cuts these rocks, and where this occurs the vein is offset to the east from a few inches to several feet (Purington 1898, p. 779; Nason, 1900, p. 682). Purington was undecided whether the vein was actually faulted or whether it turned locally to follow westward-trending joints and then resumed on a northeast-trending fissure of the same system.

The principal sulfide minerals in the vein are chalcopyrite, arsenopyrite, and pyrite. Galena is present in places, but it is not conspicuous in the vein material. The gangue is chiefly white crystalline quartz, carbonate minerals, and possibly some barite. The gold is very fine grained and, like that in many gold districts, it is apparently closely associated with arsenopyrite and chalcopyrite. Silver is present in the ore in the ratio of 3 to 1 with gold.

OTHER MINES

The Synopsis mine is in Silver Pick Basin on the west slope of Wilson Peak at an altitude of about 12,800 feet. The workings consist of an adit of unknown but probably short length by which a fissure zone, which trends N. 80° W. and dips steeply northward in the stock, evidently was prospected. The country rock is microgranogabbro and granodiorite. There is no record of any production.

The Rock of Ages mine, in Navajo Basin just below the saddle leading to Silver Pick Basin, is at an altitude of about 12,800 feet. A crosscut apparently was driven to intersect a N. 60°–75° E.-trending fissure zone in the porphyritic adamellite. At the surface the fissure zone crosses the saddle and forms a zone 5–10 feet wide within which are several narrow ½- to 1-inch quartz-pyrite veinlets. The workings were caved in 1960 and their extent is not known. No production from this property is on record.

COAL

In the western San Juan Mountains, minable coal seams have been found locally in the Cretaceous Dakota Sandstone. In this region the Dakota is divisible into a lower conglomeratic sandstone unit, a middle carbonaceous shale unit, and an upper sandstone unit. The coal is in the middle carbonaceous unit, where it occurs in local seams.

In the Mount Wilson quadrangle coal has been mined in only two places—on the south side of the Dolores River just east of Barlow Creek, and on the north side of the river just east of Coal Creek.

Both mines have been abandoned for many years and the workings are largely caved and inaccessible. The coal seams, which are flat-lying, were mined by room-and-pillar methods. Where the seams were exploited, they ranged in thickness from 16 to 24 inches.

The coal is apparently of bituminous rank, as are most coals from the Dakota in southwest Colorado (Landis, 1959). An analysis of coal from the middle unit of the Dakota near Naturita, 40 miles northwest, showed that coal to be high-volatile B bituminous in rank (U.S. Bureau of Mines, 1937, p. 110–111).

The coal seams in the quadrangle were exploited for use in early-day smelting operations at nearby Rico. The coal was utilized in making coke for smelting, and remains of beehive coking ovens are still to be seen along the Dolores River between Coke Oven and Coal Creek. The coal was also used locally for household heating. Hills (1893) reported that the use of this coal was abandoned when railway connection with Durango gave access to the better coals of that area.

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